Heat Considered as a Mode of Motion

by John Tyndall

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JOHN TYNDALL, F.R.S., &c.

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FROM TOE SECOND LONDON EDITION REVISED^ WITH ADDITIONa EMBBACINQ TUE

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PEEF AOE

IN the following Lectures I have endeayoured to bring the rudiments of a new philosophy within the reach of a person of ordinary intelligence and culture.

The first seven Lectures of the course deal with thermometric heat; its generation and consumption in mechanical processes ; the determination of the me- chanical equivalent of heat ; the conception of heat as molecular motion ; the application of this conception to the solid, liquid, and gaseous forms of matter ; to expansion and

combustion ; to specific and latent heat ; and to calorific conduction.

The remaining five Lectures treat of radiant heat ; the interstellar medium, and the propagation of motion through this medium ; the relations of radiai^t heat to ordinary matter in its several states of aggregation ; terrestrial, lunar, and solar radiation ; the constitution of the sxm ; the possible sources of his energy ; the re- lation of this energy to terrestrial forces, and to vege- table and animal life.

My aim has been to rise to the level of these ques- tions from a basis so elementary, that a person possess- ing any imaginative faculty and power of concentration, might accompany me.

Wherever additioiLal remarks, or extracts,, seemed likely to render tlie reader's knowledge of tlie sabjects referred t« in any Lecture more accurate or complete, I have introdaced such extracts, or remarks, as an Ap- pendix to the Lectnre,

For the nse of the Plate at the end of the volnme, I am indebted to the Council of the Koyal Society ; it was engraved to illustrate some of my own memoirs in the ' Philosophical Transactions.' For some of the Woodcuts I am also indebted to the same learned body.

To the scientific pubhc, the names of the boilders of this new philosophy are abeady familiar. As ex- perimental contributors, Eumford, Davy, Faraday, and Joule, stand prominently forward. As theoretic writers (placing them alphabetically), we have Clausins, Helm- holtz, KirchofF, Mayer, Bankine, Thomson ; and in the memoirs of these eminent men the student who desires it, must seek a deeper acquaintance with the subject. MM. Hegnault and Segiiin also stand in honourable re- lationship to the Dynamical Theory of Heat, and M. Tcrdet has recently published two lectures on it, marked by the learning for which he is conspicuous. To the Fnglieh reader it is superfluous to mention the well-known and highly-prized work of Mr. Grove.

I have called the philosophy of Heat a new philoso- phy, without, however, restricting tlie term to the sub- ject of Heat. The fact is, it cannot be so restricted ; for

the connection of this agent with the general ener- gies of the universe is sucli, that if we master it per- fectly, we master all. Even now we can discern, though but darkly, the greatness of the issues which connect themselves with the progress we have made — issues which were probably beyond the contemplation of

those, by whose indnstrj and geniitfi the fonndatioiiB of our present knowledge were laid.

In a Lecture on the ^ Influence of the History of Science on Intellectual Education/ delivered at the Boyal Institution, Dr. Whcwell has shown ^ that every advance in intellectual education has been the effect of some considerable scientific discovery, or group of dis- coveries.' If the association here indicated be invari- able, then, assuredly, the views of the connection and interaction of natural forces — organic as well as inor- ganic— ^vital as well as physical — ^which have grown, and which are to grow, out of the investigation of the laws and relations of Heat, will profoundly affect the intellectual discipline of the coming age.

In the study of Nature two elements come into play, which belong respectively to the world of sense and to the world of thought. We observe a fact and seek to refer it to its laws, — we apprehend the law, and seek to make it good in fact. The one is Theory, the other is Experiment ; which, when applied to the ordi- nary purposes of life, becomes Practical Science. Noth- ing could illustrate more forcibly the wholesome inter- action of these two elements, than the history of our present subject. If the steam-engine had not been in- vented, we should assuredly stand below the theoretic level which we now occupy. The achievements of Heat through the steam-engine have forced, with ang- mented emphasis, the question upon thinking minds — ' What is this ^ent, by means of which we can super- sede the force of winds and rivers — of horses and of men? Heat can produce mechanical force, and me- chanical force can produce Heat ; some common quality must therefore unite this agent and the ordinary forms

of mechanical po^er.' This relatiouBbip established, the gcaeralising intellect conld pass at once to the other energies of the universe, and it now perceivee the principle which miites them all. Thus the triumphs of practical skill have promoted the developement of phi- losophy. Thus, by the interaction of thought and fact, of truth conceived and truth executed, we have made oar science what it is, — the noblest growth of modem times, though as yet but partially appealed to as a Boaroe of individual and national might.

As a means of intellectual education its claims are still disputed, though, once properly organised, greater and more beneficent revolutions await its employment here, than those which have already marked its appli- cations in the material world. Surely the men whose ' noble vocation it is to systemize the culture of England, can never allow this giant power to grow up in their midst without endeavouring to turn it to practical ac- count. Science does not need their protection, but it desires their friendship on honourable tenns : it wishes to work with them towards the great end of all educa- tion,— the bettering of man's estate. By continuing to decline the offered hand, they invoke a contest which can have but one result. Bcience must grow. Its de- velopement is as necessary and as irresistible as the motion of the tides, or the flowing of the Gulf Stream. It is a phase of the energy of Nature, and as such is sure, in due time, to compel the recognitipn, if not to win the alliance, of those who now defiry its influence and discourage its advance.

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HEAT

COKSZDOtKD .AS

A MODE OF MOTIOIS".

LECTURE I

[Jaimary 28, 1862.]

IHSIBUICENTS — GXNKRAnON Of BEAT BT MECHANICAL ACnOI OONSUMFnON 01* HEAT IN WORK.

AFPIKDIX: — KOTXS ON THE THERMO-ELECTBIO PILE AND OALTANOlfETEB.

THE aspects of natare provoke in man the spirit of enquiry. As the eye is made for seeing, and the ear for hearing, so the human mind is formed for under- standing the

phenomena of the material universe. The natural philosophy of our day results from the irrepressi- ble exercise of this endowment. One great characteristic of Natural Science is its growth ; all its facts are fruitful, every new discovery becoming instantly the germ of fresh investigation. But no nobler example of this growth could be adduced than the expansion and development which men's thoughts and knowledge have undergone within the last two-and-twenty years, with reference to the subject which is now to occupy our attention. In scien- tific manuals, only scanty reference has, as yet, been made to the modem philosophy of Heat, and thus the public knowledge regarding it remains below the attain-

U LXCItlBB I.

able level. Bnt the reserve ia natural, for the sabject is still an entangled one, and, in entering apon it, we moet be prepared to encounter difficulties. In the whole range of Natural Science, however, there are none more worthy of being overcome, — none whose subjugation secures a greater reward to the worker. For by mafltering the laws and re- lations of Heat, we make clear to onr minds the interde- pendence of natural forces generally. Let us, then, com- mence our labours with heart and hope ; let us familiarise ourselves with the latest facts and conceptions regarding this aU-pcrvading agent, and seek diligently the links of law which underlie the facts and give unity to their most diverse appearances. If we succeed hero we shall satisfy, t« an extent unknown before, that love of order and of beauty which, I am persuaded, is unplanted in the mind of every person hero present. From the heights at which we aim, we shall have nobler glimpses of the system of Natore than could possibly be obtmncd, if I, while acting as your guide in the region which we are now about to en- ter, were to confine myself to its lower levels and already trodden roads.

It ia my first duty to nmke yoa acquainted with some of the instmments which I intend to employ in the exami- nation of this question. I must devise some means of making the indications of heat and cold visible to yon all, and for this purpose an

ordinary thermometer would be useless. Ton could not see its action ; and I am anxious that yoa should see, with your own eyes, the facts on which our subsequent philosophy is to be based. I wish to ^ve you the material on wliich an independent judgment may be founded ; to enable you to reason as I reason if yon deem me right, to correct me if I go astray, and to censure me if you find me dealing unfairly with my subjeat. To secure these ends, I have been obliged to abandon the use of a common thermometer, and to resort to the little in-

THB THEBUO-BLBOTBK) PILB AHD GALTANOKETEB. 15

■trument a b (fig. 1), which yon see before me on the table, and which is caUed a thermo-electric pile.*

By means of this instrnmeDt I canae the heat which it recuvea to generate an electric corrent. Ton know, or ought to know, that snoh a current has the power of de-flecting a freely anspended nutgnetio needle, to which it flowB parallel. Before yon I have placed each a needle m n (fig. I), sniTOimded by a covered copper wire, the iree

ends of which, to to are connected with the thermo-electric pile. The needle is sospended by a fibre, a s, of unapun eilk, and protected by a glass shade, g, from any dietorb- ance by cnircnta of air. To one end of the needle I have fixed a piece of red paper, and to the other end a piece of blue. All of yon see these pieces of paper, and when the needle moves, its motion will be clearly visible to the most distant person in this room.f

• Aj brief description of tho thermo-electric plo is given in the Appendix to llua Lecture.

f In the actml airtngcmc&t the galvAnometcr here described stood on ft stool in

front of the lecture taUe, tli« wiicB » w, btung sofflcientl]' long

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At the present moment the needle is qnite at rest, and points to the zero mark on the graduated disc underneath it. This shows that there is no current passing. I now breathe for an instant against the naked face a of the pile — 2L single puff of breath is sufficient for my purpose — observe the effect. The needle starts off and passes tlirough an arc of 90°. It would go further, did I not limit its swing by fixing, edgewise, a thin plate of mica at 90°. Take notice of the direction of the deflection ; the red end of the needle moved from me towards you, as if it disliked me, and had been inspired by a sudden affection for you. This action of the needle is produced by the small amount of warmth communicated by my breath to the face of the pile, and no ordinary thermometer could give so large and prompt an indication. We will let the heat thus communi- cated waste itself; it will do so in a very short time, and you notice, as the pile cools, that the needle returns to its first position. Observe, now, the effect of cold on the face of the pile. I have here some ice, but I do not wish to wet my instrument by touching it with ice. Instead of doing so, I will cool this plate of metal by placing it on the ice ; then wipe the chilled metal, and touch with it the face of the pile. You see the effect ; a moment's contact suffices to produce a prompt and energetic deflection of the needle. But mark the direction of the deflection. When the pile was warmed, the red end of the needle moved from me towards you ; now its likings are reversed, and the red end moves- from you towards me. Thus you see that cold and heat cause the needle to move in opposite directions. The important point here established is, that from the direction in which the needle moves, we can, with certjdnty, infer whether cold or heat has been communicated to the pile ;

to reach from the table to the stool ; for a further description of the gal- vanometer, see the Appendix to this Lecture.

HSAT or MWMIfUfm, 17

and the energy with whidi the needle

ness with whidi it is driren aside from its porilif of resi

— gives ns some idea of the coimaritife 4«Jtiti of Lest

or cold imparted to it in different caset. In a InCBe

I shall explain how we ma j cxpreas the icLtfiie

of heat with nmnerical aocnracr; but Ibrtfae

eral knowledge of the actioo of our imniiiwti wijl be

My desire now is to connect heat with the more fiKnl- iar forms of force, and I will, dieiefore, in the int ylirr. try to furnish you with a store of heu UfaMntiTe of ^e generation of heat by merhaniral pcoccgsca, I low placed some pieces of wood in the next room, which my aa inaii will now hand to me. Why hare I placed d«m thc^ ? Simply that I may perfonn my experiments w^ ifcat loi. ecrity of mind and act which edence demands trixj her cultivators. I know that the temperature of that r<»r:i i§ slightly lower than the temperatore of this coe. Cri iLtt hence the wood which is now before me ma«j \^ Ki::i*iT colder than the face of the pile with whidi I X3t«>i to t^**^ the temperature of the wood. Let us prorc this. I plicfe the face of the pile against this piece of wood ; the red ^ol of the needle moves from yon towards me. th*L§ §LoTir^ that the contact has chilled the pile. I now carefaHy r^b the face of the pile along the sar£ice of the wo<>i ; I klj ^carefuUy/ becaose the pile is a brittle instrnmect. asi rough usage would destroy it ; — mark what occur?, TLf: prompt and energetic motion of the needle toward* voa declares that the face of the pile ha« be^in heated bv tLi§ small amount of friction. The needle, vou oWrrre. cr-^y* quite up to 90^ on the si<le ofiposite to tliat towar^la whii-h it moved before the friction was applied.

Now these experiments, which illustrate the develope- ment of heat by mechanical

means, must be to us what a boy's school exerdses are to him. In order to fix them on

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our minds, and obtain due mastery oyer them, we must re- peat and vary them in many ways. In this task I ask yon to accompany me. Here is a nat piece of brass with a stem attached to it ; I take the stem in my fingers, preserving the brass from all contact with my warm hand, by envelop- ing the stem in cold flannel. I place the brass in contact with the face of my pile ; the needle move?, showing that the brass is cold. I now fab the brass against the snrface of this cold piece of wood, and lay it once more against my pile. I withdraw it instantly, for it is so hot that if I allowed it to remmn in contact with the instnunent, the current generated would dash my needle violently against its stops, and probably derange its magnetism. Yon see the strong deflection which even an instant's contact can produce. Indeed, when a boy at school, I have often blis- tered my hand by the contact of a brass button, which I had rubbed energetically against a form. Here, also, is a razor, cooled by contact with ice ; and here is a hone, with- out oil, along which I rub my cool razor, as if to sharpen it. I now place the razor against the face of the pile, and you see that the steel, which a minute ago was cold, is now hot. Similarly, I take this knife and knife-board, which are both cold, and rub the knife along the board. I place the knife against the pile, and you observe the result ; a powerful deflection, which declares the knife to be hot. I pass this cold saw through this cold piece of wood, and place, in the first instance, the surface of the wood against which the saw has rubbed, in contact with the pile. The needle instantly moves in a direction which shows the wood to be heated. I allow the needle to return to zero, and now apply the saw to the pile. It also is hot. These are the simplest and most common-place examples of the generation of heat by friction, and I choose them for this reason. Mean as they appear, they will lead us by degrees

HJEAT or OOMFBE88I0V AHD FERCUB8I0V. 19

into the secret recesses of Nstnre, sad lay open to onr Tiew the policy of the material mdverse.

Let me now make an experiment to illustrate the de- ▼elopement of heat by compression. I have here a piece of deal, cooled below the temperature of the room, and giving, when placed in contact with our pile, the deflection which indicates cold. I place this wood between the plates of a small hydraulic press, and squeeze it forcibly. The plates of the press are also, you will obserre, cooler than the air of the room. After compression, I bring the wood into contact with the pile ; see the effect. The gal- Tanometer dedares that heat has been developed by the act of compresuon. Precisely the same occurs when I place this lead bullet between the plates of the press and squeeze it thus to flatness.

And now for the effect of percussion. I have here a cold lead bullet, which I place upon this cold anvil, and strike it with a cold sledge hammer. The sledge descends with a certain mechanical force, and its motion is suddenly destroyed by the bullet and anvil ; apparently the force of the sledge is lost. But let us examine the lead ; you sec it is heated, and could we gather up all the heat generated by the shodc of the sledge, and apply it without loss mechan- ically, we should be able, by means of it, to lift this ham- mer to the height from which it fell.

I have here arranged another experiment, which is almost too delicate to be performed by the coarse apparatus neces- sary in a lecture, but which I have made several times be- fore entering this room to-day. Into this small basin I pour a quantity of mercury which has been cooled in the next room. I have coated one of the faces of my thermos electric pile with varnish, so as to defend it from the mer- cury, which would otherwise destroy the pile ; and, thus protected, I can, as you observe, plunge the pile into the liquid metal. The deflection of the needle shows you that

LEOrUBE L

the mercury is cold. Here are two glasses ▲ and b (fig. 2), swathed thickly round by listing, which will effectually prevent the warmth of my hands from reaching the mer- cury. Well, I pour the cold mercury from tfie one glass into the-othcr, and back. It falls with a certain mechani- cal force, its motion is destroyed, but heat is developed. The amount of heat generated by a single pouring out is extremely small ; I could tell you the exact amount, but shall defer quantitative considerations till our next lecture ; so I pour the mercury from glass to glass ten or fifteen times. Now mark the result, when the pile is plunged into

the mercury. The ^*^^ needle moves, and its.

motion declares that the mercury, which at the beginning of the experiment was cooler than the pile, is now warmer than the pile. We here introduce mto the lecture-room an effect which occurs in na- ture at the base of ev- ery waterfall. There are friends before me who have stood amid the foam of Niagara. Had they, when there, dipped sufficiently sensitive thermometers into the water at the top and bottom of the cataract, they would have found the latter a little warmer than the former. The sailor's tradition, also, is theoretically correct ; the sea is rendered warmer through the agitation produced by a storm, the mechanical dash of its billows being ultimately converted into heat.

Whenever friction is overcome, heat is produced, and

HEAT OP WATEBFALLfl, EIO., TUST Ain> STEEL. 21

the heat produced is the measure of the force expended in orercoming the friction. The heat is simply the primitive force in another form, and if we wish to avoid this conver- sion, we mnst abolish the friction. We usually put oil upon the surface of a hone, we grease a saw, and are care- ful to lubricate the axles of our railway carriages. What are we really doing in these cases ? Let us get general notions first ; we shall come to particulars afterwards. It is the object of a railway engineer to urge

his train bodily from one place to another ; say from London to Edinburgh, or from London to Oxford, as the case may be ; he wishes to apply the force of his steam, or of his furnace, which gives tension to the steam, to this particular purpose. It is not his interest to allow any portion of that force to be converted into another form of force which would not further the attainment of his object. He does not want his axles heated, and hence he avoids as much as possible expending his power in heating them. In fact, he has ob- tained his force from heat, and it is not his object to recon- vert the force thus obtained into its primitive form. For, for every degree of temperature generated by the friction of his axles, a definite amount would be withdrawn from the urging force of his engine. There is no force lost ab- solutely. Could we gather up all the heat generated by the friction, and could we apply it all mechanically, \re should, by it, be able to impart to the train the precise amount of speed which it had lost by the friction. Thus every one of those railway porters whom you see moving about with his can of yellow grease, and opening the little boxes which surround the carriage axles, is, without know- ing it, illustrating a principle which forms the very solder of Nature. In so doing, he is xmconsciously affirming both the convertibility and the indestructibility of force. He is practically asserting that mechanical energy may be con- yerted into heat, and that, when so converted, it cannot

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still exist as mechanical energy, but that, for every degree* of heat developed, a strict and proportional equivalent of the locomotive force of the en^e disappears. A station is approached, say at the rate of thirty or forty miles an hour; the brake is applied, and smoke and spar^ issue from the wheel on which it presses. The train is brought to rest — How ? Simply by converting the entire moving force which it possessed, at the moment the brake was applied, into heat. <

So, also, with regard to the greasing of a saw by a cas?- penter. He applies the

muscular force of his arm with the express object of getting through the wood. He wishes to tear the wood asunder, to overcome its mechanical cohedon by the teeth of his saw. When the saw moves stiffly, on account of the friction against its flat surface, the same amount of force may produce a much smaller effect than when the implement moves without friction. But in what sense smaller ? Not absolutely so, but smaller as regards the act of sawing. The force not expended in the sawing is not lost ; it is converted into heat, and I gave you an example of this a few minutes ago. Here again, if we could collect the heat engendered by the friction, and apply it to urge the saw, we should make good the precise amount of work which the carpenter, by neglecting the lubrication of his implement, had simply converted into another form of power.

We warm our hands by rubbing, and in the case of frostbite we thus restore the necessary heat to the injured parts. Savages have the art of producing fire by the skil- ful friction of well-chosen pieces of wood. It is easy to char wood in a lathe by friction. From the feet of the labourers on the roads of Hampshire sparks issue copiously on a dark night, the collision of their iron-shod shoes against the flints producing the eflect. In the common flint and steel the particles of the metal struck off are so much heated by the collision that they take fire and burn in

HEAT OF HKTBOBrCES. 23

Ihe air. Bat the heat precedes the combastioiL Davy foand that when a gnnlock, with a flint, was discharged in vacno, no sparks were produced, but the particles of steel stmck ofl^ when examined under the microscope, showed signs of fusion.* Here is a large rock-crystal ; I have only to draw this small one briskly along it, to produce a stream of light y here are two quartz pebbles, I have only to rub them together to make them luminous.

A buUet, in passing through the air, is warmed by the friction, and the most probable theory of shooting stars is that they are small jdanetary bodies, revolving round the

sun, which are caused to swerve from their orbits by the attraction of the earth, and are raised to incandescence by friction against our atmosphere. Mr. Joule has shown that the atmospheric friction is competent to produce the effect ; and he may be correct in believing that the greater portion of the aerolites are dissipated by heat, and the earth thus spared a terrible bombardment.f These bodies move with planetary velocity ; the orbital velocities of the four inferior planets are as follows : —

Miles per second. ; Mercury, ... 80*40

while the velocity of the aerolites varies from 18 to 36 mUes a second.^ The friction engendered by this enor- mous speed is certainly competent to produce the effects ascribed to it.

More than sixty-four years ago Count Rumford, who was one of the founders of the Royal Institution, exe- cuted a series of experiments on the generation of heat

• Works of Sir H. Davy, vol. ii. p. 8.

t Philosophical Magazine, 4th Scries, vol. xxxii. p. 349.

X Galbralth and Houghton's Manual of Astronomy, p. 18.

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i by friction, which, viewed by the light of to-day are of J- the highest interest and importance. Indeed, the Bervioe| 1 which this Institution has rendered, in connection widi:: this question of the brotherhood of natural forces, ctw never be forgotten. Thomas Young, a former profe^^ sor of this Institution, laid the foxmdations of the imdol** tory theory of light, which, in its fullest application, eia» braces our present theory of heat. Davy entertained sobr stantially the same views regarding heat as those which I am now endeavouring to approach and elucidate. Faradiij established the laws of equivalence between chemistry and electricity, and his magneto-electric discoveries were the very first seized upon by Mr. Joule in illustration of the mutual convertibility of heat and mechanical action.* Rum* ford, in a paper of great power

both as regards reasoning and experiment, advocated in 1198\ the doctrine regarding the nature of heat which the recent experiments of eminent men have placed upon a secure basis. While engaged in the boring of cannon at Munich, he was so forcibly struck by the large amount of heat developed in the process of boring, that he was induced to devise an apparatus for the special examination of the generation of heat by fric- tion. He had constructed a hollow cylinder of iron, into which he fitted a solid plunger, which was caused to press against the bottom of the cylinder. A box which 8ui> rounded the cylinder contained 18| lbs. of water, in which a thermometer was placed. The original temperature of the water was 60°. The cylinder was turned by horse-labour, and an hour after the friction had conmaenced the tempera- ture of the water was 107°, having been raised 47°. Half an hour afterwards he found the temperature to be 142°. The action was continued, and at the end of two hours the

• PhUosophical Magazine, 4th Series, vol. rxiil pp. 266, 847, 486. f An abstract of this paper is given in the Appendix to Lecture II.

temperature as 1 1 8=. At the eal of two hcnss mdA minutes it was 200% and at two boors aai linrn- axmnce* from the commencement i^ Koier actmaCy Ifimiaif Sam- ford's description of the eflect of tLis expesmec ol -diKi who witnessed it» is qidte deli^tXf^ * Ii woxiji *« ci&- cult,' he says, *to describe the «srpnfe izd Mynrwrni**^ expressed in the coantenanoes of tbe Ij^siaiEs ar ueour so large a quantity of water beaud. azii aessklj nok^ ': boil, without any fire. Tbov^ ibes« was xncjour 'aac conld be oonridered very Mirpsisug in liii Tracy j»': I acknowledge fadriy that it ailord&l cae a desrets: cf fflfTtawi pleasore which, were I ambitioas of Hit re^inri^uL i-f l grave philosopher, I oi^t moe; cETLksh- ziriisr v^ iS^ than to discover.** I am sore tiai l<ch jca izii I eao. 2$- pense with the application of xzij jiHisrc-lj '•^liii vifLii stifle such emotion as Rmnfor»i Lere ivi-a-^L Ii. i-.czi*::' tion with this striking experimen'L Mr. Joril-e* Lsf ^'zzuj^-rri the amomit of mechanical force ei^«e:>iei ri lo-it'in^r tiH: heat, and obt^uned a result wLicL * i* Zr'A Tirj "B-Ji^lj 1:5^7- ent ' from that which greater kz^owlrrizi izii =.::*: r-ifzi^-i

experiments emibled Mr. Joule hhnself to co^iz:. a§ r^p^ii the numerical equivalence of beat and ^ork.

It would be absurd on my part to a:*«r.p.i l-er^ & r*;;^^- tition of the experiment of Count l^zitS'jz-i tt.! ill >.» conditions. I cannot devote two Lours az:-! a L£f "•:- \ ilb- gle experiment, but I hope to be able to sLot jci »~\-^ii,- tially the same effect in ttto miro/i^ and a J^f. I L:ive here a brass tube, four inches long, and tLree qriirr^ri c f an inch in interior diameter. It i« stoppe-i it tie bo-.ror::- and I thus screw it on to a whirling tuble, bv meiiut of which I can cause the upright tube to rotate verj- rip: ilv. I have here two pieces of oak wood, united by a Llnge, atd

* Romford*! EaBajs, t<$L iL p. 4M. t PhQoeophiGal Tnumctiou, toL czL p. C2. ft

in which arc two semicircular grooves, which are intended to embrace the brass tube. Thus the pieces of wood font a kind of tongs, t (iig. 3), by gently squeezing which I cu produce friction between the wood and the brass tok^ when the latter rotates. I almost fill the tube with oold

water, and stop it with a cork, to prevent the splashing onl of the liquid, and now I put the machine in motion. Am the action continues, the temperature of the water rise^ and though the two minutes and a half have not yet elapse^ those near the apparatus will see steam escaping from tlM cork. Three or four times to-day I have projected the coik by the force of the steam to a height of twenty feet in tlie air. There it goes again, and the steam follows it, pro- ducing by its precipitation this small cloud in the at* mosphere.

In all the cases hitherto introduced to your notice, hett has been generated by the expenditure of mechanical force. t Our experiments have gone to show that where mechanical I force is expended heat is produced, and I wish now to ^ bring before you the converse experiment, that is, the conr sumptio7i of heat in mechanical work. And should you at present find it, difficult to form distinct conceptions as to the bearing of these experiments, I exhort you to be pa- tient. We are engaged on a

difficult and entangled sob-

GOLD OF DILATATION.

ject} which, I hope, we shall disentangle as we go along. I have here a strong vessel, filled, at the present moment, with compressed air. It has been now compressed for some hours, so that the temperature of the air within the vessel is the same as that of the air of the room without it. At the present moment, then, this inner aii* is pressing against the sides of the vessel, and if I open this cock a portion of the air will rush violently out of the vessel. The word * rush,' however, but vaguely expresses the true state of things ; the air which rushes out is driven out by the air behind it ; this latter accomplishes the work of urging for- ward the stream of air. And what will be the condition of the working air during this process ? It will be chilled. It performs mechanical work, and the only agent which it can call upon to perform it is the heat which it possesses, and to which the elastic force with which it presses against | the sides of the vessel, is entirely due. A portion of this ^ heat will be consumed and the air will be chilled. Observe the experiment which I am about to make. I will turn the cock c, and allow the current of air from the vessel v (fig. 4), to strike against the face of the pile p. See how

the magnetic needle responds to the act; its red end k driven towards me, thus declaring that the pile has beeft chilled by the current of air.

The effect is different when a current of air is Jxrgdi from the nozzle of a common bellows against the themu^ electric pile. In the last experiment the mechanical work of urging the sir forward was performed by the air itself and a portion of its heat was consumed in the effort. In the case of the bellows, it is my muscles which perfonn the work. I raise the upper board of the bellows and the air rushes in ; I press the boards with a certain force^ and the air rushes out. The expelled air strikes the face of the pile, has its motion stopped, and an amount of heat equiva- lent to the

destruction of this motion is instantly generated. Thus you observe that when I urge with the bellows b

{iag. 5), a current of sir against the pile, the red end of the needle moves towards you, thereby showing that the face of the pile has been, in this instance, warTnedhj the air. I have here a bottle of soda water ; at present the bottle is slightly warmer than the pile, as you see by the deflection it produces ; I cut the strings which holds the cork, and it

GOLD OF DILATAHOK.

is it driyen out hj Hie elastic force of the carbonic acid gas ; the gas performs work, in so doing consumes heat, and now the deflection it produces is that of cold. The truest romance is to be found in the details of daily life, and here, in operations with which every child is familiar, we shall gradually discern the illustration of principles from which all material phenomena flow.

APPENDIX TO LECTURE L

NOTE ON THE CONSTEUCTION OF THE THEKMO-ELECTBIC PILE.

Let a b (fig. 6) be a bar of antimony, and b c a bar of bis- muth, and let both bars be soldered together at b. Let the free ends A and c be united by a piece of wire, a d c. On warming the place of junction, b, an electric current is generated, the direction of which is irom bismuth to antimony (b to A, or against the alphabet), across the junction, and from an- timony to bismuth (a to b, or with the alpha- bet), through the connecting wire, a d c. The arrow indicates the direction of the current.

If the junction b be chilled, a current is gene- rated opposed in direction to the

former. The figure represents what is called a thermo-electric pair or couple.

By the union of several thermo-electric pairs, a more powerful current can be generated than would be obtained from a single pair. Fig. 7, for example, represents such an arrangement, in which the ehadeMcl bars are supposed to be all of bismuth, and the unshaded ones of antimony ; on warming all the junctions, b, b, &c., a current Ib generated in each, and the sum of these currents, all of which flow in the same direction, will produce a stronger resultant current than that obtained ftom a single pair.

The Y formed by each pair need not be so wide as it is shown in fig. 7 ; it may be contracted without prejudice to the couple. And if it is desired to pack seyeral pairs into a small compasB^

tacb BCparxte couple may be amnged m in flg. 8, where the black Boea repnsent amall biamnth ban, and the white ones ntall ban of sntimoDj. Hie; are soldered together at the ends, and thiotigh- out the lengtli are nsoally separated by stripe of paper merelj. A

collection of pairs thus compactlj set together constitutes a ther- mo-electric pile, a dmning of which ia given in fig. 9.

The current produced by heat being alwajs from bismuth to antimony across the heated junction, a moment's inspection of fig. 7 will show that when any one of the junctions a, a, b heated, a cniTcnt is generated, opposed in direction to that generated when the heat ia ^plied to the junctions b, b. Hence, in the case of the thermo-electric pile, the eScct of heat falling upon its two

rtft a Fig. 9.

Opporite fitcca is to produce currents in opposite directions. If the tempoatore of the two faces be alike, they neutralize each otha*, DO matter how high they may be heated absolutely, but if one of them be warmer than the other, a current is produced. The carrent is thna due to a dfff'tn-enee of temperature between the two

&cea of the pile, and within certain limits the strength of the cur- rest i> ezacUj propottiotied to this difference.

APPENDIX TO LBCTUBB I.

From the jnnction of almost any other two metals, thermo< electric currents may be obtained, but they are most copiously generated by the union of bismuth and antimony.*

NOTE ON THE CONSTBUCTION OF THE OALYANOMETEB.

The existence and direction of an electric current are shown by its action upon a freely suspended magnetic needle.

But such a needle is held in the magnetic meridian by the magnetic force of the earth. Henq^ to move a single needle, the current must overcome the magnetic force of the earth.

Very feeble currents are incompetent to do this in a sufficiently sensible degree. The following two expedients are, therefore, combined to render sensible the action of such feeble currents : —

The wire through which the current flows is coiled so as to surround the needle scyeral times ; the needle must swing freely within the coil. The action of the single current is thus mul- tiplied.

The second device is to neutralize the directive force of the earth, without prejudice to the magnetism of the needle. This is accomplished by using two nee- dles instead of one, attaching them to a common vertical stem, and bringing their opposite poles over each other, the north end of the one needle, and the south end of the other, being thus turned in the same direction. The double needle is represented in ^g. 10.

It must be so arranged that one of the needles shall be within the coil through which the cur-

• The discovery of thermo-electricity is due to Thomas Seebeck, Pro- fessor In the University of Bcriin. Nobili constructed the first thermo- electric pile ; but in Melloni^s bands it became an instrument so important as to supersede all others in researches on radiant heat To this purpose it wUl be applied in future lectures.

THB A8TATI0 NEEDUB.

rent flows, while the otiher needle swings freely aboye the coil, the vertical connecting piece passing thiongh an appropriate slit in the ooO. Werq both the needles within, the same cnzrent would urge them in opposite directiou^ and thus one needle would neu- tralize the other.^ But when one is within and the other without, the current uiges both needles in the same direction*

The way to prepare such a pair of needles is this. Magnetize both of them to saturation ; then suspend them in a yessel, or un- der a shade, so as to protect them from air-currents. Hie system will probably set in the magnetic meridian^ one needle beiog in almost all cases stronger than the other; weaken the stronger needlecarefollyby the touch of a second smaller magnet When the needles are precisely equal in strength, they will set at tight anglM to the magneUc meridian.

It might be supposed that when the needles are equal in strength, the directiye force of the earth would be completely an- nulled, that the doable needle would be perfectly attaUe^ and per-

fectly neutral as regards direction ; obeying simply the torsion of its suspending fibre. This would be the case if the magnetic axes of both needles could be caused to lie with mathematical accuracy in the same vertical plane. In practice, this is next to impos-

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sible ; the axes always cross each other. Let n 9^n* tf (fiff 11) represent the axes of two needles thus crossing, the magnetie meridian being parallel to m e ; let th<) pole n be drawn by the earth's attractire force in the direction n m ; the pole t' being urged by the repulsion of the earth in a precisely opposite direc- tion. When the poles n and «' are of exactly equal strength, it is manifest that the force acting on the pole <', in the case here sap- posed, would haye the advantage as regards leverage, and would therefore overcome the force acting on n. The crossed needles would therefore turn away still further from the magnetic men- dian, and a little reflection will show that they cannot come to rest until the line which bisects the angle enclosed by the needles is at right angles to the magnetic meridian.

This is the test of perfect equality as regards th^ magnetism of the needles ; but in bringing the needles to this state of perfec- tion, we have often to pass through various stages of obliquity to the magnetic meridian. In these cases the superior strength of one needle is compensated by an advantage, as regards leverage, possessed by the other. By a happy accident a touch is some- times sufficient to make the needles perfectly equal; but many hours are often expended in securing this result. It is only, of course, in very delicate experiments that this perfect equality is needed ; but in such experiments it is essential.

Another grave difficulty has beset experimenters, even after the perfect magnetization of their needles has been accomplished. Such needles are sensitive to the slightest magnetic action, and the covered copper wire, of which the galvanometer coils are formed, usually contains a trace of iron sufficient to deflect the prepared needle from its true position. I have had coils in which this deflection amounted to 30 degrees ; and in the splendid in- struments used by Professor Du Bois Raymond, in his researches on animal electricity, the deflection by the coil is sometimes even greater than this. Mellon! encountered this difficulty, and proposed that the wires should be drawn through agate holes, thus avoiding all contact with iron or steeL The disturb- ance has always been ascribed to a trace of iron contained

in the copper wire. Pure silver has also been proposed instead of copper. ■

To punoe his beantifiil lory maimer, Ptofeasor Hagmn. of Berfia. by a most laborioas dectrolytie been obUined, it reqoirBd to be before it ooold be dxmwn into wiie. Ib coil entiiely ritiated the aoancr ai tke any amoont of labour woold be veil eTprniVd

great defect.

My own ezperienoe of this nbyect if

tif ol instnnnent oooatmcted a €rv jtaa a^o br lin, the coil of wbidi, wl my doable needle fiill 90 possible to attain qnanlilaliie

I had the wire remofed by Ifr. BeckcE. in its stead; the ddlectioo fefl to 3 dc^TEca.

This was a great ImfumacBt, boot jgx mtfk'jmt fx aij jnp- pose. I commenced to make inif irirr abois 'At ft ■MTiiTTrj 4f obtaining pore copper, but the rsoh was -rsj t^aennaacxaz, iv^hen, almost despairing, the foij^^riz^ ibt'ss^iz xrsrr^ \\ mt . The action of the cofl most be dx z*j thit i»izilrrrr» :cf jr.c -wrx the copper, for pure copper i* ^Hxr^tr^^xx. ^ 2* fecij '^yfZri r^ a strong magnet. The magset ihs*^'.rt <rjcL:nti "zr^ lut ts % means of instant analvss : I oocH UxL by h. iz. i 3i«:aii*n£. Tiitrjifr any wire was free from the magrccac irytA? ^r icc

The wire of M. Saoerwald's caH wts scr^oc^-r zzzixsaisi \^ zut magnet. The wire of Mr. Becker s osL wis ^^c xsrusz^ u* jici in a much feebler degree.

Both wires had been corcred by jzTBei slk : I yswjr^i tiiH. but the Berlin wire was still attracted : VJt Tj^*^-^ wirt. -.c 'jla contrary, when presented uaJxd to i*^ cub^u*: ww i*^,:j repelled; it was trnly diamagnetic. aad c:^:iiis«5d !«:» «2i*C:»j* trace of iron. Thus the whole Muxrjiaxft wm IxM ^a^.^ rz^ green silk ; some iron compomid b^ \^tisi Twtd is ti^ ct^^-j of it, and to this the deriatioo of the needje ^ja zero tu :zaz^ festly due.

I had the green coating remored azid tit wire OTi!T*f^=i -"-rih white silk, clean

hands being used xn the process. A f0iTi'x.t ;pi- yanometer is the result ; the needle, when releatei from the MXxa

APPENIHZ TO LBOrnSB I.

of the current, retumB accurately to zero, and is perfectly free from all magnetic action on the part of the coiL In fact, while we have been deviBing agate plates and other learned methods to get rid of the nuisance of a magnetic coil, the means of doing so are at hand. Let the copper wire be selected by the magnet, and no difficulty will be experienced in obtaining specimens magnetically pure.

[Jnnmrj W, 1M2.]

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THKEMAL EfFKCHI OW AIM Of

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FORD, BATT, AJO) JOCLI — FHS MlTBATiraL

BEAT OEimATXD BT

BT STOPPING THB XABTH'S

HZAT — FLAME Of RB BBLATIOX TO

appendix: — EZTEACTS FEOB BACOS A3^

IN our last lecture the developement of heat br metiam- ical action was illostrated br a series of expcrimenss, which showed that heat was easDr prodnoed hr fncskm, by compression, and hj percossioiL But facts alooe esn not satisfy the human mind ; we desire to know the izmer and invisible cause of the fact ; we seardb afler the prin- ciple by the operation of whidi the phenomena are pro- duced. Why should heat be generated by mfM-h^nirfA ac- tion, and what is the real nature of the agent thus gene- rated ? Two rival theoiies hare been offisred in answer to these questions. TRll

Tery lately, however, one of t)

the material theory — had the greater number of ^flterents, being opposed by only a few oninent men. Within cer- tain limits this theory involved conceptions of a very sim- ple kind^ and this simplicity secured its general acceptance. The material theory supposes heat to be a kind of matter subtle fluid — stored up in the inter-atomic spaces of

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bodies. The laliorious Gmeliii, for example, in his Hand- book of Chemistry, defines heat to bo ' that Babstance whoso entrance into our bodies causes the sensation of warmth, and its egress the sensation of cold.'* He also speaks of heat combining with bodies as one ponderftble

/ substance does with another ; and many other eminent chemists treat the subject from the same point of view,

The developement of heat by mechanical means, inas- much as its generation seemed unlimited, was a great diffi- culty with the materialists ; but they were acqasinted with the fact (which I shall amply elucidate in a future leotnre) that different bodies possessed different powers of holding

t heat, if I may use such a. term. Take, for example, the two liquids water and mercury, and warm up a pound of each of them, say from fifty degrees to sixty. The abso- lute quantity of heat required by the water to nuse its temperature 10° is fully thirty times the quantity required by the mercury. Technically speaking, the water ia SJud to have a greater capacity for heat than the mercury has, and this term ' capacity ' is sufficient to surest the views of those who invented it. The water was snpposed to possess the power of storing up the caloric or matter of heat ; of hiding it, in fact, to such an extent that it required

I thirty measures of this caloric to produce the same sensible

I effect on it, that one measure would produce upon mercury. All substances

possess, in a greater or less degree, this apparent power of storing up heat. Lead, for example, possesses it ; and the experiment with the lead bullet, in which you saw heat generated by compression, was explain- ed by those who held the material theory in the follow- ing way. The uncompressed lead, they said, has a higher capacity for heat than the compressed substance ; the size of its atomic storehouse is diminished by compression, and

* English TnmslatioD, vol. i. p. 22.

MATERIAL AND DYNAIOOAL THEORIES OF HEAT. 39

hence, when the lead is sqneesed, a portion of that heat which, preyions to compression, was hidden, must make its appearance, for the compressed substance can no longer hold it alL In some similar way the experiments on frio- ' tion and percnssion were accomited for. The idea of call- ing new heat into existence was rejected bj the believers in the material theory. According to their views, the quantity of heat in the universe is as constant as the quantity of ordinary matter, and the utmost we can do by mechanical and diemical means, is to store up this heat or to drive it from its lurking place into open light of day.

The dynamical theart/^ or, as it is sometimes called, the • mechanical theory of heat, discards the idea of materiality ' as applied to heat. The supporters of this theory do not believe heat to be matter, but an accident or condition of matter ; namely, a motion of its ultimate particles. From the direct contemplation of some of the phenomena of heat, a profound mind is led almost instinctively to con- clude that heat is a kind of motion. Bacon held a view of this kind,* and Locke stated a similar view with singiilar felicity. * Heat ' he says, ' is a very brisk agitation of the insensible parts of the object, which produce in us that sensation from whence we denominate the object hot ; so what in our sensation is heat^ in the object is nothing

but i motion.^ In our last lecture I referred to the experiments t of Count Rumford f on the boring of cannon ; he showed that the hot chips cut from his cannon did not change their capacity for heat ; he collected the scales and powder pro- duced by the abrasion of his metal, and holding them up

* See Appendix to this Lecture.

f I hare particular pleasure in directing the reader's attention to an abstract of Count Rumford^s memoir on the Generation of Heat by Fric- tion, contained in the Appendix to this lecture. Rumford, in this me- moir, annihilates the material theory of heat. Nothing more powerful on the subject has since been written.

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before his opponents, demanded whether they belieyed that the vast amonnt of heat which he had generated had been all squeezed out of that modicum of crushed metal ? * You have not,' he might have added, ' given yourselves the trouble to enquire whether any change whatever has occurred in the capacity of the metal for heat by the act of friction. You are quick in inventing reasons to save your theory from destruction, but slow to enquire whether these reasons are not merely the finespun fancies of your own brains.' Theories are indispensable, but they some- times act like drugs upon the mind. Men grow fond of them as they do of dram-drinking, and often feel discon- tented and irascible when the stimulant to the imagination is taken away.

At this point an experiment of Davy comes forth in its true significance.* Ice is solid water, and the solid has I only one half the capacity for heat that liquid water pos- >. sesses. A quantity of heat which would raise a pound of ice ten degrees in temperature, would raise a pound of wa- ter only five degrees. Further, to simply liquefy a mass of ice, an enormous amount of heat is necessary, this heat being so utterly absorbed or rendered ' latent ' as to make no impression upon the thermometer. The question of ' latent heat ' shall be fully discussed ia a future lecture

; what I am desirous of impressing on you at present is, that £ liquid tocUer, at its freezing temperature, possesses a vastly f greater amount of heat than ice at the same temperature. Davy reasoned thus : * If I, by friction, liquefy ice, I produce a substance which contains a far greater absolute ' amount of heat than the ice ; and, ia this case, it cannot, , with any show of reason, be affirmed that I merely render ; sensible the heat hidden in the ice, for that quantity is only a small fraction of the heat contained in the water.' He

* Works of Sir H. Davy, vol ii, p. 11.

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made the experiment, and liquefied the ice by pnre friction ; and the result has been regarded as the first whidi proved the immateriality of heat.

I . When a hammer strikes a bell, the motion of the ham- mer is arrested, but its force is not destroyed; it has thrown the bell into vibrations, which affect the auditory nerves as sound. * So, also, when our sledge hammer de- scended upon our lead bullet, the descending motion of the sledge was arrested : but it was not destroyed. Its motion was trantferred to the atoms of the Uad^ and announced it- self to the proper nerves as heat The theory, then, which Rumford so powerfully advocated, and Davy so ably sup- ported,* was, that heat is a kind of molecular motion ; and that, by friction, percussion, or compression, this motion may be generated, as well as by combustion. This is the theory which must gradually developc itself during these lectures, until your minds attain to perfect clearness re- garding it. And, remember, we are entering a jungle,«and must not expect to find our way clear. We are striking into the brambles in a random fashion at first ; but we shall thus become acquainted with the general character of our work, and, with due persistence, shall, I trust, cut through aU entanglement at last.

In our first lecture I showed you the effect of projecting a current of compressed air

against the face of the thermo- electric pile. You saw that the instrument was chilled by the current of air. Now, heat is known to be developed when air is compressed ; and, since last Thursday, I have

* In Dayy^fl first scientific memoir, ho calls heat a rcpulsiye motion, which he says maj be augmented in yarious ways. * First, by the trans- mutation of mechanical into repulsive motion ; that is, by friction or per- cussion. In this case the mechanical motion lost by the masses of mat- ter in friction is the repulsive motion gained by their corpuscles : * an extremely remarkable passage. I have given further extracts from this pi4>er in the Appendix to Lecture in.

been asked how tliis heat was disposed of in the case of the condensed air. Pray listen to mj reply. Supposing the vessel which contained the compressed air to be formed of a substance perfectly impervious to heat, and supposing all the heat developed by my arm, in compressing the air, to be retained within the vessel, tha^ quantity of heat would be exactly, competent to undo what I had done and to restore the compressed air to its original volume and temperatoie. But this vessel v (fig. 12), is not impervious to heat, and it was not my object to draw upon the heat developed by my

arm; I therefore, after condensing the air, allowed the vessel to rest, tiU all the heat generated by the condensa- tion had been dissipated, and the temperature of the air within and without the vessel was the same. When, there- fore, the air rushed out, it had not the heat to draw upon, which had been developed dui-ing compression. The heat from which it derived its elastic force was only sufficient to keep it at the temperature of the surrounding air. In doing its work a portion of this heat, equivalent to the

rms SYXDroK

work done, was oonsmned, and the inning air qaently chilled. Do not be disheartened if this dionld not appear quite dear to yon. We arc paratdve darlmesSy

bat as we proceed £^ht will gEsdoaDj appear, and irradiate retrospectiTdj our pwaeiit glocni.

I wish now to make evident to joa that beat is devel- oped by the compression of air. Hoe is a stiQag cvfinder of glass T V (fig. 13), aocnratelj bored, and qpte SBoock within. Into it this pisUm fits air-d^^ so tliat, hjdmmg the piston down, I can fordhl j compress the air nndemeath it; and when the air is thns cobi- ^^^ pressed, heat is suddenly generated. Let me prove this. I take a m<»8el of cotton wool, and wet it with this volatile liqmd, the tiiwlphide of carbon. I throw this bit of wetted cbftton into the glass syringe, and instantly eject it. It has left behind it a small residue of vapour. I com- press the sir suddenly, and you see a flash of li^t within the syringe. The heat developed by the compression has been sofBdent to ignite the vapour. It is not necessary to eject the wetted cotton ; I replace it in the tube, and urge the pi»- ton downwards ; you see the flash as before. II, with this narrow glass tube, I blow out the fumes generated by the combusti<m of the vapour, I can, without once removing the cotton from the syr- inge, repeat the experiment twenty times.^

I have here arranged an experiment intended to give you another illustration of the thermal eflect produced in air. by its own mechanical ac- tion. Here is a tin tube, stopped at both ends, and con- nected with this air-pump. The tin tube is at present full of air, and I bring the ia6e of my pile up against the

* The accident which led to this form of the experimeni if referred to in the Appendix to this Lectore.

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curred surface of the tube. The instrument declares that the face of the pile in contact with the tin tube has been warmed by the latter. I was quite prepared for this resully^ having reason to know that the air within the tabe ii slightly wanner than that without. Now, what you are to observe is this : — ^My assistant shall work the pump ; the cylinders of the machine will be emptied of air, and the air within this tin

tube will be driven into the exhausted cyl- inders by its own elastic force. I have already demcoh strated the chilling effect of a current of compressed air <m the thermo-electric pile. In the present experiment I will not examine the thermal condition of the current at all, but of the vessel in which the work has been performed. As this tube is exhausted I expect to see the needle, which is now deflected so considerably in the direction of heat, descend to zero, and pass quite up to 00° in the direction of cold. The pump is now in action, and observe the re- sult. The needle falls as predicted, and its advance in the direction of cold is only arrested by its concussion against the stops.

Three strokes of the pump suffice to chill the tube so as to send the needle up to 00° ; * let it now come to rest. It would require more time than we can afford to fdlow the tube to assume the temperature of the sir around it ; but the needle is now sensibly at rest at a good distance on the cold side of zero. I will now allow a quantity of air to enter the tube, equal to that which was removed from it a moment ago by the air-pump. I can turn on this cock, the air will enter, and each of its atoms will hit the inner surface of the tube like a projectile. The mechanical mo- tion of the atom will be thereby annihilated, but an amount

* The galyanometer used in this experiment was that which I employ In my original researches : it is an exceedingly delicate one. When intro- duced in the lectures its dial was illuminated by the electric light ; and an (mage of it, two feet in diameter, was projected on the screen.

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of heat eqmvilent to UiiB motion win be generated. Thus as the air enters it will develope an amount of heat snffi. aent to re-warm the tube, to mido the present deflec^on, and to send the needle up on the heat side of aero. The air is now entering, and you see the eflRect: the needle moTea, and goes quite up to 90° on that side whidi indi- cates the heating the pile.*

I have now to direct your attenticm to an interesting effect connected with this chilling of the air by rarefaction. I place over the plate of the air pump a large ^ass receiver, which is now filled with the air of this room. This air, and, indeed, all air, unless it be dried artificially, contains m quantity of aqueous rapour whidi, as rapour, is perfectly inyisible. A certain temperature is requisite to maintain the vapour in this invisible state, and if the air be chilled so as to bring it below this temperature, the vapour will instantly condense, and form a visible cloud. Such a cIou«l, which you will remember is not rapot/r, but liquid tr<rftrr in a state of fine division, will form within this glass vef *f<:l B (fig. 14), when the air is pumped out of it ; and to make this effect visible to everybody present, to those right and left of me, as well as to those in front, these six little g^ jets are arranged in a semicircle, which half surrounds the receiver. Eadi person present sees one or more of these

* In this experiment a mere line along the suHace of the tube vas in contact with the faee of the pile, and the beat had to propagate iti^rlf throngh the tin enrelope to readi the instroment Prerioas to adopting this arrangement I had the tube pierced, and a separate pile, vith it^ naked face turned inwards, cemented air-tight into the orifice. The pile came thus into direct contact with the air, and its entire lace was expc«&d to the action. The effects thus obtained were rerj large ; soiBdent, md(.-*:'\, to swing the needle quite round. Mj desire to complicate the subject a« little as possible induced me to abandon the cemented pfle, and to make use of the instrument with

which mj audience had already become familiar. With the arrangement actually adopted the effects were, moreorer, m large, that I drew only on a portion of my power to produce them.

' jet9 oa lookiDg throngh the receiver, and -when the dond fonns, the dimness which it prodaces will at once declara its presence. The pump is now qnickly worked ; a very few Btrokea suffice to precipitate the vapour ; there it spreada throughout the entire receiver, and many of you see a ool'

oaring of the cload, as the light shines through it, umilar

to that observed sometimes, on a large scale, around the

moon. When I allow the air to re-enter the vessel, it is

, heated, exactly as in the experiment witji our tin tabe ;

the cloud melts away, and the perfect transparency of the

!; air within the receiver is restored. Again I eshaust and

'}. again the cloud forms ; once more the air enters and the

i cloud disappears ; the heat developed being more than snffi-

i cient to preserve it in the state of pure vapour,"

Sir Humphry Davy refers, in hia ' Chemical Philos- ophy,' to a machine at Schcmnitz, in Himgary, in which air was compressed by a coltunn of water 260 feet Iq height. When a stopcock was opened, so as to allow ths ■ See Note (1) at tbe end of this Lecture,

lir to eseape, a degree of coil w iLufliijoi ^vintt ms qbIj predpitaxed the aqsecNB tj^eozt ^J&aaa a -sm msl bnt caosed it to ccngal is % db-Z'Wer <j£ ^atm^ ^mintt ijtt pqie fromidiidi the air jasaed ^mh ■iim boraad ^Dr. Darwin,' writes Darr, * ki5 hssaasmtr

production of siow en the tops of ihtt raetirm 3iuiiiiiikz&. \ bj the predpitadan of tapoaj froa. 'att zarefieie mc wiuri t aaeends fixm plams aad Tilkj& Jht- AMSk^iaad.

miblx: under the line, rise in the miis of "^wnnnc aanoi : ^tnxc the middle height is a pleasact s»d v3ka eonau: "as finxL- mits are coTered with uiM'iiiiiii'ag sdc^wl*

I would now T&qpesi tost gSfaraM Ut aDDOier dgtsiTi- ment, in whidi heat will be dereirwi rj W2;ic sixk s* pear to many of yon a ^€tj mT3ccri:faf a^sxirj. auL niDkrrL the most instnxted aooogst ns tiicw. ix r^tirj. Tirj Ime about the subject. I wish to dertiMix* hec ij ^riac nu^nz : be regarded as fiiction a^auai pv^ *p^^*- -^- ju^^siri i: ' may be, and probably is. dae to a kznd cf fnr^JuL iignn?^ that inter-fteHar me£mn. to wladi 'wt aaiL iiSTi ussk&i'JL

to refer more fuDr br aad b^.

I hare here a mass of ircm — fan c^ a mi of & iixtr^ diain cable — ^which is smroaadol ly isiese imkhfnik: sri'Li • of copper wire c c (fig. 15), aad which I cbb Tiwrairj sin- * Tert into a powerful magnet by teaSas m fjfrsrir cetet: through the wire. You see, when ^ms rxrirsiiL brw p:"-- erful it is. This poker dngs to it. aad tiioae fg-'yfcA. screws, and nails c£ng to the poloer. Tcscd lyaft^ &:-wi. this maenet will hold a half hundred wea^d wsaotSfi i: eacn of its poles, and probably a loose of the hesn^f:; T*e> pie in this room, if EU^>ended from the wcb^;;:^. Ai 'l.-^ proper signal my asastant will intemipt the tiksesrjf i-rr- rent : — ^ Break ! ' The iron falls, and all the rsagae ci-x^- pears: the magnet now is mere o&nzzaco iroB. At \la ends of the magnet I place two pkees of iron t ? — EL:-r. able poles, as they are called — whidi, when the zuikgije: is

AFPASENT YlSOOfiETT OF ICAGNEIIO FIELD. 49

imexcited, I can bring within any reqnired distance of each other. When the cnrrent passes, these pieces of iron vir- toallj form parts of the magnet. Between them I will place a sabstance which the magnet, eyen when exerting its utmost power, is incompetent to attract. This substance is simply a piece of silver — ^m fact, a silver medal. I brino- it dose to the excited magnet ; no attraction ensues. In- deed, what little force — and it is so little as to be utterly insensible in these experiments —

^the magnet really exerts upon the silver, is repulsive instead of attractive.

Well, I suspend this medal between the poles p p of the magnet, and excite the latter. The medal hangs there ; it is neither attracted nor repelled, but if I seek to move it I encounter resistance. To turn the medal round I must overcome this resistance ; the silver moves as if it were surrounded by a viscous fluid. This curious eflect may also be rendered manifest, thus : I have here a rectangular plate of copper, and if I cause it to pass quickly to and fro like a saw between the poles, when their points are turned towards it, I seem, though I can see nothing, to be sa^-ing through a mass of cheese or butter.* Nothing of this kind is noticed when the magnet is not active : the copper saw then encounters nothing but the infinitesimal resistance of the mr. Thus far you have, been compelled to take my statements for granted, but I have arranged an experiment which will make this strange action of the magnet on the silver medal, strikingly manifest to everybody present.

Above the suspended medal, and attached to it by a bit of wire, I have a little reflecting pyramid m, formed of four triangular pieces of looking-glass ; both the medal and the reflector are suspended by a thread which was twisted in its manufacture, and which will untwist itself when the weight it sustains is set free. I place our electric lamp so

* An experiment of Faraday^s.

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as to cast a strong beam of light on this little pynoiud: you see these long spokes of light passing throng tlMl dusty air of the room as the mirror tarns.

Let us start it from a state of rest. Tou now see the beam passing through the room and striking againefe' the white wall. As the mirror commences to rotate, the pelA of light moves, at first slowly, over the wall and oeiliiigi But the motion quickens, and now you can no longer Hi the distinct patches of light, but instead of them yon lum this splendid luminous band fully twenty feet in diainfitBT drawn upon the wall by

the quick rotation of the reflected beams. At the word of command the magnet will be efr cited, and the motion of the medal will be instantly stopped. ' Make ! ' See the effect : the medal seems struck dead by the excitement of the magnet, the band suddenly disappears, and there you have the single patch of light upon the wall. This strange mechanical effect is produced without any visible change in the space between the two poles. Observe the slight motion of the image on the wall : the tension of the string is struggling with an unseen antagonist and producing that slight motion. It is such as would be produced if the medal, instead of being surrounded by air, were immersed in a pot of thick trea- cle. I destroy the magnetic power, and the viscous charac- ter of the space between the poles instantly disappears ; the medal begins to twirl as before ; there are the revolving beams, and there is now the luminous band. I again ex- cite the magnet : the beams are struck motionless, and the band disappears.

By the force of my hand I can overcome this resistance and turn the medal round ; but to turn it I must expend force. Where does that force go ? It is converted into heat. The medal, if forcibly compelled to tura, will be- come heated. Many of you are acquainted with the grand discovery of Faraday, that electric currents are developed

HUI OBI^BUn) Tt XACSSnC JIEIJlL

en » emdoetor of d«tricit7 is set in modon Ixiwmm ptdes of a m^n^ We hsTV these cnneots donbtibM «, and they ire competent to heat the medaL Ba mhat theae cnmnts ? how are thej: related to the tp^ be- sai dte magnetic poles — faov to the force of mr ann itb is expended in their generation ? We do not jet nr, bat ire sliaQ know hj and br. It does not in tlK It leaKU the interest of the expenment if the force &f ■nn, previons to ^ipearii^ as heat,.appean in another i m — In the form of electiieitj-. The nldnute nsoh » ' I mnm : the heat developed ultimately is the exart cqidr- nt of the qoantity of strength reqaired to more the dal in the exated magnetic

field.

I wish now to show yon the derelopement of faeat by I action. I hare here a solid metal cylinder, the core which is, howerer, composed of a metal more eaaly Ited than its outer case. The oater case is copper, and I ia filled by a hard but foible alloy. I set this cylinder ij^t between the conical poles p p (fig. 16) of the mag-

. A string s s passes from the cylinder to a whirling le, and by turning the latter the cylinder is caused to a round. It might turn till doomsday, as long as the gttet remains unexcited, without producing the efled ■gilt ; but when the magnet is in action, I hope to be f \e to devclope an amount ot heat sufficient to melt the re of that cylinder, and, if successful, I will pour the aid metal out before you. Two minutes will suffice for B experiment. The cylinder is now rotating, and its

S3 LSCrCBE'n.

upper end is open. I shall leave it tfaas open until the liquid metal is seen spattering over the poles of the mag- net. I already see the metallic spray, though a minute has scarcely elapsod since the commencement of the expen- mcQt. I now stop the motion for a moment, and cork up the end of the cylinder, so as to]irevent the scattering about of the metal. Let the aelion conlume for half a min- ute longer ; the entire mass of the core is, I am persuaded, now melted. I withdraw the cylinder, remove the cork, and here is the liquefied mass, which I thus pour out before you.*

It is now time to consider more closely than we luTe hitherto done, the relation of the heat developed by me- chanical action to the force which produces it. Doubtless I this relation floated in many minds before it received either distinct cnimciation or experimental proof. Those who reflect on vital processes — on the changes which occur in the animal body — and the relation of the forces involved in food, to muscular force, are led naturally to entertwn the idea of interdependence between these forces. It is, there- fore, not a matter of surprise that the man who first raised the idea of the equivalence between heat and mechanical energy to philosophic

clearness in his own mind, was a physician. Dr. Mayer, of Heilbronn, in Germany, enund- atcdf the exact relation which subsists between heat and work, giving the number which is now known as the ' me- chanical equivalent of heat,' and following up the state- ment of the principle by its fearless application.^ It is,

* Tlie dcrelopcmcnt of heat b; caoaag a conductor to revolve betireeii the potcs of a mignct vaa first effected by Ur. Joule (Phil. Ilag. ml. ziiii Srd Scries, jear 1843, pp. 355 nod 439), and Us eipeiimeDt ma aflo irarda rciivcd in a slrilting form b; M. Foucault. Tbe artifice above described, of fusing the core out o(the cylinder, rendcis the cipetimeat Tcry cdective in the lecture-room.

f In 1842. Sec Note (S) at the ead of (lus Lecture^

i See Lectures III. and XUL

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however, to Mr. Joule, of Manchester, that we are ahnost wholly indebted for the expertmentcU treatment of this im- portant subject. Entirely independent of Mayer, with his mind firmly fixed upon a principle, and undismayed by the coolness with which his first labours appear to have been received, he persisted for years in his attempts to prove the invariability of the relation which subsists between heat and ordinary mechanical force. He placed water in a suitable vessel, and agitated that water by paddles, driven by measurable forces, and determined both the amount of beat, developed by the stirring of the liquid, and the amount of labour expended in the process. He did the same with mercury and with sperm oil. He also caused disks of cast iron to rub against each other, and measured the heat produced by their friction, and the force expended in overcoming it. He also urged water through capillary tabes, and determined the amount of heat generated by the friction of the liquid against the sides of the tubes. And the results of his experiments leave no shadow of doubt upon the mind that, imder all circumstances, the quantit}^ of heat

generated by the same amount of force is fixed and invariable. A given amount of force, in causing the iron disks to rotate against each other, produced precisely the game amount of heat, as when it was applied to agitate water, mercury, or sperm oil. Of course, at the end of an experiment, the temperatures in the respective cases would be very different ; that of the water, for example, would be ^'ffth of the temperature of the mercury, because, as we already know, the capacity of water for heat is 30 times that of mercury. Mr. Joule took this into account in re- ducing his experiments, and found, as I have stated, that, however the temperatures might differ, in consequence of the different capacity of heat for the substances employed, i the absolute amoufU of heat generated by the same expend- 1 itoie of power, was in all cases the same. '

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In this way it was fouod thai the qoaiitity of beit which would raise one pound of water one degree Fahr. in temperature, is exactly equal to what would be generated if a pound weight, afler having lallea through a height of 112 feet, has its moving force destroyed by collision with the earth. Conversely, the amount of heat necessaiy to raise a pound of water one degree in temperature, would if all applied mechanically, be competent to raise a poimd weight 772 feet high, or it would raise 772 Ibe. one foot high. The term ' foot-pound ' has been introduced to «& press, in a convenient way, the lifting of one pound to the height of a foot. Thus the quantity of heat neceasary to raise the temperature of a pound of water one degree being

^ taken as a standard, 772 foot-pounds constitute what]s

%called tTie mechanical, equivalent of heat.* ^ In order to imprint upon your minds the thermal effect produced by a body falling from a height, I will go through the experiment of allowing a lead ball to fall from our ceiling upon this floor. The lead ball is at the present mo- ment shglitly colder than the air of this room. I prove this by bringing it in contact with the thermo-electric pile, and showing you that the

deflection of the needle indicates cold. Here on the floor I have placed a tlab of iron, on which I intend the lead to fall, and which, yon observe, ia also cooler than the air of the room. At the top of the house I have an assistant, who will heave up the ball after I have attached it to this string. He will not touch the ball, nor will he allow it to touch anything else. He will now let it go ; it falls, and is received upon the plate of iron. The height is too small to get much heat by a single fall ; I will therefore have tlie bait drawn up and dropped three or four ttmes in succession. Observe, there is a length of covered wire attached to the ball, by which I lift it, so that my hand never comes near the ball. There is the fourth collision, and I think I may now examine ths * See Kote (3) at Iho eDd of this Lecture.

^UECHASKJLL EQCITALESrr^ OF KEJkT. U

tflpqperstuTe of the lead. I pbee the baE. wiaA s t^ I

1 1 ; u I r k-. ^ M I u

WIS oold, ^giin upoa the pile, aad tike im- mediate deflectum of the needle in the oppoaxe £ree5'Da. dedares that now the ball is heated ; this hea is dae es- tirdy to the destmctiiRi of the moTing ener^ whicL iLe ball possessed when it stnu^k the plate of iron. Aoecrdirg to onr theory, the common medianieal motion of xLe bill as a mass, has been transferred to the axoms of the &&£&. | prodncing among them the agitation which we call hea;:.

What was the total amount of heai thss gCDera;e*i ? The spaee fallen throogh bj the ball in each erpeiimea: is twent j-ox feet. The heat generated is proponiooal lo ihe height through which the body £dls. Not a ball of IkaL in falling throng 772 feet, would generate hesx szfExLezr. to raise its own temperature 30', its *• edacity * being j jth of that of water : hence, in filling throizgh .0 feet, vLid: is in rocmd nmnbers ^^ of 772, the heat generate! voiIL if all concentrated in the lead, raise its texnpenit^ire o=.e -ir- gree. This is the amount of heat generaurii by a ^inrle descent of the ball, and four times this aniooct wcfzlL of course, be generated by four

descents. The hea:: gen^r&tol is not, howerer, all concentrated in the ball ; it is diTi«i'.^i between the ball and the iron on which it falls.

It is needless to say, that if motion be imparte«i :o a body by other means than gravity, the destnction of tlis motion also produces heat. A rifle bullet, when it strikes a target, is intensely heated. The mechanical equivalent of heat enables us to calculate with the utmost accuracy the amount of heat generated by the buHet, when its ve- locity is known. This is a point worthy of our attention, and in dealing with it I will address myself to those of m v audience who are unacquainted even with the elements of mechanics. Everybody knows that the greater the height is from which a body falls, the greater is the force with which it strikes the earth, and that this is entirely due to

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the greater velocity imparted to the ball, in falling from the greater height. The velocity imparted to the body is not| however, proportional to the height from which it fidh. If the height be augmented four-fold, the velocity is mg- mented only two-fold ; if the height be augmented nine- fold, the vdocity is augmented only three-fold ; if tlie height be augmented sixteen-fold, the velocity is augmented only four-fold ; or, expressed generally, the height ngr mcnts in the same proportion as the square of the vdodllgr*

But the heat generated by the collision of the '&ISti$ body increases simply as the height; consequently, fli heat generated increases as the square of the vdocUy. .^

If, therefore, we double the velocity of a projckalile, at' augment the heat generated, when its moving force is da> stroycd, four-fold ; if we treble its velocity, we augment the heat nine-fold ; if we quadruple the velocity, we augment the heat sixteen-fold ; and so on.

The velocity imparted to a body by gravity in fEiDing through 772 feet is, in round numbers, 223 feet a second, that is to say, immediately before the body strikes the

earth, this is its velocity. Six times this quantity or 1,888 feet a second, would not be an inordinate velocity for a rifle bullet.

But a rifle bullet, if formed of lead, moving at a ve- locity of 223 feet a second, would generate, on striking a target an amount of heat which, if concentrated in the bul- let, would raise its temperature 30° ; with 6 times this ve- locity it will generate 36 times this amount of heat ; hence 36 times 30, or 1,080°, would represent the augmentation of temperature of a rifle ball on striking a target with a velocity of 1,338 feet a second, if all the heat generated were confined to the buUet itself. This amount of heat would be far more than suificient to fuse the lead ; but in reality a portion only of the heat generated is lodged in the ball, the total amount being divided between it and the

EELATIOX OF HEAT TO VKL0<1Tr. r,7

iargeU Were the ball iron instead of lead, the heat gen- ented, under the ooniditionB snppofled, would be competent to raiae the tempamture of the ball onlj by about ^rd of 1,060% beosase the cqMidtjr of iron for heat is about three toMatlntofkad.

Fram theae conaiderationa I think it ia mamfeat that if vtt kBKnr the vdodty and weight of any projectile, we can fflifcmhtfti with eaae, the amount of heat dereloped by the dcatrnfldon of ita moying force. For example, knowing, aa W6 do» the weight of the earth, and the Telocity with whidk it movea through qpaoe, a aimple calcuhition would enaUe us to determine the exact amomit of heat which woidd be deroloped, auppoaing the earth to bo stopped in bar iarbit, We could 'tell, for example, the number of de- grees irfdeh thia amoont of heat would impart to a globe of water equal to the earth in aize. Mayer and Helmholtz have made thia calcnlation, and fomid that the quantity of heat generated by thia colosaal shock would be quite suffi- danti not only to fnae the ^tire earth, but to reduce it, in great part, to Tapour. Thus, by Ihe simple stoppage of the earth in ita orbit ^ the elements ' might be caused ' to melt with ferrent heat.' The amount of heat thus devel- oped would be

equal to that derived from the combustion of fourteen globes of coal, each equal to the earth in mag- nitude. And if, after the stoppage of its motion, the earth shookL fall into the sun, as it assuredly would, the amount of heat generated by the blow would be equal to that de- veloped by the combustion of 6,600 worlds of solid carbon. Knowledge, such as that which you now possess, has caused philoaophers, in speculating on the mode in wliich the sun ia nourished, and his supply of light and heat kept up, to suppose the heat and light to be caused by the showering down of meteoric matter upon the sun's sur- face.^ Some philosophers suppose the Zodiacal Light to

* Ibyer propounded this hypothesis in 184S, and worked it fully out 8*

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be a cloud of meteorites, and from it, it is imagined, tha showering meteoric matter may be derived. Now, what- ever be the value of this speculation, it is to be borne in mind that the pouring down of meteoric matter, in the way indicated, would be competent to produce the light and heat of the sim. With regard to the probable troth or fallacy of the theory, it is not necessary that I should offiar an opinion ; I would only say that the theory deals widi t cause which, if in sufficient operaticm, would be competeni to produce the effects ascribed to it.

Let me now pass from the sun to something lees, — m fact, to the opposite pole of nature. And here that divine power of the human intellect which annihilates mere mag- nitude in its dealings with law^ conies conspicuously into play. Our reasoning applies not only to suns and planets, but equally so to the very ultimate atoms of which matter is composed. Most of you know the scientific history of the diamond, that Newton, antedating intellectually the discoveries of modem chemistry, pronounced it to be an unctuous or combustible substance. Everybody now knows that this brilliant gem is composed of the same substance as common charcoal, graphite, or plumbago. A diamond is pure carbon, and carbon bums in oxygen. I

have here a diamond, held fast in a loop of platinum wire ; I will heat the gem to redness in this fiame, and then plunge it into this jar, which contains oxygen gas. See how it brightens on entering the jar of oxygen, and now it glows, like a little terrestrial star, with a pure wlute light. How are we to figure the action here going on ? Exactly as you would present to your minds the conception of me- teorites showering down upon the sun. The conceptions

It waa afterwards enunciated independently by Mr. "Waterston, and devel- oped by Professor William Thomson (Transactions of the Royal Soc of Edinb., 1853). See Lecture XII.

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are, in quality, the same, and to the intellect the one is not more difficult than the other. Tou are to figure the atoms of oxygen showering against this diamond on all sides. They are urged towards it by what is called chemi- cal affinity, but this force, made dear, presents itself to the mmd as pure attraction, of the same mechanical quality, if I may use the term, as gravity. Every oxygen atom, as it strikes the surface, and has its motion of translation de- stroyed by its collision with the carbon, assumes the motion which we call heat : and this heat is so intense, the attrac- tions exerted at these molecular distances are so mighty, that the crystal is kept white-hot, and the compound, formed by the union of its atoms with those of the oxy- gen, flies away as carbonic acid gas.

Let us now pass on from the diamond to ordinary flame. I have here a burner from which I can obtain an ignited jet of gas. Here is the flame : what is its constitu- tion ? Within the flame we have a core of pure unbumt gas, and outside the flame we have the oxygen of the air. The external surface of the core of gas is in contact with the air, and here it is that the atoms clash together and produce light and heat by their collision. But the exact constitution of the flame is worthy of our special attention,

and for our knowledge of this we are indebted to one of Davy's most beautiful investigations. Coal-gas is what we call a hydro-carbon ; it consists of carbon and hydrogen In a state of chemical union. From this transparent gas es- cape the soot and lampblack which we notice when the combustion of the gas is incomplete. Soot and lampblack are there now, but they are compounded with other sub- stances to a transparent form. Here, then, we have a sur- face of this compound gas, in presence of the oxygen of our air ; we apply heat, and the attractions are instantly so intensified that the gas bursts into flame. The oxygen has a choice of two partners, or, if you like, it is in the

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prcscDco of two foes ; it closes with that which it likei best, or hates most heartily, as the case m&j he. It fint closes with the hydrogen, and sets the carbon free. BdSA particles of carbon thus scattered in numbers innumeraUa

(in the midst of burning matter, arc raised to a state of ia- tense incandGEccDce ; they become white-hot, and mainly to them the liffht of our lamps is due. The carbon, however, in duo time, closes with the oxygen, and becomes, or on^it to become, carbonic acid ; but in passing from the bydnh gen with which it was first combined, to the oxygen, wlHi which it enters into final nidd^ it exists, for a time, in the ri^ glc state, and, as a bachelor; It [gives us all the splendonrofitl light.

The combustion of a candle is in principle the same as that I of a jet of gas. Here you have a rod of was or tallow (fig. 17), through which is passed the cotton wick. You ignite the wick; it bums, melts the tal- I low at its hasG, the liquid as- cends tliroiigii the wick by cap- illary attraclior, it is converted by the heat into vapour, and this vapour is a hydro-carbon, which bums exactly like the gas. Ilere also you have unburat vapour within, com- mon air without, while between both ia a shell which forms the battle-ground of the clashing atoms, where they develope their light and heat. There ia hardly anything in nature more beautiful than a burning candle; the

hollow basin partially filled wilh melted matter at the base of the wick, the creeping up of the liquid ; ils vaporisation ; the structure of the flame ; ita shape, lapcring to a point, while converging air-currents rush in to supply its needs. Its

8TBUGTCSE OF VLAMK, CI

beauty, its brightnessy its mobOitj, hsre mde it m £m ite type of spiritiial essences, and its dJfBfrtion bj Dsny, far from diminishing the pleasore witb vbidi we look upon a flame, has rendered it more tfaan erer a ■linde of beauty to the enlightened mind.

You ought now to be aUe to petnre dearir before your minds the structure of a candle^ame. To* oogirt to see the unbumt core within and the boniiBg diefl widcfa envelopes this core. From the eore, tbroc^ this AdL, the constituents of the candle are incf intly ftamg and escaping to the surrounding air. In the case of a candle you have a hollow cone of bunmig matter. Lnagine this cone cut across horizontally; yoa would tben expose a burning ring. I will practicany cut the flame of a candle thus across. I have here a piece of white paper, wfaidi I will bring down upon the candle ; ptcasiug it down upon the flame until it almost touches the wide. Observe the upper surface of that paper ; it becomes charred, but how ? Sxactly in correspondence with the burning ring of the candle, we have a charred ring upoa the paper (fig. 18).

I might operate in the same manner with a jet of gas. I will do so. Here is the ring which it produces. Within the ring, you see, there is no charring of the paper, for at this place the unbumt vapour of the candle, or the unborDt gas of the jet, impinges against the surface, and no charring can be produced.

To the existence, then, of solid carbon particles the light of our lamps is mainly due. But the existence of these particles, in the single state, implies the absence of

oxygen to seize hold of them. K, at the moment of their liberation from the hydrogen with which they are -first combined, oxygen were present to seize upon them, their

state of bachelorhood would be extinguished, and we should no longer have their light. Thus, when we mix a sufficient quantity of air with the gas issuing from a jet, when we mix it so that the oxygen penetrates to the very heart of the jet, we find the light destroyed. Here is a burner, in- vented by Prof. Bunsen, for the express purpose of destroy- ing the light by causing the quick combustion of the car- bon particles. The burner from which the gas escapes is introduced into a tube ; this tube is perforated nearly on a level with the gas orifice, and through these perforations the air enters, mingles with the gas, and the mixture issues

from the top of the tube. Fig. 19 repre- sents a form of this burner ; the gas is dis- *95 charged into the perforated chamber a,

■ where air mingles with it, and both ascend

the tube a h together : cf is a rose-burner, which may be used to vary the shape of the flame. I ignite the mixture, but the flame produces hardly any light. Heat is the thing here aimed at, and this lightless flame is much hotter than the ordinary flame, because the combustion is much quicker, and there- fore more intense.* If I stop the orifices in a I cut ofif the supply of air, and the flame at once becomes luitdnous : we have now the ordinary case of a core of unbumt gas surrounded by a burning shell. The illuminating power of a gas may, in fact, be estimated by the quantity of air necessary to prevent the precipitation of the solid carbon particles ; the richer the gas, the more air will be required to produce this eflect.

An interesting observation may be made on almost any windy Saturday evening in the streets of London, on the

* Not hotter, nor nearly so hot, to a body exposed to its radiation.* but very much hotter to a ho^y plunged in thejlame.

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Bodden, and almost total extinction of the light of the hnge gas jets, exposed chiefly

in batchers' shops. When the wind blows, the oxygen is carried mechanically to the very heart of the flame, and the white light instantly vanishes to a pale and ghastly bine. During festive illuminations the same effect may be observed ; the absence of the light being dne, as in the case of Bnnsen's burner, to the pres- ence of a sofficient amount of oxygen to consume, instant- ly, the carbon of the flame.

To determine the influence of height upon the rate of combustion, was one of the problems which I had set be- fore me, in my journey to the Alps in 1859. Fortunately for science, I invited Dr. Frankland to accompany mc on the occasion, and to undertake the experiments on combus- tion, while I proposed devoting myself to observations on solar radiation. The plan pursued was this: six candles were purchased at Chamouni and carefully weighed ; they were then allowed to bum for an hour in the Hotel de ITTnion, and the loss of weight was determined. The same candles were taken to the summit of Mont Blanc, and on the morning of Aug. 21, were allowed to bum for an hour in a tent, which perfectly sheltered them from the action of the wind. The aspect of the six flames at the summit surprised us both. They seemed the mere ghosts of the flames which the same candles were competent to produce in the valley of Chamouni — ^pale, small, feeble, and sug- gesting to us a gi'eatly diminished energy of combustion. The candles being carefully weighed on our return, the un- expected fact was- revealed, that the quantity of stearine consumed above was almost precisely the same as that consimied below. Thus, though the light-giving power of the flame was diminished in an extraordinary degree by the elevation, the energy of the combustion was the same above as it was belo\(r. This curious result is to be ascribed mainly to the mobility of the air at this great height. The

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particles of oxygen could penetrate the flame with com* parative freedom, thus destroying its light, and making atonement for the smallness of tiieir number by the

prompt- ness of their action.

Dr. Frankland has made these experiments the basis of a most interesting memoir.* He shows that the quan- tity of a candle consumed in a given time is, within wide limits, independent of the density of the air ; and the rea- son is, that although by compressing the air we augment the "liumber of active particles in contact with the flame, we almost, in the same degree, diminish their mobility, and retard their combustion. When an excess of air, moreover, surrounds the flame, its chilling effect will tend to prolong the existence of the carbon particles in a solid form, and even to prevent their final combustion. One of the beauti- ful experimental results of Dr. Frankland's investigation is, that by condensing the air around it, the pale and smokeless flame of a spirit lamp may be rendered as bright as that of coal gas, and, by pushing the condensation suffi- ciently far, the flame may actually be rendered smoky, the sluggish oxygen present being incompetent to effect the complete combustion of the carbon.

But to return to our theory of combustion : it is to the clashing together of the oxygen of the air and the constitu- ents of our gas and candles, that the light and heat of our flames are due. I scatter steel filings in this flame, and you see the star-like scintillations produced by the com- bustion of the steel. Here the steel is first heated, till the attraction between it and the oxygen becomes sufficiently strong to cause them to combine, and these rocket-like flashes are the result of their collision. It is the impact of the atoms of oxygen against the atoms of sulphur which produces the flame observed when sulphur is burned in

• Philosophical Transactions for 1861.

CLABBISa OF Aiona. €S

oxygen or in air; to the coIIisi<m of the same atanss against phosphonu are due tlie intense beat and

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oxygen gas. It is the collision of dik»ine and Trhich produces the light and heat observed where tbcae 1>odies are mixed together ; and it is the rfarfiing of ««1-phor and copper which causes the Jncandf^encc of tbe mass when these substances are heated together m a Ro- Tcnce flask. In short, all cases of combostioo are to be a§- oribed to the collision of atoms which bare been uged to- other by their mntnal attractioiis.

(1) A far more beandful mode of BOrted to. BemoTXDg tbe kns firom the camen, of Ae rays from the coal-points issued dirergeoL I plaeed a 2xr?» j* lens in front, so as to convert the dirergect cooe cso a eucrezszc -xa, and caused the cone to pass throng the reaxrer. 1:2 mek wm tz £=k invisible, but two or three strokes of tbe pocp preczpcusei St» -ricrnr. and then the track of the beam r^embkd a vbise sobd bar. Jiber rrv^- ing the receiver, the light feQ upon a vbite icrttn, aad ^iiZJztui RiVjuuii diffraction colours when the dood formed.

(2) Liebig's Annaleo, vol xliL p. 233; FbiL Ifa^ 4^ serSo. vX xzr. p. 871 ; and in rhume^ PhiL Xag. toL xxt. p. 3T«. I sb JoAsAefi ta Xz. Whcatstone for the perusal of a rare and cnxioai j— «7^V \,j t^ J^jsat- stein, with the foDowmg (translated) title : * IVo^na «f «? T5BK. O^i.^ eration of Heat without Fud ; or, Descriptaoa of a ^^^-^^^' Trvyf^L based on physical and mathematical proofe, by wiie& Oucraff iwy "Jt tz- tracted from Atmospheric Air, and in a YaA ^z**^ 'yxtaaszx:^^ TiJt. cheapest Substitute for Fud in most csms wber* WBL^nauo. s &s»«us^.' Rebenstein deduces from the experimesta of I>dac^ t&e ^i^u:^ ^i i^xl evolved in the compression of a gas. Xo gSa^K of Ui» ^rjzxsdjKL, tu»fir^ is, however, to be found in his paper : Ids iitas is vugSLtr IST-^^.t^jC.. ^ which is squeezed out of the air ta ymtst a cics of a i^jurt.

(3) In 1843 an essay entitled 'Ih^sma vxifxr^us f'/r^, -rw T'-v Bented to the Royal Sodety of CopesJttj»s ^7 % l^tsia^i: y>Zj-^r,r.fi>T tiamcd Colding. At this early date IL Oiiis^ K/sri' v* a»»<^«ir-^n. %>► quantity of heat generated by tbe frbuoe

«f vanr/ia ab^Ujsi ac^wiac A^Kak

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otber and ajuiut other BubfltaocoB, and to detenolno the uDcnmt of id^ chaoiol work coDBumed in iU geoemlion. Id bq account of his reMMchc* given by himself in the Philosophical Uagaiine (voL xxriL p. 6S), ba ■taUs that the reeult of his experiments, neariy 200 in Dumber, was tbat tlie beat diaecgaged was always In proportion to the mediaidcal vtaigf loBt Independently of the maleriak bjr which the heat was g«Mnlad, M. Colding found that an amoont of heat competent to ndse a poaud of water 1° C. wonld raise a wei^t of a pound 1118 tbet Ugh. IL CoUU^ starts from the principle tbat ' as the forces of nature are something qlf- itual and Immaterial — entiliefl whereof we are cognisant only bj their ua% tcry over nature, tliose mtlties must of course be very superior to nw^ thing material in the worid ; and as It Is obvioos that it is throat tttp only tbat the wisdom we perceive and admin In nature iinmaiig ItM^ these powers must evidently be in relation to the spiritual, immatoial, ul intcllectaal power itself that guidea nature in its progrees ; bat if tooh b the case It Ib consequently quite impo^ible to conceire of those forcea is anytlung naturally mortal or periahablc. Surely, therefore, the toToea ought to be regarded as absolutely im perishable.' Whatever indtieesa man to work has tome value ; and Inasmuch as these speculations iudnccd H. Colding to become an eipetimenter, they are on Ibis account entitled to a certuu decree of respect.

APPEXDIX TO LECTTEE IL

EXTRACTS FBOM THE TWXSTIITZ aTS^I^S^ €■* rSK SCXfZl BOOK 0¥ TBS, WHE3r I fiij of modaa thai s k de ^sim if ^vastit jbk 3i & species, I would be imdBstood to motion, or that motioo gcxnaa htat certain cases), but that beaz mnf. 5a •ssBesoe mbL jpuaSrr. m motion, and nothing else : risised. JufjwrvsL tj -^e iqKzSe mfff- ences which I will presert'y <^jk:o. w Km » I iht^ uuzez. i. few

cautions, for the sak-e cf rrro^y icii:£iri-i; -

Nor, again, muft ibe ccc^L-skacitai aT ii*ar. tt is mcHnrrt nature, by means of which. & t'^fj t*K;:mj» i'X "riiB. l ii r z^vi-^ is applied to it, be confc-irritd whi lin 5-.EI1 if iean J ^ ii»ac is one thing, and beadrz a izirchiSL Htac » ir-jaicsfi 17 -^it motion of attrition -rjiltzm Krj |jM»»f^TTy ijgcL

Ilcat is an expansre Bcoic wiff«n- ^ Vurj flZTvis 11 iHiBK and stretch itself to a luw 'ii^ii 1 ^r '^iiisuuxn. Tjaa x ia: ir*- viously occupied. This drSr^ggg i* 3u:j5C insmmsii^ jl lamft whcre the smoke or thick nzci:? ausfSseiT -^flasa mii »:z:;axii jt into flame.

It is shown also in all tc£j=^ Sro-L wifk-j. 3xa3:d«i7 fTr»:lii. rises, and bubbles, azid carTies cc Hgt ^jxa \t ¥tii^j2:yi:iiEj'M^ till it turns into a hoflj fir r>:ct txUfzrjfui oii ±Ias*i Tiiin "UAt liquid itself^ namely, into Tajr^rir. ffi:»'-kft. -ir tr.

The third specific diferesot is ^>U r^^ •««: if t, ^^.ris'M '.f expansion, not uniformly of tbe wl^,> V>*t vjsp^siies'. '•-•'-'•• — *^ smaller parts of it : and at XiMt taeut tiiae cii«i«l rtf*-!*!. tii - beaten back, so that the body ftcq^drei a mcickiB aJx^mJiTt, p^tr-

petiully quirering, striving and Btru^Ung, and irritated bj re- percoBsioD, 'whence springs the fury of fire and heat.

Again, it is shown in this that when the air is expanded in a calender gloss, without impediment or repulsion, that is to say, uniformly and equably, there is no perceptible heat. Also, when wind escapes fh>m confinement, although it bm^ta Jbrth with the greatest violence, there is no very great heat perceptible ; becanse the motion b of the whole, without a motion alternating in the particles.

And this specific difference is eonunon also to the nature of cold ; for in cold contractive motion is checked by a resisting tendency to expand, Just as in heat the expannve action is checked by a renting tendency to contract. Thns whether the

pwticles of a body work inward or outward, the mode of action ja the

Now from this our firat vintage it follows, that the form or true definition of heat (heat that is in relation to the universe, not simply in relation to man) is in a few words as follows : Heal ii a motiim, erpatitive, rettrained, and acting in itt ttri/e vpon the tmaUer partidei of bodiet. But the eipnnsion is thus modified: vihile it eqtandt all leayt, it hot at the same time an indinatUm vp- wardt. And the struggle in the particles is modified also ; it it not AuggOh, hvi hurried and v:ith violence.*

ABSTRACT OF COUNT EUMFOBD'S EBSAT, ENTITLED 'AN ENQtrlST CONCEENINO THE 8O0ECE OF THE HEAT WUICU IS EXCITED BY

lUemt bffon tit Jloyal Sacttls, January Ej, 17BS.]

Being engaged in snperintending the boring of cannon in the workshops of the military arsenal at Munich, Count Romford was struck with the very considerable degree of heat which a brass gun ocquires, in a short time, in being bored, and with the atill more intense heat (much greater than that of boiling water) of

* Bacon's Works, vol. iv. : Spcddlng's Translation.

buxfobd's xxFEEnoona. G9

the metallic chips separated firom it by the borer, he proposed to himself the following questions :

' Whence comes the heat actually prodnced in the mechanical operation above mentioned ?

*' Is it furnished by the metallic chips which are separated from the metal f

If this were the case, then the eapadtyfcr heal of the parts of the metal so reduced to chips ought not only to be changed, but the change undergone by them should be sufSdently great to ac- count fiir aJSL the heat produced. No such change, howeyer, had taken place ; lor the chips were found to have the same capacity as slices of the same metal cut by a fine saw, where heating was aroided. Hence, it is evident that

the heat produced could not possibly have been furnished at the expense of the latent heat of the metallic chips. Rumford describes those experiments at length, and they are conclusive.

He then designed a cylinder for the express purpose of gener- ating heat by firiction, by having a blunt borer forced against its solid bottom, while the cylinder was turned round its axis by the force of horses. To measure the heat developed, a small round hole was bored in the cylinder for the purpose of introducing a small mercurial thermometer. The weight of the cylinder was 113.13 lbs. avoirdupois.

The borer wss a flat piece of hardened steel, 0*63 of an inch thick, 4 inches long, and nearly as wide as the cavity of the bore of the cylinder, namely, 8) inches. The area of the sur£&ce by which its end was in contact with the bottom of the bore was nearly 2} inches. At the beginning of the experiment the tem- perature of the air in the shade and also that of the cylinder was 60 degrees Fahr. At the end of 80 minutes, and after the cylinder had made 960 revolutions round its axis, the temperature was foxmd to be 180 degrees.

Having taken away the borer, he now removed the metallic dust, or rather scaly matter, which had been detached from the bottom of the cylinder by the blunt steel borer, and found its weight to be 837 grains troy. ^ Is it possible,^ he exclaims, ^ that the very considerable quantity of heat produced in this experi- ment— a quantity which actually raised the temperature of above 113 pounds of gun metal at least 70 degrees of Fahrenheit's ther-

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mometer — could have been furnished by so inconsiderable a qtiaii> tity of metallic dust, and this merely in consequence of a dumg$ in its capacity for heat ?

' But without insisting on the improbability of this snppon- tion, we haye only to recollect that from the results of actual and decisive experiments, made for the

express purpose of asoertaining that fact, the capacity for heat of the metal of which great guna are cast is not aennUy changed by being reduced to the fonn of metallic chips, and there does not seem to be any reason to think that it can be much changed, if it be changed at all^ in being re* duced to much smaller pieces by a borer which is less sharp.*

He next surrounded his cylinder by an oblong deal box, in such a manner that the cylinder could turn water-tight in the cen- tre of the box, while the borer was pressed against the bottom of the cylinder. The box was filled with water until the entire cylinder was coYcrcd, and then the apparatus was set in action. The temperature of the water on commencing was 60 degrees.

* The result of this beautiful experiment,' writes Rumford, ' was very striking, and the pleasure it afforded me amply repaid me for all the trouble I had had in contriving and arranging the complicated machinery used in making it. The cylinder had been in motion but a short time, when I perceived, by putting my hand into the water, and touching the outside of the cylinder, that heat was generated.

* At the end of an hour the fluid, which weighed 18*77 lbs., or 2^ gallons, had its temperature raised 47 degrees, being now 107 degrees.

' In thirty minutes more, or one hour and thirty minutes after the machinery had been set in motion, the heat of the water was 142 degrees.

* At the end of two hours from the beginning, the temperature was 178 degrees.

* At two hours and twenty minutes it was 200 degrees, and at two hours and thirty minutes it actually boiled I '

It is in reference to this experiment that Rumford made the remarks regarding the surprise of the bystanders, which I have quoted in Lecture I.

He then carefully estimates the quantity of heat possessed by each portion of his apparatus at the conclusion of the experiment^

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fated b; dte frKcoe cf nrg -i^-^'V rt^wl ■

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s si« RaIllf<l^i'«.J I: U iirilj Mr,it»*.-T --. ; whicb any ittfi^^tnl bfyij r.f fTie,>c -.^ ^r.<-LJ<

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•Ohim; and it appe&ra to me to be extremely dUScnlt, if not quite impOBsible, to fonn any distinct idea of anything cspaUe of being excited and commanicated la thoao esperiments, except it be MOTION.

When the hiatorj of the dynamical theory of heat ia written, the man who, in opposition to the scientific belief of his time, could experiment and reason upon experiment, as Rnmford did in the inyeatigatioii here refeired to, cannot be lightly pamed over. Hardly anything more powerfiil against the mat^iality of heat has been since adduced, hardly anything more concltudve in the way of establishing that heat is what Romford considered it to be, MotioTt.

' A very singular phenomenon was repeatedly observed during the experiments with bisulphide of carbon. AAcr determining the absorption of the vapour, the tube was exhausted as perfectly as possible, the trace of vapour left behind being exceedingly minute. Dry air was then admitted to cleanse the tube. On again exhausting, after the first few strokes of the pump, a jar was felt and a kind of explosion heard, while dense volumea of blue smoke immediately issued fi-om the pump cylinders. The action was confined to the latter, and never propagated itself backwards into the experimental tube.

' It is only with bisolphide of carbon that this effect has been observed. It may, I think, be explained in the following man- ner : — To Open the valve of the piston, the gas beneath it most have a certain tendon, and the compression necessary to produce Qia appears sufficient to cause the combination of the constitncnta of the bisulphide of carbon with the oxygen of the air. Such a combination certainly takea place, for the odour of sulphurotu acid is unmistakeable amid the fumes.

' To test this idea I tried the effect of compresaon in the air syringe. A bit of tow or cotton wool moistened with bisulphide of carbon, and placed in the syringe, emitted a bright flash when

or JUHUtFlilAflB or GABBQET TAFOUB. 73

tube, this experiment Mt of cotton.

' It k not iieoesBary the syringe. If the out again as quickly the Inminooa flash IB tiian atmospheric air, explanatum.' *

By blowing out the fames with a glass may be xepeated twenty times with the same

eren to let the moistened cotton remain in

bit of tow or cotton be thrown into it, and

as it can be ejected, on compressing the air

Pore oxygen prodnces a brighter flash

Hiese &cts are in hannony with the above

• Phfl. Trans., 1861 ; Phfl. Mag,^ Sept. 186L

LECTURE III.

[February 6, 1862.]

EXPANSION : TDK SOLID, LIQUID, AND GASEOUS FORMS Of

THESES RSQARDIMa TH« CONSTITUTION OF GASW^^JOIFFICIKKT OF IS-

PAN8I0N — HEAT IMPARTED TO A GAS UNDER CONSTANT PRESSURE — HEAT IMPARTED TO A GAS AT CONSTANT VOLUME — MATER'S CALCULATION Of THE MECHANICAL EQUIVALENT OP UEAT — DILATATION 07 GASES WITHOUT REFRIGERATION— ABSOLUTE ZERO Of TEMPERATURE — EXPANSION OF LI- QUIDS AND SOLIDS: ANOMALOUS DEPORTMENT Of WATER AND BISMUTH — ENERGY Of THE FORCE Of CRYSTALLIZATION — ^TUERMAL EffECT Of STRETCHING WIRES — ANOMALOUS DEPORTMENT Of INDIA-RUBBER.

APPENDIX: — ADDITIONAL DATA CONCERNING EXPANSION — ^EXTRACTS fROM

SIR n. Davy's riRST sciENTiric memoir: rusiON of igb by fRicnoN, kc

TOUR reappearance here to-day, after the stram which has already been put upon your attention, encourages me to hope that our present experiment will not be entirely unsuccessful. I need not tell an audience like this that nothing intellectually great is either accomplished or ap- propriated without effort. Newton ascribed the difference between himself and other men to his patience in steadSy looking at a question, until light dawned upon it^ and if we have firmness to imitate his example, we shall, no doubt, reap a commensurate rewardi

In our first lecture I permitted a sledge-hammer to de- scend upon a mass of lead, and we found that the lead be- ^ came heated, as soon as the mechanical motion of the ham- I mer was arrested. Formerly it was assumed that the force

SKPAKBIQN. 75

of the hammer was simply lost by t&e cononssion. In elas* tic bodies it was supposed that a portion of the force was restored by the elasticity of the body, which caused the descending mass to rebound ; bat in the collision of inelas- tic bodies it was taken for granted that the force of impact was lost. This, according to our

present notions, was a fundamental mistake ; we now admit no loss, bnt assume, « that when the motion of the descending hammer ceases, it -a is simply a case of transference^ instead of annihilation. I> The motion of the mass, as a whole, has been transformed j into a motion of the molecules of the mass. This motion of heat, however, though intense, is executed within limits too minute, and the moving particles are too small, to bo visible. To discern these processes we must make use of a finer eye and higher powers, namely, the eye and powers of the mind. In the case of solid bodies, then, while the force of cohesion still holds the particles together, you must conceive a power of vibration, within certain limits, to be possessed by the particles. You must suppose them oscillatiiig to and fro across their positions of rest ; and the greater the amount of heat we impart to the body, or the greater the amount of mechanical action which we in- vest in it by percussion, compression, or friction, the more mtense will be the molecular vibration, and the ^vider the an^tade of the atomic oscillations.

Now, nothing is more natural than that particles thus vibrating, and ever as it were seeking wider room, should urge each other apart, and thus cause the body of which they are the constituents, to expand in volume. This, in general, is the consequence of imparting heat to bodies — expansion of volume. We shall closely consider the few apparent exceptions to this law by and by. By the force of cohesion, then, the particles are held together ; by the force of heat they are pushed asunder : here are the two antagonist principles on which the molecular aggregation

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of the body depends. Let us sopposo Oie communication of heat to continue ; every increment of heat pnshm Uw particles more widely apart ; but the force of cohesion, Hka all other known forces, oots more and more feebly, as the distance between the particles which are the seat of flte force is augmented. As, therefore, the heat BtrengUwm, its opponent grows weak, until, finally, the partidea are so far loosed

from the rigid thrall of cohesion, that they an at liberty, not only to vibrate to and fro across a fixed po- sition, but also to roll or glide around each other. Cohemot is not yet destroyed, but it is so for modified, that while the particlea still oSer resistance to being torn directly asunder, their lateral mobility over each other's surfaces is secured. ■ 2%is 13 ike liquid condition of matter.

In tho interior of a mass of liquid tlie motion of every atom is controlled by tho atoms which surround it. But suppose you devclopo licat of sufficient power within the body of a liquid, what occurs ? Why, tlio particles break the last fettera of cohcKion, and fly asunder to form bubbled of vapour. If one of the surfaces of the liquid be quite free, that ia to say, uucontrolled either by a liquid or solid ; it ia quite easy to conceive that some of the vibrating su- perficial particles will Le jerked quite away from the hquid, and will fly M-ith a certain velocity through space, l^ui /reed from t/ie irfluence ofeofiesion, ice have matter in the vaporous or gaseous form.

My object hero is to familiarize your minds with tho general conception of atomic motion. I have spoken of the vibration of the particles of a solid as causing its expan- sion ; the particles have heeu thought by some to revolve round each other, and the communication of heat, by aug- menting the centrifugal force of the particles, was supposed to push them more widely asunder. I have here a weight attached to a spiral spring ; if I twirl the weight ronnd in the tai it tends to fly away from me, the spring stretches to

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extent^ and as I augment the speed of reyolatioiiy f stretches still more, the distance between my the weight being thos augmented. It has been hat the angmentation of the distance between a sms by heat, may be also dne to a revolation of les. And imagine the motion to continue till the ips ; the ball attached to it would fly off along a o its former orbiti and thus represent an atom heati ih>m the force of cohesion, which is rudely ^ by our spring. The ideas of the most well- philosophers are as yet

uncertain regardmg the ure of the motion of heat ; but the great point, ;, is to regard it as motion of some kind, leaving >recise character to be dealt with in future inves-

light extend the notion of reyolving atoms to , and deduce their phenomena from a motion of . But I have just thrown out an idea regarding particles, which is at present very ably main- the idea, namely, that such particles fly in ines through space. Everybody must have re- ow quickly the perfume of an odorous body fills nd this fact harmonizes with the idea of the di- xstion of the particles. But it may be proved, 16 theory of rectilinear motion be true, the parti- move at the rate of several hundred feet a sec- ace it might be objected that, according to the pothesis, odours ought to spread much more lan they are observed to do. iswer to this objection is, that they have to make ' through a crowd of air particles, with which e into incessant collision. On an average, the

lie, Kronig, Maxwell ; and, in a scries of extremely able papers,

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distance through which an odorous particle can travel in common air, without striking against a particle of air, is infinitesimal, and hence the propagation of a perfume through air is enormously retarded by the air itself. It is well known that when a free communication is opened be- tween the surface of a liquid and a vacuum, the vacuous space is much more speedily filled to saturation with the vapour of the liquid, than when air is present.*

According to this hypothesis, then, we are to figure a gaseous body as one whose' particles are fiying in strai^t lines through space, impinging like little projectiles upon each other, and striking against the boundaries of the space which they occupy. Mr. Anderson will place this bladder, half filled with air, under the receiver of the ^-pump ; he will now work the pump, and remove the air that surrounds the bladder. The bladder swells ; the air within it appears quite to fill it, so as to remove all its folds and creases. How is this expansion of the bladder produced ? Accord- ing to

our present theory, it is produced by the shooting of atomic projectiles against its interior surface, which drive the envelope outwards, until its tension is able to cope with their force. When air is admitted into the re- ceiver, the bladder shrivels up to its former size ; and here we must figure the discharge of the air particles agdnst the outer surface of the bladder, which drive the envelope in- wards, causing, at the same time, the particles within to concentrate their fire, xmtil finally the force from within equals that from without, and the envelope remains quies- cent. All the impressions, then, which we derive from heated air or vapour are, according to this hypothesis, due to the impact of the gaseous atoms. They stir the nerves in their own peculiar way, the nerves transmit the motion to the brain, and the brain declares it to be heat. Thus the impression one receives on entering the hot room of a Turkish bath, is caused by the atomic can- * Sec Note (4) at the end of this Lecture.

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nonade whidh is there maintained agains the surface of the body.

If^ mstead of pladmg this bladder under the receiver of an ab-pumpy and withdrawing the external air, I augment, by heati the projectile force of the particles within it, these particles, though comparatiYely few in number, will strike with BQch impetuous energy against the inner surface as to cause the enyelope to retreat : the bladder swells and be- comes apparently filled with air ; I hold the bladder close to the fire, and here it is, you see, with all its creases re- moved. But you will retort, perhaps, by saying that this ought not to be the case, inasmuch as the air outside the bladder is also near the fire, and therefore animated with a like projectile energy, which tends to drive the envelope in. True, the bladder and the air in contact with it are equally near the fire ; but in a future lecture you will learn that the air outside the bladder allows the rays of heat to pass through it with very little augmentation of tempera- ture, while the bladder intercepts the radiant heat ; the efi- veiope becomes first warmed and then communicates its heat, by contact, to the air within. The air,

moreover, in con- tact with the bladder on the outside, though heated by the bladder, has free space to dilate in, and is the: efore incom- petent to resist the expansion of the confined air which the bladder contains.

This, then, is a simple illustration of the expansive force of heat, and I have here an apparatus intended to show you the same fact in another manner. Here is a flask, f (fig. 20), empty, except as regards air, which I intend to heat by this little spirit-lamp underneath. From the flask a bent tube passes to this dish, containing a coloured liquid. In the dish, a 2-foot glass tube, ^ ^ is inverted, closed at the top, but with its open end downwards ; you know that the pressure of the atmosphere is competent to keep the column of liquid in this tube, and here you have it quite filled to

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ls^in2 from tlic flask

the top with llio i;.)iii.l. Till' tiilit ifl caused to turn up csactly midiTiuMtli llu' cipvii oiiil of this npright tube, bo that if a babble of air t^huuld i^iuc from tiifl former, it will ascend the latter. I now beat the

flask, and as I do so, the lur expands, for the reasons al- ready given ; bubbles are driven from the end of tlie bent tnbo, and they ascend in the tube ((. The air speedily de- presses the liquid column, until now, in the course of a very fow seconds, the whole colunm of liquid has been sjiper- seded by air.

It is perfectly manifest that the air, thus e]q)anded by heat, is lighter than the unoxpanded air. Our flask, at the conclusion of this experiment, is lighter than it was at the commencement, by the weight of the air transferred from it into the upright tube. Supposing, therefore, a light bag to be filled with snch air, it is plain that the bag would, with reference to the heavy air outside it, be like a drop of oil in water j the oil being lighter than the water, will

EZPAHBIOSr OF QASMB BT HEAT. 81

twend throng the latter; so abo onr bag, filled with heated air, will ascend in the

atmosphere ; and this is the principle of the so-called fire-balloon* * Mr. Anderson will ignite some tow in this vessel, over it he will place this fmmel, and over the funnel I will hold the month of this paper balloon. The heated air ascending from the burning tow enters the balloon, causes it to swell ; its tendency to rise is already manifest. I let it go, and thus it sails alofl till it strikes the ceiling of the room.

But we must not be content with regarding these phe- nomena in a general way ; without exact quantitative de. terminations our discoveries would confound and bewUder us. We must now enquire what is the amount of expan- idon which a given quantity of heat is able to produce in a gas ? This is an important point, and demands our special attention. When we speak of the volume of a gas, we should have no distinct notion of its real quantity, if its temperature were omitted, the volume varies so largely with the temperature. Take, then, a measure of gas at the precise temperature of water when it begins to freeze, or of ice when it commences to melt, that is to say, at a tem- perature of 32° Fahr. or 0° Cent, and raise that volume of gas one degree in temperature, the pressure on every sgniare inch of the envelope which holde the gae being preserved constant. The volume of the gas will become expanded by a quantity which we may call a ; raise it another degree in temperature, its volmne will be es^anded by 2a, a third degree will cause an expansion of So, and so on. Thus, we see, that for every degree which we add to the temperature of the gas, it is es^anded by the same amount. What is this amount ? No matter what the quantity of gas may be at the freezing temperature, by raising it one degree Fahr- enheit we augment its volume by Ti^th of its own amount ; while by raising it one degree Centigrade we augment the

volume by 777^^ ^^ ^^^ ^^^^ amount. A cubic foot of gas,

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for example, at 0° C, becomes, on being heated to 1% lif| J cubic foot, or, expressed in decimals,

1 voL at 0" C. becomes 1 + '00367 at 1° G at 2° C. it becomes 1 + -OOSeY X 2 at 3° C. it becomes 1 + *00367 X 3, and so on.

The constant number *00367, which expresses the frac- tion of its own Tolume, which a gas, at the freezing tem- perature, expands on being heated one degree, is called the coefficient of expansion of the gas. Of ^' ^ course if we use the degrees of Fahrenheit, the co- efficient will be smaller in the proportion of 9 to 5?

This much made clear, we shall now approach, by "Blow degrees, an interesting but difficult sub- ject. Suppose I have a quantity of air contained in a very taU cylinder, a b (fig. 21), the transverse section of which is one square inch in area. Let the top A of the cylinder be open to the air, and let p be a piston, which, for reasons to be explained immediately, I will suppose to weigh two pounds one ounce, and which moves air-tight and without friction, up or do^vn in the cylinder. At the com- mencement of the experiment, let the piston be at the point p of the cylinder, and let the height of the cylinder from its bottom b to the point p be 273 inches, the air underneath the piston being at a temperature of 0° C. Then, on heating the air from 0° to 1° C. the piston will rise one inch ; it will now stand at 274 inches above the bottom. If the temperature be raised two degrees, the piston will stand at 275, if raised three degrees it will stand at 276, if raised ten degrees it will stand at 283, if 100 degrees it will stand at 373 inches above the bottom ; finally, if the temperature were raised to 273° C, it is quite manifest 273 inches would be added * See Note (6) at the end of this Lecture.

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to the hei^t of the colmmi, or, in other words, by heating i the air to 273*^ C, its volume would be doubled.

It is evident that the gas, in this experiment, executes work. In expanding from p upwards, it has to overcome the downward pressure of the atmosphere, which

amounts to 15 lbs. on every square inch, and also the weight of the piston itself, which is 2 lbs. 1 oz. Hence, the section of the cylinder being one square inch in area, in expanding from p to p' the work done by the gas is equivalent to tlie raising a weight of 17 lbs. 1 oz^ or 273 ounces, to a height of 273 inches. It is just the same as what it would accom- plish, if the air above p were entirely abolished, and a pis- ton weighing 17 lbs. 1 oz. were placed at p.

Let us now alter our mode of experiment, and instead of allowing our gas to expand when heated, let us oppose its expansion by augmenting the pressure upon it. In other words, let us keep Ue volume constant while it is being heated. Suppose, as before, the initial temperature of the gas to be 0^ C, the pressure upon it, including the weight of the piston p, being, as formerly, 273 ounces. Let us warm the gas from 0° C. to 1° C. ; what weight must we add to p in order to keep its volume constant ? Exactly one ounce. But we have supposed the gas, at the conmiencement, to be under a pressure of 273 ounces, and the pressure it sustains is the measure of its elastic force ; hence, by being heated one degree, the ebstic force of the gas has augmented by t^^r^ of what it possessed at 0"^. If we warm it 2^, 2 ozs. must be added to keep its voluino constant ; if 3"^, 3 ozs. must be added. And if we raise its temperature 273°, we should have to add 273 ozs. ; that is, we should have to double the original pressure to keep tlie volume constant.

It is simply for the sake of clearness, and to avoid frac- tions in our reflections, that I have supposed the gas to be under the original pressure of 273 ozs. No matter what its

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pressure may be, the addiUon of 1° C. to its temperatora produces an augmentation of sljrd of the elastic force which the gas possesses at the freenng temperature ; and by raising its temperature 273°, while its volume is kept constant, its elastic force is doubled. Let us nov compare this experiment with the last one. 7K«» wo heated a

cer- tain amount of gaa from 0° to 273°, and doubled its vol- ume by so doing, the double volume being atUuned while tfae-gas lifted a weight of 273 ozs. to a height of 273 inches. Mere we heat the same amount of gas from 0° to 27ft°, but we do Dot permit it to lift any weight. We keep its volume constant. The quantity of matter heated in both cases is the same ; the temperaiure to which it is heated is in both cases the some ; but are the abtoitUe guantilies of heat imparted in both cases the same F By no means. Supposing that to raise the temperature of the gaa, whose volume is kept ccmstaut, 273% 10 grmna of combustible matter are necessary ; then to nuse the tem- perature of the gas whose pressure is kept constant an equal number of degrees, would require the consumption of 14i grains of the same combustible matter. The heat produced by the combustion of the additional 4i graina, in the latter caee, is entirely consumed in liJXinff the vteiffht. Using the accurate numbers, the quantity of heat applied when the volume is constant, is to the quantity applied when the pressure is constant, in the proportion of

This extremely importaut fact coustitntes the basis from which the mechanical equivalent of heat was first cal- culated. And here we have reached a point which is wor- thy of, and which will demand, your entire attention. I will endeavour to make tliis calculation before you.

Let c (fig. 21ct) be a cylindrical vessel with a base one square foot in area. Let p f mark the upper surface of a

HXAT nfPABTED TO GAS AT A OQKBTABT TOLtrXE. 85

cubic foot of air at a temperature of 32^ Fahr. The height A p will be then one foot. Let the air be heated till thia

Yolmne is doubled ; to effect this it most, as before explaiaed, be raised 273^ C, or 490^ F. in temperature; and, when ex- panded, its upper surface will stand at p' p\ one foot above its initial position. But in rising firom p p to p' p! it has forced back the atmosphere, which exerts a pres- sure of 15 lbs. on every square inch of its upper

surface ; in other words, it has lifted a weight of 144 X 15 = 2,160 lbs. to a height of one foot. The ^ capacity ' for heat of the air thus expanding is 0'24 ; water being unity. The weight of our cubic foot of air is 1*29 oz., hence the quantity of heat required to raise 1-29 oz. of air 490"* Fahr. would raise a little less than one- fourth of that weight of water 490^. The exact quantity of water equivalent to our 1*29 oz. of air is 1*29 X 0*24 =s 0-31 oz.

But 0-31 oz. of water, heated to 490^, is equal to 152 ozs. or 9^ lbs. heated 1^ Thus the heat imparted to our cubic foot of air, in order to double its volume, and enable it to lift a weight of 2,160 lbs. one foot high, would be competent to raise 9^ lbs. of water one degree in tempera- ture.

The air has here been heated under a constant pressurCy and we have learned, that the quantity of heat necessary to raise the temperature of a gas under constant pressure a certain njmiber of degrees, is to that required to raise the gas to the same temperature, when its volume is kept con- stanty in the proportion of 1*42: 1 ; hence we have the statement —

iiM. n>flb 1-42 : 1 = 9-5: 6-7

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which shows that the quantity of heat necessary to aug- ment the temperature of our cabio foot of air, at constant Tolome, 490°, would heat 6'7 lbs. of water 1°.

Deducting 6*7 lbs. from 9*5 Ibs^ we find that the excess of heat imparted to the air, in the case where it is permit- ted to expand, is competent to raise 2*8 lbs. of water 1° in temperature.

As exphuned already, this excess is employed to lift the weight of 2,160 lbs. one foot high. Dividing 2,160 by 2-8, we find that a quantity of heat sufficient to raise one pound of water 1° Fahr. in temperature, is competent to raise a weight of 771*4 lbs. a foot high.

This method of calculating the mechanical equivalent of heat was followed by Dr.

Mayer, a physician in Heil- bron, Germany, in the spring of 1842.

Mayer's first paper contains merely an indication of the way in which he had foimd the equivalent ; but does not contmn the calculation. The paper was evidently a kind of preliminary note, from which date might be taken. In it were enunciated the convertibility and indestructibility of force, and its author referred to the mechanical equiva- lent of heat, merely in illustration of his principles. Had this first paper stood alone, Mayer's relation to the dynami- cal theory of heat would be very difierent from what it now is; but in 1845 he published an Essay on Organic Motion, which, though exception might be taken to it here and there, is, on the whole, a production of extraordinary merit. This was followed in 1848 by an Essay on ' Celes- tial Dynamics,' in which, with remarkable boldness, saga- city, and completeness, he developed the meteoric theory of the sun. Taking him all in all, the right of Mayer to stand, as a man of true genius, in the front rank of the founders of the dynamical theory of heat, cannot be dis- puted.

On August 21, 1843, Mr. Joule communicated a paper

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to the BritkhAflflooiadoo, then meeting at Cork, and in the third part of this paper* he describes a series of ezperi^ ments on magneto-dectridty, executed with a view to de- termine the ^ mechanical yalue of heat.' The results of this elaborate investigation gave the following weights raised one foot high, as eqaiTalent to the warming of 1 lb. of water 1** Fahr.

1. 896 lbs. 5. 1026 lbs.

2. 1001 „ 6. 587 „

3. 1040 „ 7. 742 „

4. 010 „ 8. 860 „

In 1844 Mr. Joulo deduced from experiments on the condensation of air, the

following equivalents to 1 lb. of water heated 1^ Fahr.f

823 foot pomids

As the experience of the experimenter increased, we find that the coincidence of his results becomes closer. In 1845 Mr. Joule deduced from experiments with water, agi- tated by a paddle-wheel, an equivalent of

890 foot pounds.

Summing up his results in 1845, and taking the mean, he found the equivalent to be

817 foot pounds.

In 1847 he found the mean of two experiments to ^ve as equivalent

781*8 foot pounds.

• PhiL Mag., 1813, toI. xxiu. p. 436. t Sec Note (C) at the end of this Lecture.

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Finally, in 1849, applying all llie precautionB suggeBted by seven years' experience, he obtained the following nmn- bers for the mechanical equivalent of heat : —

772*692, from friction of water, mean of 40 experiments 774*083, „ „ mercury, ' „ 50 „ 774*987, „ „ cast-iron, „ 20 „

For reasons assigned in his j^aper, Mr. Joule fixes the exact equivalent of heat at

772 foot pounds.

According to the method pursued by Mayer, iu 1842, the mechanical equivalent of heat is

771*4 foot pounds..

Such a coincidence relieves the mind of every shade of uncertainty, regarding the correctness of our present me- chanical equivalent of heat.

Do I refer to these things in order to exalt Mayer, at the expense of Joule ? It is far from my intention to do so. The man who through long years, without encourage-

ment, and in the face of difficulties which might well be deemed insurmountable, could work with such unswerving steadfastness of purpose to so triumphant an issue, is safe from depreciation. And it is not the experiments alone, but the spirit which they incorporate, and the applications which their author made of them, that entitle Mr. Joule to a place in the foremost rank of physical philosophers. Mayer's labours have, in some measure, the stamp of a pro- found intuition, which rose, however, to the energy of un- doubting conviction in the author's mind. Joule's labours, on the contrary, are an experimental demonstration. True to the speculative instincts of his country, Mayer drew large and weighty conclusions from slender premises, while the Englishman aimed, above all things, at the firm estab- lishment of facts. And he did establish them. The future

of Bcieooe will not, I think, place thes^ men in antagoniflnL To each belongs a reputation which will not quickly fade, for the share he has had, not only in estab- lishing the dynamical theory of heat, but also in leading the way towards a right appreciation of the general energies of the universe.

Let us now check our condusicm regarding the influence which the performance of work has on the quantity of heat communicated to a gas. Is it not possible to allow a gas to expand, without performing work ? This question is an- swered by the following important experiment, which was first made by Gay Lussac I have here two copper vessels, A, B (fig. 22), of the same size, one of which, a, is exhaust- ed, and the other, b, filled with air. I turn the cock c ; the air rushes out of b into a, until the same pressure exists

in both vessels. Now the air in driving its own particles out of b performs work, and experiments which we have already made in- form us, that the residue of air which remains in b must be chill- ed. The particles of air enter a with it certain velocity, to generate which the beat of the air in b has been sacrificed ; but they inmiedi- ately strike against the interior surface of a, their motion of trans- lation is annihilated, and

the exact quantity of heat lost by b appears in a. Mix the contents of a and b together, and you have air of the original temperature. There is no work performed, and there is no heat lost. Mr. Joule made this experiment by compressing twenty-two atmospheres of air into one of his vessels, while the other was exhausted. On surrounding both vessels by water, kept properly agitated, no augmentation of temperature was observed in the water,

90 LEcruBE in.

when the gas was allowed to stream from one vessel into the other.* In like manner, supposing the top of the cylin- der (fig. 20) to be closed, and the half above the piston a perfect vacuum ; and suppose the air in the lower half to be heated 273"", its volume being kept constant. If the pressure were removed, the air would expand and fill the cylinder ; the lower portion of the column would thereby be chilled, but the upper portion would be heated, and mixing both portions together, we should have the idiole column at a temperature of 273°. In this case we raise the temperature of the gas from 0° to 273% and afterwards al- low it to double its volume ; the state of the gas at the commencement, and at the end, is the same as when the gas expands against a constant pressure, or lifts a constant weight ; but the absolute quantity of heat in the latter case is 1*421 times that employed in the former, the difference being due to the fact that the gas, in the one case, per- forms mechanical work, and in the other not.

We are taught by this experiment that mere rarefaction is not of itself sufficient to produce a lowering of the mean temperature of a mass of air. It was, and is still, a ciurent notion, that the mere expansion of a gas produced refriger- ation, no matter how that expansion was effected. The coldness of the higher atmospheric regions was accounted for by reference to the expansion of the air. It was thought that what we have called the ' capacity for heat ' was greater in the case of the rarefied than of the imrare^ fied gas. But the refrigeration which accompanies expan- sion is, in

reality, due to the consumption of heat in the performance of work by the expanding gas. Where no work is performed there is no absolute refrigeration.

All this needs reflection to arrive at clearness, but every effort of this kind which you make will render your subse-

• PhiL Mag. 1846, vol. xxvl p. 878.

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quent eBbrto earner, and ahould yoa fail, at present, to gain clearness of comprehension, I repeat mj recommendation of patience. Do not quit this portion of the subject with- oat an effort to comprehend it — wrestle with it for a time, but do not despair if you fail to arrive at deamess.

I have now to direct your attention to one other inter- esting question. We have seen the elastic force of our gas augmented by an increase of temperature. In an inflexible envelope we have, for every degree of temperature, a cer- tun definite increment of elastic force, due to the augment- ed energy of the gaseous projectiles. Reckoning from 0^ C. upwards, we find that every degree added to the tem- perature produces an augmentation of elastic force, equal to T^ ^rd of that which the gas possesses at 0^, and hence, that by imparting 273° we double the elastic force. Sup- posing the same law to hold good when we reckon from 0° dowfitectrda — ^that for every degree of temperature teithr drawn from the gas we diminbh its elastic force, or the motion which produces it, by ^l^rd of what it possesses at 0°, it is manifest that at a temperature of 273° Centigrade below 0° we should cease to have any elastic force what- ever. The motion to which the elastic force is due must here vanish, and we reach what is called the absolute zero of temperatvTe.

No doubt, practically, every gas deviates from the above law of contraction before it sinks so low, and it would become solid before reaching — 273° C, or the abso- lute zero. This is considerably below any temperature which we have as yet been able to

obtain.

I will not subject your minds to any further strain in connection with this subject to-day, but will now pass on to illustrate experimentally the expansion of liquids by heat.

Here is a Florence flask filled with alcohol, and tightly corked ; through the cork a tube, t' (fig. 23), passes water.

OS LSOTDBB HL

tight, and tlie liquid rises a foot or so in this tabe. I viO heat this flask, the alcohol will expand, and it Till rise in the tube. But I wish you to aee it rising, and to enable you to do BO I -will place the tube * «' in front of the eleo- trie lamp B, and send a strong beam of light aorofis it, at

the place t', where the liquid column ends ; I thus illumi- nate the tube and column. In front of the tube I place this lens L, and arrange its distance so that it shall cast an en- larged image i i, of tlie column upon tlie screen, Tou now see clearly where the column ends ; you see this quivering of the top of the column, and if it mores, you will be able to see its motion. I now fill this beaker, b, with hot war

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bear, and I trill rftise the beakeir so that the hot water shall nirroimd the Florence flask. It is needless to say that the inuyge upon the screen is inverted, and that when the liquid expands, the top of the column will descend along the screen. Observe the experiment from the conunencement ; the flask is now in the hot water, and the head of our col- umn ascends^ as if the liquid contracted. Now it stops and commences to descend, and it will continue to do so permanently. But why the first ascent ? It is not due to the contraction of the liquid, but to the tnomentixn/ expcai- Han x>f the

flasky to which the heat is first communicated. The glass expands before the heat can fairly reach the liquid, and hence the column falls ; but soon the expansion of the liquid exceeds that of the gl&ss, and the column rises. Two things are here illustrated ; the expansion of the solid glass by heat, and the fact that the observed dila- tation of the liquid does not give us its true augmefitation of volume, but only the difference of dilatation between the glass and it.

I have here another flask filled with water, exactly similar in size to the former, and furnished with a similar tube. I place it in the same position, and repeat with it the experiment made with the alcohol. You see, first of all, the transitory eflect due to the expansion of the glass, and afterwards, the permanent expansion of the liquid ; but you can observe that the latter proceeds much more slowly than in the case of alcohol ; the alcohol expands more speedily ihan the water. Now we might go over a hundred liquids in this way, and find them all expanding by heat, and we might thus be led to conclude that expansion by heat is a law without exception ; but we should err in this conclu- sion. And it is really to illustrate an exception of this kind that I have introduced this flask of water. I will cool the flask by plimging it into a substance somewhat colder than water, when it first freezes. This substance I obtain by

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mixing pounded ice with salt You see the colmnn gradu- ally sinkings the heat is being given up to the fireesing mix- ture, and the water contracts. This contraction is now very slow, and now it stops altogether. A slight motion com- mences in the opposite direction, and now the liquid is vU- iUy expanding. I stir the freezing mixture, so as to bring colder portions of it into contact with the flask ; the colder the mixture the quicker is the expansion. Here then we have Nature stopping in her ordinary course, and reversing her ordinary habits. The fact is, that the water goes on contracting till it reaches a temperature of 39° Fahr., or 4^ Cent., at which point the

contraction ceases. This is the so-called pomt of maximum density of the water ; from this downwards, to its freezing point, the liquid expands ; and when it is converted into ice, the expansion is large and sudden. Ice, we know, swims upon water, being lightened by this expansion. If I now apply heat, the series of changes are reversed : the column descends, show- ing the contraction of the liquid by heat. After a time the contraction ceases, and permanent expansion sets in.

The force with which these molecular changes are effected is all but irresistible. The changes usually occur under conditions which aUow us no opportunity of observing the energy involved in their accomplishment. But to give you an example of this energy, I have confined a quantity of water in this iron bottle. The iron is fully half an inch thick, and the quantity of water is small, though sufficient to fill the bottle. The bottle is closed by a screw firmly fixed in its neck. I have here a second bottle of the same kind, and prepared in a similar manner. Both of them I place in this copper vessel, and surround them with a freez- ing mixture. They cool gradually, the water within ap- proaches its point of maximum density ; no doubt, at this moment, the water does not quite fill the bottle, a small vacuous space exists within. But soon the contraction

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ceafles, and expannon sets in ; the Taonons space is slowly fined, the water gradnany changes from liquid to solid ; in doing so it requires more room, which the rigid iron re- fuses to grant. But its rigidity is powerless in the pres- ence of the atomic forces. These atoms are giants in dis- guise ; you hear that sound ; the bottle is shivered by the crystallising molecnleft— there goes the other ; and here are the fragments of the vessels, which show their thickness, and impress you with the might of that energy by which they were thus riven.*

Yon have now no difficulty in understanding the effect of frosty weather upon the

water pipes of your houses. I have here a number of pieces ofsuch pipes, all rent. You become first sensible of the damage when the thaw sets in, but the mischief is really done at the time of freezing ; the * pipes are then rent, and through the rents the water es- capes, when the solid within is liquefied.

It is hardly necessary for me to say a word on the im- portance of this property of water in the economy of na- ture. Suppose a lake exposed to a clear wintry sky ; the superficial water is chilled, contracts, becomes thus heavier, and sinks by its superior weight, its place being supplied by the lifter water from below. In time this is chilled, and sinks in turn. Thus a circulation is established, the cold, dense water descending, and the lighter and warmer water rising to the top. Supposing this to continue, even afler the first pellicles of ice were formed at the surface ; the ice would sink as it was formed,! and the process

* Metal cylinders, %n inch in thickness, arc unable to resist the decom- posing force of a small galvanic battery. M. Gassoit has burst many such cylinders by electrolytic gas.

f Prof. William Thomson has recently raised a point which dcserrcs the grare consideration of theoretic geologists : Supposing the constituents of the earth*8 crust to eontraet on solidifying, as the experiments thus for made indicate, a breaking in, and sinking of the crust would assuredly

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would not cease until the entire water of the lake would be solidified. Death to every living thing in the water would be the consequence. But just when matters become critica], Nature steps aside from her ordinary proceeding, causes the water to expand by cooling, and the cold water swims like a scum on the surface of the warmer water mider- neath. Solidification ensues, but the solid is much lighter than the subjacent liquid, and the ice fonns a protecting roof over the living things below.

Such facts naturally and rightly excite the emotiona^ indeed, the relations of life to

the conditions of life — ^the general adaptation of means to ends in Nature, excite, in the profoundcst degree, the interest of the philosopher. But in dealing with natural phenomena, the feelings must be carefully watched. They often lead us unconsciously to overstep the .bounds of fact. Thus, I have heard this wonderful property of water referred to as an irresistible proof of design, unique of its kind, and suggestive of pure benevolence. ' Why,' it is urged, ' should this case of wa- ter stand out isolated, if not for the purpose of protecting Nature against .herself? ' The fact, however, is, that the case is not an isolated one. You see this iron botUe, rent from neck to bottom ; I break it with this hanmier, and you see a core of metal within. This is the metal bismuth, which, when it was in a molten condition, I poured into this bottle, and closed the bottle by a screw, exactly as in the case of the water. The metal cooled, solidified, ex- panded, and the force of its expansion was sufficient to burst the bottle. There are no fish here to be saved, still the molten bismuth acts exactly as thQ water acts. Once for all, I would say that the natural philosopher, as such.

follow its formation. Under these circumstances, it is extremely difficaU to conceive that a solid shell should be formed, as is generally assumed, round a liquid nucleus.

XXFASBKiS OF BOLIDB.

has nothing to do with pnrposes and designs. His voca- tion is to enquire what Natnre is, not why she is ; tbongh he, like oUiers, and he, more than others, must stand' at times rapt in vonder at the mystery in which he dwells, and toirards the final solution of which his studies furnish him with no due.

We must now pass on to the expansion of solid bodies, by best, and I will illustrate it in this way : I have here two wooden stands, a. and b (fig. 24), with plates of brass, p p', riveted agtunst them. I hold in my hand two bars of eqnal lengthy one of brass, the other of iron, and thcEC, as yoa obe^re, are not sufficiently long to stretch from stand to stand. I will support them on two little projec- tions of wood attached to the

stand at^ and;;'. I connect one of the plat«s of brass, p, with one pole of a small voltaic battery, d, and from the other, p', a wire proceeds to

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the little instnmiGnt c, vhich yon see in front of the tabk ; and agiiin from that iostrnmeiit a wire retiims direct to the otJier pole of the battery. The instrument in firoot c<»>- Bists merely of on arrangement to support a spiral c of [Ja- tinmn wire, which will glow with a pure white light when the current from d paasea through it. At the prearatt mo- ment the only break in the circnit is dne to the insuffident length of the bars of brass and iron to bridge the Bpaoe from stand to stand. Undenieath the bars ia a row of gaa jeta, which I will now ignite ; the bars are heated, the metals expand, and I expect that in a few minutes they will stretch quite across from plate to plate ; when this oconn^ the current will pass, and the fact of tbe gap being bridged will be declared by the sudden glowing of the platinum spiral. It ia still non-luminous, the bridge is not yet com- plete ; but now it brightens up, showing that one, or botb, of these bars Iiavo expanded so as to stretch quite across from stand to stand. Which of the bars is it ? I remove the iron, but the platinum still glows : I restore the iron, and remove tbe brass ; the light disappears. It was the brass that bridged the gap. So that we have here an illus- tration, not only of the general fact of expansion, but also of the fact that different bodies expand in different degrees. The expansion of both brass and iron is very small : and various instruments have been devised to measure the ex- pansion. Such instruments go under the general name of pyrometers. But I have here a means of multiplying tbe effect, far more powerful than the ordinary pyrometer. Here is a solid upright bar of iron two feet long, and on a mirror connected with the top of the bar I throw a beam of light from the electric lamp, which beam is reflected to the upper part of the wall. If the bar shorten, the mirror will turn in one direction : if it lengthen, the mirror will turn in the opposite direction. Every movement of the mirror, I^owever alight, is multipUed by this long index of

SSTEBOT OF VOBOE COT EXPANSIOir. 99

light ; which, beaideB its length, has the adyantage of moT- ing with twice the angular rdocity of the mirror. Even the breath, projected against this massive bar of iron, pro- daces a sensible motion of the beam ; and if I warm it for a moment with the flame of a spirit-lamp, the lomineiis in- dex win travel downwards, the patch of light npon the wall moving through a space of foil thirty feet. I with- draw the lamp, and allow the bar to cool ; it contracts, and the patch of light reascends the wall : I hasten the con- traction 1^ dirowing a little alcohol on the bar of iron, the l^t moves more speedily upwards, and now it occupies a place near the ceiling, as at the commencement of the ex- perimient.*

I have stated that different bodies possess different powers of expansion ;f that brass, for example, expands more, on being heated, than iron. Here are two rulers, one of brass and the other of iron, riveted together so as to form, at this temperature, a straight compound ruler. But if the temperature bo changed, the ruler is no longer straight. I heat it, it bends in one direction : I cool it, it bends in the opposite direction. When heated, the brass expands most, and forms the convex side of the curved ruler. When cooled, the brass contracts most, and forms the concave side of the ruler. Facts like these must, of course, be taken into account, in structures where it is ne- cessary to avoid distortion. The force with which bodies expand when heated, is quite irresistible by any mechanical appliances that we can make use of. All these molecular forces, though operating in such minute spaces, are almost infinite in energy. The contractile force of cooling has

* The piece of apparatus with which this experiment was made is in- tended for a totally different purpose. I therefore indicate its principle merely.

f The coefficients of expandon of a few well-known substances are given in the Ai^>endlx to this Lecture.

100 LKCTUBK m.

been applied hy engineers to draw leaning walls into an upright position. If a body be brittle, the beating of one portion of it, producing eipaneion, may bo press or strain another portion, as to produce fracture. Hot water poured into a glass often craclcs it, through the sudden expansion of the interior. It may also be cracked by the contraction produced by intense cold.

I have here some flasks of very thick glass, which, when blown, were allowed to cool quickly. The external por- tions become first chilled and rigid. The internal portions cooled more gradually, but they found tbemselTes, mi cooling, surrounded, as it were, by a rigid shell, on which they exerted the powerful strdn of their contraction. The consequence is, tiiat the superficial portions of these flasks are in such a state of tension that the slightest scratch pro- duces rupture. I throw into this glass a grain of quartz ; the mere dropping of the little bit of hard quartz into the flask causes the bottom to fly out of it. Here, also, I have these so-called Rupert drops, or Dutch toars, produced by glass being fused to drops, which are suddenly cooled. The eitenial rigid shell has to boar the strmn of the inner contraction ; but the strain is distributed so equally all over the surface, that no part gives way. But by simply break- ing this filament of glass, which forms the tail of the drop, the solid mass is instantly reduced to powder. I dip the drop into a small flask filled with water, and break the laO of the drop outside the flask ; the drop is shivered with such force that the shock, trimsferred through the water, is sufficient to break the bottle in pieces.

A very curious effect of expansion was observed, and explained, some years ago by the Reverend Canon Mosely. The choir of Bristol Cathcdr.il was covered with sheet lead, the length of the covering being 60 feet, and its depth 19 feet 4 inches. It had been Md on in the year 1851, and two years afterwards — viz., in 1863 — it had moved bodily

KEnSROT OF FOBCE OF EXPANSION* 101

down for a distance of eighteen inches. The descent had been continually going on from the time the lead had been laid down, and an attempt made to stop it by driviDg nails into the raflers had fiuled^ for the force with which the lead descended was sufficient to draw out the nails. The roof was not a steep one, and the lead would have rested on it for ever, without diding down by gravity. What, then, was the cause of the descent? Simply this. Thp lead was exposed to the varying temperatures of day and ni^t. During the day the heat imparted to it caused it to expand. Had it bun upon a horizontal surface, it would have expanded equally all round, but as it lay upon an in- clined surface, it expanded more freely downwards than upwards. When, on the contrary, the lead contracted at night, its upper edge was drawn more easily downwards than its lower edge upwards. Its motion was therefore exactly that of a common earthworm ; it pushed its lower edge forward during the day, and drew its upper edge after it during the night, and thus by degrees it crawled through a space of eighteen inches in two years. Every local change of temperature during the day and during the night contributed also to the result ; indeed Canon Moscly aftierwards found the main effect to be due to these quicker alternations of temperature.

Not only do different bodies expand differently by heat, but the same body may expand differently in different di- rections. In crystals the atoms are laid together according to law, and along some lines they are more closely packed than along others. It is also likely that the atoms of many crystalline bodies oscillate more freely and widely in some directions' than in others. The consequence of this would be an unequal expansion by heat in different directions. This crystal I hold in my hand (Iceland spar) has been proved by Professor Mitscherlich to expand more along its crystaUographic axis than in any other direction. Nay,

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while the crystal expands as s whole— that b to say, while its volume is augmented

by heat — it aotnaUy contracts in a direction at right angles to the crystallogr^hio axis. Many other crystals also expand differently in different direction:; ; and, I doubt not, most organic stractnrea would, if exam- ined, exhibit the same fact.

Nature ia full of anomalies whidi no foresight can pre- dict, and which experiment alone can reveal. From the deportment of a vast nUmber of bodies, we ahonld be led to conclude that heat always produces ezpan^cHi, and Uutt cold always produces contraction. But water steps in, and bismuth steps in to qualify this concludon. If a metal be compressed, heat is developed : but if a metal wire be strctehcd, cold is developed. Air. Joule and others have worked at this subject, and found tlic above fact all but general.

One striking exception to this rule (I have no doubt there are many olhere) has been known for a great number of years ; and I wiD now illustrate this exception by an ex- periment. My assistant will hand me a sheet of India- rubber, which I hare placed in the next room to keep it quite cold. From this sheet I cut a strip three inches long, and an inch and a half wide ; I turn my thermo-electric pile upon its back, and upon its exposed face I lay this piece of India-rubber. From the deflection of the needle, yon see that that piece of rubber is cold. I now lay hold of the ends of the strip, suddenly stretch it, and press it, while stretched, on the face of the pile. See the effect 1 The needle moves with energy, and showing that the stretched rubber has heated the pile.

But ono deviation from a rule always carries other de- viations in its train. In the physical world, as in the moral, acts are never isolated. Tlius with regard to our India- rubber ; its deviation from the rule referred to is only part of a series of deviations. In many of his invea

DEPOBTHENT OF ISDIA. BTBBSS.

Mr. Joule baa been associated [with an eminent natural pliiloft- opher — Professor

William Thont- 8011 — and when Mr. Thomson waa made aware of the deviation of India-mbber from an almost gen- eral role, he suggested tbat the stretcbed India-mbber might shorten, on being heated. Tba test vas applied by Mr. Joule, and the shortening vas found to take place. Tbia singular exper- iment, thrown into a soitaUa form, I will now perfonn before you.

I fasten to this arm, a a (Sg, 26), a length of comnum mlaii' iscd Iiidi»mbber tubing, and Htrcteh it by a wetgbt, w, of ten poonds, to about three times iu former length. Here is an index, t f, formed first of a |MEoe of light wood moring freclj co a

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pivot, and prolonged by a stout straight straw. At the end of the straw I place a spear-shaped piece of paper, which can range over the graduated circle drawn on this black board. The index is now pressed down hj a projection which I have attached to the weight ; but if the weight should be lifted by the contraction of the IndiMrubber, the lever will follow it, being drawn after it by a spring, a s^ which acts upon the short arm of the index. The Ludis- rubber tube, you observe, passes through a sheet iron chimney, c, through which I will now allow a current of hot air to ascend from this lamp l. You see the eflEect ; the index rises, showing that the rubber contracts, and by continuing to apply the heat for a minute or so, I cause the end of my index to describe an arc fully three feet long. I withdraw the lamp, and as the India-rubber returns to its former temperature, it lengthens ; the index moves down- wards, and now it rests even below the position which it first occupied.

(4) It is not difficnlt to determine the average Telodties with which the particles of rarious gases more, according to the hypothesis of trans- lation. Taking, for example, a gas at the pressure of an atmosphere, or of 15 lbs. per square inch, and placing it in a vessel a cable inch in size and shape ; from the weight of the gas we can calculate the velocity irith which its particles must strike each side of the vessel in order to counter- act a pressure of 16 lbs. It is manifest at the outset, that the lighter the gas

is, the greater must be its velocity to produce the required effect Accorbing to Clausius (PhiL Hag., 1867, voL xiv. p. 124), the following are the average velocities of the atoms of oxygen nitrogen, and iiydrogen, at the temperature of melting ice : —

Oxygen ..... 1,614 feet per second.

Nitrogen 1,616 •» •»

Hydrogen 6,030 " •»

In 1848, Mr. Joule found the velocity of hydrogen atoms to be 6,066 foet per second.

(5) It is a yety roBAriuible and dgnificant fact that all pcnnanent gases shook! expand by almost precisely the same amount for every degree added to their temperatore. We can deduce from this with extreme prob- ability the important condoaon, that where heat caosos a gas to expand, the woik it performs consists bcMj in overcoming the constant pressure from withoot — that, in other words, the heat is not interfered with by the mutnal aitractioii of the gaseous molecules. For if this were the case, we should have every reason to expect, in the case of different gases, the same irregularities of e^Mmsion which we observe in liquids and solids. I said intentionally ' by abnoti precisely the same amount,' for many gases whidi are pennanent at all ordinary temperatures deviate slightly from the rule. This will be seen fhnn the following table : —

KHD««f6aii CoiSklMt of Etpmilon.

Bydrogea .... (HWBM

Afar 0-<Ktt67

Gubonie oxide 0-0086T

Caxtonic add (HNMm

lYotoxIde of nitrogen 000873

BnlphnrooB add 0*00890

Here hydrogen, air, and carbonic oxide agree very closely ; still there u a slight difference, the coefficient for hydrogen being the least We re- mark in the other cases a greater deviation from the rule; and it is par- ticularly noticeable Uiat the gases which deviate most are those which are nearest their point of liquefaction. The first three gases in the table never have been liquefied, all the others have. They are. In fact, imjjer- fed gases, occupying a kind of intermediate place between the liquid and the perfect gaseous state.

(6) From the passage of water through narrow tubes, Mr. Joule de- duced an equivalent of

*I10 foot pounds.

APPENDIX TO LECTURE III.

ruRTOEE BEMABK3 OJT SILATATIOK.

It is not within the scope of these lectures to dwell In detail on all the phenomcau of expauMon b; beat ; but for the sake of my ;oung readers, I will eupplement this lecture b; a few addi- tional remarka.

The linear, Buperflcial, or cubic coefficient ofexpanaon, is that fraction of a body's Icngtb, surlacc, or Tolume, which jt cxpandB on being beat^d one degree.

Supposing one of the sides of a square plate of metal, whose length is 1, to expand, on being heated one degree, by the quanti- ty a ; then the side of the new square is 1 + a, and its al«a b

l + 2a + a'. In the ease of expansion by beat, the quantity a is so small, that its square is almost insensible ; the square of a Hmall fraction is, of course, greatly less than the fraction itself. Hence without sensible error, we may throw away the a' in the above eiprea- sion, and then we should have the area of the new square

3o, then, is the superficial coefficient of expansion ; hence we infer that by multiplying the linear cocfEcieat by 3, we obttun the su- perScial coefficient

Suppose, instead of a square, that we had a cube, having a side = 1 ; and that on heating the cube one degree, the side ex- panded to 1 + o ; tlien the volume of the expanded cube would bo

1 + 3a + 8a' + a*.

EXPAHBIOIf : THB

In thu, as in the fonner Gaae, the sqiiaio of a, and much more the cobe of O) may be neglected, on aooomit of their exceeding small- we then hsTS the Tolnme of the expanded cube

that is to say, the cubic coefficient of expansion is found by treb- ling the linear coefficient.

The following table contains the coefficients of expansion, for a number of well-known substances : —

Copper

Iron

The second column here giyes the linear coefficient of expansion for 1^ C. ; the third column contains this coefficient trebled, which is the cubic expansion of the substance ; and the fourth column gives the cubic expansion of the same substance, deter- mined directly by Professor Eopp.* It will be seen that Eopp's coefficients agree almost exactly with those obtained by the treb- ling of the linear coefficients.

The linear coefficient of g^ass for 1^ C. is

That of platinum is

Hence glass and platinum expand nearly alike. This is of the greatest importance to chemists, who often find it necessary to fvM platinum wires into their glass tubes. Were the coefficients different, the fhu^ture of the glass would be ineritable during

the contraction.

The ThenMmeUr.

Water owes its liquidity to the motion of heat; when this motion sinks sufficiently, crystallisation, as we haye seen, sets in.

• Phil. Mag., 1852, vol. iU. p. 268.

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The temperature of crystollisation is perfectty constant if the water be kept under the same pressure. For example, water crys- tallises in all climates at the sea-level, at a temperature of 83** P., or of 0** C. The temperature of condensation from the state of steam is equally constant, as long as the pressure remains the same. The melting of ice and the freeang of water touch each other, if I may use the expression, at 82** P. ; the condensation of steam and the boiling of water touch each other at 818" : 92** then is the freezing point of water, and it is the melting point of ke ; 212° is the condensing point of steam and the boiling point of water. Both are invariable as long as the pressure remuns the same. Here, then, we have two invaluable standard points of temperature, and they have been used for this throughout the world. The mercurial thermometer consists of a bulb and a stem with capillary bore. The bore ought to be of aquable diameter throughout. The bulb and a portion of the stem are filled with mercury. Both arc then plunged into melting ice, the mercury shrinking, the column descends, and finally comes to rest. Let the point at which it becomes stationary be marked ; it is the freezing point of the thermometer. Let the instrument be now removed and thrust into boiling water ; the mercury expands, the column rises, and finally attains a stationary height. Let this point be marked ; it is the l)oiling point of the thermometer. The space between the freezing point and the boiling point has been divided by Reaumur into 80 equal parts, by Fahrenheit into 180 equal parts, and by Celsius into 100 equal parts, called degrees. The thermometer of Celsius is also called the Centigrade thermometer.

Both Reaumur and Celsius call the freezing point 0°, Fahren- heit calls it 32°, because he started from a zero which he incor- rectly imagined was the greatest terrestrial cold. Fahrenheit's boiling point is therefore 212°. Reaumur's boiling point is 80°, while the boiling point of Celsius is 100".

The length of the degrees being in the proportion of 80 : 100 : 180, or of 4 : 5 : 9 ; nothing can 1x5 easier than to convert one into the other. If you want to convert Fahrenheit into Celsius, mul- tiply by 5 and divide by 9 ; if Celsius into Fahrenheit, multiply by 9 and divide by 5. Thus 20° of Celsius are equal to 86° Fahrenheit ; but if we would know what temperature by Fah- renheit's tlicrmonietcr corresponds to 20° of Celsius, we must

GALOBIO DOEB KOT EXIST. 109

add 83 to the 86, idiich would make the temperattire 20^, as shown by Cdaiua, equal the temperature 68"*, as shown by Fah- renheiti.

EXTBACTS FROM BIB H. DAYT^ FIB8T SCIENTIFIC HEMOIB, BEAR- ING THE TITLE *0N HEAT, LIOHT, AHD TUE COMBINATIONS OF LIGHT/*

Ths i>eciiliar modes of existence of bodies, solidity, fluidity, and gaadty, depend (according to the calorists) on the quantity of the flidd of heat entering into their composition. This sab- stance insiniiating itself between their corpuscles, separating them from each other, and preventing their actual contact, is by them supposed to be the cause of repulsion.

Other philosophers, dissatisfied with the eyidences produced in favour of the existence of this fluid, and perceiving the genera- tion of heat by friction and percussion, have supposed it to be the motion. Ck)nsidering the discovery of the true cause of the repul- sive power as highly important to philosophy, I have endeav- oured to investigate this part of chemical science by experiments ; from these experiments (of which I am now about to give a detail) I conclude that heat or the

power of repulsion is not matter.

The Phenomena of RejmUion are not dependent on a peculiar dastie fluid for tJteir exkUneej or CdLoricdoes not exUt,

Without considering the effects of the repulsive power on bodies, or endeavouring to prove from these effects that it is mo- tion, I shall attempt to demonstrate by experiments, that it is not matter; and in doing this, I shall use the method called by mathematicians, reductio ad dbnirdum.

First, let the increase of temperature produced by friction and percussion be supposed to arise f^om a diminution of the capaci- ties of the acting bodies. In this case it is evident some change must be induced in the bodies by the action, which lessens their capacities and increases their temperatures.

Experiment. — I procured two parallelopipedons of icet, of the

• Sir Humphry Davy's works, vol. ii.

f The result of this cxpcrimcut is the suuic, if wax, tallow, rcsin, or

temperature of 30", eix inches long, two wide, and two-lhtidiot QQ inch thick ; they were fustened b; wires to two bare of inn, Bj a peculiar mediniiisiu, their surfaces were placed in ccmttd, and kept in a continued and most violent friction for some iu» utea. They were almost cntin:ly coarerted into water, wtud water was collected, and its temperature asccrtaiaed to be 31', after remaining in an atmosphere " ' lower temperature for foai « minutes. The fusion took pluct j at the plane of contutii | the two pieces of ice, and no bodies nerc in friction but ice.

From this experiment it is evident that ice by fHction ie eat I Tertcd into water, and according to the BuppoaitioD, its capidt} is diminished ; but it ia a well-known fuct, that the capaciljtf j water for heat ia much greater than that of ice ; and ice must ban I an absolute quantity of beat added to it, before it con be ctairB^ I ed into water. Friction coneeqiienlly does not tJiininjrfi the tt padties of bodies for heat.

From this esperiment it is likewise eyident, that the incmt of temperature conscciuent on friction cunnot arise from lilB^l^ composition of the osygen gas in contact, for ice has tjon for oxygen. BLnco the increase of temperature t on friction cannot arise from the diniinution of capacity, oro^ dation of the acting bodies, the only remaining supposition 'n that it arises from ho absolute quantity of heat added t which heat must be attracted Q'om the bodies in contact, llitf friction mnat induce some change in bodies, enabling them to it- tract beat from the bodies in contact.

Experiment. — I procured a piece of clockwork, so constradd OS to be Bet at work in the exhausted re ' vheels of this machine came in contact with a thin metallic plil& A considerable degree of Ecnaible heat was produceit l>v (Hctiai tctween the wheel and plate when the macbino worked, ui " lated from bodies capable of communicating heat. I nex: cured a email piece of ice ; ' round the superior edge of this *

any subalance fusible at a low tempcrotare, he uEed ; even iron wj 1* fuacd by eollkion.

* TLi! lempersturc of Iho ice ond of llie surrounding a.

:«mcDt of Iht experiment was S2°, (lint of the niadiii At the end of the experiment the lemperaturc oTths

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Since bodies become eipanded bj fHctioii, It is evident tbst fheir corpuscles must move or sepaiate £rom each other.

Now a motion or vibration of the corpasdes of bodies most be necessarily generated by finction and peraudoo. TheteHom we may reasonably condnde that this motion or vibration Is heat, or the repulsive power.

Heat, then, or that power which prevents the actual oontaet of the corpuscles of bodies, and which is the cause of our peculiar sensations of heat and cold, may be defined a peculiar motion, probably a vibration of the corpuscles of bodies, tending

to separate them. It may with propriety be called the repubive motion.

Since there exists a repulsive motion, the particles of bodies may be considered as acted on by two. opposing foroes; the ap- proximating power, which may (for greater ease of expression) be called attraction, and the rcpulsiyc motion. The first of these* is the compound effect of the attraction of cohesion, by which the particles tend to come in contact with each other ; the attraction of gravitation, by which they tend to approximate to the great contiguous masses of matter, and the pressure under which they exist, dependent on the gravitation of the superincumbent bodies.

The second is the cfiect of a peculiar motory or vibratory im- pulse given to them, tending to remove them farther from each other, and which can be generated, or rather increased, by friction or percussion. The effects of the attraction of cohesion, the great approximating cause, on the corpuscles of bodies, is exactly simi- lar .to that of the attraction of gravitation on the great masses of matter composing the universe, and the repulsive force is analo- gous to the planetary projectile force.

In his * Chemical Philosophy,' pp. 94 and 05, Davy expresses himself thus : — * By a moderate degree of friction, as it would appear fit)m Rumford's experiments, the same piece of met^l may be kept hot for any length of time ; so that, if the heat be pressed out, the quantity must be inexhaustible. When any body is cooled, it occupies a smaller volume than before ; it is evident, therefore, that its parts must have approached each other ; when the body has expanded by heat, it is equally evident that its parts must have separated from each other. The immediate cause of the phenomenon of heat, then, is motion, and the laws of its

DAVT as THB XOnOV OF HKAT. 113

communication sre predBdy the same as the lawi of the eomma- nication of motion.'

Since all matter may be made to fill a smaller fpaoe by oool- ing, it is evident that the particles of matter most hare wp&» f^e- tween them ; and sinoe ereiy body can commonicate the pcnrer of expanmon to a body of a lower temperature — that is,

can {nre anexpansiTe motion to its particles — ^it is a probaUe iiilenn.')^ that ita own particles are possessed of motion ; bat as there ut xto change in the position of its parts, as long as its temperstore is Qnifiirm, the motion, if it exist, most be a Tibfatciry or mAaiMX/irj motion, or a motion of the particles roond their axes, or a tatAyju of the particles round each other.

It seems posdble to acooont for all the phenomena of iKst, if it be snpposed that in solids the particles are in a crjmtatTt i^uU: of Tibratory motion, the particles of the iKittwt t^/dl«4 mfrrinj/; mth. the greatest Telocity, and throogfa the grv.-atert vj/tct: : tLut in fluids and elastic floids, besides the Ti\^uVjrr r/jotion, wlrich most be conceived greatest in the last, the part j«;!«rit hare a vjfAifJU roond their own axes with diifisrent velocity, th*:]^nirticie% fjf elastic floids moving with the greatest quickn^tti, an'i iLat In ethereal sobstances the particles move rrmnd tbeir *jwn u%», ms*4 separate firom each other, penetrating in right lines thmo^ i^ybf^i. Temperatore may be conceived to depend vpfm the iftUjcHy of the vibrations ; increase of cqiacity in the jofAvm Mng iftgif/nssfA in greater space ; and the diminotion of temperstcre doriug the conversion of solids into floids or gasea, may be trpUinfA on the idea of the loss of vibratory motion, in omserjoence <4 the j^'>-lotion of particles roond their axes, at the moment when the U>iy becomes fluid or aC'riform, or from the Ions <^ rapidity of vibnttiou in coDseqoence of the motion of the particles throogh ffpaoe.

[February 13, 1862.]

THK TRSTELTAN INSTRUMSNT — GOBX'S RKVOLTIRO BALLS — UlTLCEKCK OF PRX8SURE ON FCSINO POINT — LIQUSrACTION AND LAMIHAnON OF 101 BT PRESSURE — DISSECTION OF ICE BT A CALORIFIC BEAM — LIQUID FLOWERS AND THEIR CENTRAL SPOT — MECHANICAL PROPERTIES OF WATER PURGED OF AIR — TUE BOILING POINT OF LIQUIDS : INFLUENCING CIRCUMSTANCES — ^TIIE GEYSERS

OF ICELAND.

APPENDIX : — NOTE ON THE TREVELTAN INSTRUMENT — PHYSICAL PROPERTIES

BEFORE finally quitting the subject of expansion, I wish to show you an experiment which illustrates in a curious and agreeable way the conversion of heat into me- chanical energy. The fact which I wish to reproduce was first observed by a gentleman named Schwartz, in one of the smelting works of Saxony. A quantity of silver which had been fused in a ladle was allowed to solidify, and to hasten its cooling it was turned out upon an anvil. Some time afterwards, a strange buzzing sound was heard in the locality, and was finally traced to the hot silver, which was found quivering upon the anvil. Many years subsequent to this, Mr. Arthur Trevelyan chanced to be using a hot sol- dering-iron, which he laid by accident against a piece of lead. Soon afterwards, his attention was excited by a most singular sound which, after some searching, was found to proceed from the soldering-iron. Like the silver of

YIBBATIGHB OF HEATED METALS.

Schwartz, the soldering-iran was found in a state of vibra- tion. Mr. Treyeljan made his disooveiy the subject of a yery interesting investigation. He detennined the best form to be given to the ^ rocker ' as the vibrating mass is now called, and throughout Europe at present this instru- ment is known as ^Treveljan's Instrument.' Since that time the subject has engaged the attention of Prof. J. D. Forbes, Dr. Seebeck, Mr. Faraday, M. Sondhaus, and my- self; but to Trevelyan and Seebeck we owe most.

Here is such a rocker made of brass. Its length, a c (%. 26), is five inches, the width a b, 1*5 in., and the length of the handle, which terminates in the knob f, is ten

inches.

A groove runs at the back of the rocker, along its centre ; ^e cross section of tlie rocker and its groove is given at m. I heat the rocker to a temperature somewhat higher than that of boiling water, and lay it on this block of lead, al- lowing its knob y. ^ to rest upon the table. You hear a quick succes- sion of forcible taps. But you cannot see the osciUatioDs of the rocker to which the taps are due. I therefore place on it this rod of brass, a b (fig. 27), with two balls of brass at its end,

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the ofldllaticais are therel>y zendered mndt stoirer, and yon can eamlj follow with the eje the pendnloua motion of Um rod and balls. This motion will cootinne as long m die rocker is able to commonicate enffident heat to the caiiier on wbidi it restB. Thoa we render the vibrations slow, hat I can also render tbom quick by nnng a rocker with a wider groove. The sides of this rocker do not overhang so modi as those of the last ; it is virtnally a shorter pendn- Inm, and will vibrate more quickly. Placed upon the lead, as before, it commences an nnsteady and not altogeUier pleasant mnmc It is still restless, sometimes seoning to expostulate, sometimes even to objurgate, as if it ^sliksd the treatment to which it is subjected. Now It becomes mellow, and fills the room with a clear full note. Its taps have become periodic and regular, and have linked them- selves together to produce music Here is a third rocker, with a still wider groove, and with it I qan obtain a shrills tone. You know of course that tho pitch of Doto angmmti with the number of the vibrations; this wide-grooved rocker osdllatea more quickly, and therefore emits a higher note. By casting a beam of light upon the rocker I obtain a better index than the rod and balls. This index is with- out weight, and therefore does not retard the motion of the rocker. To the Litter I have fastened, by a single screw at its centre, a small disk of polished silver ; on which tbe beam of the electric lamp now foils, and is reflected agiunst the screen. When the rocker vibrates, the beam vibrates also, but with twice

the angular velocity, and there you see the patch of light quivering upon the screen.

What is the cause of these singular vibrations and tones ? They are due simply to the sudden expansion by heat of the body on which the rocker rests. Whenever the hot rocker comes into contact with its lead carrier, a nipple suddenly juts from the ktter, being produced by the heat commnnicated to the lead at the point of contact. The

TUB ^BBVKLTAH DrSTKUlIENT. 117

rocker is tilted np, and aome other point of it comes into contact with the lead, a fresh nipple is prodoced, and the rocker ia agiun tilted. Let a b (tig. 28) be the eorface of the lead, and B the cross section of the hot rocker ; tilted to the right, the nipple is fonncd as at b ; tilted to Uie left, i as at I. The consequence is that until its t«in-

peratore falls sufficiently, the rocker is tossed to and fro, and the quick sucoeasion of its taps against the lead pro- duces a mufflcal sound.

I have here fixed two pieces of sheet load in a vice ; their edges are exposed, and are about half an inch asun- der. I balance a long bar of heated brass across tho two lead edges. It rests first on one edge, which expands at the point of contact and jerks it npTards ; it then falls upon the second edge which also rejects it ; and thus it goes on oscillating, and will continue to do so as long as the bar

can communicate sufficient heat to the lead. This fire-shovel will answer quite as well as the prepared bar. I balance

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the heated Bhovel thus upon the edges of the lead, and it oscillates exactly as the bar did (fig. 29). I may add, that by properly laying either the poker or the firenshovel upon a block of lead, supporting the handle so as to avoid fric- tion, you may obtain notes as sweet and musical as any which you have heard to-day. A heated hoop pbiced upon a plate of lead may be caused to vibrate and sing ; and a hot penny-piece or half crown may be caused to do the same.*

Looked at with an eye to the connection of natural forces, this experiment is interesting. The atoms of bodies must be regarded as all but infinitely small, but then they must be regarded as all but infinitely niunerous. The aug- mentation of the amplitude of any oscillating atom by the communication of heat, is insensible, but the summation of an almost infinite number of such augmentations become sensible. Such a summation, effected almost in an in- stant, produces our nipple, and tilts the heavy mass of the rocker. Here we have a direct conversion of heat into conmion mechanical motion. But the tilted rocker falls again by gravity, and in its collision with the block restores almost the precise amount of heat which was consumed in lifting it. Here we have the direct conversion of common gravitating force into heat. Again the rocker is surrounded by a medium capable of being set in motion. The air of this room weighs some tons, and every particle of it is shaken by the rocker, and every tympanic membrane, and every auditory nerve present, is similarly shaken. Thus we have t?ie conversion of a portion of heat into sound. And, finally, every sonorous vibration which speeds through the air of this room, and wastes itself upon the walls, seats, and cushions, is converted into the form with which the cycle of actions commenced — namely, into heat.

* For further information see Appendix to thia lecture. *

BOTATION BT ELBCTBICITT.

fiere is another curious etEdCty for which we are indebt- ed to Mr. George Gore, and which admits of a simihir ex- pbioation. You see this line of rails. Two strips of brass, s 8, s' s' (fig. 30), are set edgeways, and about an inch asnnder. I place this hollow metal ball b upon the rails ; if I push it, it rolls along them; but if I do not push it, it stands stilL I connect these two rails, by the wires

tr w\ with the two poles of a Voltaic battery. A current now passes down one rail to the metal ball, thence along the ball to the other rail, and finally back to the battery.

In passing from the rail to the ball, and from the ball to the other rail, the current encounters resistance, and where- ever a current encounters resistance, heat is developed. Heat, therefore, is generated at the two points of contact of the ball with the rails ; and this heat produces an clevar tion of the rail at these points. Observe the effect ; the ball which a moment ago was tranquil is now very uneasy. It vibrates a little at first without rolling ; now it actually rolls a little way, stops, and rolls back again* It gradually augments its excursion, now it has gone further than I intended : it has quite rolled off the rails, and injured itself by falling on the floor.

Here is another apparatus for which I am indebted to Mr. Gore himself, and in which the rails form a pair of concentric hoops ; when the circuit is established, the ball F (fig. 31) rolls round the circle.* Mr. Gore has also ob- tained the rotation of light balls, by placing them on cir-

* PhU. Mag., vol. 16, p. 631.

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onlar raiU of hot copper, the rbUing force in this case being the Bame as the rocking force ia -the TreTelfsn in- Btniment.

In my last lecture I made evident to yon the expanuon of -water when it passes from the liquid to the solid condi- tion; with most other sabstances solidification is aoocnn-

panied by contraction. I have here a round glass dish into which I pour gome hot water. Over the water I ponr fnm a ladle a quantity of melted bees'-wai. The wax now forms a liquid layer nearly half an inch thick above the water. We will suffer both water and wax to eool, and when they aro cool you will find that the wax which now overspreads the entire surface, and is attached all ronnd to the glass, will retreat, and we shall finally obtain a cake of wax of considerably smaller area than the dish.

The wax, then, in passing from the solid to the iiqiud state eapands. To aSHumo the

liquid form, its particles must be poshed more widely apart, a certain play between the particles being necessary to the condition of liquidity. Now supposing we resist the expansion of the wax by an external mechanical force ; suppose we have a very strong vessel completely filled with solid wax, and which offers a powerful resistance to the expansion of the mass within it ;

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what would yon expect if yon sought to liquefy the wax in this vessel ? When the wax is firee, the heat has only to c(mqner the attraction of its own particles, but in the strong yessel it has not only to conquer the attraction of the par- ticles, bnt also the resistance offered by the vesseL By a mere process of reasoning, we should thus be led to infer that a greater amount of heat would be required to melt the wax under pressure, than when it is free ; or, in other words, that the point of fusion of the wax is eknated by pressure. This reasoning is completely justified by experiment, not only with wax, but with other substances which contract on solidifying, and expand on liquefying. Messrs. Hopkins and Fairbaim have, by pressure, raised the melting point of some substances which contract considerably on solidify- ing as much as 20" and 30^ Fahr.

These experiments bear on a very remarkable specula- tion. The earth is known gradually to augment in temper- ature as we pierce it deeper, and the depth has been calcu- lated at which all known terrestrial bodies would be in a state of fusion. Mr. Hopkins, however, observes that owing to the enormous pressure of the superincumbent layers, the deeper strata would require a far higher tem- perature to fuse them, than would be necessary to fuse the strata near the earth's surface. Hence ho infers that the solid crust must have a considerably greater thickness than that ^ven by a calculation, which assumed the fusing points of the superficial and the deeper strata to be the same.

Now let us turn from wax to ice. Ice, on liquefying, contracts ; in the arrangement of

its atoms to form a solid, more room is required than they need in the neighbouring liquid state. No doubt this is due to crystalline arrange- ment ; the attracting poles of the molecules arc so placed that when the crystallising force comes into play, tlic mole- cales unite so as to leave larger inter-atomic spaces in the

mass. We may mppoie tium to tttadi themaelns I7 tbcor oomen ; and in taming oomer to corner, to oatue • moM- rion of the atomic centres. At all events their eentm 19- treat from each other vhen aolidifioadon aets in. By oool- ing, then, this power of retreat, aad of oonaeqaent enlarge ment of volume, ia conferred. It ia evident that preawra in this case vonid reoat the expansion which ia necMsaiy to BolidiBoation, and henoe the tenden^ of pTeasare, in du ease of water, ia to keep it liquid. Thna teaatming, we shonld be led to the condnmon that tiie funng pcnnts of ■abstanoes which expand cm aolidi^ring are levMnd by presanre.'

Professor James Thomson first drew attention to this fact, and his theoretio reasonings have been verified by the experiments of his brother Professor William Thomson.

Let ns illostrate these principles by a striking experi- ment. I have here a square pillar of clear ice an inch and a half in height and about a square inch in cross section. At present tho tempemtore of this ice is 0° C. But snp- pose I subject this ice to pressure, I lower its point of fu- sion: tho ice under pressure will melt at a temperature mider O" C, and hence the temperatpre which it now pos- sesses is in excess of that at which it will melt under pres- Bure. I have cut this ice so that its planes of freezing are perpendicular to the height of the pillar. The direction of the stratified lur-bnbbles in the ice from which this dear piece was taken, enabled me to fix at once upon its planes of freezing. Well, I place the coluron of ice, i., npright between two slabs of boxwood, b b' (fig. 32), and place the whole between the plates of this small hydraulic press ; through the ice I send a beam front the electric lamp. In front of tho ice I place a lens, and by it project a magnified image of the ice upon

the screen before yon. The beam which passes through the ice has been purified beforehand, so that, although it is still hot, its heat is not of each a

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qoality as can melt the ioe ; henoe the light passes through the substance without causing fosion. I work the arm of the press ; the pillar of ice is now gentlj squeezed between the two slabs of boxwood. I apply the pressure cautiously, and now yon see dark streaks beginnihg to show them- sdves across the ice, at right angles to the direction of pressure. Right in the middle of the mass they are ap-

pearing ; and as I continue the pressure, the old streaks expand and new ones appear. Ilie entire colamn is now scarred across by these striae. What are they ? They are amply liquid layers foreshortened, and when you examine this column and look into it obliquely, you see these sur- faces. We have liquefied the ice in planes perpendicular to the pressure, and these liquid planes interspersed through- out the mass give it this strongly pronounced laminated s^pearance.*

Whether as a solid, a liquid, or a gas, water is one of

See Appendix to this lecture for further information.

the moflt vanderfiil labBtanoes in tutve. Let u ccniider its vonderB a litUe farther. At all tempenttnm tbove 88° Fahr. or 0° C, the iiioti<Hi of heat is niSdent to keq> the moleciiles of -water from rigid antoD. But at 0° C. tlw mo- tioa heoomea so redaoed that the atoms tfaen seue vptmi each other and aggregate to a solid. Hub unian, howerer, is a union acoording to law. To many penoni here proaont this block of ice may seem of no more interest and bean^ than a block of glass ; but in the estimation of Mnotoe it ' boan the same relation to g^aas, that an oratorio of TTairfftl does to the cries of a market-plaoe. The ioe is mnsiiG^ the gloss is noise ; the ioe Is order, Hie glass is oonAimon. Jn the glass, molecular forces constitute an inextricably entanr gled skein ; in the ice they arc woven to a symmetric web; the miraculous texture of which I will now try to reveal.

How shall I dissect this ice ? In the solar beam, — or, failing that, in the beam of an electric lamp, we have on anatomist competent to perform this work. I removo the agent by which this beam was puriified in the last experi- ment, and will send the rays direct from tlie lamp through this slab of pellucid ice. It shall pull the crystal edifice to pieces by accurately reverrang the order of its ardiitoctnre. Silently and symmetrically the crystalling force bmlds the atoms up, silently and symmetrically the electric beam will take them down. I place this slab of ice in front of the lamp, the light of which now passes through the ioe. Com- pare the beam before it enters with the beam after ite pass- age through the substance : to the eye there is no sensible difference ; the light is scarcely diminished. Not so with the heat. As a thermic agent, the beam, before altering, is far more powerful than it is after its emergence. A poi^ Uon of the beam has been arrested in the ice, and that por- tion is our working anatomist. Well, what is he doing ? I place a lens in front of the ice, and cast a magnified image

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of the slab upon the screeiL Obflerve that image (fig. 3d), which, in beantj, fiills hr short of the actual effect. Here we have a star and there a star ; and as the action contin- ues, the ice appears to resolve itself into stars, each one possessing six rays, each one resembling a beautiful flower of six petals. And as I shift my lens to and fro, I bring new stars into view, and as the action continues, the edges of the petals become serrated, and spread themselves out like fern leaves upon the screen. Probably few here pres- ent were aware of the beauty latent in. a block of common ioe« And only think of lavish Nature operating thus throughout the world. Every atom of the solid ice which sheets the frozen lakes of the North has been fixed accord- ing to this law. Nature ^ lays her beams in music,' and it is the function of science to purify our organs, so as to enable us to hear the strain.

And now I have to draw your attention to two points connected with this

experiment, of great minuteness, but of great interest. You see these flowers by transmitted light — ^by the light which has passed through both the flowers and the ice. But when you examine them, by al- lowing a beam to fall upon them and to be reflected from them to your eye, you find in the centre of each flower a spot which shines with the lustre of burnished silver. You might be disposed to think this spot a bubble of air ; but you can, by immersing it in hot water, melt away the ice all round the spot ; and the moment the spot is thus laid bare, it collapses, and no trace of a bubble of air is to be seen. The spot is a vacuum. Observe how truly Nature works ; observe how rigidly she carries her laws into all her operations. We learned in the last lecture, that ice in melting contracted, and here we find the fact turning up. The water. of these flowers cannot fill the space occupied by the ice by whose fusion they are produced, hence the

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podactiGD. of a yaeanm necessarily accompanies the forma- tion of every liquid flower.

When I first observed these beantifhl figures, I thought at the moment when the central spot appeared, like a point of light suddenly formed within the ice, that I heard a dink, as if the ice had split asunder when the bright spot was formed. At first I suspected that it was my imagina- tion which associated sound with the appearance of the spot, as it is sdd that people who see meteors often ima- gine a rushing noise when they really hear none. The dink, however, was a reality ; and if you will allow mc, I will now make this trivial fact a starting point from which I will conduct you through a series of interesting phenom- ena, to a far-distant question of practical science.

All water holds a large quantity of air within it in a state of solution ; by boiling you may liberate this impris- oned air. On heating a flask of water you see air bubbles crowding on its sides long before it boils, and you see the bubbles rising through the

liquid without condensation, and often floating on the top. One of the most remarkable eflccts of this air in the water is, that it promotes the ebul- lition of the liquid. It acts as a kind of elastic spring, pushing the atoms of the water apart, and thus helping them to take the gaseous form.

Now suppose this air removed ; having lost the cushion which separated them, the atoms lock themselves together in a far tighter embrace. The cohesion of the water is vastly augmented by the removal of the air. Here is a glass vessel, the so<)alled water hammer, which contains water purged of air. One effect of the withdrawal of the elastic buffer is, that the water here falls with the sound of a solid body. You hear how the liquid rings against the end of the tube when I turn it upside down. Here is another tube, ▲ b o (fig. 34), bent into the form of a Y, and intended to show how the cohesion of the water is affected

by long boiling. I bring iba» mter into one am of fte y ; by tilting the tnbe it flows, u yon, mo, fieefy into tlM other ann. I roBtoro it to the first ann, and now tap the end of this ann against the table. Toa hear, at fcat, ■ loose and jingling sonnd. Am long as yoa hear it the wa- ter is Dot in tme (XRitaot witli the snrfiioe of tbe tobe. I

oontiano my tapping : yon marie on alteration in the soimd ; thfl jingling has disappeared, and the aonnd is now hard, like that of Bolid agunst solid. I now raise my tnbe. Ob- serve what oooars. I turn the column of water Tipode down, but there it stands in x b. Its particles cling so to- naciously to tbe sides of the tube, and lock themselvea so firmly together, that it refoses to behave like a liqnid body ; it declines to obey the law of gravity.

80 mnch for tbe angmentation of cohesion ; bat this very cohedon enables the liquid to reust ebnlliticoil Wa- ter thns freed of its air can be rused to a temperatare 100°

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and more above its ordinary boiling point, without ebulli- tion. Bat mark what takes

place when the liquid does boiL It has an enormous excess of heat stored up ; the locked atoms finally part company, but they do so with the violence of a spring which suddenly breaks under strong tension, and ebullition is converted into explosion. For the discovery of this interesting property of water we are indebted to M. Donny, of Ghent.

Turn we now to our ice : — ^Water, in freezing, complete- ly exdudes the air from its crystalline architecture. All foreign bodies are squeeaed oi\}i in the act of freezing, and ice holds no air in solution. Supposing then that we melt a piece of pure ice under conditions where air cannot ap- proach it, we have water in its most highly cohesive condi- tion ; and such water ought, if heated, to show the effects to which I have referred. That it does so has been proved by Mr. Faraday. He melted pure ice under spirit of tur- pentine, and found that the liquid thus formed could be heated far beyond its boiling point, and that the rupture of the liquid, by the act of ebullition, took place with al- most explosive violence. And now, let us apply these facts to the six-petaled ice-flowers and their little central star. They are formed in a place where no air can come. Imag- ine the flower forming and gradually augmenting in size. The cohesion of the liquid is so great, that it will pull tlie walls of its chamber together, or even expand its own vol- ume, sooner than give way. But as its size augments, the space which it tries to occupy becomes too large for it, until finally the liquid snaps, a vacuum is formed, and a clink is heard.

Let us now take our final glance at this web of rela- tions. It is very remarkable that a great nimiber of loco- motives have exploded on quitting the shed where they had remained for a time quiescent. The number of explo- .

vons which have occurred just as the engineer turned on

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the steam is quite snrprisiiig. Now soppoaiiig that a looo- motiYe had' been boiling soffidently long to eipel the air contained in its water ; thai liquid would poesciaSi in

a greater or less degree, the high cohesiye quality to whidi I have drawn your attention. It is at least eonoeiTable that while resting previous to starting on its journey, an excess of heat might be thus stored up in the boiler, and if stored up, the certdn result would be, that the engineer on tnm- ing on the steam would, by a meohanieal act, produce the rupture of the cohesion, and steam of explosive force would instantly be generated. I do not say that this U the case ; but who can say that it is nd the case. . We have been dbaling throughout with a real agency, which is certainly competent, if its power be invoked, to produce the most terrible effects.

We have here touched on the subject of steam ; let us bestow a few minutes' further consideration on its forma- tion and action. As you add heat, or in other words, mo- tion, to water, the particles from its free surface fly off in augmented numbers. Wc at length approach what is called the boiling point of the liquid, where the conversion into vapour is not confined to the free surface, but is most co- pious at the bottom of the vessel to which the heat is ap- plied. When water boils in a glass beaker, the steam is seen rising in spheres from the bottom to the top, where it often swims for a time, enclosed above by a dome-shaped liquid film. Now, to produce these bubbles, certain remst- ances must be overcome. First, we have the adhesion of the water to the vessel which contains it, and this force varies with the substance of the vessel. In the case of a glass vessel, for example, the boiling point may be raised two or three degrees by adhesion ; while in metal vessels this is impossible. The adhesion is overcome by fits and starts, which may be so augmented by the introduction of salts into the liquid, that a loud bumping sound accompa-

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nies the ebnllUion ; the detachment is in some cases so sad- den and Tiolent as to cause the liqmd to jump bodily out of the yesseL

A second antagonism to the boiling of the liquid is the attraction of the liquid particles for each other, a force irhieh, as we have seen, may become very powerfhl

when the liquid is purged of air. This is not only true of water, but of other liquids—of all the ethei]p and alcohols, for example. If we connect a small flask containing ether or alcohol with an air pump, a Tiolent ebullition occurs in the liquid when the pump is first worked ; but after all the air has been removed, we may, in many cases, continue to work the pump, without producing any sensible ebullition ; the free surface alone of the liquid yielding vapour.

But that steam should exist in bubbles, in the interior of a mass of liquid, it must be able to resist two other things, the weight of the water above it, and the weight of the atmosphere above the water. What the atmosphere is competent to do may be thus illustrated. I have here a tin Vessel containing a little water, which is kept boiling by this small lamp. At the present moment all the space above the water is filled with steam, which issues from this stop- cock. I shut off the cock, withdraw the lamp, and pour cold water upon the tin vessel. The steam within it \a con- densed, the elastic cushion which pushed the sides outwards in opposition to the pressure of the atmosphere is withdrawn, and observe the consequence. The sides of the vessel are crushed and crumpled up by the atmospheric pressure. This pressure amounts to 15 lb. on every square inch : how then, can a thing so frail as a bubble of steam exist on the surface of bailing water ? simply because the elastic force of the steam within is exactly equal to that of the atmos- phere without ; the liquid film is pressed between two clas- tic cusliions which exactly neutralize each other. If the steam were predominant, the bubble would burst from

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within ontwardB ; if the lir were predoiniiUBit» the ImbUe wonld be omahed inwarcb. Here, then, we hsve the tme definition of the boiling point of a liquid. It is that tem- perature at which the tensioa of its vapour exactly balanoes the pressure of the atmosidiere.

As we ascend a mountain the pressure of the atmoa- phere aboye us diminishes, and

the boifing point is oonea- pondingly lowered. On an August morning in 1850 I found the temperature of boiling water on the summit of Mont Blano to be 184*05" Fahr. ; that is, about 27** lower than the boilmg point at the sea leveL (hi August 8, 1858, the temperature of boiling water on the summit of the Finsteraarhom was 187^ Fahr. On August 10, 1858, the boiling point on the smmnit of Monte Rosa was 184*02** Fahr. The boiling point on Monte Rosa is shown by these observations to be almost the same as it was found to be on Mont Blanc, though the latter exceeds die former in height by 500 feet. The fluctuations of the barometer are however quite sufficient to account for this anomaly. The lowering of the boiling point is about 1° Fahr. for every 500 feet that we ascend; and from the temperature at which water boils we may approximately infer the eleva- tion. It is said that to make good tea in London, boiling water is essential ; if this be so it is evident that the bever- age cannot be procured, in all its excellence, at the higher stations in the Alps.

Let us now make an experiment to illustrate the de- pendence of the boiling point on external pressure. Here is a flask, f (fig. 35), containing water ; here is another and a much larger one, o, from which I have had the air re- moved by an air pump. The two flasks are connected to- gether by a system of cocks, which enables me to establish a communication between them. The water in the small flask has been kept boiling for some time, the steam gen* erated escaping from the cock y. I now remove the spirit

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lamp and torn tluB oock bo u to shot ovt the air. Tho vster ceaaes to boil, and pare steam now fills the flask above it. <^ve Hm water time to oool a little. At inter- valfl yoa see a bubble of steam rimng, becaase the preBsore of the vapomr above is gradnally becoming leas throogh its slow oondensatJon. I hasten the condensation hy poiuing cold water <m the flask, the bubbles are more oopionsly generated. By plon^g the flask bodily into cold water ve mi^t oanse it to boil violently. The water

is now at

t and some degrees below its ordinary boiling point. I ■n this oock c, whioh opens a way for the escape of the

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vapour into the ezfaaosted T«Mel o ; ibe mament the pns- flure is diminiflhed ebnUidofi ieto in in r ; and ohwfvo how the condensed steam showers in a kind of run againat the sides of the exhausted yesseL By intentionally promoting this condensation, and thereby preventing the ▼aponr in the large flask fnnn reacting npon the sorfaoe of tiiewvter, we can keep the small flask bubbling and boiling for a oonsid* erable length of time.

By high heating, the elastic foroe of steam beocanea enormous. The Marquis of Worcester burst camion with it, and our calamitbus boiler ezploeions are so mai^ illns- trations of its power. By the skill of man thia migfaty agent has been controlled : by it Denis Papin raised a jns- ton, which was pressed down again by the atmocfphere, when the steam was condensed ; Savery and Newcomen turned it to practical account, and James Watt completed the grand application of the moving power of heat. Push- ing the piston up by steam, while the space above the pis- ton is in communication with a condenser or with the free air, and again ptlshing down the piston^ while the space below it is in communication with a condenser or witii the air, we obtain a simple to and fro motion, which, by mechanical arrangements, may be made to take any form we please.

But the grand principle of the conservation of force jb illustrated here as elsewhere. For every stroke of work done by the steam-engine, for every pound that it lifts, and for every wheel that it sets in motion, an equivalent of heat disappears. A ton of coal furnishes by its combuistion a certain definite amount of heat. Let this quantity of coal be applied to work a steam-engine ; and let all the heat communicated to the machine and the condenser, and all the heat lost by radiation and by contact with the

air be collected ; it would fall short of the amount produced by the simple combustion of the ton of coal, and it would fall

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short of it by an amoant exacUj equivalent to the quantity of work performed. Suppose that work to consist in lift- ing a weight of 7,720 llw. a foot high ; the heat produced by the coal would faU short of its wiATimnm^ by a quantity just sufficient to warm a pound of water 10°.

But my object in these lectures is to deal with nature rather than art^ and the limits of our time compel me to pass quickly over the triumphs of man's skill in the application of steam to the purposes of life. Those who have walked through the workshops of Woolwich, or through any of our great factories where machinery is ex- tensively employed, wiU have been sufficiently impressed with the aid which this great power renders to man. And be it remembered, every wheel which revolves, every chis- el, and plane, and saw, and punch, which forces its way through solid iron as if it were so much cheese, derives its moving energy from the clashing atoms in the furnace. The motion of these atoms is communicated to the boiler, thence to the water, whose particles are shaken asunder, and fly from eadh other with a repellent energy commen- snrate with the heat conmiunicated. The steam is simply the apparatus through the intermediation of which the atomic motion is converted into the mechanical. And the motion thus generated can reproduce its parent. Look at the planing tools ; look at the boring instruments— streams of water gush over them to keep them cool. Take up the curled iron shavings which the planing tool has pared off: you cannot hold them in your hand they are so hot. Here the moving force is restored to its first form ; the energy of the machine has been consumed in reproducing the power from which that energy was derived.

I must now direct your attention to a natural steam- engine which long held a place among the wonders of the world. I allude to the Great Geyser of Iceland. The sur-

face of Iceland gradually slopes from the coast towards the

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centre, There tibe general level ii abont 2,000 feet ftbers the eea. On this, aa a pedestal, are planted the JAknll or icy mountains, urtiich extend both :ira7B in a norflieitcifr direction. Along this chain occur the active voloanoea of the island, and the thermal ipringa follow the aame genenl direction. From the ridges and «*«"« whidi divnge from the mountains enormous mttsooa of steam imoe at intemla hiarang and roaring; and Then the esoapo oocotb at the month of a cavern, the resonance of the cave often laiBea the sound to the londnees of thunder. Lower down in the more porous strata we hare smoUng mod pools, where ■ repuldvc blue-black alnininouB paste is boiled, ridag at times in hugh bubbles, which, on bursting, scatter their elimy spray to a height of fifteen or twenty feet From the bases of the hills upwards extend the glatners, and above these are the snow-fields which crown the Biunndta. From the arches and fissures of the gladen vast massee of water issue, falling at times in cascades over walla of ice, and spreading for miles over the country before they find definite outlet. Extensive morasses are thus formed, which add their comfortless monotony to the dismal scene already before the traveller's eye. Intercepted by the cracks and fissures of the land, a portion of this water finds its way to the heated rocks underneath ; and here, meeting with the volcanic gases which traveree these underground regions, both travel together, to issue, at the first conve nient opportunity, either as an emption of steam or a boil- ing spring.

The most famous of these ^rings is the Great Geyser. It consists of a tube V4 feet deep and 10 feet in diameter. The tube is stirmonntcd by a basin, which measures from north to south 62 feet across, and from east to west 60 feet. The interior of the tube and basin is coated with a beautiful smooth siliceous plaster, so hard as to resist the Uows of a hammer, and the first question ia, how waa

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ihiti wonderfol tube constmcted— how was this perfect pilaster laid on f Chemical anialysifl shows that the water holds nlica in solution, and the conjectnre might therefore arise that the water had deposited the silica against the sides of the tube and basin. But this is not the case : the water deposits no sediment ; no matter how long it may be kept, no solid snbstanoe is separated fix>m it. It may be bottled np and inreserved for years as dear as crjrstal, with- out showing the slightest tendency to form a precipitate. To answer the question in this way would moreover assume that the shaft was formed by some foreign agency, and that the water merely lined it. The geyser basin, however, rests iqpon the summit of a mound about 40 feet high, and it is evident, firom mere inspection, that the mound has been deposited by the geyser. But in building up this mound the spring must have formed the tube which per- forates the mound, and hence the conclusion that the gey- ser is the architect of its own tube.

If we place a quantity of the geyser water in an evapor- ating basin the following takes place : In the centre of the basin the liquid deposits nothing, but at the sides, where it is drawn up by capillary attraction, and thus subjected to speedy evaporation, we find silica deposited. Round the edge a ring of silica is laid on, and not until the evapo- ration has continued a considerable time do we find the slightest turbidity in the middle of the water. This exper- iment is the microscopic representant of what occurs in Iceland. Imagine the case of a simple thermal siliceous spring, whose waters trickle down a gentle incline ; the water thus exposed evaporates speedily, and silica is de- posited. This deposit gradually elevates the side over which the water passes until finally the latter has to take another course. The same takes place here, the ground is elevated as before and the spring has to move forward. Thus it is compelled to travel round and round, discharg-

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ing its silica and deepening the shaft in vhich it dwffls, until finaUy, in the coarse of

ages, the simple spring has produced that wonderful apparatus which has so long pn& zled and astonished both the traveller and the philosopher.

Previous to an^ruption, both the tube and basin are filled with hot water ; detonations which shake the ground, are heard at intervals, and each is succeeded by a violent agitation of the water in the basin. The water in the pipe is lifted up so as to form an eminence in the middle of the basin, and an overflow is the consequence. These detonar tions are evidently due to the production of steam in the ducts which feed the geyser tube, which steam escaping into the cooler water of the tube is there suddenly con- densed, and produces the explosions. Professor Bunscn succeeded in determining the temperature of the geyser tube, from top to bottom, a few minutes before a great eruption ; and these observations revealed the extraordi- nary fact, that at no part of the tube did the water reach its boiling point. In the annexed sketch (fig. 36) I have given, on one side, the temperatures actually observed, and on the other side the temperatures at which water would boil, taking into account both the pressure of the atmos- phere and the pressure of the superincumbent colunm of water. The nearest approach to the boiling point is at a, a height of 30 feet from the bottom ; but even here the water is 2° Centigrade, or more than 3i° Fahr. below the temperature at which it could boil. How then is it pos- sible that an eruption could occur imder such circum- stances ?

Fix your attention upon the water at the point a; where the temperature is within 2° C. of the boiling point. Call to mind the lifting of the column when the detona- tions are heard. Let us suppose that by the entrance of steam from the ducts near the bottom of the tube, the geyser colunm is elevated 6 feet, a height quite within the

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linftts of actual obflonratioii ; the water at ▲ is thereby transferred to b. Its boiling point at a is 123*8% and its actual temperatore 121*8^; but at b its boiling point is

only 120*8% hence, iriien transferred fix>m a to b the beat which it possesses is in excess of that necessary to make it boiL This excess of heat is instantly applied to the gen- eration of steam : the column is thus lifted higher, and the

water below is further relieved. More steam is generated ; from the middle downwards the mass suddenly bursts into

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ebunition, the water above, mixed with steam douds, is projected iato the atmosphere, and we have the geyser eruption in all its grandeur.

By its contact with the air the water is cooled, falls back into the basin, partially refills the tube, in which it gradually rises, and finally fills the basin as before. Deto- nations are heard at intervals, and risings of the water in the basin. These are so many futile attempts at an erup- tion, for not until the water in the tube comes sufficiently near its boiling temperature, to make the»lifting of the col- umn efifective, can we have a true eruption.

To Bunsen we owe this beautiful theory, and now let us try to justify it by experiment. Here is a tube of gal- vanized iron, 6 feet long, a b (fig. 37), and surmounted by this basin c d. It is heated by a fire imdemeath ; and to imitate as far as possible the condition of the geyser, I have encircled the tube by a second fire F, at a height of 2 feet from the bottom. Doubtless the high tem- perature of the water at the corres- ponding part of the geyser tube is due to a local action of the heated rocks. I fill the tube with water, which gradually becomes heated ; and regularly, every five minutes, the wa- ter is ejected from the tube into the atmosphere.

But there is another famous spring in Iceland, called the Strokkur, which is usually forced to explode by stop- ping its mouth with clods. We can imitate the action of this spring by stopping the mouth of our tube a b with a cork. I do so: and now the heating progresses. The steam below

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will finally attain suffident tension to eject the oork, and the water, suddenly relieved from the pressure, will burst forth in the atmosphere. There it goes! The ceiling of this room is nearly 80 feet from the floor, but the eruption has reached the ceiling, from which the water now drips plentifully. In fig. 88, I have given a section of the Strokkur.

By stopping the tube with corks, through which tubes of various lengths and widths pass, the action of many of the other eruptiTe springs may be accurately imitated. Here, for example, I have an intermittent action; dis- charges of water and impetuous steam gushes follow each other in quick succession, the water being squirted in jets 15 or 20 feet high. Thus, it is proved experimentally, that the geyser tube itself is the sufficient cause of the eruptions, and we are relieved from the necessity of uoflr gining underground caverns filled with water and steam, which were formerly regarded as necessary to the produc- tion of these wonderful phenomena.

A moment's reflection will suggest to us that there must be a limit to the operations of the geyser. When the tube has reached such an altitude that the water in the depths below, owing to the increased pressure, cannot at- tain its boiling point, the eruptions of necessity cease. The spring, however, continues to deposit its silica, and often forms a 1mu(/ or cistern. Some of those in Iceland are 40 feet deep. Their beauty, according to Bunsen, is inde- scribable ; over the surface curls a light vapour, the water is of the purest azure, and tints with its lovely hue the fan- tastic incrustations on the cistern walls ; while, at the bot- tom, is often seen the mouth of the once mighty geyser. There are in Iceland vast, but now extinct, geyser opera- tions. Mounds are observed whose shafts are filled with rubbish, the water having forced a passage underneath and retired to other scenes of action. We have in fact the

OX7SKB OFKRA3IO0B IN ICKLAin).

gejBcr in its yoath, nmnliood, old age, and death, here pre- aoited to na. In its youth, as a simple thermal spring ; in its manhood, as the eruptive colmnn ; in its old age, as the tranquil Lotug ; while its death is recorded by the rained shaft imd monnd which testify the fact of its once active existence.

APPENDIX TO LECrUKB W.

ABSTSACT OF A LECTCBE OH TUE YIBgATIOy AHD TQEn» PRO- DUCED BY THE COIITACT OF BODIES OF DIFFBBXHT TSMFKB- ATUBE8.

In the year 1805, M. Schwartz, an inspector of one of the smelting works in Saxony, placed a cup-shaped mass of hot silTer upon a cold anvil, and was surprised to find that musical tones proceeded from the mass. In the autumn of the same year, Professor Gilbert of Berlin yisited the smelting works and repeated the experiment. He observed, that the sounds were accompanied by a quivering of the hot silver, and that when the vibrations ceased, the sound ceased also. Professor Gilbert merely stated the &cts, and made no attempt to explain theuL

In the year 1829, Mr. Arthur Trevelyan, being engaged in spreading pitch with a hot plastering iron, and once observing that the iron was too hot for his purpose, he laid it slantingly against a block of lead which chanced to be at hand ; a ahriU note, which he compared to that of the chanter of the small Northumberland pipes, proceeded from the mass, and, on. nearer inspection, he observed that the heated iron was in a state of vi- bration. He was induced by Dr. Reid of Edinburgh to pursoe the subject, and the results of his numerous experiments were subsequently printed in the Transactions of the Royal Society of Edinburgh.

On April 1, 1831, these singular sounds and vibrations formed the subject of a Friday evening discourse by Professor Faraday at the Royal Institution. Professor Faraday expanded and fbrther established the explanation of the sounds given by Mr. Trevelyan

GENERAL LAWS OF FB0FBB80B FOBBE8. 145

and Sir John Leslie. He referred them to the tapping of the hot mass against the cold one mulenieath it, the taps being in many cases sufficiently quick to produce a high musical note. The al- ternate expansion and contraction of the cold mass at the points where the hot rocker descends upon it, he regarded as the sus- taining power of the vibrations. The superiority of lead Le es- cribed to its great expansibility, combined with its feeble power of conduction, which latter preyented the heat from being quick- ly difiused through the mass.

Professor J. B. Forbes of Edinbuigh was present at this lec- ture, and not feeling satisfied with the explanation, undertook the £uther examination of the subject ; his results are described in a highly ingenious paper communicated to the Royal Society of Edinburgh in 1838. He rejects the explanation supported by Professor Faraday, and refers the vib^tions to *■ a new species of mechanical agency in heat ' — ^a repulsion exercised by the heat itself on passing from a good conductor to a bad one. This con- clusion is based upon a number of general laws established by Professor Forbes. K these laws be correct, then indeed a great step has been taken towards a knowledge of the intimate nature of heat itself, and this consideration was the lecturer's principal stimulus in tesuming the examination of the subject.

He had already made some experiments, ignorant that the sub- ject had been fiEirther treated by Seebeck, until informed of the fact by Professor Magnus of Berlin. On reading Seebeck's inter- esting paper, he found that many of the results which it was his intention to seek had been already obtained. The portion of the subject which remained untouched was, howeyer, of sufficient in- terest to induce him to prosecute his original intention.

The general laws of Professor Forbes were submitted in succes- sion to an experimental examination. The first of these laws affirms that ' tJie vibrations never taJce place hetteeen substances of the same nature,^ This the lecturer found to be

generally the case when the hot rocker rested upon a blocks or on the edge of a thick plate of the same metal ; but the case was quite altered when a thin plate of metal was used. Thus a copper rocker laid upon the edge of a penny-piece did not vibrate permanently ; but when the coin Was beaten out by a hammer, so as to present a thin sharp edge, constant vibrations were obtained. A silver rocker restiig

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resting on the edge of a half^oo^m leftaaed to Tibnto bnt on the edge of a dxpence contimioiis Tibimtioiis were obtained. An iron rocker on the edge of a dinner knife gate ootannoiii H- bratione. A flat brass rocker placed upon the pointa of two-oom-men brass pins, and haying its handle ioitablj siqipoited, gave distinct Tibrations. In these ezperimeols the plates and piu were fixed in a Tice, and it was fi>mid that the thinner the plal^ within its limits of rigidity, the more certain and stiikii^ waa tfaa effect Vibrations were thus obtained with iron on iroDy oopper on copper, brass on brass, sine on sLno, silTer cm rfhWi Ub. on tin. The list might be extended, but the cases dted an rafllelaBfe to show that the proposition aboTe dted cannot be v^gaidad as expressing a ' general law.'

The second general law ennndated by Professor Foibesis^fliat ' both iubitanees must he metaUic'^ This is the law which fint at- tracted the lecturcr^s attention. During the progress of a kindred enquiry, ho had discovered that certain non-metallic bodies are endowed with powers of conduction far higher than has been hitherto supposed, and* the thought occurred to him that such bodies might, by suitable treatment, be made to supply the place of metals in the production of yibrations. This anticipation was realized. Rocks of silycr, copper, and brass, placed upon the natural edge of a prism of rock crystal, gave distinct tones ; on the clean edge of a cube of fluor spar, the tones were stiU more musical ; on a mass of rock-salt the yibrations were yeiy forcible. There is scarcely a substance, metallic or non-metallic, on which yibrations can be obtained with greater ease and certainty than on rock-salt. In most cases a

high temperature is necessary to the production of the tones, but in the case of rock-salt the tem- perature need not exceed that of the blood. A new and singular property is thus found to belong to this already remarkable sub- stance. It is needless to enter into a fiill statement regarding the yarious minerals submitted to experiment. Upwards of twenty non-metallic substances had been examined by the lecturer, and distinct yibrations obtained with cycry one of them.

The number of exceptions here cxliibited far exceeds that of the substances which are mentioned in the paper of Professor Forbes, and are, it was imagined, sufficient to show that the sec- ond general law is untenable.

!B TESTED EXI^EROCENTALLT.

?ral law states, that ' the Tihrations tale place rojKoiumal (within certain limits) to the differ- '(/ jf*yirer» of the metaU for heat, tite metal lutein^ f 2Hfica\ Ih iiitj ne'^enffirify t?ui eoldistJ' The evi- iiinst the tir^t law api>ears to destroy this one ■nsity of the vihnitiuns be proportional to the >uducting j)owers, then, where there is no such u<;ht to he no vibrations. But it has l)een)zi."n cases that vibrations occur between diffcr- imo metal. TTie condition stated by Professor er, revcrsf.-<l. Silver stands at the head of con- * the metal was fixed in a vice, and hot rockers nd iron, Avere successively laid upon its edge : were obtained with all of them. Yibrations with a braids rocker which rested on the eilge These* and otlicr experiments show that it is the worst conductor should l>e the cold metal, :hird general law above quoted. Among the and bismuth were found piTfoctly inert by the h'cturcr however had obtained musical tluvc sub.stanccs.

of lead as a cold block. Professor Faraday, as rrcd to its high expansibility, combined with cting])ower. Against tliis notion, which he I obvious oversight,' Professor Forbes contends nd nj)panmtly unanswerable manner. Tlie vi- , deiK-nd upon the difference of temperature 10 ror^ker and the block ; if the latter be a bad lin

the heat at its surface, the tendency is to ■faces in contact to the same temperature, and ibratjon instead of exalting it. Farther: the ity of heat transmitted from the rocker to the :act. the greater must ?>e the expansion ; and tioiis I;e due to this cause, the effect must l>e a le Mock is the be^t conductor possible. But n tliis argimicnt, seems to have used the term iffi-rent si^ns^.s. The expansion which jiroduces le sudilen u])heavul of the point where the 1 contact with the cold mass underneath : but

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the expansion due to good conduction would be an txpanAm of the general mass. Imagine the condnctiTe power of the block to be infinite— that is to say, that the heat imparted by the xodcer ii instantly diffused equally throughout the block; ihen, though the general expansion might be Tery great, the local ezpanrfon at the point of contact would be wanting, and no Tibntkms would be possible. The ineritable consequence of good condnctloii ii^ to cause a sudden abstraction of the heat firom the point of ocm- tact of the rocker with the substance undenieath, and fhia Ae lecturer conceiTed to be the precise reason why Proteaor IMws had failed to obtain vibrations when the cold metal waa a good conductor. He made use of Uaeki, and the abstractioa of Inai from the place of contact by the circumjacent man oi metdy was so sudden as to extinguish the local eleyation on which the ^bra- tions depend. In the experiments described by the lecturer, this abstraction was to a great extent ayoided, by reducing the metalr lie masses to thin lamins ; and thus the yery experiments adduced by Professor Forbes against the theory supported by Professor Faraday, appear, when duly considered, to be conyerted into strong corroborative proofs of the correctness of the yiews of the philosopher last mentioned.

EXTRACT FROM A PAPER ON SOME PnYSICAL PROPESTIES OF

In a yery intcrcstiDg paper communicated to the British Asso- ciation during its last meeting, Mr. James Thomson has explained the freezing together of two pieces of ice at 82® Fahr., in the fol- lowing manner : — * The two pieces of ice, on being

pressed to- gether at their point of contact, will at that place, in yirtue of the pressure, be in part liquefied and reduced in temperature, and the cold eyolved in their liquefaction will cause some of the liquid film interyening between the two masses to freeze.'

I am far from denying the operation under proper circum- stances of the vera causa to which Mr. Thomson refers, but I do

• PhiL Trans., 1868, p. 225.

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link it ezplaina the fiuste. For fipee&ng takeB place without ntenrentioii of any pranare by which Mr. Thomson's effect . tenaibly come into play.

is not neoenaiy to sqneexe the pieces of ice together ; one ay be 8inq>ly hud upon the other, and they will still freeze, r sabstances besides ice are also capable of being frozen to «. If a towel be folded roond a piece of ice at 82° the towel ce will fieese together. Flannel is still better ; a piece of il wrapped roond a piece of ice, freezes to it sometimes so r that a strong tearing force is necessary to separate both. B, wool, and hair may also be frozen to ice, without the In- xtion of any pressure which would render Mr. Thomson's ■ensibly active.

It there is a class of effects to the explanation of which the ing of the freezing point of water, by pressure, may, I think, operly applied. The following statement is true of fifty ex- tents, or more, made with ice from yarious quarters. A cyl- of ice, two inches high and an inch in diameter, wfls placed sen two slabs of box-wood, and submitted to a gradually ising pressure. Looked at perpendicularly to the axis, y lines were seen drawing themselyes across the cylinder ; lirhen the latter was looked at obliquely, these lines were L to be sections of dim hazy sur&ces which traversed the ler, and gave it an appearance closely resembling that of a il of gypsum whose planes of cleavage had been forced out tical contact by some external force.

ig. 89 represents the cylinder looked at perpendicularly to is, and ^, 40 the oame

cylinder when looked at obliquely.

AFPENDIX TO LEOTDBE IY»

To ascertain whether the rapture of optical cootaet irfaidi these experiments disclosed was due to the intnuioii of air be- tween two separated sorlaces of ice, a cylinder of ice, two indies long and one inch wide, was placed in a copper Teswl containing ice-cold water. The ice cylinder projected half an inch aboTe the surface of the water. Placing the copper Tessel on a alab of wood, and a second slab of wood upon the cylinder of ioe, the whole was subjected to pressure. When the hazy vaAces were well developed in the portion of ice above the water, ibe cylinder was removed and examined. The planes of rupture extended throughout the entire length of the cylinder, just the nine as it had been squeezed in free air.

Still the removal of the cylinder from its vessel might be at- tended with the intrusion of air into the fissures. I thoefore placed a cylinder of ice, two inches long and one inch wide, in a stout vessel of glass, which was filled with ice-cold water. Squeez- ing the whole, as in the last experiment, the surfaces of discontin- uity were seen under tlve UquUi quite as dbtinctly as in air.

The surfaces are due to compression, and not to any tearing asunder of the mass by tension, and they are best developed where the pressure, within the limits of fracture, is a maximum. A cylindrical piece of ice, one of whose ends was not parallel to the other, was placed between slabs of wood and subjected to pressure. Fig. 41 shows the disposition of the experiment. The

Fig. 41. //////V////////y/y/////^V/A

'v/////////y/^y/////////^^^^^^

??>^^5^?:j^^^^5555^i^^^

^^^/'//////A//////////^^^^^'

effect upon the ice-cylinder was that shown in fig. 42, the sur- faces being developed along that side which liad suffered the pressure.

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Sometimes the suifaces commence at the centre of the cylin- der. A dim small spot is first observed, which, as the pressure continnes, expands until it sometimes embraces the entire trans- Tcacse section of the cylinder.

On examining these surflEMies with a pocket lens, they appeared to me to be composed of yery minute water-parcels, like what is {Hodaced upon a smooth cold sar&uce by the act of breathing. Were they either yacuous plates, or plates filled with air, their iq)ect would, on optical grounds, be fiur more yivid than it really

A ooncaTO minor was so diq>osed, that the diffused light of day was thrown full upon the cylinder while under pressure. Obflerring the expanding sui&ces through a lens, they appeared in a state of intense commotion ; this was probably due to the molecular tensions of the little water-parcelB. This motion fol- lowed closely on the edge of the surfiM^ as it advanced through ihe solid ice. Once or twice I observed the hazy surfaces pio- neered through the mass by dim ofi&hoots apparently liquid. They constituted a kind of negative crystallization, having the exact form of the crystalline spines and spurs produced by the congelatioa of water upon a surface of glass. I have no doubt, then, that these surfaces are produced by the liquefaction of the solid in planes perpendicular to the direction of pressure.

The sui&ces are developed with great facility when they cor- respond to the surfiMses of freezing. By care I succeeded in some cases in producing similar effects in surfaces at right angles to the planesof freezing, but this was difficult and uncertain. Wherever the liquid disks before described were observed, the surfaces were always easily developed in the planes of the disks.

[February 20, 1862.]

AnUOAXlOU OF THE DTNAXICAL THIORT TO TBI FSBHOMIIA. OV

BTICIPIO AND LATENT HEAT — ^DEFINITION OF ENEBGT: POTENTIAL AND DTXAIUO ENBBGT — ENEBGT OF MOLECULAB F0B0E8— BXPBBDOEHTAL ILLUBXmA- TI0N8 OF SPECIFIC AND LATENT HEAT — ^MECOANIOAL TALUn OP THE ACTS OF COMBINATION, CONDENSATION, AND CONGELATION IN THE CASE OF WATER — SOLID CARBONIC ACID — ^THB SPHEROIDAL STATS OF U(2UIDS — FLOATING OF SPHEROID ON ITS OWN VAPOUR — FREEZING 07 WATER AND MERCURY IN A RED-HOT CRUCIBLE.

WHEXEVER «i difficult expedition is undertaken in the Alps, the experienced mountaineer commences the day at a slow pace, so that when the real hour of trial arrives, he may find himself hardened instead of exhausted by his previous work. We, to-day, are about to enter on a difficult ascent, and I propose that we commence it in the same spirit ; not Avith a flush of enthusiasm which the necessity of labour extinguishes, but with patient and determined hearts which will not recoil should a difficulty arise.

I have here a lead weight attached to a string which passes over a pulley at the top of the room. We know that the earth and the weight are mutually attractive ; the weight now rests upon the earth and exerts a certmn press- ure upon its surface. The earth and the weight here tauch each other/ their mutual attractions are as far as possible satisfied, and motion by their mutual approach is no longer possible. As far as the attraction of gravity is

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concerned, the possibility of producing motion ceases as soon as the two attracting bodies are actually in contact.

I draw up this weight. It is now suspended at a height of sixteen feet above the floor ; it is just as motionless as when it rested on the floor ; but by introducing a space

between the floor and it, I entirely change the condition of the weight. By raising it I have conferred upon it a motion-producing power. There is now an action possible to it, which was not possible when it rested upon the earth ; it can faU^ and in its descent can turn a machine or per- form other work. It has no energy as it hangs there dead and motionless ; but energy is possible to it, and we might fairly use the term possible energy^ to express this power of motion which the weight possesses, but which has not yet been exercised by falling ; or we might call it ' poten- tial energy,' as some eminent men have already done. This potential energy is derived, in the case before us, from the pull of gravity, which pull, however, has not yet eventuated in motion. But I now let the string go ; the weight falls, and reaches the earth's surface with a velocity of thirty-two feet a second. At every moment of descent it was pulled down by gravity, and its final moving force is the summa- tion of the pulls. While in the act of falling, the energy of the weight is active. It may be called actual energy, in antithesis to possible ; or it may be called dynamic energy, in antithesis to potential^ or we might call the energy with which the weight descends moving force. Do not be inat- tentive to these points ; we must be able promptly to dis- tinguish between energy in store and energy in action. Once for all then, let us take the terms of Mr. Rankinc, and call the energy in store ' potential,' and the energy in action * actual.'* If, after this, I should use the terras

• Ilclmboltz, in his admirable memoir on *Die Erhaltung der Kraa/ (1847), divided all energy into Tension and vw viva, (Spaunkrafte und Lebcndige Krafte.)

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* possible energy,' or * dynamic energy,' or * moving force,' you will have no difficulty in affixing the exact idea to these terms. And remember exactness is here essentiaL We must not now tolerate vagaeness in oar conceptions.

Oar weight started from a hdght of sixteen feet ; let as fix our attention upon it after

it has accomplished the first foot of its fall. The total pull, if I may use the term, to be expended on it has been then diminished by the amount expended in its passing through the fihit foot. At the height of fifteen feet it has one foot less of potential energy than it possessed at the height of sixteea feet, but at the height of fifteen feet it has got an equivalent amount of dynamic or actual energy which, if reversed in direction, would raise it again to its primitive height. Hence as po- tential energy disappears, dynamic energy comes into play. Throughout the universe the sum of tJieae two energies is constant.

It is as yet too early to refer to organic processes, but could we observe the molecular condftion of my arm as I drew up that weight, it would be seen that in accomplishr ing this mechanical act, an equivalent amount of some other form of motion was consumed. If the weight were raised by common heat, a portion of heat would disappear exactly equivalent to the work done. The weight is about one poimd, and to raise it sixteen feet would consume as much beat as would raise the temperature of a cubic foot of air about 1° F. Conversely, this quantity of heat would be generated by the falling of the weight from a height of sixteen feet. It is easy to see that, if the force of gravity were immensely greater than it is, an immensely greater amount of heat would have to be expended to raise the weight. The greater the attraction, the greater would be the amount of heat necessary to overcome it ; but conversely, the greater would be the amount of heat which a falling body would then develope by its collision Tiith the earth.

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Having made our minda dear tliat heat is consumed when a weight is forcibly separated from the earth by this agenty and that the amomit of heat oonsmned depends on the energy of the attracting force oyercome, we must turn these conceptions, regarding sensible masses, to account, in forming conceptions regarding insensible masses. As sn intellectual act it is quite as easy to conceive of

the sep- aration of two mutually attracting atonu^ as to conceive of the separation of the earth and weight. I have already had occasion to refer more than once to the energy of molecular forces, and here I have to return to the subject. Closely locked together as they are, the atoms of bodies, though we cannot suppose them to be in contact, exert enormous attractions. It would require an almost incred- ible amount of ordinary mechanical force to widen the dis- tances intervening between the atoms of any solid or liquid, 80 as to increase the volume of the solid or liquid in any considerable degree. It would also require a force of great magnitude to squeeze the particles of a liquid or solid to- gether, so as to make the body less in size. I have vainly tried to augment the density of a soft metal by pressure Water, for example, which yields so freely to the hand plunged in it, was for a long time regarded as absolutely incompressible. Great force was brought to bear upon it ; but sooner than shrink sensibly, it oozed through the pores of the metal vessel which contained it, and spread like a dew on the surface.* By refined and powerful means wc

* I haTo to thank my friend, Mr. Spedding, for the following extract in reference to this experiment : —

*Kow it is certain that rarer bodies (such as air) allow a considerable degree of contraction, as has been stated ; not that tangible bodies (such as water) suffer compression with much greater difficulty and to a less extent How far they do suffer it, I have investigated in the following experiment: I had a hollow globe of lead made capable of holding about two pints, and sufficiently thick to bear considerable force ; having made a hole in it, I

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can now compress water, but the force necessary to aocon^ plish this is very great.

When we wish to overcome molecnlar forces we must attack them by their peers. Heat accomplishes what me- chanical energy, as generally wielded, is incompetent

to perform. Bodies when heated erpand, and to eflEect this expansion their molecnlar attractions mnst be overcome. In masses equally large this is a work, in conqNuison with which the erection of the Egyptian pyramids dwindles to the labour of mites ; and where the attractions to be over- come are so vast, we may infer that the qoanti^ of heat necessary to overcome them will be commensorate.

And now I must ask your entire attention. I hold in

filled it with water, and then stopped up the hole with melted load, so that the globe became quite solid. I then flattened the two oppofflte ades of the globe with a heavy liammcr, bj which the water was necessarily contracted into less space, a sphere being the figure of largest capacity ; and when the hammering had no more effect in making the water shrink, I made use of a mill or press; till the water, impatient of further pressure,, exuded through the solid lead like a fine dew. I then computed the space lost by the compression, and concluded that this was the extent of compression which the water had suffered, but only when constrained by great yiolencc' (Bacon^s Novum Organwn published in 1G20: vol. ir. 209 of the transla- tion.) Note by R. Leslie Ellis, vol. i. p. 824. — This is perhaps the most remarkable of Bacon^s experiments, and it is singular that it was so little spoken of by subsequent writers. Nearly filly years after the production of the " Novum Organum,^ an account of a similar experiment was publish- ed by Megalotti, who was secretary of the Academia del Cimento at Floi^ ence ; and it has since been familiarly known as the Florentine experiment I quote his account of it, *' Facemmo lavorar," ' &c.

The writer goes on to remark that the absolute incompressibility of water is not proved by this experiment, but merely that it is not to be com- pressed in the manner described ; but the experiment is on other grounds inconclusive.

It is to be remembered that Leibnitz (* Nouveaux Essais*) in mentioning the Florentine experiment, says that the globe was of gold (p. 229 Erd- mann), whereas

the Florentine academicians expressly say why they pre- ferred silver to either gold or lead.

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mj hand a lump of lead ; suppoBe I oommnnicate a certain amount of heat to the lead, how is that heat disposed of within the substance ? It is applied to two- distinct par- poses — it perfonns two different kinds of work. One por- tion of it imparts that species of motion which raises the temperature of the lead, and which is sensible to the ther- mometer ; but another portion of it goes to force the atoms of the lead into new positions, and this portion is lost as heat. The pushing asunder of the atoms of the lead in this case, in opposition to their mutual attractions, is exact- ly analogous to the raising of our weight* in opposition to the force of gravity. Let me try to make the comparison between the two actions still more strict ; suppose that I have a definite amount of force to be expended on our weight, and that I divide this force into two portions, one of which I devote to the actual raising of the weight, while I employ the other to cause the weight, as it ascends, to oscillate, or revolve, like a pendulum or governor, and to oscillate, moreover, with gradually augmented energy ; wo have, then, the analogue of that which occurs when heat is imparted to the lead. Tlie atoms are pushed apart, but during their recession they vibrate, or revolve, with grad- ually augmented intensity. Thus the heat communicated to the lead resolves itself, in part, into atomic potential energy, and in part into a kind of atomic music, the music- al part alone being competent to act upon our thermome- ters or to affect our nerves.

In this case, then, the heat accomplishes what we may call interior work;* it performs work within the body heated, by forcing its particles to take up new positions. When the body cools, the forces which were overcome in the process of heating come into play, and the heat which was consumed by the forcing asunder of

the atoms is now restored by the drawing together of the atoms.

* Sec the excellent memoins of Clausiua in the Philosophical Magazine.

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Cihemists have determined the rebtivB weights of the atoms of difierent substances. Calling the wdght of a hy- drogen atom 1, the weight of an oxygen atom, yon know, is 16. Hence to make np a pound wei^t of hydrogen, sixteen times the number of atoms contained in a pound of oxygen would be necessary. The number of atoms re- quired to make up a pound is evidently inyersely propor- tional to the atomic weight. We here approach a very delicate and important point. The experiments of Duloog and Petit, and of MM. Regnault and Neumann, render it extremely probable that all elementary atoms, great and small, light and heavy, when at the same temperature^ possess the same amount of the energy which we call heat, the lighter atoms making good by velocity what they want in mass. Thus, each of the atoms of hydrogen has the same moving energy as an atom of oxygen at the same temperature. But, inasmuch as a pound weight of hydro- gen contains sixteen times the number of atoms, it miist also contain sixteen times the amount of heat possessed by a pound of oxygen, at the same temperature.

From this it follows that to raise a pound of hydrogen, a certain number of degrees in temperature — say from 60° to 60"^ — would require sixteen times the amount of heat needed by a pound of oxygen under the same circumr stances. Conversely, a pound of hydrogen, in falling through lO"", would yield sixteen times the amoxmt of heat yielded by a pound of oxygen, in falling through the same number of degrees.

In oxygen and hydrogen we have no sensible amount of ' interior work,' to be performed ; there are no molecu- lar attractions of sensible magnitude to be overcome. But in solid and liquid bodies, besides the differences due to the number of atoms present in the unit of weight, we have also differences due to the

consumption of heat in interior work. Hence it is clear that the amount of heat which

SELATIONB OF ATOMIO NUICBESS TO HEAT.

different bodies contain is not at all declared by their tem- perature. To raise a pound of water, for example, 1% would require thirty times the amount of heat necessary to raise a pound of mercury 1^. Conversely, the pound of water, in falling through 1^, would yield up thirty times the amount of heat yielded up by the pound of mercury.

Let me illustrate, by a simple ez])eriment, the differ- ences which exist between bodies, as to the quantity of beat which they contain. I have here a cake of beeswax dx inches in diameter and half an inch thick. Here I have a vessel cont:uning oil, which is now at a temperature of 180^ C. In the hot oil I have immersed a number of balls of different metals— of iron, lead, bismuth, tin and copper. At present they all possess the same temperature, namely, that of the oil. Well, I lift them out of the oil, and place them upon this cake of wax c d (fig. 43), which is supported by the ring of a retort-stand ; they melt the wax underneath and sink in it. But I see that they are sinking with different ve- locities. The iron and the cop- per are working themselves much more vigorously into the fusible mass than the others ; the tin comes next, while the lead and the bismuth lag entirely be- hind. There goes the iron clean through, the copper follows ; I can see the bottom of the tin

ball just peeping through the lower surface of the cake, but it cannot go farther ; while the lead and bismuth have made but little way, being unable to sink to much more than half the depth of the cake.

Supposing, then, I take equal weights of different sub-

stances, heat them all (say to 100^) and then detennine the exact amount of heat which each of them gives out in cooling from 100^ to 0% I should find very diflferent amounts of heat for the different substances. How ooold this problem be solved ? It has been solved by eminent men by observing the time which a body

requires to cooL Of course the greater the amount of heat possessed and generated by its atoms, the longer would the body take to cooL The relative quantities of heat yielded up by difier* cht bodies have also been determined by plung^g them, when heated, into cold water, and observing the gain on the one hand and the loss on the other. The problem has also been solved by observing the quantities of ice which different bodies can liquefy, in" falling from 212° Fahr. to 32% or from 100° C. to 0°. These different methods have given concordant results. According to the celebrated Erench experimenter Regnault, the following numbers express the relative amounts of heat given out by a unit of weight of each of the substances the names of which are annexed, in cooling from 98° C. to 15° C.

Alnmlninm

Cobalt

Anthnonj

Copper

Anenlo

Diamond

Bifunalh

Gold

Iodine

Bromino

Iridium

Cadminm

Iron

Carbon

Lead

Lithlnm

Selenium

Magncsiam

Silicon

Manganese

Silver

Mercury

Sodium

Nickel

8uli)hur (native) .

Osmiam

" (recently m

rallndiam

Tellurium

rhosphoms (solid)

" (amorphous)

Platinum

Potassium

Water

Bhodium

Zinc

A moment's inspection of tliis tabic explains the reason

UECHASIOAL VALUE OF SPECIFIO HEAT. 161

irliy the iron and copper balls melted through the wax, while the lead and hismnth balls were incompetent to do so; it will also be seen that tin here occupies the position which we should assign to it, after our experiment with the cake of wax; water, we see, yields more heat than any other substance in the list.

Each of these numbers denotes what has been hitherto called the * specific heat,' or the * capacity for heat,' of the substance to which it is attached. As stated on a former occasion, those who considered heat to be a fluid, ex- plained these differences by saying that some substances had a greater store of this fluid than others. We may, without harm, continue to use the term ' specific heat,' or ^ capacity for heat,' now that we know the true nature of the actions denoted by the term. It is a noteworthy fact, that as the specific heat increases, the atomic weight di- minishes, and vice verad; so that the product of the atomic weight and specific heat is, in almost all casc8, a sensibly constant quantity. This illustrates a remark already made, that the lighter atoms make good by velocity what they want in mass.

The magnitude of the forces engaged in this automic motion, and interior work, as measured by any ordinary mechanical standard, is enormous. I have here a pound of iron, which, on being heated from 0° C. to 100° C. ex- pands by about -^^th of the volume which it possesses at 0**. Its augmentation of volume would certainly escape the most acute eye ; still, to give its atoms the motion corresponding to this augmentation of temperature, and to shift them through the small space indicated, an amount of heat is requisite which would raise about eight tons one foot high. The force of gravity almost vanishes in comparison with these molecular forces ; the pull of the earth upon the pound weight, as a mass, is as nothing compai-ed with the mutual pull of its own molecules.

Water fanushea s still sabtler exftmplek Water ezpaada on both ddea of 4" O, or 80' F. ; at 4" 0. it has its maxi- ■ mam density. Suppose a pomid of irater to be heated from Si" C to 4° C — that is, one degree— its volume at both temperatnrea is de

same; there has been do forcing asnnder whatever of the atomic centres, and still, tboDgh the Tolome is nncbanged, an amoont of heat has been impnrted to the water, si^oient, if mechanically applied, to raise a w^ght of 1,800 lbs. a fbot high. Hie interior work, done here by the heat, is simply tbat of oausing tiie atoms of water to rotate. It separate* the attracting poles of the atoms by a tangential movement, but Icayos their centres at the same distauce asunder, first and lost. The conceptions with which I here deal may not be easy to those nnaccnstomcd to such studies, but they can be realized, with perfect cleamesB, by all who have the patience to dwell upon them for a sufficient length of time.

Here we may note further, that there are descriptions of interior work, dificrent from that of pushing the atoms more widely apart. An enormous quantity of interior work may be accomplished, while the atomic centres, in- stead of being pushed apart, approach each other. Polar forces — forces emanating from distinct atomic points, and acting in distinct directione, give to crystals their sym- metry, and the overcoming of these forces, while it ueces- sitates a consumption of beat, may also be accompanied by a diminution of volume. This is illustrated by the deportment of both ice and bismuth in liquefying.

The most important experiments on the specific heat of elastic fluids we owe to M. Kegnault. Uc determined the quantities of heat necessary to raise eqnol weights of gases and vapours, and also the quantities necessary to raise equal volumes of them, through the same namber of degrees. Colling the specific heat of water 1, here azs some of the resnlta of thiff invaluable investigation ^—

Bpedfle beaU

Equal welghto Equal roluiuea

Oxygen

introgen

Hydrogen

Chlorine

Broonne

We» have already arrived at the conclusion that, for yquzl weights, hydrogen would be found to possess six- ;een times the amount of heat possessed by oxygen, and burteen times that of nitrogen, because hydrogen consists >f sixteen times the number of- atoms, in the one case, and burteen times the number, in the other. Now, we find ins conclusion verified experimentally. Equal volumes, noreover, of all these gases contain the same num])cr of itoms, and hence we should infer that the specific heats >f equal volumes ought to be equal. They are very learly so for oxygen, nitrogen, and hydrogen ; but chlo- ine and bromine differ considerably from the other ele- nentary gases. Now bromine is a vapour^ and chlorine a ^as, easily liquefied by pressure; hence, in both these »scs, the mutual attraction of the atoms, which is insen- Able in oxygen, nitrogen, and hydrogen, requires a por- ion of heat to overcome it. Tlie specific heats of chlorine md bromine at equal volumes are, therefore, higher.

Certain simple gases unite to form compound ones, (vithont any change of volume. Thus, one volume of chlorine combines with one volume of hydrogen, to form \wo volumes of hydrochloric acid. In other cases the act)f combination is accompanied by 'a diminution of vol- ime ; thus, two volumes of nitrogen combine with one of >xygen to form two volumes of the protoxide of nitrogen. By the act of combination, three volumes have, in this ^ase, been condensed to two. M. Kegnault finds that the impound gases which do not change volume, have, at

equal Tolnmes, ths lame Bpedfio heat as oxygen, nitrogen, and bydrogeti ; while irith those vhioh change Tolnm^ this is not the case.

Ifitrio oxide Cubode oddo . H;<IrocIilorio add

0-S88 0-S4S OlM

Tho epecifio heat of equal volumes of these oomponnd gases is the same as that of

the three simple gases already mentioned.

COIiPODlID OiSta — 3 TOLtTMES

Eqiulw«l^u EqiulTolamM

Cfltbonio acid . Nitroui oiido AqueooB vapour Sulphurous acid Sulphide of hydrogen, Biaulphido of carbon.

Hero we find tlio specific heats of cqaal Tolumes nei- ther equal to those of the elementary gases, nor equal to each other. It ia worth bearing ia uiind that the specific heat of water is about double that of aqueous vapour, and also double that of ice.

The high specific heat of water has one important bearing which I do not wish to pass over here. Compaq ing egruai weigfUt, the specific heat of water being 1, that of air is 0-237. Hence, a ponnd of water, in losing one' degree of temperature, would warm about 4*2 lbs. of air one degree. But water is 770 times heavier than air ; hence, comparing egiial volumes, a cubic foot of water, in losing one degree of tcmperatore, wonld raise 770 x 4*2= 3,231 cubic feet of air, ono degree.

The vast influence which the ocean must exert, as a moderator of climate, here suggests itscl£ The beat of

THE OOEAir A HODERATQB OF CLDCATE. 165

summer is stored up in the ocean, and slowly given out dnring the winter. Hence one cause of the absence of extremes in an island climate. The sammers of the island can never attain the fervid heat of the continental summer, nor can the winter of the island be so severe as the conti- nental winter. In various parts of the continent fruits grow which our summers cannot ripen ; but in these same parts our evergreens are unknown ; for they cannot live through the winters. The winter of Iceland is, as a gen- eral rule, milder than that of Lombardy.

We have hitherto confined our attention to tne neat consmned in the molecular

changes of solid and liquid bodies while these bodies continue solid and liquid. Wo shall now direct our attention to the phenomena which ac- company changes of the state of aggregation. When suffi- ciently heated, a solid melts, and when sufficiently heated, a liquid assumes the form of gas. Let us take the case of ice, and trace it through the entire cycle. This block of ice has now a temperature of 20** F. I warm it ; a ther- mometer fixed in it rises to 32% and at this point the ice begins to melt ; the thermometric column, which rose pre- viously, is now arrested in its march, and becomes perfectly stationary. I continue to apply warmth, but there is no augmentation of temperature ; and not till all the solid has been reduced to liquid does the thermometer resume its motion. It is now agsdn ascending ; it reaches 100°, 200% 212® : here steam-bubbles show themselves in the liquid; it boils, and from this point onwards the thermometer re- mains stationary at 212®.

But during the melting of the ice and during the evap- oration of the water, heat is incessantly communicated : to simply liquefy the ice, as much heat has been imparted to it as would raise the same weight of water 143° Fahr., or as would raise 143 times the weight 1° F. in temperature ; and to convert a pound of water at 212° into a pound of

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steam at the same temperature, 007 times as much heal is required as would raise a pound of water 1° in temperature* The former number, 148% represents what has been hither- to ealled the latent heat of water ; and the latter number, 067'^, represents the latent heat of steam. It was manifest to those who first used these terms, that, throughout the entire time of melting, and throughout the entire time of boiling, heat waft communicated ; but inasmuoh as this heat was not revealed by the thermometer, the fiction was in- vented that it was rendered latent. The fluid of heat Ud itself in some unknown way in the interstitial spaoes of the water and of the steam. According to our present theory, the heat expended in meltmg is consumed in

conferring potential energy upon the atoms. It is virtually the lifting of a weight. So likewise as regards the steam, the heat is consumed in pulling the liquid molecules asunder, confer- ring upon them a still greater amount of potential energy ; and when the heat is withdrawn, the vapour condenses and the molecules again clash with a dynamic energy equal to that which was employed to separate them, and the precise quantity of heat then consumed now reappears.

The act of liquefaction consists of interior, work ex- pended in moving the atoms into new positions. The act of vaporisation is also, for the most part, interior work ; to which however must be added the external work performed in the expansion of the vapour, wliich makes place for it- self by forcing back the atmosphere.

We are indebted to the eminent man to whom I have referred so often, for the first accurate determinations of the calorific power of fuel. * Rumford estimated the cal- orific power of a body by the number of parts, by weight, of water, which one part, by weight, of the body would, on perfect combustion, raise 1° in temperature. Thus one part, by weight, of charcoal, in combining with 2| parts of oxygen to form carbonic acid, will evolve heat sufficient

I.ATEHT BXAT OV LIQUIDfi. 167

to raise the temperature of aboat 8,000 parts by weight of water 1^ C. Similarly, one potmd of hydrogen, in com- bining with eight pounds of oxygen to form water, will raise 34,000 lbs. of water 1^ C. The relative calorific pow- ers, therefore, of carbon and hydrogen are as 8 : 34.'* The recent refined researches of Favre and Silbermann en- tirely confirm the determinations of Rmnford.

Let ns, then, fix our attention npon this wonderful sub- stance, water, and trace it through the various stages of its existence. First we have its constituents as free atoms, which attract each other, fall, and clash together. The mftftliMiiftftl value of this atomic act is easily determined ; knowing the number of foot-pounds corresponding to the heating of 1 lb. of water I" C, we can readily calculate the

number of foot-p4:>und8 equivalent to the heating of 34,000 lbs, of water 1° C. Multiplying the latter number by l,390,t we find that the concussion of our 1 lb. of hydrogen wth 8 lbs. of oxygen is equal, in mechanical value, to the raising of forty-seven million pounds one foot high ! I think I did not overrate matters when I said that the force of gravity, as exerted near the earth, was almost a vanish- ing quantity, in comparison with these molecular forces ; and bear in mind the distances which separate the atoms before combination — distances so small as to be utterly immeasurable ; still it is in passing over these distances that the atoms acquire a velocity sufficient to cause them to clash with the tremendous energy indicated by the above numbers.

After combination the substance is in a state of vapour, which sinks to 212°, and afterwards condenses to water. In the first instance the atoms fell together to form the compound ; in the next instance the molecules of the com-

• Percy's Mctallurgj, p. 63.

f 772 foot-pounds being the mechanical equivalent for 1° F., 1)890 foot-pounds is the equivalent for 1*" C.

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pound fall together to form a liquid. Hie mftchanifliil Tat ne of this act is also easilj calculated: 9 lbs. of steam in falling to water, generate an amomit of heat sufficient to raise 967x0 ==8,703 lbs. of water l"" F. Hnll^Tiiig this number by 772, we have a product of 6,718,716 foot- pomids as the mechanical Talne of the mere act of conden- sation.* The next great fall of onr 9 lbs. of water is firom the state of liquid to that of ice, and the mechanical valne of this act is equal to 998,564 foot-pounds. Urns our 9 lbs. of water, in its origin and progress, falls down three great precipices : the first fall is equivalent to the descent of a ton weight urged by gravity down a predpce 22,820 feet high ; the second fall is equal to that of a ton down a precipice 2,900 feet high ; and the third is equal to the descent of a ton down a precipice 433

feet high. I have Been the wild stonc-avalanchcs of the Alps, which smoke and thunder down the declivities with a vehemence almost sufficient to stun the observer. I have also seen snow-flakes descending so sofUy as not to hurt the fragile spangles of which they were composed ; yet to produce, from aqueous vapour, a quantity of that tender material which a child could carry, demands an exertion of energy competent to gather up the shattered blocks of the largest stone-avalanche I have ever seen, and pitch them to twice the height from which they fell.

I will now relieve the strain which I have hitherto put upon your attention, by introducing a few experimental illustrations of the calorific effects which accompany the change of aggregation. I place my thermo-electric pile thus upon its back on the table, and on its naked face I

* In Rumford^s experiments the heat of condensation was indaded in his estimate of calorific power ; deducting the above number from that found for the chemical union of the hydrogen and oxygen, forty millions of foot-pounds would still remain as the mechanical value of the act of oom* bination.

KZPJUUMENTAL ILLU0TSATION8«

place this thin sUyer basm, b (fig. 44), into which I poor a quantity of water slightly warmed, the needle of the gal- yanometer moves to 00^, and remains permanently deflected to 70^. I now place a little powdered nitre, not more than can fit npon a three-penny piece, in the basin, and allow it to dissolve. I had placed the nitre previously before the fire, so that not only was the liquid warm, but the solid powder was also warm. Observe the effect of their mix- Fig. 44.

ture ! The nitre dissolves in the water ; and to produce this change, all the heat which both the water and the nitre possess, in excess of the temperature of this room, is con- sumed, and, indeed, a great deal more. The needle, you see, sinks not only to zero, but goes strongly up at the other side, showing that now the face of the pile is

power- fully chilled.

I remove the basin, pour the liquid out, and resupply it with warm water, into which I introduce a pinch of com- mon salt. The needle was at 70° when the salt was intro- duced : it is now sinking, reaches zero, and goes up on the side which indicates cold. But the action is not at all so strong as in the case of saltpetre. The reason is that the amount of interior work required by the salt, and which necessitates the consumption of heat, is much less than that demanded by the nitre. As regards latent heat, then, we have differences similar to those which we have already illustrated as regards specific heat. Again, I cleanse the basin, put fresh water in it, and put a Uttle sugar in the water ; the amount of heat absorbed in the solution of the

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sugar is sensible, the liquid is chiDed, but the amoant of chilling is mncb less than in either of the former cases. Thus, when you sweeten your hot tea, yon cool it in the most philosophical manner; when yon put salt in your soup, you do the same j and if you were concerned with the net of cooling alone, and careless of the flavonr of yonr sonp, you might hasten its refrigeration by adding saltpetre. In a fonncr lecture I made use of a mixture of ponnded ice and salt to obt^ great cold. Both the salt and the ioe when they are thus mixed together, change their state of aggregation ; the amount of interior work is here so great, that during its perfonnanco the temperature of the mix- ture eiiiks 30° Falir., and more, below the freezing point of water. Here is a nest of watch-glasses which I have wrapped in tinfoil, and immersed in amixture of ice and salt. Into eacli watch-glass I had poured a little water, in which the next glass rested. They are now all frozen together to a solid cylinder, by the cold of this mixture of ice and salt. I will now rei'crse the process, and endeavour to show you the heat developed in pass- ing from the liquid to the solid state. But first let me show you that lieat is rendered l.ilent when sulphate of soda is dissolved. I cxpeiimcnt with the substance exactly as I experimented with the nitre, and you see,

that as the crystals melt in the water the pile is chilled. And now for the complementary experiment. This largo glass bolt-head n (fig, 45), with this long neck, is now filled with a solution of sulphate of so- da. Yesterday Mr. Anderson dissolved the substance in a pan

HEAT AOOOMPAHYINa SOUDIFIGATION. 171

over our laboratory fire, and filled this bolt-head with the solution. He then covered the top carefuUj with a piece of bladder, and placed the bottle behind this table, where it has remained undistorbed throughout the night.

The liquid is, at the present moment, supersaturated with sulphate of soda. When the water was hot, it melted more than it could melt when cold. But now the temperature has sunk much lower than that which corresponds to the point of saturation. This state of things is secured by keeping the solution perfectly still, and permitUng nothing to fall into it. Water, kept thus still, may be cooled many degrees below its freezing point. Some of you may have noticed the water in your jugs, after a cold winter night, suddenly freeze on being poured out in the morning. In cold climates this is not uncommon. Well, tlie particles of sulphate of soda in this solution are on the brink of a preci- pice, and I can push them over it, by simply dropping a small crystal of the substance, not larger than a grain of sand, into the solution. Obser>'e what takes place ; the bottle now contains a clear liquid ; I drop the bit of crys- tal in, it does not sink ; the molecules have closed round it to form a solid in which it is now embedded. The passage of the atoms from a state of freedom to a state of bondage goes on quite gradually ; you see the solidification extend- ing down the neck of the bottle. Observe where I have placed my thermo-electric pile p. Its naked face rests against the convex surface of the bottle, and the needle of the galvanometer points to zero. The process of crystiilli- sation has not yet reached the liquid in front of the pile, but you see it approaching. It is now solidified opposite the pile, and mark the efiect. The atoms, in falling to the solid form, develope heat ;

this heat communicates itself to the glass envelope, the glass envelope warms the pile, and the needle, as you see, flies to 90^ The quantity of heat

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thus rendered sensible by solidifieation is ezaotly equal to that which was rendered latent by liquefaction.

We have, in these experiments, dealt with the latent heat of liquids ; let me now direct yoor attentimi to a few experiments illostrative of what has been called the latent heat of vapours — ^in other words, the heat conaomed in conferring potential energy, when a body passes fronk.the liquid to the gaseous state. As before,'! turn my pile upon its back with its naked face iq>W2urds, and on this face I place the silver basin already used, into which I have poured a small quantity of a volatile liqiud, wfaibh I have purposely warmed. The needle now moves, indicating heat. But scarcely has it attained OO'^ when it turns promptly, descends to 0°, and flies with violence up on the side of cold. The liquid here used is sulphuric ether ; it is very volatile, and the speed of its evaporation is such that it consumes, rapidly, the heat at first communicated to it, and then abstracts heat from the face of the pile. I re- move the ether, and supply its place by alcohol, slightly warm ; the needle, as before, goes up on the side of heat. But wait a moment ; I will use these small bellows to pro- mote the evaporation of the alcohol ; now you see the nee- dle descending, and now it is up at 90° on the side of cold. Water is not nearly so volatile as alcohol, still I can show the absorption of heat by the evaporation of water also. We use a kind of pottery for holding water, which admits of a slight percolation of the liquid, so as to cause a kind of dewiness on the external surface. Evaporation goes on from that surface, and the heat necessary to this work, being drawn in great part from the water within, keeps it COoL Butter-coolers are made on the same principle.

To show you the extent to which refrigeration may be carried by the evaporation of

water, I have here an instru- ment (fig. 46), by which water is frozen, through the sim- ple abstraction of its heat by its own vapour. The instru-

LAT2NT HEAT OF VAFOBS.

ment is called the cryophorus^ or ice-carrier, and it was invented by Dr. Wollaston. It is made in this way — a lit- tle water is put into one of these bulbs ; the other bnlb, b, when softened by heat, had a tnbe drawn out from it with a minute aperture at the end. Well, the water was boiled in A, and steam was produced, until it had chased all the air away through the small aperture in the distant bulb. When the bulbs and connecting tube were filled with pure steam, the smaD orifice was sealed with a blow-pipe. Here,

then, we have water and its vapour, with scarcely a trace of air. You hear how the liquid rings, exactly as it does in the case of the water-hammer.

I turn all the liquid into one bulb, a, which I dip into an empty glass to protect it from currents of air. The empty bulb, b, I plunge into a freezing mixture ; thus, the vapour which escapes from the liquid in the bulb, a, is con- densed by the cold, to water, in b. This condensation permits of the formation of new quantities of vapour. As the evaporation continues, the water which supplies the vapour becomes more and more chilled. In a quarter of an hour, or twenty minutes, it will be converted into a cake of ice. Here is the opalescent solid formed in a sec- ond instrument, which you saw me arranging before the commencement of the lecture. The whole process consists in the uncompensated transfer or motion from the one bulb to the other.

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But the most striking example of the ooaramptikMi of heat in chan^g the Btate of aggregation is Aunidied by the substance which I have imprisoned in this strong iron bottle. This bottle contains carbonio add, liquefied by enormous pressure. The

substance you know is a gas under ordinary circumstances ; here is a jar fbU of it, which, though it manifests its nature by eztinguishing a taper, is not to be distinguished, by the eye, from oommoa air. When the cock attached to the iron bottle is turned, the pressure which acts upon the gas is reliered, the liquid boils — ^flashes, as it were, suddenly into gas, whidi rushes from the orifice with impetuous force. But you can see this current of gas ; mixed up with it you see a white substance, which is now blown against me, to a distance of eight or ten feet, through the air. What is this white substance ? It is carbonic acid snow. The cold produced in passing from the liquid to the gaseous state is so intense that a portion of the carbonic acid is actually frozen to form this snow, and mingles in small fiakcs with the issuing stream of gas. I can collect this snow in a suitable vessel. Here is a cylindrical box with two hollow handles, through which I Avill allow the gas to pass. Right and left you see the streams, but a large portion of the frozen mass is retained in the box. I open it, and you see it filled with this perfectly white carbonic acid snow.

The solid very gradually disappears ; its conversion into vapour is slow, because it can only slowly collect from sur- rounding substances the heat necessary to vaporise it. You can handle it freely, but not press it too much, lest it should bum you. It is cold enough to bum the hand. I plunge a piece of it into water, and hold it there : you see bubbles rising through the water — these are pure carbonic acid gas. I collect this gas, and show you that it possesses all the properties of the gas as commonly prepared. The solid acid does not melt in the water ; when I release it, it rises

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to the Bwrtause^ and floats upon it. I put a bit of the acid into my month, taking care not to inhale while it is there. I breathe agsdnst this candle ; ibj breath extinguishes the flame. Before the conclusion of the lecture, I will show you how it is possible to

preserve so cold a body in the month without injury. A piece of iron of equal coldness would do serious damage.

Here, then, we have a solid body intensely cold, which, however, does not chill bodies in contact with it, as it might be expected to do. In fact, no real contact has been established with the acid. Water, we see, will not dissolve it, but sulphuric ether will ; and by pouring a quantity of this ether on the snow, I obtain a pasty mass, which has an enormous power of refrigeration. Here I have some thick and irregular masses of glass — the feet, in fact, of drinking-glasses. I place a portion of the solid acid on them, and wet it with ether ; you hear the glass crack ; it has been shattered by the contraction produced by the in- tense cold.

In this basin I spread a little paper, and over the paper I pour a pound or two of mercury ; on the mercury I place some solid carbonic acid, and over the acid I pour a little ether. Mercury, you know, requires a very low tempera- ture to freeze it. Well, here it is frozen ; I turn it out bo- fore you, a solid mass ; I can hammer the solid ; I can also cut it with a knife. To enable me to lift the mercury out of the basin, I have dipped this wire into it ; by this I nuse it, and plunge it into a glass jar containing water. It liquefies, and showers downwards through the water ; but every fillet of mercury freezes the water with which it comes into contact, and thus round each fillet is formed a tube of ice, through which you can see the liquid metal descending. These experiments might be multiplied al- most indefinitely ; but enough, I trust, has been shown to illustrate our present subject.

I have now to direct jaar attcntitm to anoAer and Toy Bmgnlar class of phenomeiu, oonneoted with the prodooliao of vtspom. Here is a broad pcnoelam basn, b {%. 41), fiUed with hot water, ^re is a nlver basin, ■> irtnidL I DOW heat to redness. If I plaoe the nlnr bann in tike hot water, what will ooonr F Yon might natorally reply, that the baan will in^ttrt itt ' exceosof heatiiurtaiiUjto'

the water, and be oodled down to the temperBtore of the latter. Bot nothing of thia

kind ooema. Tbe badn for a time derelopcs a snffident amoimt of vaponr nndemeath it, to lift it entirely out of contact with the water ; or, in the lan- guage of the hypothesis, developed in our third lecture, it is lifted by the discharge of molecular projectiles against its under surface. This will go on until the tempenttore of the basin sinks, and it ia no longer able to produce vapour of snfGcient tendon to support it. i Tbea it comes into con- tact with the water, and the ordinary hiedng of a hot metal, together with the cloud which forms overhead, de- dares the fact.

I DOW reverse the experiment, and instead of placing the basin in the water, I place the water in the badn — first of all, however, heating the latter to redness by a lamp. Ton hear no noise of obnllition, no hissing of the water as I pour it into the hot basin ; the drop rolls about on its own vapour — that is to say, it is sustained by the recoil of the molecnlar projectiles ^scharged from its under sorface. I withdraw the lamp, and allow the basin to cool, until it is no longer able to produce vapour strong enough to support the drop. The liquid then toudies the metal ; the instant

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it does 80, Tioleat ebollition sets in, and the dood which yoa now obeeire fonns above the basin.

Ton cannot, from yonr present position, see this flat- tened ^heroid rolling about in the hot basin, but I can show it to yon, and, if I am fortnnate, I shall show jou Bomething very beautiful. Yon will bear in mind that there is an incessant deTcIopcment of vapour nndomcath the drop, which, as incessantly, escapes from it laterally. If the drop rest upon a flattish surface, so that .the lateral

escape is very difficult, the vapour will burst op through the middle of the drop. But I have here arranged matters, bo that the vapour shall issue latendly ; and it sometimes hap- pens that the escape of the vaponr is rythmic ; it issues in r^ular pulses, and then we have our drop of water mould- ed to a most beautiful rosette. I have it now, — a round mass of liquid, two inches in diameter, with a beautifully

crimped border. I will throw the beam of the electi-io lamp Qpon this drop bo as to illuminate it, and holding this lens over it, I hope to cast its image on the ceiling, or on the screen. There it is (fig. 48), a figure eighteen inches in 8*

diameter, and the vapoor breakiiig, aaif in mndi^ firom Hi edge. If I add a litUe ink, bo as to darken the Uqaid; the definitiaii of its outline is augmented, bnt tlie pearly Instre of its surface is lost. I withdraw the heat ; the nndnlation con^ues for some time : the border flnallj beoomea nmn- dent«d. The drop ia now perfectly motionlen — a liquid spheroid — and now it soddeiil; spreads upon the anriace,

contact has been established, aad the spheroidal conditioa ends.

I diy the silver basin and place it, with its bottom ap> wards, in front of the electric lamp, and with a lens in front I bring the rounded outline of the basin to a focus OD the screen ; I dip this bit of sponge in alcohol and squeeze it over the cold basin, so that the drops fall upon the surface of the metal : you sec their magnified images upon the screen, and you observe that when they strilie the surface they spread out and trickle down along it. Now I will heat this basin by placing a lump underneath. Ob-

THI I>BOP 18 SCFFtffiTED OS A TAPOUB SPBIItO. 179

eerre what oocnrs : when I squeeze the sponge the drops descend as hefore, but when they come in contact with the basin they no hmger spread bnt roll over the surface as liquid spheres (fig. 49). See how they bound and dance OS if they had fallen upon elastic springs ; and so in fact they have. Every drop, as it strikes the hot surface, and as it rolls along the surface, developes vapour which lifts it oat of contact, thus destroying all cohesion between the surface and the drop, snd enabling tiie latter to prescne its spherical or spheroidal form.

I have here an arrangement suggested by Professor Poggendorf, which shows, in a very beautiful manner, the interruption of contact between the spheroidal drop and its supporting surface. From this silver basin, b (fig. 50), in-

tended to hold the drop, I carry a wire, w, round yonder magnetic needle ; the other end of the galvanometer wire I attach to one end of tliis battery, A. From the opposite pole of the little battery I carry a wire, m', and so attach it to the arm, a b, of this retort-stand, k, that I can readily lower it. I heat the basin, pour in the water, and lower my wire till the end of it dips into the spheroidal mass : yoa see no motion of the galvanometer needle ; the only

gap in the entire drei^t is tint whUta now taiat§ nndar-

neath tlie drop. If the drop were in oontMt the oorrent vonld pass. I provo thia tfatu : I withdniv the lan^t ; the Bpheroidal state will soon end ; the liqnid will touch the bottom. It now does bo, and tlie needle nutantljr flies aside.

Ton can actually see the interval between the drop and the hot Bnr&oe apoa whieh it rests. A private ezperiment may be made in this way : Let a flattiah basin, b (fig. 61), be tnmed upside down, and let tiie bottom of it be alight^ indented so as to be able to beu a drop ; heat the basin 1^ a spirit lamp, and place npon it a drop of ink, d^ with which a littlo alcohol has been mixed. Stretob s platinam wire,

a b, vertically behind the drop, and render the wu% incan- descent by sending a cnrrent of electricity through it. Bring yonr eye to a level with the bottom of the drop, and yon will be able to see the red-hot wire through the interval between the drop and the surface which supports it. Let me show yon this interval. I place my baon, n {fig. 62), as before, with its bottom upward in front of the lamp ; I heat the basin and bring carefully down upon it a drop, d, dependent from a pipette. "Wheu it rests upon the prop-

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cr part of tlie Burfiux), and tlie lens in front ia brought to its proper position, yoa Bee a lino of bright light between the drop and Ae nlver, indicating that the beam of the lamp has passed ondemeath the drop to the soreen.

The aphenndal condition was fint obsoired by Leiden- frost, and I might give yon

fifty other illufltrations of it.

Liquids con be made to roU on liquida. If, moreover, I take this red-hot tiopper ball and plunge it into a vessel of hot water, a load spattering is produced, due to the escape of tho vapour generated ; Btill the contact of the liqaid and solid is only very partial : let the ball cool, the liquid at length touches it, and then the ebullition is so violent as to project the water from the vessel on all sides.

M. Bontigny has of late lent new interest to this sub- ject by expanding the field of illostration, and applying it to tbe explanation of many extraor^nary effects. If the hand be wet, it may be passed thongh a stream of molten metal without injnry. I have seen M. Boatigny myself pass his wet hand through a stream of molten iron, and toss with his fingers the fused metal from a crucible : a blacksmith will llok a white hot iron without fear of burning his

tongue. The tongae is eBaettaiHj prceerrod frou omtkot with the iron, by the vaponr derelc^ed ; and it vsb to the vapoor of the carbonie add, which shielded me from its contact, that I owed my safety when I -pot tlie mbetanoe 'into my month. To the same proteotiTe infloenoe many escapes from the fiery ordeal of ancient times have been attributed by M. Bontigny. I may add, that the explana- tion of the spheTOidal condition given by M. Boatigny has not been accepted by scientific men.

Boiler exploBiona have also been asoribed to the water in tlie boiler assuming the spheroidal state t the snddm developement of steam, by sabseqaest ocmtaot witb the heated metal, canong the ezplodon. We are more igno- rant of these thbgs than we onght to be. Experimental

science has broaght a series of true causes to light, which may produce these terrible catastrophes, but practical sci- ence has not yet determined the extent to which they ac- tually come into operation. The effect of a sadden genera- tioQ of steam has been illnstrated by an experiment which I will now make in your preaence. Here is n copper ves- sel, T (fig. 63), with a neck wliich I can stop with this cork, throngfa

which half an inch of fine glass tubing passes.

nXBT QRDKAL : BOIUEB EXPLOSIONS. 183

I heat the copper vessel, and pour into it a little water. The liquid is now in the spheroidal state. I cork the vessel, and the small quantity of steam developed, while the water remains spheroidal, escapes through the glass tube. I now remove the vessel from the lamp, and wait for a minute or two : very soon the water will come into contact with the copper ; it now does so, and you observe the result : the cork is driven, as if by the explosion of gunpowder, to a considerable height in th^ atmosphere.

I have reserved what you will probably think the most interesting experiment in connection with this subject, for the conclusion of to-day's lecture. M. Boutigny, by means of sulphurous acid, first froze water in a red-hot crucible ; and Mr. Faraday subsequently froze mercury, by means of solid carbonic acid. I will try and reproduce this latter re- sult ; but first let me operate with water. I have here a hollow sphere of brass about two inches in diameter, now accurately filled with water ; into the sphere I have had this wire screwed, which is to serve as a handle. I heat this platinum crucible to glowing redness, and place within it some lumps of solid carbonic acid. I pour some ether on the acid — ^neither of them comes into contact with the hot crucible — they are protected from contact by the elastic cushion of vapour which surrounds them; I lower my sphere of water down upon the mass, and carefully pile fragments of carbonic acid over it, adding also a little ether. The pasty mass within the red-hot crucible remains intensely cold ; and now you hear a crack ! I am thereby assured that the experiment will succeed. The freezing water has burst the brass sphere, as it burst the iron bottles in a former experiment. Round the sphere I have wound a bit of wire to prevent the ice from falling out. I now raise the sphere, peel off the shattered brass shell, and there you have a solid sphere of ice, extracted from the red-hot crucible.

i qnantity of mercnrj in a conical copper spoon, ani -^ it into tbe crucibJe. The ether in Ihe crucible has taken fire, which I diJ not intend it to do. The cipcnnient ought to be ao made, that tlie carbonic add gas — the choke- damp of mines — onght to keep the ether from ignition.

But the mercury will fre • in th standing. Ont of the

fire^and through the flan-" w the spoon, and Uiere ia

the frozen mass turned oi i fou on the table.

LECTURE VI

[February 27, 18C2.]

COSTXCnON OY BSATID AIB — ^WIITDS— TBI UPPSB ASD LOWIB * TRADES* -HETFECT 07 TDJE SABTn*S BOTATION ON TBB DIUCnOlT Of WIND— IN- TLUENCV or AQUIOUS TAPOUR UPON CLUfATI — EVROPB TBI CONDENSER or THE WESTERN ATLANTIC — RAINTALL IN IRELAND— THE GULP STREAM — FORMATION OP SNOW — ^FORMATION OF ICE FROM SNOW— GLACIERS — PHENOMENA OF GLACIER MOTION — REOELATION — ^MOULDING OF ICE BY PBESSCRE — ^ANQENT GLACIERS.

appendix: — DATA CONCERNING GLACIER MOTION.

I T PROPOSE devoting an hour to-day to the considera- X tion of Bomc of the physical phenomena which exhibit i themselves on a large scale in Nature. And first, with rc- ' gard to winds. You see those sunbumers now almost wholly turned down, which are intended to illuminate this room when the daylight is intercepted or gone. Not to give light alone were tiiey placed there ; they were set up, in part, to promote ventilation. The air, heated by the gas flames, expands, and issues in a strong vertical current into the atmosphere. The' air of the room is thereby inces- santly

drawn upon, and a fresh supply must be introduced to make good the loss. Our chimney draughts arc so many vertical winds due to the heating of the air by our fires.

I ignite this piece of brown paper, the flame ascends ; I blow out the flame, leaving the edges of the paper smok- ing ; the heated edges warm the air, and produce currents which carry the smoke upward. I dip the smoking paper

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into a large glass vessel, and stop the nedk of the Tesid to prevent the escape of the smoke ; the smoke ascends with the light air in the middle, spreads out laterally above, is cooled, and falls like a cascade of dond along the odes of the vessd. I have here a heavy iron spatola, heated to dull redness ; as I hold it thns, you cannot see the onnents of heated air ascending from it. But I can diow them to you by their action on strong light. I place the qiatiila in the beam of the electric lamp ; here is the diadow of the spatula on the screen, and those waving lines of ligiht and shade mark the streammg upwards of the heated air. Here also is an iron spoon containing a fragment of solphar, which I heat until it ignites ; I plunge the sulphur into this jar of oxygen : the combustion becomes more brilliant and energetic, and the air of the jar is thrown into intense com- motion. The fumes of the sulphur enable you to track the storms which the heating of the air produces within the jar. I use the word ' storms ' advisedly, for the hurricanes which desolate the earth are nothing more than large illus- trations of the effect which we have produced in this glass jar.

From the heat of the sun our winds are all derived. We live at the bottom of an aerial ocean, which is to a re- markable degree permeable to the sun^s rays, and is but little disturbed by their direct action. But those rays, when they fall upon the earth, beat its surface ; the air in contact with the surface shares its heat, is expanded, and ascends into the upper regions of the atmosphere. Where the rays fall vertically on the earth, the heating of the sur- face is greatest, that is to say, between the tropics.

Here aerial currents ascend and flow laterally north and south towards the poles, the heavier air of the polar regions streaming in to supply the place vacated by the light and warm air. Thus Ave have an incessant circulation. Yes- terday I made the following experiment in the hot room

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of a Torldflh bath. I opened wide the door, and held a Hghted taper in the doorway, midway between top and bottom. The flame rose straight from the taper. I phiccd the taper at the bottom, it was blown violently inwards ; I placed it at the top, it was blown violently outwards. Here we had two corrents, or winds, sliding over each other, lod moving in opposite directions. Thus, also, as regards our hemisphere, we have a current from the equator setting in towards the north and flowing in the higher regions of the atmosphere, and another flowing towards the equator in the lower regions of the atmosphere. These are the upper aid the lower Trade Winds.

Were the earth motionless, these two currents would nm directly north and south, but the earth rotates from vest to east round its axis once in twenty-four hours. In virtue of this rotation, an individual at the equator is car- ried round with a velocity of 1,000 miles an hour. You have observed what takes place when a person incautiously steps out of a carriage in motion. Ue is animated by the motion of the carriage, and when his feet touch the earth he is thrown forward in the direction of the motion. This is what renders leaping from a railway carriage, when tlie train is at full speed, almost always fatal. As we with- draw from the equator, the velocity due to the earth's ro- tation diminishes, and becomes nothing at the poles. It is

proportional to the radius of the parallel of latitude, and diminishes as these circles diminish in size. Imagine, then, an individuxd suddenly transferred from the equator to a place where the velocity, due to rotation, is only 900 miles an hoar ; on touching the earth here he would be thrown forward in an easterly direction, with a velocity of 100 miles an hour, this being the difference between the equa- torial velocity with which he started, and the velocity of the earth's surface in his new locality.

Similar considerations apply to the transfer of air from

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the equatorial to the northem regioioui, and Tioe yenL At ' the equator the air possesses the velocity of the earth's sniw \ fsLoe there, and on quitting this poation,it not only has iti { tendency northwards to obeyi but also a tendency to the \ east, and it must take a resultant direction. Hie fifftfaer it j goes north the more is it deflected from its original oomae; j the more it turns towards the east, the more it beoomea ' what we should call a westerly wind. Hie <q)ponte hoUa . good for the current proceedingyW>m the north ; this paassa ■ from places of slow motion to places of quick motion: it ia = met by the earth ; hence the wind which started aa a nortk wind becomes a north-east wind, and as it approadiee tiia equator it becomes more and more easterly.

It is not by reasoning alone that we arrive at a knowt edgo of the existence of the upper atmospheric current, though reasoning is sufficient to show that compensati(»i must take place somehow, — that a wind cannot blow in any direction without an equal displacement of air taking place in the opposite direction. But clouds are sometimes seen m the tropics high in the atmosphere, and moving in a direction opposed to that of the constant wind below. Could we dis- charge a light body with sufficient force to cause it to pen- etrate the lower current, and reach the higher, the direcdou of that body's motion would give us the direction of the wind above. Human strength cannot perform this experi- ment, but it has nevertheless been made.

Ashes have been shot through the lower current by volcanoes, and, from the places where they have subsequently fallen, the direction of the wind which carried them has been inferred.. Pro- fessor Dove in his ' Witterungs Verh&ltnisse von Berlin ' cited the following iastance : ' On the night of -A^ril 30th, explosions like those of heavy artillery were heard at Barba- does, so that the garrison at Fort St. Anne remained all night under arms. On May 1, at daybreak, the eastern porticm of the horizon appeared dear, while the rest of the firma-

CUBBEHTS OF THE ATHDSPIIERE. !I89

nent was covered by a black doud, which soon extended :o the east, quenched the light there, and at length pro- heed a darkness so dense that the windows in the rooms sould not be discerned. A shower of ashes descended, imder which the tree branches bent and broke. Whence erne these ashes ? From the direction of the wind, we di0ald infer that they came from the Peak of the Azores : iey came, however, from the volcano Mome Garou in St. Tmcent, which lies about 100 miles west of Barbadoes. The Mhes had been cast into the current of the upper trade. A ncond example of the same kind occurred on January 20, 1835. On the 24th and 25th the sun was darkened in Ja- maica by a shower of fine ashes, which had been discharged from the mountain Coseguina, distant 800 miles. The peo- ple learned in this way that the explosions previously heard srere not those of artillery. These ashes could only have been carried by the upper current, as Jamaica lies north- east from the mountain. The same eruption gives also a beautiful proof that the ascending air-current divides itself ibove, for ashes fell upon the ship Conway in the Pacific, It a distance of 700 miles south-west of Coseguina.

* Even on the highest summits of the Andes no traveller las as yet reached the upper trade. From this some notion nay be formed of the force of the explosions ; they were ndeed tremendous in both instances. The roaring of Cose- j^oina was heard at

San Salvador, a distance of 1,000 miles. iTmon, a seaport on the west coast of Conchagua, was in ibeolute darkness for forty-three hours ; as light began to lawn It was observed that the searshore had advanced 800 eet upon the ocean, through the mass of ashes which had alien. The eruption of Mome Garou forms the last link »f a chain of vast volcanic actions. In June and July 1811, near St. Miguel, one of the Azores, the island Sabri- la rose, accompanied by smoke and flame, from the bottom ^f a sea 150 feet deep, attained a height of 800 feet and a

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circtunference of a mile. The snull AntiQem war Js shfikcn, and subsoqucntly tliu vuUeys of ft sippi, Arkansas, aud Ohio. But the clastic fotwH vent ; tliey songht one, then, on tJbe uorih coiri *f bia. March 28 began as a day of exli Cariiocis; the air was clear and the SnaamiXit It was Oroeu Thursday, aud a regiment of b lino stood under arms in the barracks of tl Carlos ready to join in the proceMiian. streamed to the churchcH. A loud oul was beard, and immediately afterwards fnUavid'ri quake »book so violent, Uiat the church of Ahsfl feet in height, bomo by pillars fift«cu feet thiftii heap of crushed rubbish not more than idx TmI ■ the evening the almost fiill moon looked down in lustre upon the ruins of the to^ni, under wfai* CTUBhed bodies of upwards of 10,000 of its ii But oven here there was no esit granted to ll forces undemealh. Finally, on April 27, ihcy w ojiening once more the crater of Jlome Garon, » been closed for a century ; and the earth, ft equal to tliat from Vesuvius to Paris, rung H der-shout of tlie liberated prisoner,'

I have here a terrestrial globe, on whidi I ti with my hand two meridians ; they start from ti of the globe a foot apart, which would c 1,000 miles on the earth's surface. But these n as they proceed northward, gradually approach « and meet at the north pole. It is manifest tf which rises between these meridians in the c giona must, if it went direct to the pole, » an ever-narrowing bed. Were the earth a cylin of a sphere, we might have a circulation i of the cylinder quite to each end, and a return ci each

end to the middle. But this, in the ease of th

THS TTFPEB AND LOWER TBADE8. 191

ia imposfflblo, Bimplj because the space around the poles is unable to embrace the air from the equator. The cooled equatorial air sinks, and the retmn current sets in before the poles arc attained, and this occmB more or less irregu-> larl J. The two corrents, moreover, instead of flowing one orer the other, often flow beside each other. They con-^ Btitnte riyers of air, with incessantly shifting beds.

Hiese are the great winds of onr atmosphere which, ^ however, are materially modified by the irregular distribu- tioii of land and water. Winds of minor importance also oecor, through the local action of heat, cold, and evapora- tion. There are winds produced by the heating of the air in Alpine valleys, and which sometimes rush with sudden and destructive violence down the guUeys of the moun- tains : gentler down-flows of air are produced by the prcs- I ence of glaciers upon the heights. There arc the land breeze and the sea breeze, due to the varying temperature of the 6ca-board soil, by day and night. The morning sun heating the land, produces vertical displacement, and the air from the sea moves landward. In the evening the land IB more chilled by radiation than the sea, and the conditions are reversed ; the heavy air of the land now flows seaward.

Thus, then, a portion of the heat of the tropics is sent by an atrial messenger towards the poles, a more equable distribution of terrestrial warmth being thus secured. But in its* flight northward the air is accompanied by another substance — ^by the vapour of water, which, you knoAv, is perfectly transparent. Imagine the ocean of the tropics, giving forth its vapour, which promotes by its lightness the ascent of the associated air. They expand as they ascend : at a height of 16,000 feet the air and vapour occupy twice the volume which they embraced at the sea level. To se- cure this space they must, by their clastic force, push away the air in all directions round

them ; they must perform work ; and thb work cannot be performed, save at the ex-

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pense of the wannth vith which they vers in tite first ok

stance charged.

The vapour thns chilled is no longer competent to retain the gaaeons form. It ia pTedjntated as dond : the clood descends as rain ; and in the region of calms, or directlj under the ann, where the ur is first drained of its aqneons load, the descent of nun is enormous. Tlie ami does not remain always vertically over tlie same parallel of latitude — ^he is Bometdmes norUi of the equator, stmtetimes sooth of the equator, the two tropics limiting his exoorBoiL When he is sooth of the equator, the earth's aar&oe north of it is no longer is the region of calms, bnt in a region across which the aerial cmrent from the north fiowa towards tlie region of calms. The moving air is bnt slightly charged with vaponr, and as it travels from north to south it becomes ever warmer ; it conBtitntes a dry wind, and its capacity to retain vaponr is continnally aug- menting. It is plain, from these considerations, that each place between the tropics most have its dry season and rainy season ; dry when the son is at the opposite side of the equator, and wet when the snn is overhead.

Gradually, however, as the tipper 'stream, which rises from the equator, and flows towards the poles, becorocs chilled and dense, it sinks towards the earth ; at the Peak of Tenerifib it has already sunk below the summit of the mountain. With the contrary wind blowing at the base, the traveller finds the stream from the equator blowing strong over the top. Farther north the equatorial wind sinks lower still, and finally quite reaches the surface of the earth. Europe, for the most part, b overflowed by this equatorial current. Here in London, for eight or mne months in the year, south-wcsteriy winds prevuL But mark what an influence this must have upon our climate. The moisture of the equatorial ocean comes to ns endowed with potential energy ; with its molecules separate, and

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therefore oompetent to dash and develope heat by their collision ; it comes, if 70a will, charged with latent heat. In onr northern atmosphere the collision takes place, and the heat generated is a main source of warmth to our cli- mate. Were it not for the rotation of the earth, we should have over ns the hot dry blasts of Africa ; but owing to this rotation, the wind which starts northward from the Golf of Mexico is deflected to Europe. Europe is, there- fore, the recipient of those stores of latent heat which were amassed in the western Atlantic The British Isles come in for the greatest share of this moisture and heat, and this drcumstance adds itself to that already dwelt upon — the high specific heat of water — ^to preserve our climate from extremes. It is thib condition of things which makes our fields so green, and which gives the blossom to our maid- ens^ cheeks. A German writer, Moritz, expresses himself on these points in the following ardent words : — ' Ye blooming youthful faces, ye green meadows and streams of this happy land, how have ye enclianted me ! O Rich- mond, Richmond ! never can I forget the evening when, fnll of delight, I wandered near you up and down along the flowery banks of the Thames. This, however, must not detain me from that dry and sand-strewn soil on which fate has appointed me my sphere of action.' AH this poe- try and enchantment are derived directly from aqueous vapour.*

As we travel eastward in Europe, the amount of aque- ous precipitation grows less and less ; the air becomes more and more drained of its moisture. Even between the east and west coasts of our own islands the difference is sensi- ble, and local circumstances also have a powerful influence on the amount of precipitation. Dr. Lloyd finds the mean yearly temperature of the western coast of Ireland about

* Its relation to Radiant Heat is developed in Lecture XF. 9

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two degrees higher than that of the eaetexu ooast^ ait the same height, and in the

same parallel of latitude. Hie total amount of rain which fell in the year 1851, at yaiioaa stations in the island, is given in the foOowing table-^

Statloa BalB In Indies

PortMlington 21-2

KiUoQC^ 23*2

Donaghadco 27*9

Coortown 29*6

Anna^ S8*l

KiUybogs 88*2

Dunmorc . -. . . . 83*5

Portrush 37.2

Burincrana . . . . 39'8

Markrcc 40*8

Castlctownscnd 42*5

Wcstport 46-9

Cahlrcivccn 69*4

With reference to this table, Dr. Lloyd remarks —

* 1. That there is great diversity in the yearly amotmt of rain at the different stations, all of which (excepting four) are but a few feet above the sea level ; the greatest rain (at Cahirciveen) being nearly three times as great as the least (at Portarlington).

* 2. That the stations of least tain are cither inland or on the eastern coast, while those of the greatest rains are at or near the western coast.

* 3. That the amount of rain is greatly dependent on the proximity of a mountain chain or group, being always considerable in such neighbourhood, unless the station lie to the north-east of the same.

*Thus, Portarlington lies to the north-east of Slieve- bloom ; Killough to the north-east of the Moume range ; Dublin, north-^ast of the Wicklow range, and so on. On

SAIK-FALL nr IBELAND.

the other hand, the stations of greatest rain, Cahirciyeen, Castletownsend, Westport, &c^ are in the yicinity of high monntains, but on a different side.' *

This distribution of heat by the transfer of masses of heated air from phice to place, has been called ^ convection^^ in contradistinction to the process of conduction, which will be treated in our next lecture. Heat is distributed in a similar manner through liquids. I have here a glass cell, c (fig. 54), containing warm water ; I place it in front of

the electric lamp, and by means of a converging lens, tlirow a magnified image of the cell upon the screen. I now introduce the end of this pipette into the water of the cell, and allow a little cold water to gently enter the hot. The difference of refraction between both enables you to see the heavy cold water falling through the lighter warm water. The experiment succeeds still better when I allow a fragment of ice to float upon the surface of the water. As the ice melts, it sends long heavy striie downwards to the bottom of the cell. You observe, as I cause the ice to

* The greatest rainfall recorded by Sir John Herschel in his table (Meteorology, 110, kc.) occurs at Cherra Pungee, where the annual fall is 592 inches. It is not my object to enter far into the subject of meteor- ology ; for the fullest and most accurate information the reader will refer to the exceUent works of Sir John Herschel and Professor Dove.

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move along the top, how these streanu of oold water descend through the hot. I now revene the experiment, placing cold water in the cell, and hot water in the pipette. Care is here necessary to allow the warm water to enter without any momentum,

which would cany it mechanically down. You notice the effect. The point of the pipette is in the middle of the cell, and you see, as the warm water

enters, it speedily turns upwards (fig. 65) and orerflows the top, almost as oil would do under the same circumstances.

Wlien a vessel containing water is heated at the bot- tom, the warmth communicated is thus difiused. You may see the direction of the ascending warm currents by means of the electric lamp, and also that of the currents which descend to occupy the place of the lighter water. Here is a vessel containing cochineal, the fragments of which, being not much heavier than the water, freely follow the direction of its currents. You see the pieces of cochineal breaking loose from the heated bottom ; ascending along the middle of the jar, and descending again by the sides. In the Geyser of Iceland this convection occurs on a grand scale. A fragment of paper thrown upon the centre of the water which fills the pipe is instantly drawn towards the side, and there sucked down by the descending current.

Partly to this cause, but mainly, perhaps, to the action of winds, currents establish themselves in the ocean, and

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powerfully influ^ioe cUmate by the heat which thej db- tribute. The most remarkable of these cureDts, and by far ihe most important for us, is the so-called 6ulf-strcam, which sweeps across the Atlantic from the equatorial re- gions through the Gulf of Mexico, whence it derives its name. As it quits the straits of Florida it has a tempera- ture of 83" Fahr., thence it follows the coast of America as far as Cape Fear, whence it starts across the Atlantic, tak- ing a north-easterly course, and finally washing the coast of Ireland, and the north-western shores of Europe gen- erally. As might be expected, the influence of this body of warm water makes itself most evident in our winter. It then entirely abolishes the difference of temperature due to the difference of latitude of north and south Brit- jun ; if we walk from the

Channel to the Shetland Isles, in January, we encounter everywhere the same temperature. The Isothermal line runs north and south. Tlie presence of the water renders the climate of western Europe totally difierent from that of the opposite coast of America. The river Hudson, for example, in the latitude of Rome, is frozen over for tliree months in the year. Starting from Boston in January, and proceeding round St. John's, and thence to Iceland, we meet everywhere the same tempera- ture. Tlie harbour of Hammerfest derives great value from the fact that it is clear of ice all the year round. This is due to the Gulf-stream which sweeps round the North Cape, and so modifies the climate there, that at some places, by proceeding northward, you enter a warmer re- gion. The contrast between northern Europe and the east coast of America caused Halley to surmise that the north pole of the earth had shifted ; that it was formerly situate somewhere near Behring's Straits, and that the intense cold observed in these regions is really the cold of the an- cient pole, which had not been entirely subdued since the axis changed its direction. But now we know that the

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Gulf-Stream and thedifiuaioii of heal by winds and Taponrs are the real causes of European mildness. On the western coast of America, between the Bodky mountains and the ocean, we find a European climate.

Europe, then, is the condenser of the Atlantic ; and the mountiuns are the chief condensers in Europe. On them, moreover, when the^ are sufficientlj high, the condensed vapour descends, not in a liquid, but a solid form. Let us look to this water in its birthplace, and follow it through its subsequent course. Qouds float in the air, and hence the surmise that they are composed of vesicles or bladders of water, thus forming «Ae£b instead of epherea. Eminent travellers say that they have seen these bubbles, and their statements are entitled to all respect. It is certain, however, that the water-particles at high elevations possess, on or after precipitation, the powers of building themselves into crystalline forms ; they thus bring forces into

play which wc have hitherto been accustomed to regard as molecular, and which could not be ascribed to the aggre- gates necessary to form vesicles.

Snow, perfectly foimcd, is not an irregular aggregate of ice-particles ; in a calm atmosphere, the aqueous atoms arrange themselves so as to form the most exquisite figures. You have seen those six-pctalled flowers which form them- selves within a block of ice when a beam of heat is sent through it. -Tlic'snow-crj'stals, formed in a calm atmos- phere, are built upon the same type : the molecules arrange themselves to form hexagonal stars. From a central nuc- leus shoot six spiculae, every two of which are separated by an angle of 60°. From these central ribs smaller spic- ula) shoot right and left with unerring fidelity to the angle 60°, and from these again other smaller ones diverge at the same angle. The six-leaved blossoms assume the most wonderful variety of form ; their tracery is of the finest frozen gauze ; and round about their comers other

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rosettes of smaQer dimensions often ding. Beauty is su- perposed upon beauty, as if Nature, once committed to her task, took delight in showing, even within the narrowest limits, the wealth of her resources.*

These frozen blossoms constitute our mountain snows ; they load the Alpine heights, where their frail architecture is soon destroyed by the accidents of the weather. Every winter they fall, and every summer they disappear, but this lythmic action does not perfectly compensate itself. Be- low a certain line warmth is predominant, and the quantity which falls every winter is entirely swept away; above this line cold is predominant, the quantity which falls is in excess of the quantity melted, and an annual residue re- mains. In winter the snows reach to the plains ; in sum- mer they retreat to the enorxMney — ^to that particular lino where the snow-fall of every year is exactly balanced by the consumption, and above which is the region of eternal gnows. But if a residue remains annually above the snow line, the mountains

must be loaded with a burden which increases every year. Supposing at a particular point above the line referred to, a layer of three feet a year is added to the mass ; this deposit, accumulating even through the brief period of the Christian era, would produce an elevation of 5,580 feet. And did such accumulations con- tinue throughout geologic instead of historic ages, there is no knowing the height to which the snows would pile themselves. It is manifest no accumulation of this kind takes place ; the quantity of snow on the mountains is not augmenting in this way ; for some reason or other the sun is not permitted to lift the ocean out of its basins and pile its waters permanently upon the hiUs.

But how is this annually augmenting load taken off the

* See fig. 66, in which are copied some of the bcauUful drawings of Mr. GUuaher.

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BhonldeiB of the monntams ? The snowB sometimes detach themselves and rush down the slopes in avalanches, melting to water in the warmer air below. But the violent rush of the avalanche is not their only motion ; thej also creep by almost insensible degrees down the slopes. As layer, moreover, heaps itself upon layer, the deeper portions of the miass become squeezed and consolidated ; the air first entrapped in the meshes of the snow is squeezed out, and the compressed mass approximates more and more to the character of ice. You know how the granules of a snow- ball will adhere ; you know how hard you can make it if Biiflchievonsly inclined : the snow-ball is incipient ice ; aug- ment your pressure, and you actually convert it into ice. Bat even after it has attained a compactness which would entitle it to be called ice, it is still capable of yielding more or less, as the snow yields, to pressure. When, there- fore, a sufficient depth of the substance collects upon the earth's surface, the lower portions arc squeezed out by the pressure of the upper ones, and if the snow rests upon a slope, it will yield principaUy in the direction of

the slope, and move downwards.

This motion is incessantly going on along the slopes of every snow-laden mountain; in the Himalayas, in the Andes, in the Alps ; but in addition to this motion, whicb depends upon the power of the substance itself to yield to pressure, there is also a sliding motion over the inclined bed. The consolidated snow moves bodily over the moun- tain slope, grinding off the asperities of the rocks, and pol- ishing their hard surfaces. The under surface of the mighty polisher is also scarred and furrowed by the rocks over which it has passed ; but as the compacted snow de- scends, it enters a warmer region, is more copiously melted and sometimes, before the base of its slope is reached, it is wholly cut off by fusion. Sometimes, however, large and

deep valleys receive the gelid masses thus sent down ; in

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these vaDeTB it is farther consolidflted, and through tb^ it moves, at a slow but measurable pace, imitatiDg in all its motions those of a river. The ioe is thus carried far be- yond the limits of perpetual snow, mitil, at lei^^ the con- smnption below equals the supply above, and at tibia point the glacier ceases. From the snow-line downwards in sum- mer, we have ice; above the snow-line, both summer and winter, we have, on the surfiioe, snow. Hie portion below the snow-Une is called a glacier^ that above the anow-Iine is called the nkm. The n6v^, then, is the feeder of the glacier.

Several valleys thus filled may unite in a angle valley, the tributary glaciers welding themselves together to fonn a trunk glacier. Both the main valley and its tributaries are oflen sinuous, and the tributaries must change their di- rection to form the trunk. The width of the valley, also, often changes ; the glacier is forced through narrow gorges, widening after it has passed them ; the centre of the glacier moves more quickly than the sides, and the surface more quickly than the bottom. The point of swiftest motion follows the same law as that observed in the floAV of rivers,

changing from one side of the centre to the other, as the flexure of the valley changes.* Most of the great glaciers in the Alps have, in summer, a central velocity of two feet a day. There are points on the Mer- de-Glace, opposite the Montenvert, which have a daily mo- tion of thirty inches in summer, and in winter have been found to move at half this rate.

The power of accommodating itself to the channel through which it moves has led eminent men to assume that ice is viscous ; and the phenomena at first sight seem to enforce this assumption. The glacier widens, bends, and narrows, and its centre moves more quickly than its sides ;

* For the data on which this law is founded see Appendix to this Lecture.

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a Yiscoos mass would undoubtedly do the same. But the most delicate experiments on the capacity of. ice to yield to strain, to stretch out like treacle, honey or tar, have failed to detect this stretching power. Is there, then, any other physical quality to which the power of. accommoda- tion possessed by glader ice, may be referred ?

Let us approach this subject gradually. We know that Tapour is continually escaping from the free surface of a liquid ; that the particles at the surface attain their gaseous^ liberty sooner than the particles within the liquid ; it is natural to expect a similar state of things with regard to ice; that when the temperature of a mass of ice is uni' fonnly augmented, the first particles to attain liquid liberty are those at the surface ; for here they are entirely free, on one side, from the controlling action of the surrounding particles. Supposing, then, two pieces of ice raised throughout to 32"^, and melting at this temperature at their surfaces ; what may be expected to take place if we place the liquefying surfaces close together ? We thereby vir- tually transfer these surfaces to the centre of the ice, where the motion of each molecule is controlled all round by its neighbours. As might reasonably be expected, the liberty

of liquidity at each point where the surfaces touch each other, is arrested, and the two pieces freeze together at these points. Let us make the experiment : Here are two masses which I have just cut asunder by a saw ; I place their fiat surfaces together ; half a minute's contact ^vill suffice ; they are now frozen together, and by taking hold of one of them I thus lift them both.

This is the effect to which attention was first directed by Mr. Faraday in June 1860, and which is ijow known under the name of Hegdation. On a hot summer's day, I have gone into a shop in the Strand where fragments of ice were exposed in a basin in the window ; and •with the shopman's permission have laid hold of the topmost piece

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of ioe, and by means of it have Efted the whole of the pieces bodily out of the dish. Though the thennometer at the time stood at 80% the pieces of ice had finoaen together at their points of jonction. Even imder hot water this effect takes place ; I have here a basin of water as hot as my hand can bear ; I plmige into it these two jdeoes of ice, and hold them together for a moment : they are now frozen together, notwithstanding the presence of the heat- ed liquid. A pretty experiment of Mr. Faraday's is to place a nmnber of small fragments of ice in adish of water deep enough to float them. When one peoe tooofaes the other, if only at a single point, regelation instantly sets in. Thus a train of pieces may be caused to touch each other, and, after they hare once so touched, you may take the terminal piece of the train, and, by means of it, draw all the others after it. When we seek to bend two pieces thus united at their point of junction, the frozen points suddenly separate by fracture, but at the same moment other points come into contact, and regelation sets in be- tween them. Thus a wheel of ice might be caused to roll on an icy surface, the contacts being incessantly ruptured, with a crackling noise, and others as quickly

established by regelation. In virtue of this property of regelation, ice is able to reproduce many of the phenomena which are usu- ally ascribed to viscous bodies.*

Here, for example, is a straight bar of ice : I can by passing it successively through a series of moulds, each more curved than the last, finally turn it out as a semi-ring. The straight bar in being squeezed into the curved mould breaks, but by continuing the pressure new surfaces come into contact, and the continuity of the mass is restored. I take a handful of those small ice fragments and squeeze

* Sec note on the Regelation of Snow Granules in the Appendix to this Lecture.

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them together, they freeze at their points of contact and now the mass is one aggregate. The making of a snow- ball, as remarked by Mr. Faraday, illostratcs the same prin- ciple. In order that this freezing shall take place, the snow ought to be at 32^ and moist. When below 32° and dry, on being squeezed it behaves like salt^ The crossing of snow-bridges in the upper regions of the Swiss glaciers is often rendered possible solely by the regelation of the SQOW granules. The climber treads the mass carefully, and causes its granules to regelate: he thus obtains an amount of rigi^ty which, without the act of regelation, would be quite unattainable. To those unaccustomed to sudi work, the crossing of snow bridges, spanning, as they often do, fissures 100 feet and more in depth, must appear quite appalling.

If I still further squeeze this nmss of ice fragments, I bring them into still closer proximity. My hand, however, is incompetent to squeeze them very closely together. I place them in this boxwood mould, which is a shallow cyl- inder, and placing a flat piece of boxwood overhead, I io- troduce both between the plates of a small hydraulic press, and squeeze the mass forcibly into the mould. I now relieve the pressure and turn the substance out before you : it is converted into a coherent cake of ice. I place it in this lenticular cavity and again squeeze it. It is crushed by the

pressure, of course, but new contacts establish themselves, and there you have the mass a lens of ice. I now transfer my lens to this hemispherical cavity, h (fig. 57), and bring dovm upon it a hemispherical protuberance, p, which is not quite able to fill the cavity. I squeeze tlie mass: the ice, which a moment ago was a lens, is now squeezed into the space between the two spherical sur- faces : I remove the protuberance, and here I have the in- terior surface of a cup of glassy ice. By care I release it from the mould, and there it is, a hemispherical cup, which

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^ tho spongy mass vithin this spberieal cavity, c (fig. I squeeze it and add to it, till finally I can bring dom anotbor spherical cavity, d, upon it, enclosing it as a sphere between both. As I work the press the mass becomes more and more compacted. I add more material, and again squeeze ; by every such act tho mass is made harder, and tbero you have a snow-ball before you such as yoa never saw before. It is a sphere of hard translncent ice, B. Thus, you sec, broken ice can be compacted together

by pressure, and in virtue of the property of regcladoa, which cements its touching surfaces, the substance may be made to take any shape we please. Were the experiment worth the trouble, I feel satisfied that I could form a ropt of ice from this block, and afterwards coil tho rope into a knot. Nothing of course can be easier than to prodnoo statnettos of the substance from suitable moulds.

It is easy to understand how a substance so endowed

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can be squeezed through the gorges of the Alps— can bend 80 as to accommodate itself to the fiezurcs of the Alpine vallejrs, and can permit of a differential motion of

its parts, without at the same time possessing a sensible trace of vis- cosity. The hypothesis of viscosity, first started by Ren- du, and worked out with such ability by Prof. Forbes, ao^ counts, certainly, for half the facts. Where pressure comes into play, the deportment of ice is apparently that of a ^-iscous body ; where tension comes into play, the anal- ogy ^-ith a viscous body ceases.

I have thus briefly sketched the phenomena of existing glaciers, as far as they are related to our present subject ; but the scientific explorer of mountain regions soon meets with appearances which carry his mind back to a state of things very different from that which now obtains. The unmistakable traces which they have left behind them show that vast glaciers once existed in places, from which they have for ages disappeared. Go, for example, to the gla- cier of the Aar in the Bernese Alps and obsen-e its present performances ; look to the rocks upon its flanks as they are at this moment, rounded, polished, and scarred by the moving ice. And having by patient and varied exercise educated your eye and judgment in these matters, walk down the glacier towards its end, keeping always in view the evidences of the glacier's action. After quitting the ice, continue your walk down the valley towards the Grim- 8el: you see everywhere the same unmistakable record. The rocks which rise from the bed of the vaUey are round- ed like hogs' backs ; these are the .* roches moutonnes ' of Charpentier and Agassiz ; you observe upon them the larger flutings of the ice, and also the smaUcr scars scratched by pebbles, which the glacier held as emery on its under sur- face- All the rocks of the Grimsel have been thus planed down. Walk down the valley of Hasli and examine the mountain sides right and left ; without the key which I

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now suppose jou to possess, yoa would be in • land of enigmas ; but with this kej all is plain, yoa see efeajwlwi the well-known scars and flntings and furrowinga. In tin bottom of the valley yoa have the rooks filed down in bobn I^aoes to dome-shaped

masses, and, in others, polished si smooth that to pass over them, even when the w**"'^'^^^*^ b moderate, steps most be hewn* All the wa^ down tD Meyringen and beyond it, if yoa wish to poraoe the ca- quiry, these evidences abound. For a pi;eluninary lesson k the recognition of the traces of ancient gladera no bettar ground can be chosen than this.

Similar evidences are found in the valley of the Bhow; you may track them through the valley for eighty mileii and lose them at Icogth in the lake of Geneva. But on the flanks of the Jura, at the opposite side of the Canton de Vaud, the c^ide^ccs reappear. All along these limestone slopes you have strewn the granite boulders of Mont Blanc Right and left also from the great Rhone valley the lateral valleys show that they were once held by ice. On the Italian side of the Alps the remains are, if possible, more stupendous than on the northern side. Grand as are the present glaciers to those who explore them in all their lengths, they are mere pigmies in comparison with their predecessors.

Not in Switzerland alone — not alone in proximity with existing glaciers — are these well-known vestiges of the an- cient ice discernible ; in the hills of Ciunberland they are almost as clear as in the Alps. Where the bare rock has been exposed for ages to the -act ion of the weather, the finer marks have in most cases disappeared ; and the mam- millatcd foi^ns of the rocks arc the only evidences. But the removal of the soil which has protected them, oflen discloses rock surfaces ivtiich are scarred as sharply, and polished as cleanly as those which are now being scratched and polished by the glaciers of the Alps. Round about

AKCIEST GLACIEBS. 209

Scawfell the traces of the andent ice appear, both in roehea mouiannia and Noes percMs; and there are ample fiMSta to show that Borrodale was once occupied by glacier ioe. In North Wales, also, the ancient glaciers haye placed thdr stamp so

firmly upon the rocks, that the ages which have since elapsed have failed to obliterate even their mperficial marks. All round Snowdon these evidences abomid. On the south-west coast of Ireland also rise the Beeks of MagiDiouddy, which tilt upwards, and catch upon their cold crests the moist winds of the Atlantic ; precipitation is copious, and rain at EUlamey seems the rule of Nature. In this moist region every crag is covered with rich vegetation; but the vapours which now descend as mild and fertilising rain, once fell as snow, which formed the material for noble glaciers. The Black Valley was once filled by ice, which planed down the sides of the Pur- jde Mountain, as it moved towards the Upper Lake. The ground occupied by this lake was entirely held by the an- cient ice, and every island that now emerges from its sur- face is a glacier-dome. The fantastic names which many of the rocks have received are suggested by the shapes into which they have been sculptured by the mighty moulding plane which once passed over them. North America is also thus glaciated. But the most notable observation in con- nection with this subject is one recently made by Dr. Hooker during a visit to Syria : he has found that the celebrated cedars of Lebanon grow upon ancient glacier moraines.

To determine, the condition which permitted of the for- mation of those vast masses of ice has long been a problem with philosophers, and a consideration of the solutions which have been offered from time to time will not be un- instructive. I have no new hypothesis, but it seems pos- sible to give a truer direction and more definite aim to our enquiries. The aim of all the writers on this subject, with whom I am acquainted, has been directed to the attain-

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ment of coUL Some eminent men have thoughty and mow Btill think, that the redaction of temperature during the glacier epoch was dno to a temporary diminution of loltt radiation ; others have thought that, in its motion thzouj^ space, our system may have traversed regions of low temt perature, and that during its

passage through these r^gionsi the ancient gladers were produced. Others, with greater correctness, have sought to lower the temperature by a le- distribution of land and water. If I underatand the wri^ ings of the eminent men who have propounded and advo- cated the above hypotheso^ many of them seem to have overlooked the fact, that the enormous extension of f^ cicrs in bygone ages, dcmonBtratcs, just as rigidly, the operation of heat as the action of cold.

Cold will not produce glaciers. You may have the bit- terest north-east winds hero in London throughout the winter without a single flake of snow. Cold must have the fitting object to operate upon, and this object — the aqueous vapour of the air — is the direct product of heat. Let us put this glacier question in another form : the latent heat of aqueous vapour, at the temperature of its production in the tropics, is about 1,000° Fahr., for the latent heat grows larger as the temperature of evaporation descends. A pound of water then vaporised at the equator, has absorbed 1,000 times the quantity of heat which would nusc a pound of the liquid one degree in temperature. But the quantity of heat which would raise a pound of water one degree would raise a pound of cast-iron ten degrees : hence, simply to convert a pound of the water of the equatorial ocean into vapour, would require a quantity of heat sufficient to im- part to a pound of cast-iron 10,000 degrees of temperature. But the fusing point of castriron is 2,000 Fahr. ; therefore, for every pound of vapour produced, a quantity of heat has been expended by the sun sufficient to raise 6 lbs. of cast- iron to its melting point. Imagine, then, every one of

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mt glaciers with its mass of ice qnintnpled ; and loe of the mass, so augmented, be taken by an of cast-iron raised to the white heat of fusion, ive the exact expression of the solar action in- thc production of the ancient glaciers. Substi- 3t iron for the cold ice — our speculations would e directed to account for the high temperature cial epoch, and a complete reversal of some of eses above quoted would probably ensue,

rfectly manifest that by weakening the sun's ac- • through a defect of emission, or by the steep- entire solar system in space of a low tempera- lould be cutting off the glaciers at their source. 2s of mountain ice indicate, infallibly, commen- ses of atmospheric vapour, and a proportionately on the part of the sun. In a distilling appara- required to augment the quantity distilled, you surely attempt to obtain the low temperature

0 distillation, by taking the fire froni under your t this, if I understand them aright, is what has by those philosophers who have sought to pro- icient glaciers by diminishing the sim's heat. It lifest that the thing most needed to produce the in improved condetiser ; we cannot afford to lose olar action ; wo need, if anything, more vapour, id a condenser so powerful that this vapour, in- Iling in liquid showers to the earth, shall be so

1 in temperature as to descend in snow. The think, is thus narrowed to the precise issue on jlution depends.

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Olace of C'hamouL year, fonncd the ha

The law first esi f [M. Agassiz and] (Yrf:

Forbes, that llic central portions ()r a glacier uu'vcd Me tlio sides, was amply illuatmted bj the tk-portmcnt of M stakes placed across the Mer-de-Glace at several place, tti\ the tributariis of the glacier. The portions of the Ma* derived from these tributsrica were easily traceabiu the glacier by means of Uie nwruincj. Thus, fo portion of the trunk Btream derive il from thcGladerdj' might be diatinguished, in a

moment, from the portioB i from the other tributaries, by the absence of the dct«' monuncs npon the surface of the former. The comiww* the dirt formed n distinct junction l>etween both portiois, • tion has been drawn by Prof. Forbes to the fact, thatliC aide of the glacier in particular is 'exccsavely crevafflrf;" accounts for this crevassing by supposing that the OW Gfant moves most swiiWy, and in its efforts to drag its n* gish companions along with it, tears them asunder, sad Qi duces the fissures and dislocations for which tbeeasten' the glacier is remBrkablc. The speaker said that tixi mad' must not be altadied to tjiis explanation. ItwaioDt^ suggestions which are perpetually thrown out bj mMn^!

MOmOK OF XEB-DS-OLACE. 218

tming the conrse of an inyesdgaticm, and the folfillment or non- yfiUment of nrhich cannot materially affect the merits of the in- restigator. Indeed, the merits of Forbes must be judged on far broader grounds ; and the more his labours are compared with those of other observers, the more prominently does his compara- tive intellectual magnitude come forward. The speaker would aot content himself with saying that the book of Prof. Forbes was ttie best book which had been written upon the subject. The qualities of mind, and the physical culture inyested in that excel- lent work, were such as to make it, in the estimation of the phys- ieil inrestigatar at least, outweigh all other books upon the sub- ject taken together.* While thus acknowledging its merits, let a floe and frank comparison of its statements with facts be insti- tvted. To test whether the Glacier du Gdant moycd quicker than its feUows, five different lines were set out across the Mer-de- GHaoe, in the yicinity of the Montenvert, and in each of these it iras found that the point of swiftest motion did not lie upon the fflacier du G^ant at all ; but was displaced so as to bring it com- pmtiTely dose to the eastern side of the glacier. These measure- ments prove that the statement referred to is untenable ; but the ieyiation of the point of swiftest motion from the centre of the gilacier will doubtless be regarded by Prof Forbes as of far great- ar importance to his theory. At the place where these measure- ments were

made, the glacier turns its convex curvature to the eastern side of the valley, being concave towards the Montenvert. Let us take a bolder analogy than even that suggested in the ex- planation of Forbes, where he compares the Glacier du G6ant to a itrong and swiftly-flowing river. Let us enquire how a river irould behave in sweeping round a curve similar to that here sxisting. The point of swiftest motion would undoubtedly lie on

* Since the above was written, my * Glaciers of the Alps* has been lobllshed, and, soon afUr its appearance, a * Reply * to those portions of the)ook which referred to the labours of M. Rendu was extensively circulated }j Principal Forbes, For more than two years I have abstained from iDswering my distinguished censor ; not from inability to do so, but because '. thought, and think, that, within the limits of the case, it is better to sub- nit to misconception, than to make science the arena of a purely personal iontroverpy.

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that ride of tite centra of the atnun towarda wUtdi it tomi ito convex cmratare. Can this be tbo cue with the ke I Xfao^tkB we ongtit to have a ehiftuig of the point of muimiDB moliai towarda the western tide of the Tallej, when the cnmtan of die glacier bo changea aa to tcm ita oonrexilT to die wwtMB ridt. Sndi a change of Seim^ ocean opporite the paawgii cdled Lm PaiOi, and at thia place the view Jntt enunciated waa teitad. S waa Boon Rscertained that the point of flwiftot motion hen 1^ rt a di^rent side of the azla ftom that obaored lows down. Bit to confer etrict numerical accurate npoo tiie Knit, atakea was flied at certain distance! frcnn the wcrtem ride of the ^Mei; n& others of «gti<il diibnuM from tiw eartent ride. IhoTriodtiMtf tbeee atakea were compared with each ottur, two bj two ; k rtato on the western side being always coiapaied with -a aecond €M, which stood st the same distance from the eastern aide. The »■ suits of this measurement are given in the following table, the nuiubefs denoting inches : —

lit pair 2nd p>1r Srd pair ttb pili (tbpalr

Wc8ll6 Wfstni WMt22J West 381 Weat iSJ East Ui East 15} East IGt East 18^ Eut 19i

It is here seen that in each cose the western etake mored mora rapidly than ita eastern fellow stake; thns proring, beyond a doubt, that opposite the Fonts the western ride of the Ucr-dc- Olncc moves quickest— a result precisely the reretw of that ob- Bcrvtd where the curvature of the valley was different.

But another test of the explanation is possible; Between the Fonts and the promontory of Trtlaporte, the glacier passes a point of contrary flexure, its convex curvature opposite to Tr£Ia- portc being turned towards the base of the Aiguille da Hoinc, which stands on the eastern side of the valley. A Beties of stakes WHS placed across the glacier here ; and the velodtiea of those placed at certain distances from the western ride were compsied, OS before, with those of stakes placed at the same distances from the easlcm side. TIic following table shows the result of these measurements ; the numbers, as before, denote inches : —

litpilr Indpilr Irdpalr

WcBt . . 121 West . . IB We« IJJ

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re we find that in each case the taritm stake moved Aster ta fellow. The potDt of nuurimnm motjon hos therefore lore crossed the axis of the gl&cier, bemg now upon its east-

tcrmining the points of maximum motion for a great nnm- transTcntc sections of the Her^e-Qlace, and uniting these , we have the loeut of the cnrre described bj the point n»- to. Fig. G9 represents a sketch of the Herde-Olace. The . line is drawn along the centre of the glo- Ite defined lino, which crosses the axis of icier at the points a a, is then the locns of int of swiftest motion. It is a curre more ' nnuons than tbe valley itself, and croasea Btral lino of the valley at each point of ' 17 fleinre. The speaker

drew attention to ct that the position of towns upon the of rivers is usually on the convex side of 'Cam, where the rush of the water renders -np impiissible : the Thames was a case in and tlie same law which regulated its id dctcrmmcd the position of tbe adjacent is at this moment operating, with silent \ among the Alpine glaciers, other peculiarity of glacier motion is now •oticeil.

ore any oliscrvalionshad been made upon gect, it nos surmised by Prof. Forbes that 'Ftions of a glacier near its bed were retarded by fHction t the latter. Tbu view was afteiwards confirmed by his jaervations, and by those of M. Martins. Nevertheless the f our knowledge npon the suiiject, rendered further con- jon of the fact highly desirable. A rare opportunity for ; the question was furnished by an almost vertical precipice constituting the side of the Glacier de G<5ant, which was id ne.ir the Tacul. The precipice was about WO feet in ;. At the top and near the bottom stakes were fixed, and *ing steps in the ice, the speaker succeecTcd in fixing a in the face of the precipice, at a point about 40 feet above ise. After the lapse of a sufficient number of days, the prog-

▲PPKHDIZ TO XJBOnm TL

xeBB of the three stakes wis measuied; Teduoed to tlw dSagaad rate, the motion was as follows : —

Top stake lliddle stake Bottom stake

. SHMfaidies .4-69 „ . 2-66

Wo thus see that the top stake mored with more tban tvte the yelodly of the bottom one; while the telodtj of the middPi stake lies between the twa Bat it also appean that the tation of Telocity upwards is not proportional to fhe firom the bottom, but increases in a qoicker ratio. At a of 100 feet from the bottom, the yelodly would imdoubtad^ practically the same as at the smfaoe. MeasarementB mida an adjacent ice-cliff proyed this. We thns see the perlbct yallddl^'^ of the reason assigned by Forbes for the continued yerticality of the walls of transverse crevasses. Indeed a

comparison of the le- snlt with his anticipations and reasonings will prove alike tiiflir sagacity and their truth.

The most commanding view of the Mcr-de-Glace and its trib- utaries is obtained from a point above the remarkable cleft in the mountain range underneath the Aiguille de Charmoz, which li sure to attract the attention of an observer standing at the Mont- envert. This point, which is marked G on the map of Fdita, the speaker succeeded in attaining. A Tubingen professor once ivk- itcd the glaciers of Switzerland, and seeing these apparently rigid masses enclosed in sinuous valleys, went home and wrote a book, flatly denying the possibility of their motion. An inspection from the point now referred to would have doubtless confirmed him in his opinion ; and indeed nothing can be more calculated to im* press the mind with the magnitude of the forces brought into play than the squeezing of the three tributaries of the Her-de- Glace through the neck of the valley at Tr61aporte. But let ni state numerical results. Previous to its junction with its feUowi, the Glacier du Geant measures 1,134 yards across. Before it is influenced by the thrust of the TalOfre, the Glacier de L^diand had a width of 825 yards ; while the width of the TaUfto branck across the base of the cascade, before it joins the L^hand, is ap- proximately 038 yards. The sum of these widths is 2,697 yarda At Trelaporte those three branches are forced through a goigs

lionosr OF ues-de-olace.

898 yards wide, with a oentnl ydocity of 20 inches a day I The Tesalt is still more astonishing, if we confine our attention to one of the tribntaries — ^that of the Ldchaud. Before its junction with the Tale&c, the ghuder has a width of 37^ English chains. At Tr61aporte this broad ice river is squeezed to a driblet of less than 4 chains in width — ^that is to say, to about one-tenth of its prerious horizontal transverse dimension.

Whence is the force derived which drives the glacier through file gorge t The

speaker believed that it must bo a pressure from Wiind. Other facts also suggest that the Glacier du G6ant is thiooghoat its length in a state of forcible longitudinal compres- WHL Taking a series of points along the axis of this glacier— if time points, during the descent of the glacier, preserved their .diftmoes asunder perfectly constant — there could be no longitu- dinal compression. The mechanical meaning of this term, as ap- plied to a substance capable of yielding like ice, must be that the lander joints arc incessantly advancing upon the forward ones. The speaker was particularly anxious to test this view, which Ihrst oocnned to him from tk priori considerations. Three points, A b c, ▼ere therefore fixed upon the axis of the Glacier du Gtant, a be- ing the highest up the glacier. The distance between a and B Was 545 yards, and that between b and c was 487 yards. The daily velocities of these three points, determined by the theodo- lite, were as fullows : —

. 20*55 inches

The result completely corroborates the foregoing anticipation. The hinder points are incessantly advancing upon those in front, and that to an extent sufficient to shorten a segment of this gla- cier, measuring 1,000 yards in length, at the rate of 8 inches a day. Were this rate uniform at all seasons, the shortening would imoont to 240 feet in a year. When we consider the compactness of this glacier, and the uniformity in the width of the valley which it fills, this result cannot fail to excite surprise ; and the exhibition of force thus rendered manifest must, in the speakcr^s opinion, be mainly instrumental in driving the glacier through the jaws of the granite vice at Trelaporte.

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In virtue of wli&t qnall^, Uien, can in be bent and iqaeend, and change its form in the manner indicated In the fimgolng ob- aerTftUons ? The only theory worthy of aerloni cooddaratioa at the present day b tliat of ProC Forbes, irhieh attribntea then effects to the viscosity of the ice. The speaker did not agree with this theory ; as the term Tiscodty appeared to him to be TiKdty Inapplicable as ezpreesire of the

phyncal constitntion ot tbo gla- cier ice. Bo had already moulded ice into copa, bent it Into tings, changed its form in a variety of ways by aidfloal piuHiui, and he had no doabt of Ms aUlity to monld a conqwct dibm of Norway ice which stood upon the table into » ttataette; but would viscosity be the proper term to apply to the proceM cf bhddng and r^elation by which this resnlt could be sttalnedl He thought not. A mass of ice at B2° is very easily crushed, hot it has OS sharp and definite a fracture 03 a mass of gloss. There is no sensible cvideucc of viscosity.

The very essence of viscosity is the ability of yielding to a force of Umioa, the texture of the substance, after yielding, bdng in a state of equilibrium, so that it has no stroin to recover from ; and the substonccs chosen by Prof Forbes, as illuBtrotive of the physical condition of a glocier, possess this power of being drawn out in a very eminent degree. But it lias been urged, and justly urged, that ive ought not to conclude thot viscosity is absent be- cause hand specimens do not show it, any more than we ought to conclude that ice is not blue because small fragments of the sub- stance do not exhibit this colour. To test the question of viscos- ity, then, ire must appeal to the glacier itself Let us do sa First, an analogy between the motion of o glacier through a ranu- ous volley, and of a river in a sinuous channel, has been already pointed out. But the analogy fails in one important particular : the river, and much more so a mass of flowing treacle, honey, tar, or melted caoutchouc, sweeps round its curves without rupture of continuity. The viscous mass ttrftchet, but the icy moss ireait, and the • excessive crcvassing ' pointed out by Prof. Forbes himself is the consequence. Secondly, the inclinations of the Mer-de-Olace and its three tributaries were taken, and the association of trans- verse crevasses with tbe changes of inclination was accurately noted. Every Alpine traveller knows the utter di^ocation and confusion produced by the descent of the Her-de-Glace from the

FBAGHJIT OF ICS. 219

Chapeau downwards. A similar state of things exists in the ice- cascade of the TaUfire. Descending finom the Jardin, as the ice approaches the fall, great transverse chasms are formed, which at length follow each other so speedily as to reduce the ice masses hetween them to mere plates and wedges, along which the explorer has to creep cautiously. These plates and wedges are in some cases bent and crumpled by the lateral pressure, and on some masses vortical forces appeared to have acted, turning large pyramids 90*^ round, so as to set their structure at right angles to its normal position. The ice afterwards descends the fall, the portions exposed to view being a fimtastic assemblage of frozen boulders, pinnacles, and towers, some erect, some leaning, falling at intervals with a sound like thunder, and crushing the ice crags on which they fall to powder. The descent of the ice through this outlet has been referred to as a proof of its viscosity ; but the description just given does not, it was believed, harmonise with our ideas of a viscous substance.

But the proof of the non-viscosity of the substance must be sou^t at places where the change of inclination is very small. Nearly opposite FAngle there is a change from 4 to 9 degrees, and the consequence is a system of transverse fissures, which renders the glacier here perfectly impassable. Further up the glacier, transverse crevasses are produced by a change of inclination from 3 to 5 degrees. This change of inclination is accurately protracted in fig. 60 ; the bend occurs at the point b ; it is scarcely percep-

tible, and still the glacier is unable to pass over it without break- ing across. Thirdly, the crevasses are due to a state of strain, from which the ice relieves itself by breaking : the rate at which they widen may be taken as a measure of the amount of relief demanded by the ice. Both the suddenness of their formation, and the slowness with which they widen, are demonstrative of the non- viscosity of the ice. For were the substance capable of stretching even at the small rate at which they widen, there would be no necessity for their formation.

Further, the marginal crevasses of a glacier are known to be a

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conBeqnenoe of the swifter flow of its oentnl portknii^ wlikli ihiowB tlie sides into a state of strain, ftom which tluy leliefe themselyes by breaking. Now it is easj to calculate tlie amoont of stretching demanded of the ice in order to accommodate itself to the speedier central flow. Take the case of a glader, half a mile wide. A straight transverse element, or sUce, of wadk a gla- cier, is bent in twenty-four hours to a cnrre. Ilia ends of the dice moye a li^e, but the centre moves more : let us sniipose the versed side of the carve fonned by the slice in twenty-four hqgmi to be a foot, which is a fair average. Having the choid of this arch, and its versed side, we can cakulate its length. In the esse of the Mcr-de-Glace, which is abont half-armile wide, the amoimt of stretching demanded would be about the eightietJi €i an indi in twenty-four hours. Surely, if the glacier possessed a property which could with any propriety be called viscosity, it ought to be able to respond to this moderate demand ; but it is not able to do so : instead of stretching as a viscous body, in obedience to this slow strain, it breaks as an eminently fragile one, and mar- ginal crevasses arc the consequence. It may be urged that it is not fair to distribute the strain over the entire length of the curve : but reduce the distance as we may, a residue must remain which is demonstrative of the non-viscosity of the ice.

To sum up, then, two classes of facts present themselves to the glacier investigator — one class in harmony with the idea of vis- cosity, and another as distinctly opposed to it. Where presture comes into play we have the former, where tension comes into play we have the latter. Both classes of facts arc reconciled by the assumption, or rather the experimental verity, that the fragility of ice and its power of rcgelation render it possible for it to change its form without prejudice to its continuity.

NOTE ON THE EEGELATION OF SN0W-GKANULE8 .•

I this morning (March 21, 1862) noticed an extremely interest- ing case of rcgelation. A layer of snow, between one and two

* FhiL Mag. 18C2, vol. xxiii. p. 812.

inches thick, had fSiUen on the glass roof of a small groen-house into which a door opened from the mansion to which the green- house was attached. Air, slightly warmed, acting on the glass sorfiice underneath, melted the snow in immediate contact with the glass, and the layer in consequence slid slowly down the glass rooC The inclination of the roof was Tery gentle, and the motion correspondingly graduaL When the layer overshot the edge of the roof^ it did not drop oflE^ but bent like a flexible body and hung down oyer the edge for several inches. The continuity of the layer was broken into rectangular spaces by the inclined lon- gitudinal sashes of the roofj and from local circumstances one side of the roof was warmed a little more than the other : hence the subdivisions of the layer moved ^th different velocities, and over- hung the edge to different depths. The bent and down-hanging layer of snow in some cases actually curved up inwards.

Faraday has shown that when small fragments of ice float on water, if two of them touch each other, they instantly cement themselves at the point of contact ; and on causing a row of frag- ments to touch, by laying hold of the terminal piece of the row, you can draw all the others after it. A similar cementing must have taken place among the particles of snow now in question, which were immersed in the water of liquefaction near the surface of the glass. But Faraday has also shown that when two fragments of ice are thus united, a hinge-like motion sets in when you try to separate the one frx>m the other by a lateral push : one frtigmcnt might, in fact, be caused to roll round another, like a wheel, by the incessant rupture, and re-establishment of r^elation.

The power of motion thus experimentally demonstrated, ren- dered it an easy possibility for the snow in question to bend it- self in the manner observed. The lowermost granules, when the support of the roof had been withdrawn, rolled over each other without a destnictionof continuity, and thus enabled the snow-layer to bend as if it were viscous. The curling up was evidently due to a contraction of the inner surface of the layer, produced, no doubt, by the accommodation of the granules to each other, as

they slowly diminished in size.

LECTURE VII.

[Ifardi 6, 1862.]

COHDVCnOV A TBA5S3n88X0X OF XOTIOir— OOOD OOHMrOfOBS AB9 BAD C01IDnCT0RS--C0KDUCTlTnT OF THB MXTAU FOB BBAT: BBLATIOB BB- TWKEN THB GOMDUCTltTT OF UEAT AND THAT OF BLBCTBICITT— IBILIT* EMCE OF TEMPERATURE ON THE CONDUCTIOX OF ELECTRICRT — IBFLU- ENCE OF MOLECULAR CONSTITUTION ON THE CONDUCTION OP HEAT — RE- LATION OF SPECIFIC HEAT TO CONDUCTION — PHILOSOPHY OF CLOTHES: RUMFORD's EXPERIMENTS — INFLUENCE OF MECHANICAL TEXTURE ON CONDUCTION — INCRUSTATIONS OF BOILERS — THE SAFETY LAMP — CON- DUCTIVITY OF LIQUIDS AND GASES: EXPERIMENTS OF RUMFORD AND DESPRETZ — COOLING EFFECT OF HYDROGEN GAS — EXPERIMENTS OF MAG- NUS ON THE CONDUCTITITY OF GASES.

ITlllNK wc are now sufficiently conversant with our subject to distbguish between the sensible motions pro- duced by heat, and heat itself. Heat is not the clash of winds ; it is not the quiver of a flame, nor the cbullitioii of water, nor the rising of a thermometric column, nor the motion which animates steam as it rushes from a

boiler in which it has been compressed. All these are mechanical motions into which the motion of heat may be converted ; but heat itself is molecular motion — it is an oscillation of ultimate particles. But such particles, when closely grouped, cannot oscillate without communication of motion from one to the other. To this propagation of the motion of heat, through ordinary matter, we must tliis day devote our attention.

Here is a poker, the temperature of which I am scarce-

CONDUCTION OF HEAT.

ly coDiBcions of: I feel it as a hard and heavy body, but it ndther warms me nor chills me ; it has been before the £re, and the motion of its particles at the present moment chances to be the same as that which actuates my nerves ; there is neither commmiication nor withdrawal, and hence the temperature of the poker on the one hand, and my sensations on the other, remun unchanged. But I thrust the end of the poker into the fire ; it is heated ; the parti- cles in contact with the fire are thrown into a state of more intense oscillation ; the swinging atoms strike their neigh- bours, these again theirs, and thus the molecular music rings along the bar. The motion, in this instance, is com- municated from particle to particle of the poker, and finally appears at its most disant end. If I now lay hold of the poker, its motion is communicated to my nerves, and pro- duces pain ; the bar is what we call hot, and my hand, in popular language, is burned. Convection we have already defined to be the transfer of heat, by sensible masses, from place to place ; but this molecular transfer, which consists m each atom taking up the motion of its neighbours, and sending it on to others, is caUed the conduction of heat.

Let me exemplify this property of conduction in a homely way. I have here a basin filled with warm water, and in the water I place this cylinder of iron, an inch in

^ameter, and two inches in height ; this cylinder is to bo my source of heat. I lay my

thermo-electric pile, o (fig. 61), thus flat, with its naked face turned upwards and on 224 usGnruBB vn.

that face I place a cylinder of copper, 0^ libidi now poft- Besses the temperature of this room. We observe no d^eo- tion of the galvanometer. I now place my warm cylinder, t, having first dried it| upon the cool cylinder, wludi is supported by the pile. The upper cylinder is not at more than a blood heat ; but you see thivb I have scarody time to make this remark before the needle flies adde, indicatiDg that the heat has reached the &oe of the pile. Thus the molecular motion imparted to the iron cylinder by the warm water has been communicated to the copper <»ie, through which it has been transmitted, in a few aeoonds, to the face of the pile.

Different bodies possess different powers of transmit- ting molecular motion ; in other words, of conducting- heat. Copper, which we have just used, possesses this power in a very eminent degree. I will now remove the copper, allow the needle to return to 0% and then lay upon the face of the pile this cylinder of glass. On the c}'linder of glass I place my iron cylinder, which has been re-heated in the warm water. There is, as yet, no motion of the needle, and you would have to wait a long time to see it move. We have already waited thrice the time which the copper required to transmit the heat, and you see the needle continues motionless. I place cylinders of wood, chalk, stone, and fireclay, in succession on the pile, and heat their upper ends in the same manner ; but in the time which we can devote to an experiment, not one of these substances is competent to transmit the heat to the pile. The molecules of these substances arc so hampered or entangled, that they are incompetent to pass the motion freely from one to another. The bodies are all bad conductors of heat. On the other hand, I place cylinders of zinc, iron, lead, bismuth, &c., in succession on the pile ; each of them, you see, has the power of transmitting the motion of heat swiftly through its mass. In comparison with the wood,

ooimircfnozr of heat. 225

stone, chalk, glass, and day, they are all good conductors of heat.

As a general rule, though it is not without its excep- tions, the metals are the best conductors of heat. But the metals differ notably among themselves as regards their powers of conduction. In illustration of this I will com- pare copper and iron. Here, behind me, are two bars, a b,

A c (fig. 62), placed end to end, with balls of wood at- tached by wax at equal distances from the place of junction. Under the junction I place a spirit-lamp, which heats the ends of the bars ; the heat will be propagated right and left through both. This bar is iron, this one is copper; the heat wiU travel to the greatest distance along the best conductor, liberating a greater number of its balls.

But for my present purpose I want a quicker experi- ment. Here, then, are two plates of metal, the one of coj)- per, the other of iron, which are united together, so as to form a long continuous plate c i (fig. 63). To it a handle is attached, which gives the whole instrument the shape of a T. From c to the middle, the plate is copper, from i to the middle it is iron. At c I have soldered a small bar of bismuth to the pkte ; at i a similar bar ; and from both bars wires, g g^ lead to the galvanometer. I warm the junction i by placing my finger on it; an electric cur- rent is there generated, and you observe the deflection. The red end of the needle moves towards you. I with- draw my finger, and the needle sinks to 0°. I now warm,

in the same manner, the junction c ; the needle is deflected,

bat in the opposite direction. If I plM« a fingor «n eadi end, at the some time, these coirenta nentraliM eadi other, and -wo have no deflection. I nov plsee a Bi»ritJainp^ -with

a very small flame, directly nnder the middle of the com- pound plate ; the heat will propagate itself from the cen- tre towards the two ends, passing on one side through copper, and oo the other through iron. If the heat reach both ends at the same instant,

the one end will neutralize the other, and the needle will rest quiescent. But if one end be reached sooner than the other, we shall obtain a deflection, and the direction in which the needle mores wiD declare which end is heated. Now for the experiment : I place the lamp iindemoalh, and in three ecconds the needle flies aside. The red end moves towards me, which proves that the end c is heated ; the molecular motion has propa- gated itself most swiftly throngh the copper. I allow the lamp to remain until each metal has taken up as much heat as it can appropriate, until the ends of the plates become stationary in temperature ; that is to say, until the (Quan- tity of heat which they receive from the lamp is exactly equal to the quantity dissipated in the space around them. The copper still asserts its predominance ; the needle Btill indicates that the end c is most heated : and thus we prove cop]>er to be a better conductor of heat than iron. This little experiment illustrates how in natural philosophy we turn one agent to account in the investigation of an-

EXPKBIUEMTAL ILLUSTBATIOHS OF CONDUCTION. 227

Other. Every new discovery is a new instmment : it was onoe an end, but it is soon a means ; and thus the growth of science is secured.

One of the first attempts to determine with accuracy the condactivity of different bodies for heat^ was that sug- gested by Franklin, and carried out by Ingenhausz. lie coated a number of bars of various substances with wax, and immersing the ends of the bars in hot oil, he obser\ ed the distance to which the wax was melted on each of the bars. The good conductors melted the wax to the great- est distance ; and the melting distance furnished a measure of the conductivity of the bar.

The second method was that pointed out by Fourier, and followed out experimentally by M. Despretz. a b (fig. 64) represents a bar of metal with holes drilled in it, in- tended to contain small thermometers. At the end of the

bar was placed a lamp as a source of heat ; the heat propa- gated itself through the bar, reaching the thermometer a first, b next, o next, and so on. For a certain time the thermometers continued to rise, but afterwards the state of the bar became stationary, each thermometer marking a constant temperature. The better the conduction, the smaller is the difference between any two successive ther- mometers. The decrement, or fall of heat, if I may use the term, from the hot end towards the cold, is greater in the bad conductors than in the good ones, and from the

decrement of temperature shown by the ihennometen w« can deduce, and express hy a nmnber, the oondnciivitj of the bar. This same method was followed by IQL Wied^ mann and Franz, in a very important inTestigatioD, but in- stead of nsmg thermometers they employed a ndtaUe modification of the thermo-eleotric jule. Of the nmnerons and highly interesting results of these experiments the fiA* lowing is a resmne : —

GondaottTltj

Kudo of SabsUnee For Ktoobteltj

Silver 100

Copper

Platinum

German Silver

Bismuth

This table shows, that, as regards their condactive powers, the metals differ very widely from each other. Calling, for example, the conductive power of silver 100, that of German silver is only 6. You may illustrate this difference in a very simple way by plunging two spoons, one of German silver and the other of pure silver, into the same vessel of hot water. After a little time you find the free end of the silver

spoon much hotter than that of its neighbour ; and if bits of phosphorus be placed on the ends of the spoons, that on the silver will fuse and ignite in a very short time, while the heat transmitted through the other spoon will never reach an intensity sufficient to ignite the phosphorus.

Nothing is more interesting to the natural philosopher than the tracing out of connections and relationships be- tween the various agencies of nature. We know that they

TABLE OF OONDVOnvrnES. 229

«re a oommoii brotherhood, we know that thej ore mutual- ly convertible, but as yet we know very little as to the pre- cise form of the conversion. We have every reason to Conclude that heat and electricity are both modes of mo- tion ; we know experimentally that from electricity we can get heat, and from heat, as in the case of our thermo-elec- tric pile, we can get electricity. But although we have, or think we have, tolerably clear ideas of the character of the motion of heat, our ideas are very unclear as to the precise nature of the change which this motion must undergo, in order to appear as electricity — ^in fact, we know as yet nothing about it.

Our table, however, exhibits one important connection between heat and electricity. Beside the niunbcrs express- ing conductivity for heat, MM. Wiedemann and Franz have placed the numbers expressing the conductinty of the same metals for electricity. They run side by side : the good conductor of heat is the good conductor of electricity, and the bad conductor of heat is the bad conductor of electri- city.* Thus wc may infer, that the physical quality which interferes with the transmission of heat, interferes, in a proportionate degree, with the transmission of electricity. This common susceptibility of both forces indicates a relor tionship which future investigations will no doubt clear up.

Let me point out another evidence of communion be- tween heat and electricity. I have here a length of wire made up of pieces of two different kinds of wire ; there

are three pieces of platinum, each four or five inches long, and three pieces of silver of the same length and thickness. It is a proved fact that the amoimt of heat developed in a wire by a current of electricity of a certain strength, is di- rectly proportional to tlie resistance of the wire.f We

• Professor Forbes had previously noticed this, t Joule, Phil. Mag. 1841, vol. xix. p. 263.

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may figure the atoms as throwing themsdveB as iMurrien aoroBs the track of the electric current — the current knock- ing against them, and imparting its motion to them^ and rendering the wire hot. In the case of the good condod- or, on the contrary, the current may be figured as gliding freely round the atoms without disturbing them in any great degree. I will now send the self-same current from a battery of twenty of Grove's cells through this ami- pound wire. You see three spaces white-hot, and three dark spaces between thenu The white-hot portions of the wire are platinxun, and the dark portions are silyer. The electric current breaks impetuously upon the molecules of the platinum, while it glides with little resistance among the atoms of silver thus producing, in the metals, different calorific effects.*

Now I wish to show you that the motion of heat inter- feres with the motion of electricity. You are acquainted with the little platinum lamp which stands in front of the table. It consists simply of a little coil of platinum wire suitably attached to a brass stand. I can send a current through that coil and cause it to glow. But you see I have introduced into the circuit two feet additionsd of thin plati- num wire, and on establishing the connection, the same current passes through this wire and the coil. Both, you see, are raised to redness — ^both are in a state of intense molecular motion. What I wish now to prove is, that this motion of heat, which the electricity has generated in these two feet of wire, and in virtue of wliich the wire glows, offers

a hindrance to the passage of the current. The eleo- tricitv has raised up a foe in its o\\ti path. I will cool this wire, and thereby cause the heat to subside. I shall thus open a wider door for the passage of the electricity. But

* May not the condonscd ether which surrounds the atoms be the vehicle of electric currents ?

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r AMD ELEXTTBICTrr,

if more electricity passes, it will amKKmce itself at the pla- tinaiQ lamp ; it will raise that red beat to whiteness, and the diange in the iotensitj of the li^t will be Viuble to TonalL

Thna, then, I plonge my red-hot wire into a beaker of water w (fig. 65) : observe tbe lamp, it becomes almost too bright to look at. I raise the wire out of the water and allow tbe motion of heat cmce more to develope itself; the motion of electridty is instantly impeded, and the lamp sinks in brightness. I again dip the wire into the cold water, deeper and deeper : observe how the light becomes intcnufied — deeper still, so as to qaench the entire two feet of wire ; the augmented current raises the lamp to its maxi- mam brightness, and now it suddenly goes out. The cir^ cuit is broken, for the coil bas actually been fused by the additional flow of electricity.

Let us now devote a moment's time to the conduction of cold. To all appearance cold may be conducted like heat. Here is a copper cylinder, which I warm it little by holding

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it foramomentinmyhancL Iplaoeitontiiepile^iiidtlift needle goes up to 90% dedaring heaL On thiii eylmder I place a second one, which, as yon observe, I have dbiDed by sinking it for some time in this mass of ioe. We mpft a moment, the needle moves: it is now descending to aeni^ passes it, and goes on to 90^ on the ride of cold. Anak^ might well lead yon to suppose that the cold is oondnctei downwards

from the top cylinder to the bottom onOi as the heat was conducted in our former experiments. I ham no objection to the term * conduction of cold,' if it be used with a dear knowledge of the real physical prooesi in- volved. The real process is, that the warm intennediata cylinder first delivers up its motion, or heat, to the old cy- linder overhead, and, having thus lost its own possession of heat, it draws upon that of the pile. In our former ex- periments we had conduction of motion to the pile ; in our present one we have conduction of motion from the pile. In the former case the pile is lieated, in the latter chilled ; the heating produces a positive current, the chilling pro- duces a negative current ; but it is in both cases the propar gation of motion with which we have to do, the heating and the chilling depending solely upon the direction of propagation. I place one of these metal cylinders, which I have purposely cooled, on the face of our pile ; a violent deflection follows, declaring the chilling of the instrument Are we to suppose the cold to be an entity communicated to the pile ? No. The pile here is the warm body ; its molecular motion is in excess of that possessed by the cyl- inder ; and when both come into contact the pile seeks to make good the defect. It imparts a quantity of its own motion to the cylinder, and by its bounty becomes impov- erished : it chills itself, and generates the current due to cold.

I remove the cold metal cylinder, and place upon the pile a cylinder of wood, having the same temperature as

ooimTroTiozr of gold. 233

tbe metal one. Hie chill is very feeble, and the consequent deflection very smaU. Why does not the cold wood pro- duce an action equal to that of the cold metal ? Simply be- cause the heat communicated to it by the pile is accumulat- ed at its under surface ; it cannot escape through the bad eonducting wood as it escapes through the metal, and thus the quantity of heat withdrawn from the pfle, by the wood, 18 less than that withdrawn by the copper. A similar effect is produced when

the human nerves are substituted for the {nle. Suppose you come into a cold room and hiy your hand upon the fire-irons, the chimney-piece, the chairs, the carpet, in succession ; they appear to you of different tem- peratures : the iron chills you more than the marble, the marble more than the wood, and so on. Your hand is affected exactly as the pile was affected in the last experiment. It 18 needless to say that the reverse takes place when you enter a hot room ; that is to say, a room hotter than your own bodies. I should certamly suffer if I were to lie do\vn upon a plate of metal in a Turkish bath ; but I do not suffer when I lie down on a bench of wood. By preserving the body from contact with good conductors, very high tern* peratures may be endured. Eggs may be boiled and beef- steaks cooked, by the heat of an apartment in which the living bodies of men sustain no injury. .

The exact philosophy of this last experiment is worthy of a moment^s consideration. With it the names of Blag- den and Chantrey are associated, those eminent men hav- ing exposed themselves, in ovens, to temperatures consider- ably higher than that of boiling water. Let us compare the condition of the two living human beings, -svith that of two marble statues placed in the same oven. The stat- ues become gradually hotter, until finally they assume the temperature of the air of the oven ; the two sculptors, under the same circumstances, do not similarly rise in tem- perature. If they did, the tissues of the body would be

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infallibly destroyed, tilie tempentme whidi they endmed being more than suflScient to stew the muscles in their own liquids. But the fact is, that the heat of the Uood is scarcely affected by an augmentation of the eztenud heat. This heat, instead of being applied to increase the tem- peratore of the body, is applied to the performanoe of work, in altering the aggr^ation of the body ; it prepares the perspiration, forces it throiigh the pores, and in put vaporises it. Heat is here converted into potential eneik^ gy ; it is consmned in work. This is the waste-pipe, if Z may use the term,

through which the excess of heat ovw^ flows ; and hence it is, that under the most varying oondi- tions of climate the temperature of the human blood is practically constant. The blood of the Laplander is sensi- bly as warm as that of the Hindoo ; while an Englishman, in sailing from the north pole to the south, finds his blood-temperature hardly heiglitened by his approach to the equator, and hardly diminished by his approach to the ant- arctic pole.

When the communication of heat is gradual — as it al- ways is when tlie body is surrounded by an imperfect conductor — the lieat is consumed in the manner indicated as fast as it is supplied ; but if the supply of heat be so quick (as it would .be in the case of contact with a good conductor) tliat the conversion into this harmless potential energy cimnot be executed with sufficient rapidity, the in- jury of the tissues is tlie result. Some people have pro- fessed to see in tliis power of the living body to resist a high temperature, a conservative action peculiar to the vital force. No doubt all the actions of the animal organ- ism arc connected with what wc call its vitality ; but the action here referred to is the same in kind as the melting of ice, or the vaporisation of water. It consists simply in the diversion of heat from the purposes of temperature to the performance of work.

HEAT OF nrHAN BODY OOKBTAST. 235

far we have compared the conducting power of

bodies together ; bat the same enbBtance may lificrent powers of condnction in different direo- Anny crystals are so built that the motion of beat h greater facility along certain lines of atoms than liers. Here, for instance, is a large rock-crystal —

of quartz forming an hexagonal pillar, which, if I would be terminated by two fiiz-sided pyramids, ivele with greater facility along the axis of this iuin across it. Tliis has been proved in a very nanner by JI. de Senarmont. I have here two f quartz, one of which is cut parallel to the axis siystal, and the other perpendicular to it. I coat » with a layer of white wax, laid on by a cameTs EiL Tie plates are pierced at

the centre, and into

I inser^ " wire, which I warm by an electric cnr-

(fig. G6) is the battery whence the current pro- is a capsule of wood, through the bottom of which ■needle passes ; rf is a second capsule, into which point of the needle, and Q U the perforated pUte

of quartz. Each capsiUo contaius a drop When the current passes from c to d, tlie nci and the heat is propagiitvd in all directioi melts around the placa where the heat is ap this plate, which is cut perpendicular to tli quarts, I find the tigara of the melu>d wax t circle {fig. 67). The heat has traTelled wit pidity all round, and melted the wax to the in all Erections. I make a similar esperii other plate : the was is now melting ; but I figure is no longer a circle. The heat travels along the axis than across it, and hence the w ellipse instead of a circle (fig. 67a). Whai I will project minified images of these t the screen, and you will then st-o the circula melted wax on the one, and the oval figure the other. Iceland spar conducts better alo lographic axis than at right angles to it, wh tourmaline conducts best at right angles to metal biBmiith, with which you aro alrca cleaves with great facility in one direction, a well shown by MM. Svanberg and Mattenc both heat and electricity better along the] ago than across thom.

In wood we have an eminent example ot of conductivity. Upwards of twenty year la Rivo and De Candolle instituted an inqni ductive power of wood,* and, in the case of examined, established the fact lliat the veloc sion was greater along the fibre than across i of experiment was that usually adopted in i nature, and which was applied to metals b;

■ Ufim. do la Boc. de Gentvc. vol. iv, p. t Annales de Chim. ct do Plija. Dcceml

KFFECt OF MOLBCCLAB BTBUOTUBE. 237

A bar of the snbstanoe was taken, one end of which was bTonght into contact with a sonrce oif heat, and allowed to remain so until a stationary temperature was

assumed. Hie temperatures attained by the bar, at various distances from its heated end, were ascertained by means of ther- mometers fitting into cavities made to receive them ; from these data, with the aid of a well-known formula, the coii- doctivity of the wood was determined.

To determine the velocity of calorific transmission in £Serent directions through wood, the instrument shown in %. 68 was devised some years ago by myself, q q' b b' is tn oblong piece of mahogany, a is a bar of antimony, b is a bar of bismuth. The united ends of the two bars are kept in dose contact by the ivory jaws 1 1', and the otlier ends are let into a second piece of ivory, in which they are firmly fixed. Soldered to these ends are two pieces of platinum wire, which proceed to the little ivory cups m m, enter through the sides of th*^ cups, and communicate with a drop of mercury placed in the interior. The maliogany is cut away, so that the bars a and b are sunk to a depth which places their upper surfaces a little below the general level of the slab of mahogany. The ivory jaws 1 1' are sunk similarly. Two small projections are observed in the figure jutting from i i' ; across, from one projection to the other, a fine membrane is stretched, thus enclosing a little cham- ber m, in front of the wedge-like end of the bismuth and antimony junction ; the chamber has an ivory bottom, s is a wooden slider, which can be moved smoothly back and forward along a bevelled groove, by means of the lever l. This lever turns on a pivot near q, and fits into a horizontal slit in the slider, to which it is attached by the ^mp' pass- ing through both ; in the lever an oblong aperture is cut, through which p' passes, and in which it has a certain amount of lateral play, so as to enable it to push the slider forward in a straight line. Two projections are seen at

cDNDuonoir of gbtstalb akb of wood.

the end of the slider, and across, from projection to projec- tion, a thin membrane is stretched ; a chsonber m is thus formed, bomided on three sides and the bottom bj wood, and in front hj the membrane. A thin platinum wire, bent up and down several

times, so as to form a kind of grating, is laid against the back of -this chamber, and imbedded in the end of the slider by the stroke of a hammer ; the end in which the wire is imbedded is then filed down, until about half the wire is removed, and the whole is reduced to a uniform flat surface. Against the common surface of the slider and wire, an extremely thin platQ of mica is glued, sufficient, simply, to interrupt all contact between the bent wire and a quantity of mercury which the cham- ber m is destined to contain ; the ends w to' of the bent wire proceed to two small cisterns c c\ hollowed out in a dab of ivory ; the wires enter through the substance into the cisterns, and come thus into contact with mercury, which fills the latter. The end of the slider and its bent wire are shown in fig. 68a. The rectangular space e fg h (fig. 68) is cut quite through the slab of maliogany, and a brass plate is screwed to the latter underneath ; from this plate (which, for reasons to be explained presently, is cut away, as shown by the dotted lines in the figure) four conical ivory pillars abed project upwards ; though appearing to be upon the same plane as the upper surfaces of the bis- muth and antimony' bars, the points arc in reality 0*3 of an inch below the said surfaces.

The body to be examined is reduced to the shape of a cube, and is placed, by means of a pair of pliers, upon the four supports abed; the slider s is then dra^vn up against the cube, and the latter becomes firmly clasped between the projections of the piece of ivory i i' on the one side, and those of the slider s on the other. The cliambers m m' being filled with mercury, the membrane in front of each is pressed gently against the cube by the interior fluid

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mass, and in this way perfect oontacti whioh ia abfldnteiy essential, is secured.

The problem which requires solutiim is the following: — ^It is required to apply a source of heat of a strioCly measurable character, and always readily attainable, to

that face of the cube which is in oontaot witili the mem- brane at the end of the slider, and to determine the quan- tity of this heat which crosses the cube to the opposite face, in a minute of time. For the solution of this prob- lem, two things are required-— first, the souroe of heat to be applied to the left hand of the ftoe of the cube, and see* ondly, a means of measuring the amount which has made its appearance at the opposite face at the expiration of a minute^

To obtain a source of heat of the nature described, the following method was adopted : — b is a small galvanic bat- tery, from which a current proceeds to the tangent galvan- ometer T ; passes round the ring of the instrument, deflect- ing in its passage the magnetic needle, which hangs in the centre of the ring. From t the current proceeds to the rheostat b ; this instrument consbts of a cylinder of 8e^ pentino stone, round which a (xerman silver wire is coiled spirally; by turning tlie handle of the instrument^ any required quantity of this powerfully resisting wire is thrown into the circuit, the current being thus regulated at pleasure. The sole use of these two last instruments, in the present series of experiments, is to keep the current per- fectly constant from day to day. From the rheostat the current proceeds to the cistern c, thence tlirough the bent wire, and back to the cistern c\ from which it proceeds to the other polo of the battery.

The bent wire, during the passage of the current, be- comes gently heated ; tliis heat is transmitted through the mercury in the chamber m' to the membrane in front of the chamber ; this membrane becomes the proximate source

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of heat wluch is applied to the leftJiand face of the cube. The quantity of heat transmitted from this source, through the mass of the cube, to the opposite face, in any given tune, is estimated from the deflection which it is able to produce upon the needle of a galvanometer, connected with the bismuth and antimony pair, g is a galvanometer used for this purpose; from it proceed wires to the mercury cups M II,

which, as before remarked, are connected by pla- tinum wires with ▲ and b.

The action of mercury iq>on bismuth, as a solvent, is wen known ; an amalgam is speedily formed when the two metals come into contact. To preserve the thermo-electric couple from this action, their ends are protected by a sheathing of the same membrane as that used in front of the chambers m m\

Previous to the cube's being placed between the two membranes, the latter, by virtue of the fluid masses behind them, bulge out ja little, thus forming a pair of soft and dightly convex cushions. When the cube is placed on its supports, and the slider is brought up against it, both cush- ions are pressed flat, and thus make the contact perfect. The surface of the cube is larger than the surface of the membrane ; * and thus the former is always firmly caught between the opposed rigid projections, the slider being held fast in this position by means of the spring r, which is then attached to the pin p. The exact manner of experiment is as follows : — ^Having first seen that the needle of the gal- vanometer points to zero, when the thermo-circuit is com- plete, the latter is interrupted by means of the break-cir- cuit key k\ At a certain moment, marked by the second- hand of a watch, the voltaic circuit is closed by the key ^, and the current is permitted to circulate for sixty seconds ; at the sixtieth second the voltaic circuit is broken by the

• The edge of each cube measured 0*8 inch. 11

JeA hand at k, while, at the same i cnit is closed hj the right hand at ifc'. Hie needle of the galvanometer is instantly deflected, and the liimt'of Ute first iinpulfflon ia noted ; the amount of thia impnlvoii d» pends, of course, upon Uie quantity of heat wlucb baa reached the bismuth and antimonj jooction thrm^ tlie mass of the cube, during the time of actiim. Hie limit of the first impnlBioii bong noted, the onbe ia remored and the inBtmment is allowed to oool, until the needle of the galvanometer returns to zero. Another cnibe being intio- duoed, the voltuo circuit is once mors dosed, the eaiWBt permitted to circnlate raxty eeoonds, then interrupted hf the left

hand, the thermo-circuit being closed at the same moment with the right, and the limit of the first swing is noted as before.

Judging from the description, the mode of experiment may appear complicated, but in reality it is not so. A tin- gle experimenter has the most complete command over the entire arrangement. The wires from the small gal^'anic battery (a single cell) remain undisturbed from day to day ; all that is to be done is to connect the battery with thou, and everything is ready for experiment.

There are in wood three lines, at right angles with each Other, which the mere inspection of the substance enables us to fix njjon as the necessary resultants of molecular ac- tion : the first line is parallel to the fibre ; the second is perpendicular to the fibre, and to the ligneous layers which indicate the annual growth of the tree ; while the third is perpendicular to the fibre, and parallel, or rather tangential, to the layers. From e.ich of a number of trees a cube was cut, two of whoso faces were parallel to the ligneous lay- ers, two perpendicular to them, while the remaining two were perpendicular to the fibre. It was proposed to exam- ine the velocity of calorific transmission through the wood in these three directions. It may be remarked that the

UfBTttUMENIB. 243

oabes were fair avenge specmieiis of the wooAb^ and were in all cases weU-seasoned and dry.

The oabe was first placed upon its four supports ab cd^ so that the line of flax from m' to m was parallel to the fibre, and the deflection produced by the heat'transmitted in sixty seconds was observed. The position of the cube was then changed, so that its flbre stood vertical, the line of flux from m' to m being perpendicular to the Sbre^ and parallel to the ligneous layers ; the deflection produced by a minute's action in this case was also determined. Final- ly, the cube was turned 90^ round, its fibre being still ver- tical, so that the line of flux was perpendicular to both fibre and

layers, and the consequent deflection was observed. In the comparison of these two latter directions the chief delicacy of manipulation is necessary. It requires but a rough experiment to demonstrate the superior velocity of pn^gation along the fibre, but the velocities in all di- rections perpendicular to the fibre are so nearly equal that it is only by great care, and, in the majority of cases, by numerous experiments, that a difference of action can be securely established.

The following table contains some of the results of the enquiry ; it will explain itself: —

314 LECTTBE TIL

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25 HondoTttsMahogaDy

32 &otchnr .._■;■:;:::;

The above table furnishes us with a corrobonti Iho result arrived at by De la Rive and De CanM garding the superior conductidty of the wood in tl* tion of the fibre. Evidence is also afordod aa to bo*

AXES OF ooHDuonozr m wood. 245

mere density affects the velocity of trazismission. There appears to be neither law nor general rule here. American Birch, a comparatively light wood, possesses

undoubtedly a higher transmissive power than any other in the list. Inm-wood, on the contrary, with a spedfic gravity of 1*426, stands low. Again, Oak and Coromandel-wood — the latter BO hard and dense that it is used for sharp war-instruments bj savage tribes — stand near the head of the list, while Scotch Fir and other light woods stand low.

If we cast our eyes along the second and third columns of the table, we shall find that in every instance the velocity of propagation is greatest in a direction perpendicular to the ligneous layers. The law of molecular action, as re- gards the transmission of heat through wood, may there- fore be expressed as follows : —

At aU the points not situate in the centre of the tree^ wood possesses three unequal axes of calorific conduction^ which are at right angles to each other. The firsts and principal axisy is parallel to the fibre of the wood; the second, and intermediate axis, is perpendicular to the fibre and to the ligneous layers / while the third and least axis , is perpendicular to the fibre and parallel to the layers.

MM. De la Rive and De CandoUe have remarked upon the influence which its feeble conducting power in a lateral direction must exert in preserving within a tree the warmth which it acquires from the soil. In virtue of this property a tree is able to resist sudden changes of temperature which would probably be prejudicial to it : it resists alike the sud- den abstraction of heat from within and the sudden acces- sion of it from without. But Nature has gone further, and clothes the tree with a sheathing of worse-conducting ma- terial than the wood itself, even in its worst direction. The following are the deflections obtained by submitting

of cnbes of bnrk, of the sajnc gIzc as tho cubes 1 wood, to the same condilions of experiment : —

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Beech-lreo Bark , Olk-Irec Bark . Elni-treo Bark . Ptoc-treo Bark .

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Tho average -^ when tho fliut is

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in these cases, was from

cod by a cube of wood,

ken at

a cube of rock crystal (pnro silica), of the same aize, pro- duces the deflection of

Two bodies so diverse, where they cover any conmder- able portion of the earth's sarfoce, must affect the climate very differently. There are the strongest experimental grounds for believing that rock-crystal poeseBses a higher conduotive power than some of the metals.

The following numbers express the transmissive power of a few other organic structures : cubes of tho Bubstaooea were examined in the osual manner : —

Tooth of W]ilru3

Tusk orEkat-Indkn Elepbaot

Whalebone

Ilhiiiocero*'-hom

CowVhom

Sudden changes of temperature are prejudicial to ani- mal and vegetable health ; tho Bubstances nsed in the con- etruction of organic tissues arc exactly such as are best cal- culated to resist those changes.

The following results further illustrate this point. Each

LOW OONDUCIiyiTT OF OROANIO TISSUES. 247

of the SQbetanoes menticmed was reduced to the cabical form, and submitted to an examination similar in every respect to that of wood and quartz. WhUe, however, a cube of the latter substance produces a deflection of 90°, a cube of

Sealing-wax produces a deflection of • .0^

Sole leather 0

Glue 0

Gutta-percha 0

India-rubber 0

Filbert-kcmel 0

Almond-kcmcl 0

Boiled ham-muscle 0

Haw Tcal-musclc 0

The substances here named are animal and vegetable productions ; and the experiments demonstrate the extreme imperviousness of every one of them. Starting from the principle that sudden accessions or deprivations of heat are prejudicial to animal and vegetable health, we see that the materials chosen are precisely those which are best calcu- lated to avert such changes.

I wisb now to direct your attention to what may, at first sight, appear to you a paradoxical experiment. Here is a short prism of bismuth, and here another of iron, of the same size. I coat the ends of both prisms with white wax, and then place them, with their coated surfaces up- wards, on the lid of this vessel, which contains hot water. The motion of heat will propagate itself through the prisms, and you are to observe the melting of the wax. It is already beginning to yield, but on which ? On the bis- muth. And now the white has entirely disappeared from the bismuth, the wax overspreads it in a transparent liquid layer, while the wax on the iron is not yet melted. How is this result to be reconciled vnth the fact stated in our

S LECTUEE VII,

tab igG 224), tlint, the conduction of iron being 1!,

coDuuunon of bismuth is only 2 ? In tbis experiment the bismuth seema to be tbe best coDductor, We solve tliia enigma by turning to oor table of «]iecific heat {Lecture V.) ; wo there find that, the Gnccilic heat of iron bmg 1138, that of bismuth is < ; to raise it, therefore, a certain number of dcgret mperature, iron requires more than tliree timcB tl" lute quantity of heat required hy bismuth. Thus. the iron is really a much better conductor than t th, and is at this moment accepting, in every unit v a much greater amoimt of. heat than the bismuth, consequence of tlie number of its atoms, or tbe magmtaue of its interior irork, the augmentation of temperature, in the case of iron, is glow, Dismuth, on the contrarj', can immediately devote a Urg'v proportion of the heat imparted fo it to the augmentation of temperature ; and thus it apparently outetrips the iron in the transmission of that motion to which tempcratnte u due.

Yon see hero very plainly the incorrectneas of the Btatemente sometimes made in books, and certmnly nude very frequently by candidates in our edeoce examinations, regarding the eKperiment of Ingcnhaosz, to which I bave already referred. It is usually stated, that the greater the quickness with which the wax melts, the better is the con- ductor. If the bad conductor and the good conductor have the same specific heat, this is true, but in other cases, as proved by our last experiment, it may be entirely incorrect The proper way of proceeding, as abeady indicated, is to wait until both tbe iron and the bismuth have attained a constant temperature — till each of them, in fact, has ac- cepted, and is transmitting, all the motion which it can ac- cept, or transmit, from the source of heat ; when this is done, it is found that the quantity transmitted by the iron is six times greater than tliat transmitted by the bismuth.

. TSFLUESOE OF BPBOIFIO HEAT. 249

Toil remember oar experiments with the Treveljan instrn- ment, and know the utiUtj of having a highly expansible body as the bearer of the rocker. Lead is good, because it IS thus expansible. But the coefficient of expansion of anc is slightly higher than that of lead ; still zinc does not iDSwer well as a block. The reason is, the specific heat of ane is more than three times that of lead, so that the heat oonmmnicated to the zino by the contact of the rocker, produces only about one4hird the augmentation of tem- perstnre, and a correspondingly small amount of local ex- pansion.

These considerations also show that in our experiments <m wood the quantity of heat transmitted by our cube in one minute's time, cannot, in strictncr^, be regarded as the expression of the conductivity of the wood, unless the specific heat of the various woods be the same. On this point no experiments have been made. But as regards the influence of molecular structure, the experiments hold good, for here we compare one direction with another, in the aame cube. With respect to organic structures, I may add that, even allowing them time to accept all the motion which they are capable of accepting, from a source of heat, their power of transmitting that motion is exceedingly low. They are really bad conductors.

It is the imperfect conductibility of woollen textures which renders them so eminently fit for clothing. They preserve the body from sudden accessions or losses of heat. The same quality of non-conductibility manifests itself when we wrap flannel round a block of ice. The ice thus pre- served is not easily melted. In the case of a human body on a cold day, the woollen clothing prevents the transmis- sion of motion from within outwards ; in the case of the ice on a warm day, the self-same fabric prevents the trans- mission of motion from without inwards. Animals which inhabit cold climates are furnished by Nature with their

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n iothing. Birds oepcdally nwd this proteoUon,

for iDcy aro slill mora wanu-bloodod tliiin iho mnmmalu. They are furobhed with feathers, and betwecu the fcatLcrs Uic interstices aro tilled witii down, tlio molecular consti-

tulion aad mecbauiuil Icxf"' the woret of all coiiducton plo of that harmonious rel' life, which ia uiccssai: ural science.

The indefatigal of experiments ou il clothing,* His nf ctcr wns Rusjicndfd in tbc a ending with a {

I' which render it, perhaps, « wc have another txiun- ' life to the conditions of id to iho student of nat-

aade an elaborate series " of the subiitauces used in ; — A mercurial thcrmom- tbc aMS of a cylindrical ffiiijis tube n such a manner that the centre of the bulb of the thermometer occupied the centre of the globe i the space between the internal surface of the globe and the bulb was filled with the substance whose conduct- ive power was to be determined ; the instrument was then heated in boiling water, and afterwards, being plunged into a freezing mixture of ponnded ice and ealt, the times of cooling down 135° Fahr, were noted. They are recorded in the following table : —

BecBiidi

Twisted sUk . . .917

CoUODWOOl

12S4

1S93

Eiderdown

1S05

Hares' fur .

• Phil. Trans. 1792, p. 48.

ACTION OF CLOTHING. 251

Lmong the substances here examined, hares' fur offered greatest impediment to the transmission of the heat. rhe transmission of heat is powerfully influenced hj aiechanical state of the body through which it passes, raw and twisted silk of Rumford's table illustrate Pure silica, in the state of hard rock-crystal, is a Br conductor than bismuth or lead ; but if the crystal winced to powder, the propagation of heat througb powder is exceedingly slow. Through transparent HHdt heat is copiously conducted, through common d«alt very feebly. I have here some asbestos, which imposed of certain silicates in a fibrous condition; I • it <m my band, and on it I place a red-hot iron ball : mee I can support the ball without inconvenience. The WKtos intercepts the heat. That thi^ division of the sub- De should interfere with the transmission might reason- be inferred ; for, heat being motion, anything which arbs the continuity of the molecular chain, along which notion is conveyed, must affect the transmission. In aase of the asbestos the fibres of the silicates are sepa- 3 from each other by spaces of air ; to propagate itself, efore, the motion has to pass from the silicate to the a very light body, and again from the air to the sili- ^ a comparatively heavy body ; and it is easy to see the transmission of motion through this composite tex- must be very imperfect. In the case of an animal^s this is more especially the case ; for here riot only do es of air intervene between the hairs, but the hairs iselves, unlike the fibres of the asbestos, are very bad luctors. Lava has been known to flow over a layer of 18 tmdemeath which was a bed of ice, and the non-con- ivity of the ashes has saved the ice from fusion. Red- cannon-balls may be wheeled to the gun's mouth in den barrows partially filled with sand. Ice is packed Eiwdust to prevent it from melting ; powdered charcoal

2iJ3 LEcrOEE VU.

is also an eminently bad conductor. But there are cases where sawdust, chafi*, or charcoal could not be used with safety, on account of tlieir combustible nature. In such cases, powdered gypsum may be used with advantage ; in the solid orj-stalline state it is incomparably a worse con- ductor than silica, and it may be safely inferred, that in the powdered state its imperviousness far tranaccnds that of Band, each grain of which is a good conductor. A jacket of gypsuni powder rom steam boiler would ma- terially lessen its loss of heat.

Water usually holds certjun minerals iu solution. In percolating through the eart^ it dissolves more or leas of the substances wil "omes into contact For

example, ha chalk • t! water always contains a

quantity of carbonate f ich water is called hard

water. Sulphate of lit i common ingredient of

water. In evaporating 1 1 1.3 only driven off, the min- eriil is left behind, and often m (juantities too great to be hold in solution by the water. Many springs arc strongly Impregnated by carbonate of lime, and the consequence is, that when the waters of such springs reach the surface and are exposed to the air, where they can partially evaporate, the mineral is precipitated, and forms iucmstations on the surfaces of plants and stones over wliich the water trickles. In the boiling of water the same occurs ; the minerals are precipitated, and there is scarcely a kettle in London which is not internally coated with a mineral incmstaUon. This is an extremely serious difficulty as regards steam boilers ; the crust is a bad conductor, and it may become so thick as materially to intercept the passage of beat to the water. I have here an example of this mischief. This is a portion of a boiler belonging to a steamer, which was all but lost through the exhaustJon of her coals : to bring this veasd into port her spars and every piece of available wood were burnt Od examination thia formidable incnutatifHi was

WITHDKAWAL OF HSAT BT GOOD CX)NDUCIOB8. 253

foimd within the boiler : it is mainly carbonate of lime, which by its nonrcondaoting power rendered a prodigal ex- penditure of fiiel necessary to generate the required quan- tity of steam. Doubtless the slowness of many kettles in boiling would be found due to a similar cause.

I wish now to bring before you one or two instances of the action of good conductors in preventmg the local ac- cumulation of heat. I have here two spheres of the same size, both covered closely with white paper. One of them is copper, the other is wood. I place a spirit lamp under- neath each of them, and after a time we will observe the effect. The motion of heat is, of course, communicating it- self to each ball, but in one it is quickly conducted away from the place of contact with the flame, through the entire mass of the ball ; in the other this quick conduction does not take place, the motion therefore accumulates at the point where the flame plays upon the ball ; and here you have the result. I turn up the wooden ball, the white pa- per is quite charred ; I turn up the other ball, — so far from being charred, it is toei at its under surface by the condensa- tion of the aqueous vapour generated by the lamp. Hero is a cylinder covered closely with paper ; I hold its centre thus over the lamp, turning it so that the flame shall play all round the cylinder : you see a well-defined black mark, on one side of which the paper is charred, on the other side not. The cylinder is half brass and half wood, and this black mark shows their line of junction : where the paper covers the wood, it is charred ; where it covers the brass, it is not sensibly afiected.

If the entire moving force of a common rifle bullet were communicated to a heavy cannon-ball, it would pro- duce in the latter a very small amount of motion. Sup- posing the rifle bullc{i to weigh two ounces, and to have a velocity of 1,600 feet a second, the moving force of this bullet communicated to a 100 lb. cannon-ball

would impart

S LKCTOBE Vn,

■ a velocity of only 32 feet a sevoQiL Thus Willi cl to a flame; its molecular motion is very in-

tense, out its weight is extremely small, and if oommuni' cated to a heavy body, the intensity of the motion must fall. For example, I have here a sheet of wire gaozc, with meshes wide enough ir to pass through them

with the utmost freedoi re is a jet of gas buming

brilliantly. I bring re gauze upon the fiame ;

you would iaxngiab ame could readily pass

through the meshes but no, not a flicker gets

through (6g. tiO). on is entirely confined to

the space under the gauze. I extinguish the flame, and al- low the unignit«d gas to stream from the burner. I place the wire gauze thus above the burner : the gas, I know, ii now freely passing through the meshes. I Ignite the gai above ; there you have the flame; but it does not propagate itself downwards to the burner (fig. 70). Yon see a dark space of four inches between the burner and the gauze, s space ^led with gas in a condition eminently favourable to ignition, but still it does not ignite. Thus, yon see, this metallic gauze, which allows the gas to pass freely througli, intercepts the flame. And why ? A certain heat is neces- sary to cause the gas to ignite ; but .by placing the wire gauze over the flame, or the flame over the wire gauze, yoa transfer the motion of that light and quivering thing to

THE BAFETY-LAMP. 255

mparatively heavy gauze. The intensity of the mole- aaotion is greatly lowered by being communicated great a mass of matter — so mnoh lowered, indeed, is

incompetent to propagate the combustion to the te side of the gauze.

e are all, unhappily, too well acquainted with the ter- 49cidents that occur through explosions in coal mines. 0OW that the cause of these explosions is the presence ertain gas — a compound of carbon and hydrogen — ited in the coal strata. When this gas is mixed with sient quantity of air, it explodes on ignition, the car- f the gas uniting with the oxygen of the air, to pro- »rbonic acid ; the hydrogen of the gas uniting with ygen of the air to produce water. By the flame of plosion the miners are burnt ; but even should this 58troy life, they are often suffocated afterwards by rbonic acid produced. The original gas is the miner's amp,' the carbonic acid Ls his ' choke-damp.' Sir hry Davy, after ha>'ing assured himself of the action ■e gauze, which I have just exhibited before you, ap- t to the construction of a lamp which should enable ner to carry his light into an explosive atmosphere. iUB to the introduction of the safety-lamp^ the miner J content himself with the light from sparks pro* by the collision of flint and steel, for it was found hese sparks were incompetent to ignite the flre-

vy surrounded a common oil lamp by a cylinder of ;auze (flg. 71). As long as this lamp is fed by pure B flame bums with the ordinary brightness of an oil- but when the miner comes into an atmosphere which as ' fire-damp,' his flame enlarges, and becomes less ►us ; instead of being fed by the pure oxygen of the is now in part surrounded by inflammable gas. This 5ht to take as a warning to retire. Still, though a

266 LVnOBB TIL

oontinnoas ezplomve atmoRpIiera m^ oztcnd fiuni the air outside, throagh the mesbes of the gwixe, to the flnie _ within, the igniUon ia not jmrpmgfUei

acroos the gauze, llie lamp maj he filled with an almost lightlen flame, and atill . ezplOBion does not ooctir, A defeat m the ganze, tho destnwtitMi of the -win at any point bj oxidaUtHi, hastened bj the flnme playing agaioBt it, would auue M

explosion. Hie motion of the laap through the wr might alio foroe, mednn. ioally, the flame tbrongh the meahe^ 1m short, a certain amount of intelligence and caution is nccegsary in using the lamp. The intelligeuce, unhappily, ib not always poesGssed, nor the caution always I exercised, by the miner ; and 'the conse- c ia, that even with the safety4amp, I explosions still occur. Before pemiittjug a man or a boy to enter a mine, would it I not be well to place these results, by ex- periment, visibly before him ? Mere ad- snforce caution ; but let the miner have the physical image of what he is to expect, clearly and vividly before his mind, and he will find It a restrmning and a monitory infiuencc, long after the effect of cauti<ming words has passed away.

A word or two now on tho conductivity of liquids and gases. Rtimford made numerous experiments on this sub- ject, showing at once clearness of conception and skill of cxecntion. He Btijiposed liquids to be noD-conductors, clearly distinguishing the ' transport ' of heat by conveo- ' tion from true conduction ; and in order to prevent convefr tion in Lis liquids, he heated them at the lop. In this way ho found the heat of a warm iron cylinder incompetent to

vice will not t

CHUXINO BY HTDBOOEN AND AIB. 257

lownwards through 0*2 of an inch of olive oil ; he also I water in a glass tube, over ice, without melting the ince. The later experiments of M. Despretz ^ow, eer, that liquids possess true, though extremely feeble, ni of conduction. Rumford also denied the condnctiv- * gases, though he was well acquainted with their con- ML.* The subject of gaseous conduction has been re- r taken up by Professor Magnus, of Berlin, who con- ^that his experiments prove that hydrogen gas con- heat like a metal.

he cooling action of air may be thus prettily illustrat- lere is a platinum wire, formed

into a coil ; I send a b eorrent through the coil, till it glows bright red. I Itretch out the coil so as to form a straight wire ; the Instantly sinks — you can now hardly see it. This effect) entirely to the freer access of the cold air to the bed wire. Here, again, is a receiver r (fig. 72) which B exhausted at pleasure ; attached to the bottom is a al metal rod, m /t, and through the top another rod, ■sses, which can be moved up and down through an)it collar, so as to. bring the ends of the two rods I any required distance of each other. At present >ds are united by two inches of platinum wire, b m, . I can heat to any required degree of intensity by a D current. I have here a smaU battery, and now I my connections ; the wire is barely luminous enough seen ; in fact, the current from a single cell only is lent through it. It is surrounded by air, which, no , is carrying off a portion of its heat. I exhaust soeiver — the wire glows more brightly than before, ►w air to enter — the wire, for a time, is quite bed, rendered perfectly black ; but after the sir has I to enter, its first feeble glow is restored. The cur-

• rhil. Trans. 1792: Eesayg, voL ii. p. 66.

rent lere paaaing over tho wire, and dostroying its

glow, acta like the current wliich iho n-ire ilself ostaljlifibos by healing the air in contact with it. The cooling of tho wiro in both cases b diiG to convection and not to true con- duct]

! B set is obtained in a great-

ly lU' Tee, if hydrogen be nwd

inst Wo owe this interesting

ob' kir. Grove, and it formed

tb It of M. Magnus's investi-

gaiii, ceiver is now cxhansted,

and tiio wire is ahnost white-hot Air cannot do more than redncc that white- ness to

bright redness ; but observe what hydrogen can do. On tho entrance of this gas the wire is totally quenched, and even after tho receiver has been filled with the f;as, and the inward current has ceased, the glow of tho wire is not rc- Blored. The electric current now passing through the wire is from two cells ; 1 tiy three cells, the wire glows feebly ; five canse it t« glow more brightly, but even with five it is bat a bright red. Were the hydrogen not there, tho cnrrent now pasdng through the wire would infallibiy fuse it.)Jet ns sea whether this ia not the case. I commence exhaustion,- — the first few strokes of the pump produce a Bcarcely Beneihle efi'ect; but I continne to work tlie pump, and now the effect begins to be visible. The wire whitens and appears to thicken. To those at a distance it is now aa thick as a goose-quill ; and now it glows upon the point of fnsion ; I continne to work the pump, the light suddenly vauiahes^ the wire is fused.

This extraordinary cooling power of hydrogen has been

EXPERIMENTS OF UAONUS. 259

f ascribed to the mobility of its particles, which ena- irrents to establish themselves in this gas with great- litj than in any other. But Prof. Magnus conceives tiling of the wire to be an effect of conduction. To e, if not prevent, the formation of currents, he passes itinum Mdre along the axis of a narrow glass tube, he fills with hydrogen. Although in this case the I surrounded by a mere film of the gas, and currents, ordinary sense, are scarcely to be assumed, the film itself just as competent to quench the wire, as when Aer is caused to pass through a large vessel contun- 0 gas. He also heated the closed top of a vessel, and that the heat was conveyed more quickly from it to mometer, placed at some distance below the source It, when the vessel was filled with hydrogen, than it was filled with air. He found this to be the case, rhen the vessel was loosely filled with cotton wool or down. Here, he contends, currents could not bo 1 ; the heat must be conveyed to the thermometer by 18

process of conduction, and not by convection, autiful and ingenious as these experiments are, I do ink they conclusively establish the conductivity of 5en. Let us suppose the wire in Prof. Magnus's first ment to be stretched along the axis of a wide cylin- ataining hydrogen, we should have convection, in the ry sense, on heating the wire. Where does the heat ispersed ultimately go ? It is manifestly given up to les of the cylinder, and if we narrow our cylinder we ' hasten the transfer. The process of narrowing may ue till a narrow tube is the result, — the convection en centre and sides will continue and produce the tsooling effect as before. The heat of ^the gas being Hy lowered by communication to the heavy tube, it spared to re-abstract the heat from the wire. With i also to the vessel heated at the top, it would require

i IBCTUEK Vn,

a Bnrface mathematicaUy horizontal, and a porfoctly oniforta application of heat to that surface — it would, moreover, necessary to cut the heat sharply off from the sides of th» vessel — to prevent convection. Even in the interstices of the eider down and of the cotton wool the convective Ijility of hydrogen will u ;lf felt, and taking every^

thing into account, I th] experimental question ot

gaseous conduction is u one.*

• In mj opinion ■ investigation.

jd conduction 11I90 demtuidjj teh

LECTURE VIII.

[March 13, 1862.] k LOSS or motion: to what is this motioh imparted ?^ez*

3IT8 ox SOUND BEARINO ON THIS QUKSTION — nPIEIMENTS OH BXARINO ON THIS QUESTION — ^THE THEOIUES 07 EMISSION AMD LTION — LENGTH OF WAVES AND NUMBER 07 IMPULSES 07 LIGHT

ICAL CAUSE OF COLOUR — INVISIBLE RATS 07 THE SPECTRUM—

LORIFIC RAYS BEYOND THE RED THE CHEMICAL RATS BETOND

.UE — DEFINITION OF RADIANT HEAT — REFLECTION OF RADIANT ROM PLANE AND CURVED SURFACES : LAWS THE SAME AS THOSE IT — CONJUGATE MIRRORS.

appendix: — ON singing flames.

E have this day reached the boundary of one of the two great divisions of our subject ; hitherto we alt with heat while associated with solid, liquid, or bodies. We have found it competent, to produce of volume in all these bodies. We have also ob- t reducing solids to liquids, and liquids to vapours ; e seen it transmitted through solids by the process [uction, and distributing itself through liquids and f the process of convection. We have now to fol- into conditions of existence, different from any re have examined hitherto.

ing this heated copper ball in the air ; you see it ie glow sinks, the ball becomes obscure ; in popular e the ball cools. Bearing in mind what has been the nature of heat, we must regard this cooling as

263 LXOTDBS ym.

a loss of motion on the part of the balL But motiaii can- not be lost withoat being imparted to Bomething ; to what then is the molecular motion of this ball

tranflfefiedF Yon wonld, perhaps, answer to the air, and thia ia partly true : over the ball idr is passing, and rising in a heated column, which is quite visible against the screen, whan we allow ihe electric beam to pass through the warmed air. But not the whole, nor even the chief part, of the nudeoii- lar motion of the ball is lost in this way. If the ball wen placed in vacuo it would still cooL Rumford,of wfaomm have heard so much, contrived to hang a small ihennoai- eter, by a Hnglefbre ofsilk^ in the middle of a glaaa ^Ubt exhausted by means of mercury, and he found that the cal- orific rays passed to and fro across the vacuum ; thus pro?- ing that the transmission of the heat was independent of the air. Davy, with an apparatus which I have here be- fore me, showed that the heat rays from the electric ligbt passed freely through an air-pump vacuum ; and we can repeat his experiment substantially for ourselves. I simplv take the receiver made use of in our last lecture (fig. 72), and removing the remains of the platinum wire, then de- stroyed, I attach to each end of the two rods, m n and aft, a bit of retort carbon. I now exhaust the receiver, bring the ooal points together, and send a current from point to point. The moment I draw the points a little apart, the electric light blazes forth : and here I have the thermo-electric pile ready to receive a portion of the rays. The galvanometer needle at once flies aside, and this has been accomplished by rays which have crossed the vacuum.

But if not to the air, to what is the motion of our cool- ing ball communicated ? We must ascend by easy stages to the answer to this question. It was a very considerable step in science when men first obtained a dear conception of the way in which soimd is transmitted through air, and it was a very important experiment which Ilauksbee made

ANAJLOQIES OF LIGHT, HEAT, AND SOUND. 263

ore the Royal Society in 1705, by which he showed that nd could not propagate itself through a vacuum. Now mh to make manifest to you this conveyance of the vi-

rions of sound through the air. I have here a bell ■ed up-sidc-down, and supported by a stand. I draw a De-bow across the edge of the bell, you hear its tone ' bell is now vibrating, and if I throw sand upon its flat- ^ bottom, it would arrange itself there so as to form a hdte figure, or if I filled it with water I should see the IJMe fretted with the most beautiful crispations. These fttdons would show that the bell, when it emits this 1^ divides itself into four swinging parts, which are sep- ted from each other by lines of no swin^g. Here is leet of tracing paper, drawn tightly over this hoop, so \0 form a kind of fragile drum. I hold it over the vi- Img bell, but not so as to touch the latter ; you hear the pering of the membrane. It is a little too slack, so I I tighten it by warming it before the fire, and repeat experiment. You no longer hear a shivering, but a loud Bcal tone superadded to that of the bell. I raise the nbrane and lower it ; I move it to and fro, and you hear lifiing and the sinking of the tone. Here is a smaller m, which I pass round the bell, holding the membrane \icfil ; it actually bursts into a roar when I bring it within r en inch of the bell. The motion of the bell, communi- id to the air, has been transmitted by it to the mem- De, and the latter is thus converted into a sonorous

I have here two plates of bras§, a b {Gg. 73), united to- iler by this metal rod. I have darkened the plates by Bzmg them, and on both of them I strew a quantity of ite sand. I now take the connecting brass rod by its •re, between the finger and thumb of my left hand, and 3idg it upright I draw, with my right, a piece of flan- Over which I have shaken a little powdered resin, along

LECrCHE Tin.

tbe rofl. Ton hear the Bound ; but observe the bebAvtour of the Eand : z siiigle stroke of my finger, yott nee, has closed it to jiUDp into a Eerier of concentric rings, wliich must be quite \-isible to you all. I repeat Ihc experiment operating more gently ; you hear i the clear, weak, mnsjcal KOtmd, you see tbe saod fihivering, and creeping, by degrees, to the lines which it formerly oceo- pied ; and there are the

curves as sharply drawn upon the surface of the lower disk as if they had been arranged with a carael'H hair pencil. On the upper disk you see a series of concentric cir- cles of the same kind. In fact, the vibrations wiiich I have imparted to tbe rod have conuno- nicated themaelveB to both the disks, and di- vided each of them into ' a seriea of vibrating seg- ments, which are aepa- ratcd from each ' other by lines of no vibration, on which the sand finds peace. Now let me show yon the transmission of these ribra-

OOipnTNIGATION OF VIBBATIONS THBOUOH AIB. 265

tions firom the lower disk throtigh the air. On the floor I place this paper drum, d, strewing dark-coloured sand uni- fonnly over it ; I might stand on the table — I might stand as high as the ceiling, and prodnce the effect which I am now going to show you. Pointing the rod which unites my plates in the direction of the paper drum, I draw my lesined rubber vigorously over the rod : observe the eflcct, -^ single stroke has caused that sand to spring into a reti- enlated pattern. A precisely similar effect is produced by saund on the drum of the ear ; the tympanic membrane is caused to shudder in the same manner as that drum-head of paper, and its motion, conveyed to the auditory nerves and transmitted thence to the brain, awakes in us the sen- sation of somid«

Here is a still more striking example of the conveyance of the motion of sound through the air. By permitting a jet of gas to issue through the small orifice of this tube, I obtain a slender flame, and by turning the cock I reduce the flame to a height of about half an inch. I introduce the flame into this glass tube, a b {^g. 74), which is twelve inches long. Now I must ask your permission to address that flame, and if I am skilful enough to pitch my voice to the precise note, I am sure the flame will respond ; it will start suddenly into a melodious song, and continue singing as long as the gas continues to bum. The burner is now arranged within the tube, which covers it to a depth of a couple of inches. If I were to lower it more, the flame would

start into singing on its own account, as in the well- known case of the hydrogen harmonica ; but, with the present arrangement, it cannot sing till I tell it to do so. Now I emit a soimd, which you will pardon if it is not musical. The flame does not respond ; I have not spoken to it in the proper language. Let me try again ; I pitch my voice a little higher ; there, the flame stretches its little throat, and every individual in this large audience honrs

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the Bound of it. I stop the song, and Btaad at a greater distance from the flame, and now that I have aseertajned

the proper piidiy the ez- ^^^ periment is nore to auo-

ceed; fiom a diatanoe of twenty or thirty feet I oan canae that flame to riii(^ I now atop it| tam my hack upon it| and atrike the note as before; yon aee how obedient it ia tomyfoioe; when I call, it anawerai and with a little practice I have been able to command the flame to sing and to stop, and it has strictly obeyed the injunction. Here, then, we have a striking example of the conveyance of the vibrations of the organ of voice throngh the air, and of their communication to a body which is eminentiy sensitive to their action.*

Why do I make these

experiments on sound ?

Simply to give you clear

conceptions regarding what takes place in the case of heat ;

to lead you up from the tangible to the intangible ; from

the region of sense into that of physical theory.

After philosophers had become aware of the manner in

• Though not belonging to our present subject, so many peraoDB hare evinced an interest in this experiment that I have been induced to reprint two short papers in the

Appendix to this Lecture, in which the experiment is more fully described.

THBOBUS of EiaBSIQN AHD UHDULATIOK. 267

which sound was produced and transmitted, analogy led some of them to suppose that light might be produced and transmitted in a somewhat similar manner. Anfl. perhaps in the whole history of science there was never a question more hotly contested than this one. Sir Isaac Newton sup- posed light to consist of minute particles darted out from luminous bodies : this was the celebrated Emission Theory. Huyghens, the contemporary of Newton, found great diffi- culty in conceiving of this cannonade of particles ; that they should shoot with inconceivable velocity through space and not disturb each other. This celebrated man enter- tained the view that light was produced by vibrations sim- ilar to those of sound. Euler supported Huyghens, and one of his arguments, though not quite physical, is so quaint and curious that I will repeat it here. Ho looks at our various senses, and at the manner in which they are afiected by external objects. * With regard to smell,' he says, * we know that it is produced by material particles which issue from a volatile body. In the case of hearing, nothing is detached from the sounding body, and in the case of feeling we must touch the body itself. The dis- tance at which our senses perceive bodies is, in the case of touch, no distance, in the case of smell a small distance, in the case of hearing, a considerable distance, but in the case of sight greatest of all. It is therefore more probable that the same mode of propagation subsists for sound and light, than that odours and light should be propagated in the same manner ; — ^that luminous bodies should behave, not as volatile substances, but as sounding ones.'

The authority of Newton bore these men down, and not until a man of genius within these walls took up the subject, had the Theory of Undulation any chance of co- ping with the rival Theory of Emission. To. Dr. Thomas Young, who was formerly Professor of Natural Philos- ophy in this Institution, belongs the immortal honour of

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stemming this tide of authori^, md of tistiWi'ihnig od a safe basis, the theory of imdolstitHL lliere hkT« beea great things done in this edifice, bnt hardly a greater than this. And Yoimg vas led to hU oondnson reguding light, by a Botiei of investigatiims on sound. He, like onnelna, at the present momeDt, rose from the knovn to tlie nnknown, from the tangible to the intangible, lliis snbjeet has been illoBtroted and enriched by the laboon of genina enr rinoe the time of Young ; bnt one name cmly vill I here aiso- date vith his, — a name irMch, in conneotion vidi this mib- ject, can never be forgotten: that ia, the name of Angutin Frcsnel.

According to the notion now universally received, light consists, first, of a vibratory motion of the particles of the luminous body ; but li6w is this motion transmitted to our oignns of sight ? Sound has the air as its medium, and long pondering on the phenomena of light, and refined and conclusive experiments, devised with the ciprcss inten- tion of testing the idea, iiavo led philosophers to the con- clusion, that space is occupied by a substance almost in- finitely elastic, through which the jiulses of light make their way. Hero your conceptions must be perfectly dear. The intellect knows no difference between great nnd small : it is just as easy, as an intellectual act, to conceive of a vi- brating atom as to conceive of a vibrating caomon-ball ; and there is no more difficulty in conceiving of this Ether, as it is callod, which fills space, that in imagining all space to bo fined with jelly. Yon must imagine the atoms vibrating, and their vibrations you must figure as communicated to the ether in which they swing, being propagated through it in waves ; these waves enter the pupil, cross the ball of the eye, and break upon the retina at the back of the eye. The act, remcnibor, is as real, and as truly mechanical as the breaking of the sea waves upon the shore. Their motions are communicated to the retina, transmitted thence along

INTEB8TELLAB KEDIUIL 269

the optic neire to the brain, and there announce them- selves to consciousness as light.

I have here an electric lamp, known well to all of you, and on the screen in front of you I project an image of the incandescent coal points which produce the electric light. I win first bring the points together and then separate them. Observe the e£^t. You have first the place of contact ren- dered luminous, then you see the glow conducted downwards to a certain distance along the stem of coal. This, as you know, is in reality the conduction of motion. I interrupt the circuit. The points continue to glow for a short time ; the light is now subsiding. The coal points are now quite dark, but have they ceased to radiate ? By no means. At the present moment there is a copious radiation from those points, which, though incompetent to afiect sensibly the nerves of vision, are quite competent to afiect other nerves of the human system. To the eye of the pldlosopher who looks at such matters without reference to sensation, these obscure radiations are precisely the same in kind as those which produce the impression of light. You must there- fore figure the particles of the heated body as being in a state of motion ; you must figure the motion communicated to the surrounding ether, and transmitted through the ether with a velocity, which we have the strongest reason for be- lieving is the same as that of light. Thus when you turn towards a fire on a cold day, and expose your chilled hands to its influence, the warmth that you feel is due to the im- pact of these ethereal billows upon your skin ; they throw the nerves into motion, and the consciousness correspond- ing to this motion is what we popularly call warmth. Our task durins: the lectures which remain to us is to examine heat under this radiant form.

To investigate this subject we possess our valuable ther- mo-electric pile, the face of which is now coated with lamp- black, a powerful absorber of radiant heat. I hold the in-

8TO LEcruBE vin. ^^^

strnment in front of the cheek of Mr. Anderson ; he ii a n- diant body, and obsene the effect produced by his rays; the pile drinks tliem iji, they generate electricity, and tho needle of the galvanometer moves np to 00°. I withdraw the pile from the Bourcu of beat, and allow the needle to come to rest, and now I_ phice thia slab of ice in front of tho pile. You have a deflection in the oppodle direction, as if raya of cold wera etriking on the pile. But yon know that in this case the pile ia the hot body ; it radiates its heat agwnst the ice ; the face of the pile is thus chilled, and the needle, aa you see, moves uji to flO" on the side of cold. Our pile is therefore not only available for the exaniiiiiilioo of bent I'limmiiraialvil to it by direct contact, but also for the examination of radiant heat Let us ap- ply it at onco to a most important investigation, and exam- ioe, by means of it, tho distribution of thermal power in the electric spectrum.

Let me in the first place show yon this Bpectmm. I do so by sending a slice of pure white light from the orifice o (fig. 75), through tliis prism, a be, which is built np of

plane glass sides, but is filled with the liquid bisulphide of carbon. It gives a richer display of colour than glass docs, and this is one reason why I use it in preference to glass. Here then you havo the white beam disentangled, and re-

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daoed to the ooloara which compose it; 70a have this bom- ing red, this viyid oraage, this dazzling yeUow, this brill- iaxxt green, and tiiese varions shades of blue ; the blue space bong nsoaDy sabdivided into blue, indigo, and violet. I will now cause a tiienno-electric pile of particiilar constrao- tion to pass gradually through all these colours in succes- sion, so as to test their heating powers, and I will ask you to obserre the needle of the galyanometer which is to de- clare the magnitude of that power.

For this purpose I have here (fig. 76) a beautiful piece of apparatus, designed by

Melloni, and executed, with his aocustcnned skill, by M. Ruhm- korff ♦ You observe here a pol- ished brass plate, a b, attached to a stem, and this stem is mounted on a horizontal bar, which, by means of a screw, has motion imparted to it. By turn- ing this ivory handle in one di- rection I cause the plate of brass to approach ; by turning it in the other, I cause it to recede, and the motion is so fine and gradual, that I could, with ease and cer- tamty, push the screen through a space less than ^^V^th of an inch. You observe a narrow vertical slit in the middle of this plate, and something dark behind it.

That dark space is the blackened face of a thermo-electric pile, p, the elements of which are ranged in a single row, and not in a square, as in our other instrument. I will al- low distinct slices of the spectrum to fall on that slit ; each will impart whatever heat it possesses to the pile, and the

* Kindly lent to me by M. Gasnot.

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qnantity of iLw heat will be marked by the needle of oar galvanometer.

At present a fmsUl but brilliant epectrnm fatU upon iLe plate, A B, but the slit is quite out of the spectrum. I turn the handle, and the slit gradually approaches the \io\tt end of the spectnim ; the violet light now falls upon tliB sUt, but the needle does not move sensibly. I pass on to the indigo, the needle ia etill quiescent ; the blue also shows no action. I pass on to the green, tlie needle barfr ly stirs : now the yellow falls upon the slit ; the motion of the needle is now perhaps for the first time visible to job; but the deflection ia small, though I now expose the pilfl to the moat luminmis part of the spectrum.* I will noir paaa on to the orange, which ia Icsa luminous than the yel- low, bat you observe, though the light diminishes the he«t increases ; the needle moves still farther. I pass on to the red, which is still less lunoinoas than the orange, and yoi see that I here obtain the greatest thermal power exhibited by any of the visible portions of the spectrum.

The appearance, however, of this burning red might lesd you to suppose it natural for such a colour to be hotter than any of the others. But now pay attention. I will cause my slit to pass entirely out of the spectram, quite beyond the extreme red. Look to the galvanometer 1 Hie needle goes promptly up to the stops. So that we have here a heat-spectrum which we cannot see, and whose ther mal power is far greater than that of any visible part of the spectrum. In fact, tho clcctrio light with which we deal, emits an infinity of rays which are converged by our lens, refracted by our prism, which form the prolongatim of our spectrum, but which are utterly incompetent to ex- cite the optic nerve to vision. It is the same with the bod. Our orb is rich in these obscure rays ; and though th^ are

* I am hero dealing vith a large lecture-room galTauometcr.

XXTRA BEET AKD EXTBA VIOLET RAYS. 273

for the most part cat off by our atmosphere, multitudes of them still reach us. To the great William Herschel wc arc indebted for the discovery of them.

Thus we prove that the spectrum extends on the red side much beyond its.visible limits ; and were I, instead of being compelled to make use of lenses and prisms of glass, fortunate enough to possess lenses and prisms of rock salt, I could show you, as Melloni has done, that those rays extend a great way farther than it is now in my power to prove. In £m^ glass, though sensibly transparent to light, is, in a great measure, opaque to these obscure rays ; instead of reaching the screen, they are for the most part lodged in the glass.

The visible spectrum, then, simply marks an interval of radiant action, in which the radiations are so related to out organisation that they excite the impression of light ; be- yond this interval, in both directio7u^ radiant power is exerted— obscure rays fall — those falling beyond the red being powerful to produce heat, while those falling beyond the violet are powerful to promote chemical action. These latter rays

can actually be rendered visible ; or more strict' ly expressed, the undulations or waves which are now striking here beyond the violet against the screen, and which are scattered from it so as to strike the eyes of every person present, though they are incompetent to excite vision in those eyes ; those waves, I say, may bo caused to impinge upon another body, and to impart their motion to it, and actually to convert the dark space beyond the violet into a brilliantly illuminated one. I have here the proper substance. The lower half of this sheet of paper has been washed with a solution of sulphate of quinine, while I have left the upper half in its natural state. I will hold the sheet, so that the straight line dividing its prepared from its unprepared half, shall be horizontal and shall cut the spectnmi into two equal parts ; the upper half will remain

LECTURE vrn. ■ ^^1

1 nd yon will be able to compare with it the

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You see tliis effect ; we lia.ve hero it Rplendid fluorescent

band, several inches in width, where a raoruent ago them

was nothing but darl—"'"' ' ™'

nove the prepared paper.

and the light disap

itroduce it, and the light

flashes out again, bI i

1 the most emphatic man-

ner, that the visible

ordinary spectrum by no

means mark the 11"

action. I dip my brush

in this Bolatiun of

■nine, and dab it ag^nst

the paper ; wherev

falls, light flashes forth.

The esjstcnoc of tc

olet rays has been long

known; it was known to Tr.oin:ia

Ydiiiii::, who noLii;Jly e\-

pcrimented on tiiem ; hut to Prof. Stokes ve are indebted for tlie complete invcstigatioii of this subject. lie rendered the rays thus visible.

How then arc wo to conceive of the rays, visible wd invisible, which fill this large space upon the screen ? Wby are some of them visible and others not ? Why are the visible ones distinguished by various colours? Is there anything that we can lay hold of in the undulations which produce these colours, to which, aa a physical caose, we must assign the colour? Observe first, that the entire beam of white light is draivn aside, or refracted by the prism, but the violet is pulled aside more than the indigo, the indigo more than the blue, the blue more than the green, the green more than the yellow, the yellow more than the orange, and the orange more than the red. Tliese colours are differently refrangible, and upon this depends the possibility of their separation. To every particular de- gree of refraction belongs a definit* colour and no other. But why should light of one degree of refrangibility pro- duce the sensation of red, and of another degree the sensa- tion of green ? This leads us to consider more closely the cause of these sensations.

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A reference to the phenomena of sonnd will materially belp our coneeptioDB here,

ilgare clearly to your minds a luup-gtring vibrating to and fro ; it advances and causes the particles of air in tnmt of it to crowd together ; it thus produces a condensation of the air. It retreats, and the sir particles behind it separate more widely; in other words, a rartfttdion of the air occurs behind the retreating wire. The string again advances and produces the conden- saticn as before, it again retreats and produces a rarefac- tion« Thus the condition of the air through which the sound of the string is propagated consists of a regular sequence of condensations and rarefactions, which travel with a velodty of about 1,100 feet a second.

The condensation and rarefaction constitute what is called a sonorous pulse or wave, and the length of the wave is the distance from the middle of the condensation to the middle of the rarefaction. Of course these blend gradually mto each other. The length of the wave is also measured by the distance from the centre of one condensation to the centre of the next one. Now the quicker a string vibrates the more quickly will these pulses follow each other, and the shorter, at tbe same time, will be the length of each in- ^yidual wave. Upon these differences the pitch of a note in mumc depends. If a violin pliayer wishes to produce a higher note, he shortens his string by pressing his finger on it ; he thereby augments the rapidity of vibration. If Iiis point of pressure exactly halves the length of his string, he obtains the octave of the note which the string emits when vibrating as a whole. * Boys are chosen as choristers to produce the shrill notes, men to produce the bass notes ; the reason being, that the boy's organ vibrates more speed- ily than the man's ; ' and the hum of a gnat is shriller than that of a beetle, because the smaller insect can send a greater number of impulses per second to the ear.

We have now cleared our way towards the clear com-

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preheoaioQ of the pby^cal caase of colocr. lUt q U to the cjc what the gamut is to the car ; its i mlonra represent notes of 4liSereiit pilcb. The til which produce the

impression of red ar« down, ethereal waves which they generate are longer, thi which produce the impression of violet, wlule w colours are cscited by wares of some intenoedi** The length of the waves both of sound anJ ^^U niunber of ahocka which they respectively impsrt to and eye, have been etriotly determined. Let os ■ through a simple calculatioa. Light travels throq at a vdodty of 192,000 miles a second. Reduei|| inches, we find the nomber to be 12,165,120,00(1. is foimd tliat 36,000 waves of red Ught plai^B^ wtiiild iii.iko up :m inch ; multiply ihf niimlier cf n 192,000 miles by 39,000, we obtain the nnnibMS of red light in 192,000 miles : this namber is 474,< 000,000. AU these Kaoes enter the eye in a «»J* To produce the impression of red in the braD,li most be hit at this almost incredible rate. To pio impression of violet, a still greater number of n^ necessary ; it would take 57,500 waves of violet inch, and the number of shocks required to fnw impression of this colour, amounts to six himdrrfi ty-ninc millions of millions per second. The olhe of the spectrum, as already stated, rise graduallj from the red to the violet.

But beyond the violet wc have rays of too higl to be visible, and beyond the red we have rays of a pitch to be ^'isiblc. The phenomena of light*" case also paralleled by those of sound. If it ^ volve a contradiction, we might say that there «" sounds of too high a pitch to be heard, and also* loo low a pitch to be heard. Speaking stridlji' waves transmitted through the air from vibralinj

THBQBT OF SX0HANGE8. 277

wladif thongh they strike iipon the air in regular rccnr- raooe, are incompetent to excite the sensation of a mosical note. Probably sounds are heard by insects which entirely escape onr perceptions ; and, indeed, as regards human be- ings, the selfsame note may be of piercing shrillness to one person, while it is absolutely unheard by another. Both as regards light and sound, our organs of sight and hearing embrace a certain practical range, beyond which, on both sides, though the objectiye

cause exists, our nerves cease to be influenced by it

When, therefore I place this red-hot copper ball before yon, and watch the waning of its light, you will have a perfectly dear conception of what is occurring here. The atoms of the ball osciOate, but they oscillate in a resisting medium on which their moving force is expended, and which transmits it on all sides with iaconceivable velocity. The oscillations competent to produce light are now ex- hausted ; the ball is quite dark, still its atoms oscillate, and still their oscillations are taken up and transmitted on all ndes by the ether. The ball cools as it thus loses its molecular motion, but no cooling to which it can be prac- tically subjected can entirely deprive it of its motion. Tliat is to say, all bodies, whatever may be their temperature, are radiating heat. From the body of every individual here present, waves are speeding away, some of which strike upon this cooling ball and restore a portion of its lost motion. But the motion thus received by the ball is far less than what it communicates, and the dificrence be- tween them expresses the ball's loss of motion. As long as this state of things continues the ball will continue to show an ever-lowering temperature : its temperature will sink until the quantity it emits is equal to the quantity which it receives, and at this point its temperature becomes constant. Thus, though you are conscious of no reception of heat, when you stand before a body of your own tem-

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pemtnre, an intorchango of rays is passing between yoa Every 8ii]jerficial atom of each mass U ecndiiig forth iu waves, wiiicb cross iboee that move in the oppoeite direc- tion, every wave asBcrting its own individoality amid the entanglement of ita fellows. When the sum of motion re- ceived is greater than that given out, warming is tlic con- aequcnce; when the sum of motion given out is greater than that received, chilling takes place. This is Provost's Theory of Exchanges, expressed iit the langnagc of tbe Wave Theory.

Let ua occupy the remmnder of this lecture by illostrat- ing experimentally the analogy between light and radiant heat, as regards reflection. You observed when I placed my thermo-electric pile in front of Mr. Anderson's face, that I had attached to it an open cone which I did not ose in my former experiments. This cone ia aiivered inside, and it is intended to augment the action of feeble radiations, by converging them upon the face of tbe tbermo-electiie pile. It does this by reflection ; instead of shooting wide of the pile, as they would do if the reflector were removed, they meet the silvered surface and glance firom it against tho pile. Tbe augmentation of the efllect is thus shown. I place tbe pile at this end of tbe table with its reflector o^ and at a distance of four or five feet I place tMs copper ball, hot — but not red-hot ; you observe scarcely any motion of the needle of the galvanometer. Disturbing nothing, I now at- tach the reflector to the pile ; the needle instantly goes up to 00°, declaring the augmented action.

The law of this reflection is precisely the same as that of light. Observe this apparently solid luminous cylinder, issuing fVom our electric lamp, and marking ita track thus vividly upon the dust of our darkened room. I take a mir- ror in my band, and permit tbe beam to faU optm it ; the beam rebonnds from the mirror ; it now fltrikes the ceiling. This horizontal beam is the incident beam, this vertioal

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one is the reflected beam, and the law of li^t, u many of joa know, is, that the angle of inoidence ia equal to the angle of reflection. The incident and reflected beams now enclose a right angle, and when this is the case I ma; be

sore tbat both beams form, witb a perpendicular to the Burfaoe of the nurror, an angle of 45°.

I place the lamp at this comer, x, of the table (fig. 11) ; behind the table I place a looking-glass, l, and on the table yoD observe I have drawn a large arc, a b. Attached to the mirror is this long straight lath, m m, and the looking- glass, resting

upon rollers, can be turned by the lath, which ig to serve as an index. I have here drawn a dark central line, and when the mirror ezactlj faces the middle of tho audience, our lath and this line coincide. Those in front taxj see that the lath itself and its reflection in the mirror form a straight line, which proves that the central dark line is now perpendicular to the mirror. Bight and left of this central lino I have divided the arc into ten equal parts ; commencing at the end b with 0°, I have graduated the arc np to 20°. I first tnm the index so that it shall be in the lute of the beam emitted by the lamp. The beam now falls upon the mirror, striking it as a perpendicular, and yon see it ia reflected back along the line of incidence. I now move my index to 1 ; the reflected beam, as you ob-

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serve, draws itself alcmg ihe taUe, entluig the figue 2. I moTe the index to 2, the beam is now at 4 ; I mora the » dez to 3, the beam is now at 6 ; I move it to 5, the bent is now at 10 ; I move it to 10, the beam is now at 20i. If I stand midway between the incident and reflected beimi^ and stretch out my anns, my finger tips touch each of them. One lies as much to the left of the perpendicular as the other does to the right. The angle of incidence ia oqoal to the angle of reflection. But we have also demaoatntad that the beam moves twice as fiuit as the index ; and tUs is usually expressed in the statem^it, that the angidar y^ locity of a reflected ray is twice that of the mirror wlucli reflects it.

I have already shown you that these incandescent coal- points emit an abundance of obscure rays — of rays of pure heat, which have no illuminating power ; my object now is to show you that those rays of heat emitted by the lamp, have obeyed precisely the same laws as the rays of light. I have here a piece of black glass ; so black that when I look through it at the electric light, or even at the noonday sun, I sec nothing. You obser\'e the disappearance of the beam when I place this glass in front of the lamp. It cuts off every ray of light ; but, strange as it may appear to you,

it is, in a considerable degree, transparent to the ob- scure rays of tlic lamp. 'I now extinguish the light by in- terrupting the current, and I lay my thermo-electric pile on the table at the number 20, where the luminous beam fell a moment ago. The pile is connected with the galvanometer, and the needle of the instrument is now at zero. I ignite the lamp, no .light makes its appearance, but observe the galvanometer; the needle has already swung to 90°, through the action of the non-luminous rays upon the pile. If I move the instrument right or left from its present po- sition the needle immediately sinks ; the calorific rays have pursued the precise track of the luminous rays; and for

BADIAHT HXAT AHD LIGHT OBXT THE SAME LAW. 281

them, alflOy the angle of inddenoe is equal to the angle of Tefleetion* Repeating the experiments that I have abready execated with li^t, brin^g the index in succession to 1, 2, 8, 5, Ac^ I prove that in the case of radiant heat also, the angular Telocity of the reflected ray is twice that of the mirror.

The heat of the fire obeys the same law. I have here a sheet of tin — a homely reflector, bat it will answer my pur- pose. At this end of the table I place the thermoelectric pile, and at the other end my tin screen. The needle of the galvanometer is now at zero. Well, I turn the reflector so as to caose the heat striking it to rebound towards tlio pile ; it now meets the instrument, and the needle at once declares its arrival. Observe the positions of the fire, of the reflector, and of the pile ; you sec that they are just in the positions which make the angle of incidence equal to that of reflection.

But in these experiments the heat is, or has been, asso- dated with light. Let me now show that the law holds good for rays emanating from a truly obscure body. Hero w a copper ball, c (fig. 78), heated to dull redness ; I plunge it in water nntU its light

totally disappears, but I leave it warm. It is still giving out radiant heat of a slightly greater intensity than that emitted by the human body. I place it on this candlestick as a support, and here I place my pile, p, turning its conical reflector away from the ball, so that no direct ray from the latter can reach the pile. You Bee the needle remains at zero. I place here my tin reflect- or, X K, so that a line drawn to it from the ball, shall make the same angle with a perpendicular to the polished tin re- flector, as a line drawn from the pile. The axis of the con- ical reflector lies in this htter Ime. True to the law, the heat-rays emanating from the ball rebound from it and strike the pile, and you observe the consequent prompt mo- tion of the needle.

Like the raya of light, the rays of heat emanaUng from

our ball proceed in etraig^ht lines througli Bpaoe, diminish-

ing in intensity exactly as light diminishes. Thus, this ball, which whan close to the pile cansee the needle of iha gal- vanometer to fly up. to 80°, at a distance of 4 feet 6 iiudiei^ Bhows scarcely a sensible action, ltd mys are Btjaandered oo all sides, and comparatively few of them reach the |uie. Bnt I now introduce between the pile and the ball this tin tabe, A B (fig. 7S), 4 feet long. It is polished within, and tberfr

fore capable of reflection. The calorific rayB which strike the interior surface obUquely, are reflected from dde to side

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of the tabe, and thus those rays which, when the tabe is ibsent, are squandered in space, are caused, by internal re- lecdon, to reach the pile. You see the result : the needle, rhich a moment ago showed no sensible action, moves romptly to its stops.

We have now dwelt sufficiently long on the reflection of idiant heat hj plane surf aces ; let ns tom for a moment to eflection from curved surfaces. I have here a concave umr, X K (fig. 80) foimed of copper, but coated with sil-

ver. I place this warm copper ball, b, at a distance of eighteen inches from the pile, which has now its conical reflector removed ; you observe scarcely any motion of

the needle. If I placed the reflector, m n, properly behind a andle, I should collect its rays, and send them back in a cyl- nder of light. I shaU do the same with the calorific rays nutted by the ball b ; you cannot, of course, see the track f these obscure rays, as you can that of the luminous nes; but you observe that while I speak, the galvano- leter has revealed the action ; the needle of the instrument as gone up to 00°.

I have here a pair of niudt Ixrgvr mii U plitcctl fiat upon tlie Uihle : aov, llie iiiiiTor is BO regulated that if I pluctt a whioli is called the focits of tbe minor, i divergent upon the mirror are reflected uj nllel. Let U3 mnko tb« cxperimont : In iiur coal-pointa, bring tliem into cental tiicm a Ultle apart ; there is the cIc<ririo a splendid vertical cylinder, cast upward and marked by the action of the ligLt < room. If we reversed the experiment, j allcl beam of light to fUU upon the mirro beam, after refieotioii. would be colleete tlio mirror. Wc can actually make tbia IroduL-iiig a second uurror ; here it ia sl coiling, I will now draw it up to a heig! above the table ; the vertical bc;mi, wbie the ceiling, ia now received by tlie iippc biuig in tlie focua of the upper mirror a to cu;ib]c you to see the collection of the You observe how intensely that piece of niiimted, not by the direct light from bol fleeted light converged upon it from aboi Miiny of you know the ertraordinai upon a mixture of hydrogen and chlorin transpiirent collodion balloon filled witli I lower my upper reflector, and suspend a hook attached to it, so that the little in the Aictia ; we ivill now draw the rain ceiling {fig, 81) ; and as before I place the focu3 of the lower mirror ; the mon np.irt, the light gnsbcs from them, and t And remember this is the action of the collodion to be an inflammable Bubstance. suppose tliat it was the /leat of the coal-p

Id that it commn- WditB combnation if gases ; but look

* yoa ficc, as I ftthe flakes of tbo BBdesceDding on pUe; the lumi- P^ went hami- 'flirongh it, cans-

• gasea to oi- tttkd the hydro- '- acid, formed ■Cr combustion, Kially preserved Mtninablc envcl- ttm sharing in i^btifition. "wer the nppcr i ftnd hang in its Vecond balloon, itig a mixture (en and by dro- ll which light sensible effect ; the mirror, and

focns of the one place thia i

copper ball. j>rific rays are lected and con- above, as the X8 ones were d and converg- le last experi- ■hnt they act

I.ECrCBE Tin.

upon the envelope, which I have purpoeel tie, 80 aa to enable it to intercept th« kea is not SO sudden as in the last case, but i Bion, and you now Bee no tr»cc of the ba nmble substance is entirely dissipated.

But here, you may object, light is ai heat ; very well, I lower the upper mjn Buspend in its focus a flask of hot water, mo-electric pile to the focus of the low(turn the face of the pile upwards, so as ■ diiect radiation of the warm Qaik — then tion produced by the direct raya. Bat I with its face downwards. If light and the rays from the flast which strike th Cdllocled at its focus. You sec that Ih needle, whicli was not sensibly affected 1 goes up to its stops. I would ask yon rection of that deflection ; the red end ol towards yon.

I again lower the mirror, and, in the of hot water, suspend a second one con mixture. I raise the mirror and, aa in bring the pile into the focus of the lowci rectly towards the upper flask there is i downwards, the needle moves : obser^-e t motion — the red end comes tow.ards me.

Does it not appear as if this body were now emitting rays of cold which the lower mirror exactly as the rays of i experiment. Tho facts are esactly comj would seem that we have precisely tlie s: from tho experiments, the existence aui these cold rays, as we ha^-e to infer the i vergence of the heat rays. But many • have already peroei\-ed the real state of t]

badiahok gv gold.

^arm body, but in the last experiment the quantity i. it lost by radiation was more than made good by Qantity received from the hot flask above. Now the IS reversed, the quantity which the pile radiates is in a of the quantity which it receives, and hence the pile .Ued ; — ^the exchanges are against it, its loss of heat t^ partially compensated — and the deflection due to la the necessary consequence.

APPENDIX TO LECTURE VUL

Ik llie Aist volntno of NicliolsoD's Journat, publitbnlJl ■oaods produced by the combuaUon of fajdrogcn H referred to tu haying been ' nude in luly : ' Dr. 1

Biirae place, shows i.hiil lie hiii.l discovcrpil tbem in >— » while obacrriog t ho water formed in a gLiss vtssei I^B combustion of a slender stream of bytlrogen. ClliiH 'Akufitik,' publisheil in 1802, page 74, speaks of** mentioned, and incorreetlj expl^neil, by De Luc in tt Ideas un Meteorology : ' I do not know the date of lb' Oikdni liimaelf showed tlict the tonea produwd wae 4 as those of an open pipe of the same length m tiictdl eucompassed the fiame. He also aucceeded in olitaifflU and its octave from the same tnbc, and in one cascoM fifth of the octave. In a paper published iu the 'Jounall flique ' in 1803, G. Dc la Rive endeavoured to acwo* sounds hj referring them to the alternate controctioa at sion of aqueous vapour; basing liia opinion upon**"" perimpnts of great lieauty and ingenuity made witblb"" thermometers. In 1818 Mr. Faraday took up the solj* Bhowed that the tones were produced when the gUai* enveloped by an atmopphere higher in temperatuw ti" Fahr, That they were not due to aqueous vapourini' shown by the fact that tliey could he produced bj theei»l

■ From llic Philosopliical Magazine for Julv, 1S57, HvJota' F.R.S.

t Joumnl of Science and lUe Arts, vol. v. p. 274.

SINGIXG FLAMES. 2S'.)

of carbonic oxide. lie referred the sounds to successive explo- sions produced by the periodic combination of the atmospheric oxygen with the iasning jet of hydrogen gaa.

I am not aware that the dependence of the pitch of the note oatiieflizeaf the flame has as yet been noticed. To this point I wD], in the flrst plaoe, briefly direct attention.

A. tube 26 inches long was placed oyer an ignited Jet of hydro- gen : the sonnd produced was the fhndamental note of the tube.

A. tube l%i inches long was brought oyer the same flame, but no sound was obtained.

The flame was lowered, so as to make if as small as possible, and the tube last mentioned was again brought oyer it ; it gaye ft dear melodious note, which was the octaye of that obtained with the 25-inch tube.

The 25-inch tube was now brought oyer the same flame ; it no loDger gaye its fundamental note, but exactly the same note as tiiat obtained from the tube of half its length.

Thus we see, that although the speed with which the ezplo- nms succeed each other depends upon the length of the tube, the flame has also a yoice in the matter : that to produce a musi- cal sound, its size must be such as to enable it to explode in miison either with the fimdamental pulses of the tube, or with Hud pulses of its harmonic diyisions.

With a tube 6 feet 9 inches long, by yarying the size of the flame, and adjusting the depth to which it reached within the tube, I haye obtained a series of notes in the ratio of the numbers 1,2,8,4,5.

These experiments explain the capricious nature of the sounds sometimes obtained by lecturers upon this subject. It is, how- eyer, always possible to render the sounds clear and sweet, by suitably adjusting the size of the flame to the length of the

tube.'*' Since the experiments of Mr. Faraday^ notMng, that I am aware of^ has been added to this subject, until quite recently. In a recent number of PoggendorfiTs ' Annalen ' an interesting

* With a tube 14| inches in length aod an exceedingly minute jot of gas, I obtained, withoat altering the quanUty of gas, a note and its octave : the flame possessed the power of changing its own dimensions to suit both notes.

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experiment la described by IL toil Sdnffepotedh, and mede fhe wilject of 8ome remarlcs by Frot PoggwdorfThlmjirif. A note WB8 obtained with a jet of oidineiy ooel-gu^ ud Ik found that when the Toice was pitched to the Mma nota^ Oe flame asBomed a liyely motion, which could be angmiiited miSL the flame was actually eztinguiahed. IL Ton BtSbtiSfga/ttA dam not describe the conditiooB neoeHaiy to the wcceM of Me eiqwri" ment; and it was while endeavouring to find out thoM ooodir tiona that I alighted upon the flute which flnm the prind^ subject of this brief notice. I may nmaik that IL roa Brhaff gotsch's result may be produced, with certainty, if the gas be caused to issue under suffident pimsuio thxoQi^ a toj aMB orifice.

In the first experiments I made use of a tapering bnas bunur, 10} inches long, and haying a superior orifico about -fgih of an inch in diameter. The shaking of the unging flame within the glass tube, when the voice was properly pitched, was so manifest as to be seen by several hundred people at once.

I placed a syrene within a few feet of the singing-fiame, and gradually heightened the note produced by the instrument. As the sounds of the flame and syrene approached perfect unison, tlie flame shook, jumping up and down iivdthin the tube. The inter- val between the jumps became greater until the unison was per- fect, when the motion ceased for an instant ; the syrene still in- creasing in pitch, the

motion of the flame again appeared, the jumping became quicker and quicker, until flnally it escaped cognisance by the eye.

This experiment showed that the jumping of the flame, ob- served by M. von Schafigotsch, is the optical expression of the heats which occur at each side of the perfect unison : the beats could be heard in exact accordance with the shortening and lengthening of the flame. Beyond the region of these beats, in both directions, the sound of the syrene produced no ^nsible motion of the flame. Wliat is true of the syrene is true of the voice.

While repeating and varying these experiments, I once had a silent flame within a tube, and on pitching my voice to the note of the tube, the flame, to my great surprise, instantly started into song. Placing the flngcr on the end of the tube, and silencing

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the melody, on lepeating the experiment the same result was obtained.

I placed the syrene near the flame, as before. The latter was banung tranqoilly within its tube. Ascending gradually from the lowest notes of the instnunent, at the moment when the soond of the syrene reached the pitch of the tube which surronndcd the gas flame, the latter suddenly stretched itself and commenced its wng, which continued indefinitely after the syrene had ceased to Boond.

With the burner which I haye described, and a glass tube 13 indies long, and from ^ to f of an inch internal diameter, this re- ntt can be obtained with ease and certainty. If the yoice be thrown a little higher or lower than the note due to the tube, no Tiaible effect is produced upon the flame : the pitch of the yoice must lie within the region of the audible beats.

By yarying the length of the tube we yary the note produced, and iiie yoice must be modified accordingly.

That the shaking of the flame, to which I hayo already re- ferred, proceeds in exact

accordance with the. beats, is beautifully shown by a tuning-fork, which giyes the same note as the flame. Loading the fork so as to throw it slightly out of imison with the flame, when the former is sounded and brought near the flame, the jompings are seen at exactly the same interyals as those in which the beats are heard. When the tuning-fork is brought oyer a resonant jar or bottle, the beats may be heard and the jumpings seen by a thousand people at once. By changing the load upon the tuning-fork, or by slightly altering the size of the flame, the quickness with which the beats i^cceed each other may be changed, but in all cases the jumpings address the eye at the same moment that the beats address the ear.

With the tuning-fork I haye obtained the same results as with the yoice and syrene. Holding a fork oyer a tube which responds to it, and which contains within it a silent flame of gas, the latter immediately starts into song. I haye obtained this result with a scries of tubes yarying from 10 J to 29 inches in length. The fol- lowing experiment could be made : — ^A series of tubes, capable of producing the notes of the gamut, might be placed oyer suitable jets of gas ; all being silent, let the gamut be run oyer })y a musician with an instrument sufficiently powerful, placed at a

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distance of twentj or thirtjyaidi. AtfbBWcnaidoimApi^ ular note, the ga»-jet contained in tlia oorratpaiiilfag tabs mUi instantly start into song.

Imnst remark, howerer, that witili the Jet whldi I hawed, the experiment is most easily made with a tnba about 11 cr 11 inches long : with longer tabes it is more difkult to pranstthi flame from singing spontaneously, that i% withovt f»*f—fl enip tation.

The prindpal point to be attended to is this. Wifii a tab^ say of 12 inches in length, the flame requires to oooiqix a ukIA poation in the tabe in older that it diall afaig with % intensity. Let the tabe be raised so that the flami it to a less extent; the energy of the soimd wHl' be ttsnlif diminished, and a point (a) will at length be

attained, wtoslt will cease altogether. Above this point, for a certain distance, the flame may be caused to bom tranquilly and silently for any length of time, but when excited by the voice it will sing.

When the flame is too near the point (a), on being excited by the voice or by a tuning-fork, it will respond for a short time, and then cease. A little above the point where this cessation occurs, the flame bums tranquilly, if nnexcited, but if once caused to sing it will contniue to sing. With such a flame, which is not too sensitive to external impressions, I have been able to retem tha effect hitherto descrihedy and to stop the song at pleasure by the sound of my voice, or by a tuning-fork, without quenching the flame itself. Such a flame, I find, may be made to obey the word of command, and to sing or cease to sing, as the experimenter pleases.

The mere clapping of the hands, producing an explosion, shouting at an incorrect pitch, shaking of the tube surrounding the flame, are, when the arrangements arc properly made, ineffec- tual. Each of these modes of disturbance doubtless affects the flame, but the impulses do not accumulate, as in the case where the note of the tube itself is struck. It appears as if the flame were deaf to a single impulse, as the tympanum would probably be, and, like the latter, needs the accumulation of impulses to give it sufficient motion. *A difierence of half a tone between two tuning-forks is sufliciCnt to cause one of these to set the flame singing, while the other is powerless to produce this effect.

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I have said that the voice muat be pitched to the note of tlie tube which surrounds the flame ; it would bo more correct to say the note produced by the flame when singing. In all cases this note is sensibly higher than that due to the open tube which sur- RHDids the flame ; this ought to be the case, because of the high temperatore of the yibrating column. An open tube, for exam- ple, which, when a tuning-fork is

held oyer its end, giyes a maxi- mum reinforcement, produces, when surrounding a singing flame, a note higher than that of the fork. To obtain the latter note the tube must be sensibly longer.

What is the constitution of the flame of gas while it produces ihflBe musical sounds f This is the next question to which I will briefly call attention. Looked at with the naked eye, the sound- ii^ flame appears constant, but is the constancy real ? Supposing F esdb pulse to be accompanied by a physical change of the flame, ' nch a change would not be perceptible to the naked eye, on account of the yelocity with which the pulses succeed each other. The light of flame would appear continuous, on the same princi- ple that the troubled portion of a descending liquid yet appears continuous, although by proper means this portion of a jet can be shown to be composed of isolated drops. If we cause the image of the flame to pass speedily oyer different portions of the retina, the changes accompany the periodic impulses will manifest tbem- selyes in the character of the image thus traced.

I took a glass tube 3 feet 2 inches long, and about an inch and a half in internal diameter, and placing it oyer a yery small flame of olefiant gas (common gas will also answer), obtained the fun- damental note of the tube : on moying the head to and fro, the image of the sounding flame was separated into a series of dis- tinct images; the distance between the images depended upon the yelocity with which the head was moyed. This experiment is suited to a darkened lecture-room. It was still easier to obtain the separation of the images in this way, when a tube 6 feet 9 inches in length, and a large flame, were made use of.

The same result is obtained when an opera glass is moyed to and firo before the eye.

But the most conyenient mode of obserying the flame is with a mirror ; and it can be seen either directly in the mirror, or by projection upon a screen.

APl'ENDII TO I,BCTtJEB TUI, 1

3 ccntimrtrcs focus was placed in front of a flaioB un gas, upwards or aa inch long,

and a pajter scrven was ^ ; about 0 or 8 feet diatance behiud the flame. In front of lui! luuB a small looking-glass was hold, which receircd the light that had passed through tlie lens, and reflected it back npon tbe screen placed bchitul <' idjosting the position oftbo

len^ a wcll-defiucd i of the flame was obtwiod

upon the screen. Oi" "■ "or the image was displaced,

and owing to the rcl presaion by the retina, when

the moTemciit was su the image described a coa-

tinuous laminous tri<' ic mirror motionless, the 6-

foot 9-inch tube wop ; flame ; the latter changed

ita shape the momcc o sound, remainiag howerer

well defined npon Wo bcic „ now moving the mirror, a totatly different efiect was produced : instead of a continuons track of light, a series of distinct imagea of the pnnnding flame was observed. The distance of those ima^rcs .ijart Tiiri(dwith thu motion of the oiirrur ; cuiJ, tii'tAiaioc, ainixl Ik iou^lti, bj Buii-

ably turning the reflector, to form a ring of images. The experi- ment is beautiful, and in a dark room may ho made visible to a large audience.

Tho experiment was also varied in the following manner: — A triangular prism of wood had its sides coated with rectangular pieces of looking gloss : it was smpended by a thread with its axis vertical ; torsion was imparted to the thread, and tho prism, acted upon by this torsion, caused to rotate. It was bo placed that its three faces received, in saccessioD, tho beam of light sent from tho flame through the lens in front of it, and threw tho images upon the screen. On commencing its motion the im^^ were but shghtly separated, but became more and more bo ob the motion approached its masimum. This once past, the images drew closer together again, imtil they ended in a kind of luminous ripple. Allowing the acquired torsion to react,

the same series of effects could be produced, the motion being in an opposite direction. In these experiments, that half of the tube which was turned towards the screen was coated with lamp-black, so as to cut off tho direct light of tho jet from the screen.*

* Since Uicae cipcrimcnta were made, Hr. Whe&tstone hu draini mj

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But what ia the state of the flame hi the interval between two images ? The flame of common gas, or of olefiant gas, ow^ its Inminoiisness to the solid jiarticleB of carbon discharged into it. • If we blow against a lominous gas-flame, a sound is heard, a Boiall explosion in fact, and by sach a puff the light may be caused to disappear. During a windy night the exposed gas-jets in the ahope are often deprived of their light, and bum blue. In fike manner the conmion blowpipe-jet deprives burning coal-gas of its brilliant light. I hence concluded, that the explosions, the wgedHafa of which produces the musical sound, rendered, at the nMHnent they occurred, the combustion so perfect as to extin- guish the solid carbon particles ; but I imagined that the images on the screen would, on closer examination, be found united by qnoes of blue, which, owing to their dimness, were not seen by the m(^od of projection. This in many instances was found to be the case.

I was not, however, prepared for the following result : — A flame of olefiant gas, rendered almost as small as it could be, was procured. The 3-foot 2-inch tube was placed over it ; the flame, on singing, became elongated, and lost some of its light, still it was bright at its top ; looked at in the moving mirror, a beaded line of great beauty was observed ; in front of each bead was a little luminous star, after it, and continuous with it, a spot of rich blue light, which terminated, and left, as far as I could judge, a perfectly dark space between it and the next following luminous star. I shall examine this further when time permits me, but as flu: as I can at present judge, the flame was actually extinguished and relighted in accordance with the

sonorous pul- sations.

When a silent flame, capable, however, of being excited by the voice in the manner already described, is placed within a tube,

attention to the foUowing passage, which proves that he had already made use of the rotating mirror in examining a singing flame: * A flame of hy- drogen gas burning in the open air presents a continuous circle in the mirror; but while producing a sound within a glass tube, regular intermis- sions of intensity are obserred, wluch present a chain-like appearance, and indicate alternate contractions and dilatations of the flame corresponding with the sonorous yibrations of the colunm of air.' — PbiL Trans., 1834,'p. 686.

A lens of 38 contimctrca focus wv of COtamon gas, upwiirda of au inch t bung at about Q or 8 fett distance l-fi the lens a sniiill looklng-glusB was h> that had passed ttirough the lens, ai". screen placed behind the lal'i'" lens, a wcll-dcQncd i upoD the screen. and Owing to the retention the tnoviMneiit was sufBcier tiDQOUs luniinouB track. '. foot 9-iiicU tube was place its shape the moment it coi well defined upon the sci totallj difierent effect was track of light, a scries of d. was cibaiTViid. The dislaucc the motion of the n nbly turning the rcfluctor, to for rncnt is bcftutiiiil, and in a dark large audience.

The e.vpcrimcnt was aiao var A triangular prism of wood had i pieces of looking glass : it was sl axis vertical ; toreinn was iiiipartoo. acted upon by this torsion, caused that its three faces rccciTed, in succe*-" from the flamt through tlie lens in

were but slightly atpanitcd, but became motion approached its maximum. Tbi drew closer together again, until tliey endi ripple. Allowing the acquired t(effecta could be produced, the motion beinp tion. la these experiuieiits, that half ol turned towards the screen was coated with I cut off the direct light of the jet from the sere*

■ Since tlicse cspei'imcntd ncre maiie, Mr. IVhealr"

2'JG Al'PESDIX TO LECTL'HK Vm.

ami tlic coutinuoua lino of liglit produccil by it in the movbg mirror is oUservLil, I know no experiment mora pretty than the rcaolutiou of tliis liac into a striog of riclil; luminous pearls at

I voice IB pitched to tlie proper note. This maj be < I iderabla distanco IVom the jet, and with the back

I 3 produced in the line of beads wheo u timiag-Catk,

I iug beats with the flume, is brought over tbe tube,

1 J, lEoonant jaf uear it, is also cxtrcmdj intcresling to

b .,d. I will not ot present enter into & more minute descrip- tion of these results. Sufficient, I trust, lias been said to induce cipeiimcutcrs to rcproii ta for themselves ; the sight

of them will ^vb man m any description of mine

could poaably do.

TEANSLaTION OF KIU8

A glass tubo open a when simply blown npoa by

thomoutb, gives itsfimu , i. a the deepest tone belongs

ing to it, as an open organ- j but distinctly. On placing

the open hand upon one oi tri e openings and rapiiUy witlidraiv- iog it, the tube yields two notes, one after the oiher ; first tbe fbndamctital note of the closed pipe, and then the note of the open pipe, already mentioned, whidi is on oetoM higher. By Hu application of heat these fundamental tones, of which only tbe higher one will be taken into consideration here, are raised, sa is well known ; this is observed immediately on blowing npon ■ tube heated externally, or by a gas-flame burning in its interior. For example, a tube 243 millims. in length, and 30 millima. in diameter, heated throughout its whole length, when blown upon even before it reaches a red heat, gives a tone raised a mqor thirdf namely, the second Q sharp in the treble clef|

instead of the corresponding E. If a gas-flame 14 millima, in length, and 1 millim. in breadth at the bottom, is bnming in the tabe, the tone rises to the second treble F sharp. The same gas-flame nisn

* By Count ScfaaDgotsch: PhiL Mig., December 1SS7.

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the tone of a tabe 273 xnillims. in length, and 21 millims. in width, from the second treble D to the corresponding E. These two tubes, which for brevity will hereafter be refeired to as the £ tabe and the D tube, served' for all the following experiments, the otgect of which was to show a well-known and by no means sarprising fact, in a striking manner, namely, that the coluom of air in a tabe is set in vibration when its fundamental tone, or one nearly aUied, for example, an octave, is sounded outside the tabe. The existence of the aerial vibrations was rendered per- ceptible by a column of smoke, a current of gas, and a gas flame.

1. A glimmering smoky taper was placed close imder the E tobe held perpendicularly, and the smoke passed through the tube in the form of a uniform thread. At a distance of 1'5 mc^re from the tube, the first treble E was sung. The smoke curled, and it appeared as if a part of it would be forced out at the upper, and the other part at the lower opening of the tube.

2. Two gas-burners, 1 millim. in the aperture, were applied near each other to the same conducting tube. Common gas flowed from both of them ; one projected from below into the D tube for about one-fifth of its length ; the gas flame of the other was 8 millims. in height. At a distance of 1*5 metre therefrom the first treble D was sung ; the flame increased several times in breadth and height, and consequently in size generally ; a larger qoantitj of gas therefore flowed out of the outer burner, which can only be explained by a diminution of the stream of gas in the imier burner, that is, in the one surrounded by the glass tube.

8. A burner, with an aperture of 1 millim. projecting from below into the D tube,

about 80 millims., yielded a gas flame 14 wiiiKnM^ in length. At 50 metres therefrom the first treble E was song: the flame was instantaneously extinguished. The same thing took place at 7 metres, when the flame is only 10 millims. b height, and the first treble D sharp is sung.

4. The last-mentioned fiame is also extinguished by the note G dkirp sounded close to it. Noises, such as the clapping of hands, poshing a chair, or shutting a book, do not produce this eficct.

5. A bamer with an aperture of 0*5 millim., projecting from bdow 80 millims. into the D tube, yielded a globular gas flame S to 8*5 mUlims. in diameter. By gradually closing a stopcock file peseagie of gas was more and more limited. The flame sud-

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which was open, the four legs of a chair were stamped simulta- neonsl J upon the wooden floor. The phenomenon of the chemi- cal harmonica immediately occurred. A very small flame is of ootuae extingaiflhed, after sounding for an instant, by the noise of a chair. A tambourine, when struck, acts sometimes, but in general not.

11. The flame burning in the excited singing condition in the interior of the D tube, the latter was slowly raised as high as poenble without causing the return of the flame to the ordinary condition. The note, the flrst treble D, was sung strongly and Vnkok 0ff midderdy at a distance of 1*5 metre. The harmonic tone ceased, and the flame fell into a state of repose without being extinguished.

18. The same result was produced by acting upon the draught of air in the tube by a fanning motion of the open hand close tbore the upper aperture of the tube.

13. In the D tube there were two burners close together ; one of them, 0'5 millim. in aperture, opened 5 millims. below the other, the diameter of which was 1 millim. or more. Currents of gaa, independent of each other, flowed out of both; that flowing from the narrower burner being very feeble, and burning when ignited, with a flame about 1*5 millim. in length, nearly inyisible in the day ; the first treble D was sung

at a distance of three metres. The strong current of gas was immediately in- flamed, because the little flame situated below it, becoming elongated, flared up into it. By a stronger action of the tone, the small flame itself is extinguished, so that an actual transfer of the flame from one burner to the other takes place. Soon after- wards the feeble current of gas is usually again inflamed by the large flame, and if the latter be again extinguished alone, every- thing is ready for a repetition of the experiment.

14. The same result is furnished by stamping with the chair, &c It is evident that in this way gas-ilames of any desired aze and any mechanical action may be produced by musical tones and noises, if a wire stretched by a weight be passed through the glass t^he in such a way that the flaring gas-flame must bum upon it

15. If the flame of the 'chemical harmonica be looked at stead- fiwtly, and at the same time the head be moved rapidly to the

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right tad left attematclf, an aninterrupted Btteak of UgHt i> nrt seen, sncli as b ^veo by eveij other lamiDons body, but & eeriia of doscl; spproxunatcd flames, and often dentated and unOulatol figtirea, especially when tubes of a metre ajid flames of a centi- metre in length arc employed.

This experiment also eneceeds very easily wjlhont moving the cye«i, when the Same is loot ' t throogh an Dpcra-gkM..I)ic object-glasa of which is moved i and also when the picture of i mirror shaken about. It is, L csperiment long since described for which a mirror turned by wai

ly to and fro, or in a diele; amc is observed in a luad- rcr, only a variation of tbo d explained by Wheatebui^ raik was employed.

[It is perhaps but riglit that 1 jnw attention to ilio relition tit

the foregoing paper to one that I Idicfced on the Nme nbJMt. Ot

Hay e, and the days inmwdiatel} j^ttftjjA^Hl&eUdeseribedta

tny paper were discovered ; bat o. [SO, du fcr^tung icnilB wot

Through tbc kindness of Mr. SebnlTgot^h himscir, I recL'lrud Lis piper i' Clianiouni, numj weeks after the publication of mj onn, and imlil dicii 1 ffm not anore of hia having continued his eiperimenls upon the su'ijscl.

We thus irortcd independently of each other, but as far as the describ- ed phenomena are common to both, all Iho merit of priority resU "ill Count Schaffgolsch,— J. T.]

[Hardi 20, 1862.] uw or DiMiinrnoai inrH m distaxob— the wates or boukd longi-

TTDDIAL ; TBOSB Or LIGBT TRAmYXBaAL — ^WIIXN TUKT OSCILLATE THE I0LBCULE8 or DirrXSBHT BODIES GOMKUNICATE DirTERENT AMOUNTS or MOnOX to the ETHEB— EADLiTION THE COMMUHICATION OE MO- nOS TO THE XTOEB; AB80BPTI0H THE ACCEPTANCE OE MOTION FBOM THE SmEB — THOSE SURFACES WHICH BADIATE WELL ABSORB WELL — ^A CLOSE WOOLLEN COTERINO EACIUTATES COOLING — FRE8ERTATIYE IN- lUTEXCB or GOLD-LEAT— ^HE ATOMS OE BODIES SELECT CERTAIN WAVES lOR BESTRUCnON AND ALLOW OTHERS TO PASS — TRANSPARENCY AND mATHlRMANCT — DIATHERMIC BODIES BAD RADIATORS — ^TDE TERM QUAL- ITT AS APPLIED TO RADIANT HEAT — THE RATS WHICH PASS WITHOUT IBBORmON DO NOT HEAT THE MEDIUM : THE MOST POWERFUL SOLAR EATS MAT PASS THROUGH AIR WHILE THE AIR REMAINS BELOW A FEEEZINO TEMPERATURE — PROPORTION OE LUMINOUS AND OBSCURE RAYS 15 TARIOrS FLAMES.

1HAVE said that the intensity of radiant heat dimin- ishes with the distance, as light diminishes. What is the law of diminution for light ? I have here a square sheet of paper, each side of the square measuring two feet ; I fold it thus to form a smaller square, each side of which is a foot in length. The electric lamp now stands at a distance of sixteen feet from the screen ; at a distance of eight feet, that is exactly

midway between the screen and the lamp, I hold this square of paper ; the lamp is naked, nnsnrronnded by its camera, and the rays, uninfluenced by any lens, are emitted on all sides. You see the shadow of the square of paper on the screen. My assistant shall meas- ure the boundary of that shadow, and now I unfold my sheet of paper so as to obtain the original large square ;

■il'li LEfTTITEE IX.

vuii soe l)y the crease?, that it is cxnclly four times the area (iT the Piuulkr ouf. I jplace this large ishtet against llic ecrecn, and find that it exactly covers the space fonnral; occupied by the ehudow of the BmaiH equitre.

On the small square, tlierefore, when it etood midway between the lamp and eereon, a quantity of light fell which, w hen tlie small square is removed, h difin^ed over lour times the area upon the screen. But if the same quantity of light is diffused over four times the area, it must be dilu- ted to one-fourth of its original intensity. Hence, by doubling the distance fr ircG of light, we diminish

the intensity to onc-f^ a precisely similar mode

of experiment we ;hat by trebling the dis-

tance we should d icnsity to one-ninth ; and

by quadrupllnf itiiild reduce the intensily

to onc-sixteeu lus demonstrate the law '

that the intensity oi shes as the square of thssM

distance increases. clebratcd law of luvcrs^s

Squares as applied to _

But I have said tL... minishcs according to tht^

some- 1.1W. Objit^ne the experiment \vliiih I am now iiboiiti- to perform before you. I have Lere a tin vessel ; narrow^ but presenting a side a square yard in area, hn (fig. 82). This side, you observe, I have coated with lampblack. E fill the vessel with

hot water, intending to make this large surface my source of radiant heat. I now place the conical reflector on the thermo-electric pile, p, but instead of per- mitting it to remain a reflector, I push into the hoUow cone this lining of black paper, which fits exactly, and which, instead of reflecting any heat that may fall obliquely on it, completely cuts ofT the oblique radiation. The pile is now connected with the galvanometer, and I place its reflector close to this large radiating surface, the face of the pile being about sis inches distant from the surface. . The needle of the galvanometer moves: let it move

vatmnnaa with DmAHCE.

ntil H takes up its final poaitioii. It now points steadilf to 110°, and there it will remain as long as the temperature

^f the radiating surface reiiuunB sensibly constant. I will toow gnidnally withdraw the pile from the surface, and will ask yon to obaerve the effect upon the galvanometer. Of «onree yon will expect that as I retreat from the source of heat, the Intensity of the heat wilt diminish, and that the deflection of tho galvanometer will diminish in a corre- sponding degree. I am now at double the distance, but the needle does not move ; I treble the distance, the needle is still stationary ; I snccessiTely quadruple, quintuple — go to ten times the distance, but the needle is rigid in its adher- ence to the deflection of 60°, There is, to all appeamncc, no diminntion at all of intensity with the increase of dis- tance.

Prom this experiment, which might at first sight appear fatal to tho law of inverse squares, as applied to heat, Mcl- loni, in the most ingenious manner, proved the law. Mark his reasoning. I again place the pile close to the radiating surface. Im^ine the hollow cone in front of the pile pro- longed ; it would cut the radiating surface in a circle, and

30A, LEcruas ix. ^^H

this circle ia the only portion of the Eiirf^ioG n-hose rays est reach iho pile. All the

other rays are cut off by the non reflecting lining of tht' COnC. I inoTe tbc i)ilc to double tb distanco ; the eection of the cone prolongud now enclose a circle of the radiating surface, exactly four times the are of the former circle ; at treble the distanco the mdlatuij eurfaco is augmented nine times ; at ten times the distanoi the radiating surface is augmented 100 times. But tht constancy of thu deflection jiroYes that the augmenlatioi of the radiating surface must be exactly neutralised by the diminution of intensity ; tho radiating surface augments !U the square of the dUtauce, hence the intensity of tho heal must diminish as the square of the distance; and thus tht experiment, which mijjlit at first sight ap])ear f;ital to tlit law, demonstrates the law in the most simple and conclo- sivc manner.

Let us now revert for a moment to our fimdamentil conceptions regarding radiant heat. Its origin is an oscil- latory motion of the ultimate particles of matter — a motion taken up by the ether, and jiropagated through it in wares. The particles of ether in these waves do not osciUatc in the same manner as the particles of air in the case of sound. The mr-parlicles move to and fro, in the direction in which tho sound travels, the ether particles move to and fro, across the lino in which tho light travels. The nndulatioos of the air are longitudinal, the undulations of the ether are transversal. Tho ether waves resemble more the ripples of water than they do the aerial pulses which produce sound ; that this is the case has been inferred from optical phenomena. But it is manifest that tho disturbance pro- duced in tho ether must depend upon the character of the oscillating mass ; one atom may be more unwieldy than an- other, and a single atom could not be expected to produce so great a disturbance as a group of atoms oscillating aa a system. Thus, when different bodies are heated, we may

LAW OF INYESSB BQITABES.

fidrly expect that they will not all create the same amount of diBtnrbance m the

ether. It is probable that some will oommonicate a greater amonnt of motion than others : in other words, that some will radiate more copionslj than others ; for radiation, strictly defined, is the communication ofmoUon from the pcarticka of a heated bodt/j to the ether in which thesepartidea are immersed.

Let us now test this idea by experiment I have here a cabical vessel, c (fig. 83) — a * Leslie's cube ' — so called from its having been used by Sir John Leslie in his beauti- fbl researches on radiant heat. The mass of the cube is pewter, but one of its sides is coated with a layer of gold, soother with a layer of silver, a third with a layer of cop- per, while the fourth I have coated with a varnish of isin- glass. I fill the cube with hot water, and keeping it at a constant distance from the thermo-electric pile, r, I allow

its four faces to radiaie, in succession, against the pile. The hot gold surface, you see, produces scarcely any deflec tion ; the hot silver is equally inoperative, the same is the case with the copper ; but when I turn tliis varnished but-

face towards tho pile, Uie gu«li of Leat bcoora«s sudilcnl; augmented ; and llie needle, aa you see, movca up to it« stops, llencc ve infer, ibat throagh some pliyaoJ eaoso or other, the molecules of the varnish, when set in motioa by tho hot water within the cube, communicate more mo- tion to the clher thaji tlie atoms of the metals ; in other words, tlio varnish is a beltef radiator than the metals are. I obtain a similar result when I compare this silver teapol with this earthenware one ; filling them both with boiling water, the silver, you see, produces but little cfiect, whil» tlie radiation from the earthenware is so copious as to dnn the needle up to 90°. Thus, also, if I compare this pcwW pot with this ghiss beater, when both are filled with hot Witter, llie radiation from tlie glass is much more powerful than th;it from tho pewter.

You have often heard of the eCfect of colours on radia- tion, and heard a good de^l, no doubt, which is unwarranl- cd by exjierimcnt. I have here a cube, one of whose

sidei is coated with whiting, another with canninc, a third with lampblack, wliilo the fourth h Itft imcoatod. I present tho black surface first to tho pile, the cube being filled with boiling water ; the needle moves up, and now points stead- ily to C5°. The cube rests upon a little turn-table, and by turning the support I present the white face to the pile; the needle remains stationary, proving that the radiati<xi from the white surface is just as copions as that from the black. 1 turn the red surface towards the pile, there is no change m the position of the needle. I tnm the oncoated side, the needle instantly falls, proving the inferiority of the metallic surface as a radiator. I repeat precisely the same experiments with this cube, the sides of which are covered with velvet ; one face with bbck velvet, another with white, and a third with red. The results are precise- ly the same as in the former instances ; the three velvet surfaces radiate alike, while tiie naked surface radiates less

INFLUENCE OF OOLOUBS ON BADIATION. 307

than any of them* These experiments show that the radiar tion from the clothes whidb cover the hmnan body, is inde- pendent of the colour of these clothes ; the colour of an animal^s fur is equally incompetent to influence the radia- tion. These are the conclusions arrived at by Melloui f(yr obscure heal.^

Bat if the coated surface communicates more motion to the ether than the unooated one, it necessarily follows that the coated vessel will cool more quickly than the uncoated one. I have here two cubes, one of which is quite coated wilii lampblack, while the other is bright. At the com- mencement of the lecture I poured boiling water into these vessels, and placed in each a thermometer. A short time ago both thermometers showed the same temperature, but now one of them is two degrees below the other. The ve- locity of cooling in one vessel is greater than in the other, and the vessel w^hich cools quickest is the coated one. Hero are two vessels, one of which is bright and the other close- ly coated with flannel. Half an hour ago two

thermometers plunged in these vessels showed the same temperature, but they show it no longer ; the covered vessel has now a tem- perature two or three degrees lower than the naked one. It is usual to preserve the heat of teapots by a woollen covering, but the cover must fit very loosely. In this case, though the covering may be a good radiator, its goodness is more than counterbalanced by the diflSiculty encountered by the beat in reaching the outer surface of the covering. A closely fitting cover would, as we have seen, promote the loss which it is intended to diminish, and thus do more harm than good.

One of the most interesting points connected with our subject is the reciprocity which exists between the power

* Bj the application of a more powerful and delicate test than that employed by Mellon!, I find that his conclusions will require modification.

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of a body to commnnicato motion to the etlier, or to raiB- ate ; and its capacity to accept motion from the fiher, to absorb. As regards radiation we have already compai«d lampblack and chalk with metallio surfaces ; ve will now compare tlie same stibBtances with reference to tLoir powew of absorption, I have here two sheets of tin, m s, o !■ {fig: 84), one of them coated with wbitini^ and tbe oilier left uncoated. I place them tlms parallel to each other, ond

at a distanco of abont two feet astmder. To the edge of «ach sheet I have soldered a screw, and from one screw to she other I stretch a copper wire, a b, which now connectE tbe two sheets. At the back of the sheet I have soldered one end of a little bar of biamutb, to the other end, e, of which a wire la soldered, and terminated by a binding t«rew. To these two binding screws I attach the two ends

BEOIPBOCnT OF SABEATIOH AND ABSOBFTION. 309

pf the wire ooming from my galvanometer at o, and you observe I have now an unbroken circuit, in which the gal- vanometer is included. You know already what

the bis- muth bars are intended for. I place my warm finger on this left-hand one, a current is immediately developed, which passes from the bismuth to the tin, thence through the wire connecting the two sheets, thence round the gal- vanometer, to the point from which it started. You ob- serve the efiect. The needle of the galvanometer moves through a large arc ; the red end going towards you. The junction of tin and bismuth is now cooling, the needle re- turns to 0^, and now I will place my finger upon the bis- muth at the back of the other plate — ^you see the efiect — a large deflection in the opposite direction ; the red end of the needle now comes towards me. I withdraw my finger, the junction cools, and once more the needle sinks to zero.

I set this stand exactly midway between the two sheets of tin, and on the stand I intend to place a heated copper ball ; the ball will radiate its heat against both sheets ; on the right, however, the rays will strike upon a coated sur- face, while on the left they will strike upon a naked metal- lic surface. If both surfaces drink in the radiant heat — ^if both accept with equal freedom the motion of the ethereal waves — ^the bismuth junctions at the backs will be equally warmed, and one of them will neutralise the other. But if one surface be a more powerful absorber than the other, that which absorbs most will heat its bismuth indicator most ; a deflection of the galvanometer needle will be the consequence, and the direction of the deflection will tell us which is the best absorber. The ball is now upon the stand, and you see we have not long to ^vait for a decision of the question. The prompt and energetic deflection of the needle informs us that the coated surface is the most powerful absorber. In the same way I compare lampblack

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and vamisli with tin, and find the two foiiner hy far tie best absorbers.*

The thinnest metallic coating furaiahes a powerful de- f(.-ncc against thc^

absorption of radiant heat. I have hen a shoot of ' gold paper,' tlie gold being merely copper re- ducod to great tenuity. Here is a red powder, the iodide of mercury, with which I coat the under surface of the gold paper. Tliis iodide, as many of you know, has its red col- our discharged by heal, the powder becoming a pale yel- low. I lay the paper fiat on this board with the coloured Burfuco downwards, and on this upper metallic Burfice I pEtete pieces of paper— common letter paper will answermy jiui-pose. A figure of any desired ehape is thus formed on the surface of the copper. I now take a red-hot spatula in my hand and pnsa it Kpreral times ovlt the sheet; the spatiiU radiates strongly against the sheet, hut I nppreliend this its rays are absorbed in veryditferent degrees. TiK metallic surface will absorb but little ; the paper surfaces will absorb greedily ; and, on turning up the dieet, you see the effect : the iodide underneath the metallio portion !■ perfectly unchanged, while under every bit of paper the colour is discharged, thus forming below an exact copy of the figure pasted on the opposite surface of the sheet. Here ia another example of the same kind, for which I am indebted to Mr. Hill, of the eetabh'shment of Mr. Jacob Bell in Oxford Street. A hot fire sent its rays against this pmnted piece of wood (fig. 85), on which the namber 338 was printed in gold leaf letters ; the paint is blistered and charred all round the letters, but underneath the latter the wood and paint are quite unaffected. This tliin film of gold has been quite sufficient to prevent the absorption, to which the destruction of the surrounding surface is due.

* Colour, Bcconling to Mdloni, tiaa no influence on tbc ilMOTption of obKure heat : on luminoua bent, micb ai Ihat of tbe sun, it has grcAt ii>-

WTTTAIJI TUTi RADIATOBS AND ABSOBBEBS.

Hie luminiferoiu etber filb stellar space ; it makes the universe a vhole, and renders the intercommuiiicatioa of light and energy hetween star and star pos^t^le. But the subtle substance penetrates further ; it surrounda the very

attnog of solid and liquid substances. Transparent bodies ate such, because the ether

and their atoms nrc so related to each other, that the waves which excite light can pass through them, without transferring their motion to the atoms. In coloured bodies certiun waves arc broken or ab- sorbed; but those which ^ve the body its colour])ass without loss. Thrangh this solution of sulphate of copper, for example, the blue waves speed unimpeded, but the red waves are destroyed. I form a spectrum upon the acrccn ; lent through this solution yon see the red end of the Epcc- tmm is cut away. This piece of red glass, on the contrary, owes ita redness to the fact that its substance can be trav- ersed freely by the longer undulation of red, wliUe tlio shorter waves are absorbed. Interposing it in the path of this light you see it cuts the blue end of the spectrum quite away, leaving merely a vivid red band upon the screen. This blue liquid then cuts off the rays which are trausmit- ted by the red glass ; and the red glass cuts off the rays which are transmitted by the liquid ; by the union of both we ought to have pcrfuc-t ojiacity, and so we Ii.avc, When

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both sre placed in the path of the beam, the entire fp«y tram disappears ; the onion of these two tnuisparent bodief prodnoe an opacity equal to that of pitch or conl.

I have here another liquid — a solution of Iha pennan- gUiate of potash — which I introduce into the]>ath of the beam. Sen the cfibct upon the spectrum ; the tn'o ciidf pan freely throui;h, yon huve the red and the blue, but be- tween both a ppace of intense blackness. The yellow of the Bpeotntm is pitilosflly destroyed by this liquid ; through tlie entanglement of ita atoms these yellow raj-s cannot pasB, while the red and the blue glide round them and gel through the inter-atomio spaces without sensible hindranoei And hence the gorgeous colour of this liquid. I will turn tho lamp roiuid and project a disk of light two feet in diameter upon llie screen. I now introduce this liquid j can anything- be moro splendid than tlio colour of that dj^ t * I again turn the lamp obliquely and introduce a prism ; here you have the

components of that beautiful colour; the Tiofet component has slidden away from the red. Ton see two definite disks of these two colours upon the screen, which overlap in the centre, and exhibit there the colour of the composite light which passes through the liquid.

Thus, as regards the wavra of light, bodies exenase is it were an elective power, singling out certain waves for destruction, and permitting others to pass. Transpareoey to one wave does not at all imply transparency to otlwrs, and from this we might reasonably infer, that transparency to light docs not imply transparency to radiant heat. Hit conclusion is entirely verified by experiment. I have here a tin screen, si w {fig. 86), pierced by an aperture, behind which is Boldered a small stand s. I place this copper ball, D, heated to dull redness, on a candlestick, which wiU serve as a support for the ball. At the other side of the screen I place my thermo-electric pile, p; the rays from the ball now pass through the aperture in the screen and fall upon

tfic jiilp — tlio needle goes iij), and finally comes to rest with a bteaJj deflection of 80°. I bare here a glass cell, a qaaTt«r of an inoti vide, vluoh I nov fin with distilled wa- ter. I plaee tin oell oa the stAnd, so that all rajrs reaching the pilA mnit paas tivongh it; what takes place? The

needle' iteadily sinks almost to Eero ; scarcely a ray from the ban can ctobb this water ; — ^to the tmdolatioiis issuing frcan the boll the water is practically opaqac, thongh so extremdy transparent to the rays of light. Before remor- ing the eeU of water I place behind it a similarcell, con- taining transparent bienlphide of carbon ; so that now,

len I remore the wst«r cell, the aperture is still barred by the new liqnid. Tniat oocnrs P The needle promptly mores npwards and describes a large arc ; so that the self-

oe rays that fonnd the water impenetrable, find easy so- cesa through the bisulphide of carbon. Id the same way I compare this alcohol with this chloride of phosphoms,

and find the former almost opaque to the rays emitted by our warm ball, while the latter permits them to pass freely.

So also OS regards solid bodies ; I have here a plate of 14

3U tMjxtmmtx.

■mj pnre glaas, wUdh I plaoe on Hm ■taad, lad, vmag • onbe of hot 'mter instead of tlte btU b^ I poinit the n^ from the heated cnbe to pua timn^ it, if thi|j' can, So morement of the needle is peraeptible. Iiunrdu|ilue.tke plate of gla§B by s plate of roolndt of tea timea tilie tloA- new ; yoa see hov promptly die vedle morea^ tDtil it ti arrested by its stops. To &tae r^s, ibtn, tiw rookult ii emineDtly transparent, vhile the glass ia praotioilly OfUpt totheoL

For these, and namborleBa similar reiblts, we v« in- debted to Melloni, who may be almost r^vded aa da oreator of this branoh of our enbjeot To vxjnm dni povcr of instan tan eons transmiBsion of radiant heat, he proposes the word diathermancy. Diathermancy bean tLe some relation to radiant heat that transparency does to r light. Instead of giving you determinations of my otd f of the diathermancy of various bodies, I will make a seleo- . tion from the tables of the eminent Italian philosopher jost l referred to. In these dct^nninations Melloni oses four dif- fi:»%nt sources of hoat, the Same of a Locatelli lamp ; a spiral of platinum wire, kept incandescent by the flame of an alcohol lamp ; a plate of copper heated to 400° Cnt, and a plate of copper heated to 100° Cent^ the last mea- tioned source being tho surface of a copper cube contain- ing boiling water. The experiments were made in the fol- lowing manner : — First, the radiation of the soorce, that is t to say the galTanometerio deflection produced by it, was I determined when nothing but wr intervened between the ' source and the pile ; then the substance whose diatheinuui- cj was to bo examined was introduced, and the consequent deflection noted. Calling the quantity of heat'represented by tho former deflection 100, the proportionate qoantities transmitted by twenty-fivo different substances are given in the following

table :—

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r nbtUneet redneed to IbkiMM of ^th of M Inch

TnamlMioiM: per emtac» of Um total ndUUiOD.

lit nsnlphur

• crystal (dear) rquartz Mite of Potash Topaz

Date of Lead ite of Baryta r

lyst (Tiolet) iai amber > of Soda laline (deep green) on gum te

add . ite of Potash il amber

LoeateUl Lamp

Incftn- deieent PlAtLDum

1B55

CoDpcrat

92*8 60 42 18

Omperat

table shows, in the first place, what very difierent siye powers different solid bodies possess. It I also that, with a single exception, the transparen-) bodies mentioned for radiant heat varies with the >f the heat. Rocksalt alone is equally transparent Tom the four sources experimented with. It must I in mind here that the luminous rays are also oalo- 3; that the selfsame ray, falling upon the nerve ^ produces the impression of light ; while, imping- i other nerves of the body, it produces the imprech

810 laanam ai

aoa of heit. He Inmiiunu oalorifio n^ bare, hcnrara, % shorter length than the obeoara ny», and knoiriDg, u we do, how differently wtiTM of difbrcnt longtha k« ibwnbed by bodiee, we are in a meacme pr^ated fin- the rMoIta of the toiegoiiig

table, llins, while glaai^ of the tiuoknen spedfied, permits 39 per oenL of the rays of IjoeKUSB^ lamp, ind 24 per oenb of the raya tram, the mamdeecent plstdnnm to pass, it gires panssge to only 6 per oenb of the rays irom copper, at a temperature of 400° G^ iridle it ia absolntely opaque to all rays emitted from a soaroa of 100° C. We also see that limpid ioe, whidi is lo bi^ily tnas- parent to light, allows to pass only 0 per oent. of ^ n^a of the lamp, imd 0'5 per cent, of the rays emitted by the incandescent platinum, while it utterly cuta off all rays iasu- ing from the other two sources. We have here an intima- tion, that by far the greater portion of the rays emitted by the lamp of LoeatcUi must be obscure. Lnminona rays pass through ice, of the thicknesa here given, without sen- sible absorption, and the fact that 94 per cent, of the rays isswng from Locatelli's flame are destroyed by the ice, proves that this proportion of these rays Tmat be ohaeurt. As regards the influence of transparency, clear snd rano^ qnartz are very instructive. Here are the two substances, one perfectly pellucid, the other a dark brown ; still, for the luminous rays only, do these two specimens show a difierence of transmission. The clear quartz transmits 38 per cent., and the smoky quartz 37 per cent, of the rajn from the lamp, while, for the other three sonrces, the trans- missions of both substances are identicaL

Melloni supposed rocksalt to be perfectly transparent to all kinds of calorific rays, the 7"7 per cent, less than a hundred which the foregoing table exhibits, being dno, not to absorption but to reflection at the two snr&ces of the plate of salt. But the accurate experiments of MJL de la ProTostaye and Desains prove that this substance ia permeable in diflbrent degrees to heat of different binds;

RADIATION THBOTTGH 80LIDB AND LIQUIDS. 817

Blmalphide of atrtxm . . . • • ^

Bidilaildt of folidiiir . • • • M

Frotodklorlde of pboephoras • . . • 68

Sfsenoe of torpentiBe . • . • • • 81

QliTeoU , . 80

Naphtha 88

Eaaenoe of lATond«r . . • . • . • 26

Bvlphnrio ether 21

Bolphiirie Mid IT

Hjdnte of ammonia • . • • • . .16

Nltrfeadd 15

Abeolsto alcohol 15

Hydnto of potash 18

Aeetleadd 12

Fyroligneoiia add . . f . .12

Conoentnted aolatlon of sugar • 12

Solution of rocksalt 12

White of egi; 11

Distilled water 11

while Mr. Balfoar Stewart has established the important fact, that rocksalt is particularly opaque to rays issuing from a heated piece of the same substance.

In the preceding table, which I also borrow from Mel- loni, the caloric transmissions of nineteen different liquids are given. The source of heat was an Argand lamp, furnished with a glass chimney, and the liquids were enclosed in a cell with glass sides, the thickness of the liquid layer being 0*21 millimetres, or 0*36 of an inch. Liquids are here shown to be as diverse in their powers of transmis- sion as solids ; and it is also worthy of remark, that water maintains its opacity, notwithstanding the change

in its state of aggregation.

The reciprocity which we have already demonstrated between radiation and absorption in the case of metals, varnishes, 4&c., may now be extended to the bodies contain- ed in Melloni's tables. I will content myself with one or two illustrations, borrowed from Mr. Balfour Stewart. Here is a cdpper vessel in which water is kept in a state of gen- tle ebullition. On the flat copper lid of this vessel I place plates of glass and of rocksalt, till they have assumed the temperature of the lid. I place the plate of rocksalt upon

818 LEOTtTBK IX.

this stand, in front of tlie thi^mia-electric pile. Yon ob- Bervo the deflection ; it is bo small as to be scarcely GGnei- ble, I nov remoTe tbo roeksalt, and pat iu its place a, pUte of heated glass ; tLc nccdlo moves npn-ards through a large arc, thus conclusively showing that the glass, which is the more powerful absorber of obacnre heat, is also the more powerful ratliator. Alum, nn fortunately, melta at a temperature lower than that here made use of; but though its temperature is not so high as that of ibe glass, you can sec that it transcends the glass as a radiator ; the action on the galvanometer is still more energetic than in the case of the last experiment. •

Absorption takes place -within the alisorhing body ; unA it requires a certain thickness of the body to accomplish the absorption. This is true of both light and radiant heat. A very thin stratum of pale beer is almost as colou> less as a stratum of water, the absorption being too incon- siderable to produce the decided colour which larger masses of the beer exhibit. I pour distilled water into a drinking glass ; in this quantity it exhibits lio trace of colour, but I have arranged here an experiment which will show you that this pellucid liquid, in suffident thickness, exhibits a very decided colour. Here ia a tube fifteen feet long, x b (fig. 87), placed horizontal, the ends of which are stopped by

pieces of plate glass ; at one end of the tube stands an elec- tric lamp, L, from which I intend to send a cylinder of light through the tube. The tube is now half filled with water, the upper surface of which cuts the tube in two

JSTLUESCB OF THKXKKEBS.

sqjoal -pants horismtally. Thus I send half of my beam liroagh air and balf through water, and with this lens, c, [intend to project a magnified image of the adjacent end if the tube, upon the screen. Here it is ; yon see the image, o p, composed of two semicircles, one of which is Ine to the light which has passed through the water, the other to the l^t which has passed through the air. Side bj side, thus, you can compare them, and you notice that while the air semicircle is a pure white, the water semicir- de is a bright and delicate blue green. Thus, by augment- ing the thickness through which the light has to pass, you deepen the colour ; this proves that the destruction of the G^t rays takes place within the absorbing body, and is not u eflfect of its surface merely.

Melloni shows the same to be true of radiant heat. In our table, at page 311, the thickness of the plates used was 2*6 nullunetres, but by rendering the plate thinner wo en- «Ne a greater quantity of heat to get through, and by ren- dering it sufficiently thin, we may, with a very opaque sub- stance, almost reach the transmission of rocksalt. The fol- lowing table shows the influence of thickness on the trans- missive power of a plate of glass.

Tblekncmof

Tnoamiaslon bj GItfs of different thfcknosMs; per centoffs of

the total BadlaUon

Plate* In MUH- metrw

Locatelli Lamp

Ineandeeeent Platinum

Copper at 400* C

Copper at lOO'C.

2-6 0-5 (K)7

Thus, we sec, that by diminishing the thickness of the Jate from 2*6 to 1*07 mllimetres, the quantity of heat ransmitted rises, in the case of the lamp of Locatelli, from

LEtJTUHB tX.

39 to ?7 per cent. ; in tlio case of tho incandescent phli- num, from 24 to 57 percent.; in the case of copper at 400° C. from 6 to 34 per cent. ; and in the caso of conntat 100° C, from absolute opacity to a transmission of la per cent.

The influence of the thickness of a plate of seleidte on the quantity of heat which it traasnutB is exhibited in the follo^'iiig- table.

ThloknсB of

uf total ndiKtDD.

LontdUEamp

18 Gl

7 El

Tho dcoompoaition of the solar benm gives us the solar ppectmm; luminous in tho centre, calorific at one end, and chemical at the other. Tbo sun is therefore a sonrce of heterogenons rays, and there can scarcely be a donbt that all other Bonrcea of heat, limiinons and obscore, partake of this heterogeniety. In general, when snch mixed rays enter a diathermic snbstance, some are Btmck down and others permitted to pass. Sapposing, then, that we take a aheaf of calorific rays which h&ve already paseed throogh a dia- thermio platfi, and permit &em to fall upon a second plate of the same material, the transparency of this second plate to the heat incident upon it

will be greater than the trtou- parency of the first plate to the heat inddent on it In fact the first plate, if sofficiently thick, has already extin- guished, in great part, the rays which the anbstaitce is capable of absorbing ; and the residual rays, as a matter of coarse penetrate a second plate of the aame sabatanoe vith

STFTLN'd OF CALORIFIC EF^A^IS. ol! I

c«:»riii»ar:itivo frctMloin. The origmal beam ih Sf/hjd by the first plate, and the puritied beam possesses, for the same gabstanoc, a higher penetrative power than the original

This power of penetration has usually been taken as a of the ^uo^i^ of heat ; the heat of the purified beam is Bid to be different in quality from that of the unpurified beam. It is not, however, that any individual ray has AsDged its quality, but that from the beam, as a whole, certain rays have been withdrawn, and that their with- drawal has altered the proportion of the incident heat tranBmitted by a second substance. This, I think, is the true meaning of the term * quality ' as appled to radiant beat. In the path of the rays from a lamp let plates of rocksalt, alum, bichromate of potash, and selenite be suc- eessiYcly placed, each plate 2'6 millimetres in thickness ; let the heat emergent from these plates fall upon a second se- ries of the same thickness ; out of every 100 rays of this litter heal, the following proportions are transmitted.

Bocksalt . . 92*8

Chromato of Potash . 71

Selenite . , 01

Referring to the table, p. 311, we find that of the whole of the rays emitted by the Locatelli lamp, only 34 per cent, are transmitted by the chromato of potash ; here we find the percentage 71. Of the entire radiation, sele- nite transmits only 14 per cent., but of the beam which has been purified by a plate of its own substance it transmits 01 per cent. The same remark applies to the alum, which transmits only 9 per cent,

of the unpurified beam, and 90 per cent, of the purified beam. In rocksalt, on the con- trary, the transmissions of the sifted and unsifted beam

are the same, because the substance is eqiially transparent

SSB' LECTtrSE IX.

to ra;^ of all kiiidfi.* In tJicso cases I have supposed tlti rays emergent frum rocksnlt to pass through rocksalt; Ibe rays emergent from nluni to pass tlirongh alum, and so of the others ; hut, a» might be expecIeJ, the eit'tJng of the beaoi, by any substance, will alter the propoilion in which it will bo transmitted by almost any other second silr elance.

I will conclude these observations with an cxperimvnt whieh will isliow you the in6uenco of sifting in a yaj striking manner. I have licre a seneitive dlflWential aii- thcrmomtiter with a clean glass bulb. You eee the aligbt- cst touch of my hand oauaes & depression of the thenno- inetric cohmm. llero is our electric lamp, and from it I will convergu a powerful btam on the bulb of that thec- mometer. The fot'ua now falls directly on the bulb, and the air willliji U is travcrsetl by u bi>aiu of iiituiit-c power; but not tiie slighLesl depressiun li' tlie tiieriuuuitiuiv vuJ- unm is discernible. When I first showed this experiment to an individual here present, he almost doubted the eri- dence of his senses ; bnt the explanation is simple. The beam, before it reaches the bulb, is already sifted by the glass lens used to concentrute it, and having passed through 12 or 14 feet of air, the beam cont:uns no constit uent that can be sensibly absorbed by the air within the bulb. Hence the hot beam passes through both air and glass vithout warming either. It is competent, however, to warm the thermo-electric pile ; exposure of the pile to it, for a single instant, suffices to drive the needle violently aside ; or let me coat with lampblack the portion of the glass bulb struck by the beam ; yon see the effect : the heat is now absorbed, the air expands, and the thermo- mctric colnnm is forcibly depressed.

" ThU WM Melloni'fl condu^on; but thDeipcHmentaof IH. Pronxtaje and perains,

and of Mr. Balfour Stewart, prove tbat the tmxiaiiai Is not

ACTION OF GLASS FmE-SCKEENS.

*>.)'» 'j1'>

We use glass fire-screens, AvLicli allow the pleasant light of the fire to pass, while they cut off the heat ; the reason is, that by far the greater part of the heat emitted by a fire coiunsts of obscure rays, to which the glass is opaqae. Bat in no case is there any loss. The rays ab- sofbed by the glass go to warm the glass ; the motion of the ethereal waves is transferred to the molecules of the solid. But you may be inclined to urge, that under these cironmBtances the glass screen itself ought to become a source of heat, and that therefore we ought to derive no benefit from its absorption. The fact is so, but the conclu. aon is unwarranted. The philosophy of the screen is this :

— Let F (fig. 88) be a fire from which the rays proceed in straight lines towards a person at p. Before the screen is introduced, each ray pursues its course direct to p ; but now let a screen be placed at s. The screen intercepts the rays of heat and becomes warmed ; but instead of sending on the rays in their original direction only, it emits them, as a warm body, in aU directions. Hence, it cannot re- store to the person at p all the heat intercepted. A por- tion of the heat is restored, but by far the greater part is diverted from p, and distributed in other directions.

Where the waves pursue their way unabsorbed, no mo- tion of heat is imparted, as we have seen in thacase of the

8S4 LEOTOtE nc

^ tliennoraotcr. A joint of meat might bo roasU'd btfore a fire, with the Mr around the joint as cold as ice The mi on high moimtains may be intcnBoly cold, while a burning soil is overhead ; the solar rays which, strikiiig on the ho- mim ekin, are almost intoleTable, are incompcU'nt to best tho air eenaibly, and we have only to withdraw into perfect Bhado to feel tho cMU of the atmosphere. I never, on any

occasion, snifered so much from solar heat as in deecendinf from the ' Corridor ' to the Grand Plateau of Mont Blaue, on August 13, 1667 ; though hip deep in enow at the tim^ the Bun blazed against mo with vmondurable jiowor. Ist mersioa in the shadow of tho Dome da Gout6 at ontt changed my feelings ; for here the air was at a freeang temperature. It was not, however, aciisibly colder than the nir through which the sanbeams passed ; and I enffered, not from the contact of hot air, but from the impact of calorific rays which had reached me through a medium icy cold.

The beams of the Pun also penetrate glass without sen- sibly heating it, and tho reason is, tliat having pasGCil throug-h our atmoi^ph^re, tha beamd hare bsea ux a great measure deprived of those rays which can be absorbed by glass.* I made an experiment in a former leotnre which yon will now completely understand. I sent a beam from the electric lamp through a mass of ice without' melting the substance. I had previonaly sliced the beam by aend- ing it through a vessel of water, in which the rays capable of being absorbed by the ice were lodged — and so oopion>- ly lodged — that the water was raised almost to the boiling

* On (t priori grounds I should conclude (hat the obscnre aokr nji which have succeeded in gctUng through our atmosphere, must be able lo penetrate the honoun of the eje and reach the retina t the raocat eiperi- nients of M. Frani prove this. Tbeir not produdog ndoB ia, therefbn, not due to their abwiption bj the homouta of the e^e, btt to (hdr own Intrinsic incompetence to eicite tho retica.

BAmAnON THBOUOH OPAQUB BODDES. 325

point during the ezperixnent. Itiahere worthy of remark that the liquid water and the solid ioe appear to be pervi- 0118 and impervious to the same rays; the one may be used as a Mcoe for the other ; a result which indicates that the quali^ of the absorption is not influenced by the difference of aggregation between solid and liquid. It is easy to prove that the beam whidi has traversed the ice without melting it, is really a calorific beam, by aUowing it to Ml upon our theimo-electrio pile. Here

is a beam which has passed through a layer of water ; I permit it to fall upon the piley and yon instantly see its effect upon the galva- nometer, causing the needle to move with energy to its stops. Here is a beam which has passed through ice, but yon see that it is equally competent to affect the pile ; here, finally, is a beam which has passed through both water and ice ; yon see it still possesses heating power.*

When the calorific rays are intercepted, they, as a gen- eral rule, raise the temperature of the body by which tiiey are abiAirbed; but when the absorbing body is ice at a temperature of 32^ Fahr., it is impossible to raise its tem- perature. How then does the heat absorbed by the ice employ itself? It produces internal liquefaction, it takes down the crystalline atoms, and thus forms those lovely liquid flowers which I showed you in a former lecturcf

We have seen that transparency to light is not at all a test of diathermancy ; that a body highly transparent to the Inminous undulations may be highly opaque to the non- luminous ones. I have also given you an example of the opposite kind, and showed you that a body may be abso- lutely opaque to light and still, in a considerable degree, transparent to heat. I set the electric lamp in action, and

* Mr. Faraday has fired gunpowder by conyer^ng the solar rays upon it by a lens of ice.

f For the bearing of these results on air and water bubbles of ioe, see AppeniUx to Lecture IX«

LECrUfiE IX.

you see tUis convergent beam tracking itsGlf through tlie dust of the room : you see the point of convergence of the rays here, at a distance of fifteen foet from the lamp; 1 will mark that point accurately by the end of this rod. Here is a plate of rocksiUt, coated so thickly with soot thai, the light, not only of every gas lamp in this room, bat the electrio light itself, is cut off by it. I intcqx)se this plMc of smoked salt in the path of the beam ; the light is into^ cepted, bnt the rod enables me to find with my

pilo the place where the focus fell. I place the pile at this focna: yon see no beam £illing on the pile, but tho violent »cfim of the needle instantly Feveols to the mind's eye a focus of heat at the jKiint from which tho light has been wilb- drawu.

You might, perhaps, be disposed to think that tlie heat ihllhig on the- y'llc h^s bcuu jlvscrLcJ hy tho soot, iuid theo radiated from it as an independent source. Melloni has re- moved every objection of this kind ; bnt none of his expe^ iments, I think, are more conclusive, as a reftitationi of the objection, than that now performed before yon. For if the smoked salt were the source, the rays could not con- verge here to a focus, for the salt ie at thit side of t^e con- verging lens, and you aee when I displace my pile a little laterally, still keeping it turned towards the smoked salt, the needle sinks to zero.

Tho heat, moreover, falling on the pile is, as shown by Melloni, practically independent of the position of the plate of rocks^jt ; you may cut off the beam at a distance of fif- teen feet from the pile, or at a distance of one foot ; the result is sensibly the same, which could not be the case if the smoked salt itself were the source of heat.

I make a similar experiment with this black glass, and the result, as yon see, is the same. Kow the glasa r^fkOs a considerable portion of the light and heat from the lamp ; if I hold it a little oblique to the beam you can see the re-

PBOPOBTIQir OF YIBIBLE TO DTVISIBLE BAYS. 827

fleeted portion. While the glass is in this position I will oost it with an opaqne layer of lampblack so as to cause it to absorb, not only all the rays which are now entering it, bt also the portion which it reflects. What is the result ? Ihoiigh the glass plate has become the seat of augmented ibsorption, it has ceased to affect the pile, the needle de- cends to zero, thos furnishing additional proof that the ays which, in the first place, acted upon the pile, came di- eet from the lamp, and traversed the black glass, as light raTerses a transparent substance.

Rocksalt transmits all rays, luminous and obscure; Imn, of the thickness already given, transmits only the lu- ainous rays;* hence the difference between alum and rock- alt will give the value of the obscure radiation. Tested a this way, Melloni finds the following proportions of lu- oinons to obscure rays for the three sources mentioned : —

Sonree Lamlnoos Obacnro

Flame of Oil . 10 90

Incandescent Platinum 2 98

Flame of Alcohol . 1 99

rhus, of the heat radiated from the flame of oil, 00 per icnt. is due to the obscure rays ; of the heat radiated from acandesocnt platinum, 08 per cent, is due to obscure rays, rhile of the heat radiated from the flame of alcohol, fully ^ per cent, is due to the obscure radiations.

* Ifore recent experimenta prove that this ia not correct

APPENDIX TO LECTURE IX.

SI- I AVAILED myself of ttie flno Bunn; veafher wiUi whidi M

were favoured last Septcmbur and October, to examine the efiwls of solar heat upon ice. The cipcrimenta were made with Wen- haiu Lake and Norwiiy ice. Blabs were formed of the suliistanec, Tnrying from one to several inches iu thickness, anil these were placed iu Ibe path of a bciiii rendeieil convergent bva doable convex lens, 4 inches in diameter, posaesdtig a focal di>- tanee of 10^ inches. The slabs were usaaUy bo placed, that the focna of parallel rays fell within the ice. Having firet found ths position of the focus in the air, the lens was screened ; the ice wii then placed in position, the screen was removed, and the edect was watched through an ordinary pocket lena.

A plate of ice an inch thick, with parallel sides, was fint examined : on removing the screen the transparent mass wu crossed by the sunbeams, and the path of the rays through it wu instantly studded by a great number of little luminous spola, produced at the moment, and resembling shining air-bubbles. When the beam was sent through the edge of the plate, so that it trav- ersed a considerable thickness of the ice, the path of the beam could be traced by those brilliant spots, as it is by tho floating motes in a dark room.

In lake ice the planes of freezing are easily rccognixed by the stratified appearance which the distribution of the air bubUea gives to the substance. A cube was cut from a perftetly trans-

■ Phil. Trans. December 1867.

LIQUID FLOWEES IN ICE. ollO

parent portion of the ice, and the solar beam ^vas sent througli the cube in three rectangular directions successively. One was perpendicular to the plane of freezing, and the other two parallel to it. The bright bubbles were formed in the ice in all three

When the sur&ces perpendicular to the planes of freezing were examined by a lens, after exposure to the light, they were found to be cot Jsp by innumerable small parallel fissures, with here and there minute gpuiB shooting from them; which gave the fissures, in some cases, a feathery appearance. When the portions of the ioe trayersed by the bcsun were examined parallel to the surface of freezing, a very beautiful appearance revealed itscll Allow- ing the lig^t from the window to fiill upon the ice at a suitable incidence, the interior of the mass was found filled with little ilower-diaped figures. Each flower had six petals, and at its cen^ tie was a bright spot, which shone with more than metallic bril- llm^. The peUtU were manffegUif composed of teater, and were consequently dim, their visibility depending on the small difier- cnoe of xefhmgibility between ice at Sd"* Fahr. and water at the sune temperature.

For a long time I found the relation between the planes of these flowers and the planes of freezing perfectly constant. They were always parallel to each other. The devdopement of the flowers was independent of the direction in which the beam trav- ersed the ice. Hence, when an irregularly shaped mass of trans- parent ice was presented to me, by sending a sunbeam through it I could tell in an instant the direction in which it had been fkozen.

Allowing the beam to enter the edge of a plate of ice, and caumng the latter to move at right angles to the beam, so that the radiant heat traversed diflerent portions of the ice in succession, when the track of the beam was observed through an eye-glass, the ioe, which a moment ago was optically continuous, was in- stantly starred by those lustrous little spots, and around each of them the formation and growth of its associated flower could be distinctly observed.

The maximum efiect was confined to a space of about an inch from the place at which the beam first struck the ice. In this space the absorption, which resolved the ice into liquid fiowers,

> LECTTBG a.

for Iho moat part took place, but 1 liavn tmcod llxt effect to ■ depth of BL'verJil inches iu large blocks of ica

At n distance, Uowever, from the point of incidence, the epocsa Iictn'ccn the flowers became greater; anil it was no Dnconiinnn tiling to SCO flowers developed in planes » quarter of an indx apart, while no change wliaterer was observed in tlie ice between these planes.

The pieces of ice experimented on appeared to bo quite homo gecoas, and their traDsparenRy was very perfect. Why, then, did the BQbstance yield at partieuUr points } Were they weak poinls of crystalline structure, or did the yielding depend npon the Ban- ner in which the calorific waTCS impingod upon the moleculs of the body at these points) Howctbt these and other qntMioni may be answered, the

e-cpcriments have an important bearing upon ih.- miL-^lioii of aliforplion, Li ice tlif iiii-iirjilion whirli produces the flower is fitful, and not continuona ; and there ia do reason to suppose that in other solids the case is not the same, though their constitution may not be such aa to reyeal it.*

I have applied the tenn ' bubbles ' to the little bright disks in the middle of the flowers, simply becanae they resembled the Ut- tle mr-globules entrapped in the ice ; but whether they confained air or not could only be decided by experiment.

Pieces of ice were therefore prepared, thrangh which the sun- beams were sent, so as to doTslope the flowers in conndenbh quantity and magnitude. These pieces were then dipped into warm water contained in a glass Teasel, and the effect, when tba melting reached the bright spots, was careMly obserred through a lens. The momeat a liquid amneetion vku etUAUAed between (A«M and the atmotpKere, the hilNei tuddeidy eoBapmd, and no traee oj air rate to the tur/aca of the iearm teater.

This is the result which ought to be expected. Hie Tolome of water at 32° being less than that of ice at the same tempeiv ture, the formation of each flower ought to be attended with the formation of a vacuum, which disappears in the manner described when the ice surrounding it is melted.

■ XotirithstaQdiDe the incomparable diathcrmnac; of the Guhetance, U-KDubl:)ui:h finils that when plates of rockftit arc thick enough, theyalinjl ciliibit an elective absorption. EITccta like those above d poaaiUy be the cause of this.

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Similar ezpoimento wero inade with ice, in which trae air- nbbles were endoBed. When the mehing liberated the air, the obbles rose slowly through the liquid, and floated for a time [pan its snrfiuse.

Exposure for a second, oar eyen leas, to the action of the son was sufficient to derelope the flowers in the ice. The flrst appear- mce of the central star of light was often accompanied by an an- fiMa dink, as if the sabstance had been suddenly

mptored. The Bc^es of the petals were at the commencement definitdy curved ; but when the action was permitted to oontinae, and sometimes even withont this, when the sun was strong, the edges of the petals bo- cmie serrated, the beauty of the figure being thereby aug^mented.

Sometimes a number of dementary flowers grouped together to form a thichly-leayed duster resembing a rose. Here and there dso amid the flowers a liquid hexagon might be obseryed, but nch were of rare occurrence.

The act of crystalline dissection, if I may use the term, thus poformed by the solar beams, is manifestly determined by the aanner in which the crystalline forces have arranged the molc- cdes. By the abstraction of heat the molecules are enabled to Cmild themselyes together, by the introduction of heat this archi- tecture is taken down. The perfect symmetry of the flowers, from #hich there is no deyiation, argues a similar symmetry in the molecular architecture ; and hence, as optical phenomena depend upon the molecular arrangement, we might pronounce with per- lect certainty from the foregoing experiments, that ice is, what Sir Dayid Brewster long ago proyed it to be, optically speaking, Qoiazal, the axis being perpendicular to the surface of freezing.

On September 25, while examining a x>erfectly transparent piece of Norway ice, which had not been traversed by the con- deuaed sunbeams, I found the interior of the mass crowded with pualld liquid disks, varying in diameter from the tenth to the bondredth of an inch. These disks were so thin, that when looked it in section they were reduced to the finest lines. They had the ixact appearance of the circular spots of oily scum which float on he surface of mutton broth, and in the pieces of ico first exam- ned they always lay in tf:e planes of freezing.

As time pn^rceeed, tliU mtcmal diainte grotion of the Ice ap- peared to become more pronocnced, so that acme piK«e of Nor vra; ice oxaminoJ in the middle of NoTcmber appearei] lo b«»- duccd to a coDgeries of water-cells entangled in a

ekeletnn of ict The effect of this waa rendered mauifcst to the hand on aairii^ i block of this ice, b; the facility with which the siv went through it.

There; aeema io Ik; do sinch thing oa aboolutc homogiciiclt; in niiture. Change commeucea at distinct centres, instead of bdng unifomilj iind continuously dietributed, and iu the most itpp*!- cntly bumogeneoua eubatoDcc we ahould diBcovra* defecbi, if onr meana of observation were fine enough. The above obMrvationi show that eome portions of & mass of ioe molt moni RadU; tlt*n othen. The melting t«mpeisture of the sabstance ia rat down it i 38° Fuhr., but the absence of perfect homogeneity, whether from difference of crystalline teiture or some other cnuac, mak« Ibe melting temperature oscillate to a slight extent on both ddcsnf the ordinary itoudard. Let this limit, expressed in parts of a de- gree, be (. Some parts of a Mock of ice will melt at a tctnpen- ture of 83— f, while ijtbers reiiuire a tempenUore of S2+t: the conscqnence is, that snch a block raised to thetempcratweaf 32°, will have some of its parts liquid, and others solid,]

When a mass exhibiting the water-disks was examined by a ' concentrated sunbeam, the six-leaved flowers bcforo releEnd.lg , wen ali£ayi/orm«d infill planet of thcduh. ^i

What has been already said will prepare na for the condder*- tion of an associated class of phenomena of great physical inter- est. The larger masses of ice which I examined exhibited layen, in which bubbles of air were collected in oninual qnantity, maik- ing, no doabt, the limits of snccesdve acta of freezing. Tbtat bubbles were usually elongated. Between two such beds of bub- bles a clear stratum of ice intervened ; and a clear siii£k8 Isye^ which, fhim its appearance, seemed to have sufierad more £roiB external influences than the rest of the ice. Was aBsodated with each block. In this superficial portion I obeenred detached air- bubbles irregulariy distributed, and associated with cftch veeide

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bleb of water which had the appearance of a drop of clear A the solid. The adjacent figure will give a notion of nponte caTities : the nnshaded dr- aents the air-babble, and the shaded m^//m??m>^m^^K jacent, the water. W d i

a the quantity of water was snffir

uge, which was usually the case, on p /^ ^

the ice round, the bubble shifted its W. ^^ |

,Tiang always at the top of the bleb v/////////////////^^^^^^^ . Sometimes, howerer, the cell was , and the air was then quite snirounded by the liquid, mposite cells often occuired in pellucid ice, which showed f no other sign of disintegration. Is manifestly the same phenomenon as that which struck ris so forcibly during his ealier investigations on the gla- ihe Aar. The same appearances have been described by m. Schlagintweit, and finally attention has been forcibly 0 the subject in a recent paper by Mr. Huxley, published Philosophical Magazine.' *

only explanation of this phenomenon hitherto given, and apparently without hesitation, is that of M. Agassiz and isrs. Schlagintweit. These obserrers attribute the phe- ito the diathermancy of the ice, which permits the radi- to pass through the substance, to heat the bubbles of air, se them to melt the surrounding ice.t apparent simplicity of this explanation contributed to » general acceptance ; and yet I thin]^ a little reflection w that the h3rpothesis, simple as it may appear, is attend- grave difliculties.

^ sake of distinctness I will here refer to a most interest- observed first by M. Agassiz, and afterwards by the Messrs. ttweit In the * Systdme Gladaire ' it is described in these

It Evident pour qniconque a suivi leprogrte do la physique mo-

16 ce phSnom6ne est dft uniqaement k la diatherman6it6 de la

tMae, Systdmc, p. 167).

Vmbot ist dadnrch enstanden dass die -Loft Wftrmestrablen absor-

Iche das Eis als diathermaner Eorper dorchliess (Schlagintweit,

ivngon, S. 17).

DH'S iiuizimni liisciisiMU . oimhi, in |nupuiiiuii il^» iiiv-\ tran^parnit drop sliows itself at some point of the bub drop, in (iilnrLiiiiii, contril'Utcs on its j)art to the enlar the < avit y, and I'ollowin*^ its])ro^ress a little, it liui?h doMiinating over the bul)ble of air. The latter then sw midst of a zone of water, and tends incessantly to read clcyated point, at least if the flatness of the cavity do derit.'

The satisfactory explanation here spoken of is tfai mentioned : let us now endeayoor to foUow the hypgti consequences.

Comparing equal weights of both sabstancea, fhe fl| of water being 1, that of air is 0*26. Hence t9 raise i water one degree of temperature, a pound of air won! lose four degrees.

Let us next compare equal volumes of the substai specific gravity of water l)eing 1, that of the air is i^l pound of air is 770 times the volume of a pound of t hence, for a quantity of air to raise it$ own tdume of degree, it must part with 770x4, or 8,080 degrees of te

Now the latent heat of water is 142*6® Fahr., hence tity of heat required to melt a certain weight of ice is 1 the quantity required to raise the same weight of wa grcc in temperature ; hence, a measure of air, in order its own volume of ice to the liquid condition, must Ic 142-6, or 439,208 degrees of temperature.

This, then, gives us an itlea of the amount of heat

AflSOGEAnED BUBBLES 07 AIB AHD WATER. 335

nenoeB to the deniflenB of the earth ; for we ehonld dwell at the lottom of an atmospheric ocean, the upper strata of which would Ifectnally arrest all calorific radiation.

It is established by the experiments of Ddaroche and Mel- 4»i,^ that a cal(»ific beam, emerging from any medium which it liaa tiay^sed for any distance, possesses, in an exalted degree, die power of passing through an additional length of the same mbstance. Absorption takes place, for the most part, in the por- doii of the medium first traversed by the rays. In the case of a plate of glass, for example, 17^ per cent of the heat proceeding from a lamp, is absorbed in the first fifth of a millimetre ; where- Bs, after the rays haye passed through 6 millimetres of the sub- stance, an additi<mal distance of 3 millimetres absorbs less than 2 per cent, of the rays thus transmitted. Supposing the rays to haye passed through a plate 25 millimetres, or an inch, in thick- nen, there is no doubt that the heat emerging from such a plate would pass through a second layer of glass, 1 millimetre thick, without suffering any measurable absorption. For an incompar- ably stronger reason, the quantity of solar heat absorbed by a bubble of air at the earth^s surface, after the rays haye trayersed the whole thickness of our atmosphere, and been sifted in their passage through it, mut be wholly inappreciable.

Such, if I mistake not, are the properties of radiant heat which modem physics haye revealed ; and I think they render it evident that the hypothesis of M. Agassiz and the Messrs. Schlagintweit was accepted without due regard to its consequences.

But the question stiU remains, how are the water-chambers produced within the ice ? . . . One simple test will, I think, de- cide the question whether the liquid is, or is not, the product of melted ice. If it be, its volume must be less than that of the ice which produced it, and the bubble associated with the water must he composed of rarefied air. Hence, if on establishing a liquid con- nection between this bubble and the atmosphere a diminution of

* La Thermochrosc, p. 202.

yalome be observed, this will indic&te that tlic water liU Uta] produced by the mcltiog of the ic«.

From a block of Norway ice, eontaiiiing euch compound ban- ■ blea, I cut a prism, and immereing it in warm water, coutaiiicd in a glasa vcsset, I cnrefully watched through the dde of the tmmI the effect of the melting opon the bubblea, T'hty inrariiMy thmii in vohim^ at tlie mome'tt tie aumninding ice wot milud, and the dimioished globulea of air rose to the Eurfuce of the water. I then arranged matters so that the wall of the can^ might lie melted away undtineath, without permitting the bubble of sir tt the top to escape. At the moment the melting reached the Mfitj the air-bubbles instantly collapsed to a Ephere possesung, in fmi case«, far leas than the hundredth part of ita ori^nal TolDiot i The experiments were repeated with sereral dbtinct tatae» flf ke, and always wiih the same result. I think, therefore, it may bo regarded as certain that the liquid cells are the product of melted

Considering the manner in which ice imported into this coun- try ia protected from the solar rays, I think we must infer that in the specimens examined by me, (A* im inronta^ with tliebvM* hat been tneUed by heat, Khidi liat been condueted through tki « ~ Itatice a-ithovt vintHe pnjudice to iU totidUy.

Paradoxical as this may appear, I think it is no more tltsa might reasonably l)c oipecled from A priori con si 'i prat ions. The beat of a bo.ly is refi^rreil, at \U<- t'ri.M-nl &.<y. t.i a motion of its particles. When this motion reaches an intenity sufficient to liberate the particles Of a solid from their mutnal ottractionB, the body passes into the liquid condition. Now, as r^arda the amount of motion necessary to produce this liber^ of liquidity, the particles at the surface of a mass of ice must be very differmt- ly circumstanced from those in the interior, which are infloenoed and controlled on every side by other parliclea. But if we nip- poae a cavity to exist within the mass, the particlea bounding that cavity will be in a state resembling that of the particles at the surface ; and by the removal of all oppo^g action on one side, the molecules may be bberated by a force which the sominndiiig moss has transmitted without prejudice to its solidity. Suppoa-

■ This of course refera only to the lake ice eioiniiied as described.

LIQUEFAOHOlf BY OQNDUCfnON THBOUOH ICE. 337

for example, that solidity is limited by molecnlar yibrations certain amplitade, those at the sor&ce of the internal caTity exceed this limit, while those between the cavity and the ex- il snr&ce of the ice may, by their reciprocal addons, be pre-)d within it, just as the terminal member of a series of elastic Is detached by a force which has been transmitted by the r members of the series without yisible sqmration.* Hiere, however, experiment is within reach we ought not to . to specolation ; and I was particolarly anxious to obtain an uivocal reply to the question whether an interior portion of » of ice could be melted by heat which had passed through nhstance by the process of ccmdueUon, A piece of Norway »ptaining a great number of the liquid disks already de- led, and several cells of air and water, was enveloped in tin- and placed in a mixture of pounded ice and salt. A few iCes sufficed to freeze the disks to thin dusky circles, which tared, in some cases, to be formed of concentric rings, and uded me of the sections of certain agates. Looked at side- ii these disks were no thicker than a fine line. The water- were also frozen, and the associated air-bubblcs were greatly nished in size. I placed the mass of ice between me and a ight, and observed it through a lens : after some time the I and vfrater-cells showed signs of breaking up. The rings of tisks disappeared ; the contents seemed to aggregate so as to , laiger liquid spots, and finally, some of them were reduced ear transparent disks as before.

hit an objection to this experiment is, that the ice may have liquefied by the radiation from the lamp, and I have experi- ss to describe which will show the justice of this objection. Btangular slab, 1 inch thick, 8 inches long, and 2 wide, was ifore taken fh>m a mass of Norway ice, in which the associat- LT and water-cells were very distinct. I enveloped it in tin- and placed it in a freezing mixture. In about ten minutes vater-blebs were completely frozen within the mass. It was ediately placed

in a dark room, where no radiant heat could ibly afiect it, and examined every quarter of an hour. The frozen spots gradually broke up into little water parcels, and

* Of course I intend this to help the conception merely. 15

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in two bonre tbe watcr-bleba wore pcrTocUy restored in tho centre of the Blab or ice. When last ex:iinineil, tliis plate via h&lf u inch thick, and the drops of liquid were Rcen right at its centre.

A second piccir, Bimiliifl}' frozen and wrapped up in tlannd, showed the sunic deportment. In in hour nnd a half the &oun water BuiTounding the UJ-bubblea was restored to its liquid md- dition. Ilcnce no doubt can remain as to the possibilitj of effect- ing liquefaction in the interior of a mass of ico, by bissl wbich has parsed by ei>ndiietioii through the BUbetance without oM^tiiig iL

I hare already referred to tbe formntion of the liqaid cariiiffl ohaerred by M. Agoasiz, when glacier ice uraa exposed to the ain. The eame effect may he produced b; exposure to n glowtcg rail fire. On the Slst and S2od of Noveinber, 1 thus exposed plalo of clear Wenham Lalte Ice, which contained Bome Bcnttered u^ bubbles. At first the bubbles were aliarjily rounded, and wilUonl any trace of water. Boon, Lowever, those near the surface, on which the radiant heat fcU, appeared encircled by a liquid rin^,

©which expanded nnd finally became crimped at ita border, as shown in the adjitcent figure. The crimping becaiiK more pronounced 09 the action waa permitted tocoutinm.' A second plate, crowded with bubbles, was held oa near to the fire 03 the band could bear. On withdrawing it, and csanrining it through a pocket lens, the appearance was perfectly beantiM In many cases the bubbles appeared to be surrounded by a scria of concentric rings, the outer ring surrounding all the otheiB like a crimped frill.

I could not obtain these efTecIs by placing the ice in contact with a plate of metal

obscurely hented,+ nor by the radiation from an obscure source. Indeed ice, as before remarked, is impcrrions to radiant heat from such a souTce.| The rays irom a couunun

■ The blcba observed In glacier ice nlso cjhibit this form : see fig. B, plate 6, of the Atlns to the ' Systenic Glaciaire.' In Eg. 13 hc huve alM i close reacmblunce of the flowcr-sliapcd figures produwd bj radiant heit in lake icf.

f TodoTeiope water-cavities witfiin ice a conBirferable time ianecesstir; more time, indeed, than naa sufficient to melt Ihe entire pieces of ice nuuie "Hse of in these contact eipcrimente.

{ Hence the soundness of the ice under the morunes ; the son's np are eonverted hito obscure heat by the OTcrlying debris ; this only aflbctt a

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ire a]flo are wholly absorbed near the sor&oe upon which they (trike, and hence the described internal liquefaction was confined U> a thin layer close to this surface.

But not only does liquefaction occur in connection with the tmbblea, but the * flowers,* already described as produced by the lolar beams, start by hundreds into existence, when a sUib of bransparent ice is placed before a glowing coal fire. They, how- Bver, are also confined to a thin stratum of the substance close to the Burface of incidence. In the experiments made in this way, the central stars of the flowers were often bounded by sinuous finea of great beauty.

The fbregqing considerations show that liquefaction takes pkoe at the sur&ce of a mass of ice at a lower temperature than Ihai required to liquefy the interior of the solid. At the surface Qie temperature 82° produces a yibration, to produce which, with- bi the ice, would necessitate a temperature of 82*^+^; the incre- ■ent it being the additional temperature necessary to oyercomc Qie resistance to liquefaction, arising from the action of the mole- cules upon each other.

Now let us suppose two pieces of ice at 82°, with moistened to be brought into contact with each other, we therd>y trarufer the touching portions of these pieces from the sur- foes to the interior, where Z2+x is the melting temx)erature. Liquefaction will therefore be arrested at those surfaces. Before being brought together, the surfaces had the motion of liquidity, but the interior of the ico has not this motion ; and as equilibrium will soon set in between the masses on each side of the liquid film and the film itself, the film will be reduced to a state of motion inconsistent with liquidity. In other toords, it tDtll he frozen, and mU cement the two surfaces of ice letween which it is enclosed*

K I am right here, the importance of the ph3r8ical principles

layer of infiniteaimal depth, and cannot produce the disintegration of the deeper ice, as the direct sunbeams can.

* It is here implied that the contact of the moist surfaces must be so perfect, or, in other words, the liquid film between them must be so thin, as to enable the molecules to act upon each other aeroaa it The extreme tenuity of the film may be inferred from this. A thick plate of water within the ice would facilitate rather than retard liquefaction.

APPENDIX TO LECTCHE n.

BiilBciciitly manifest ; if I am wrong, I hope I hm D. BBcii mj'scif as to render the iktectioo of mj error eur.

Rif^ui. vt wrong, m; aim has been to give as explicit utteraitutt m; mcanisg as the subject will admit of.

Mr. Farodoy's cxperi tnxuTig togethcrofpieMsof

ico at 82" Fahr., and al muted in thb paper publiiilud

by Mr. Huilej and n explanation in the prindplfi

htce laid down. TIi anow into nfivf, and of Mink

iDt4> glacier, is pci illustration of the Bame)

ciple. It has lieei tied to mo that the itiG]

together of two pieeee i^. .» ^_j ~^ an act of cofac^on, ginili that which enables pieces of wetted glass, and other HffiilM i bodies, to stick together. This is not the case. There is no diii- ing motion posaiblo to the ice. When contact is broken, it breafe witit the snap due to the rupture of a solid. Glass and ice canDot ' be made to stick thus ti-^gethcr, neither can glass and glass, nor alum and alum, nor nitre and lutre, at common temperaturra. I have, moreover, placed pieces of ice together over night nnd KinDtl them in lip mominy so rigidly fi-oicn togcihcr that whea 1 soEglil

to separata them, the Biuface of fracture passed throngli one of them in preference to taking the snribce of r^elation. Many BogacioQS persons have also su^ested to me that the ioe tran*- ported to this country from Norway and Wenham Lake may poambly retain a residue of its cold, sufficient to freeze a thin fiha enclosed between two pieces of the substance. But the &ct8 al- ready adverted to are a sufficient reply to this snimise. The ice experimented on camiot be regorded as a magazine of cold, leeaim paraU of liquid itatfr erut teithin U.

[March 27, 1862.]

AfiBORPnOH or HIAT BT GASEOUS MATTER — ^APPARATUS EMPLOTED^EAIILT DimCrLTIES — ^DIATHERMAKCT OF AIB AMD OP THE TRAKSPARENT ELE- MEVTAmT OASES — ^ATHERMAKCT (oPACITT) OP OLEPIAMT GAS AMD OF TUE OOMPOUKD GASES — ABSORFTIOM OF RADIAMT HEAT BT TAPOCRS — RADIA- TION OF HEAT BT GASES — RECIPROCITT OF RADIATION AMD ABSORPTION —INFLUENCE OF MOLECULAR COKSTITUTION ON THE PASSAGE OF RA- DIANT HEAT.

IN our last lecture we examined the diathermancy, or transparency to heat, of solid and liquid bodies ; and we then learned, that closely as the atoms of such bodies are

packed together, the interstitial spaces between the atoms afibrd, in many cases, free play and passage to the ethereal undulations, which were transmitted without sensible hin- drance among the atoms. In other cases, however, we found that the molecules stopped the waves of heat which impinged upon them ; but that in so doing, they them- selves became centres of oscillation^ Thus we learned that while perfectly diathermic bodies allowed the waves of heat to pass through them without suffering any change of temperature, those bodies which stopped the calorific flux became heated by the absorption. Through ice, itself, we sent a powerful calorific beam ; but as the beam was of such a quality as not to be intercepted by the ice, it passed through this liighly sensitive substance without melting it. "We have now to deal with gaseous bodies ; and here the interatomic spaces are so vastly augmented, the molecules

849 LEcmtE X.

are so completely released from all mutual entanglemenl, that we Bhould be alinost justified in eoiiclmling that g, and vapours furnish a perfectly open door for the passage of tlie calorific waves. This, indeed, untol quite recently, , was tho nniversal belief, and the conclusion was verified by \ Buch esperiiticnts as had been made on atmospheric air, which was found to give no evidence of absorption.

But each succeeding year augments our expcriraeaia] powers ; our predecessors were often obliged to fight wiUi flints, where we may nsc swords, and hence the conflict i with Nature is not decided by their discomfiture. LetoS, then, test once more the diathermancy of atmospheric air. We may make a preliminary essay in the following way: I have here a hollow tin cylinder a b (fig, 89), i feet long, and neiirly 3 inches in diniiicter, through which we may seud our calorific rays. AYe must, howivcr, be able to cora- [lai'u the poeeagu uf lite ra-ya through tha air, with tticir passage through a vacuum, and hence we must have some means of stopping the ends of our cylinder, bo as to be able to exhaust it. Here we encounter onr first

experi- mental difficulty. As a general rule obBcure heat is more greedily absorbed than luminous heat, and as our object is to make the absorption of a highly diatJiermio body senu- ble, we are most likely to efiect this object by employing obscure heat.

Our tube, therefore, most be Etopped by a substance which permits of the free passage of such heat. Shall we use glass for the purpose ? An inspection of tho table at pi^ 311 shows ue, that for such rays plates of glass would be perfectly opaque ; we might as well stop our tube with plates of metal. ObBor\-e here how an liivestigator's results are turned to account by his successors. From one experi- ment buds another, and science grows by the continual deg- radation of ends to means. Had not Melloni discovered the diathermic properties of rocksalt, we should now be nt-

FIEST EXrEEDIIIXTS Wrril tJAEES. .,lo

terlj at tk loss. For a time, however, I tab extremely hain> pered by the difficulty of obtaining plates of salt Boffiuendy large and pare to stop the ends of my tnbe. But a sdentifio Torker does not long lack help, and, thanks to such fiiend- ly aid, I have here plates of ^lie precious substanoe vhich, by means of these caps, I can screw ur-tight on to the ends

of my cylinder*. Yon observe two stopcocks attached to the cylinder ; this one, c, is connected with an alr-pnmp, by

* At K time when I ms ^reatl j in need of > mpply of rocksolt, I etatcd Dij wants in tlie ' Fhiloeopbical UagKzinc,' uvX met with to immediale re- •poDBo from Bir John HerscheL Ho sent mc a block of salt, ftccompamed bj a note, fram which, as it refen to Ifao purpose for wMch the salt vu originally designed, I will make an extract. I hayo not yet been able to examine Ihe eitremelj lemaikable point to which the eminent writer dj- raotR mj attenSon. I am also greatly indebted to Dr. Siabo, the Hunga- rian CanmiMioQei to the International EitdbiUon, by whom I have been

lately raised to compantive opulence, as regarda the poasGaaJonoTrockaalt To the HcBra. Fletcher, of Northwicb, and to Ur. Corbett, of Brom»- grave, my best thanks are also due for their obliging kindncsti.

Hecefollowi the extract from 8ir J. Heiecbel's note : — 'After the pabli- oation of my paper in the Fbll. Trans., 1840, 1 was very dcalroui to disen- gage myself from tha influenca of glass prions and lensee, and ascertain, if poaaible, whether in reality my insulated heat qwta ^7>iin thcspectnun

.be COD be exhaiieUtd ; while tbi'ougfa this oUier , ^uoi allow air or an; otiier gas to enter Lhe tube.

ciL one end of the cylinder I place this Leslie's csbe r, vJnt:uning boiling water ; smd which is coated vilh tuup- black, to augment its nowor of radiation. At tlie other end of Iho cylinder etatii i^slectric pile, from which J

wires lead to the gai Between the eud of the l,

cylinder and the so I have introduced a tin ^|

screen, t, which, whtu a, will allow the calorific

rays to pass tlirough tl he pile. We first eihaort

the cylinder, then en a little aside, and now

the rays are travet and falling npon lhe pile

The tin screen, you uuserY _ only partially withdrawn, and the steady deflection produced by the heat at present transmitted is 30 degrees.

Let ns now admit dry air ; I can do so by means of the cock c', from which a piece of flexible tubing leads to the bent tubes r, u', the use of which I will now explain ; c is filled with fragments of pumice utone moii^tciJed with a fo- lulion of caustic potash ; it is dfstiucd to withdraw what-

were of solar or tcrrcatiiil origin. RocVsalt waa the obvloua resource, uA titer man; and fruitlcsa cndenvoura to obtain Bufficientlj' targe tni pan specimens, the late Dr.

Somcrvilje waa so good as to send me (u I under stood from a friend in Ctieshirc) the very Gne block which I now fbrwird. It IB, however, much cracked, but T hare no doubt pieces large enough Tor lensea and prisma (especially if cemented together) might be got from it.

' But I was not prepared for the worliing of it — eridentlj a very delicate and difficult process, (I proposed to diuolve off the eomen, Ac, and, as it were, lick it into shape) and though I hare never quite lost sigbt of tbe matter, I have not jct been able to do anything with it : meanwhile, I put it by. On looking at it a year or two oiler, I was digmayed to find it had lost much by deliquescence. Accordingly, I potted it up in aalt in u earthen dish, with iron rim, and placed it on an upper ibelf ta a room with an Arnott eUtvc, where it has remained ever since.

' If you should find it of any uac I would aak yon, if posrible, to repeat my cipcrimcnt ta described, and settle that pwnt, whidibaa always stnck nc OS a very important one.'

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nrer oarbonio sdi may be contuned in the air ; u' is a sim- br tube, filled with fragments of pmnice stone moistened irith snlphoric acid ; it is intended to absorb the aqueous rqioiir of the air. Thus the air reaches the cylinder de- prived both of its aqueous vapour and its carbonic acid. It if now entering, — the mercury-gauge of the pump is de- icending, and as it enters I would beg of you to obser\'c the needle. If the entrance of the air diminish the radia- tion through the cylinder — ^if air be a substance which is eompetent to destroy the waves of ether in any sensible d^ree — ^this will be declared by the diminished deflection of the galvanometer. The tube is now full, but you see no diange in the position of the needle, nor could you sec any diange even if you were close to the instrimient. The air thus examined seems as transparent to radiant heat as the vacuum itself.

By changing the screen I can alter the amount of heat fidling upon the pile ; thus, by withdrawing it, I can cause the needle to stand at 40% 60°, 60°, 70° and 80° in succes- Bon ; and while it occupies each position I can repeat the experiment which I have just performed before you. In DO instance could you recognize the slightest movement of the needle. The same is the case if I push the screen for- ward, so as to reduce the deflection to 20 and 10 degrees.

The experiment just made is a question addressed to Nature, and her silence might be construed into a negative reply. But a natural philosopher must not lightly accept a negative, and I am not sure that we have put our question in the best possible language. Let us analyse what we have done, and first consider the case of our smallest do- flection of 10 degrees. Supposing that the air is 7iot per- fectly diathermic ; that it really intercepts a small portion — say the thousandth part of the heat passing through the tube — that out of every thousand rays it struck down one ;

should we be able to detect this execution ? This absorp-

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tion, if it took place, would lower the Jcflcction the thon- Bondth part of ten degrees, or the huixlreiltli part of one degree, a diminution which it would he impossihlc for yon to nee, even if yon were close to the galvanometer.* lu the case here supposed, rfw total quantity of iieat faUiny upon the pile is go ineonsideraMe, that a tmutU ^fraction t{f iV, even \f absorbed, might wvU escape detection.

But we have not coidined ourselves to a email qoantity of heat ; the result was the same when the doflcctioD was 80*" as when it was 10°. Here I must ask you to sharpea your attcnlion and accomiwiny me, for a time, over rather difficult ground. I want now to make clearly intolligible to you an hnporlrtnt peculiarity of the galvanometer.

The needle being at zero, let us suppose a quantity of heat to fall upon the pUe, Buflicient to prodnce a deflection of one degree. Suppose that I afterwards augment

the quantity of heat, so as to produce deflections of two de- grees, three degrees, four degrees, five degrees ; I then know that the quantities of heat which prodnce these de- fleclions stand to each other in the ratios of 1 : 2 : 3 : 4 : 5 ; the quantity of heat which produces a deflection of 5° be- ing exactly five times that which produces a deflection of 1°, But this proportionality exists only so long as the de- flections do not exceed a certain magnitude. For, aa the needle is drawn more and more aside from zero, the cui^ rent acts upon it at an ever augmenting disadvantage. The case is illustrated by a sailor working a capstan ; he always applies his strength at right angles to the lever, for, if he applied it obliquely, only a portion of that strength would be effective in turning the capstan round. And in the case of our electric current, when the needle is very oblique to the current's direction, only a portion of its force

*Tt win tw borne in mind tbati era here spctluog of galvanonulrit

not of Ihcrmomtlrit degrees.

is effective in moYing the needle round* Thus it happens, that though the quantity of heat may be, and, in our case, is, accurately expressed by the strength of the current which it excites, still the larger deflections, inasmuch as they do not give us the action of the whole current, but only of a part of it, cannot be a true measure of the amount of heat falling upon the pile.

The galvanometer now before you is so constructed that the angles of deflection, up to 30^ or thereabouts, are proportional to the quantities of heat ; the quantity neces- sary to move the needle from 30^ to 31° is nearly the same as that required to move it from O" to l'^. But beyond 30" the proportionality ceases. The quantity of heat required to move the needle from 40° to 41° is three times that ne- cessary to move it from 0° to 1° ; to deflect it from 50° to 51° requires five times the heat necessary to move it from 0° to 1° ; to deflect it from 60° to 61° requires about ten times the

heat necessary to move it from 0° to 1° ; to de- flect it from 70° to 71° requires nearly twenty times, while to move it from 80° to 81° requires more than fifty times the heat necessary to move it from 0° to 1°. Thus, the higher we go, the greater is the quantity of heat represent- ed by a degree of deflection ; the reason being, that the force which then moves the needle is only a fraction of the force really circulating in the wire, and hence represents only a fraction of the heat falling upon the pile.

By a certain process, which I will not stop here to de- scribe,* I can express the higher degrees in terms of the lower ones; I thus learn, that while deflections of 10°, 20°, 30°, respectively, express quantities of heat represented by the numbers 10, 20, 30, a deflection of 40° represents a quantity of heat expressed by the number 47 ; a deflection of 50° expresses a quantity of heat expressed by the num-

* See Appendix to I^^cturo X.

MS LECTTBB X.

bcr 80 ; wliUo the doflections 60", 10°, SO", exproEB qufr titiea of heat wliich increase in a modi more rajiid ia& than the defiectioos theniBelves,

What is the upshot of this analysia ? It will drive w, I think, to ft better method of questioning Nature. It leatls to the reflection that, when we make onr auglea tmall, the quantit}' of heat faUhig on the pile is 8o inconaidcrabie, that oven if a fraction of it were absorbed, it might escape do- teotion ; while, if we make our dcflecdona large, by em- j)!ojTng a powerful flux of heat, the needle is in a pontion from which it would reqnire a considerahlo additicm or abstraction of heat, to move it. The l,0OOUi part i>f tho whole radiation in the one ease would be too Bmall, abso- liit^ly, to bo measured ; the 1,000th part in the other case might be somelhing considerable, witiiont, however, being considerable enough to affect the needle in any aensible de- gree. When, for example, the deflection is over 80°, an augmentation or diminution of heat, equivalent to 15 or 20 of the lower degrees of

the galvanometer, would be scarce- ly measurable.

We are now face to face with our problem ; it !b this, to work with a flux of heat so lai^ that a small fractional part of it will not be inflnitesimal, and still tji keep out needle in its most sensitive position. If we can accom- plish this we shall augment Indeflnitcly our experimental power. If a fraction of the heat, however small, be inter- cepted by the gas, we can augment the absolute v<dae of that fraction by augmenting the total of which itiaa fraa- tion.

The problem, happily, admits of an efieotive practical solution. You know that when we allow heat to fall opon the opposite faces of the thenno-electrio pile, the currents generated neutralise each other more or less ; and, if the quantitieB of heat falling upon the two faces' be perfectly equ^ the nentralisatton is complete. Our galvaaometer

DIFBOVED AFPASATUS. 849

needle ib now deflected to 80^ by the flux of heat passing throngh the tube ; I nncoyer the second face of the pile, famish it with its conical reflector, and place a second cube of boiling water in front of it ; the needle, as yon see, de- scends instantly.

By means of a proper adjusting screen I can so regulate the quantity of heat falling npon the posterior face of the pile, that it shall exactly neutralise the heat incident npon its other face : this is now efiected ; and the needle points to zero.

Here, then, we have two powerful and perfectly equal fluxes of heat, falling upon the opposite faces of the pile, one of which passes through our exhausted cylinder. If I allow air to enter the cylinder, and if this air exert any ap- preciable action upon the rays of heat, the equality now existing will be destroyed ; a portion of the rays passing through the tube being struck down by the air, the second source of heat will triumph ; the needle, now in its most sensitive position, will be deflected ; and from

the magni- tude of the deflection we can accurately calculate the ab- sorption.

I have thus sketched, in rough outline, the apparatus by which our researches on the relation of radiant heat to gaseous matter must be conducted. The necessary tests are, however, at the same time so powerful and so delicate, that a rough apparatus like that just described would not answer our purpose. But you will now experience no diffi- culty in comprehending the construction and application of the more perfect apparatus, with which the experiments on gaseous absorption and radiation have been actually made. See Plate I., at the end of the volume.

Between s and b' stretches the experimental cylinder^ a hollow tube of brass, polished within ; at s, and s', are the plates of rock salt which close the cylinder air-tight ; the length from s to s', in the experiments to be first recorded,

t6(t I,ECTtTBE Z.

in 4 feet, c, the source of heat, is a cube of cast oo]i|)er, filled with wat«r, which is kept continually lioiling by tlie lauip i~ Attnchcrl to tJie cuho c by brazing is the ehort cylinder f, of Ilic same diamelor as liie expcrimcntul cyUn- der, and capable of being conneotcil air-tigiit with the lat- ter at s. Tims between the source c and the end s' of the c-\periniental tube, wo have the front chanib^ f, from which the uii- can be removed, eo thut the rays from (he eourco will enter the cylinder b s' unsifted. To prerenl the heat from the source c parsing by conduction to lite plate at s, the chamber f is caused to pass through the vessel T, in which a Btream of cold water continually drcn- latcB, entering through the pipe » i, which dips to the bot- tom of the vessel, and escaping through the woBte-pipe e t. The experimental tube and the front chamber are connect- ed, independently, with the air-pump a a, so that either of them may bo exhausted or filled without interfering with the other, I may remark that in later arrangementB tio experimental cj-linder n';is aiippoitcd spurt from ihe pump, being connected with the latter by a flexible tube, lie tremulous motion of the pump, which occurred when the connection was rigid, was thns completely avoided.

p is the thermo-electric pile, placed on its stand at the end of the experimental tube, and furuished with its two conical reflectors, c' is the compeiwxting cube, used to neutralise the radiation from c ; h is the a^tuting screen, which is capable of an exceedingly fine motion to and fro. N N is a delicate galvanometer connected with the pile p, by the wires w w'. The graduated tube o o (to the right of the plate), and the appendage m k (attached to the cen- tre of the experimental tube) shall be referred to more par- ticularly by and by.

I should hardly sustain your interest in stating the ^ffi- cnlticB which at first beset the investigation condacted with this apparatus, or the numberless precautious which the

AGfnON OF ATMOBPHKBIO AIB. 351

ezJKSt balancing of the two powerfiil sources of heat, here rasorted to, rendered necessary. I believe the experiments made with atmospheric air alone might be numbered by tens of thousands. Sometimes for a week, or even for a fortnight, coincident and satisfactory results would be ob- tained; the strict conditions of accurate experimenting would i^pear to be found, when an additional day's ex- perience would destroy the superstructure of hope, and ne- cessitate a recommencement, under changed conditions, of the whole enquiry. It is this which daunts the experi- menter ; it is this preliminary fight with the entanglements of a subject, so diurk, so doubtful, so uncheering ; without any knowledge whether the conflict is to lead to anything wortfi possessing, that renders discovery difficult and rare. But the experimenter, and particularly the young experi- menter, ought to know, that as regards his own moral man- hood, he cannot but win if he only contend aright. Even with a negative result, the consciousness that he has gone fair- ly to the bottom of his subject, as far as his means allowed — ^the feeling that he has not shunned labour, though that labour may have resulted in laying bare the nakedness of his case — reacts upon his own mind, and ^ves it firmness for future

work.

But to return ; — ^I first neglected atmospheric vapour and carbonic acid altogether, concluding, as others did afterwards, that the quantities of these substances bemg so small, their effect upon radiant heat must be quite in- appreciable ; after a time, however, I found this assump- tion leading me quite astray. I first used chloride of cal- cium as a drying agent, but had to abandon it. I next used pumice stone moistened with sulphuric acid, and had to give it up also. I finally resorted to pure glass broken to small fragments, wetted with sulphuric acid, and inserted by means of a funnel into a XJ tube. I found this arrange- ment best, but even here the greatest care was needed. It

3M LECTliEE X,

was necessary to cover each colamn with a layer of dry glass fragments, for I found that the eniallest particle of (liist from the cork, or a quantity of sealing wax not more than the twentieth -part of a pin'a head in size, was qiritt

sufficient, if it reached Iho ao drying-tubes moreover had iho organic matter of the a1 it was, soon introduced dlsti To remoio the carbonic Lroken into fragments, wet! troduced into a U tube. ' drying the gas and romoi used at present ; but previi ployed, to dry the air, the a

! (he glass tulies marked i

'itiate the results. The frequently changed, as Te, tniinitosimal Uioii^

ire Carrara marble was I caustic potash, and in- hen, arc the agents for larbonic acid whioh m eir iiual adoption, I an- ient shown in Plate L, Y, each three foot Ions, ! filled with chloride of calcium, after which were placed two U tubes k z, filled with pumice etono and sul- phuric acid. Ilcnco, the air, in the firet place, had to pass over 1 8 feet of chloride of.ealcium, and afterwards through the sulphuric acid tubes, before it entered the esperimcnial tube B e'. A g-aK-holder, c o, w.ns employed for other gases than atmospheric air. In the investigation on wliich I am at present

en<;ngcd, this arrangement, as I have said, ia abandoned, a simpler one being foimd inoro efiectual.

Jly assistant has now exhausted both the front cliaiubcr F and the experimental tube s s'. The rays are passing from the source c through the front chamber ; across the plate of rocksalt at s, through the experimental tube, across the plate at s', aftenvards impinging upon the anterior sur- face of the pile p. This radiation is neutralised by that from the compensating cube c'. The needle, yon will ob- serve, is at zero. We will commence our experiments by "Pp'j'ing this powerful lest to dry air. It is now entering the experimental cylinder ; but, at your distance, you see no motion of the needle, and thus our more powerful mode

ABSOBFTIOH OF RADIAST HXAT BT OLKFIAlirr GAS. 853

'ezperiment faik to detect any absorption on the part of e air. Its atoms, apparently, are incompetent to shatter rin^e calorific -wave ; U is apraetical vacuitm as regards 0 rays of heoL Were yon quite near, however, yon o<ald see a deflection of the needle amounting to abont le degree. Oxygen, hydrogen, and nitrogen, when care- iDy pmified, exlubit the action of atmospheric air ; they •e almost nentral.

Bat the neutral quality of atmospheric air was thought > extend to transparent gases generally. Let us see hether this is correct. I have here a gas-holder of olefiant M, — common coal gas would also answer my purpose. I iadiarge a little of the olefiant gas in the air, but you see Tthing; the gas is perfectly transparent. The expcri- ental tube is exhausted, and the needle points to zero ; td now we wiU allow the olefiant gas to enter. Observe 16 effect. The needle moves in a moment ; the transpar- it gas strikes down the rays wholesale — ^the final and per- anent deflection, when the tube is full, amounting to 70

I will now interpose a metal screen between the pile P id the end s' of the experimental tube, thus entirely cut- Dg off the radiation through the tube. The face of the le turned towards the metal screen wastes its heat speed- f by radiation; it is

now at the temperature of this Njm, and the radiation from the compensating cube alone)tB on the pile, producing a deflection of 75 degrees. But r the commencement of the experiment the radiations from >di cubes were equal, hence the deflection 75° corresponds » the total radiation through the experimental tube, when 16 latter is exhausted.

Taking as unit the quantity of heat necessary to move 16 needle from 0° to I*', the number of nnits expressed by deflection of 75° is

S54 LECTUEE X.

Tlie number of aohs expressed by a deflection of ro*i»' 211.

Out of a total, therefore, of 276, olefiant gaa hasetnA down 211; Uiat is about seven-nmthH of the whole, or about 80 per cent.

Dots it not seem to you as if an opaque layer had bxa euddenly precipitated on our plates of salt, when the gas entered? The substance, however, deposits no such layer. I discharge a current of the dried gaa against a polished plate of salt, but you do not perceive the slightest dimnesfi. Tlie rocksalt plates, moreover, though necessary for eiad measurements, are not necessary to show the deatnictin powcra of tlds gas. Here is an open tin cylinder whldil interpose between the pile and our radiating source;! force olefiant gas gently into the cylinder from this gafr holder and you see the needle fly up to its stops. Observe the smallncsa of the quantity of gas which I shall next use. I cleanse Uie open tube by forcmg a current of air ihrougfa it ; the neclle i;; now at zero ; and I will simply tiim this cock on and olT, as speedily as I can. A mere bnbbic of the gas enters the tube in this brief interval ; still you see that its presence causes the needle to swing to 10°. I next abolish the open tube, and leave nothing but the free aii between the pile and source ; from the gasometer I discharge olefiant gas into this space. Ton see nothing in tie air, but the swing of the needle through an arc of 60° de- clares the presence of this invisible barrier to the

calorifio rays.

Thus, it is shown that the ethereal tmdnlations whid glide among the atoms of oxygen, nitrogen, and hydrogen, without hindrance, are powerfully absorbed by the mole- cules of olefiant gas. We shall find other transparent gases also almost immeasurably superior to air. We can limit st pleasure the number of the gaseous atoms, and thus vary the amount of destruction of the ethereal waves. In this

BXLATIQK Of QUABTITr TO ABSOBFTION.

gaseons bodies possess a great advantage over and solids, in experiments on radiation. Attached air-pump is a barometric tube, by means of which I nit measured portions of the gas. The ezperimen- nder is now exhausted, and turning this cock slowly L observing the mercury gauge, I allow the olefiant enter, till the mercurial column has been depressed L I observe the galvanometer and read the defleo- Determining thus the absorption produced by one Qother inch is added, and the absorption effected by shes of the gas is determined. Proceeding thus we for tensions from 1 to 10 inches the following ab-

Tensions inincbes

Olefian

it Gas

AbeorpUoQ 90

3 unit here used is the amount of heat absorbed a tohoie atmosphere of dried air is allowed to enter >e. The table, for example, shows that one-thirtieth itmospherc of olefiant gas exercises ninety times the tion of a whole atmosphere of air. 0 table also informs us that each additional inch of t gas produces less destruction than the preceding A single inch, at the commencement, strikes down s, but a second inch strikes down only 33, while the m of an inch, when nine inches are already in the

;te the destrncUon of only 3 rays. Thi« U vliU> nuj^iiu reasonably be cxpetled. The

number of raj-s aab ted is linite, and tbc discb&rgc of the first inch of olefisi gas amongst them has so thinned their ranks that the cifr cution produced by the -"""""^ inch is naturally less than that of the first. This ion must diminish, m tin

number of rays capable » j destroyed by the gas, lie-

comes leas ; until, finally, a, irbable rays l>eing remo\-eil,.

the rcBidual heat would dj ough the gas nniiDpeded*

But supposing the qt 'f gas first introduced to ba

ao inconsiderable, that ll ier of raya extinguished hj.

it ia a vanishing quantity, coojp&red with the total number capable of being destroyed, we might then reasonably ei- peet that, for some tliue at least, the quantity of execution done would be jiroportional to the quantity of gas present. Tliat a double quantity of gas woidd produce a double effect, a treble quantity a treble cfibet ; or, in general terms, that the absorption would, for a time, be fouiid portionnl to the density.

To test this idea we will make use of a portion of tbe ai)paratu8 omitted in the general description, o o {Plsie I.) is a graduated glass tube, the end of whieli dips into tbc basin of water b. The tube is closed above by means of the stopcock r; d d'la^ tube containing fragmenta of chlo- ride of calcium. The tube o o ia first filled with water Dp to the cock r, and tbe water is afterwards carefully dis- placed by olcfiant gas admitted in bubbles from below. The gas is admitted into the experimental cylinder by tiie cock r, and as it enters, the water riaes in o o, each of whoso divisions represents a volnme of ^V*^ ^^ '^ cubic indk Successive measures of this capacity are permitted to enter the tube, and the absorption ia each particular case is de- termined.

In the foUowing table the first column contains the quantity of gas admitted into tbe tube ; tho second coa- * See Note (7) at the end of tbia Lectunk

ABSOBPnOir BY STHEB VAPOUB.

ifl the corregponding absoq>tion ; the third column con- is the absorption, calculated on the supposition that it is portional to the density.

Unit metraro g^Ui of a eable Inch.

[flisaicaorGaa.

1 . . . 22^ .

This table proves the correctness of the surmise, that len very small quantities of the gas are employed, the sorption is sensibly proportional to the density. But isider for a moment the tenuity of the gas with which I have here operated. The volume of our experimental ye is 220 cubic inches ; imagine 3^5 th of a cubic inch of B suffused in this space, and you have the atmosphere rough which the calorific rays passed in our first ezperi- mU This atmosphere possesses a tension not exceeding } Yvth of that of ordinary air. It would depress the mer- rial column connected with the air-pump not more than lyth of an English inch. Its action, however, upon the .orific rays is perfectly measurable.

But the absorptive energy of defiant gas, extraordinary

ns it is shown to be by the foregoing experiment*, ii teeded by that of various vapours, the action of wliidi I j, will now endeavour to illustrate. Here is a gUssflukiV-T (lig. 90), provided with a brasa cap, into which a stopcoA can be screwed air-tight. I pour a small quantily of id- phuric ether into the flast, and eomplclcly rf move, in the first place, the air which fills tlw flask above the liquid. I attach the flask to the experimental tube, which is now cihanH* cd — the needle pointing to zero — and peninl' the vapour from the flask to enter the oxperi-. mental tube. The mercury of the gangAj sinks, and now that it is depressed one indil will stop the further aupjily of vapour. The . moment the vapour entered, the needle moved, , and it now points to 65", I can add another' inch, and again determine the absorption,!' third inch and do the same. Tlie absorpticu effected by four inches,

introduced in this way, arc giTen in the following table. For the sake of comparisoa I place the corresponding absorptions of olefiant gas in the third column.

Sulphterie Ether.

Id Incbrl. AbMtliUoiL of OleOut Gb.

For these tensions the absorption of radiant heat by the vapour of sulphuric ether is about two and two-third times the absorption of olefiant gas. There is, moreover, no pro- portionality between the quantity of vapour and the ab sorption.

But reflections similar to those which we have alrcadj applied to olefiant gas are also applicable to the ether. Supposing we make our unit measure small enough, tlw

BELATI0N OF QnABTITY TO ABSOBPnON.

mber of rays first destroyed will vanish in comparison th the total number, and, for a time, the fact will proba- f manifest itself, that the absorption is directly propor- »nal to the density. To examine whether this is the case, d other portion of the apparatus, omitted in the general Bcription, was made use of. k is one of the small flasks ■eady described, with a brass cap, which is closely "ewed on to the stopcock c\ Between the cocks c' and which latter is connected with the experimental tube, is 9 chamber h, the capacity of which was accurately deter- ned. The flask h was partially filled with ether, and the r above the liquid removed. The stopcock c' being shut ^ and e turned on, the tube s s' and the chamber m arc hausted. The cock c is now shut ofl*, and c' being turned , the chamber m becomes filled with pure ether vapour. r turning c' off and c on, this quantity of vapour is allow- to diffuse itself through the experimental tube, where absorption is determined ; successive measures are thus It into the tube, and the effect produced by each is noted. In the following table the unit measure made use of had rolume of rlvth of a cubic inch.

StdpkuTic Ether.

WOKiL

Obflerred. Colcnlated.

W« hero find that the proportion between dcm«ty ind absor[Jtioii holds sensibly good for tlie first eleven measnrM, after which the doviation from i>ro]iortionaUty gradoaliy augments.

No doubt, for smaller measures tlian , iitb of a oubi* inch the abovo law holds still more rigidly true ; and ia a suitable locality it would be easy to determine, with po foot accuracy, y'^th of tho absorption produced by the fint measure ; this would correspond to yj'jjlJi of a cubic ia(i of vapour. Bat, before entering the tube, the vapour hid only the tension due to the temperature of Uie laboratory, namely 12 inches. This would require to be multiphedby 2-5 to bring it up to that of the atmosphere. Hence the Tu'jgth of a cubic inch would, on being diffused tbroaghi tube possessing a capacity of 220 cubic inches, liave a ten- sion of jJjX5'j>^Tii'o-u=SB5V!tith of an atmospherel

These experiments with ether and olefiant gas show that not only do gaseous bodies, at the ordinary tension of the atmosphere, offer an impediment to the transmission of n- diaut heat ; not only arc tbe interstitial spaces of such gasw incompetent to allow the ctbereal nndulations free passage; but, also, that their density may be reduced vastly belo* that which corresponds to the atmosplicrio pressure, and still the door thus opened is not wide enough to let the un- dulations through. There is something in the constituti<m of the individual molecules, thus sparsely scattered, which enables them to destroy the calorific waves. The dcstmfr tion, however, is merely one of form ; there is no absolute loss. Through dry ^r the heat rays pass without sen^bly warming it; through olefiant gas and ether vapoor they cannot pass thus freely ; but every wave withdrawn from the radiant sheaf produces its equivalent motion in the body of the absorbing gas, and raises its temperature. It is a case of transference, not of annibilation. I might extend tbe experiments to all available volatile liquids, and show

ABSORPTION BY GASES.

yoa that the same role holdB good for the yaponrs of alL

Before duinging the source of heat here made use of, I wish to direct your attention for a moment to the action of a few of the peimanent gases on radiant heat. To measure the quantities introduced into the experimental tobe, the mercmy gauge of the air-pmnp was made use of. Li the case of carbonic oxide, the following absorptions oorreapond to the tensions annexed to them, the action of a fnll atmosphere of air, which, as 70a remember, produces a deflection of 1% being taken as unit : —

Ccarbonie Oxide.

TCBfllOO

iBliiei 0.6 1-0 1*5 2-0 2-5 3-0 8*5

As in former cases, the third column is calculated on the assumption that the absorption is directly proportional to the density of the gas ; and we see that for seven measures, or up to a tension of 3*5 inches, the proportionality holds strictly good. But for large quantities this is not the case ; when, for instance, the unit measure is 5 inches, instead of half-an-inch, we obtain the following results :

Tenakm Inlndiei.

Obserred. 18 . 82-5 45 .

Calculated. 18 86 54

The case of carbonic oxide is therefore similar to that of defiant gas. Carbonic acid, sulphide of hydrogen, nitrous oxide, and other gases, though differing in the energy of

363 LECTCRE X.

their absorption, and all of them exceeding caxbomc oiidsi exhibit, when gmall and large quantitiea are used, a similv deportment towards radiant heat.

Thus, then, in tiie case of Eomo gases, sre iind an almoit absolute is competence on the pait of their atoms to be shaken by the ethereal waves. They remain practically at rest when the undulations speed amongst them, while the atoms of other gasea, struck by these same undolations, ab- sorb tlieir motion, and become themselves centres of hesL Wo have now to examine what gaseous bodies are compe- tait to do in this latter capacity; we have to enquire vhctber these atoms and molecules, which can accept mo- tioQ from the ether in such very different degrees, are nol also charactcnsed by their competency to impart motion to the ether in diflkrent degrees ; or, to use the cominoa language, having learned something of the power of differ- ent gases, as absorbers of radiant heat, we have now to I'H- quire into their capacities as radiatori.

I have lierc an arrangement, by means of which we can put the necessary question, which has hitherto received only a negative reply, v (fig. 91) is the thermo-electric pilf ■with its two conical reflectors ; s is a double screen of pol- ished tin ; A is an argand burner, consisting of two concen- tric perforated rings ; c is a copper ball, which, during tJw ejqjerimonts, is heated under redness ; while the lube I < leads to a gas holder. AVhen the hot ball c is placed on the burner it warms the air in contact with it ; an ascend- ing current ia thus established, which, to some extent, act* upon the j)ile. To neutralise this action a large Leslie's cube, L, filled with water, a few degrees above the air ia temperature, is placed heJbre the opposite face of the pile. The needle being thus brought to zero, the gas is forced, by a gentle water pressure, through the orifices of the burner ; it meets the ball c, glides along its snrface, and ascends, in a warm current, in front of the pile. The rays

BASUTIOS BT OAflXS.

It the bnted gaa gnsh forth in the direcdon of the ar- B against the pile, uid the

consequent deflection of the

galvanometer needle indicates the magnitude of the r&dia- tion.

The rosnlts of the experimenta arc given in the second colnmn of the following tahlc, the numbers there recorded marking the extreme limit to which the needle swung, when the rays from the gas fell npon the pile : —

BidUUdn. AtHorpllon,

Air ... 0 . . 0-2

Oif^n , . 0 . . . O'S

Nitn^en . . 0 . . .0-3

Bjdn^GD . 0 . . .0-2

Carbonic oiido 12 . . 18-0

CartWDic acid . . IS . . . S5-0

Nitrous oxide . . 39 . . . M'O

OIcBintgaa . . 03 . . 610

to compftro the radiation with the absorptioo, I placed in the third coliimn the deflections due to the

absorption of tho fiamo gascB, at a common tension of S inches. We see that radiation and absorption go hnnd in

hand ; that the m intercept a calorific Jlu portionato degree, to short, a capacity 1" ' impart motion to tive properties. And here, b BideratioDB regs

ihowe itself competent to Itself competent, in & pro- a calorific flux. That, in on from the ether, and to ascous bodies, are corrals '

! are relieved from aS tat , ICC of cobeeion, o

Fults. lu Bolida and liquids tbe particles arc more or less in thrall, and cannot be considered aa individually free.

The dlflerence in point of radiative and abBorptive power, between alum and rocksalt, for example, might be fiiirly

BLAGEBTEBS OT TRAXHRABEETT OASES TO HEAT. 365

regarded as doe to their character as aggregates, held to- gether hj crystallising force. But the difference between olefiant gas and atmospheric air cannot be explained in this way ; it is a difference dependent on the individual mole- coles of these substances, and thus oar experiments with gases and vapours probe the question of atomic constitution to a depth, quite unattainable with solids and liquids.

I have refrained thus far from giving you as full a tabular statement of the absorptive powers of gases and Tapours as the experiments made with the apparatus al- ready described would enable me to do, knowing that I had in reserve results, obtained with another apparatus, which would better illustrate the subject. This second ar- rangement is the same in principle as the first ; only two changes of importance have been made in it. The first is, that instead of making a cube of boiling water my source of heat, I employ a plate of copper, against which a thin steady gas-flame from a Bunsen's burner is caused to play ; the heated plate forms the back of my new front chamber, which latter can be exhausted independently, as before. ThLs portion of the apparatus is sketched in ^g. 02, the chimney o being added. The second alteration is the sub- stitution of a tube of glass of the same diameter, and 2 feet 8 inches long, for the tube of brass s s', Plate I. All the other parts of the apparatus remain as before. The gases were introduced in the manner already described into the experimental tube, and from the galvanometric dcflco- • tion, consequent on the entrance of each gas, its absorption was calculated.

The following table gives the relative absorptions of several gases, at a common tension of one atmosphere : —

Attrarptton At Name. 80 incbes tenalOD.

Air • 1

Oxygen • . . . 1

Nitiogen

Chlarioc

BydrocUoric ncid CtirboDJc oiide Carbonic acid Nilroiu aiido gulpliiile of bydnigen Hajsh gaM Sulphuroua tdd OUBiDt gai

The most powerfiil and delicate ttsts ttat I Lave beto aT)le to apply have not yet cnjibled me to catablish a diffcp encc between oxygen, uitrogcn, hydropcn, and air. Tbe absorption of these Bubsiancea is exceedingly Email — prob- ably even smaller than I have made it. The more perfect- ly the above-named gases are purified, the more closely does their action approach to that of a vacuom. And who can say that the best drying apparatus is perfect ? I cai>- not even say that sulphuric acid, however pare, may not yield a modicum of vapour to the gases pasung through it, and thus make the absorption by those gases appear great- er than it ought. Stopcocks also must be greased, and hence may contribute an infioitedmal impurity to the air passing through them. But however this may be, it ii certain that if any further advance should be made in the purification of the more feebly acting gases, it will only serve to augment the enormous dificrenccs of absorption exhibited by the foregoing table.

Ammonia, at the tension of an atmosphere, exerts an absorption at least 1,19S times that of the air. If I inter- pose this metal screen between the pile and the experiment- al tube, the needle will move a little, but so little that you entirely fiul to see it. What does this experiment mean ?

ES'FLUENXE OF ATOMIC CONSTITUTION. :>t>7

Why, tliat this ammonia Avhirh, within our glass tube, is as transparent to light as

the air we breathe, is so opaque to the heat radiatmg from our source, that the addition of m plate of metal hardly augments the opacity. I have rea- 0on to believe that it does not augment it at all, and that tbis light transparent gas is really as black, at the present anoment, to the calorific rays, as if the experimental tube ^rere filled with ink, pitch, or any other impervious sub- stance.

In the case of oxygen, nitrogen, hydrogen, and air, tho acUon of a whole atmosphere is so small that it would be quite useless to attempt to determine the action of a frac^ tional part of an atmosphere. Could we, however, make Boch a determination, the difference between them and the otber gases would come out still more forcibly than in the last table. In the case of the energetic gases, we know tluit the calorific rays are most 'copiously absorbed by the portkm of gas which first enters the experimental tube, the qoaotities which enter last producing, in many cases, a merely infinitesimal effect. If, therefore, instead of com- paring the gases at a common tension of one atmosphere, we were to compare them at a common tension of an inch, we ahoiild doubtiess find the difference between the least abeorbent and the most absorbent gases greatly augment- ed. We have already learned that for small quantities, the heat absorbed is proportional to the amount of gas present. Aflsmning this to be true for air and tho other feeble gases referred to ; taking, that is, their absorption at 1 inch of tennon to be ^jth of that at 30 inches, we have the follow- ing comparative effects. It will be understood that in every case, except the first four, the absorption of 1 indi of tho gas was determined by direct experiment.

Absorption at Name. 1 inch tcnsioo.

Oxygen 1

Kiifogcn

i Laeb'tcrBdaL 1

Hjilrogen

CWorine

BronOoe

Cubonie oiide

Hfdrobromle add

Nitric oiide .

Kitrous oniJo .

Eulptuiie of hjdragcn .

Olefiantgifl .

Sulphoroiu add

if f"Tt.rnnr(iinnrw (lifflTnnpon

n the /<nnat!tiTl>nn *n^

cbaractcr of tbo ultimate particles of varions gases do the above resalta reveal ! For every individnal ray stmck down by the air, oxygen, hydrogen, or nitrogen — tbe am- monia strikes down a brigade of 7,260 rays ; the olcfianl gas a brigade of 7,950 ; while the Bulphurous acid dcetroja 8,600. With these resnlts before us, wo can hardly help attempting to v-isualise tbe atoms tbemselveB, trying to dis- cern, with tbo eye of intellect, the actual pliyMcal qualiUes on which these vast difTerenoea depend. These atoms are particles of matter, plunged in an elastic inediom, accepting its motions and imparting tlicir motions to it. Is the hope onwarranicd, thac we may be able fCnally u> make radiant heat snch a /"eeter of atomic conatitntion, that we shall be able to infer from their action upon it, the mechaniam of the ultimate particles of matter themselves f

Have we even now no glimpse of the atomic qnalitkt necessary to form a good absorber ? Ton remember onr experiments with gold, silver, and copper i you recolleet how feebly they radiate and how feebly they abeorb. Wo heated them by boiling water ; that is to say, we imparted, by tbe contact of the water, motion to their atoms ; still this motion waa imparted with extreme downess to the

OrFLUENCE OF ATOMIO OOKaTTrUTION. 369

ether in which those atoms swung. That their particles glide through the ether with scarcely any resistance may also be inferred from the length of time which they require to cool in vacno. But we have seen that when the motion which the atoms of the above bodies possess, and which they are incompetent to transfer to the ether, is imparted, by contact, to a coat of varnish, or to a coat of chalk or lampblack, or even to flannel or velvet, these bodies soon waste the motion on the ether. The same we found true for glass and earthenware.

In what respect do those good radiators differ from the metals referred to ? In one profound particular — ^the mct- ib are dements; the others are compounds. In the metals the atoms swung singly ; in the varnish, velvet, earthen- irare and glass, they swung in groups. And now, in bodies as diverse from the metals as can possibly be conceived, we find the same significant fact makmg its appearance. Oxy- gen, hydrogen, nitrogen, and air, are elements, or mixtures of elements, and, both as regards radiation and absorption, their feebleness is declared. They swing in the ether with scarcely any loss of moving force. They bear the same relation to the compound gases as a smooth cylinder turn- ing in water does to a paddle-wheel. They create a small comparative disturbance.

We may push these considerations still further. It is impossible not to be struck by the position of chlorine and bromine in the last table. Chlorine is an extremely dense and coloured gas ; bromine is a far more densely-coloured vapour ; still we find them, as regards perviousncss to the heat of our source, standing above every transparent com- pound gas in the table. The act of combination with hy- drogen produces, in the case of each of these substances, a transparent compound ; but the chemical act, which aug- ments the transparency to light, augments the opacity to heat ; hydrochloric acid abeorbB more than cUorioe ; hydrobromic acid absorbs more than bromine.

Further, I have hero the elomcnt bromine in the liqiud * condition ; I enclose a portion of it in Uiis glass cell; the layer is of a tbicknesa sufficient to extinguisli utterly tli« flame of a liunp or candle. But I place a candle ia front of the cell, and a thermo-electric pile behind it ; tlie prompt movement of the ueedle declares the passage of radiut beat through the bromine. This consists entirely of the obscure rays of tlie eaiidle, for the light, as I hare stated, is utterly cut off. I remove the candle, and put in its place our copper ball, beated not quit« to redness. The needle at once flies to ito stops, showing the transparency of Uie bromine to the lie;it eniilt4.'d by the ball. I caiiuot use iodine in a solid state, but, happily, it dissolTes in t>iBaipfiiile of carbon. I have here the densely coloured liquid in ihii , glass celh Itbrow the parallel electric beam upon the screen; •- this solution of iodine completely cnts the Ught off; but if I bnng my pile into the path of the beam, the violeuce of the needle's motion shows how copious is the transmit fiion of the obscure rays. It is impossible, 1 think, to cloeo our eyes upon this convergent evidence that the free atonu swing with ease in the ether, while when grouped to oadt lating systems, they cause its waves to swell, imparting to it, as compound molecnlea, an amount of motion which w» quite beyond their power to communicate, as long as th^ remained oncombined.

But it will occur to you, no doubt, that lampblack, which is an elementary Gubstancc, is one of the best al^ Rorbers and radiators in nature. Let us examine this buIk stance a little : ordinary lampblack contains many impni' ities ; it has various hydro-carbons condensed witbin it, and these hydro-carbons are all powerful absorbers and radia- tors. Lampblack, therefore, as hitherto applied, can hardly be considered an element at all. I have, however, had these

RADIATION THBOUOH LAMPBLACK, ETC. 371

^dro-carbons in great part removed, by carrying through d hot lampblack a current of chlorine gas ; but the sub- ince has continued to be both a powerful radiator and a

iwerful absorber. Well, what is lampblack ? Chemists in tcdl you that it is an allotropic form of the diamond : tre, in fact, is a diamond reduced to charcoal by intense at. Now, the allotropic condition has long been defined due to a difference in the arrangement of a body's parti- es ; hence, it is conceivable that this arrangement, which uses such a marked physical difference between lampblack A diamond, may consist of an atomic grouping, which uses the body to act on radiant heat as if it were a com- mand. I say such an arrangement of an element, though :oeptional, is quite conceivable ; and I shall show you this be eminently the case as regards an allotropic form of ir highly ineffectual oxygen.

But, in reality) lampblack is not so impervious as you ight suppose it to be. Melloni has shown it to be trans- irent, in an unexpected degree, to radiant heat emanating om a low source, and I have prepared an experiment hich will corroborate his. Here is a plate of rock-salt, hich, by holding it over a smoky lamp, has been so thick-coated with soot that it does not allow a trace of light om the most brilliant gas jet to pass through it. I place le plate upon its stand, and between it and this vessel of)iling water, which is to serve as our source of heat, I ace a screen. The thermo-electric pile is at the other side : the smoked plate. The needle is now at zero, and I ithdraw my screen ; instantly the needle moves, and its lal and permanent deflection is 52^. I now cleanse the It perfectly, and determine the radiation through the un- ooked plate, — ^it is 71°. Now, the value of the deflec- on 52°, expressed with reference to our usual unit, is), and the value of 71°, or the total radiation, is about K). Hence, the radiation through the soot is to the whole idiation as

232:8S=-100: 88

8 to say^, 38 pw cent, of the Incident faeat has been t ittcd by the layer of lampblack,

.ido of methyl is formed by the union of the ele- ment iodine with the " " ethyl. Exposure to light usually sets a portion "* ^ino free, and colours the

liquid a rich broi — ^s of experiments on the

radiation of heat Is, I compared, as regard*

their powers of tr strongly coloured speci-

men of the iodide Lh a perfectly transparent

one ; there was nc ween them. The iodine,

which produced bo feet on light, did not een-

siblj aS'cct radiant he.tt. Jlcrc are llio iimnbers which express the portion of the total radiation intercepted by the transparent and coloured liquids respectively: —

AbaarpUon pet ml Iodide of methj'l (tranapamit) . . S3-9

" " (strongly coloured with lod'me) . fi3-3

The source of beat, in this case, was a spiral of platinum wire raised to bright redness by an electric current. On looking through the coloured liquid, the incandesceDt spiral was visible. I therefore intentionally deepened tie colour by adding iodine, aotil the solation was of suffi- cient opacity to cut off wholly the light of a brilliant jet of gas. The transparency of the liquid to the radiant heat was not sensibly affected by the addition of the iodine. The luminons heat was, of course, out offj bnt this, as compared with the whole radiation, was so smsU as to be insensible in the experiments.

It is known that iodine dissolves freely in the bisnl* phide of carbon, the colour of the solution in thin layen being a splendid purple; but in layers of moderate thick- ness it may be rendered perfectly opaque to light. I dis- solved a quantity of iodine in the liquid, BufGdent, when introduced into a cell 0-07 of an inch wide, to cat off the

HEAT BPEOTBDII BT OFAQDE FKISM8. 373

light of the most brilliant gaa'flame. Comparing the opaqae boIdUoq vith the tranBparcnt bbulphidc, the fol- lowing-resnlts were obtained: —

BiaolpUde of carbon (optqne) . . I2'a

" " (tnnspueat) . 12'9

Here the preaence of a qnantit; of iodine, perfectly opaque to a brilliant light, was without measurablo effect upon the heat emanating from our platinam spiral.

The same liquid was placed in a cell 0*27 of an inch in width; that is to say, a solution which was perfectly opaqae to light, at a thickness of 0*07, was employed in a layer of nearly four times this thickness. Here are the results: —

AbAorptton. Knipblde of carbon fbanaparent) . IB'S

" " (opaque) . . . 190

The difference between both measurements lies within the limits of possible error,

I have already had occasion to decompose in your presence the light of the electric lamp, and to project the Bpectmm of the light npon the screen behind mc. For thia parpose, I employed a prism of traofparcnt bisulphide of carbon. The liquid is contained in a wcdgc-sliaped flask with plane glass sides ; it draws the colours very widely apart, and prodacea a more beautiful effect than could be obtained with a glass prism. My object is now to project a little spectrum on this smalt screen. Behind the screen I hxTC placed my thermo-electric pile, which is connected with the large galvanometer in front of the table. The spectmm,AS you observe, is about 1^ inches wide and 2 inches long, its colours being reiidci-cd very livid by concentration. If I removed the screen, tlio red ind extra-red of the spectrum would fall upon the pile behind, and doubtless produce a therrao-clcclric current. Bat I do not wish any of the light to full upou-thc inatru-

sh to show yon that we have here a spectrum whii'fi you cannot ece, and that you may entirely dctack the non-luminous epectrum from the luminous one. Here, then, is a second prism, filled with the bisulphide of carbon, in which iodine ' ' dissolved. I remove the transparent prism, I apaque one exactly in its

place. The sped ^ icared ; there is no longer

a trace of light u^ ; but a thermal Gpoctrum

is still there. The of the electric lamp hare

traversed the optu] e been refracted like the

luminous ones, ant)ngh invisible, impinging

upon the screen bei prove this, by removing

the screen : no light strikes the pile, but you see thut the heat falling upon it is competent to dash violently aside the needles of our large galvanometer,

I have shown you the action of gases upon radiant heat, with our glass experimental tube and our new source of heat. Let me now refer to the action of vapours, as examined with the same apparatus. Here I have several glass flasks, each fuinishcd with a brass cap, to which a stopcock can be screwed. Into each I pour a qnaotity of a volatile liquid, reserving a fiask for each liquid, so as to render admixture of the vapours impossible. From each flask I remove the air,— not only the air above the liquid, but the air dissolved in it. This latter bubbles freely away when the flask is exhausted ; I now attach my flask to the exhausted experimental tube, and allow the vapour to enter, without permitting any ebullition to occur. The mercury column of the pnmp sinks, and when the re- quired depression has been obtain^gd, I cut off the supply of vapour. In this way, the vapours of the substances mentioned in the next table have been examined, at pres- sures of O'l, 0'5, and 1 inch, respectively.

ACnON OF TAFOUBS ON BADIAHT HEAT.

Abfloq>tfon of Taponn at the pressures

Bisnlphide of carbon Iodide of methyl

Chloroform

MethjHc alcohcd Amjlene Sulphuric ether

Alcohol

Formic ether •

Aoetao ether

Propionate of ethyl Boradc add

, 696 970 . 620

These numbers refer to the absorption of a whole at- mosphere of dry air as their unit ; that is to say, ^th of an inch of bisulphide of carbon vapour does fifteen times the execution of 30 inches of atmospheric air ; while tS^th of an inch of boracic ether vapour does 620 times the execution of a whole atmosphere of atmospheric air. Comparing air at a pressure of O'Ol with boracic ether at the same pressure, the absorption of the latter is probably 180,000 times that of the former.

(7) A wave of ether starting from a radiant point in all directions, in a miifonn medium, constitutes a spherical shell, which expands with the Telocity of light or of radiant heat A rai/ of light, or a ray of heat, is a line perpendicular to the wave, and, in the case here supposed, the rays would be the radii of the spherical shell. The word * ray,' however, is nsed in the text, to avoid circumlocution, as equivalent to the term unii of hecU, Thus, calling the amount of heat intercepted by a whole atmos- phere of air 1, the amount intercepted by -^ih of an atmosphere of ole- fiant gas is 90.

APPENDIX

I oiTS bcrc the m ing the giUyanoinetix wMcSi

Uelloni recommcnt ling to be desired as i^aids

facility, promptacs-, Hia own statemest of tbc

method, trauslated from LA 'incnuodirosc, page 50, is u Jul Iowa ; —

Two small vessels, T v, are half- filled with mercury, and connected, Bepnratcly, bj two short wires, with the oxtTcmitics o g of the galvano- nicter. The vessels and

wires thus disposed make no change in the ac- tion of the instninicnt ; the thermo-electric current lieing freely trans- mitted, as before, from the pile to the galvanometer. But if, by means of a nirc p, a commuui cation be established between the two vessels, part of the carreDt will pass through this wire and return to the pile. The quantity of electricity circulating In the galvanometer will be thus dinua- bhed and with it the deflection of the needle.

Suppose, then, that by this artifice we have reduced the gal- vanomctric deviation to its fourth or fifth part ; ia other words, supposing that the needle being at 10 or 12 degrees, andei the action of a constant source of heat, placed at a fixed distance from the pile, that it descends to 2 or 3 degrees when a portiott of the current is diverted by the external wire ; I say that by cauMDg the source to act from various diataDces, and obecrving 'ii each case the tolnl deflection, and the reduced deflection, w»

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htye all the data neoeasaiy to determine the ratio of the defleo- tbnB of the needle, to the forces which produce these deflections.

To render the exposition clearer, and to furnish, at the same time, an example of the mode of operation, I will take the num- bers relating to the application of the method to one of my thermo-mnltiplierB.

The external drcnit being inteimpted, and the source of heat being sufficiently distant from the pile to give a deflection not exceeding 5 d^;ree8 of the galvanometer, let the wire be placed from T to T ; the needle &lls to 1^-6. The connection between the two Tessebi being again intermpted, let the source be brought near enough to obtain successiyely the deflections : —

5% 10% n% 20% 25% 80% 86% 40% 46^

Interposing after each the same wire between y and y we ob- tain the following

numbers : —

l'-6, S% 4*'-5, 6'-8, 8°-4, ll'^, 15°-3, 22'-4, 29''Y.

Assuming the force necessary to cause the needle to describe each of the first degrees of the galvanometer to be equal to unity, We have the number 6 as the expression of the force corresponding to the first obsenration. The other forces are easily obtained by the proportions : —

1-5: a=a: x= A a=3 333 a*

Where a represents the deflection when the exterior circuit is closed. We thus obtain

5, 10, 16-2, 21, 28, 87-3. &r the forces, corresponding to the deflections,

6% 10% 15% 20% 25% 30°.

la this instrument, therefore, the forces arc sensibly propor- tional to the arcs, up to nearly 15 degrees. Beyond this, the pro- portionality ceases, and the divergence augments as the arcs in- crease in size.

The forces belonging to the intermediate degrees ore obtained With great case either by calculation or by graphical construc- tion, which latter is sufficiently accurate for these determinations.

• That is to say, one reduced current is to the total current to which it eorresponds, as any other reduced current la to its corresponding "total

APPENDIX TO LECTCHE X

By these means we find, DegrcPB

13°, 14', 16', 10*, ir. 18'', 19% 20 13, U'l, 1^-2, lG-3, IT'4, 18-6, 19-8, 21, £ DitTerencGfl . II, 11, 11, I'l, l.S, 1-2. 12. 1-3. Degrcea . , 22% 23'', SV, SS'. S*'', 27% aa% 29°, 80*. Forces . 23S, £49, 36-4, SS, 207, 31'B, 33-4, 3S-8, t

Differences . 1'4. IE, IB, 1-T, 1-8, 1-9, 2. In tliis table we do not take into account anj of the d<^gm« preceding the 13th, because tlie force correspondiDg to each of

them po«i:tcsscs the game value as the deflection.

The forces corresponding tc the Bret 30 dcfp^ea being known, nothuig is easier than to determine the valuea uf tlic furces com- apondiug to 35, 40, 45 degrees, and upwards. Tiic reduced deflcctiom* of these three arcs are,

1& -3, 22-4, 29-7.

Let UB consider them separately ; commencing with the first In the first place, then, IS degrees, according to our calculation, arc equal to 132 ; we obtain the Taltie of the decimal 0-8 by mot tiplying this fraction by the dificrence 11 which exists betwM9 the ISth an J 16th degrees ; for wo have evidently the propoltioo

l:Il=0-3:i=08. The value of the reduced deflection corresponding to the SSth degree will not, therefore, be iS'S, but IB'-a+O'-SsW-S. Bj similar considerations we find 23"-5-(-0°-6=24"-l, instead of 23"-4, and 36°-7 instead of 29°-7 for the reduced deflectiooa of 40 and 45 degrees.

It now only remains to cslcnlate the forces belon^g to then tlm;e deflections, 15°-0, 24°I, and 86°-7, by means of the oipio- siou 3-333 a ; this gives us,

the forces, Sl'T, 803, 122-3. for the decrees, 30, 40, 46.

Comparing these nambers with those of the preceding table, wo sec that the sensitiveness of our galvanometer diminishes con- siderably when wc use deflections greater than 80 degrees.

[April 3, 1862.]

ACnON OF ODOROUS BUDSTANCES UPON RADLilST HKAT — ACTION OF OZONI UPON RADIIHT HEAT — DKTKRMINATION OF THE RADIATION AND ABSORP- TION OF OASES AND TAPOURS WITOOUT ANT SOURCE OF HEAT EXTERNAL TO THE GASEOUS BOOT — DTNAMIC RADIATION AND ABSORPTION — RADIA- TION THROUGH THE EARTH^S ATlfOSPHERE — INFLUENCE OF THE AQUEOUS TAPOUR OF

THE ATMOSPHERE ON RADIANT HEAT— CONNECTION OF THE RADIANT AND ABSORBENT POWER OF AQUEOUS TAPOUR WITH METEORO- LOGICAL PHENOMENA.

appendix: FURTHER DETAILS OF THE ACTION OF HUMID AIR.

SCENTS and effluvia generally have long occupied the attention of observant men, and they have formed fa- Tom-itc illustrations of the ' divisibility of matter.' No chemist ever weighed the perfume of a rose ; but in ra- diant heat we have a test more refined tlian the chemist's balance. The results brought before you in our last lecture Vould enable you to hear me without surprise, were I to assert that the quantity of volatile matter removed from a hartshorn bottle by any person in this room, by a single act of inhalation, would exercise a more potent action on ra- diant heat, than the whole body of oxygen and nitrogen which the room contains. Let us apply this test to otlier odours, and see whether they also, notwithstanding their almost infinite attenuation, do not exercise a measurable in- fluence on radiant heat.

I w^ill operate in this simple way : here is a number of small and equal squares of bibulous paper, which I roll up thus, to form little cylinders, each about two inches in length. I moisten the paper cylinder by dipping one end

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of it^to iin aromatic oil ; tlie oil creeps by capillary aU IJou tlirougli the paper, arid tlie whole of the cylintk now moist. I inlrodace the rolled paper thiis into a p tube of such a diameter that the cylinder fills it wiU being aqneczed, and between my drying apparatus and experimental cylinder I plooo the tube containing Bcented paper. The experimental cylinder ia now extia cd, and the needle at zero ; turning this cock on, I il dry Mr to pass gently through the folds of the satnn paper. Here the air takes up the perfume of tlie anjni oil, and carries it into the experimental tube. The ab» lion of an atmosphere of drj- air we know to he nntly produces a deflection of one degree ;

hence, any a-Mlri absorption which these experiments reveal, most be dii> the scent which accompanies tlie air.

The following table will give a condensed view of absorption of the substances mentioned in it ; air at tension of one atmosphere being regarded as unity : —

Kama ofPeiniino AtnrptiDD

Pachouli Sandat Wood Gcnuiium Oil of Clovea Oth) of Roses BergiUDOt

Lavender

Portugal Thymo ItoKoiary Oil of Laurel . Camomile Flowers .

Bpikcnard

ACnON or 8GENTB ON BADIANT HEAT. 381

Tlie number of atoms of air here in the tube must be regarded as almost infinite in comparison with those of the odours ; still the latter, thinly scattered as they are, do, in the case of pachouli, 30 times the execution of the air ; otto of rosea does upwards of 36 times the execution of the lir ; thyme, 74 times ; spikenard, 355 times ; and aniseed S72 times the execution of the air*- It would be idle to ■peculate on the quantities of matter implicated in these RSoltB. Probably they would have to be multiplied by millions to bring them up to the tension of ordinary air. Thus, —

The sweet south That breathes upon a bank of Tiolcts, Stealing and giving odour,

ores its sweetness to an agent, which, though almost infi- ntely attenuated, may be more potent, as an intcrccpter of terrestrial radiation, than the entire atmosphere from 'bank' to sky.

Li addition to these experiments on the essential oils, others were made on aromatic herbs. A number of such ^ere obtained from Covent Garden Market; they were dry, in the common acceptation of the term ; that is to «ay, they were not green, but withered. Still I fear the ^ults obtained with them cannot be regarded as pure, on ftocount of the probable admixture of aqueous vapour. The ikromatic parts of the

plants were stuffed into a glass tube ^gbteen inches long and a quarter of an inch in diameter. Previous to connecting them with the experimental tube, they were attached to a second air-pump, and dry air was carried over them for some minutes. They were then con- liected with the experimental cylinder, and treated as the essential oils ; the only difference being that a length of Eighteen inches, instead of two, was occupied by the herbs. Thyme, thus examined, gave an action thirty-three times ttat of the air which passed over it.

3S3 LEoruBB XI. ^^H

Peppermint oxercised thirty-four tiinee the flction of tb« air.

Speamiint exercised thirty-«iglit times the action of llie air.

Lavender exercised thirty-two times 'the action of the

Wormwood exercised forty-one times the action of the

Cinnamon exercised fifty-three times llie action of th* air.

As already hinted, I fear that these results may be complicated -with the action of aqnooos vajwar : its qiB» titv, liowevcr, iniist have "been iufiiiilcsiiaal.

There is another enbstance of great interest to tin chemist, bat the attainable qoantities of which are so n^ nutc as almost to elnde measurement, to which we may if ply the test of radiant heat. I mean that extraordiniiy substance, ozone. This body is known to he libented it the oxygen electrode, when water is decomposed by ■ electric current. To investigate its action Z had oonstroct- cd three dificrent decomposing cells. In the first, which I shall call Xo. 1, the platinum plates nscd as electrodes bad about four square inches of surface ; the plates of the seo- ond (No, 2) had two square inches of surface ; while tie plates of the third (No. 3) had only one square inch of sur- face, each.

My reason for using electrodes of different dzes ml this : — On first applying radiant heat to the examination of ozone, I constructed a decomposing cell, in which,

to &■ minish the resistance of the current, very large platinum plates were used. The oxygen thus obtained, and wludi ought to have embraced the ozone, showed scarcely any of the reactions of this substance. It hardly discoloured iodide of potassium, and was almost without action on ra- diant heat. A second decomposing apparatus, with smaller

ACTION OF OZONB ON BADIANT HEAT* 383

plates, was tried, and here I foimd both the action on iodide of potassium, and on radiant heat, very decided. Being unable to refer these differences to any other cause than the different magnitudes of the plates, I formally attacked the subject by operating with the three cells above described. Galling the action of the main body of the electrolytic oxy- gen unity ; that of the ozone which accommpanied it, in the respective cases, is given in the following table : —

Nmnlwr of Cell Absorption.

Thus the modicum of ozone which accompanied the oxygen, and in comparison to which it is a vanishing quan- tity, exerted, in the case of the first pair of plates, an action twenty times that of the oxygen itself, while with the third pwr of plates the ozone was forty-seven times more ener- getic than the oxygen. The influence of the size of the plates, or, in other words, of the density of the cuiTent where it enters the liquid, on the production of the ozone, is rendered strikingly manifest by these experiments.

I then cut away portions of the plates of cell No. 2, so as to make them smaller than those of No. 3. The reduc- tion of the plates was accompanied by an augmentation of the action upon radiant heat ; the absorption rose at once from 34 to

The reduced plates of No. 2 hero transcend those of No. 3, which, in the first experiments, gave the largest action.

The plates of No. 3 were next reduced, so as to make them smallest of all. The ozone

now generated by No. 3, effected an absorption of

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Thus WO eee tliat the action npon radiant heat a(lir3£«« Bs the size of the electrodes is diminished.

Heat is kaoivTi to be very destmcliye of ozoi»,uid suspectmg the devclopement of heat at the Bm&ll clectrodM of the cell hist made uso of, I Burroimded the cell with i mixture of poonded ice and salt. Kept thus cool, tbcsb- sorptioD of the ozone generated rose to 136.

Theso experimentB oa the action of ozone npon radiant heat were made, before I was acquainted with the re- eenrches of IVDl. De la Rive, Soret, and Meidinger, on this Babstance. There is a perfect correspondence in oni re- sults, though there is no resemblance between our modes of experiment. Such a correspondence is calculated lo augmont our confidence in radiant heat, aa an iDvestigalor of molecular condition.*

■ U. Meidinger commences biapaper by ehowing die a!)s«ice of »gw*- I iDcnt bctH-cea Iheorj and cipcHnKnit in tho decompoEition of ir&ur, tin differEoce showing ilaclf verj deddedljinadeficieccj of oxygen tthmllu eamnt icaj itfonrj. On heating liis cleetroljle, he foond that tlu9 (iif- fcrvncc disappeared, Uic proper quoDtitj of oijgen being then libcraleJ. He at onee Gnnnised that ttio defect of oijgen might be due to lie fonra- lion of ozone \ but how did the substanoe net to produce (he diminulian ot the oxygen ? If the defect -mere duo to the great dcn^ty of the OEonf , the destruction of this subntjince, bj hflal, would rwtore Iho oxygen lo iB tei« Toliunc. Strong heating, howcTer, which destroyed the oioiie, prodnred no alieraliou of volume, hence H. Ucidingcr eondudcd that the ettM trhich he obscrred wna not due to tbo ovma ivbicb rcmaiQed mixed sidi the oxygen iUelf. He finally condudod, and juatified hia conelnaioa by eatisfactory ciperimenta, that the loea of oxygen was due to the fonnttioa in the water, of peroxide of hydrogen by the oioue ;

the oxyKea being thn withdrawn from the tube to which it belonged. He also, as IL De la Bin had preTioualy done, eipetimented with electrodes of diSbrant tfmo, and found the 1o39 of oxygen much more conmdeiable when ft null electrode was used than with a large one ; whence he inferred that the formation o(oione was facilitated by au^mtniing the dentUy of Aa atmnt at (Mt ptaa uhart tUclrodi and dtclrolgte meet. The same condndon is dedooed Itcoi

ooNSirrnnoN of ozone. 385

The quantities of ozone with which the foregomg ex- periments were made, mnst be perfectly mmieasnrablc by Oirdfaiary means. Still its action upon radiant heat is so energetic, as to place it beside defiant gas, or boracic ether, as an absorbent— bulk for bulk it might transcend either. No demerUary g<u that I have examined behayes at all like ozone. In its swing through the ether it must powerfully disturb the medium. If it be oxygen, it must, I think, be oxygen atoms packed into groups. I sought to decide the ^estion whether it is oxygen, or a compound of hydrogen, b the following way. Heat destroys ozone. If it were oxygen only, heat would convert it into the common gas ; if it were the hydrogen compound, which some chemists oonfiider it to be, heat would convert it into oxygen, plus aqueous vapour. The gas alone, admitted into my tube, would give the neutral action of oxygen, but the gas, plus the aqueous vapour, I hoped might give a sensibly greater action. .The dried electrolytic gas was caused to pass through a glass tube heated to redness, and thence direct into the experimental tube. It was next, after heating, made to pass through a drying tube into the experimental tube. Hitherto I have not been able to establish, with cer- tainty, a difference between the dried and undried gas. If, therefore, the act of heating develope aqueous vapour, the experiifiental means which I have employed have not yet enabled me to detect it For the present, therefore, I hold

the above experiments on radiant heat No two thiogs could be more di- Tene than

the two modes of proceeding. M. Meidingcr sought for the oxjgen which had disappeared, and found it in the liquid ; I examined the oxygen actually liberated, and found that the ozone mixed with it aug- ments in quantity as the electrodes diminish in size. It may be added that since the perusal of M. Meidinger's paper I have repeated his experiments with my own decomposition cells, and found that those which gave me the greatest absorption, also showed the greatest deficiency in the amount of oxygen liberated.

that ozone is produced bj the pnclcing of tlK „„ -. i,icincntary oxygen into oscillating groups; and thai nc^iting dissolves the bond of union, and allocs th« atoms to swing singly, thus disqualifying them for eilhcs j

intercepting or gc""- tliey are competeDV. iv I have now to dii wliieh surprised ani: ihcm. ^Vliilc erpcr wcasion I jiermitt to depress the mi experimental tube ^ the needle pointed i

" "notion, which, as systenu^ I ind generate. entioQ to a series of f;ictl I me when I first observed] November (1861), on a f alcohol vapour, suffident I -S of an inch, to enter Om I ide8ectionof 72^ While 1 mgu figure, and previously to

pumping out the vapour, I allowed dry air to stream into the tube, aiul happened, as it entered, to keep my eye npon the galvanometer.

The needle, to my astonishment, sank speedily to zero, and went to 25° on the opposite side. The entry of the almost neutral air, not only neutralised the absorption pre- viously observed, but left a considerable balance in favour of the face of the pile turned towards tho source. A repe- tition of the experiment brought the needle down from 70^ to zero, and sent it to SS° on the opposite side. In Ukc manner, a very small quantity of tbo vapour of sulphuric ether produced a deflection of 30° ; on allowing dry lur to fill the tube, the needle descended speedily to zero, and swung to 60" at the opposite side.

My first tlionght, on observing flie^o cxti'aordinarT cOhctif, was, (hut llie vapours

had deposited themselves in opaque films on the plates of rock-salt, and that tho dry air on entering had cleared these films away, and aUovred the heat from the source free transmission.

But a moment's reflection dissipated this supposition. The clearing away of such a film could, at best, bat restore the state of things existing prior to the entmnce of the

DTNAiaO SADEAnON. 387

Taponr. It might be conoeiyed to bring the needle again to 0°, bat it could not possibly prodnce the negative deflec- tion. Nevertheless, I dismounted the tnbe, and subjected the plates of salt to a searching examination. No such de- posit as that above surmised was observed. The salt re- midned perfectly transparent while in contact with the vapour. How, then, are the effects to be accounted for ?

We have already made ourselves acquainted with the thermal efiects produced when air is permitted to stream into a vacuum (page 44). We know that the air is warmed by its collidon against the sides of the receiver. Can it be the heat thus generated, imparted by the air to the alcohol and ether vapours, and radiated by them figainst the pile, that was more than sufficient to make amends for the absorption? The e3q)erimenium crucis at once sug- gests itself here. If the effects observed be due to the heating of the air on entering the partial vacuum in which the vapour was diflused, we ought to obtain the same effects when the sources of heat made use of hitherto are entirely abolished. We are thus led to the consideration of the novel and at first sight utterly paradoxical problem — namely, to determine the radiation and absorption of a gas or vapour witAatU any scwrce of heat external to the gaseous hodyUadf,

Let us, then, erect our apparatus, and omit our two sources of heat. Here is our glass tube, stopped at one end by a plate of glass, for we do not now need the passage of the heat through this end ; and at the other end by a plate of rocknsalt. In front of the salt is placed the pile, con- nected with its galvanometer. Though there is now no

spedal source of heat acting upon the pile, you see the nee- dle docs not come quite to zero ; indeed, the walls of this room, and the people who sit before me, are so many sources of heat, to neutralise which, and thus to bring the needle accurately to zero, I must slightly warm the defect-

'■"""" Hi nie tube

communicntin^ ti,c "liouldhavofronj,

Jflott radioed by nectionpredBjedis But thene ?• ,re *"■. To»I„^a,ei,i penmMUl tob., .^

r"^";th,p,pe„

"■«n.t,rior»rf.ce„, Iel<>»th,t„be„d„

.!. r!?,°™« the bit „,

DTBAiaO KADUTION 07 OABE8.

Iiutead of citrous oxide, I now allov olefiant gaa to stream into the exhausted tube. We have already learned that this gaa is highly gifted with the power of radiation. Its atoms are here wanned, and everyone of tfaem asserts its power ; the needle swings throngh an arc of 07°. I<ct it wastA its heat, and let tho needle come to zero. I now pomp ont, and the consequent chilling of the gaa, within the tube, produces a deflection of 40° on the side of cold. We b«ve cert^uly here a key to tho solution of the enig- matical efiects observed with the alcohol and ctber vapour.

For tho sake of convenience we may call tho heating of the gas on entering the vacuum dynamic heating / its radi- ation I have called dynamic radiation, and its absorption, when chilled by pumping out, dynamic absorption. These terms being nnderstood, the following tabic explains itself, la each case the extreme limit to which the needle swung, DB the entry of the gas into the experimental tube, is re- corded.

Dynamic Hadtation of Gases.

NuDD Lloilt dTIH impuliioti

Oiygen . Hjdrogcn ,

Carbocic Oiido Carbonic acid Kilroiis oiiJe OlcGaat gaa

Wo obser\'o that the order of the radiative powers, de- termined in tliis novel way, is the same as that already ob- tained from a totally difTcrcnt mode of experiment. It must be borne in mind that the discovery of dynamic radi- ation is quite recent, and that the conditions of perfect ac- curacy have not yet been developed ; it is, however, cer-

laii t the mod© of experiment is sHsceplible of Uie last degree of preciaion.

Let OS now tnm to our Tnponrs, ami while dealing with thctn I sliall endeavour to unite two effects which, st first

Mght, might appear uttei" learned that a polished a. feeble radiation ; bnt that with vamiah the radiati lion of motion to the <" mediator, and tliis tlic nicate their motion to tue u. latter aro so related to the

We have alreadj rfnee emits an extremely he same surface is coated ona. In the commniiira- (oms of the metal need a 3 varnish. They commn- cs of the vamiiih, nnd the itiferous ether* that thej

can communicate their motion to it. You may vamtdi a melallic surface by a film of a powerful gas. I have here

■ ir wc could change cither the name given to the iDteislellar medium, or that giren to ccriiiiti volatile liquids b<r chemists, it would be uk adno- tagc. It Is difficult to aroid coufuaion in the use of the aune name fin ol^jccu 80 utterly diTerae.

DYNAiaO RADIATION OF TAFOTTBS. 391

an arrangemeiii which enables me to cause a thin stratum of olefiant gas from the gasholder a (fig. 94) to pass through the slit tube a bj and over the heated surface of the cube c. The radiation from c is now neutralised by that from c' ; but I allow the

gas to flow over the cube c ; and though the surface is actually cooled by the passage of the gas, for the gas has to be warmed by the metal, you see the effect is to augment considerably the radiation : as soon as the gas begins to flow the needle begins to move, and reaches an amplitude of 45°.

We have here varnished a metal by a gas, but a more interesting and subtle effect is the varnishing of one gaseous body by another. I have here a flask containing some ace- tic ether ; a volatile, and, as you know, a highly absorbent substance. I attach the flask to the experimental tube, and permit the vapour to enter the tube, until the mercury col- umn has been depressed half an inch. There is now vapour possessing half an inch of tension in the tube. I intend to use that vapour as my varnish ; and I intend to use the ele- ment oxygen instead of the element gold, silver, or copper, as the substance to which my vapour varnish is to be ap- plied. At the present moment the needle is at zero, and I now permit dry oxygen to enter the tube : the gas is dynam- ically heated, and we have seen its incompetence to radi- ate its heat ; but now it comes into contact with the acetic ether vapour, and, conmiunicating its motion to the vapour by direct collision, the latter is able to send on the motion to the pile. Observe the needle — it is caused to swing through an arc of 70° by the radiation from the vapour particles. I need not insist upon the fact that in this ex- periment the vapour bears precisely the same relation to the oxygen, that the varnish does to the metal in our foi"- mer experiments.

Let us wait a little, and allow the vapour to pour away the heat : it is the discharger of the calorific force gene-

rated by tbe oxygen — the needlo is ogam at zero. I work the pump, the vapouv Trithin the tube becomes chilled, and now you obHerve tlie needle swing nearly 45° on the other i Bide of zero. In this way the dynamic radiation and alh

Borption of the vapours *"-ed in the following tabto

have been fictcrmined ; h ever, instead of oxygen,

being the substance om o heat the vapour. The

limit of the first swin idle ia noted nd before.

•sorption of Vapours.

Di/namic Itadiation

1. Bisulpbida ar(;arbaQ a. lodiJa of mcthj-l

4. Iodide of othyl C. Mclhjlic nicobol C. Chloride of BID}'!

9. Sulphuric other

10. Fonnic ether

11. Acetic ether .

We have here used eleven diflerent kinds of vapour as varnish for our wr, and we find that the dynamic radiation and absorption angment exactly in the order established by experiments with external sources of heat. Wo also see how beautifully dj-naraic radiation and absorption go hand in hand, the one augmenting and diminishing with the other.

The smalhiess of the quantity of matter concerned in Bomc of these actions on radiant heat has been often re- ferred to ; and I wisli now to describe an experiment which shall furnish a more striking example of this kind than onj hitherto brought before you. The absorption of boracio ether

YASNiBBma Am by yafoub.

iponr, as given at page 368, exceeds that of any other ibstance there referred to ; and its dynamic radiation may d presumed to be commensurate. I exhaust the experi- lental tube as perfectly as possible, and introduce into it quantity of boracic ether vapour sufficient to depress the lercory column ^'^th of an inch. The barometer stands to- ay at 30 inches ; hence the tension of the ether vapour [>w in our tube is ^J^th of an atmosphere.

I send dry air into the tube ; the vapour is warmed, id the dynamic radiation

produces the deflection 56°.

I work the pump until I reduce the residue of ^r within to a tension of 0*2 of an inch, or ^ ^^th of an atmosphere. L residue of the boracic ether vapour remains of course in le^tube, the tension of this residue being the t jgth part f that of the vapour when it first entered the tube. I let 1 dry air, and find the dynamic radiation of the residual apour expressed by the deflection 42°.

I again work the pump till the tension of the air within i is 0*2 of an inch ; the quantity of ether vapour now in le tube being jli,th of that present in the last experi- lent. The dynamic radiation of this residue gives a de- ection of 20°.

Two additional experiments, conducted in the same ay, gave deflections of 14° and 10° respectively. The aestion now is, what was the tension of the boracic ether apour when this last deflection was obtained ? The fol« »wing table contains the answer to this question : —

Dynamic Hadiation of Boracic Ether.

Tension In {larts of an atmosphere Deflection

lioXiiijXTbxiio 17*

TTmifMiJTnni

394 LECTORS XI.

The air itJiclf, wanning llie interior of tbe tabe, pro- duces, as wc have seen, ;i deflection of 7° ; hence the cadre deflection of 10^ n as not iIug to the radiation of the va- pour. Deducting 7", it «ould leave a residue of 3^. But supposing we ouldrcly omit the List experiment, we can then have no doubt that at due to the residue of borj: we find, by gtrict ii

plied by owe thousand mil Bion of ordinary atmospheri Another reflection here of oar cou»ideration. \Vi radiation of olefiant gas, b tube, until tbe latter waa i

oflhew;irni r^di^ilinp: coliim

lalf the deflection 14° is er vapour; this rcsidoe ouJd have to be multi- briug it up to tbe tt?u-

! Hself, which is worthy measured the dynamic ng the gas to enter onr d. What waa the G^te

of olofianl p;ns in lliis e\[icri. nieiit ? It is manifest that the portions of the column moit distant fiom the pile must radiate Ihrovgk l/te gas in front of them, and, iu this forward portion of the column of pis, a large (juantity of the rays emitted by its hinder portion will be absorbed. In fact, it is quite certain that if we made our column EufUciently long, the frontal portions would act as a perfectly impenetrable screen, to the laJia- tion of the hinder ones. Thus, by cutting off the part of the gaseous column most distant from the pile, we migbt diminish only in a very smaU degree the amount of radia- tion which roaches the pile.

Let us now compare the dynamic radiation of a vapour with that of olefiant gas. In the case of vapour wc use only 0'5 of an inch of tension, hence the radiating mole- cuJes of the etJier arc much wider apart than those of t!w olefiant gas, which have CO times the tension ; and cousc- qiienlly tlie radi.ation of the hinder portions of the column of \'apour will have a comparatively open door throuirli whicli to reach the pile. These considerations render it manifest that in the case of the vapour a. ffrcaier length of

EFFECT OF IHSTAKOB BKTWJCKN BADIANT CENTRES. 395

tube is svailable for radiation tiian in the case of olcfiant gas. This leads to the condnsion, that if we shorten the tube, we shall diminish the radiation in the case of the vapour more considerably than in the case of the gas. Let ns now bring onr

reasoning to the test of experiment.

We foond the dynamic radiation of the following four substances, when the radiating oolomn was 2 feet 9 inches long, to be represented by the annexed deflections : —

defiant gas . . .63

Solphuric ether . .64

Formic ether .... 68*5 Acetic ether • • . .70

oltffiant gas givuig here the least dynamic radiation.

Experiments made in precisely the same manner with a tube 3 inches long, or j'^th of the former length, gave the following deflections : —

defiant gas 89

Sulphuric ether . . .11

Formic ether . . , .12

Acetic ether 15

The verification of our reasoning is therefore complete. It is proved, that in the long tabe the dynamic radiation of the vapour exceeds that of the gas, while in a short one the dynamic radiation of the gas exceeds that of the vapour. The result proves, if proof were needed, that though dif- fused in ^r, the vapour molecules are really the centres of the radiation.

Up to the present point, I have purposely omitted all reference to the most important vapour of all, as far as our world is concerned — I mean, of course, the vapour of wa- ter. This vapour, as you know, is always difiused through the atmosphere. The clearest day is not exempt from it :

ii e Alps, the purest nkiea are oflen tbc mosl

tit urouB, the blue deepening wilh the amonnt of aque- ous vapour in Ihe air. It is needlcES, therefore, to remind you, that when I speak of aqueous vapour, I mean

notlitng visihlc ; it ia not fug ; it is not cloud ; it is not mist of any kind. These are formed lur which has been con-

densed to water ; but the > pour with wliich we have

to deal is an impalpa irent gas. It is djfiuscd

CTcrywhero throughoui, osphcrc, though in very

diETerent proportions.

To prove the cxiett cous vapour in tho urof

tlua room, I have plao of the table a copper ves*

sel, which was filled an huui ajjo with a mixtura of pound- ed ice and salt. The surface of the vessel was then black, but it is now white — furred all over vnth hoar-frost — ^pro- duced by .the condensation, and Huhsequent congelation upon ' its surface of the aqueous vapour. I can scrape off this wbitu substance, and collect it in my hand. As I remove the frozen vapour, the black surface of the vessel reajv jjeara ; and now I have collected a sufficient quantity to form a respectable snow-ball. Let us go one step furUier. I place this snow in a mould, and squeeze it before yoa into a cup of ice — there ia the cup ; and thus, without quilr ting this room, we have experimentally illustrated the maa- ufacturo of glaciers from beginning to end. On the plate of glass which I have used to cover the vessel the vapour is not congealed, but it ia condensed so copiously, that when I hold the pbte edgeways the water runs off it in a stream.

The quantity of this vapour is small. Oxygen and ni- trogen constitute about 90J per cent, of our atmosphere ; of the remaining 0'5, about 0'45 is aqueous vapour; the re- sidue is carbonic acid. Had we not been already acquit- cd with tbe action of almost infinitesimal qnantities of mat^ tcr on radiant beat, we might well dcspur of bong «ble to

ABSORPTION OF RADIAJ9T HBAT BY HdMID AIR. 397

establish a measurable action on. the part of the aqueous vapour of our atmosphere. Indeed, I quite neglected the action of this substance for a time, and could hardly credit my first result, which made the action of the aqueous vapour of our laboratory fifteen times that of the air in which it was ^fiiised. This, however, by no means expresses the true relation between aqueous vapour and dry air.

I will make an experiment before you which shall illus- trate this. Here, you see, I have resumed our first ar- rangement, as shown in Plate I., with a brass tube, and with two sources of heat acting on the opposite faces of the pile. I exhaust the experimental tube, and repeat to-day the experiment with dry air, which I made at the com- mencement of the last lecture. The needle does not move sensibly. If close to it you would, as I have already stated, observe a motion through about one degree. Prob- ably, could we get our air quite pure, its action would be even less than this. I now pump out, and allow the air of this room to enter the experimental cylinder direct, with- out permitting it to pass through the drying apparatus. The needle, you observe, moves as the air enters, and the final deflection is 48°. The needle will steadily point to this figure as long as the sources of heat remain constant, and as long as the air continues in the tube. These 48° correspond to an absorption of 72 ; that is to say, the aque- ous vapour contained in the atmosphere of this room to-day exerts an action on the radiant heat, 72 times more power- ful than that of the air itself.

This result is obtained with perfect ease, still not with- out due care. In comparing dry with humid air it is per- fectly essential that the substances be pure. You may work for months with an imperfect drying apparatus and fail to obUun]ur, which shows this almost total absence of action on radiant heat. An amount of organic impurity, too smaU

I f tlio eye, in sufficient to nngmpnt liAyfoIil (h*

n Ji t&c air. Knowing tbe vSbct which no almost in-

fiiiitoBimal amount of mattei-, in certain casea, can produce,

u arc better prepared for such facts than I was when they

first forced themselves uuon careful in oar enquiriea, we have just obtained w inSucQcc on the science admitted, it ought to I First of all, look at 1 the next roora, wher" tank, but not in cont! wet ; it in a liy^jroscopic moisture upon it3 surface.

attention. Bat let us bi^ xperimcntal result n-hich -uc, have so important an srology, that, before it is 3d to the closest scnitinj-. rocksalt brought in from lod for some time near a ble moisture. The salt is hstance, and freely condcnsrs Here, also, is a polished plate of the Bubstance, which is now quite dry ; I breatbe upwi it, and instantly its affinity for moisture causes the vapour of my breath to overspread the surface in a film which ex- hibits beautifully the colours of thin plates.* Now we know from the tabic, at page 313, how opaque a solntioD of rocksalt is to tlie calorific rays, and henco arises tbe question whether, in the above experiment with imdried air, we may not in reality be measuring the action of a thb stratum of such a solution, deposited on our plates of salt, instead of the pure action of the aqueous vapour of tbe air. If you operate incautiously, and, more particularly, if it be your actual intention to wet your plates of salt, yon may readily obtain the deposition of moisture. This is a pomt on which any competent experimenter will soon instruct himself; but the essence of good experimenting consists in the exclusion of circumstances which would render the pure and simple questions which we intend to put to Nature, impure and composite ones. The first way of replying to the doubt here raised is to examine our plates of salt ; if the experiments have been properly condacted, no trace of moisture is found upon the surface. To render the « ' See Not* (8) at the erd of this Lectnre.

WJMI'UIO BOGKSALT PLATES.

of this experiment more certain, I will slightly alter the ar- rangement of our

apparatus. Hitherto we have had the thermo-electric pile and its two reflectors entirely otUside the experimental cylinder. I now take this reflector from the pile, and removing this terminal plate of rocksalt, I push the reflector into the cylinder. The hollow reflectiug cone is * sprung ' at its base a b (fig. 95), (our former ai*- rangementi with the single exception that one of the re- flectors of the pile p is now within the tube) so that it is

held tightly by its own pressure against the inner surface of the cylinder. The space between the outer surface of the reflector and the inner surface of the tube I fill with fragments of fused chloride of calcium, which are prevent- ed from falling out by a little screen of wire gauze. I now reattach my plate of salt, agamst the inner surface of which abuts the narrow end of the reflector ; bring the face of the pile dose up to the plate, though not into actual con- tact with it, and now our arrangement is complete.

In the first place it is to be remarked, that the plate of salt nearest to the source of heat c is never moistened, un- less the experiments are of the grossest character. Its proximity to the source makes it the track of a flux of heat, powerful enough to chase away every trace of humidity

V LEcnTHK xr. '

fro surface. Tlie. distant plate U the one in dangei;,

anauuw ve bav? the circumferential portions of thisplatft, kept perfectly dry by (he diloride of c.ilciiiiu ; do tnoiet aut can at all reach the rim of the plate ; while upon its centrali portion, measuring about a eauarc inch in area, we htm, converged our entire radi On d priori grounds we

t-hould conclude that it i impossible that a film of

moietnrc could coUoct th(this conclusion is JuElified

by fact. I test, as befo Iriod air and the undried

air of this room, and f the former itifitance, that

the latter produces se s the effect of the former.

The needle is now dCi the absorption of the aD>

dried air; allowing this air to remain in tlje tube, I unscrew my plate of salt, aud CKaminc its surface. I even use % lens for this purpose, taking care, however, that nay breath does not strike the plate. It was carefully polished when attached to the tube ; it ia perfectly polished now. Glass, or rockcrystal, could not show a surface more exempt from any appearance of moisture. I place a dry handkerchief over my finger, and draw it along the surface : it leases no trace behind. Tiiere is not the slightest deposition of mois- ture ; atill we see that absorption has taken place. This experiment is conclusive against the hypothesis that the effects observed are due to a film of brine instead of to aqueous vapour.

The doubt may, however, linger, that although we are unable to detect the film of moisture, it may still be there. This doubt is answered in the following way ; — I detach the experimental tube from the front chamber, and remove the two plates of rocksalt ; the tube is now open at both ends, and my aim will be to introduce dry and moist air into this open tube, and to compare their effects upon the radiation from our source. And here, as in all other cases, the practical tact of the experimenter must come into play. The source, on the one hand, and the pile on the other, are

ABBOBPnON WITHOUT BOCSBALT PLATES.

now freely exposed to the air ; and a very slight agitation acting npon either would disturb, and might, indeed, alto- gether mask the effect we seek. The air, then, must be in- troduced into the open tube, without producing any com- motion either near the source or near the pile. The length of the experimental tube is now 4 feet 3 inches ; at c (fig. 9G) is a cock connected with an Indiarrubber bag containing common air, and subjected by a weight to gentle pressure ;

at D is a second cock connected by a flexible tube, t, with an air-pump ; between the

cock c and the India-rubber bag our drying tubes are introduced ; when a cock near the bag is opened, the air is forced gently through the drying tubes into the experimental cylinder. The air-pump is slowly worked at the same time, and the dry air thereby drawn towards d. The distance of c from the source s is 18 inches, and the distance of d from the pile p is 12 inches, the compensating cube c, and the screen u, serve the same purpose as before. By thus isolating the central portion of the tube, we can displace dry air by moist, or moist air by dry, without permitting any agitation to reach either the source or the pile.

At present the tube is filled with the common air of the laboratory, and the needle of the galvanometer points steadily to zero. I now allow air to pass through the dry- ing apparatus and to enter the open tube at c, the pump being worked at the same time. Mark the effect. When the dry air enters the needle commences to move, and the

1^ LCCTUBB XI.

I its motion shows that more heat is now pin-

ing uian «el'orc. Tlie substitution of dry air for the air of the laboratory haa rendered tlie tilbo more transparent lo the rays of heat. Tito final deflection thus obtained is IS degrees. Here the — ■^'~ —~ -ijly remains, and beyond this point it ciinnot ly any further pumping in

of the dry air.

I now shnt off I dry nir and cease worldng

the pump ; the net with great slowness, indi-

cating a correspoi diffusion of the aqucoos

vapour of the adjac e dry air of the tube. If

I work the pump 1 ^inoval of the dry aii-, and

the needle sinka more sjieedilv, — it now points to zero. The experiment may be

made a hundred times in succee- sion without any deviation from this result; on the en- trance of the dry air the needle invariably goes np to 4S°, showing the augmented transparency ; on the entrance of tlie undried air tlie needle sinks to O", showing augmented absoiption.

But the atmosphere to-day is not saturated with mois- ture ; hence, if I saturate the air, I may expect to get a greater action. I remove the drying apparatus and put in its place a U tube, which is filled with fragments of glass moistened by distilled water. Through this tube I force the air from the India-rubber bag, and work the pomp at before. We are now displacing the humid air of tho labor- atory by still more humid air, and see tho consequence. The needle moves in a direction which indicates augmented opacity, the final deflection being 15°.

Here then we have substantially the same result as that obtained when we stopped our tube with plates of rock- salt ; hence the action cannot be referred to a hypothetical film of moisture deposited upon the surface of the plates. And be it remarked that there is not the Blight«st caprice er uncertainty in these experiments when properly con-

FBOFOBTIOir ABSORBED BT HUIOD AIB. 403

ducted. They have been executed at different times and fieasons ; the tube has been dismounted and remounted ; the snggestions of eminent men who have seen the experi- ments, and whose object it was to test the results, have been complied with ; but no deviation from the effects just recorded has been observed. The entrance of each kind of air is invariably accompanied by its characteristic action ; the needle is under the most complete control : in short, no experiments hitherto made with solid and liquid bodies, are more certain in their execution, than the foregoing experi- ments on dry and humid air.

We can easily estimate the per centage of the entire radiation absorbed by the common air between the points cand D.

Introducing this tin screen between the experimental cylinder and the pile, I shut off one of the sources of heat. The deflection produced by the other source indicates the total radiation.

This deflection corresponds to about 780 of the units which have been hitherto adopted; one unit being the quantity of heat necessary to move the needle from 0° to 1°. The deflection of 45** corresponds to 62 units ; out of 780, therefore, 62, in this instance, have been absorbed by the moist air. The following statement gives us the ab- sorption per hundred : —

780:100 — 62:7-9.

An absorption of nearly 8 per cent, was, therefore, ef- fected by the atmospheric vapour which occupied the tube hetween c and d. Air perfectlf/ saturated gives a still greater absorption.

This absorption took place, notwitlistanding the partial sifting of the heat, in its passage from the source to c, and from D to the pile. The moist air, moreover, was, prob- ably, only in part displaced by the dry. In other cxpcri-

I md, Trilh a tiibo 4 feet long, and poliehod v

tuai. me ftunospheric vapour, on a day of avorage dryncaii, absorbed over 6 per cent, of the radi:ttioa from our eonrw. Regarding the earth as a source of heat, no doubt, irt leatt

10 per cent of its hea' -' gurfaee.* Tliis einglu which Ibis newly dc> must have in the]>he But we have noi been intimated to bo impure ; and tl>u doQ ail have also beci

•'~ied tcil/iin ten J'let of tht 'sts the enormous inflttcnoe operty of aqueous vaponr . noteorology. i

1 of all objections. It ha* I ir of our laboratory migfat irbon particles of the Loop >, as a pos»ble caufie of tlu ,

absorption, aacrilied to aqueoua vapour.

I reply : 1st. The results Troro obtained when the s^ paratuH waa removed from the laboratory — ^thoy are ob- tainable in this room. 2ndly. Air was brought from tba following localities in impervious bags ; — Hyde Park, Priio- rose Hill, llampstead Heath, Epsom Downs (near the Grand Stand) ; a field near Newport, Isle of Wight ; St Catharine's Down, Isle of Wight; the sea beach near Black-gang Chine. The aqueotu vapour of Ike air fnm all tliem localities-, examined in the tieual teay, exerted an absorption scoent>/ times tliat oftlte air in which Che vapour ieas diffused.

Agam, I experimented thus. Tlie air of the Uboratory was dried and purified until its absorption fell below unity; this purified air was then led through a XT tube, filled with fragments of perfectly clean glass moistened with distilled water. Its neutrality, when dry, showed that all prejudi- cial substances had been removed from it, and in passing tbrougli the U tube, it eould take up nothing but the pure va])our of water. The vapour thus carried into the eipen-

coDsiderabtf cicecda tliia unouDt.

olisorptioD, I liave lesHU to beliere,

OBJBOfnORB JkNBWEBED.

nental tube prodooed an action ninety times greater than hat of the air which carried it.

But fair and philosophic criticism does not end even lere. The tube with which these experiments were made I polished within, and it was surmised that the vapour of he humid air might, on entering, have deposited itself pon the interior surface of die tube, thus diminishing its eflective power, and producing an effect apparently the ame as absorption. But why, I would ask, should such a leposition of moisture take place ? On many of the days rhen these experiments were made the air was at least 25 ler cent, under its point of saturation. It can hardly be ssumed that such mr would deposit its moisture on a mc- allic surface, against tohich^ moreover^ the rays from

our ouree of heat toere at (he time impinging. The mere con- ideration of the objection must deprive it of weight. further, the absorption is exerted when only a small frac- icHi of an atmosphere is introduced into the tube, and it is nroportional to the quantity of air present. This is shown jy the following table, which gives the absorption, by hu- nid air, at tensions varying from 5 to 30 inches of mercury.

Teiwlon n incites

AbaorpUon

OtecrveU

Calculated

The third column of this table is calculated on the as- mnption that the absorption is proportional to the quan- ity of vapour in the tube, and the agreement of the calcu- ated and observed results show this to be the case, within he limits of the exi)eriment. It cannot be supposed that

■nipos.ilJc., and „■ ■lould cleMioj, by

tilie, ofheatsoare matter present.

My desire, how. tion quite ont of t) Mfongtbismiglita, »ot only the plate, tube ii«.lf, and tod

ABSOBPnOK OF AQUSOUB YAPOUB IN FBEE AIR. 407

mo-electiic pile, and c' a compenBating cube, between which and p ia an acyosting screen, to regulate the amount of ra- diation fSEdling op the posterior surface of the pile. The whole arrangement was surrounded by a hoarding, the •pace within which was divided into compartments by sheets of tin, and these 8))aces were stufifed loosely with paper or horsehidr. These precautions, which required time to be learned, were necessary to prevent the formation of local air-currents, and also to intercept the irregular ac- tion of the external lur. The effect to be measured here is very small, and hence the necessity of removing all causes of disturbance which

could possibly interfere with its clear- ness and purity.

A rose-burner r was placed at the bottom of the cylin- der T, and from it a tube passed to an India-rubber bag containing mr. The cylinder t was first filled with frag- ments of rockcrystal, moistened with distilled water. On subjecting the India-rubber bag to pressure, the air from it was gently forced up among the fragments of quartz, and having there charged itself with vapour it was discharged m the space between the cube c and the pile. Previous to this the needle stood at zero ; but on the emergence of the saturated air from the cylinder, the needle moved and took up a final deflection of five degrees. The direction of the deflection showed that the opacity of the space between the source c and the pile was augmented by the presence of the saturated air.

The quartz fragments were now removed, and the cyl- inder was filled with fragments of fresh chloride of cal- cium, through which the air was gently forced, exactly as in the last experiment. Now, however, in passing through the chloride of calcium, it was in great part robbed of its aqueous vapour, and the air, thus dried, displaced the com- mon air between tbe source and pile. The needle moved, declaring a permanent deflection of 10 degrees ; the direc-

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tion of the deflection fihowed that the transparency of Uw: space was augmented hy tlio prcspnco of the di-y air. Sfi prOfwrly timing the discharges of Uie air,,lLe swing of the needJc could be augmented to 15 or 20 degreee. Repeti- tion showed no deviation from this result; the saturated air always augmented the oi y, the dry air always ang- mented the transparency c space between the sourco ,

and the pile. Not only, thi e, have the pktea of rock- '

salt l>een abandoned, but ah ■■ espcrimental tabe itself, j and the results are all peri concurrent aa regarda the

action of aqueous vapour i diant heat.

Were this subject les irtant I should not have t

dwelt upon il so long. I .t it right to remove every I

objection, so that meteoroi might apply, without the

faintest misgiving, the results of experiments. The appli- cations of these results to thoir Bcicnco must be innumer- able ; and here I cannot but regret that the incompleteness of my knowledge prevents me from milking the proper ap- plications myself. I would, however, ask your permLisioQ to refer to siieh points as I can now call to mind, with which the facts just estabhshed appear to be more or less btl- m.itely connected.

And, first, it is to be remarked that tlic ^'apour wbicfa absorbs heat thus greedily, i-adiates it copiously. TbiJ fact must, I imagine, come powerfully into play in tho tropics. We know that the sim raises from the equatorial ocean enormous quantities of vapour, and that inuediately under him, in tlio region of calms, tlie rain, due to the con- densation of the vapour, descends in deluges. Hitherto, this has been ascribed to the chilling which acconipanios the expansion of the ascending air, and no doubt this, as a true cause, must produce its proportional efTect. But I c.innot help thmking that the radiation from the vapour il- solf is also influential. Imagine a column of saturated air ascending from the equatorial ocean ; for a time the vapour

TOBRENTIAL BAIN8 OF THB TBOFICS. 409

entangled in this air, is Burronnded bj air almost fully saturated. Its vapour radiates, but it radiates into vapour, and the vapour into it. To the radiation from any vapour, a screen of the same vapour is particularly opaque. Hence, for a time, the radiation from our ascending column is in- tercepted, and in great part returned by the surrounding vapoor ; condensation under such circumstances cannot oc- cur. But the quantity of aqueous vapour in the air dimin- ishes speedily as -we ascend ; the

decrement of tension, as proved by the observations of Hooker, Strachy, and Welsh, is much more speedy than that of the air ; and, finally, our vaporous column finds itself elevated beyond the protecting screen which, during the first portion of its ascent, was spread out above it. It is now in the presence of pure space, and into space it pours its heat without stoppage or re- quital. To the loss of heat thus endured, the condensation of the vapour, and its torrential descent to the earth, must certainly be in part ascribed.

Similar remarks apply to the formation of cumuli in our own latitudes ; they are the heads of columnar bodies of vapour which rise from the earth's surface, and are precipi- tated as soon as they reach a certain elevation. Thus the visible cloud forms the capital of an invisible pillar of sat- urated air. Certainly the top of such a column, raised above the vapour screen which clasps the earth, and oficr- ing itself to space must be chilled by radiation ; in this ac- tion alone we have a physical cause for the generation of clouds.

Mountains act as condensers, but how? Partly, no doubt, by the coldness of their own masses ; which cold- ness they owe to their elevation. Above them spreads no vapour screen of sufficient density to intercept their heat, which consequently gushes unrequited into space. When the sun is withdrawn, this loss is shown by the quick and

large descent of the thermometer. This descent is not due

ti I from tbe air, but to radiation from the earth, Oi J 11 me thermometer itself. Thus the difference be- twfi:ii a thermometer which, properly c3oafiiicd, give* the true temperature of the night air, and one which is permit- ted to radiate freely ' ' ^e, mmst be greater at high

elevatioa» than at U, This conclusioa is eatircly

confirmed by obsorv lie Grand Plateau of Moot

Blanc, for example, qb and Bravois fonnd tlio

difierence between mometera to be 24° Fahr,;

when a didereuce ls observed at CbanioimL

But mountains ndeneers by tbe deflection

upwards of moist etr consequent expsoaioa;

the chilling thus produced ia tfic same as tii.it which accom- panies the direct ascent of a column of wann air into tbe atmosphere ; the elevated air performs work, and its heat is correspondingly consumed. But in addition to these causGB, I think we must take into account the radiant power of the moist air when thus tilted upwards. It is thereby lifted beyond the protection of the aqueous hiyer which lies close to the earth, and tiierefore pours its heat freely into space, thus effecting its own condensation. No doubt, I think, can bo entertained, that the extraordinary energy of water as a radiant, in all Us states of aggrtga- tion, must play a powerful part in the coDdensation of a mountidn region. As vapour it pours its beat into space and promotes condensation ; as liquid it poors its heat into space and promotes congelation ; as snow it pours its heat into space and thns converts the surfaces on which it falls into more powerful condensers than they otherwise would be. Of the numerous wonderM properties of water, not the least important is this extraordinary power which it possesses, of discharging the motion of heat upon the In- terstellar ether.

A freedom of escape similar to that from bodies of vapour at great elevations would occur at the earth's sui-

GOLD OF CENTRAL ASIA, ETO. 411

Ituse generallj, were the aqueous vapour removed from the air above it, for the bodj of the atmosphere in a practical vacuum as regards the transmission of radiant heat. The withdrawal of the sun from anj region over which the at- mosphere is dry must be followed bj quick refrigeration. The moon would be rendered entirely

uninhabitable by be- ings like ourselves through the operation of this single, cause ; with an outward radiation iminterrupted by aqueous vapour, the difference between her monthly maxima and minima must be enormous. The winters of Thibet are almost unendurable from the same cause. Witness how the isothermal lines dip from the north into Asia, in winter, as a proof of the low temperature of this region. Humboldt has dwelt upon the * frigorifio power ' of the central por- tions of this continent, and controverted the idea that it was to be explained by reference to its elevation, for there were vast expanses of country, not much above the sea level, with an exceedingly low temperature. But not know- ing the influence which we are now studying, Humboldt, I imagine, omitted one of the most important of the causes which contributed to the observed result. Even the ab- sence of the sun at night causes powerful refrigeration when the air is dry. The removal, for a single summer night, of the aqueous vapour from the atmosphere which covers England, would be attended by the destruction of every plant which a freezing temperature could kill. In Sahara, where *' the soil is fire and the wind is flame,' the refrigeration at night is often painful to bear. Ice has been formed in this region at night. In Australia, also, the di- urnal range of temperature is very great, amountmg, com- monly, to between 40 and 50 degrees. In short, it may be safely predicted, that wherever the air is cfry, the daily thermometric range will be great. This, however, is quite diflerent from saying that when the air is dear the ther- mometric range will be great. Great clearness to light is

4 LECTUBK XI. ^t^

pe ompatible vith great opacity to beat ; the at-

mi. iie may be charged with aqueous vaponr while a deep blue fiky is overhead, and on anch occasions the ter- rcBtriat Tadiation would, not withstanding the ' clearness,' be intercepted.

And hero we are IctJ isy explanation of a fact

which f I perplexed Sir Joba Les-

lie. T)rated experimenter con-

strui ;niinent which be named

an , the function of which

wa' ine the radiation against

the usialed of two glass bulhs

united hy a vortical glass Inbe, so nar- row that a little column of liquid was supported in tho tube by its own adhe- sion. The lower bulb d (fig. 98) was protected by a metallic envelope, and gave the temperature of the air ; the up- per bulb B, was blackened, and was sur- rounded by a metallic cop c, which pro- itected the bulb from terrestrial radia- tion. ' This instrument,' says its inventor, ' exposed to the open air in clear weath- er will at all times, both during the day and the night, indicate an impression of cold shot downwards from th« bigbei regions. . . . The sensibility of the instrument is very striking, for the liquor incessantly falls and rises in the stem, with every passing cloud. But the cause of its varia- tions does not always appear so obvious. Under a fine blue sky the (ethrioscope will sometimes indicate a cold of 50 millesimal degrees ; yet on other days, when th» air aeems e^uaUy bright^ the effect is hardly 30°.' This anom- aly is simply due to the difference in the quantity of

<GL£A9' DATS AND ^DBY' DAYS. 413

aqueous vaponr present in the atmosphere. Indeed, Leslie himself connects the efiect with aqueous vapour in these words, *The pressure of hygrometric moisture in the air probably affects the instrument.' It is not, however, the

* pressure ' that is effective ; the presence of invisible vapour intercepted the radiation from the sethrioscope, while its absence opened a door for the escape of this radiation into space. As regards experiments on terrestrial radiation, a new

definition will have to be given for ^ a dear day ; ' it 18 manifest, for example, that in experiments with the pyrheliometer,* two days of equal visual clearness may ^ve totally different results. We are also enabled to ac- count for the fact that the radiation from this instrument is often intercepted when no cloud is seen. Could we, however, make the constituents of the atmosphere, its vapour included, objects of vision, we should see sufficient to account for this result.

Another interesting point on which this subject has a bearing is Melloni's ' theory of serein. * Most authors,' writes this eminent philosopher, * attribute to the cold, re- sulting from the radiation of the air, the excessively fine rain which sometimes falls in a clear sky, during the fine season, a few moments after sunset.' ^ But,' he continues,

* as no fact is yet known which directly proves the emissive power of pure and transparent elastic fluids, it appears to me more conformable,' Ac, Ac. If the difficulty here urged against the theory of serein be its only one, the the- ory will stand, for transparent elastic fluids are now proved to possess the power of radiation which the theory assumes. It is not, however, to radiation from the air that the chil- ling can be ascribed, but to radiation from the body itself, whose condensation produces the serein.

Let me add the remark, that as far as I can at present

* The Instroment is described in Lecture XII.

j] IS T{ipour and liquid water absorb the eamc

cbsa VI xsys ; liia is nnollier way of stating that the colour

. of pare water is ebarod by ita vapour. In virtue of aqueous

vapour the atmosphere is therefore a blue medium. I be-

lieve it has been remarkeil i- al blue, and of distant Rqueous vapour in the duces a variation of dn of color. Whether question of metcoro ■will not at present

! colour of the fimuuneDt- CTM with the amotmt of ,he substance which pro- be effective as an ori^ le sky — the most difficult be thus accounted for, T uirc.*

■ In connectioii vith the uiTMtigatiDii oT the nn^boo ud iboorptica of ticut by gases and vapours, it girca me pleasure to nfer to the prompt »Dd intelligent aid reDdered me bj Mr, Becker, of the firm of EUiolte', 30 Weet Strand.

From the more energetic gas«a and vapours, a SGriee of rcr; strilung class cipcrinicnti maj be derived, interesting alike to the cliemist and Ihe natural philoaophcr. Mr. Becker bas coDBliuctcd a cbeap fonn of appa- ratus suitable for ibe ciperimcnls. Where quanUtatire results arc not required, two cubes of bot irater, an open lin tube, a thermo-electric pile, and a ealTanomclcr, magnetized, aa deacribed in the Appendii to Lectore I., vrill BulBcc to illustrate the action of the stronger gases and rapours. A current of air from a common bellows will carry the rapour into the

The fear of being led too far from mj subject caoscs me lo witbhcdd nU speculation as to the cause of atmospheric polarisation. I may, how ever, remark, that the polarisation of beat was iUustrated by means of the mica piles with nhicb ProfeEsor (noir Prinnpol) J. D. Forbes first euo ceeded ia establiiihing the fact of poloriMtioo.

KOTK (e) Rccdving the beam from the electric lamp npon the polished plaU of sail, go OS to reflect the light on to a screen ; and placing a lens in &onl of the salt, so ss to produce an image of its polished surface on the screen ; OD breathing against the Salt through a glass tube, beautiful iridesccDCO instantly flash forth, vlucb may be seen by hundreds at once.

APPENDIX TO LECTURE XL

SXTBA0T8 F£OM A DISCOUBSE *Oir RADIATION THBOUGn THB

EABTH^ ATMOSPHEBE.'

* Nobody ever obtfdned the idea of a line from Enclid^s dcfinitioD of it — " length without breadth." The idea is obtained from a real ph jncal line, drawn by a pen or pencil, and therefore poA- sessing width; this idea being afterwards brought, bj a process of abstraction, more nearly into accordance with the conditions of the definition. So, also, with regard to physical phenomena ; we most help onrselves to a conception of the invisible, by means of proper images derived from the visible, afterwards purifying oar conceptions to the needfol extent. Dofiniteness of conception, even though at some expense to delicacy, is of the greatest utility in dealing with physical phepomena. Indeed, it may be questioned whether a mind trained in physical research can at all enjoy peace, without having made clear to itself some possible way of conceiv- ing those operations which lie beyond the boundaries of sense, and in which sensible phenomena originate.

' When we speak of radiation through the atmosphere, we ought to be able to affix definite physical ideas, both to the term atmos- phere and the term radiation. It is well known that our atmos- phere is mainly composed of the two elements, oxygen and nitro- gen. These elementary atoms may be figured as small spheres, scattered thickly in the space which immediately surrounds the earth. They constitute about 99^ per cent, of the atmosphere. Mixed with these atoms, we have others of a totally different character; we have the molecules, or atomic groups, of carbonic acid, of ammonia, and of aqueous vapour. In these substances diverse atoms have coalesced, forming little systems of atoms.

410 ArPENDlX TO LKCnfKK XJ. ^^^

The moloeule of aqneons vapour, for eiample, coneids of two nl- oms of hjdrogaii, united to one of oxygen; and tb^j mingle, u little triads, amoDg tie monads of OJtygea and nitrogen wLicli ton- eUtate the great mass of the atmojipliere.

' These atoms and molecnleB are separate, bnt they are embniced by a common medinm. Witbin onr atmosphere ezisU a second, and a finer atinospliere, in wliicli

the atoms of oxrgen and nilro- gen Imng like suspended grains. Tins finer atmosphere aniiaa not only atom with atom, bnt star nith star ; and the light of all sons, and of all stars, is in reality a kind of mnsic, propagated throngli this inlcrstollar air. This image mmt be clearly aeizcd, and then we have to advance a step. "We must not only figure our atomi anspeuded in tbia medimn, bnt fibrating in it Id this motion of the atoms oonnsta what wo call their heat. "What ia beat in na,^ aa Locke baa perfectly esprcsaej it, " is in the boily heated notJi- ing but motion." Well, we most Cgcre this motion commnnicaicd to the medium in which the atoms swing, and sent in rippki through it, with inconceivable velocity, to the bonnds of spuca, Motion in this form, unconnected with ordinary matter, but speed- ing throagb the interstellar medinm, receives the name of Itadiaul Heat; and, if coinpctont" to excite tlio nervea of vision, we ealiil Ught.

'Aqncons vapour was defined to bo an invisible gas. Vapow was permitted to issue horizontally with considerable force fnm B. tube connected with a small holier. The track of the cloodof condensed steam was vividly illuminated by the electric ligliL What was seen, however, was not vapour, but vapoor condcnsri to water. Beyond the visible end of the jet, the eloud resolvfd iteelf iuto true vapour. A lamp was placed under the jet, at va- rious points; the cload was cut sharp}}- nffat Uiat point, aad wbta the flamo was placed near the efflux orifice, the cloud entirely dis- appeared. The heat of the lamp completely prevented predpita- tion. This samo vapour was condensed and congealed on thesar face of a vessel containing a freezing mixture, fi'om which it wu scraped, in quantities sufficient to form a small snowball. The beam of the electric lamp, moreover, waa sent throngh a large re- ceiver placed on an nir-pninp. A single stroke of the pump caused the precipitation of the aqneons vapour within, which becuna beautifully illuminated by the beam ; while, upon a screen behind.

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a richlj-colonred halo, dne to difEraction by the little dond within the receiver, flashed forth.

*' The waves of heat speed from onr earth through the atmos- phere towards space. These waves dash in their passage against the atoms of oxygen and nitrogen, and against the molecules of aqaeoos vaponr. Thinly scattered as these latter are, we might naturally think meanly of them, as barriers to the waves of heat. We might imagine that the wide spaces between the vaponr mole- cules wonld be an open door for the passage of the nndnlations; Bad that if those waves were at all intercepted, it wonld be by the Bobfltances which form 99^ V^^ ^^^ o^ ^^® whole atmosphere. Three or fonr years ago, however, it was fonnd by the speaker that this small modicnm of aqneons vaponr intercepted fifteen times the quantity of heat stopped by the whole of the air in which it was diffnsed. It was afterwards found that the dry air then ex- perimented with was not perfectly pure ; and that the purer the lir Became, the more it approached the character of a vacuum, and the greater, by comparison, became the action of the aqueous va- [KNir. The vapour was found to act with 80, 40, 50, 60, 70 times the energy of the air in which it was diflused ; and no doubt was mtertained that the aqueous vapour of the air which filled the Etoyal Institution theatre, during the delivery of the discourse, ab- iorbed 90 or 100 times the quantity of radiant heat which was ab- sorbed by the main body of the air of the room. Looking at the Bin^e atoms, for every 200 of oxygen and nitrogen there is about 1 of aqueous vapour. This 1 is 80 times more powerful than the 200; and hence, comparing a single atom of oxygen or nitrogen with a single atom of aqueous vapour, we may infer that the action of the latter is 16,000 times that of the former.

* No doubt can exist of the extraordinary opacity of this sub- stance to the rays of obscure heat ; particularly such rays as are emitted by the earth, after being warmed by the sun. Aqueous vapour is a blanket, more necessary to the vegetable life of Eng- land than clothing is to man. Remove for a single summer-night the aqueous vapour from the air which overspreads this country, and you would assuredly

destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens wonld pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost. The

APPENDIX TO LKCTCBK XI.

• r ccposritntes a local &im, hj which the lennpcratan

ai ... ti anrfaco is deepened; the dam, however, finally ovcr-

flowg, mm wo give to spac* oil that wo recoivo from the sim.

' The Bun raises the vapours of the equatorial ocean ; th*y nee, bnt for a time a vapour ecrcen snrcads nhore imd aronnd Ihem. Uiit the higher (hey ■ they wrnie into tlie p

of pnre spH*ie; and wr"-" evity, they have penetriited

the vapoiir BcreoD, whi to the eartVa snrface, what

' It lias bc«n said t torn for atoio, the obMirplioD

of en atom of aqaeo')00 times that of tur. Now

the power to ahsorb o radiate are perfectly recip-

rocal and proportionai f squcona vapoor wiQ there-

fore rudiiHo Willi 10,000 umos ti.c onerpy of nil ntom of air. Im- agine, then, tliis powerful radiant in the presence of space, and with no screen above it to check its radiation. Into spww it poors its heat, chills itself, condenses, and the tropical toirenU are the consequence. The eipandon of the (ur, no doaht, aln refrigerates it; hut in acconnUng for delages, the ohilling of tlie vapour by its own radiation tmist play a moat important part The rain qniU the ocean as vaponr; retnms to it as wal«r. Hot are the vast (.tores of heat, set free by the change from the vapw oos to the liqfiid coaditjon, disposed of 3 Doubtless, in great part, they are wasted by radiation into space. Similar remarka applj to the camuli of our latitades. The warmed air,

charged witb vapour, rises in colnmns, so as to penetrate the vaponr flcre*n which bugs the earth; iu the presence of space, the head of each pillar wastes its heat by radiation, condenses to a comnlas, which constitutes the visible capital of an invisible column of satnrottd ^r. NnmherlesB other meteorological phenomena recuve theif solotion by reference to the radiant and absorbent properties of aqneons vnponr,'

The radiant power of a vaponr is proportional to its absorbent power. Experiments on the dynamic radiation of dried and nn- dried air prove the superiority of the latter as a radiator. TI» following eiperiment, performed by Dr. Frankland in the theatre of the Royal Institution, showed the effect to a large andience. A charcoal cbaaffer, 14 inches high and G inches in diameter, wii!

HOOKER AND UVINGSTONE's OBSEBYATIONB. 419

placed in front of a thermo-electrio pile, and at a distance from it of two feet. The radiation from the chauffer itself was inter- cepted bj a metallic screen. The deflection due to the radiation fit>m the ascending oolomn of hot carbonic acid was then carefullj neutralised bj a constant source of heat, radiating against the op- posite &oe of the pile. A current of steam was then forced yerti- callj throngji the chauffer. The deflection of the galvanometer was prompt and x>owerfuL When the current of steam was in- terrupted, the needle returned to. zero. When, instead of a cur- rent of steam, a current of air was forced through the chauffer, the slight effect produced showed the pile to be chilled instead of warmed. In this experiment Dr. Frankland compared aqueous yapoor, not with air, but with the more powerful carbonic acid, and demonstrated the superioritj of the yapour as a radiator.'^

The following remarkable passage from Hooker^s ' Himalayan Journals,' 1st edit. yoL ii. p. 407, also bears upon the present sub- ject: 'From a multitude of desultory observations I conclude that, at 7,400 feet, 126'7°, or 67° above the temperature of the air, is the average effect of the sun's rays on a black bulb ther- mometer. . . •

These results, though greatly above those obtained at Calcutta, are not much, if at all, above what may bo obeerved on the plains of India. The effect is much increased by elevation. At 10,000 feet, in December, at 9 a. m., I saw the mer- cury moonl to 182°, while the temperature of shaded snow hard bj was 2S^« At 18,100 feet, in January, at 9 a. m., it has stood at 98% with a difference of 68-2°, and at 10 a. m. at 114", with a difference of 81*4°, tohilst the radiating thermometer en the snow hadfaUen at iunrise to 0'7°.'

These enormous differences between the shaded and the un- shaded air, and between the air and the snow, are, no doubt, due to the comparative absence of aqueous vapour at these elevations. The air is incompetent to check either the solar or the terrestrial radiation, and hence the maximum heat in the sun and the maxi- mum cold in the shade must stand very wide apart The differ- ence between Calcutta and the plains of India is accounted for in the same way.

Dr. livingstone, in his * Travels in South Africa,' has given lome strikiog examples of the difference in nocturnal chilling

• PhiL Mag. vol xxvii, p. 82«.

APPESDIX TO LECniEE XJ, ^T^

\a dry and when lAdtm with moisture. Tlias h« I J Centnil Africa during tlte month of June, 'tha

tnL.»vUieu;r carlj in tliB mornings nt from 42° to 53' ; at noon, 9i° to 96°, or a mean ditFerenca of 46" between sunriao and mid- day. The range wonld prohably have been found etill greato had not the thorraon:"""" '--— -""d in lie shade of his tent, which vas pitched n -st tree he could 6nd. He

adds, morooTor, ' the ^^,.. I after the heat of the d«7

wa« very keen. Tlie Baloi leason never leave their firai

til! nine or ten in Uie be cold w«£ bo great here, it

was probably A-osty al erefore feared to expose taj

jonng trees there,'*

Dr. Xjvingstone I i the continent snd rcschn

the river Zambesi al ^ pf the jear. Hero tlio Iher-

mometric rtmge is reduced Trora iS" to 12°. He tlius describes the change ho felt on entering the valley of the river : ' We wera struck by the fact, that as soon aa we came between the range of hills which flank the Zambesi, the riuns felt warm. At snnrisA the thermometer stood at from 82° to 86° ; at midday, in the cool- est sliade, namely, in my little tent, under a shady tree, at 96° to 08° ; and at sunset at 86'. This is different from anything wo experienced in the interior.' t

Proceeding towards the month of the river, on January IS tit makes the following additional observation : ' The Zambesi is verj broad hero (at Zumbo), but contains many inlutbitod ialands. We fdept opposite one on the 16th, called Shibanga. The nigbti are warm, the tomperntnro never falling below 80°; it was 91* even at suuset. One cannot cool the water by a wet towel roond the vessel. . . .'t

In Central Australia the daily range of the thermometer is Btill greater. The following oitract is from a paper by Mr. W. S, Jevons ' On some Data concerning the Climate of Australia and New Zealand ' ; ' . , . In the interior of the continent of An*- tralia the fluctuations of temperature are immensely increased. The heat of the air, as described by Captain Stnrt, is foarfiil during summer; thus, in about lat. 30° 60' 8., and Ion. 141° 19' E., he writes: " Tho thermometer every day rose to 113° or 116^ in tho shade, whilst in tho direct rays of the sun from I*)'

■ LivinEslonc's Travels, p. 481, \ Ibid. p. 676. { Ibii p. 689.

THEBMaMKIBIO RAKGE IN AUSTRALIA. 421

to 150\^ Again, *^ac a quaixer past three p.m. on January 21 (1845), the thermometer had risen to isr in the shade, and to IM"* in the direct rays of the san."

... In the winter the thermometer was observed as low as 24", giving an extreme range

* The flnctoations of temperature were often very great and sadden, and were severely felt. On one occasion (October 25), the temperatore rose to llO** daring the day, bat a squall coming on, it fell to 88° at the following sunrise; it tJius varied 72" in less than twenty-four hours. . . • Mitchell, on his last journey to the N. W. interior, had very cold fifosty nights. On May 22, the thermometer stood at 12^ in the open dr. . . . StUl, in the day time, the air was warm, and the daily range of temperature was enormous. Thus, on June 2, the thermometer rose from 11° at sunrise to 67** at four p. m. ; or through a range of 56°. On Jmie 12, the range was 53°, and on many other days nearly as great.

Even at Sydney the average daily range of the thennoraoter is 21°, whilst at Greenwich the average range is only 17°. ' It thus appears that even close to the ocean the mean daily range of the Australian climate is very considerable. It is least in the autumn and greatest during the cloudless days of spring.' After giving a table of the seasonal variation of the rainfall in Australia, Mr. Jev- ons remarks that 4t is plainly shown that the most rainy season of the year on the east coast is the autumn, that is, the three months, March, April, May. The spring season appears the driest, sunmier and winter being intermediate.'

Without quitting Europe, we find places where, while tlie day temperature is very high, the hour before sunrise is intensely cold. I have often experienced this in the post-wagens of Germany ; and I am informed that the Ilungarian peasants, if exposed at night, take care, even in hot weather, to protect themselves by heavy cloaks against the nocturnal chill. The observations of 3iM. Bra- vals and Martins on the Grand Plateau of Mont Blanc have been already referred to. M. Martins has recently added to our knowl- edge by making observations on the heating of the soil at great elevations, and finds on the summit of the Pic du Midi the heat of tlie soil

exposed to the sun, above that of the air, to be twice as great as in the valley at the base of the mountain. * The immense

APPENIIIX TO I.ECTIJKE XL

heating of the soil,' writes M, MartinB, ' compnrcd with that of tin sir on high moantdns, is the more remarkable, eince, daring tb* nights, the cooling b; radiation ia there mnch greater than in tb«. plain.' The observations of Uio Messrs, Sohlagentweit fiimish, if I mistake not, many illastrationa ff *ho action of aqnewiB raponrj and I do not doabt, that the r" a qoestion is test^, tho mora

clearly will it appear that the u and absorbent powers of this

Bab«tiince enable it to play f important part in the pbcnoot-

ona of meteorology.

LECTURE XII.

UBOKFTIOH OP BKAT BT TOLATUB UQUID6 — ^ABSOBITIOll OF HIAT BT THI TA- YOUBS OP TH06E UQUIDS AT ▲ GOXMOH FBIS8UBI — ^ABSOBFTION OP HEAT BT TBI SAIB TAPOUBS WHXir THB QUAVrmBS OP TAPOUB ABE FBOPOO- nOSAL TO THB QUAXTITIBS OP LIQUID— OOMPABATITB TIBW OP THE A0> nON OP LIQUIDS AXD THEIB TAPOUBS UPOH BAOIAST HEAT — PHTSICAL CAUSE OP OPACITT AXD TBAB8FABEXCT — IBPLUEKCB OP TEXFEEATUBE 05 THE TBASBlCiaBIOB OP BADIABT HEAT— CHANQEB OP POSITION THBOUOH CHAXGES OP TEXFEEATUBE — RADIATIOX PBOX PLAXES — IXPLUENCE OP OS- CILLATIXO FEBIOD OX THE TBAX8XI8BI0X OP BADIAXT HEAT — ^EXFLANATIOX OF BBSULTB OP XELLOXI AXD KKOBLAUCH.

THE natural philosophy of the future must, I imagine^ mainly consist in the investigation of the relations subsisting between the ordinary matter of the universe *nd the ether in which this matter is immersed. Regard- ing the motions of the ether itself, the optical investiga- tions of the last half century have left nothing to be de- sired; but regarding the atoms and molecules, whence issue the undulations of light and heat, and their relations to the medium in which they move, and by which they are set in motion, these investigations teach us little. To come closer to the origin of the ethereal waves — ^to obtain, if possible, some experimental hold of the oscillating at- oms themselves — ^has been the main object of those re- searches on the radiation and absorption of heat by gases and vapours, which, in brief outline, I have sketched be- fore you.

These enquiries have made known the differences which exist between different gaseous molecules, as re- gards their power of emitting and absorbing radiant heat.

When a gas is condensed to a liquid, the moleculeB ajf proacb and grapple with each other, by forces vfhich are insensible as long as the gaseons state is maintained. But though thus condensi-'d and enthralled, the all-pervading

ether still surrounds the ' of radiation and absorpt ually, we may expect that lieat of the free molecule molecule has reli"""" a liquid. If, on be of paramouu the part of liqiiiat that of their vapours

lies. If, then, the power tend upon them iudivid- .portmont towards radiant maintain itself after that rdom and formed part of the state of aggregation , .. e may expect to find, on ponnient altogether different from Which of these views corresponds with the truth of nature, we have now to enquire,

Melloni examined the diathermancy of various liquids, but he employed for this purpose the flame of an oil-lamp, covered by a glass chimney. His liquids, moreover, were contained in glass cells ; hence, the radiation was pro- foundly modified before it entered the liquid at all, glass being imper\'ious to a considerable

part of the emission. In the examination of the question now before us, it was my wish to interfere as little as possible with the primi- tive emission, and an apparatus was therefore devised in which a layerof liquid, of any thickness, could be enclosed between two polished plates of rocksalt.

The apparatus consists of the followiug parts : — a b c (fig. A) is a plate of brass, 3'4 inches long, 2'1 inches wide, and 0'3 of an inch thick. Into it, at its corners, are rig- idly fixed four upright pillai-s, furnished at the top with screws, for the reception of the nuts q r s :. PEFisft second plate of brass, of the same size as the former, and pierced with holes at its four corners, so as to enable it to slip over the four columns of the plate a b c. Both these plates are perforated by circular apertures, m n and op, 1'35 inch in diameter, g ii i is a third plate of brass, of

BOCSBALT CSlSJi.

the same area as d x r, and, like it, having its centre and its comeis perforated. The plate a n i is intended to

oinia

separate the two plates of rocksalt wliich arc to form the walls of the cell, and its thickness determines that of the liquid layer. The separating plate g h i was ground with the utmost accuracy, and the surfaces of the plates of salt were polished with extreme care, with a view to render- ing the contact between the salt and the brass water-tight. In practice, however, it was found necessary to introduce washers of thin letter-paper between tlie plates of salt and the separating plate.

In arranging the cell for experiment, the nuts qr si

are onaorevcd, and a wasbcr of Iniilia-nibbcr U first placed on A B c. Od tliis n'ashcr is placed cue of the plates a^ rockealt. On the plate of rocksalt is laid the vaeher letter-paper, and on this again, the separating plate o H i.

A second washer of paper ia placed on this plate, then comes the Bccond plate of Halt, on which another indl^ rubber washer ia laid. The plate d b f is finally slipped

over the colnmna, and the whole arrangement ia tightly screwed together by the nuts^rA^. Thus, when the plates of rocksalt are in position, a cylinder, as long as the plate a u I is thick, ia enclosed between them, and thb space can be filled with any liquid through the orifice t

FLATDTUX LAMP. 427

Tbe use of the india-rabber washers is to relieve the crush. hg pressure which wonld be applied to the plates of salt, if they were in actual contact with the brass ; and the use of the paper washers is, as already ezpLuDed, to render tiie cell liqmd-tight. After each experiment, the appa- ntns is unscrewed, the plates of salt are removed and thoronghl J cleansed ; the cell is then remounted, and in two or three minutes all is ready for a new experiment.

My next necessity was a perfectly steady source of leat, of sufficient intensity to penetrate the most absorb- ait of tbe liquids to be subjected to examination. This ras found in a spiral of platinum wire, rendered incandcs- lent by an electric current. The frequent use of this ionrce led to the construction of the lamp shown in fig. B. L is a globe of glass three inches in diameter, fixed upon I stand, which can be raised and lowered. At the top of he globe is an opening, into which a cork is fitted, and trough the cork pass two wires, the ends of which are inited by the platinum spiral s. The wires are carried lown to the binding screws a 5, which are fixed in the foot of the stand, so that when the instrument is attached to the battery, no strain is ever exerted on the wires which carry the spiraL The ends of the thick wire to which the spiral is attached are also of stout platinum, for when it was attached to copper wires unsteadiness was introduced through oxidation. The heat issues from the incandescent spiral by the opening dy which is an inch and a lialf in diameter. Behind the spiral, finally, is a metallic reflector, r, which augments the flux of heat without sensibly chang- mg its quality. In the open air the red-hot spiral is a

capricious source of heat, but surrounded by its glass globe its steadiness is admirable.

The whole experimental arrangement will be imme- diately understood from the sketch given in fig. C. a is the platinum lamp just described, heated by a current

EZPERDCENTAL ASRANQEU£!n'. 420

a Grove's batteiy of five cells. It is necessary that lamp fihoald remain perfectly constant tbrongbout the ; and to keep it so, a tangent gnlvnnomctcr and a ocord are iotrodaced into the circuit. In front of tfae spiral, and with an interior reflecting r&ce, is the tnhe b, throagh which the licat passes to e Tooksalt cell c. This cell' is placed on a little staj^o, ildered to the baclc of the perforated screen 8 b', so that be heat, a&er having crossed the cell, passes through the lole in the sorcen, and afterwards impinges on the thcrmo- dectric pile p. The pile is placed at some distance from the screen s b', so as to render the tcmpetstnro of the cell C itself of no acconnt c' is the compensating cube, con- tadning water kept boiling by ateam from tlie pipe^. Be- tween the eabe c' and the pile p is the ecreen q, which regulates the amount of heat falling on the posterior face of the pile. Tho whole arrangement b here exposed, but, . in practice, the pile p and the cube o' are carefully pro- tected from the capricioua action of the surrounding air, } The experiments are thus performed. Tho empty

Irocksalt cell c being placed on its stage, a double silvered screen (not shown in the figure) is first introduced be- tween the end of the tube b and the cell c ; tlie spiral bein^ thus totally cut off, and tho pile Bubjected to the action of the cube o' alon& By means of the screen q, the heat recdved by the pile from c, is reduced until the total heat to be adopted thronghout the series of experi- ments is obtiuned : say, that it is sufficient to produce a galvanometrio deflection of 60 degrees. The double screen used to intercept the radiation from the spiral is then gradually withdrawn, until this radiation completely neu- tralises that from the cube c', and the needle of

the galvanometer points steadily to zero. Tho position of the double screens, once fixed, remains subscqacntiy un- changed, the Blight and slow alteration of the source being

LECTUfiE Xn.

ncntralised by the rlicocord. TbuB, tlic rays in the instance paas from the spiral through the empty rod celL A emuU funnel, supported by a Buitablo etaod, into the apertnro which leads into the cell, and thrt this the liquid ia poured, rhe introduction of the Ix destroys the previous eqi irium, the galvanometer ne 3 a steady deflection. B ^diatcly calculate the qau nc [quid, and express it in '. di; ion.

re executed with eleven difie I liquid in five different tlucknei

Riovos, and, final!' this deflection «^n of heat abflo dredths of t) Tiie expc liquiilti, employing t The results are collected together in the following tabh

Anaonrnon of Heat bt LiauiDs.

Source

07 Heat: rLinscm S

lUtaBD TO BBIOITT REDSKS

BT A VOLTllC CraHEST.

Thlcknou of Hqnid Id paru oTui li

RisuJphlilo of carbon .

[odide of melhyl

lipniyl

71 B

Amlyena

Acetic ctlicr

formic ctlior ....

Alcohol

Wntor

Here, for a thickness of O-OS of an inch we find absorption varying from a minimum of 5-5 per cent, in case of bisulphide of carbon, to a maximum of 80'7 cent, in the case of water. The bisulphide therefore tr mits 94-5 per cent., while the water — a liquid eqa transparent to light — transmits only I9'3 per cent, of entire radiation. At all thicknesses, water, it will be

ABSOBFTIOir BY VOLATILE LIQUIDS. 431

KTYed, assertB its predominaDce. Next to it, as an ab- sorbent, stands alcohol ; a body wch also resembles it diemically.

As liquids, then, those bodies are shown to possess very different capacities of intercepting the heat emitted by oar radiating source ; and we have next to enquire whether these differences continue, after the molecules have been released from the bond of cohesion. We must, of coarse, test the yapours by waves of the same period as those applied to the liquids, and this our mode of ex- periment renders easy of accomplishment. The heat gen- erated in a wire by a current of a given strength being invariable, it was only necessary, by means of the tangent compass and rheocord, to keep the current constant from day to day, in order to obtain, both as regards quantity and quality, an invariable source of heat.

The liquids from wliich the vapours were derived were placed in small long flasks, a separate flask being devoted to each. The air above the liquid, and within it, being first care&lly removed by an air-pump, tlie flask was at- tached to the experimental tube, in which the vapours were to be examined. This tube was of brass, 49*0 inches long, and 2*4 inches in diameter, its two ends being stopped by plates of rocksalt. Its interior surface was polished. With the single exception that the source of heat was a red-hot platinum spii*al, instead of a plate of copper, the arrangement was that figured in Plate L At the commencement of each experiment, the brass tube being

thoroughly exhausted, and the radiation from the spiral being neutralised by that from the compensating cube, the needle stood at zero. The cock of the flask containing the volatile liquid was then carefully turned on, and the vapour allowed slowly to enter the experimental tube. When a pressure of 0'5 of an inch was obtained, the vapour was cut off, and the permanent deflection of

CLIorofon loJide of I lodidD Qfc

Alcohol Ponnio etbi Solphnriee

-Acetic ethei Tolft) heat

^e are now in a seriea of volatile liqu liquids, npon mdiant Commencing wit! tiye energy, and pro(following ordera of al

Uqnrdi Bisulphide of CTiIorofomi. Iodide ofmetb lodideofethfl

OBDEB OF ABBOBFTIDK OF LIQI7ID6 AND VAPOUBS. 433

Here, as far as amylene, the order of absorption is the same for both liquids and yapours. But from amylene downwards, though strong liquid absorption is, in a general way, paralleled by strong vapour absorption, the order of both is not the same. There is not the slightest doubt that, next to water, alcohol is the most powerful absorber in the list of liquids; but there is just as little doubt that the position which it occupies in the list of vapours is the correct one. This has been established by reiterated experiments. Acetic ether, on the other hand, though certainly the most energetic absorber in the state of vapour, falls behind both formic ether and alcohol in the liquid state. Still, on the whole, I think it is impossi- ble to contemplate these results, without arriving at the conclusion that the act of absorption is, in the main, molec- ular, and that the molecules maintain their power as absorbers and radiators when they change their state of aggregation. Should any doubt, however, linger as to

the correctness of this conclusion, it will speedily disap- pear.

A moment's reflection will show that the comparison here instituted is not a strict one. We have taken the liquids at a common thickness, and the vapours at a common volume and pressure. But if the layers of liquid employed were turned, bodily, into vapour, the volumes obtained would not be the same. Hence, the quantities of matter traversed by the radiant heat are neither equal nor proportional to each other in the two cases, and to render the comparison strict, they ought to be propor- tional. It is easy, of course, to make them so ; for the liquids being examined at a constant volume, their spe- cific gravities, give us the relative quantities of matter (traversed by the radiant heat, and from these, and the vapour-densities, we can immediately deduce the corre- sponding volumes of the vapour. Dividing, in fact, the

specific graviliuB of our liquids by the densities of tbei

Ttpoura, we obtain the following series of vapour vol

nines, wbose weights arc proportional to the masses ol

liquid employed: —

lUUL VOLCMKB. '

Disulphideofca

Chloroform

rodidoormelhjl

Iwlidoofeftjl

Aloohol

Sulphuric etbe

Forauc ether

Arctic clticr .

Introducing the vapours, iti the volumes here indicated into the experimental tube,

the following results were ob tained : —

QuiKTITV or ViPOCK rHDTOB- PrtMnrfl in rnrt* At*»i>ll«

RiDiATiON OF llEAi ntnocnn

Kuno ot TipoDT BUnlphidc of carbon Chloroform , Iodide of methyl lodiile of othjl Benzol

Sulphuric ctber

Formic ether Alcohol

Arranging both liquids and vapours in the order ol their absorption, we now obtain the following result :—

CULUHB OF TBABEPABENOT Al!n> OPACITY.

lAqtMiB Bisulphide of caiboo. ChlorofoniL Iodide of methyL Iodide of ethyl BenioL Amylene. Snlphinic ether. Aoetio ether. Formic ether. AlcohoL Water.

Yftponrt Bisiilphide of carboa Chloroform. Iodide of methyl Iodide of ethyl. Benzol Amylene. Snlphoric ether. Acetic ether. Formic ether.

AlcohoL

Here the discrepancies revealed by our former senes of experiments entirely disappear, and it is proved that for heat of the same qaality, the order of absorption for liquids and their vapours is the same. Wc may, there- fore, safely infer that the position of a vapour, as an ab- sorber or radiator, is determined by that of the liquid firom which it is derived. Granting the validity of this inference, the position of tocUer fixes that of aqueous va- pour. But we have found that, for all thicknesses, water exceeds the other liquids in the energy of its absorption. Hence, if no single experiment on the vapour of water existed, we should be compelled to conclude, from the de- portment of its liquid, that, weight for weight, aqueous vapour transcends all others in absorptive power. Add to this the direct and multiplied experiments, by which the action of this substance on radiant heat has been es-

tablished, and we have before us a body of evidence suffi- cient, I trust, to set this question for ever at restj and to induce the meteorologist to apply the result, without mis- giving, to the phenomena of his science.

We must now prepare the way for the consideration of an important question. A pendulum swings at a cer-

* Aqueous yapour, unmixed with {ur, condenses so readily that it can- not be directly examined in our experimental tube.

LECIUSE XEL

tain de6nitc rate, 'whicli dependa upon tbe length of the pendulum. A spring will oseillate at b rate which de- pends upon the weight and elastic force of the spring, we coil wire into a lonp spiral, and attach a buUet to the I end, the bullet will oscillate ud and down, at a rate which J depends upon its weight upon the elasticity of t]

spiral. A mnsieal string nate rate of Tibration, i weight, and tension. A also its own rate of 0(timing our raoyemonts r impulses as to cndangt pontoon bridges, tread parted to tbe pontoons b The step of 510

! manner, has its deter depends upon its len; nrhich bridges a goi^e n ; and we can of)«n, byj a beam, so accumulate [fety. Soldiers, ftrlf, lest the motioa iccumnlate to a dangeron wlio Cll heads in open paila sometimes coincides with the oscilla- tion of the water from side to side of the vessel, until, pulse being added to impulse, the liquid finally splashes over tlie rim. The water carrier instinctively alters step, anil thus reduces the liquid to comparative tranquilhty. These ordinary mechanical facts will help us to an ineight of the more subtle phenomena of light and radiant beat. Ton have beard a particular pane of glass respond to a]iarticular note of an organ ; if you ojien a jiiano, and smg into it, Bonie one string will also rosjwnd. Now, in tho case of the organ the pane responds, because its period of vibration happens to

coincide with the period of the so- norous waves that impinge upon it; and in the case of the piano, that string responds whose period of vibration cfr incides with the period of the vocal chords of the singer. In each case, there is an accumulation of tho effect, simi- lar to that observed when j-ou stand upon a plank-bridge, and time your impulses to its rate of vibration. In the cnse of the singing flame already referred to, you had the iiiflaonce of period exemplified in a very striking manucr.

AOOOSD AND DIBOQKD OF VIBBATmO PERIODS. 437

It responded to the voice, only when the pitch of the voice corresponded to its own. A higher and a lower note were equally ineffectiTe to put the flame in motion.

I have shown yon the transparency of lampblack, and the &r more wonderfhl transparency of iodine, to the purely thermal rays ; and we have now to enquire why iodine stops light and allows heat to pass. The sole dif* ferenoe between light and radiant heat is one of period. The waves of the one are short and of rapid recurrence, while those of the other are long, and of slow recurrence. The former are intercepted by the iodine, and the latter are allowed to pass. Why? There can, I think, be only one answer to this question — ^that the intercepted waves are those whose periods coincide with the periods of os- eillation possible to the atoms of the dissolved iodine. The waves transfer their motion to the molecules wLich synchronise with them. Supposing waves of any period to impinge upon an assemblage of molecules of any other period, it is, I think, physically certain that a tremor of greater or less intensity will be set up among the mole- eoles ; but for the motion to accumulate^ so as to produce sensible absorption, coincidence of period is necessary. Briefly defined, therefore, transparency is synonymous with discord^ while opacity is synonymous with accord, between the periods of the waves of ether and those of the molecules of the body on which they impinge. The opacity, then, of our solution of iodine to light shows that its atoms are competent to vibrate in all periods which lie within the limits of the visible spectrum ; while its trans- parency to the extra-red

undulations demonstrates the in- competency of its atoms to vibrate in unison with the longer waves.

The term * quality,' as applied to radiant heat, has been already defined ; the ordinary tost of quality being the power of radiant heat to pass through diathermic

bodies. If tlio heat of two beams be transmiued by the Belfsamc BubEtnnce in different proportions, the two beams uro said to be of different qualities. Strictly speaking, tliis question of riuaiity is one of period ; and if tl>e. heat of one source be more or less copiously transmitted than the heat of another source, <ecanse the waves of ether

excited by the one are difli n length and period from

those excited by the othei len we raise the tempera-

ture of oar platiuiim spii j alter the quality of iH

heat. As the temperatu raised, shorter and ever

shorter waves mingle in liation. l?r. Draper, in s

vecy beautiful investigat shown that when plati- I

num first appears lumin ^ts only red rays; but

:i9 its temperature augm: range, yellow, and green '

are sueccMsively aJded to the radiation; and when the])l.atinum ia so intensely lioated as to emit white liijlit, ihc decomposition of that light gives all the colours of l!ic Koliir s])cctrum.

Almost all the vapours which wc have hitherto exam- ined are transparent to light, while all of thorn arc, in some degree, op3(|ue to obscure rays. This pi-oves llic incompetence of the molecules of those vapours to vibrato in visual periods, and their competence to vibrate in the slower periods of the waves which fall beyond the red of the spectrum. Conceive, then, our platinum spiral to ho gi'adually raised from a state of obscure to a state of lu- minous heat; the change would manifestly tend to

pro- duce dtecord between the radiating platinum and the molecules of our vajiours. And the higher wc i-aise the temperature of our platinum, the more decided will be the discord. On d priori grounds, then, we should infer, that the raising of the temperature of the platinum spiral ouglit to augment the power of its rays to pass through our list of vajjours. This conclusion is entirely veritied by the experiments recorded in the following tables :

JSWLVESCE or IBXumtAXUSS ox THAHBMfflBIOS. 439 tBunoi nmovn Tuoom; Sovws ta Hut: FLuurro SnuL

Bianlphlde of caibon

lodldaofmdliTl

Solphnrio dher Fmnic ether Aoedo ether .

With the same platiQum tpbnl raised to a irliite heat, 9 following reanlts vere obtiuiied:-~

BiEalpbide of carbon

AbwrpUoD pa cent

Iodide rfmethji Iodide of «tiiTl BhudI.

Amjleoe Formic ether , Balpfamio ether Acetic ether

With the same spiraJ, brought still nearer to its point fiuioii, the followii^ results verc obtained with four of e Taponrs : —

Biiniinni naomm Tatodbs. Soraa: pLucm Sfdul a ui ixtaa W&in Hut.

HmM ot T^niT Abaorptliir.

Kanlphide of carbon , . S'S

CSdorofbrm .... 3X Ftmnio ether .... 21-8 SuliAaric ether , . . !S-7

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Placing Iho results obtaiued witli the reepective bodfcm side by aide, tlie iiifiuence

oi' tomperaturo on the tnkn» miBBioD comes out in & very decided maimer: —

Absoeption of Heat ht Vjpocbs,

Bucly TlEiblo Brl^btnsd fThtM-bot B«rra

Buulphidc of carboD Chloroform Iodide of methjl Iodide of ?llif 1 Benzol

Sulphuric etlipr Formic ctbcr Acetic etber

TLe gradual augmcDtation of penetrative power, as tlie temperature is augmented, ia here very manifest. By raising the spiral from a barely visible to an intense white heat, we reduce the absorption, in the case of bisulphide of carbon and chloroform, to less than one-bal£ At barely visible redness, moreover, C6'6 and 54'8 per cent, pass through sulphuric and formic ether respectively; while of the intensely white-hot spiral, 76"3 and 78'7 per cent, pass through the same i-apoura.* Thus, by augmenting the temperature of the solid platinum, we introduce into the radiation waves of shorter period, whicli, being in discord with the periods of the vapours, pass more easily through them.

Rtinniiig the eye along the numbers which express the absorptioDS of sulphuric and formic ether in the last table, we find that, for the lowest heat, the absorption of the latter exceeds that of the former; ibr a bright red heat they ai-e nearly equal, but the formic still retains a slight predominance; at a white heat, however, the sulphurio

* Tbe trantmiiiion ia faimd bj Bubtracting tbe absorption from 100.

PERIODS OF FOSiaO AND 8ULFHUBIC ETHEB. 441

alipfl in ftdyaDoe, and at the heat near fiision its predomi- nance is decided. I have tested this result in various ways, and by multiplied experiments, and placed it be- yond donbt. We may at once infer from it that the ca- pacity of the molecule of formic ether to enter into rapid vibration is less than that of sulphuric, and thus we ob- tain a glimpse of the inner character of these bodies. By augmenting the temperature of the spiral, we produce vibrations of quicker periods, and the more of

these that are introduced, the more opaque, in comparison with formic ether, does sulphuric ether become. The atom of oxygen which formic ether possesses, in excess of sul- phuric, renders it more sluggish as a vibrator. Experi- ments made with a source of 100° C, establish more de- ddedly the preponderance of the formic ether for vibra- tions of slow period.

RiDiATioar THBOiroH Yafoubs. Sovbck : Leslie's Cube, coated with Laxfblack. Temferatu&e, 212** Fahr. Hame oi Vftpoar Abflorptlon per cent

Iodide of methyl

GUoiofonn . . . ,

Iodide of ethyl

Beozol . . . .

Amylene . . . .

Sulphuric ether

Formic ether

Acetic ether . . . .

For heat issuing from this source, the absorption by formic ether is 6*8 per cent, in excess of that by sulpharic.

Bat in this table we notice another case of reversal In all the experiments with the platinum spiral thus far recorded, chloroform showed itself less energetic, as an absorber, than iodide of methyl; but here chloroform shows itself to be decidedly the more powerful of the two. This result has been placed beyond doubt, by repeated

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pyperitnenls. To the radialtoo emitted by lampblack, hcited to 212°, chloroform is certainly more opaque than iodide of methyl.

We h.ive bilberto occupied oureelves with the radia-

tion from heated solids : nation of the radiation i mentB were made with a t. small circular burner, the The top and bottom of ti most brilliant portion ws lowing results were obta:

Radutiom or HetT THBocan

> now pass on to the exami- lemes. The firet experi- jet of gas, issuing from a ijeing long and tapering, oe were esclnded, and it* m as the source. The fol-

Chlorafunn Iodide of mclh Iodide of etiiyl r^l■L^ol .

Fomiie clhcr Sulphuric etiier Aeelio ether

It is interesting lo compare the heat emitted by the white-hot carbon with that omitted by the wbtto-Iiot plati- num; and to facilitate the comparison, I have placed he- Bidc the results given in the last table those recorded in a former one. The emission from the flame ia thus proved to be far more powerfully absorbed than the emission from the sjjiraL Doubtless, however, the carbon, in roachini; incandescence, passes thi-ough lower stages of temperature, and in those stages emits heat more in accord with our vapours. It is also mixed with the vapour of water and carbonic acid, both of wlilch contribute their quota to the total radiation. It is tlicrcforc probable that the greater

KADIATIQN FROM FLAMES.

absorption of the heat emitted by the flame is dae to the slower periods of the sabstanees, which are nDayoidably mixed with the white-hot carbon to which the flame mainly owes its light.

The next source of heat employed was the flame of a Bnnsen's bnmery* the temperature of which is known to be very high. The flame was of a pale-blue colour, and emitted a very feeble light. The following results were obtained: — •

RunAnoir of Heat thbough Yapoubs. Source :

Pale-blue Flame or

BUN8EN*8 BCBREB.

HtmeofTftpoar

Abftorptlon

ChloTofonn ....

Bisalpfaide of carbon .

Iodide of ethyl ....

Benxol

Amjlene

Solphurio ether ....

Fonnio ether ... *

Acetic ether ....

The total heat radiated from the flame of Bunsen's burner ia much less than that radiated when the incandes- cent carbon is present in the flame. The moment the air is permitted to mix with the luminous flame, the radiation falls BO considerably, that the diminution is at once de- tected, even by the hand or face brought near the flame. Comparing the two last .tables, we see that the radiation from the Bunsen's burner is, on the whole, less powerfully abflorbed than that from the luminous gas jet. In some cases, as in that of formic ether, they come very close to each other; in the case of amylene, and a few other sub- stances, they difler more markedly. But an extremely interesting case of reversal here shows itself. Bisulphide of carbon, instead of being first, stands decidedly below

* Described in Lecture XL

i;)ilorofonn. With the luminonfl jet, the absorption of bfc I sulphide of carbon is to

that of cUoroform as 100: 122, " while with the flame of Bunsen's banner the ratio is 100:50; the removal of the lampblack from the flame more than donblea the relative transparency of the chloro- form. We have htsre, moreover, another instance of tlio reversal of formic and sulphuric ether. For the luminous jet, the eulphniic ether is decidedly the more opaque ; for the flame of Bunsen's bnmer, it is excelled in opadty by the formic.

The main radiating bodies in the flame of a Sanson's burner, are, no doubt, aqa eon 9 vapour and carbonic acid. Highly heated nitrogen ia also present, which may pro- duce a sensible effect. But the main source of the radia- tion ia, no doubt, the aqueous vapour and the carbonic acid. I tvished to separate these two constituents, and to study them separately. The radiation of aqueous vapour could bo obtained from a flame of pure hydrogen, while that of carbonic acid coidd be obtained Irom an ignited jet of carbonic oxide. To me the radiation from the hydro- gen flame possessed a peculiar interest ; for notwithstand- ing the high temperature of such a flame, I thought it likely that the accord between its periods of vibration and those of the cool aqueous vapour of the atmosphere would still be such as to cause the atmospheric vapour to exert a special absorbent power upon the radiation. The ibllow- ing experinicnts test this surmise : —

RUIUTIOK THBOUOH ArMOflPHIRlC AUI.

SOCBCX: 1 niDBOflEH Fuio.

AburpUon

Uudricdair .

Thus, in a polished tube 4 feet long, the aqueoos vaponr of our laboratory air absorbed 17 per cent, of the radiation fix>m the hydrogen flame. A platinum spiral, raised by

RADIATION rSOU HTDBOOEN FLAME. 445

electricity to a degree of incandescence not greater than that obtainable by plunging

a wire into the hydrogen flame, being used as a source of heat, the undried air of the laboratory was found to absorb

6*8 per cent.

of its radiation, or one-third of the quantity absorbed in the case of the flame of hydrogen.

The plunging of a spiral of platinum wire into the flame reduces its temperature ; but at the same time intro- duces vibrations, which are not in accord with those of aqueous vapour; the absorption, by ordinary undried air, of heat emitted by this composite source amounted to

8'6 per cent

On hnmid days, the absorption of tlic rays emitted by a hydrogen flame exceeds even the above large flgure. Em- ploying the same experimental tube and a new burner, tlio experiments were repeated some days subsequently, with the following result : —

RiDiATiOH TimouGn Air. Source : Hydrogen Fljlmk.

Absorption

Dry air 0

Undried wr 203

The physical causes of transparency and opacity have been already pointed ottt; and we may infer from the foregoing powerful action of atmospheric vapour on the radiation from the hydrogen flame, that accord reigns be- tween the oscillating molecules of the flame at a temper- ature of 6898° Fahr., and the molecules of aqueous vapour at a temperature of 60° Fahr. The enormous temperature of the hydrogen flame increases the amplitude but does not change the rate of oscillation.

We must devote a moment's attention, in passing, to the word * amplitude ' here employed. The pitch of a note

depends a iy on the numLer of aSrial waves whicli strike tbe ear in a Bccond, The loudness, or inttnsUy, of n note does not at all depend upon the rapidity with which the waves follow each other, but on the diatanot within Khich the separate atoms of air vibrate. This dis- tance is called the amplitu<h he vibration. When we piiU a harp-string very g« ide, and let it go, it dis-

turbs the air but little; air-atoms is small, and the But if we poll the slrin" go, we have a note of the atitpUtude of vibration " tense. While, then, the J independent of

ipiitade of the vibrating sity of the sound feehla JOBly aside, on letting it tcb as before, but, as the r, the sound is more in- igth, or period of recor- iplitude, it is tliis latter

which determines the loudness of tbe sound.

The same holds good for light and radiant beat. Here tlie individual ether particles vibrate to and fro across tbe line of propagation ; and tbe extent of their excursion ia called the amplitude of llie vibration. We may, as in the ease of sound, have the same wave-length with very dif- lerent amplitudes, or, as in the case of water, we may have high waves and low waves, with the same distance between crest and crest. Now, while the colour of light, aud the quality of radiant heat, depend entirely upon tbe length of tbe ethereal waves, the intensity of the ligbt and beat is determined l)y the amplitude. And, inasmuch as it has been shown, that the periods of vibration of a hydrogen flame coincide with those of cool aqueous va- pour, we are compelled to conclude that tbe enormous temperature of the flame is not due to the rapidity, but to tbe extraordinary amplitude of its molecular vibration.

Tbe other component of the flame of Bunscn's burner is carbonic acid, aud the radiation of tliis substance is im- mediately obtained from a flame of carbonic oxide. Of the radiation from this source, tlie small amount of car-

badiahon fbom cabbokic oxide flame. 447

bouic acid diffused in the air of onr laboratory absorbed 13'8 per cent This high

absorption proves that the vibra- tions of the molecales of carbonic acid, within the flame, are synchronous with the vibrations of those of the car- bonic acid of the atmosphere. The temperature of the flame, however, is 6508° Fahr., while that of the atmos- phere is only 60°. But if the high temperature is incom- petent to change the rate of oscillation, we may expect carbonic acid, when used in large quantities, to be highly opaque to the radiation from the carbonic oxide flame. Here follow the results of experiments executed to test this conclusion : —

Radiation thbouoh dbt Carbonic Acid.

SouBCx: Oardonio

Oxide Ft.amk.

Pressure in inches

Absorption

For ttue rays emanating from the heated solids employed in our former researches, carbonic acid proved to be one of the most feeble absorbers ; but here, when the waves sent into it emanate from molecules of its own substance, its absorbent energy is enormous. The thirtieth of an atmosphere of the gas cuts off half the entire radiation ; while at a pressure of 4 inches, 65 per cent, of the radia- tion is intercepted.

The energy of defiant gas, both as an absorbent and a radiant, is now well known. For the solid sources of heat just referred to, its power is incomparably greater than that of carbonic acid ; but for the radiation from the carbonic oxide flame, the power of defiant gas is feeble, when compared with that of carbonic acid. This is proved by the experiments recorded in the following table : —

m LECTURE xn. ^^H

lUDunod

1 THBODcn Dkr OLEFiisr Gab. Socnait : Cuaosic

Ojide FtlMI.

FniHre Id IscliH J

IbMfpttaa Frooi lm« lUla

Beside tbe absorption

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Dm tbe last table. The

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pressures; at a pressure (

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ugmentB. Here, in &ct,

Ti.l as lli.>y <lnw r absorptions, .is a matter

botli of tiiem iipproach pi-n near to this common limit, of course, approximate.

Tlicse experiments prove that the |)rcscncc of an infin- itesimal quantity of carbonic acid gas might be detected, by its action on flic rays omitted by a carbonic oxide flame. The action, for example, of the carbonic acid ex- pired by tbc binga is very decided. An india-rubber bag was filled from the l«ngs ; it contained, tlieroforc, both the aqueous vaponr and tbe carbonic acid of the breath. The air from the bag was then conducted tlirough a drying apparatus, the moisture being thus remoicd, and the neutral air and active carbonic acid permitted to enter the experimental tube. The

following results were ob- tained ; —

A[R FBOU THE Llugs cc^^T^ISl^o CO,. Sokbce: Cifibomc Oxidi Fr-iME. PrtFinre Id Indies Absorpllon

FHTHIGAL AKALY6IB OF HUMAN BREATH. M9

Thus, the tube filled with the dry exhalation from the longs intercepted 50 per cent, of the entire radiation from a carbonic oxide flame. It is quite manifest that we have here a means of testing, with surpassing delicacy, the amount of carbonic acid emitted under various circum- stances from the lungs.

The application of radiant heat to the determination <yf the carbonic acid of the breath has been illustrated, by a series of experiments, executed under my direction by my asdstant, Mr. Barrett. The deflection produced by the breath, freed from its moisture, but retaining its car- bonic acid, was first determined. Carbonic acid, artifi- dally prepared, was then mixed with perfectly dry air, in such proportions that its action upon the radiant heat was the same as that of the carbonic acid of the breath. The percentage of the former being known, immediately gave that of the latter. I here give the results of three chemi- cal analyses, determined by Dr. Frankland, as compared with three physical analyses performed by my assistant : —

Febcestaoe of Oabbonio Acid in Human Breath.

By chemlcftl aiutlysls By ohemloal analysiB 4-311 400

The agreement between the results is very fair. Doubt- less, with greater practice a closer agreement will be at- tained. We shall thus find, in the quantity of ethereal motion which it is competent to destroy, an accurate and practical measure for the amount of carbonic acid expired from the human lungs.

Water at moderate thickness is a very transparent sub- stance ; that is to say, the periods of its molecules are in discord with those of the visible spectrum. It is also

highly transparent to the extra-violet rays ; so that we may safely infer from the deportment of this substance, its incompetence to enter into rapid molecular vibration.

LECTCBE 3JL

" lui'ever, we onco quit the visible spectnim for the

r jeyond the red, the opacity of the substance begins to SHOW itself; for such rays, indeed, its absorbent power is uDequaUed. The synchronism of the periods of the water molecules ■ le eitra-red waves is thoa

demonstrated. \v* 3y seen that undried at- J

mospbcric air mat ^ordinary opacity for the I

radiation from s le, and from this deport

ment we inferred im of the cold vaponr of

the air, and the he flame.. Bat if the pe-

riods of a vapoa is those of its liquid, w«

ou2:iit to find water highly opaque to the radiation from a hydrogen flame. Here are the results obtained with five different thicknesses of the liquid : —

IUdiation nuiocon WiiEB, SorECi : Htdbooeh Flame. ThickDesg of Kqnld (KK Inch OM lEcli 007 loch 0*14 iDsb. 0«7 Inch

Through a layer of water 0'36 of an inch thick, Mel- loni found a transmiasion of 1 1 per cent, of the heat of an Argand lamp. Here wo employ a source of higher temperature, and a layer of water only 0-27 of an inch, and find the whole of the heat intercepted. A layer of water 0-27 of an inch in tliickuess is perfectly opaque to the ra- diation from a hydrogen flame, while a layer about one- tenth of the thickness employed by Melloni, cuts off more than B7 per cent, of the entire radiation. Hence, wo may infer the coincidence in period between cold water and aqueous vapour

heated to a temperature of 6898° Fahr. (3259° C.)

From the opacity of water to the radiation from aqueous vapour, we may infer the opacity of aqueous va- pour to tlie radiation from water, and hence conclude that the lory act of nocturnal refrigeration which causes the condensation of water on the earth's surface, gives to ter-

IKFLUKNOE OF TLAJSTETABY ATMOSPHERES. 451

restrial radiation that partioolar character which renders it most liable to be intercepted by our atmosphere, and thus prevented from wasting itself in space.

This is a point which deserves a moment's further con- lideration. I find that defiant gas contained in a polished tabe 4 ftet long, absorbs about 80 per cent, of the radia- tion from an obscure source. A layer of the same gas 2 inches thick absorbs 33 per cent., a layer 1 inch thick ab- sorbs 26 per cent., while a layer y^th of an inch in thick- nesB absorbs 2 per cent of the radiation. Thus the ab- sorption increases, and the quantity transmitted dimin- ishes, as the thickness of the gaseous layer is augmented. Let us now consider for a moment the effect upon the earth's temperature of a shell of defiant gas, surrounding our planet at a little dbtance above its surface. The gas would be transparent to the solar rays, allowing them, without sensible hindrance, to reach the earth. Here, however, the luminous heat of the sun would be converted into non-luminoQS terrestrial heat ; at least 26 per cent, of this heat would be intercepted by a layer of gas one inch thick, and in great part returned to the earth. Under such a canopy, trifling as it may appear, and perfectly transparent to the eye, the earth's surface would be main- tained at a stifling temperature.

A few years ago, a work possessing great charms of style and ingenuity of reasoning, was written to prove that the more distant planets of our system are uninhab- itable. Applying the law of inverse squares to their dis- tances from the sun, the diminution of temperature was found to be so great, as to preclude the

possibility of human life in the more remote members of the solar sys- tem. But in those calculations the influence of an atmos- pheric envelope was overlooked, and this omission vitiated the entire argument. It is perfectly possible to find an atmosphere which would act the part of a barb to the solar rays, permitting their entrance towards the planet,

bat preventing their vitlidrawal. For example, a layer 1 of air two inches in thiukncss, and saturated with tlifl 1 vapour of sulphuric «lhcr, wonld offer very little resist- ance to the passage of the Bolar rays, hut I find that it would cut off fully 35 per oeat, of the planetarj- radiation. It would require no inordinate thickening of the layer of vapour to double this absorption ; and it is perfectly evi- dent that, with a protecting envelope of this kind, per- mitting the heat to enter, but preventing its escape, a comfortable temperature might be obtained on the surface of our raoBt distant planet.

Dr. Akin w;is the first to maintain the opinion, which I hold to bo correct, that the vibrating periods of a hy- drogen flame must be extra red ; and that consequently, when a platinum wire is plunged into a hydrogen flame and rendered white-hot, its oscillating periods must be dil- ferent from those of t!ie flame to which it owes its incan- descence. AVc have, in this case, a conversion of unvisual periods into visual ones. Thia shortening of the periods must augment the discord between the radiating source and our scries of liquids, whose periods are long, and hence augment their transparency to the radiation. This conclusion is verified by the following experiments : —

ItijiTATioN TnnouGH LiQums. SoTTRCEs: 1. ETTtROCEN Flake ; 2. Htdroqen Flaiu! and Flatihcm Spibal. TnmaDlaalan

M»me of UqM]

blcbnew oT

llou

d <HM Inch : «n<UplraL

frfruSi

Lune only. FlAin

BisQipliide of carbon 77-7

Cblorofora. .

Iodide of methjl

Iodide of ctijl

Amjleno

Sulphuric ether

Acetic etber .

Alcohol

SHOBTENIKO OF YIBRATmO PERIOD. 453

The transmissioD is here shown to be considerably aug- mented by the introduction of the platinum wire.

And here we find ourselves in a position to offer solu- tions of yarious facts, which have hitherto stood out as enigmas in researches upon radiant heat. It was for a time generally supposed that the power of heat to pene- trate diathermic substances augmented as the temperature of the source became more elevated. Knoblauch con- tended against this notion, showing that the heat emitted by a platinum wire plunged in an alcohol fiame was less absorbed, by certain diathermic substances, than the heat of the flame itself, and justly arguing that the tempera- ture of the spiral could not be higher than that of the body from which it derived its heat. A plate of trans- parent glass being introduced between his incandescent platinum spiral and his thermo-electric pile, the deflection of his needle fell from 35° to 19° ; while, when the source was the flame of alcohol, without the spiral, the deflection fell from 36° to 16°. This proved the radiation from the flame to be intercepted more powerfully

than that from the spiral ; or, in other words, that the heat emanating from the body of highest temperature possessed the least penetrative power. Melloni afterwards corroborated this experiment.

Transparent glass allows the rays of the visible spec- trum to pass freely through it ; but it is well known to be highly opaque to the radiation from obscure sources ; or to waves of long period. A plate 0*1 of an inch thick inter- cepts all the rays from a source of 100° C, and transmits only 6 per cent, of the heat emitted by copper raised to 400° C. Now the products of an alcohol flame are aqueous vapour and carbonic acid, whose waves have been proved to be of slow period ; of the particular character, conse- quently, most powerfully intercepted by glass. But by plunging a platinum wire into such a flame, we virtually

LECrOEB HL

convert iu heat into heat of higher refrangibilily ; we change the long periods into shorter ouea, and thua estab- lish the discord between the periods of the eource and the periods of the diathermic glass, which, as before defined, is the physical cause of transtiarency. On purely d priori

grounds, therefore, we i of the platinum spiral \ power of the heat. With found the following tram spiral : —

fcr that the inlrodnction Etngment the penetrntive e of glass Mclloni, iu feot^ ns for the flame and tb»

The same remarks applj ined by Melloni. Tliis e

nd ti» to fhff"

tranflpareiit eelenite exi

!e is highly opaline to thff^ extra-red undulations; but the radiation fi-om an alcohol flame is mainly extra-red, and hence the opacity of the selenite to this radiation. The introduction of the plati- num spiral shortens the periods and augments the trans-

mission. Thns, with a specimen of selenite, Melloni found the transmissions to bo as follows: —

So far the results of Jlelloni coincide with those of iL Knoblauch ; hut the Italian philosopher pursues the mat- ter fiirtlicr, and shows that M. Knoblauch's results, ihoujli true for the particular substances examined by him, are not true of diathermic media generally. Melloni shown that ill the case of Mack glass and black mica, a striking inversion of the effect is observed; through these siili- stances tlie radiation from the flame is more copiously transmitted than that from the platinum. For black glass he found the following transmissions : —

BBBULTB OF IfELLONI AND XNOBLAUCH EXPLAINED. 455

And tor a plate of black mica the following transmis- sions:—

IVom the flame From tho pUtixmm

These results were left unexplained by Melloni, but the solution is now easy. The black glass and the black mica owe their blackness to the carbon incorporated in them, and the opacity of this substance to light, as already remarked, proves the accord of its vibrating periods with those of the visible spectrum. But it has been shown that carbon is, in a considerable degree, pensions to the waves of long period; that is to say, to such waves as are emit- ted by a flame of alcohol. Tho case of the carbon is therefore precisely antithetical to that of the transparent glass, the former transmitting the heat of long period, and the latter that of short peripd most freely. Hence it fol- lows that the introduction of the platinum wire, by convert- ing the long periods of the flame into short ones, augments the transmission through the transparent glass and selenite, and diminishes it through the opaque glass and mica.

The foDowing Appendix contaixis the last published invostigaUon od fhe Tiflible and inTisible rays emitted by Tarious bodies.

APPENDIX TO LECTURE SlI.

ON LTJMINOnS AND 0BSCC8E EADUTION.'

Sib "WrtLiAM XlEitscnEL discovered the obaenre rnjs of iIip eibi, and proved tho position of maxiiiinra heat to be beyond the red of the flolar spectmm.t Forty years snbseqaently Sir John Herechd succeeded in obtainbg a thermograph of the calorific spectrnm, and in giving striliing visible evidence of its eitension beyond tho red. I Mclloni proved that an exceedingly large proportion of th« emission from a flame of oil, of alcohol, and from incandoscent pktinnm heated by a flume of alcohol, is obscure.g Dr. Akin in- ferred from the paucity of luminous rays, as evident to the eye, and a Hlco paucity of extra-violet rnys, as proved by the experi- ments of Dr. Miller, that the radiation from a flame of hydrogen must be mainly extra-red; and he cuncladed from thia that the glowiug of a platinum wire in a hydrogen flame, and also the brightness of the Druinmond light In the oxyhydrogen flame, vera produced by a change in the period of vibration.] By a different mode of reasoning I arrived at the Kame conclusion myself^ and published the conclusion subsequently. IT

A direct experimental demonstration of the character of the radiation from a iiydrogon flame was, however, wanting, and this

* From the Pbilosophicnl Uagimne for Xoveinber 1864. f PhiL Trana. ISOO.

i Phil. Trona. 1840. I hope very soon to be able to turn my attcn- tioo to the Tcmurkable rcsull^ dt^cribcd in Kole III. of Sir J. Hecschel'i

g £a Thermochroif, p. 804. I Reports of the British Asaociation, 1863. ^ Phil. Trans, vol cKt. p. 237.

LUMINOUB AND OBSOUBE BADIATION. 457

want I haye sought to supply. I had constracted for mo, by Mr. Becker, lenses and prisms of rocksalt, of a size sufficient to permit of their being substituted for the ordinary glass train of a Du- boscqV electric lamp. A double rocksalt lens placed in the cam- era rendered the rays parallel; the parallel rays then passed through a slit, and a second rocksalt lens, placed without the cam- era, produced, at an appropriate

distance, an imago of the slit. Behind this lens was placed a rocksalt prism, while laterally stood a thenno-electrio pile intended to examine the spectrum produced by the prism. Within the camera of the electric lamp was placed a burner with a single aperture, so that the flame issuing from it occupied the position usually taken up by the coal-points. This burner was connected with a T-piece, from which two pieces of india-rubber tubing were carried, the one to a large hydrogen- holder, the other to the gas-pipe of the laboratory. It was thus in my "power to haye, at will, either the gas flame or the hydrogen flame. When the former was employed, I had a visiblo spoctmm, whieh enabled mo to fix the thermo-electric pile in its proper posi- tion. To obtain the hydrogen flame, it was only necessary to turn on the hydrogen until it reached tho gas flame and was igmted; then to turn off the gas and leave the hydrogen flame behind. In tfaia way, indeed, the one flame could be substituted for the other without opening the door of the camera, or p)*oducing any change in the jKMitions of the instruments.

The thermo-electric pile employed is a beautiful instrument constructed by Buhmkor£ It belongs to my friend Mr. Gassiot, and oonnsts of a single row of elements properly mounted and attached to a double brass screen. It has in front two silvered edges, which, by means of a screw, can be caused to close upon the pile, so as to render its face as narrow as desirable, reducing it to the width of the flnest hiur, or, indeed, shutting it off altogether. By means of a small handle and long screw, tlie plate of brass and the pUe attached to it can be moved gently to and fro, and thus the yertical slit of the pile can be caused to traverse the entire spectrum, or to pass beyond it in both directions. The width of the apeotrum was in each case equal to the length of the face of the pile, which was oonnected with an extremely delicate galvan- ometer.

I began with a luminous gas flame, the spectrum being cast on

458 APPENinx TO LEOTHEE xn.

upon the brass screen (wliicli, to render th<> cxiluurs was ooTerod with tiofoilj, tbo pile was gradually moved ia the di- rectirai from blue to red, until tlie deflection of tJio galyBnomeler beoame a maximimi. To reach this it waa nece^uirj' to pass en* tirelf throu^'li the spectrum aod bejond the red; the deflection then observed was

When Uie pile was moved in oitt rMtion from Uiis position, tba deflection diminished.

The hydrogen flaaie wna nc titntisd for the gaa flame; tb»

viable spectrum disappenred, a deflection fell to

Hence, as regards rays of llii^ jic nu.-r rofrangibility, the

from the luminous goa flame was two and a half timci^ tli.it from

the hydrogen flame.

The pile was now moved to and fro, the movement in both di- rections being accompanied by a diminished deflection. Twelve degrees, therefore, was the maiimnm deflection for tlie hydrogen flame; and the position of the pile, detennined previously bj means of the Inmiaons flarne, proves that this deflection was pro- duced by eitra-red nndulations, I moved llie pile a little for- wards, so as to reduce the deflection from 13" to 4°, and then, in order to ascertain the refranpbility of tlic rays which produced tliis small deflection, I relighted the gas. The rectilinear face of the pile was liinnd invading the red. When the pile w'as canned to pass sneccssiveJy through])ositions corresponding to the various colours of the spectrum, and to its estra-violet rays, no measiu-able deflection was produced by the hydrogen flame.

I nest placed tlie pile at some distance from the invisible spec- trum of the flame of liydrogcn, and Jelt for the spcetraia by loov- ing the pile to and fro. Having found it, I without difficulty as- certained the place of maximum heating. Changing nothing else, I substituted the luminous flame for the non-luminous one ; the po- sition of the pile, when thus revealed, was beyond the red.

It is thus proved that the radiation from a hydrogen flame is •enaibly estra-red. The other constituents of the radiation are so

LUMINOUS AND OBSCUBE BADIATION. 459

feeUe as to be thermally insensible. Hence, when a body is raised to incandescence by a hydrogen flame, the vibrating periods of its atoms mnst be more ra^nd than those to which the radiation of the flame itself is dne.

The falling of the deflection from 80" to 12", when the hydro- gen flame was substituted for the gas flame, is doabtless dae to the absence of all solid matter in the former. We may, however, in- trodaoe sndi matter, and thus make the radiation originating in the hydrogen flame mnch greater than that of the gas flam<;. A spiral of platinnm wire plnnged in the former gave a mazimnm deflection of

at a time when the maxironm deflection of the gas flame was only

It is mainly by convection that the hydrogen flame disperses its beat: though its temperature is higher, its sparsely scattered mole- cules are not able to cope, in radiant energy, with the solid carbon of the luminous flame. The same is true for the flame of a Bun- sen's burner ; the moment the air (which destroys the solid carbon particles) mingles with the gas flame, the radiation falls considera- bly. Conversely, a gu^ of radiant heat accompanies the shutting out of the air which deprives the gas flame of its luminosity. When, therefore, we introduce a platinum wire into a hydrogen flame, or carbon particles into a Bunsen's flame, we obtain not only waves of a new period, but also convert a large portion of the heat of convection into the heat of radiation.

The action was still very sensible when the distance of the pile from the red end of the spectrum, on the one side, was as great as that of the violet rays on the other, the heat spectrum thus prov- ing itself to be at least as long as the light spectrum.

Bnnsen and Kirchhoff have proved that, for incandescent me- tallic vapours, the

period of vibration is, within wide limits, inde- pendent of temperature. My own experiments with flames of hy- drogen and carbonic oxide as sources, and with cold aqueous vapour and cold carbonic acid as absorbing media, point to the same conclusion. But in Bolid metals augmented temperature

APPSNDDt TO LECT-JLE Xn.

ii wavca of shorter periods ioio tlio radiation. It mtj

he nSKwi, 'What becomes

of the long obscnra perioib when we

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Are they broken up or ch&nged into

shorter ones, or do they ma

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orth an experimental answer.

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tiuo battery ; and by varyi

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from a state of darkness to an

iutense white heat.

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the rocfcsalt traJa wa

ath of its rays, and a brilliant

Bpectrum w

ns then moved into the posi-

tion of maiimnra heat lieyond the red of the spectrum. Altering nothing bnt the strength of the current, the spiral was rednced to darkness, and lowered in tflmporatnro till the deflection of the gal- vanometer fell to 1". Our qnestion is, 'What becomes of the waves which produce this deflection when new ones are introdnccd by angmonting the temperatnre of the spiral ? '

Caaang the spiral to pass from tliis state of darkness, through Tarions degrees of incandescenoe, the following deflections were obtained :—

DeflKtlonbTobwun

Faint red

Dull red

Bright red .

Nearly white .

Full white .

The defieclJon of 60" here obtained is equivalent to 132 of tlid firjt degrees of the gaivanoineter. Hence the intensity of the ob- Bcnre rays, in the caso of the full white heat, is 122 times that of the rays of tho same refrangibility emitted by the dark spiral used at the commencement. Or, as the intensity is proportional, to the square of the amplitDdo, the height of the ethereal waves which produced the last deflection was eleven times that of the wave*

LUMDrOUB Am) OBSCUBB RADIATION. 461

wbioli prodaoed the first The wa/te-Ungth^ of course, remuned the same throaghoat.

Hie experimental answer, therefore, to the question above pro- posed Is, that the amplitude of the old waves is augmented bj the same accession of temperature that ^ves birth to the new ones. The case of the obscure rays is, in fact, that of the luminous ones (of the red of the spectrum, for example), which glow with aug- mented intensity, as the temperature of the radiant source is height- ened.

In mj last memoir ^ I demonstrated the wonderful transparency of the element iodine to the extra-red undulations. A perfectly opaque solution of this substance was obtmned by dissolving it in Msnlphide of carbon ; and it was shown in the memoir referred to, that a quantity of iodine, sufficient to quench the light of our most brilliant flames, transmitted 99 per cent of the radiation from a flame of hydrogen.

Fifty experiments on the radiant heat of a hydrogen flame, re- cently executed, make the transmission of its rays, through a quan- tity of iodine which is perfectly opaque to light,

100 per cent

To the radiation from a hydrogen flame the dissolved iodine is therefore, according to these experiments, perfectly transparent.

It is also sensibly transparent to the radiation from solid bodies heated under incandescence.

It is also sensibly transparent to the obscure rays emitted by luminous bodies.

To the mixed radiation which issues from solid bodies at a very high temperature, the pure bisulphide of carbon is also eminently transparent Hence, as the bisulphide of carbon interferes but slightiy with the obscure rays issuing from a highly luminous source, and as the dissolved iodine seems not at all to interfere with them, we have in a combination of both substances a means of almost entirely detaching

the purely thermal rays from the luminous ones.

If vibrations of a long peripd, established when the radiating body is at a low temperature, mdntaiu themselves, as before indi-

• PhU Trans, vol. cliv. p. 327. PhiL Mag., Dec. 1864.

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oated, eide brstde with the now periods whitli iinp;nicQt«'l loir atnre introduces, it would follow, that a body onoo pervious U rsdiatdoD from an; source, must olwajs remain pervious to it. cannot so alter the character of tliB radiation, tliat a bodv ud< an; me-Qsure trimsparcnt U> it, shall become quite opaqne to it.

Wo maj, by augmenting the tt tnro, iliminish the percenUgft'

of tlie totiil radiation tranami ' the body; but iunsmudi u

the old vihratious have tiieir ides enlarged by the very aO'

ceadoD of temperature which oea the oow ones, the total

qoantitj' of hcnt of any giv< agibiittjr, trangiuitted by the

body, mast increase with iuci lemperatnre.

Tliis condusion is thus ex lally illostrated. A cell willi

parallel Aiea of polieteil ro is fillod with tho aolation of

iodine^ and placed in froot onera within wbidi was thf

pla^nm spiral hoat«d by a i umnt. Behind the rocbnlt

cell was jil.iccd an ordinary lutiiuu-oleclric pile, to receive snch rnys as had passod through the solution. The rocksalt lens was in the camera in front, but a small sheaf only of the jiarallel Ijcani, ciriLTjjcnt from tho lamp, was employed. Uommeneing at a v<T/ low dark heat, the lorapcrnliiro wiis gradually augmented to full incaiidoseerice with the fullowiiig resvilts; —

ApTM^inmrc of ."spiral DnjAfrtiim

Dark but liotlor ... 3 Dark but still hotter . . 5 Dark but still holler . . 10 Fcoblo red . , , ,19 Dull red £5

Iteil 35

Full red 45

Bright red , . . .63 Very briglit red ... 63 Nearly nLite G3

Wliite 75

Iiilun3i; while ... Si)

To tho Imiiinons r.iys from Ihe intensely white spiral, the soln- tion was perfectly opaque ; but though by tho introduction of suet rays, tho transmission, as expressed in parts of tho total radiation, was diniiiiisbed, tho qiiantily absolutely transmitted was enor-

LTTlONOnB Am) OBSCUBE BADIATION. 463

moosly increased. The yalne of the lost deflection is 440 times that of the first; by raising therefore the platinom spiral from dark- ness to whiteness, we angment the intensity of the obscure rajs which it emits in the ratio of 1 : 440.

A Todksalt cell, filled with the transparent bisulphide of carbon, was placed in front of the camera which contained the dazzling wfaite-liot platinum spiral. The transparent liquid was then drawn off and its place supplied by the solution of iodine. The deflec- tions observed in the respective cases are as follows : —

BADiAnoN noM White-hot Platinuh.

Through tnmqwrent CSt Through opaque solatlon

JLU the luminous rays passed through the transparent bisulphide, none oi them passed through the solution of iodine. Still we see what a small difference is produced by their withdrawal The actoal proportion of luminous to obscure rays, as calculated from the above observations, may be thus expressed : —

Dioiding the radiation from a platinum wire raised to a doe- Mng whiteness by an

electric current into twenty-four equal partSj one of those parts is htminouSj and twenty-three obscure.

A bright gatf flame was substituted for the platinum spiral, the top and bottom of the flame being shut off, and its most brilliant portion chosen as the source of rays. The result of forty experi- ments with this source may be thus expressed : —

Dividing the radiation from the most brilliant portion of a Jlame of coal gas into twenty -flee equal parts^ one of those parts is luminous and twenty-four obscure.

I next examined the ratio of obscure to luminous rays in the electric light. A battery of fifty oeUs was employed, and the rock- salt lens was used to render the rays from the coal points paralleL To prevent the defiectionfrom reaching an inconvenient magni- tude, the parallel rays were caused to pass through a circular aper- ture 0*1 of an inch in diameter, and were sent alternately through the transparent bisulphide and the opaque solution. It is not easy to obtain perfect steadiness on the part of the electric light; but three experiments carefully executed gave the following deflec- tions:—

APPEKDIX 1i

3 LRCTUBE Xn.

mDUTioM mo

U EtMTTKIC LiaHT.

Thronch

Eiperinicnt So. I.

Eipcriuieiit No. IL .

CalcQlatJng from these meo^u.

to obscure heat, the result maj

18 espruesed :—

Ditiding the radiation fr

ftlric light emitted ly mrhon

point*, and eicited Isi a

tery <if forty

crZi*. i»lo ten

equal part», one of the

flOT* ami nine

Tbo resnlta mnj 1»

iu u tuliulsr form : —

RiDiinoB mnor

lOLTSn loDINt'

Lampblack >t 212° Fshr.

Red-hot Bpiral .

Hydrogen flame

Gas flame ■ Wliile-hot Epiml

Electric Itgbl .

Fatnro experiments may slight]; alter these 'results, bat they ore extremely near the truth.

Uavin); thus, in the eolDtion of iodine^ found a means of olmo^^t perfectly detaching the obscure from the Inminoas beat-rays of any soarco, we are able to operate at will apon the former. Here are Bomo iUostrationa : — The rocksnlt lens was bo placed in the cnmeni that the coal-pointa themselves, and their image beyond the lens, were eqoally distant from the latter. A battery of forty cells be- ing employed, tho track of the cone of rays emergent from the lamp was plainly seen in tho air, and their point of convergence therefore easily fixed. The cell containing the opaqne solntion was now placed in front of tho lamp. Tho luminona cono was

thereby entirely cnt off, bat the intolerable temperatnro of the focns, when the hand was placed there, showed that the colorific rays were * Id these experiments, Ibc pure biEulphide itas compared vith th« opaque solution ; the tnmsmisdon 100 means that Ibe same quantity of heat passed through both. Tbe iodine vm, io this case, IransparenU

LUMINOUS Am) 0B80UBE SADIATION. 465

still transmitted. Hun plates of tin and zino were placed snooes- nveljr in the dark foons and speediljr fased ; matches were ignited, gon-ootton exploded, and brown paper set oif fire. Emplojing the iodine solution and a battery of sixty of Grove's cells, all these re- salts were readily obtained with the ordinary glass lenses of Bn-boscq^s electrio lamp. They cannot, I think, fail to give pleasure to those who repeat the experiments. It is extremely interesting to observe in the middle of the air of a perfectly dark room a piece > of black paper suddenly pierced by the invisible rays, and the bnm- ing ring expanding on all sides from the centre of ignition.

On the 15th of this month (November, 1864) I made a few ex- periments on solar light. The heavens were not free from clouds, nor the London atmosphere from smoke, and at best I obtained only a portion of the action which a dear day would have ^ven me. I happened to possess a hollow lens, which I filled with the concentrated solution of iodine. Placed in the path of the solar rays, a faint red ring was imprinted on a sheet of white paper held behind the lens, the ring contracting to a faint red spot when the focus of the lens was reached. It was immediately found that this ring was produced by the light which had penetrated the thin rim of the liquid lens. Pasting a zone of black paper round the rim, the ring was entirely cut off and no visible trace of solar light crossed the lens. At the focus, whatever light passed would be in- tensified nine hundred fold ; still even here no light was visible.

Not so, however with the sun's obscure rays ; the focus was burning hot. A piece of black paper placed there was instantly pierced and set on fire ; and by shifting the

paper, aperture after i^rture was formed in quick succession. Gunpowder was also exploded. In fact we had in the focus of the sun's dark rays a heat decidedly more powerful than that of tlie electric light, simi- larly condensed, and all the efiects obtained with the former could be obtained in an increased degree with the latter.

I introduced a plano-convex lens of glass, larger than the opaque lens just referred to, into the path of the sun's rays. The focus on white paper was of dazzling brilliancy ; and in this focus the results already described were obtained. I then introduced a cell containing a solution of alum in front of the focus. The in- tensity of the light at the focus was not sensibly changed ; stUl Uiese almost intolerable visual rays, aided as they were by a con-

APPEBDIX TO LECTCBK Xll.

Bi<1orab!e qnontitf of invisiblo rajS irhich had also passed thrriugli I the alum, were incompetent to produce liffocttt, wliirh v Ijiiued with cose in tU'e perfectly dark foc^s of the ojioquc lenji.

Tliinkiog thnt this ri^actioa of power might be due in part to llio withdrowal of heat, by reflerfon, from the aides of the glass Deli, 1 p-Jt Id its place a rucksalt r~" "'led with the opnqne aulutioa-

ho power whii^ liiey eihib-

^onclnde tJiat roeisult tran»- y well, and that a sotolioa of intcrcoiitif tlie invi«ble rajs, i to pB88. nence the differ- ^ealt and alam ooght to giv9 allosi finmd that 10 per cent. M oodssts of Itiniinoiu raji. | i tfiiit llip proportion of liimi- 1 oil fiamo, is probably nut

Behind this cell the rays manife ited in the focus of the opaqno 1

Hclloiii"s oipcriments lixl Id mita obecure and lutninons rays alnm of uioderat* ttiickncss e"' while it allows all the lomint euce between the troimnimioiii the obflouro radiation. In thir onlj' of the nuUadoa from an The method iiliovo emjiloyed pnn nous lii'nt to obscure, in tbu onse more than one-third of what

MoUoni made it,

III f;ipt this distiuKiiisbcil man clearly saw the possible inaoon- racy of the eonehisioii, tliat none but luminons rays are transiuli- ted by al(un ; and the following esperinients justify the causes of limilatiun which he attached to his eonclusion: —

'ilie solution of iodine was placeil in front of the electric lamp, the luminona rays being thereby intercepted. Behind the roeksalt cell containing the opaqno solution waa placed a glass cell, empty in the first instance. The deflection produced by the iibscnrc riiyj ttliicb passed through both produced a deflection ol"

The ir'ass cell was now filled with a co?tcenlratcd sohition of alum ; tbo dclleetioa produced by the ohscure r.iys pns?ing ibroush both

Calculating from tlie values of these deflections, it was found tAitl of the oliseare Itcat emergent from the solution of iodinr, 20 jier cent, -leiii trangmittcd hy the alum.

A point of very considerable irnjiortniicc forces itself npon our attention here, namely, the vast practical difiurence which may

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eziBt between the two phrases, ' obscnre rays,' and ^ rays from an obocare soiiroe.' Many writers seem to regard these phrases as eqiiiyalent to each other, and are thus led mto grave errors. A strmtnm of alum solution ^th of an inch in thickness is, according to MeUoniy entirely opaque to the radiation from all bodies heated imder inoandeeoence. In the foregoing experiments the layer of almn sdiution traversed by the obscnre rays of onr lominons source, was thirty times the thickness of the layer which Mellon! found aofficient to quench all rays emanating from obscure sources.

Tliere cannot be a doubt that the invisible rays which have shown themselves competent to traverse such a thickness of the most powerfol adiathermio liquid yet discovered are also able to pass throng the humours of the eye. The very careful and

inter- esting experiments of M. Janssen,* prove that the humours of the eye Absorb an amount of radiant heat exactly equal to that ab- sorbed by A layer of water of the same thickness, and in our solu- tion the power of alum is added to that of water. Direct experi- ments on the vitreous humour of an ox lead me to conclude, that one-fifth of the obscure rays emitted by an intense electric light reach the retina ; and, inasmuch as in every ten equal parts of the radiation from an electric lamp nine consist of obscure rays, it fol- lows that, in the case of the electric light, nearly two-thirds of the whole radiant energy which actually readies the retina is incom- petent to excite vision. With a white-hot platinum spiral as source, the mean of four good experiments gave a transmission of 11 '7 per cent, of the obscure heat of the spiral through a layer of distilled water 1*2 inch in thickness. A larger proportion no doubt reaches the retina.t

Conver^png the beam from the electric lamp by a glass lens, I placed the opaque solution of iodine before my open eye, and brought the eye into the focus of obscure rays. The heat was im- mediately unbearable. But it seemed to me that the unpleasant effect was mainly due to the action of the obscure rays upon the eyelids and other opaque parts round the eye. I therefore cut, in a card, an aperture somewhat larger than the pupil, and allowed the concentrated calorific beam to enter my eye through this apcr-

* Annales de Chimie et de Phytiqutf torn. Iz. p. 71. f K. Franz has shown that a portion of the sun's obscare rays reach the retina.

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tare, Tbe een^c of heat entirely disappeared. Not on]y vera ibe rsTB thns received upon the retina inconipvteDt tt excite viiioD, but the optic nerve seemed uncoDseions of their existence even as heat What the eoQBeqne nee would b»Te been had I permitted the lomi- . nom third of the eondensed beam to ont^r my eje, I am not pre- ptaeA to say, nor should I like t ""3 the esperiment

On a tolerably clear night a -fiomo can be readily seen at the distance of a mile. The in of the electric light a»ed by me is COD times that of a good «ite candle, and as the non-hunlonns radiation from the t its wluch roaches the retina ia eqoel to twice the Inmino' lows that at a common di^ tanoe of a foot, the energy iviaiblo rays of the electric light vhich reach the optic nt are incompetent to provoke Tisioii, is 1, SOD times that of t of a candle. Bntthaioteo-ratj of the candle's light at thi ce of a mile is leas than «m i twenty-ralUionth of its intensity at tiie distnnca of a fo')t ; lience the eneriry which renders tlie candle perfectly visible a mile oftj would liavo to be moltiplicd by 1,300 x 20,000,C»0, or by twentj-sis thousand millions, to bring it up to the intensity of that invisible radiation which the retina receives from the electric light at a foot distance. Nothing, I tliink, could more forcibly illustrolo the spe- cial relntionsliip which subsists between the optic ner^o and llic oscillating periodn of luininons bodies. The nerve, like a musiciJ Htring, responds to tlic periods with which it is in accordance, while it refuses to bo c>:cited by others of. vastly greater cnct^y, which !iro not in unison with its own.

By menns of tlio opaqne solution of iodine, I have already shown that the inantity of luminous licat emitted by a bright red jilatinnm spiral is immeasnrably small.* Here are Eonio determina- tions since made, with the same source of heat and a solution of iodine in iodide of ethyl, the strength and thickness of the solution being such as entirely to intercept tlie luminous rays:: —

KAHiiTios fhoji REO-noT Flatlnfu Spnui. Through tmnflinrrnl llqiild Throngh opiqnt loInUon

These experiments were made with exceeding care, and all ibe • riiil. Trans, vol.

cUv. p. 327.

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oonditiQiiB were finrourable to the detection of the slightest dificr- enoe in the amount of heat reaching the galvanometer; still the qnantily of heat transmitted by the opaque solation was foand to be the same as that transmitted bj the transparent one. In other words, the Inminons radiation intercepted by the former, thongh competent to ezdte yividly the sense of vision, was, when ex- pressed in terms of actoal energy, absolutely inmieasurable.

And here we have the solution of various difficulties which from time to time have perplexed experimenters. When we see a vivid li^t incompetent to affect our most delicate thermoscopio qyparatus^ the idea naturally presents itself that light and heat must be totally different things. The pure light emerging from a combination of water and green glass, even when rendered intense by ooncentration, has, according to Melloni, no semdble heating power.* The light of the moon is also a case in point Ck)ncen- trated by a polyzonal lens more than a yard in diameter upon the ftoe oi his pile, it required all Helloni's acuteness to nurse the col- orific action up to a measurable quantity. Such experiments, how- evOT, demonstrate, not that the two agents are dissimilar, but that the sense of vision can be excited by an amount of force almost infinitely smalL

Here also we are able to offer a remark as to the applicability of radiant heat to fog-signalling. The proposition, in the abstract, is a philosoplucal one ; for were our fogs of a physical character similar to that of the iodine held in solution by the bisulphide of carbon, or to that of iodine or bromine vapour, it would bo possi- ble to transmit through them powerful fluxes of radiant heat, even after the entire stoppage of the light from our signal lamps. Bat our fogs are not of this character. They are unfortunately so con- stitnted as to act very destructively ypon the purely calorific rays; and this fact, taken in coiyunction with the marvellous sensitive- ness

of the eye, leads to the condasion that long before the light of our signals ceases to be visible, their radiant heat has lost the power of affecting, in any sensible degree, the most delicate ther- moscopic apparatus that we could apply to their detection.!

* Taylor^s Scientific Memoirs, vol i. p. 892.

t SinCe the publication of this memoir, I have greatly intensified the effects produced by invisible rays.

"VTTE have learned tliat oiir nliiiosphore is nlways more VV or less charged with aqueous vapour, the comlcBpa- lion of which forma our clouds, hail, raiD, and mow. I have now to direct your attentioD to one particular case of condensation, of great interest and beauty — one, moreover, rcgiirding which orroneous notions were for a long time en- tertained. I refer to the phenomenon of Dew. Tlie aqueous i-apour of our atmosphere is a powerful radiant, but it is diffused through air which usually exceeds its own mass more than one hundred times. Not only, then, ils own heat, but the heat of the large quantity of air which sun-ounds it, must be discharged by the vapour, before it can niok to its point of condensation. The retardation of chilling due to this cause enables good solid radiators, at the earth's surface, to outstrip the vapour in their speed of

Tefrigeration ; and hence upon these bodies aqueous vapour may be condensed to liquid, or even congealed to hoar- frost, while at a few feet above the surface it still main- tains its gaseous state. This is actually the case in the beautiful phenomenon which we have now to examine.

We are indebted to a London physician for a true theory of dew. In 1818 Dr. Wells published his admirable Essay upon this subject. He made his experiments in a garden in Surrey, at a distance of three miles from Black- friars Bridge. To collect the dew he used little bundles of wool, which, when dry, weighed 10 grains each ; and having exposed them during a clear night, the amount of dew deposited on them was determined by the augmenta- tion of their weight. He soon found that whatever

inter- fered with the view of the sky from his piece of wool, in- terfered also with the deposition of dew. He supported a board on four props ; on the board he laid one of his wool parcels, and under it a second similar one ; during a clear cabn night, the former gained 14 grains in weight, while the latter gained only 4. He bent a sheet of paste- board like the roof of a house, and placed imdemeath it a bundle of wool on the grass : by a single night's exposure the wool gained 2 grains in weight, while a similar piece of wool exposed on the grass, but quite imshaded by the roof, collected 16 grains of moisture.

Is it steam from the earth, or is it fine rain from the heavens, that produces this deposition of dew ? Both of these notions have been advocated. That it does not arise from the earth is, however, proved by the observation, that more moisture was collected on the propped board than on the earth's surface under it. That it is not a fine rain is proved by the fact, that the most copious deposition occur- red on the clearest nights.

Dr. Wells next exposed thermometers, as he had done his wool-bundles, and found that at those places where the

472 tEcruKE xro.

deto /m moat cojdotaly the lemperature tank loKta. On the propped board already referred to, lie found the tenir i peraturc 9 ' lower than under it ; beneath the pastebo&rd , roof the thermometer was 10' warmer than on the open I grass. He also found that when he laid hia thermometer upon a grass plot, on a clci it, it sank sometimea W"

lower than a eimilar therm suspended in freo air at

a height of 4 feet above th* A bit of cotton, placed

beude the former, gained ins ; a similar bit, beside

the hitter, only 11 grains it. The lowerinff of Iht

temperature atid the ckpc f the dew vient ftantl in

hand. Not only did the f artificial Bcreena iatet'

fere with the lowering of iperature and the fonna-

lion of the dew, but a do a acted in the same man-

ner, lie once observed his thermometer, which, as it lay ujion the gi-ass, showed a temperature 12° lower than the air a few feet above the grass, rise, on the])assagc ot some clouds, tmtil it was only 2" colder than the air. In fact, as the clouds crossed liis zenith, or disappeared from it, the tem]>cratiirc of liis thermometer rose and fell,

A series of such experiments, conceived ami executed witli singular clearness and skill, enabled Dr. Wells to pro- pound a Theory of Dew, which has stood tlie test of all subr'eijuent criticism, and is now universally accepted.

It is an cll'ccl, of chilling by radiatioTi. ' The upper parts of Iho grass radiate Ihoir heat into regions of einjity space, which, consequently, send no heat back in return ; its lower parts, from the smallness of their conducting power, transmit little of the earth's lieat to the upper jiarts, whieli, at the same time, receiving only a small quantity from the atmosphere, and none from any other lateral body, must remain colder than the air, and condense into dew its walcry vapour, if thi^ be suflieiently abundant in respect to the decreased temperature of the grass.' "Why llio vapour itself, being a powerful radian!, is not as quickly chilled as

THBOBY OF WELLS. 473

the grass, I haTe already explained, on the grotind that the Yi^nr has not only its own heat to discharge, but also that of the large mass of air by which it is surrounded.

Dew being the result of the condensation of atmo- spheric yaponr, on substances which have been sufficiently cooled by radiation, and as bodies differ widely in their

radiadve powers, we may expect corresponding differences in the deposition of dew. This Wells proved to be the case. He often saw dew copiously deposited on grass and painted wood, when none could be observed on gravel walks adjacent. . He found plates of metal, which he had exposed, quite dry, while adjacent bodies were covered with dew : in aU such cases the temperature of the metal was found to be higher than that of the dewed substances. Hub is quite in accordance with our knowledge that metals are the worst radiators. On one occasion he placed a plate of metal upon grass, and upon the plate he laid a glass thermometer ; the thermometer, afler some tune, exhibited dew, while the plate remained dry. This led him to suppose that Ae instrument, though lying on the plate, did not share its temperature. He placed a second thermometer, with a giU bulbj beside the first ; the naked glass thermometer— ^a good radiator — remained 9** colder than its companion. To determine the true temperature of a body is, I may remark, a difficult task : a glass thermometer, sus- pended in the air, will not give the temperature of the air ; its own power as a radiant or an absorbent comes into play. On a clear day, when the sun shines, the thermom- eter will be warmer than the air ; on a clear night, on the contrary, the thermometer will be colder than the air. We have seen that the passage of a cloud can raise the temperature of a thermometer 10 degrees in a few minutes. This augmentation, it is manifest, does not indicate a cor- responding augmentation of the temperature of the air, but

(74 LECTITKE Xm.

merely the interception and reflection, by the cloud, of tbe rays of lieat emitted by the thermomeitcr

Dr. Wellii applied his principles to the explanation of many curious eflects, and to the correction of many popular errors. Moon bliudueas h- "•f.^rg to the chill produced bj radial iou into clear space,

merely an nccompantment phere. The putrefying ' bciims is realty duo to the of dew,

on the exposed of tendiT plants by frost, is some degrees above tl be referred to chilling ■would be sufficient to prcnt AVflls lias the first to c

[lining of tbe moon being c clearness of the alnios- ?G ascribed to the moon- tion of moisture, as a kind substances. The ntppmg hen tho air of tbo garden ng temperature, is also ta

ntion. A cobweb

lem from injury.* plain the fonnation, artificially.

of ice in Uenqil, where the substance is never formed nat- urally. SJiallow pits arc dug, which arc partially filled with straw, and on tho straw flat pans, containing water which liad betn boiled, i« exposed to the clear firmament The water is i poMcful radiant, and sends off its be.it copioui^ly into =ince The heat thus lost cannot he supjilicd from the earth — this source being cut off by the nou-con- ducting straw. Before sunrise a cake of ico is formed in each vessel. This is the explanation of Weils, and it is, no doubt, the true one. I think, however, it needs supple- menting. It aj)])ears, from the description, tliat the con-

■ With rcrprcnce lo this point wc huTC Iho fotl owing bcauliful pssssge in llic E.<«iy of Wcllj :— ' 1 hud often, in the pride of half ItnottlpJse, smili-d M tlio monna frpfiiiciitlj employed by gardenci-a to protect, tender plants from cold, aa it ap[ic.irod lo me impossible llint a lliin m.it, or anv eui-h flimsy subistanco could prevent tlicm from ntlaiiiing tho temperature of the atniospliere, by wliieli alono I tbougbt Ibcni lialile to be iiyurcJ. But Blien I bud learned tliat bodies on llio Hurface of the earth become, during a Etill atid serene nigbt, colder than the ntmospbore, by radiating their heii lo the Iitavcns, I perceived itumediutely njust reasoD for the practice wl:iili I had before deemed useleas.'

NOCrrUBNAL BABIAITON. 475

dition most suitable for the formation of ice, is not only a dear air, but a dry air. The nights, says Sir Robert Barker, most favourable for the production of ice, are those

.whidi are clearest and most serene, and in which very little dew (qjpears after midnight. I have italicised a very sig- nificant phrase. To produce the ice in abundance, the nU mospbere must not only be dear, but it must be compara- tivdj free from aqueous vapour. When the straw in which the pans were laid became wet, it was always changed for dry straw, and the reason Wells assigned for this was, that the straw, by being wetted, was rendered more com- pact, and effident as a conductor. This may have been the case, bat it is also certain that the vapour rising from the wet straw, and overspreading the pans like a screen, would check the chill, and retard the congelation.

With broken health Wells pursued and completed this beautiful investigation ; and, on tlie brink of the grave, lie composed his Essay. It is a model of wise enquiry and of lucid exposition. He made no haste, but he took no rest till he had mastered his subject, looking steadfastly into it imUl it became transparent to his gaze. Thus he solved his problem, and stated its solution in a fashion which ren- ders his work imperishable.*

Since his time various experimenters have occupied themsdves with the question of nocturnal radiation ; but, though valuable facts have been accumulated, if we ex- cept a supplement contributed by Mclloni, nothing of im- portance has been added to the theory of Wells. Mr. Glaisher, M. Martins, and others, have occupied themselves with the subject. The following table contains some re- sults obtained by Mr. Glaisher, by exposing thermometers at difierent heights above the surface of a grass field. The

' * The tract of Wells is preceded by a personal memoir written by him- ■elf. It has the solidity of an essay of Montaigne.

476 LKCTt'EE mi,

ch baeired, when the thermometer was exposed oa 1

long graM, is reprosentcd by the number 1,000 ; while the (Bucceeding numbers

represent the relative cliilling of the thermometers placed in the positions indicated :

Lang grass . . , 1000

Onu iticii nbove [bi-groM . Ml

Twoiocbcs „ . 670

Eii feci „ „ 63

It may be asked why the thermometer, which is a good radiator, is not, when suspended in free air, just as much chilled as at the earth's surface. Wells has answered the question. It is because the thermometer, when cliilled, cools the air in immediate contact with it ; this air con- tracts, becomes heavy, and trickles downwards, thus allow- ing its place to be taken by warmer air. In this way the free thennomcler is prevented from falling very low be- neath the temperature of the air. Hence, also, the Dcces- Bity of a Bliil night for the copious formation of dew ; for, when the wind blows, fresh air continually circulates amid the blades of grass, and prevents any considerable chilling by radiation.

When a radiator is exposed to a clear sty it tends to keep a certain tliermometric distance, if I may use the term, between its temperature and that of the surronnding air. This distance will depend upon the energy of the body as a radiator, but it is to a great extent independent of the temperature of the air. Thus M, Pouillet has proved that in the month of April, when the temperature of the air was s'-a C, swonsdown fell by radiation to — S^-S: the whole chilJing, therefore, was ^"■l. In the mouth of June,

msllohi'b bupplekest to thb theory of dew. 477

when the temperature of the air was, I'^'IS C, the tempera- ture of the radiating swansdown was 10°'54 : the chilling of the swansdown by radiation is here 7^*2 1 ; almost precisely the same as that which occurred in ApriL Thus, while the general temperatore varies within wide limits, the diffhr- enee of temperatore between the radiating body and the sorronnding air, remains sensibly constant.

These facts enabled Melloni to make an important addi- tion to the theory of dew. He found that a glass thermom- eter, placed on the ground, is never chilled more than 2^ C. below an adjacent thermometer, with silvered bulb^ which hardly radiates at alL These 2^ C, or thereabouts, mark the thermometrio distance above referred to, which the glass tends to preserve betweeen it and the surrounding mir. But Six, Wilson, Wells, Parry, Scoresby, Glaisher, and others, have found differences of more than 10^ C, between a thermometer on grass, and a second thermom- eter hung a few feet above the grass. How is this to bo aooonnted for ? Very simply, according to Melloni, thus : — The grass blades first chill themselves by radiation, 2° C. below the surrounding air : the air is then chilled by con- tact with the grass, and forms around it a cold aerial bath. But die tendency of the grass is to keep the above constant difference between its own temperature and that of the surrounding medium. It therefore sinks lower. The air sinks in its turn, being still further chiQed by contact with the grass ; the grass, however, again seeks to re-establish the former difference ; it is again followed by the air, and thus, by a series of actions and reactions, the entire stratum of air in contact with the grass becomes lowered far below the temperature which corresponds to the actual radiative energy of the grass.

So much for terrestrial radiation ; that of the moon will not occupy us so long. Many futile attempts have been made to detect the warmth of the moon's beams. No

41 LEcnniE xm.

doubt is entertained that every laminoas ray is also a heatl ray ; bnt the light-giving power is not even an approidmate' measure of the calorific energy of a beam. With a large polyzonal lens, Mclloni converged an image of the moon upon his pile. ; but I cold of his leas far more

than sufficient to masK Uip ---b f such there were, of the] moon. lie screened off from the heavens, placed

hia [lile in the focus of i i, vaited until the needle

came to zero, and tht y removing Ids screen al-

lowed the concentratei triko his pile. The slight

air-drafts in the plaoe ui nmcnt were sufficient to dis-

guise the effect, lie then stopped llio tube in front of his pile with glass screens, through wliich the light went freely to the blackened face of the pile, where it was con- verted into heat. This heat could not (jet back through the glass screen, and thus Melloni, following the example of SauRSure, accumulated his effects, and obtained a deflection of 3° or 4°. The deflection indicated warmth, and this is the only experiment which gives us any positive evidence as to the calorific action of the moon's rays. Incomparably less powerful ttian the solar rays in the first instance, their aclion is first enfeebled by distance, and, secondly, by the fact that the obscvre heat of the moon is almost wholly ab- sorbed'by our atmospheric vapour. Even such obscure rays as might happen to reach the earth would be utterly cut off by such a lens as Melloni made nse of. It might be worth wliile to make the experiment with a metallic reflec- tor, instead of with a lens, I have myself tried a conical reflector of very large dimensions, but have hitherto been defeated by the unsteadiness of the London air.

We have now to turn our thoughts to the source from which all terrestrial and lunar heat is derived. This source is the sun ; for if the earth has ever been a molten sphere, which is now cooling, the quantity of heat which reaches its surface from within, has long ceased to be sensible.

SPBCTESDIC ANALYSIS B7 THB ELBCTRIO LIGHT. 479

Firsty tlien, let us enquire what is the constitution of this irondrons body, to which we owe both light and life.

Let OS approach the subject gradually and prepare our minds, by previous discipline, for the treatment of this noble problem. Ton already know how the spectrum of the electric light is formed. Here you have one upon the screen, two feet wide and eight long, with all its magnifi- cent gradations of colour, one fading into the other, without solution of continuity. The light from which this spec- tnua is derived, is emitted from the incandescent carbon points within our electric lamp. All other solids give a similar spectrum. When I rsdse this platinum wire to whiteness by an electric current, and examine its light by a prism, I find the same gradation of colours, and no gap whatever between one colour and the other. But by in- tense heat, — ^by the heat of the electric lamp, for example, — ^I can volatilise that platinum, and throw upon the screen, not the spectrum of the iucandescent solid, but of its in- candescent vapour. The spectrum is now changed ; instead of being a continuous gradation of colours, it consists of a series of brilliant lines, separated from each other by spaces of darkness.

I have arranged my pieces of carbon thus : — the lower one is now a cylinder, about half an inch in diameter, in the top of which I have scooped a small hollow ; in this hollow I place the metal which I wish to examine — say this piece of zinc, — ^and bring down upon it the upper point. Hie current passes ; I draw the points apart, and you see the magnificent arc that now unites them; here is its magnified image upon the screen, a fine stream of purple light 18 inches long. That coloured space contains the partides of the zinc discharged across from carbon to car- bon ; these particles are now oscillating in certain definite periods, and the colour which we perceive is the mixture of impressions due to these oscillations. Let us separate.

480 LECTCBE xm.

by ft piism, the coloured Btr«i&m into its coropooeots ; hen | they are, Hplendid bands of red and blue. Pray romenibtf \ the character and position of these bands, as I shall have to refer to ihcm again immediately.

1 interrupt the current " -'-Tt the zino, and put in iu

3u sec a stream of greea ih ve will analyse as we sa see that the Gpoctrunt hat of the ^c ; here yov hich are absent from the .h certainty, that the atoms g in perioda different front _ e whether these diSsnatJ

place a bit of cop|>er. B light bettpceu the carbons did the light of the zinc, of the copper ia different have bands of brilliant g sine. We may therefore ii of copper, in the voltaic ai those of ana. Let ns i^

periodic create any confusion, wiicn we operate upon a sub- Et:ince composed of zinc and copper, — the familiar snb- stanee brass. Its spectrum ia now before you, and if you ha^e retained the impression made by our two last esperi- mciits, you will rocogniso here a Bpectrum formed by tbo sii]ier])osition of the two separate spectra of zinc and cop- per. The alloy emits, without confusion, the rays peculiar to the mctuls of which it is composed.

Every metal emits its own system of bands, which are as characteristic of it as those physical and chemical quali- ties which give it its individuality. By a method of ei:- porimcnt sufliciently refined we can measure, accurately, the position of the bright lines of every known metal. Ac- quainted with snch lines wc t-hould, by the mere inspection of the spectrum of any single melal, be able at once to declare its name. And not only so, but in the case of a mixed spectrum, we should be able to declare the constitu- ents of the mixture from which it emanated.

This is true, not only of the metals themselves, but .ilso of their compounds, if they be volatile. I place a bit of sodium on my lower cylinder and cause the voltaic di*- charge to pass from it to the upper coal-point ; here is tbo

HBTALLIO YAPOUBS. 481

gpectmm of the sodium : a single band of brilliant yel- low. If I operated with sufficient delicacy I should divide that band into two, with a narrow dark interval

between them. I eject the sodium from the lamp and put in its place a little conmion salt, or chloride of sodium. At this high temperature the salt is volatile, and you see the exact yellow band produced by the salt that was given by the metal. Thus, also, by means of the chloride of strontium I produce the bands of the metal strontium ; by the chlo- rides of calcium, magnesium, and lithium, I produce the spectra of these respective metals.

Here, finally^ I have a carbon cylinder perforated with holes, into which I have stuffed a mixture of all the com- poundB just mentioned ; and th^re is the spectrum of the mixture upon the screen. Surely nothing more magnifi- oent can be imagined. Each substance gives out its own peculiar rays, and thus they cut transversely, the whole eight feet of the spectrum into splendid parallel bars of coloured light. Having previously made yourselves ac- quainted with the lines emitted by all the metals, you would be able to unravel this spectrum, and to tell mc what substances I have employed in its production.

I make use of the voltaic arc simply because its light is so intense as to be visible to a large audience like the present, but I might make the same experiments with a common blow-pipe flame, which is nearly deprived of light by the admixture of air or oxygen. The introduction of sodium, or chloride of sodium, turns the flame yellow; strontium turns it red ; copper green, &c. The flames thus coloured, when examined by a prism, show the exact bands which I have displayed before you on the screen.

We have already learned that gases and vapours absorb the rays of heat, the heat that we employed being obscure. I have no doubt that if those rays could make an impres- sion upon the eye — ^if I could spread them out before you

i LFXTTfltK Xm.

like the colours of the spectrum — ^j-oti would find certsun classes of rays selected, in each case, for destruction, tbe otiiors being allowed free passage Uirough the

vapours. A famous espeiiment of Sir David Brewster's, which I will throw into a forai to the lecture room, will

CDable me to illustrate u >'er of selection in the case

of light. Into this cyllnd ends of which are stopped

Ly plates of glass, I intr a quantity of nitrous acid

gas, the presence of w now indicated by its rich

brown colour. I p itrum on the screen, eight

feet long and nearly iw< 1th, and I place this cylin-

dor, oonfciiniiig the brown gns, in the path of the beam aa it issues from the lamp. You see the effect ; the contin- uous spectrum is now furrowed by numerous dark bands, the rays answering to which are struck down by the nitric gas, while it permits the inten'cning bands of Ught to pass without hindrance.

We must now take a step in advance of the principle of reciprocity, which I have already enunciated. Hitherto we have found in gases, liquids, and solids, that the good absorber is the good radiator ; we must now go further and state, that a gas or vapour, absorbs thoseprecise rays tehieh it can itself emit ; the atoms which swing at a certain rate intercept the waves excited by atoms swin^g at the same rate. The atoms which vibrate red light will stop red light ; the atoms that oscillate yellow will stop yellow ; those that oscillate green will stop green, and so of the rest. Absorption, you know, is a transference of motion from the ether to the particles immersed in it, and the ab- sorption of any atom is exerted chiefly upon those waves which arrive in periods that correspond with the atom's oivn rate of oscillation.

Let us endeavour to prove this experimentally. We already know that a sodium flame, when analysed, gives us s briUiant double band of yellow. Here is a flat vessel

ABSOBPnON B7 SODIUM YAFOUB. 483

oontaining a miztare of alcohol and water ; I warm the nuxtiire and ignite it : it gives a flame which is so feebly luminous as to be scarcely visible. I now mix salt with the liquid, and again ignite it ; the flame, which a moment ago was scarcely to be seen, is now a brilliant yellow. I project a continuous spectrum upon the screen, and iu the track of the beam, as it issues from the electric lamp, I place the yellow sodium flame. Observe the spectrum nar- rowly : you see a flickering gray band in the yellow of the spectrum ; sometimes it is shaded deeply enough to show yoa all that the flame has, at least in part, intercepted the yellow band of the spectrum : it has partially absorbed the precise light which it can itself emit.

But I wish to make the cflect plainer, and therefore abandon the alcohol light, and proceed. thus: here is a Bnnsen's burner, the flame of which is intensely hot, though it hardly emits any light. I place the burner in front of the lamp, so that the beam, whose decomposition is to form our spectrum, shall pass through the flame. I have here a little net of platinum wire, in which I place a bit of the metal sodium, about the size of a pea. I also set up a pasteboard shade, which shall cut off the light emitted by the sodium, from the screen on which the spectrum falls. And now I am ready to make the experiment. Here, then, in the first place, is the spectrum. I now in- troduce the platinum net in front of the lamp ; the sodium instantly colours the flame intensely yellow, and you see a shadow coming over the yellow of the spectrum. But the effect is not yet at its maximum. The sodium now sud- denly bursts into uitensified combustion, and there you see the yellow dug utterly out of the spectrum, and a bar of intense darkness in its place. This violent combustion will endure for a little time. I withdraw the flame, the yellow reappears upon the screen; I reintroduce it, the yellow band is cut out. This I can do ten times in succession,

't LECTCHE Xm.

and in the whole range of optics I do not think there is a more Etriking experiment. Hero, then, we have conclu- Bively proved, thai the light which the Bodium flame

ab- sorbs is the precise ""*^' "'Vii"!! it, can emit.

Let me be still in my experiment. The

yellow of the specti ver a widish interval ; and

I wish now to §hov ia the particular portion

of the yellow which emits, that is absorbed by

ila flame. I place .• ilution on the ends of my

coal points ; you nc tinuons spectrum with the

yellow band of tho t unijhlcr than the rest of the

yellow. It is thus clearly defined before your eyes. I again place the sodium flame in front, and that particular band which now stands out from the ppeclrum is cut away — a space of intense gloom occujiying its place.

You have already seen a spectrum, derived from a mix- ture of various substances, and which was composed of a succcHsion of sharply defined and brilliant bars, separated from each other by intervals of darkness. Could I take tho mixture which produced that striped spectrum, and raise it, by means of Eunseo'a burner, to a temperature Bufficicntly intense to render its vapours incandescent ; on placing its flame in the path of a beam producing a contin- uous spectrum, I should cut out of the latter the precise raya emitted by the components of my mixture. I should thus, instead of furrowing my spectrum by a single dark band, as in tho case of sodium, furrow it by a series of dark bands, equal in number to the bright bands produced, when the mixture itself was the source of light.

I think we now possess knowledge euflScient to raise ns to the level of one of the most remarkable generalisations of our age. When the light of the sun is properly decom- posed, the spectnun ia seen furrowed by innumerable dark lines. A few of these were obsened, for tho first time, by Dr. Wollaston ; but they were investigated with pro-

fbaunhofeb's lines. 485

found skill by Fraunhofer, and called, after him, Frann- borer's lines. It has long been supposed that these dark spaces were caused by the absorption of the rays which correspond to them, in the atmosphere of the sun ; but no- body knew how. Having once proved that an incandescent yapour absorbs the precise rays which it can itself emit, and knowing that the body of the sun is surrounded by an incandescent photosphere, the supposition at once flashes on the mind, that this photosphere may cut off those rays of the central incandescent orb, which the photosphere itself can emit. We are thus led to a theory of the con- stitution of the sun, which renders a complete account of the lines of Fraunhofer.

The sun consists of a central orb, liquid or solid, of ex- ceeding brightness, which, of itself, would give a contin- uous spectrum, or in other words, which emits all kinds of rays. These, however, have to pass through the photo- sphere, which wraps the sun like a flame, and this vaporous envelope cuts off those particular rays of the nucleus which it can itself emit — the Tmes of Fraunhofer marking the position of these failing rays. Could we abolish the cen- tral orb, and obtain the spectrum of the gaseous envelope, we should obtain a striped spectrum, each bright band of which would coincide with one of Fraunhofcr's dark lines. These lines, therefore, are spaces of relative, not of abso- lute darkness ; upon them the rays of the absorbent photo- sphere fall ; but, these not being sufficiently intense to make good the light intercepted, the spaces which they illuminate are dark, in comparison to the general brilliancy of the spectrum.

It has long been supposed that sun and planets have had a conunon origin, and that hence the same substances are more or less common to them all. Can we detect the presence of any of our terrestrial substances in the sun ? I have said that the bright bands of a metal are character-

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istic of the metal ; lliat wc can, 'without awing the metal, declare iu name from the inspection of the bonds. The bands are, so to speak, the voice of the metal declaring its 1 presenoc. Hence, if any of our terrestrial metals be coft- taiaed in the sun's atmospl he dark lines wliiuh they '

produce ought to coincide emitted by the vapour of i tlie ningle metal iron, abou tenmned as belonging to incandeeceiit vapour of i tiio sparks between two throngb one-half of » fin through the other half, th liffht may be placed togcth found that for every briglil

tJy with the bright lines tal itself. In the case of (right lines have been de- »Vhen the light fi-om the btained by passing clco- mcs, is allowed to paw tmd tho hght of the sim tra from both sources of and ivhen this is done it is ic of tlio iron spectrum there

* a dark line of the solar spectrum. Reduced to actual calculation, this means that the chances are more than 1,000,- 000,000,000,000,000 to 1 tliat iron ia in the atmosphere of . the K\ni. Comparing the spectra of other metals in the pamc manner, Professor Kirehliof, to ivhosc genius nc owe this KplendiJ genendisntion, finds iron, calcium, magnesium, podiinn, chromium, and other metals, to be constituents of the solar atmosphere, but as yet he has been rmable to do tei^t gold, silver, mercury, aluminium, tin, lead, arsenic, or antimony,

I c.in imitate in a way more precise than that hitherto employed, the solar constitution here supposed. I place in the electric lamp a cyrmdor of carbon about half an inch thick ; on t!io top, and round about the edge of the cylin- der, I place a ring of sodium, leaving the centr.il porlina of the cylinder clear. I biing down the ujnier coal point upon the middle of the cylinder's upjier surface, thus]iro- ducLug the ordinary eicctric light. The proximity of this light to the sodium is siiflieient to volatilise the latter, and thus I surroimd my little central sun with an atmosphere

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of aodium vapour, as the real sun is snrrotmdcd hj its photospiiere. In the spectrum

of this light yoa see the yel- low band b absent.

The energy of solar emission has been measured by Sir John Hcrschel at the Cape of Good Hope, and by M. Pouillet in Paris. The agreement between the measurements is very re- markable. Sir John Herschcl finds the direct heating effect of a vertical sun, at the sea level, to be competent to melt 0*00754 of an inch of ice per minute ; while according to M. Pouillet, the quantity is 0*00703 of an inch. The mean of the determinations cannot bo far from the truth; this gives 0*00728 of an inch of ice per minute, or nearly half an ii^ch per hour. Before you (fig. 100) I have placed an instrument similar in form to that used by M. Pouillet, and called by him a pyrheliometer. The particular in- stmment which yon now see is composed of a shallow cylin- der of Bteel, a a, which is filled with mercury. Into the cylin- der this thermometer d, is introduced, the stem of which is protected by a piece of brass tubing. We thus obtain the temperature of the mercury. The flat end of the cylinder is to be turned towards the sun, and the surface thus pre- sented is coated with lampblack. Here is a collar and screw, cc, by means of which the instrument may be at- tached to the stake driven into the ground, or into the snow, if the observations are made at considerable heights.

LECITHE IIU.

It is necessary that the surface wLJcIi reeeivefl the eun'a

rays should be perpendicular

to the rays, and this is secured

by appending to the brass tube which shields the stem of

the thermometer, a disk. ee.

of nreciaely the same diameter

as tbc steel cylindci

c shadow of the cylinder
accurately covers tlie
■e sure that the rays fall,
aa perpendiculars, on the i-
■d surface of the cylinder.
The obeen'atioDB ar" '
the following manner : —
First, the instniment i
d, not to receive the sun's
rays, but to radiate i*"
t for five minutes against
an unclouded part ol
lent ; the decrease of the

temperature of the mercury consequent on lliis radiation is then noted. Next, the instrnment is turned towards the snn, 60 that the solar rays fall perpendicularly upon it for five minutes, — the augmentation of temperature is now noted. Finally, the instrument is tiimed again towards the firmament, away from the sun, and allowed to radiate for another five minutes, the sinking of the thermometer bebg noted as before. You might, perhaps, suppose that exposure to the sun alone would he sufficient to determine his heating power ; but we must not forget that during the whole time of eiposuro to the sun's action, the black- ened surface of the cylinder is also radiating into space ; it is not therefore a case of pure gain : the heat received from tho sun is, in part, thus wasted, even while the ex- periment is going on ; and to find the quantity lost, the first and last experiments are needed. In order to obtain tho whole heating power of the sun, we must add to his observed lieating power, the quantity lost during the time of exposure, and this quantity is the mean of the first

and last observations. Supposing the letter e to represent the augmentation of temperature by five minutes' exposure to the sun, and that t and t' represent the reductions of tem- perature observed before and after, then the whole force of the Bun, which we may call t, would be thus expressed :

INFLUENOB OF THB EABTH's ATMOSFHEBE. 489

The surface on which the sun's rays hero fall is known ; the quantity of mercury within the cylinder is also known ; hence we can express the effect of the sun's heat upon a ^ven area, by stating that it is competent, in five minutes, to raise so much mercury, or so much water, so many de- grees in temperature. Water indeed, instead of mercury, was used in M. Pouillet's pyrheliometer.

The observations were made at different hours of the day, and, hence, through different thicknesses of the earth's atmosphere ; augmenting from the minimum thickness at noon, up ot the maximum at 6 p. m., which was the time of the latest observation. It was found that the solar energy diminished according to a certain law, as the thickness of the air crossed by the sunbeams increased ; and from this law M. Pouillct was enabled to infer what the atmos- pheric absorption of a beam would be, if directed down- wards to his instrument from the zenith. This he found to be 25 per cent. Doubtless, this absorption would be chiefly exerted upon the longer undulations emitted by the sun, the aqueous vapour of our air, and not the air itself, being the main agent of absorption. Taking into account the whole terrestrial hemisphere turned towards the sun, the amouiit intercepted by the atmospheric en- velope is four-tenths of the entire radiation in the direction of the earth. Thus, were the atmosphere removed, the illuminated hemisphere of the earth would receive nearly twice the amount of heat from the sim that now reaches it. The total amount of solar heat received by the earth in a year, if distributed uniformly over the earth's surface, would be suflScient to liquefy a layer of ice 100 feet thick, and covering the whole earth.

Ejiowing thus the annual receipt of the earth, we can calculate the entire quantity of heat emitted by the sim in 21*

490 LEcTi'KE xm.

a year. Conceive a hollow sphere to smroTind the sun, its centre being tha sun'e cuntrc, and ite eurfoce at the dis- tance of the earth from the sun. The section of the earth cut by this surface, ie to the whole area of iLe hollow sphere, as 1 : 2,300,G », the quantity of solar

heat intercepted by lue eai,. only TaSii'iieSir of ^6

total radiation.

The beat emitted b^ he i f used to melt a stratum of ice applied to tli face, would liquefy the

ice at the rale of 2,4 i our. It would boil, per

hour, 700,000 millioua oiiles of ice-cold water.

Expref^sed iu another form, ttie ueat jjiven out by the sun, per hour, is equal to tliat which would be generated by the combustion of a layer of solid coal, 10 feet thick, entirely Burroimding the sun ; hence, the heat emitted in a year is equal to that which would be produced by the combustion of a layer of coal 1 7 miles in thickness.

These are the results of direct measurement ; .ind should greater accuracy be conferred on them by future determinations, it will not dcpri\e them of their astound' ing character. And this expenditure has been going on for ages, without our being able, in historic times, to de- tect the loss. Wlien the tolling of a bell is heard at a dis- tance, the sound of each stroke soon sinks, the sonorous vibrations are quickly wasted, and renewed strokes are necessary to maintain the sound. Like the bell. Die Sonne tiiol nacb alter Weise.

But how is its tone sustained ? How is the perennial loss of the sun made good ? We

are apt to overlook the wonderful in the common. Possibly to many of us — and even to some of the most enlightened among us — the sun' appears as a fire, differuig from our terrestrial fires only in the magnitude and intensity of its combustion. But what is the burning matter which can thus maintain itself? All

HADITENANCB OF 80LAB POWEB. 491

that we know of cosmical phenomena declares our brother^ hood with the sun,— affinns that the same constituents enter into the composition of his mass as those already known to chemistry. But no earthly substance with which we are acquainted — ^no substance which the fall of meteors has landed on the earth — would be at all competent to maintain the sun's combustion. The chemical energy of such substances would be too weak, and their dissipation would be too speedy. Were the sun a solid block of coal, and were it allowed a sufficient supply of oyygen, to enable it to bum at the rate necessary to produce the obserred emisucm, it would be utterly consumed in 5,000 years. On the other hand, to imagine it a body originally en- dowed with a store of heat — a hot globe now cooling — necessitates the ascription to it of qualities, wholly differ- ent from those possessed by terrestrid matter. If we knew the specific heat of the sun, we could calculate its rate of cooling. Assuming this to be the same as that of water — the terrestrial substance which possesses the highest spe- cific heat — at its present rate of emission, the entire mass of the sun would cool down 15,000° Fabt. in 5,000 years. In short, if the sxm be formed of matter like our own, some means must exist of restoring to him his wasted power.

The facts are so extraordinary, that the soberest hy- pothesis regarding them must appear wild. The sun we know rotates upon his axis ; he turns like a wheel once in about 25 days: can it be the friction of the periphery of this wheel against something in surrounding space which produces the light and heat ? Such a notion has been

entertained. But what forms the brake, and by what agency is it held, while it rubs against the sun ? The ac- tion is inconceivable ; but, granting the existence of the brake, we can calculate the total amount of heat which the sun could generate by such friction. We know his mass,

LECrCEF. xm.

we know his time of rotation ; wo know the mechanical equivalent of heat ; aud from these data we dcdiio«, with certainty, that the entire force of rotation, if converte"! into heat, would cover more than one, but less than two cen- turies of enuaaioa." D hypotheaa inyolved in this calculation.

There is another tl i. however bold it may, at

first eight, appear, deai; earnest attention. I havo

already referred to i* "" eorio Theory of the sun's

heat. Solar space ' vith ponderable objecta:

Kepler's celebrated et lat ' there are more cometa

in the heavms thnn tish in the occnn,' refers to the fact that a small portion only of the total number of comets be- longing to our Byetcm, arc seen from tho earth. But besides comets, and planets, and moons, a numerous class of bodies belong to our system, — asteroids, which, from their smallness, might be regarded as cosmical atoms. Like the planets and the comets these smaller bodies obey the law of gravity, and rei'olve on elliptic orbits round the sun ; and it is they, when they come within tho earth's atmo- sphere, that, fired by friction, appear to us as meteors and falling stars.

On a bright night, 20 mbutes rarely pass at any part of the earth's surface without the appearance of at least one meteor. At certain times (the 12th of August and the 14th of November) they appear in enormous numbers. During nine hours of observation in Boston, when they were described as falling as thick as anowflakes, 240,000

meteors were calculated to have been obseiTed. The number fall- ing in a year might, perhaps, be estimated at himdreds or ousands of millions, and even these would constitute but small portion of the total crowd of asteroids that circu- late round the sun. From the phenomena of light and

• Mcjcr Djiiuinlk dcs HimmeU, p. 10.

THB ZODIACAL LIGHT. 493

heaty and by the direct observations of Encke on bis comet, we learn that the universe is filled by a resisting medium, through the friction of which all the masses of our system are drawn gradually towards the sun. And though the larger planet^ show, in historic times, no diminution of their periods of revolution, this may not hold good for the smaller bodies. In the time required for the mean distance of the earth from the sun to alter a single yard, a small asteroid may have approached thousands of miles nearer to oar oentral luminary.

Following up these reflections we should infer, that wbUe this immeasurable stream of ponderable matter rolls unceasingly towards the sun, it must augment in density as it approaches its centre of convergence. And here the conjecture naturally rises, that that weak nebulous light, of vast dimensions, v^ch embraces the sun — ^the Zodiacal lightr— may owe its existence to these crowded meteoric masses. However this may be, it is at least proved that this luminous phenomenon arises from matter which cir- culates in obedience to planetary laws ; the entire mass constituting the zodiacal light must be constantly ap- proaching, and incessantly raining its substance down upon the sun.

We observe the fall of an apple and investigate the law which rules its motion. In the place of the earth we set the sun, and in the place of the apple we set the earth, and thus possess ourselves of the key to the mechanics of the heavens. We now know the connection between height of fall, velocity, and heat of the surface of the earth. In

the place of the earth let us set the sun, with 300,000 times the earth's mass, and, instead of a fall of a few feet, let us take cosmical elevations ; we thus obtain a means of gen- erating heat which transcends all terrestrial power.

It is easy to calculate both the maximum and the mini- mum velocity, impajrted by the sun's attraction to an as-

41 tECTUKB Xni.

teroia circiilatmg round him ; the maiimum is generated when the body approaches the snn from an infinite dis-. taoce ; the entire puU of the sun being then expccded npon it ; tlio minimum is that velocity which would barely en- able the body to revi " ' " e sun close to his Borfacc. The final velocity oi c just before striking the Bun, would be 300 i d, that of the latter 276 miles a second. Tht siriking the sun with the former velocity, WO nore than 9,000 times the heat generated by tu n of an equal asteroid of solid coal ; whtlu the e le latter case, would gen- cr:ite heat c<jual to that oi mc combustion of upwards of 4,000 such asteroids. It matters not, therefore, whether the substances falling into the sun be combustible or not ; their being combustible would not add sensibly to the tre- mendous heat produced by their mechanical collision.

Hero then we have an agency competent to restore his lost energy to the sun, and to maintain a temperature at his surface which transcends all terrestrial combustion. The very quality of the Bolar rays — their incomparable penetrative power — eiiiililcs ua to infer that the tempera- ture of their origin must be enormous ; but in the fall of asteroids we find the means of producing such a tempera- ture. It may be contended that this showering down of matter must be accompanied by the growth of the eun in size ; it is bo ; but the quantity necessary to produce the observed calorific emission, even if accumulated for 4,000 years, would defeat the Bcrutmy of our best instruments. If tlie earth stnick the sun it would utterly vanish from perception, but the heat developed by its shock would cover the expenditure of the

sun for a century.

To the earth itself apply considerations similar to those which we have applied to the sun. Newton's theory of gravitation, which enables us, from the present form of the earth, to deduce its original state of aggregation, re-

THE TIDES AND THE EABTh's BOTATION. 4:95

lis to US, at the same time, a source of heat powerful 3Ugh to bring about the fluid state — powerful enough to le even worlds. It teaches us to regard the molten con-ion of a planet as resulting from the mechanical union

oosmical masses, and thus reduces to the same homo- neous process, the heat stored up in the body of the rth, and the heat emitted by the sim.

Without doubt the whole surface of the sun displays an broken ocean of fiery fluid matter. On this ocean rests

atmosphere of glowing gas — a flame atmosphere, or otosphere. But gaseous substances, when compared with lid ones, emit, even when their temperature is very high, ly a feeble and transparent light. Hence it is probable at the dazzling white light of the sun comes through the nosphere, from the more solid portions of the surface.*

There is one other consideration connected with the rmanence of our present terrestrial conditions, which is all worthy of our attention. Standing upon one of the mdon bridges, we observe the current of the Thames re- rsed, and the water poured upwards twice a-day. The Iter thus moved rubs against the river's bed and sides, id heat is the consequence of this friction. The heat thus snerated is, in part, radiated into space, and there lost, as r as the earth is concerned. What is it that supplies is incessant loss ? The earth's rotation. Let us look a ;tle more closely at this matter. Imagine the moon fixed, id the earth turning like a wheel from west to east in its umal rotation. A mountain on the earth's surface, on >proaching the moon's meridian, is, as it were, laid hold r by the moon ; forms a kind of handle by which

the oih is pulled more quickly round. But when the meridian passed the pull of the moon on the mountain would be

* I am quoting here from Mayer, but this is the exact Tiew now cnter- ined by Kirchhof. We see the solid or liquid mass of the sun through B photosphere.

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in the oppoE^ite direction ; it now tj?nds to f)imiriiali thi 1 veloaty of rotation ns much as it previously .iiigmGnted it ; I and UioB the action of all fixed bodies on tlie earth's face is neutralised.

But suppose the mountjiin H) lie always to the east of the moon's meridian, the p en would be alwajv exert-

ed i^;unat the earth's rotalir e velocity of which would be diminiBhed in a degree f louding to the Gtrengtli of the pull. The tidal teave c* this position — it lies al- i

ways to the east of the mc eridian; the waters of the J

ocean are, in part, draggo- irake along the sarfara of I

the earth, and as a br^f nost diminbh the veloci^ J

of the earth's rotation, ' inntion, thongh ioevitaUu

is, however, too small to m:.„_ self felt within the period^ over wliicli observations on the subject extend. Stippos- inir, tlien, tli.it wo turn a mill by the action of the tide, and produce heat by the friction of tlie niillslones ; that heat has an origin totally different from the lieiit produced by another pair of millstones which arc turned by a mountain stream. The former is produced at the e.vpense of tlie earth's rotation ; the latter at the expense of the sun's ra- diiition, which lifted the miilstrcam to its source*

Such is an outline of the Muteoric Theory of the sun's heat, as cxiracled frmn Mayer's Kssay on Celestial Diiiam- ics. I have licM closely to his statements, and in mo4 enses simply transhtcd his words. But the sketch conveys no .idccpiatc idea of

the firmness and consistency with which he ha.'* applied his princiiiles. Ho deals with truo causes ; and the only question that can jiffect his theory ro fcrs to thcquautity of .iction wliich he has .ascribed tothcw' causes. I do not pledge myself to this theory, nor do 1.1*1; you to .accept it as demon str.ated ; still it would be a great mistake to regard it as chimerical. It is a noble specula-

• Djiiiimik des llimmda p. 3S, tc.

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tion ; and depend upon it, the true theory, if this, or some form of it, be not the true one, will not appear less wild or leas astounding.*

Mayer published his Essay in 1848; five years after- wards Mr. Waterston sketched, independently, a similar theory, at the Hull Meeting of the British Association. The Transactions of the Royal Society of Edinburgh for 1854 contain an extremely beautiful memoir, by Professor William Thomson, in which Mr. Waterston's sketch is de- veloped. He considers that the meteors which are to fur- nish stores of energy for our future sunlight, lie principally within the earth's orbit, and that we see them there, as the Zodiacal Light, ^ an illuminated shower, or rather tornado, of stones ' (Herschel, § 897). Thus he points to the precise source of power previously indicated by Mayer. ' In con- clusion, then,' writes Professor Thomson, ' the source of energy from which solar heat is derived is undoubtedly meteoric . . • The principal source — ^perhaps the sole ap- preciable efficient source — \a in bodies circulating round the

* While preparing these sheets finally for press, I had occasion to look once more into the writings of Mayer, and the effect was a revival of the interesi with which I first read them. Dr. Mayer was a working physician in the little German towirof Heilbronn, who, in 1840, made the observation that the Tenons blood of a feverish patient in the tropics was redder than in more northern latitudes. Starting from this

fact, while engaged in the duUes of a laborious profession, and apparently without a single kindred spirit to support and animate him, Mayer raised his mind to the level indicated by the references made to his works, throughout this book. In 1842 he published his first memoir * On the Forces of Inorganic Nature ; * in 1846, his * Organic Motion' was published ; and in 1848, his * Celestial Dynamics ' appeared. After this, his overtasked brain gave way, and a cloud settled on the intellect which had accomplished so much. The shade however, was but temporary, and Dr. Mayer is now restored. I have never seen him, nor has a line of correspondence ever passed between us. Modestly and noiselessly he has done his work ; and having spoken of his merits, as accident made it my duty to speak, I confidently leave to history the care of his fame.

BUI nt inside the earth's orbit, and probably seen

in ttie smuignl by ua called " Zodiacal Light." The store of energy for future siialight la at present partly dynamical —that of the motions of these bodies round the bud ; and

partly poteatial — ths' " This latter is gradn, ing medium, and ha the former. Each mi faster, and getting ue>u lime, very suddenly, atmosphere as to be more it h at rest on i„>, ^

~ .vitation towards the sun. It, half against the resist- a coDtinnons increase of < oes on moving faster and rcr the centre, until some I ich entangled in the solar locity. In a few seconds Buriace, and the energy given

up is vibrated across the district where it was gathered during so many ages, ultimately to penetrate, as light, the remotest regions of space.'

From the tables published by Prof. Thomson I extract the following interesting data; firstly, with reference to tlie amount of heat equivalent to the rotation of the sun and planets round their axes ; the amount, that is, which would be generated, supj>osing a brake applied at the sur- faces of the 8UQ and planets, until tlie motion of rotation

was cntiiely stopped : secondly, with reference to the amount of heat due to the sun's gpavitalion — the heat, that ia, which would be developed by each of the planets in falling into the sun. The quantity of heat is expressed in terms of the time during which it would cover the solar

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ENERGIES OF THE 80LAB SYSTEM. 499

Thos, if the planet Mercury were to strike the sun, the quantity of heat generated would cover the sokr emission for nearly seven years ; while the shock of Jupiter would cover the loss of 32,240 years. Our earth, would furnish a supply for 95 years. The heat of rotation of tlie sun and planets, taken together, would cover the solar emis- sion for 134 years; while the total heat of gravitation (that produced hy the planets falling into the sun) would cover the emission for 45,589 years.

Whatever be the ultimate fate of the theory hero sketched, it is a great thing to be able to state the condi- tions which certainly would produce a sun, — to be able to \ discern in the force of gravity, acting upon dark matter, the source from which the starry heavens may have been derived. For, whether the sun be produced and iiis emis- sion maintained by the collision of cosmical masses, — whether the internal heat of the earth be the residue of that developed by the impact of cold dark asteroids, or not, there cannot be a doubt as to the competence of the cause assigned to produce the effects ascribed to it. Solar light and solar heat lie latent in the force which pulls an I apple to the ground. * Created simply as a difference of position of attracting masses, the potential energy of grav- itation was the original form of all the energy in the uni- verse. As surely as the weights of a clock run down to their lowest position, from which they can never rise again unless fresh energy is communicated to them from some source not yet exhausted, so surely must planet

afler planet creep in, age by age, towards the sun. When each comes within a few hundred thousand miles of his surface, if he is still incandescent, it must be melted and driven into vapour by radiant heat. Nor, if he be crusted over and become dark and cool externally, can the doomed planet escape its fiery end. If it does not become incan- descent, like a shooting star, by friction in its passage

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thi 13 atmosphere, hi! first graze on his Burfacc niiBt I

prouuuu a stiipcDdous flash of light and heat. It mnj be] lit onco, or it may be after two or thice bouods like a can- noTi-shot ricochctting on a surface of earth or water, tbo wbolo maes must ^^ " " Itcd, and evaporated by a crash, generating in ime thonsanda of timcB as

much heat as a co: e ate would produce by

Helmholtz, an e in physiologist, physicist,

and mathematicia what dtfiorcnt view of the

origin and maintou. igbt and heat. He starts

from the nebnlar byj.„v...„ laplace, and ossmniug the

nebulous matter, in the first instance, to have been of ex- treme tenuity, he determines the amount of heat gener- ated by its condensation to the present sol.ir system. Sup- posing tbo specific beat of tlie condensing mass to be the same as that of water, then the beat of condensation would be Biifticient to raise their temperature 28,000,000° Centigrade. By far the greater part of this heat was wasted, ages ago, in space. The most intense terrestrial combustion that we can command is that of o."cygen and hydrogen, and the temperature oi' the pure o\ybydrogen flame is 8,061° C. The temperature of a hydrogeu flame, burning in air, is 3,250° C. ; while that of the lime liglit, which shines with such sunlike brilliancy, is estimated at 2,000° C. What conception, then, can wc form of a tem- perature more than thii-tecn

thousand times that of the Drummond light ? If our system were composed of pure coal, and burnt up, the heat produced by ila combustion would only amount to Tj^ajth of that generated by the condensation of the nebulous matter, to form our solar system. Helmholtz supposes this condensation to con- tume ; that a virtual falling down of the superficial portions

• Tliomson und Tail in 'Good Wonis,' Oct. 1802. p. fi06.

HELMHOLTZ'S THEOBY OF SOLAS HEAT. 501

of the sun towards the centre still takes place, a continual derelopment of heat being the result. However this may be, he shows by calculation that the shrinking of the sun's diameter by -^J-^p^^th of its present length, would generate an amount of heat competent to cover the solar emission for 2,000 years ; while the shrinking of the sun from its present mean density to that of the earth, would have its eqniyalent in an amount of heat competent to cover the present solar emission for 17,000,000 of years.

* But,* continues Helmholtz, * though the store of our planetary system is so immense that it has not been sensi- bly diminished by the incessant emission which has gone on daring the period of man's history, and though the time which must elapse before a sensible change in the condition of our planetary system can occur, is totally be- yond our comprehension, the inexorable laws of mechan- ics show that this store, which can only suffer loss, and not gain, must finally be exhausted. Shall we terrify our- selves by this thought ? We are in the habit of measur- bg the greatness of the universe, and the wisdom dis- played in it, by the duration and the profit which it prom- ises to our own race ; but the past history of the earth shows the insignificance of the interval during which man has had his dwelling here. What the museums of Europe show us of the remains of Egypt and Assyria we gaze upon with silent wonder, in despair of being able to carry back our thoughts to a period so

remote. Still, the human race must have existed and multiplied for ages before the Pyramids could have been erected. We estimate the du- ration of human history at 6,000 years ; but, vast as this time may appear to us, what is it in comparison with the period during which the earth bore successive series of rank plants and mighty animals, but no men ? * Periods

• The absence of men may be doubted. See Lubbock's article on the ♦Antiquity of Man,' in the * Natural History Reriew,' July, 1862, p. 267.

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Sa y 'h, in our own neighliourliood (Kunigabci^, the amber-tree liloomed, and dropped its costly gum on the earth and in the sea; when in Europe and Norlh America groves of tropical palms fionrishcd, in which gi- gantic lizards, and, elephants, whose mighty rcmainB are still I e eactli, found a home. Ciflercnt geologis from different premises, have songht to esti.. gth of the above period, and they set it iov o nine millions of years. The tijne during 1 th has generated organic beings is again sm d with tho ages during which the world was a mass of molten rocks. The ex- periments of Bischof upon basalt show that our globe would require 350 millions of years to cool down from 2,000° to 200° Centigrade. And with regard to the period during which the first nebulous masses condensed, to form our planetary system, conjecture must entirely cease. The history of man, therefore, is but a minute ripple in the infinite ocean of time. For a much longer period than that during which he has already occupied this world, the existence of a state of inorganic nature, favourable to man's continuance here, seems to bo secured, so that for ourselves, and for long generations alter us, we have noth- ing to fear. But the same forcea of air .ind water, and of the volciinic interior, which produced former geologic rev- olutions, burying one series of living forms after another, Still .let upon the earth's crust. They, rather than those distant cosmical changes of which we have spoken, will put an end to the human race; and, perhaps, compel us to make

way for now and more complete forms of life, as the lizard and the mammoth have given way to us and our contemporaries,*

Witli reference to the operations of the sun upon the

" Wcibidnirkung tier Xutiirkrallc. Pliil. Mag., Scr. IV. vol. ii. p. 616.

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earth, its ocean and its atmosphere, the following i^mark- able passage was written by Sir John Herschel thirty-two years ago.* * The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By its heat are produced all winds, and those disturbances in the electric equilibrium of the atmosphere which give rise to the phenomena of lightning, and prob- ably also to terrestrial magnetism and the Aurora. By their vivifying action vegetables are enabled to draw sup- port from inorganic matter, and become in their turn the snpport of animals and man, and the source of those great deposits of dynamical efficiency which are laid up for hu- man use in our coal strata. By them the waters of the sea are made to circulate in vapour through the air, and iri-i- gate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which by a series of compositions and decompositions give rise to new products and originate a transfer of materials. Even the slow degradation of the solid constituents of the surface, in which its chief geo- logical change consists, is almost entirely due, on the one band, to the abrasion of wind or rain and the alternation of heat and frost ; on the other, to the continual beating of sea waves agitated by winds, the results of solar radia- tion. Tidal action (itself partly due to the sun's agency) exercises here a comparatively slight influence. The effect of oceanic currents (mainly originating in that influence), though slight in abrasion, is powerful in diffusing and transporting the matter abraded ; and when we consider the immense transfer of matter so produced, the increase of pressure over

large spaces in the bed of the ocean, and diminution over corresponding portions of the land, we are not at a loss to perceive how the clastic force of sub-

* Outlines of Astronomy, 1883.

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terranean fires, thus repressed on the one band and released on the other, may Lroak forth in points where the resist- ance is barely adequate to their retention, and thus bring the phenomena of even volcanic activity under the geiieril law of solar infliien<

This fine pass t the breath of recent in-

vestigation to cou espo^tion of the law of

the conservation ot iplied to both the organic

and inorganic wor icoveriea have tangbt ob

that winds and rivei r definite thermal values,

and that, in order to ; ^neir motion, an equivalent

amount of eolar heat nas been consnmed. '\Vhile they exist as winds and rivers, the heat expended in producing fhetn has ceased to exist as heat, being converted into mechanical motion ; but when that motion is arrested, the heat which produced it is restored, A river, in descending from an elevation of 7,720 feet, generates an amount of heat competent to augment its own temperature 10° Fahr., and this amount of heat was abstracted from the sun, in order to lift the matter of the river to the elevation from which it falls. As long as the river continues on the heights, whether in the solid form as a glacier, or in the liquid form as a take, the heat expended by the sun in lift- ing it has disappeared from the universe. It has been consumed in the act of lifting. But at the moment that the river starts upon its downward course, and encounters the resistance of its bed, the heat expended in its eleva- tion begins to be restored. The mental eye, indeed, can follow the omission from its source, through

the other as vibratory motion, to the ocean, where it ceases to be vi- bi-ation, and takes the potential fonn among the molecules of aqueous vapour ; to the motmtain-top, where the heat absorbed in vaporization is given out in condensation, wliilc that expended by the sun in lifting the water to ita present elevation is still uiirestorod. This W5 find paid

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back to the last nnit by the friction along the river's bed; at the bottom of the caacadca where the plniige of the torrent is Bndi3en]y arrested ; in the wannth of the ni»- chioery tnrned by the river; in the spark from the mill- Stone ; beneath the crusher of the miner ; in the Alpine «av-mill ; in the milk-chnm of the ch&let ; in the supports of the cradle in which the mountaineer, by water power, rocks his baby to sleep. All the forms of mechanical mo- tion here indicated are simply the parcelling out of an amonnt of calorific motion derived originally from the son ; and at each point at which the mechanical motion is destroyed, or diminished, it is the san's heat which is restored.

We have thus far dealt with the sensible motions and energies which the son produces and confers ; but there are other motions and other energies, whose relations are not BO obrioua. Trees and vegetables grow upon the earth, and when hnmcd they give rise to heat, from which immense quantities of mechanical energy are derived. What is the sonrce of.this energy? Sir John Herschel answered this question in a general way; while Dr. Mayer and Professor Helmholtz fixed its exact relation to the more general question of conservation. Let me try to pat th^ answers into plain words. Yon see this iron rust, prodaced by the falling together of the atoms of iron and oxygen; but though you cannot soo this transparent car- bonic acid gas, it is formed by the union of carbon and oxygen. These atoms thus united resemble a weight rest- ing on the earth ; their mntnal attraction is satisfied. But as I

can wind up the weight, and prepare It for another &11, even so these atoms can be wound up, separated from each other, and thns enabled to repeat the process of combination.

Id the building of plants, carbonic acid is the material from which the carbon of the plant is derived, while water 22

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is the aubslanco irotn which it obtains iu hydrogen. The solar beam winds up the weight; it is the agent which BGT»s the atoms, setting the oxygen free, aod allowing the carbon and the hr-" *" aggregate in woody fibre.

If the sun's rays uuon a urfaco of sand, the sand

is heated, and fujaiij i; es ya.y as mnch heat »» it re- ccivcB; but let the saiu fall upon a forest; then

the quantity of heat giv is lesB than that received,

for a portion of the su ' invested in the building

of the trees. We havE oen how heat is consumed

in forcing asiinder the sluius oi bodies; and how it reap- pears, when tlie attraction of the eeparated atoms comes again into plaj-.* The precise considerations which we then applied to heat, wo have now to apply to light, for it is at the expense of the solar light that the chemical do- composition takes place. Without the sun, the reduction of the carbonic acid and water cannot be effected ; and, in this act, an amount of solar energy is consumed, exactly equivalent to the molecular work done.

Combustion is the reversal of this process of reduction, and all the energy invested in a plant reappears as heat, when the plant is burned. I ignite this bit of cotton, it bursts into flame ; the oxygen again unites with its cai^ bon, and an amount of heat is given out, equal to that origin.illy sacrificed by the sun to form the bit of cotton- So also .is rcg.trds the 'deposits of dynamical efficiency' bid np in our coal strata ;

they arc simply the sun's rays in a potential form. We dig from our pits, annually, eighty-four millions of tons of coal, the mechanical equiv- alent of which is of almost fabulous vastness. The com- bustion of a single pound of coal in one minute is equal to the work of three hundred horses for the same time. It would require one hundred and eight millions of horses.

BELATION OF THE SUN TO ANIMAL LIFE. 507

working day and night with unimpaired strength for a year, to perform an amount of work equivalent to the en- ergy which the sun of the Carboniferous epoch invested in one year's produce of our coalpits.

The farther we pursue this subject, the more its inter- est and its wonder grow upon us. I have shown you how a sun may be produced by the mere exercise of gravita- ting force ; that by the collision of cold dark planetary masses the light and heat of our central orb, and also of the fixed stars, may be obtained. But here we find the physical powers, derived or derivable from the action of gravity upon dead matter, introducing themselves at the very root of the question of vitality. We find in solar light and heat the very mainspring of vegetable life.

Nor can we halt at the vegetable world, for it, me diately or inmiediatcly, is the source of all animal life. Some animals feed directly on plants, others feed upon their herbivorous fellow-creatures ; but all in the long run derive life and energy from the vegetable world ; all, there- fore, as Helmholtz has remarked, may trace their lineage to the sun. In the animal body the carbon and hydrogen of the vegetable^ are again brought into contact with the oxygen from which they had been divorced, and which is now supplied by the lungs. Reunion takes place, and ani- mal heat is the result. Save as regards intensity, there is no difference between the combustion that thus goes on within us, and that of an ordinary fire. The products of combustion are in both cases the same, namely, carbonic acid and water. Looking

then at the physics of the ques- tion, we see that the formation of a vegetable is a process of winding up, while the formation of an animal is a pro- cess of running down. This is the rhythm of Natui-e as applied to animal and vegetable life.

But is there nothing in the human body to liberate it from that chain of necessity which the law of conservation

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coils around ioorganic nature? Look at two raon npon a monntain side, i*-ith c(|iial health and physical strenslh; the one will sink and fail, while the Other, with determined energy, scales the anmmit. Has not TOlition, in this case a creative power? Physic " jonsidercd, the law that nilea the operations of a ste igiae rules the operations

of the climber. For everj i raised by the former, an

equivalent quantity of the Itsappears ; and for every

step the climber ascends, lonnt of heat, equivalent

jointly to his own weight the height to which it is

raised, is lost to his bo le strong will can draw

largely upon the physici fy furnished by the food;

but it can create nothing. ftuiotion of the will is to I

appl;/ and direct, not to create,

I have juKt said, that as a climber ascends a niountAiii, lieat (Hsa|i[)canj from his body ; the same statement applies to animals pertiirming work. It would appear to follow from this, that the body ought to grow colder, it) tlie act of climbing or of working, whereas universal experience proves it to grow warmer. The solution of this seeming contradiction is found in the fact, that when the muscles arc exerted, augmented respiration and increased cliemieal action set in. The bellows which urge oxygen into the lire within arc more briskly blown, and thus, though heat actually

disappears as we climb, the loss is more than cov- ered by the Increased activity of the chemical processes.

Heat is developed in a mnscle when it contracts, as was proved by 50I, Beequerel and Breschet, by means of a modification of our thermo-electric pile. 51M. Billroth and Fiek have found that in the case of persons who die from tetanns, the temperature of the muscles is sometiaics nearly eleven tlegi-ecs Fahrenheit in esccss of the normal temperature. 51, Hclmhollz has found that the muscles of dead frogs in contracting produce lieat ; and an ex- tremely important result as regards the influence of con-

BELATION OF THE BUN TO ANIMAL LIFE. 509

traction has been obtained by Professor Lndwig of Vienna and his papils. Arterial blood, yon know, is charged with oxygen : when this blood passes through a mnsclc in an ordinary ancontracted state, it is changed into venoas blood, which still retains about 1^ per cent, of oxygen* But if the arterial blood pass through a cojitracted muscle, it is almost wholly deprived of its oxygen, the quantity remaining amounting, in some cases, to only 1^ per cent. As a result of the augmented combustion within the mus- cles when in a state of activity, we have an increased amount of carbonic acid expired from the lungs. Dr. Ed- ward Smith has shown that the quantity of this gas ex- pired during periods of great exertion may be five times that expired in a state of repose.

Now when we augment the temperature of the body by labour, a portion only of the excess of heat generated is applied to the performance of the work. Suppose a certain amount of food to be oxidized, that is to say, burnt, in the body of a man in a state of repose, the quantity of heat produced in the process is exactly that which we should obtain from the direct combustion of the food in an ordinary fire. But suppose the oxidation of the food to take place while the man is performing work,

then the heat generated in the body falls short of that which could be obtained from direct combustion. An amount of heat is missing, equivalent to the work done. Supposing the work to consist in the development of heat by friction, then the amount of heat thus generated outside of the man's body would be exactly that which was wanting within the body, to make the heat there generated equal to that produced by direct combustion.

It is, of course, easy to determine the amount of heat consumed by a mountaineer, in lifting his own body to any elevation. When lightly clad, I weigh 10 stone, or 140 lbs. ; what is the amount of heat consumed, in my

5 LEOTUBB Xm.

case. fling from the sea-level to the top of Moiit

BlaiicV Tlie height of the raountiun is 15,774 feet; and for every pound of my body raised to a height of 772 feet, n quantity of heat ia conHumed. Hufficicnt to raise the tem- perature of a pound Fahr. Consequently, on climbing to a he or about 20^ times 772 feet, I consume an at sufficient to raise th« temperature of IK. r 20j° Fahr. If, on the other hand, I eoalif j the top of the mountaiD and pei-form a glissL ovel, the quantity of heat generated by the < le precisely equal to that consumed in the asceni. i Have had opcasinn more than once to direct your attention to the energy of molecular forces, and I would do so here once more. Measured by one's feelings, the amount of exertion necessary to reach the top of Mont Blanc is very great. Still, the cnei^y which performs this feat would be derived from the com- bustion of about two ounces of carbon. In the case of an excellent steam-engine, about one-tenth of the heat em- ployed is converted into work ; the remaining nino-tentha being wasted in the air, the condenser, &c. In the case of an active mountaineer, as much as one-fifth of the heat due to the oxidation of his food may be converted into work ; hence, as a working machine, the animal body is much more perfect than the steam-engine.

We see, however, that the engine and the animal do- rive, or may derive those powers from the selfsame source. We can work an engine by the direct combustion of the substances which we employ as food; and if our stomachs were so constituted as to digest coal, we should, as Ilelni- holta has remarked * bo able to derive our energy from this substance. The grand point pennauent tJironghout nil these considerations is, tJiat nothinff is crcateil. Wo

■ Phil. Mag. 1856, toI. ii. p. 610.

EFFECT OF THE SUN ON VITAL ACTIONS. 511

can mako no movement which is not accounted for by the contemporaneous extinction of some other movement. And how complicated soever the motions of animals may be, whatever may be the change which the molecules of our food undergo within our bodies, the whole energy of animal life consists in the falling of the atoms of carbon and hydrogen and nitrogen from the high level which they occupy in the food, to the low level which they oc- cupy when they quit the body. But what has enabled the carbon and the hydrogen to fall ? What first raised them to the level which rendered the fall possible ? We have already learned that it is the sun. It is at his cost that animal heat is produced, and animal motion accom- plished. Not only then is the sun chilled, that we may have our fires, but he is likewise chilled that we may have our powers of locomotion.

The subject is of such vast importance, and is so sure to tinge the whole future course of philosophic thought, that I will dwell upon it a little longer. I wiU endeavour, by reference to analogical processes, to give you a clearer idea of the part played by the sun in vital actions. We can raise water by mechanical action to a high level ; and that water, in descending by its own gravity, may be made to assume a variety of forms, and to perform various kinds of mechanical work. It may be made to fall in cas- cades, rise in fountains, twirl in the most complicated ed- dies,

or flow along a uniform bed. It may, moreover, be employed to turn wheels, wield hammers, grind com, or drive piles. Now there is no power created by the watei during its descent. All the energy which it exhibits is merely the parcelling out and distribution of the original energy which raised it up on high. Thus also as regards the complex motions of a clock or a watch ; they are en- tirely derived from the energy of the hand which winds it up. Thus also the singing of the little Swiss bird in

I LEOTDKR XIII. |

tLi lakionol Exhibition of 1862; the qmvering of its

artibciai organs, the vibratioua of the air which etrike the ear as melody, the flutter of its little wings, and all other motions of the pretty automaton, were simply derived from the force by '■■•■■ wound-np. It gives out

nothing that it hi.. 1. In tliis precise sense,

you will perceive, of man and animals, the

parcelling ont aii^i. of an energy originally

exerted by the su ;getable, aa we have re-

marked, the act ' r of winding-up, is per-

formed; and it if :ent, in the animal, of the

carbon, hydrogen, a , to the level from which

they started, that the powera of life appear.

But the question is not yet exhausted. The water which we used in our first illustration produces all the motion displayed in its descent, but theybr»iof the motion depends on the character of the machinery inteq)osed in the path of the water. And thus the primary action of the sun's rays is qualified by the atoms and molecules among which their power is distributed. Molecular forces determine the form which the solar energy will assume. In the one case this energy is so

conditioned by its atomic machinery as to result in the formation of a cah- b.tge ; in another case it is so conditioned as to result in the formation of an o.ik. So also aa regards the reunion of the carbon and the oxygen — the form of their reunion is determined by the molecular machinery through which the combining force acts. In one case the action may re- sult iu the formation of a man, while iu another it may result in tlic formation of a grasshopper.

The matter of our bodies is that of inorganic nature. There is no substance in the animal tissues which is not primarily derived from the rocks, the water, and the .air. Are tlic forces of organic matter, then, diflerent in kind from those of inorganic ? All the pliilosophy of the pros-

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ent day tends to negative the question ; and to show that it is the directing and compounding, in the inorganic world, of forces belonging equally to the inorganic, that consti- tutes the mystery and the miracle of vitality.

In discussing the material combinations which result in the formation of the body and the brain of man, it is impossible to avoid taking side glances at the phenomena of consciousness and thought. Science has asked daring questions, and will, no doubt, continue to ask such. Prob- lems will assuredly present themselves to men of a future age, which, if enunciated now, would appear to most people as the direct offspring of insanity. Still, though the progress and development of science may seem to be unlimited, there is a region apparently beyond her reach — a line, with which she does not even tend to osculate. Given the masses and distances of the planets, we can in- fer the perturbations consequent on their mutual attrac- tions. Given the nature of a disturbance in water, air, or ether, we can infer from the properties of the medium how its particles will be affected. In all this we deal with physical laws, and the mind runs along the line which connects the phenomena from beginning to end. But when we endeavour to pass, by a similar process, from the

region of physics to that of thought, we meet a problem to seize on which transcends any conceivable expansion of the powers we now possess. We may think over the subject again and again, but it eludes all intellectual pre- sentation. Thus, though the territory of science is wide, it has its limits, from which we look with vacant gaze into the region beyond. "We may fairly claim matter in all its forms, not only as it appears in external nature ; but even as it exists in the muscles, blood, and brain of man himself, it is ours to experiment and speculate upon. Rejecting the idea of a ' vital force,' let us reduce, if we

can, the physical phenomena of life to attractions and

5; LECTiiitE xm.

repulsioDB. But having thtis Gxhauatcd physics, and rencbed lis very rim, tiie real mystery yet looms beyond us. And tliiiB it will ever loom — ever beyond the boiirne of mail's intellect— ffivinff the Doeta of successive agea JQSt occasion to dcL,

Still, presented le mind, the discoverieB

and gene rails ationе icience constitute a poem

more suTilirae than has ever yet been addressed to the

imap;inatii>n. The natural philosopherof to-day may dwell amid conceptions whitih beggar those of Milton. So great and grand are they^lhat in the contemplation of them a certain force of character is requisite to preaer*-o lis from bcwildcrmcut. Look at the integrated energies of our world, — the stored power of our coal-fiolds; our winds and rivers; our fleets, armies, and guns. What are they? Thoy are all generated by a portion of the sun's energy, which does not amount to jjuTrnViniiiij ^^ *^*' whole. This is the entire frai;tion of the sun's foree intercepted by the earth, and we convert but a sm.ill fr.iction of this fraction into mechanical energy. Multiplying all our powers by millions of minions, we do not reach the sun's expenditure. And still, notwithstanding this enormous drain, in the lapse of human

history we are unable to detect a diminu- tion of his store. Measured by our largest terrestrial standards, such a reservoir of power is infinite ; but it is our privilege to rise above these standards, and to reganl the sun himself as a speek in infinite extension — a mere drop in the univcrs.al sea. We analyse the space in which lie is immersed, and which is tlie vehicle of his power. Wc pass to other systems and otlier suns, each pouring forth energy like our own, but still without infringement

CONCLUSION. 515

of the law, which reveals immatability in the midst of change, wliich recognizes incessant transference or conver- sion, bat neither final gain nor loss. This law generalises the aphorism of Solomon, that there is nothing new under the sun, by teaching us to detect everywhere, under its infinite variety of appearances the same primeval force. To Nature nothing can be added ; from Nature nothing can be taken away ; the sum of her energies is constant, and the utmost man can do in the pursuit of physical truth, or in the applications of physical knowledge, is to shift the constituents of the never-varying totaL The law of conservation rigidly excludes both creation and annihi- lation. Waves may change to ripples, and ripples to waves — ^magnitude may be substituted for number, and number for magnitude — ^asteroids may aggregate to suns, suns may resolve themselves into *florsB and faunas, and florsB and faunsQ melt in air — the flux of power is eternally the same — it rolls in music through the ages, and all ter- restrial energy — ^the manifestations of life as well as the display of phenomena — are but the modulations of its rhythm.

EXTRACT FROU A. : QE FHTSIGAL BASIS OF

Wk have now some hard work before ns; hitherto we hare been delighted bj objects which addressed thcrnselvea rather to onr (esthetic taste tlian to our scientific

faculty. We have ridden pleosantlj' to the base of the final cone of Etna, and must now dis- mount and march wearily throngh ashes and lava, if wo would enjoy tho prospect from the summit. Our problem is to connect the dart lines of Fraunhofer with t!ie briglit ones of the metals. The white beam of tlie lamp is refracted in passing through oar two prisms, but its different components are refracted in different degrees, and thus its colours arc drawn apart. Now tho colour depends solely npon the rale of oscillation of the particles of the luminous body; red light being produced by ono rate, blue light by a much qnicter rate, and tho coloiu's between red and blue by the intermediate rates. Tho solid incandescent coal-points give ns a continuooa spectrum ; or, in other words, tJiey emit rays of all possible periods between tho two ostremes of the spectrum. They hare particles oscillating so as to produce red ; others, to produce orange; others, to produce yellow, green, blue, indigo, and violet respectively. Colour, as many of you know, is to light what pilch is to sound, Wlien a yiolin-playcr presses his finger on 0 stiing ho mnlces it shorter and tighter, and thus, causing it to vibrate more speedily, augments tlio pil«h. Imagine such a player to move his finger slowly along the string, shortentng it gradually as he draws his bow, tho note would rise in pitch by a regular

• Given at the Royal Institution on Friday evening, June 7, 1861.

g-fadati^n ; there \V(.)uM be no ^;i]) iiitervL-iiiii^i: lK.l\veeii nolo ;iinl note. Hero we have the analogue to tlio continuous spectrum, whose colonrs insensibly blend together withoat gap or interrup- tioD, from the red of the lowest pitch to the violet of the highest. Bat suppose the player, instead of gradually shortening his string, to press his finger on a certain point, and to sound the correspond- ing note ; then to pass on to another point more or less distant, and sound its note ; then to another, and so on, thus sounding par- ticular notes separated from each other by gaps which correspond to the intervals of the string passed over ; we should then have the exact

andogue of a spectrum composed of separate bright bands with intervals of darkness between them. But this, though a perfectly true and intelligible analogy, is not sufficient for our purpose; we nAist look with the mind^s eye at the very oscillatang atoms of the volatilised metaL Figure these atoms connected by springs of a certdn tension, which, when the atoms are squeezed together, push them asunder, and when the atoms are drawn apart, pull tbem together, causing them, before coming to rest, to quiver at a certain definite rate determined by the strength of the spring. Now the volatilised metal which gives us one bright band is to be figured as having its atoms united by springs all of the same ten- eion, its vibrations are all of one kind. The metal which gives us two bands may be figured as having some of its atoms united by springs of one tension, and others by a second series of springs of a different tension. Its vibrations are of two distinct kinds ; so also when we have three or more bands, we are to figure as many distinct sets of springs, each set capable of vibrating in its own particular time and at a different rate from the others. If we seize this idea definitely, we shall have no difficulty in dropping the metaphor of springs, and substituting for it mentally the forces by which the atoms act upon each other. Having thus far cleared our way, let us make another effort to advance.

Here is a pendulum — a heavy ivory ball suspended from a string. I blow against this ball ; a single puff of my breath moves it a little way from its position of rest; it swings back towards me, and when it reaches the limit of its swing I puff again. It now swings farther ; and thus by timing my yuSs I can so accumu- late their action as to produce oscillations of large amplitude. The ivory ball here has absorbed the motion wldch my breath commu-

518 APPENDIX TO LECTDEE XHL

Dioatod to tbo air. I now bring the boll to rest Sap[>osa, iusteud of taj breatli, a wave of air strike ogaiDEt i^ anil tbat this nare is followed by a serica of others

which soocced each other in the same interrtils as 1117 pnffi; it \» perfectly' manifetst that theie waves wodIJ commoiiicate their motjon to the ball and coose it to Bwing as tlio i<afli did. And it ^ 1II7 mamfest that this noald

uot b« the eaao if tbo impuls le waves were not propcrl;

timed; for tbon the motiou imi o the penduloin hy one wave

would be ncotrolized by onotl tbero could not bo that accD-

molntioD of ctFoct wliicb vre en the periods of the waves

oorreepond with the periods lendnlam. So much for the

kind of impnlses absorbed b' adalum. But soch a penda-

Inm Bet oadllating in air pr aves in the lur ; and we eee

that tiie wavea which it pro isl be of the 'tame period is

those whoee motions it wonk t or absorb moat copionslf if

they strnck nfminiit it. Jnst lu ,n^i.np I niny remark, thai if (lid poi'iods of tlio naves bo double, treble, quadruple, &c., tbo periods of llic penduloin, the sliocks imparted to the latter would also bo so tlmc'd as to produce nn accumulation of motion.

'I'erhup:! tbo most curious effect of those timed impulses evor discribeil, was (loit observed by a wotebmaker, named Ellicott, iu the year 1741. lie set two clocks Icanbg agabst Iho same rail: one of them, which wo may call A, was set goiug; tho olhcr, B, not. Some time afterwards bo foittid, to his surprise, that B nai ticking also. Tho pcnduluuLs being of the sarao leugth, the shocks imparted by the ticking of A to the rail against which both clocks rested, were propagated to B, and were so timed as to set li goinc. Oilier ctirioHS cUccts woi'o at tho same time observed. When ILo pendohims differed from cacli other a certain amount, A set B goiug. But tbo rcaclion of B stopped A. Tlicn B sot A going, and tlie rcaclion of A stopped B. If the periods of oscillatiou were closo to each otlicr, but still uot quite alike, the clocks con- trolled each otlicr, and by a kind of mutual compi-omise they ticked in perfect

unison.

But wlint has all tliis to do with our present subject? Tlio questions arc mcclianicolly identical, the varied actions of the uni- veific are all modes of motion ; and the vibration of a ray clainis strict brotlierliood with the vibrations of our peoduluui. Suppose etheroa! waves slrikirijr upon ntoms wliicli oscillate in periods tlie

PHTBICAL BASIS OF BOLAB CHEHIBTBT. 519

■ome OS those id wliich the waves socceed each other, the motion of the waves will be abiorbed hj the atoms ; Buppom we send oar beam of wbita light through a aodinm flame, the particles of that flame will be chiofij affected by those nndolations which are eya- chronoas with their own periods of yibratiori. There will be on the part of those particular rajs a transfereace of motion from the agitated ether to the atoms of the volatilised sodiom, which, as alreadj defined, is absorption. We nse glass screens to defend ns fr(»ii the heat of oor fires: how do the; act? Thns: — Tho heat emanating from the fire is for tho most part dne U> rajs which are incompetent to excite the sense of viaioa ; wo coll these ra^s ob- scare. Glass, thoagli pervious to the luminoas rajs, is opaqae in a high degree to those obsonre rajs, and cuts them off, while the cheerflil light of the firo is allowed to pass. Now mark mo clearij. The heat cat off from jonr person is to be fomid in the glass, the latter becomes heated and radiates towards year person; what then is the nse of tho gloss if it merely thns acts as a tempororj Lalting-place for tho rays, and sends them on afterwards! It does this: — It not only sends the heat it receives towards jon, but scat- ters it also in all other directions, ronnd the room. Thns the rays which, were the gloss not interposed, woold be shot directly against yoar piorson, are for tho most part diverted from their original di- rection, and yoa are preserved from their impact.

Now for onr eiperiment I pass tho beam from tho electric lamp through the two

prisms, and the spectrum spreads its colours npoa the screen. Between the lamp and the prism I interpose this snapdragon light. Alcohol and water are here mixed up with a qnantity of common Bait, and the metal dish that contains them is heated by a spirit lamp. The vaponr from the mixtore ignites,- and we have this monochromatic flame. Through this flame the beam from the lamp b now passing, and observe the result npon the spectrum. Ton see a dark band cat oot of the yellow— not very dark, bat sufficiently so to be seen by everybody present. Observe how the band quivers and varies in shade, as the yellow light cat off by the ansteady flame varies in amount. The flame of this monochromatic lamp is at the present moment casting its proper yellow light upon that shaded line ; and more than this, it casts, in part, the light which it absorbs from the electric lamp upon it; but it scatters the greater portion of this light in other

52(appesdix to LBCTCKE xm,

directiona, imd thus withdraws it from ha place upon the screoo, OS the glass, in the ciuio above supposed, direrte^l the heat of tho lire from joat poreon. Houce the hand appears darli; not abso- latelf, hut dark in coraporiaou nith tlie adjacent hi'ilUiuit portions of the spectrum.

But let me exnlt t laco in tiroat of tlie elcctrio

lamp the intense flume "■ isen's hurner, I hoTO here a

platinnm spoon in whi of sodiam lefis than a pea io

mBgnitnde. Tlio sodini' la flame soon volatilises and

bunu with brilliant inc Observe the spectrum. The

yellow hand ia clowly ; iijt out, and n band of intense

obsonrity oocnpiea its pl»^ iiatt the Bodiom, tlie brilliaot

yellow of the spectram tnKC» hb proper plnce : I reintroduce the sodium, and tlio blat^k band appears.

Let nio bo more precise: — The jelloiv colour of llio Bpcctrum extends over u seiiBiblo upacc, blending on one side into orange and on the otiier into green. The tonn ' yellow band ' is tliereforo sornewli.it indefinite. I want to show you that it is the precise yellow band emitted by the volatilised sodium ivhijh the same substance absorbs, Ity dipping tho coal-point used for the positive electrode into a solution of common Bait, and replaeiiiK it in the lamp, I obtain that bright yellow band which you now see drawn across tho spectrum. Observe the fate of that band when 1 inter-pose my Eodium lifcht. It is first obliterated, and instantly that black streak occnpics its place. 8cc how it nllernHtely flashes and v.tnishes as I withdraw and introduce ttie sodiniii fl.tme.

And supposing that, instead of tlio flame of sodium alone, I introduce into tho path of tlic boani a flame in wliirh lithium, Gtrontium, magne^iim, calcium, &c., are in a state of volatilisation, each metallic vapour would cat out its own system of bands, each corresponding exactly in position with the bright band which that metnl itscll' would east upon the screen. Tho liglit of onr electiio lamp then shining tlrrongh such a composite flame would give us a pjHictrura cut up by dark lines, exactly as the solar spoctrnm is cut up by the lines of Frannbofer.

And hence we infer tho constitution of tlie great centre of our system. Tho san coiiBista of a nucleus which is surrounded by a flaming atmosphere. The light of the nucleus would give lis a continuous spectrum, as our common coal-points did; but having

FHYBICAL BASIS OT BOLAB OHBiaSTBY. 531

to pass through the photosphere, as our beam through the flame, tkoee nijs of the naclens which the photosphere can itself emit, are absorbed, sod ehoded spaces^ oorreepondiDg to the pnrticolar rajB absorbed, occur in the Bpecbum. Aboliah the solar nocleos,' and we should have a spectram showing a bright band in tbe place of every dark line of Frannhofer. These lines are therefore not abeolatelf dark, hut diirk

b^ an amount corresponding to the dif- ference between the light of the naclens intercepted bj the photo- sphere, and the light which issnes from the latter.

Tbe man to whom we owe this beantifol generalisation is Eirobhof^ Professor of Natural Philosophy in the University of Heidelberg; bat, like ererj other great disooveir, it is compoouded of rariona elements. Mr. Talbot observed the bright lines in the epectra of colonred ftames. Sixteen years ago I>r. Uiller gave drswinga and descriptions of the spectra of various coloured flames. Wheatstone, with hia accustomed ingenuity, analysed tlie light of the electric Bpork, and showed that the metoU between which the spark passed determined the bright bands in the spec- tram of the ^ark. Masson published a pnze essay on tbeae bands. Van der Villigen, and more recently PlQcker, have ^ven as hean- tiful drawings of the spectra obtuned from the discharge of Bahm- korff's coil. But none of these distinguished men betrayed the least knowledge of the connection between the bright bands of tbe metals and tlie dark lines of the aolar spectram. The man who came nearest to tbe philosophy of the subject, was Angstrom. In a paper translated from Poggendorff's 'Annalen' by myself, and published in the ' Philosophical 'Uogazine ' for 1865, he indicates that the rays which a body absorbs ore precisely those which it can emit when rendered Inminons. In another place, he speaks of one of his spectra giving the general impression of retertal of the solar Bgectrum. Foncault^ Stokes, Thomson, and Stewart, have all been very dose to the discovery ; and, for my own part, the examination of the nidation and absorption of heat by gases and vaponrs, some of the resalts of which I placed before yon at the commence- ment of this discoarse, woold have led me in 18B9 to the law on which all £irchhoff's spconlatioos are fonndcd, hod not an acci- dent withdrawn me from the investigation. But Kirchhoff's cluma are unaffected by these circumstances. True, much that I have referred to formed the necessary basis of his discovery ; bo

ArPEKDEt TO LECTUEE Xm.

did ttie lava of Kepler famish to Newton tlio basis of the tbeoiT- □f gTOTitution. But what Kirclihoff baa doDO carries us far bft- yoad all tlmt hod bcforo been accomplisbed. He baa iotrodnc^d the order of law amid r Tost asaemblnge of empirical obscrrations, and lias eani~jblt>d our ; ' " 'edge bj showing its relatioB- (hip to some of the mi latiiral pbi

EXTRACT I BT ME. JOULE

In a postaoript to a pa[racember unmber of tho * Phil-

osophical Mngniino' for liSia, jnr. Joule made the followiDU ei- tremcly important remark : —

' Oq converjiing a fow days npo with my friend Mr. JoIlu Danes, he tuld me that ho had himself a few years ago attempted to ac- count for that part of animal heat which Crawford's theory has left ancxpimncd, by the friction of the blood in the vcuia and arte- ries, but thiit, finding a similar hypothesis in llaller's " Physiol- ogy," ho fiail not pursnod tlie subject farther. It is unqneslbn- fthle that heat is produced by such friction, but it must bo under- stood tliat tho mechanical force expended in tho friction is n part of tho force of affinity, which causes tlie venous blood to unite with tho oxygen, so that tho whole heat of the system must still bo referred to the chemical changes. But if tho animal were en- gaged in turning a piece of macliinerj, or in ascending a moan- tain, I apprehend tliaf, in proportion to the muscular eflbrt put forth for the purpose, a diminution of tho heat evolved in the sys- tem by a given chemical action would be esperienced,'

Tlie following brief extracts are from an Essay by Dr. Mayer on Organic Motion and Nutrition — one of tho most important of contributions to the science of our time : —

'Measured by human standards, the sun i» an incxhsoGtiblo

MAYEB ON VITAL DYNAMICS. 523

sooTce of physical energy. This is the continually wound-up spring which is the source of all terrestrial activity. The vast amount of force sent hy the earth into space in the form of wave motion would soon hring its surface to the temperature of death. But the light of the sun is on incessant compensation. It is the sun's light, converted into heat, which sets our atmosphere in mo- tion, which raises the water into clouds, and thus causes the rivers to flow. The heat developed hy friction in the wheels of our wind and water miUs was sent from the sun to the earth in the form of vibratory motion.

* Nature has proposed to herself the task of storing up the light which streams earthward from the sun^-of converting the most volatile of all powers into a rigid form, and thus preserving it for her purposes. To this end she has overspread the earth with or- ganisms, which, living, take into them the solar light, and by the consumption of its energy generate incessantly chemical forces.

' These organisms are plants. The vegetable world constitutes the reservoir in which the fugitive solar rays are fixed, suitably deposated, and rendered ready for useful application. With this process the existence of the human race is inseparably connected. The reducing action of the sun's rays on inorganic and organic Substances is well known ; this reduction takes place most copiously in full sunlight, less copiously in the shade, and is entirely absent in darkness, and even in candle-light. The reduction is a conver- sion of one form of force into another— of mechanical effect into chemical tension.

^ The time does not lie far behind us when it was a subject of contention whether, during life, plants did not possess the power of changing the chemical elements, and indeed of creating them. Facts and experiments seemed to favour the notion, but a more accurate examination has proved the contrary. We now know that the sum of the materials employed and excreted is equal to the total quantity of matter token up

by the plant. The tree, for example, which weighs several thousand pounds, has taken every grsdn of its substance from its neighbourhood. In plants a conver- sion only, and not a generation of matter, takes place.

* Plants consume the force of light, and produce in its place chemical tensions. Since tlie time of Saussure, the action of light has been known to be necessary to the reductiofl. In the first

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place we most cnqniro whether tie light which fiJU npon living plants finds a diflVrwit oj'iiliciition from tliM wlikli MU upon deitd matter; tint is to eay, whclhw, oaUrit jiarihii*, plants ore less warmed by solar light thsu other bodies equallj^ dsrk-coloiireil. The results of tlie ohseiratione bltbcrto made nn a stnsll sciilo fi lie within tliQ limits ot Ic error. On the otlicr hand,

overj-daj oiperienco teaches son's rajs on largo areas or powerAilJT tliau bj a rich vej of die darlcness of their leav qoantitf of hi'nt tlinn the hn iDg actioo, the evnporntiou & the qneetioD aliovo propose<l i ' Tbe aeeoad qncation refe prodnccd in the plant. Thi^ v(Hiiv;ilL'i!l lo llif huiit obtain^') re<

t Iho heating action of th« | moderated hr nothing mor* althoDgh plants, on socoant ho able to absorb a grouUr If^ to aceount for tliis oool- pluDts be aot soflicient, theil' EUiMwered iu tbe affirmaUre. oanMof tbe cbemiGal tcsMM n is a phjsiml fbree. It b

Dues Iliis furi'O, llicn, cume IVinn llie vil;i! prucuss^'s, and without the i^jiiiiditiirc of some of licr form of furce? The iroation of .1]4iysi.:d I'or.-i', of itsdf lianlly lhi[ili:iMe, woin* jill tlie more para- doxic^a ivliwi wc coii.-i.kT that it U only l.y tliv h,l[. ,.r tlic .-iiui's r:iys tli;a jiljiils can pcdomi tlidr work. Ity llio ii^Mimplinn .if such a liy)nilliC'tical ai'lion of tliu "vital forpu'" ull further in v.-ti- pltioii is lul off, and the Bp[ilk-alion of tho liii-lhods of ox:icl pel- cncc to the pluTHinn'Uii of vitality is remiiTiiil iniimssihlc, Tlio« who liolil a notion so oppo.-icd In the Bplrit

of science would In- thereby carrieil into the chaos of unbridled]ilinntas;r. I tlierefore liopo that I may reckon on the reader's assent when I state, as an asiomatic truth, r/mt iliiriny ril'il prorofKi a canrcr»ian oiilij <•/ vuilU r. 'M irdl iis of fore; o.r,ir>, a„.l thai n ere<Jtwii ofcU/i.-r the one or Ihf olhci- mnr t,dci I'hice.

"I'lii.' i>by-iieal force collected by plant? becomes Ihe proj)ortyof uiiotliiT cla'^s of crcalarea — of animals. Tlio livinj; animal cmi- stinie-- I'liinlmstiblc siibslimces belonpiig to tbe vesctuhle world, and cause,-! them lo reunite with the oxyjicn of the fltt[ios|iheri.'. Parallel lo this pi'oees.s I'uris the work done by aninmls. This work is tlie end imd aim of animal e^tistcnee. Planls cert.tinly produce iiiethanieal ellects but it is evident that for equal masses and timM tlio sum of iho tffotls produced by a plant is vanUldngly sraaH

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compared witli those produced by an animaL While, then, in the plant the production of mechanical effects plays quite a subordinate part, the conversion of chemical tensions into useful mechanical effect is the characteristic sign of animal life.

' In the animal body chemical forces are perpetually expended. Ternary and quaternary compounds undergo during the life of the animal the most imi)ortant changes, and are, for the most part, given off in the form of binary compounds-^as burnt substances. The magnitude of these forces, with reference to the heat developed in these processes, is by no means determined with sufficient aoenracy ; but here, where our object is simply the establishment of a principle, it will be sufficient to take into account the heat of combustion of the pure carbon. When additioQal data have been obtained, it will be easy to modify our numerical calculations so as to render them accordant with the new facts.

* The heat of combustion of carbon I assume with Dulong to be 8660**.* The

mechanical work which corresponds to the combus- tion of one unit of weight of coal corresponds to the raising of 9,670,000 units to a height of 1 foot.

* K we express by a weight of carbon the quantity of chemical force which a horse must expend to perform the above amount of work, we find that the animal in one day must apply 1*84 lb. ; in an hour 0*167 lb. ; and in a minute 0*0028 lb. of carbon, to the production of mechanical effect.

' According to current estimates, the work of a strong labourer 10 ^th of that of a horse. A man who in one day lifts 1,850,000 lbs. to a height of a foot must consume in the work 0*19 lb. of carbon. This for an hour (the day reckoned at eight hours) amounts to 0*024 lb. ; for a minute it amounts to 0*0004 lb. — > 3*2 grains of carbon. A bowler who throws an 8-lb. ball with a ve- locity of 80' consumes in this effort -^th of a grain of carbon. A man who lifts his own weight (150 lbs.) 8 feet high, consumes in the act 1 grain of carbon. In climbing a mountain 10,000 feet high, the consumption (not taking into account the heat generated by the inelastic shock of the feet against the earth) is 0*155 lb. — > 2 0Z8. 4 drs. 50 grs. of carbon.

*If the animal organism applied the disposable combustible ma-

* Mayer always uses Centigrade degrees.

6E AFPEmax TO lectdse xm.

teHal xiltiy to the perfoitnanc^ of work, tho i]aaDtitie« of oarbon just coImUtcd woiilJ siiEQce for the times mentioned. In reulitjr, however, beaidea tlio prodnction of roephanical effects, tlipro ia in the niiiinal bod? b. continaons generatioD of hcnt. - The chemical force cootaioed in thoi" ired oxygen is tlicrefore the

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of boat correi])oqding to the cljeraien] proccA^es that have taten pbcc.

' In the active animal, the chemical chanp^s are moch greater than in the resting one. Let the amount of the chemical processes accomptishcd in a certain time in the resting animal be t, and in the active one x+y. If during activity the same quantity of heat were generated aa during rest, the additional chemical force y would correspond to the work performed. In general, however, more heat is produced in the active organism than in the resting one. During work, therefore, wo sliall have x plus a portion of y heat, the rcsidno of y being converted into mechanical effect.

' I must now prove th.at the extra quantity of corobnstihlo mat- tor consumed by the working animal contains the necessary force for the performance of the work. A strong horse, not working, is amply nourished on 15 lbs. of hay, nnd 5 lbs. of oats per d.ny. If the animal performed daily the work of lifting a weight of 12,960,000 lbs. 1 foot high, it could not exist on the same nutri- ment. To keep it in good condition wo must add 11 lbs, of oaL*. The 20 lbs. of nutrinieat first mentioned is the quantity which wo haTC immed t, and contains, according to Boussingault, 8'074 lbs. of eai'hon. The additional 11 lbs. of oats, our quantity y, contains, according to the same authority, 4'734.

'According to Bonssiugault, al*o, tJie carbon inlroduceil is to that excreted in a combustible form as S939: 1364-4. Calculating from these data, wo find r, or the quantity of carbon burnt by the resting animal, 5-2760 lbs., and ?/ =- 3-094 lbs. The quantity con- SLimed in mechanical effect is 1-34 lb., which wo will call ?.

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* We have therefore the following relations: 1. The mechani- cal effect is to the total consumption as zix+y'^O'lQ, 2. The mechanical effect is to the surplus consumption of the working animal as « : y — 0*43. 3. The generation of heat at' rest is to the generation of heat while working as a;: a;+y— « — 0*75.'

In the same way Mayer, taking the data furnished by Liebig, regarding the prisoners and soldiers at Giessen, determines the fol- lowing relations for a man : 1. The mechanical effect is to the total consumption as 96*7: 540 —0-177. 2. The mechanical effect is to the surplus consumption of the man at work as 957 : 285 — 0*336. 8. The generation of heat in the resting man to that in the work- ing man 255 : 540—95*7 — 0*57.

In these calculations, he continues, *' 1 have confined myself to the consumed carbon. If the heat of combustion be set equal to the carbon + the hydrogen, the additional heat of the hydrogen may be regarded as nearly — one-fourth of that of the carbon. According to tlie individual constitution and habits of life, the labour and the consumption must be liable to considerable varia- tions. The above results, however, serve to demonstrate the fol- lowing propositions : —

* (1) The surplus nutriment consumed in the working organism completely suffices to account for the work done.

' (2) The maximum mechanical effect produced by a working mammal hardly amounts to one-fifth of the force derivable from the total quantity of carbon consumed. The remaining four-fifths are devoted to the generation of heat.*

' In order to enable them to convert chemical force into me- chanical work, animals are provided with specific organs, which are altogether wanting in plants. These are the muscles, f * To the activity of a muscle two things are necessary : 1. The influence of the motor nerves as the determining condition ; and 2. The material changes as the cause of the mechanical effect.

* Like the whole organism, the organ itself, the muscle, has its psychical and its

physical side. Under the former we include the nervous influence, under the latter the chemical processes.

* The motions of the steamship are performed in obedience to the will of the steersman and engineer. The spiritual influence, however — without which the ship could not be set in motion, or.

limiting n'liich, would go to pieces on the nearest reef— gaidea, bol ' moves not. For the progreas of the vessel we need phyrical forrt — tlie force of coni; in its abgence tlie ship, however strong thd Tolition of iU nuvigatflr, remains dead,'

Here follow it few ' arks on niaecnlar motion r —

' In the firdt part i the part played by combus-

tion in inorgonio oppo ^^m-ongine, for instance, woa,

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siilcr tiio phonoinonft i mnection with their physical

cnascs, and thtu give Idona of physiology the bn^

of exact science.

' It lins beeu nlrcody , i an active working man pon-

vcrts in a day 0-19 lb. of carbon into mechanical effect. The weight of tlio whole mnscfes of such a roan, who woiglis IBO lbs., is 64 Itis.; and, subtracting 77 per cent, of water, 16 lbs. of dry conibnstible material remains. Let it be assumed (thongh not granted) tliat the heat-giving power of this mass (with 40 per cent, of nitrogen and ox.vgen) is equal to lliat of au equal m.Ts3 of pure carbon ; then, if llic work wore done ot the cspenso of the mus- cles themselves, tli* whole of the muscles must be oiidiscd and consumed in inecliaiiical effect in eighty days.

' Tliis nritlimeticid deduction bocoines still more evident if no confine our attention to the work performed hy a single muscle— the heart, I assume, with Valentin, the quantity of blood in the left ventride to be at every Bystolo on an average 130 cubic

centi- metres. The hydrostatic pressure of llie blood in the arteries ia, according to Poiaeuille, equal to the pressure of a column of mer- cury IU centimetres In lieight. The mechanical work done by the left ventricle diu-ing a systole may bo calculated from these tLita. It is equal to the rnising of a column of mercury 16 centimetres long, and with the base of a square centimetre, to a height of 150 centimetres. The weight of the mercury amonnts to 217 graimnes. The mecliaiiical effect of a systole therefore is — _ j 325'6 grammes raised 1 metre, (2 lb><. " 1 foot,

which is equivalent to 0887 of a thermal unit, or equivalent to the combustion of 0'000]037 of a granime of carbon. Taking for a minute 70 strokes, ond for a day 100,800 strokes of the pulse, the work done by the left ventricle in a day is equivalent to the

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raising of 202,000 lbs. to a height of one foot. This is eqnal to

89,428 thermal nnits, which is eqnal to the

(10*45 trnns) combustion of •{ ^^^« ' f-of carbon. According to Valen-

{ 168-3 grs.)

tin, the work done hj the right ventricle is half that done by the

left. The work of both chambers in a single day is therefore eqnal

to the raising of 803,000 lbs. 1 foot high — 134,148

thermal nnits= \ ^^ , ®^ ' > of carbon.

(252-4 grs.)

* Assnming the weight of the whole heart to be 500 grammes, and deducting from this 77 per cent, of water, we have remain- ing 115 grammes of dry combustible material. Assnming this ma- terial to be eqnal to that of pure carbon, it would follow that the entire organ, if it had to furnish the matter necessary to its action, would be

oxidised in eight days. Taking the weight of the two ventricles alone as 202 grammes, under the same conditions the complete combustion of this muscular tissue would be effected in 8^ days.'

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