ABSTRACTS

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proceed from the region of the "zona"; and probably have their origin in the cells by which the latter is surrounded. If so, the author thinks we cannot suppose them to arise in any other way than that which, according to his observations, appears to be the universal mode of reproduction; namely, by division of the nuclei of the parent cells. Nor can we suppose that minuteness is any hinderance to their subsequent increase by the same means.

December 17, 1840.

The MARQUIS OF NORTHAMPTON, President, in the Chair.

The following communications were made to the Society, viz.

1. "Present state of the Diamond Mines of Golconda." By T. J. Newbold, Esq., of the Madras Army, A.D.C. to Major-General Wilson, K.B. Communicated by S. H. Christie, Esq., M.A., Sec. R.S.

The author gives an account of the tract of country in which the diamond mines of Golconda are situated, and of the processes by which the diamonds are obtained. The latter consist merely in digging out the rolled pebbles and gravel, and carrying them to small square reservoirs, raised on mounds, having their bottom paved with stones, and then carefully washing them. Dry weather is selected to carry on these operations, in order to avoid the inconvenience and expense of draining. A description is then given of the mines of Banaganpully, Munimudgoo, Condapilly, Sumbhulpoor, and Poonah in Bundlekund.

2. "Magnetic-term Observations made at Milan." By Professor Carlini, Director of the Observatory at that place: also "Magnetic-term Observations made at Prague." By Professor Kreil, Director of the Observatory at that place.

3. "On the Production of Heat by Voltaic Electricity." By J. P. Joule, Esq. Communicated by P. M. Roget, M.D., Sec. R.S.

The inquiries of the author are directed to the investigation of the cause of the different degrees of facility with which various kinds of metal, of different sizes, are heated by the passage of voltaic electricity. The apparatus he employed for this purpose consisted of a coil of the wire, which was to be subjected to trial, placed in a jar of water, of which the change of temperature was measured by a very sensible thermometer immersed in it; and a galvanometer, to indicate the quantity of electricity sent through the wire, which was estimated by the quantity of water decomposed by that electricity. The conclusion he draws from the results of his experiments is, that the calorific effects of equal quantities of transmitted electricity are proportional to the resistances opposed to its passage, whatever may be the length, thickness, shape, or kind of metal which closes the circuit: and also that, *cæteris paribus*, these effects are in the duplicate ratio of the quantities of transmitted electricity; and consequently also in the duplicate ratio of the velocity of transmission. He also infers from his researches that the heat produced by the combustion of zinc in oxygen is likewise the consequence of resistance to electric conduction.

The President informed the Meeting that the Council had voted the following Address to Her Majesty, the Queen:—

"*To the Queen's Most Excellent Majesty.*

"The Humble Address of the President, Council, and Fellows of the Royal Society of London for improving Natural Knowledge.

"Most Gracious Sovereign,

"We, Your Majesty's most dutiful and loyal subjects, the President, Council, and Fellows of ~~the Royal Society of London~~ for improving Natural Knowledge, approach Your Majesty with the most heartfelt satisfaction at the birth of the Princess Royal. We feel the deepest gratitude to the Almighty Disposer of events for His gracious protection vouchsafed to Your Majesty in your late confinement, and we ardently pray that the same protection may continue to be long afforded to a life so precious to all the inhabitants of these realms.

"It is also our most ardent hope that Your Majesty's daughter may grow up to be a pattern of every virtue that can adorn and dignify her high station, and that Your Majesty may continue to be blest with every happiness, both public and private."

The President also stated to the Meeting, that the Council had adopted the following Address to His Royal Highness Prince Albert, of Saxe Coburg and Gotha:—

"*To His Royal Highness Prince Albert of Saxe-Coburg and Gotha, K.G., F.R.S.*

"The humble Address of the President, Council, and Fellows of the Royal Society of London for improving Natural Knowledge.

"May it please Your Royal Highness,

"We, the President, Council, and Fellows of the Royal Society of London for improving Natural Knowledge, beg leave to tender to Your Royal Highness our warmest congratulations on the safety and recovery of Your Royal Highness's Consort, our beloved Sovereign, and on the birth of Your Royal Highness's daughter. That she and sometimes at their base: in the first case, parts similar to those removed were invariably reproduced in different states of development, and in the latter, entire new limbs were formed; in some instances, at the second change of the larva, when it passed into the pupa state; but in two or three instances no reproduction took place. At first view, this difference in the results might appear to favour the opinion that this reproduction of limbs depends on the existence of parts especially adapted to perform this function, and which, in those experiments that had failed to exhibit the phenomenon, had been themselves removed. But the author found that in every instance of the mutilations thus practised, the perfect insect possessed a coxa, or basilar part of the limb; and this was the case even in those in which a new organ was not reproduced. From this fact, taken in conjunction with the formation of new entire limbs in the Iulidæ after the removal of every portion of the previous ones, the author infers that the power of reproduction resides in the whole of the organized tissues.

The author found that each newly produced limb is, in every case, composed of all its essential parts, namely coxa, femur, tibia, tarsus and claw; but its development is scarcely ever entirely normal, being either deficient in some of the tarsal joints, or irregular in the development of its armature.

The following are the general conclusions which the author deduces from his investigations. Slight wounds in the larvæ of insects always heal, except when the viscera have protruded, or excessive hemorrhage has occurred: severe wounds, such as those attending the excision of a limb, also frequently heal. It is when the wound is in the line of action of the principal muscles of the body that protrusion of the viscera takes place. For the healing of wounds, the first requisite is the arrest of the hemorrhage; and this is effected, as in the higher animals, by the coagulation of the blood, and the formation of a clot; and then a complete union of the separated parts takes place beneath the eschar formed by the clot. After this union, the reparation of the injury is commenced by a development, from the injured surface, of parts corresponding to those that had been removed. For the production of a new limb, one change of skin, at least, is necessary. The healing of the wound after the removal of a part, and the subsequent reproduction, although they do not prevent, yet certainly retard the natural changes. Lastly, the author has established the fact, that reproduction of lost parts takes place in metabolic as well as in the ametabolic articulata.

The paper is accompanied with drawings of reproduced parts.

5. "On the Changes of Temperature produced by the Rarefaction and Condensation of Air." By James Prescott Joule, Esq. Communicated by P. M. Roget, M.D., Sec. R.S.

In order to estimate with greater accuracy than has hitherto been done the quantities of heat evolved or absorbed during the condensation or rarefaction of atmospheric air, the author contrived an apparatus where both the condensing pump and the receiver were immersed in a large quantity of water, the changes in the temperature of which were ascertained by a thermometer of extreme sensibility. By comparing the amount of force expended in condensing air in the receiver with the quantity of heat evolved, after deducting that which was the effect of friction, it was found that a mechanical force, capable of raising 823 pounds to the height of one foot, must be applied in the condensation of air, in order to raise the temperature of one pound of water one degree of Fahrenheit's scale. In another experiment, when air condensed in one vessel was allowed to pass into another vessel from which the air had been exhausted, both vessels being immersed in a large receiver full of water, no change of temperature took place, no mechanical power having been developed. The author considers these results as strongly corroborating the dynamical theory of the nature of heat, in opposition to that which ascribes to it materiality; but he reserves the further discussion of this question to a future communication, which he hopes soon to present to the Royal Society.

The Society then adjourned over the long vacation, to meet again on the 21st Nov. next.

ANNALEN

DER

PHYSIK UND CHEMIE.

BAND LXXI.

Diese Untersuchungen erfordern minutiöse Vorsichtsmafsregeln, wenn das Endresultat fehlerfrei seyn soll. Das Rheometer mufs hinreichend entfernt seyn, damit es nicht von dem durch den Volta'schen Strom erregten Magnetismus afficirt werde. Die durch Magnetisirung und Entmagnetisirung der Elektromagnete in dem Schliefsdraht der Thermosäule erzeugte Induction mufs in Rechnung gezogen werden. Die Elektromagnete dürfen nur mit dicken Drähten construirt werden, und man mufs sich versichern, dafs der Durchgang der Elektricität sie nicht auf eine für das Mefsinstrument merkliche Weise erwärme. Man mufs alle nicht durch den diathermanen Körper gehenden Wärmestrahlen der Quelle ausschliefsen, die Glimmersäulen so wählen und aufstellen, dafs sie von der durchgehenden Wärme die möglich gröfste Menge polarisiren u. s. w.

Die von Hrn. W. beobachteten Effecte sind nicht sehr beträchtlich, aber er hält sie dennoch für entscheidend. Er glaubt, dafs man durch kräftigere elektrische Apparate und ein emfindlicheres Rheometer die Unterschiede in der Ablenkung der Nadel vergröfsern würde. Man darf nicht vergessen, dafs das Mittel, welches er zur Polarisation der Wärme hat anwenden gemufst, nur einen Theil derselben polarisirt, und dafs nur bei diesem mehr oder weniger grofsen Bruch von der gesammten Stralung eine Drehung der Polarisationsebene und ein Unterschied im Durchgang durch die zweite Glimmersäule stattfindet.

XI. *Ueber das Maximum der Dichte des Wassers; von James P. Joule und Lyon Playfair.*

(*Phil. Magaz., Ser. III, Vol. XXX, p.* 41. Auszug.)

Zur Lösung der oftmals behandelten Aufgabe, das Dichtigkeits-Maximum des Wassers zu bestimmen, haben sich die Verfasser der von Hope erfundenen und später von

Tralles, Rumford, Eckstrand, (Hällström)[1]) und Despretz angewandten Methode bedient, welche darauf beruht, dafs in Wasser, dessen Schichten eine ungleiche Temperatur besitzen, diejenigen von der Temperatur des Maximums niedersinken, während die übrigen sich erheben. Sie halten diese Methode für genauer als die, bei welcher entweder die Ausdehnung des Wassers in einem Gefäfse gemessen, oder das Gewicht eines starren Körpers bei verschiedenen Temperaturen in Wasser bestimmt wird, glauben aber, dafs Hope und seine Nachfolger sie noch nicht in der vortheilhaftesten Weise ausgeführt haben. Sie fanden es nöthig, zu diesem Behufe ein Instrument von folgender Einrichtung zu gebrauchen.

aa, Fig. 11, Taf. II, sind zwei cylindrische Gefäfse von Weifsblech, $4\frac{1}{2}$ Fufs in Höhe, 6 Zoll im Durchmesser, und am Boden durch eine Messingröhre *b* mit wohl schliefsendem Hahn mit einander verbunden. Die Röhre ist 6 Zoll lang, und tritt einen Zoll tief in jedes Gefäfs hinein. Bei geöffnetem Hahn ist zwischen beiden Gefäfsen eine freie Communication von einem Zoll Durchmesser. Oben sind die Gefäfse verbunden durch eine rechteckige Rinne von Blech *c*, 6 Zoll lang und 1 Zoll breit. In der Mitte dieser Rinne findet sich ein Schieber, durch welchen nöthigenfalls die Bewegung des Wassers in der Rinne gehemmt werden kann.

An zwei Stellen werden die Gefäfse durch Holzleisten *d*, *d* gehalten, und um zu verhüten, dafs durch die Atmosphäre gröfsere oder geringere Erwärmungen oder Erkältungen als die gewünschten eintreten, sind sie vollständig mit Heubändern (*Haybands*) bekleidet. Während der Versuche steht das Instrument auf einem Dreifufs, und dieser wiederum auf einer vom Fufsboden getrennten Unterlage, um alle Erschütterungen fern zu halten.

Sind nun die beiden Gefäfse mit Wasser gefüllt, und sowohl durch Oeffnung des Hahns als durch Fortnahme

1) Dessen Untersuchung den Verfassern unbekannt geblieben zu seyn scheint. *P.*

des Schiebers in Gemeinschaft gesetzt worden, so wird sich offenbar in der Rinne oben an den Gefäfsen ein Strom einstellen, sobald die Dichtigkeit des Wassers in dem einen Gefäfse im Mindesten anders ist als in dem zweiten.

Die angewandten Thermometer waren von äufserster Genauigkeit, ihrer ganzen Länge nach calibrirt, und so empfindlich, dafs sie Temperatur-Aenderungen von weniger als 0,01 eines Fahrenheit'schen Grades angaben. Ihr Frostpunkt war einige Stunden vor den Versuchen sorgfältig bestimmt worden. Jedes Gefäfs war mit einem *Rührer* versehen, bestehend aus einer an einem dünnen Eisenstab befestigten Blechscheibe von 4 Zoll Durchmesser; vor jedem Versuch wurde das Wasser mit diesem Werkzeug wohl umgerührt.

Um die Bewegung des Wassers in der Rinne am oberen Ende der Gefäfse zu messen, legte man auf dasselbe eine hohle Glaskugel von drei Viertelzoll Durchmesser und so abgepafstem Gewicht, dafs sie so eben schwamm. Sorgfältig sah man darauf, dafs sie nicht an den Seiten anhing.

Das angewandte Wasser hatten die Verfasser selber in sauberen Blechgefäfsen destillirt, und möglichst luftfrei gehalten.

Das Verfahren war folgendes. Nachdem die Gefäfse mit destillirtem Wasser von etwa 37° F. gefüllt worden, wurde die Temperatur des einen Gefäfses, durch Zusatz von heifsem Wasser, auf 41°,5 F. gebracht. Dann tauchte man zwei empfindliche Thermometer, von Stativen gehalten, mit ihren Kugeln bis zu einer Tiefe von sechs Zoll in das Wasser, rührte, bei verschlossenem Hahn und eingesetztem Schieber, das Wasser in jedem Gefäfse wohl durch, und zeichnete die von den Thermometern angegebenen Temperaturen auf.

Nun öffnete man den Hahn und entfernte vorsichtig den Schieber, setzte nach drei Minuten die Glaskugel in die Rinne und beobachtete zwei bis drei Minuten lang die Bewegung derselben mit Hülfe einer an der Rinne befindlichen Scale.

Auf

Auf diese Weise wurden die folgenden Beobachtungsreihen erhalten, bei deren erster die Lufttemperatur im Laboratorio 38° F. und deren übrigen 41° F. betrug.

Temp. des Wassers im wärmeren Gefäſse	Temp. des Wassers im kälteren Gefäſse	Mittl. Temp. beider Gefäſse.	Geschwindigkeit des Stroms, Zolle pro Stunde.
		Reihe I.	
41°,183	37°,348	39°,265	280 aus dem wärmeren Gefäſs
41 ,129	37 ,368	39 ,246	240 - - dito -
40 ,959	37 ,363	39 ,161	20 - - dito -
40 ,905	37 ,368	39 ,136	8 - - dito -
40 ,711	37 ,317	39 ,014	40 - - kälteren -
		Reihe II.	
40°,742	37°,368	39°,055	22 - - kälteren -
40 ,758	37 ,420	39 ,089	8 - - wärmeren -
40 ,773	37 ,470	39 ,121	60 - - dito -
		Reihe III.	
40°,332	37°,633	38°,982	70 - - kälteren -
40 ,402	37 ,682	39 ,042	80 - - dito -
40 ,425	37 ,709	39 ,067	60 - - dito -
40 ,440	37 ,745	39 ,092	8 - - dito -
40 ,448	37 ,791	39 ,120	30 - - dito -
40 ,467	37 ,837	39 ,152	12 - - wärmeren -
40 ,483	37 ,873	39 ,178	30 - - dito -
		Reihe IV.	
39°,921	38°,382	39°,151	30 - - wärmeren -
39 ,864	38 ,398	39 ,131	0 - - dito -
39 ,821	38 ,362	39 ,091	0 - - dito -
39 ,782	38 ,332	39 ,057	2½ - - kälteren -

Indem nun die Verfasser mittelst einer graphischen Construction die Temperatur bestimmen, bei welcher, nach diesen Beobachtungen, die Geschwindigkeit des Wassers in der Rinne Null ist, finden sie den Punkt des Maximums der Dichte des Wassers:

Aus I	39°,102 F.
- II	39 ,078 -
- III	39 ,134 -
- IV	39 ,091 -
Mittel	39°,101 F. = 3°,945 C.

und sie halten diesen Werth bis auf ein Hundertel eines Fahrenheit'schen Grades für richtig. Sehr nahe stimmt damit der von Depretz nach der Hope'schen Methode gefundene Werth =39°,177 F. =3°,987 C. (S. Ann. Bd. 41, S. 64), was die Verfasser als ein Kennzeichen der Güte dieser Methode ansehen, während sie in den beträchtlichen Abweichungen, welche die auf anderen Wegen erhaltenen Resultate theils unter sich, theils mit dem obigen Werthe darbieten, einen Beweis der Unzulänglichkeit dieser Methoden erblicken [1]).

XII. *Genaue Bestimmung der Dispersion des Menschenauges durch directe Messungen; von Hrn. Adolph Matthiessen aus Altona.*

Die *Comptes rendus* (*T. XXIV*, *p.* 875) theilen von dieser, der Pariser Academie überreichten Arbeit folgende Resultate mit:

1) Der Abstand des deutlichen Sehens einer Theilung auf Glas im Durchschein von rothem monochromatischem Lichte, dessen Wellenlänge im Mittel dem Strahl *B* des Sonnenspectrums entspricht, ist für Fernsichtige mehr als

1) Man darf dabei aber wohl nicht übersehen, dafs die Unzuverlässigkeit dieser zu sehr verschiedenen Zeiten erhaltenen Resultate (deren ältere man von Hällström in dies. Ann., Bd. 1, S 148, tabellarisch zusammengestellt findet) nicht allein in den Methoden, sondern auch und gewifs mehr noch in der Art ihrer Ausführung, in der Beschaffenheit der dabei angewandten Thermometer u. s. w. zu suchen ist. In seiner letzten Abhandlung setzt Hällström den wahrscheinlichsten, aus Wägungen sich ergebenden Werth =3°,90±0,04 C. (Ann., Bd. 34, S. 245) was nicht gar sehr von dem obigen abweicht. Nach der Hope'schen Methode, die derselbe, nach der älteren Weise ausgeführt, für nicht sehr zuverlässig erklärt, fand er im Mittel =4°,004 C (beim Erkalten 4°,575 beim Erwärmen 3°,433) (Ann., Bd. 9, S. 543). Der letztere Werth stimmt nahe mit dem von Despretz durch 18 Versuche mit Wasserthermometern gefundenen =4°,007 C. (Ann, Bd. 41, S. 65 und Bd. 62, S. 284). *P.*

skeleton is highly developed, the vertebræ appear to have the double concave articulation common amongst fish and enaliosaurs.

The author, in conclusion, acknowledges his obligations to Sir Philip M. de Grey Egerton, M.P., Dr. Mantell, Mr. Binney, Mr. J. E. Gray and Mr. Searles Wood, for their valuable co-operation in supplying many important specimens for examination.

4. "On the Mechanical Equivalent of Heat." By J. P. Joule, Cor. Associate R. Acad. Sciences, Turin, &c. Communicated by M. Faraday, D.C.L., F.R.S., Foreign Memb. Acad. of Sciences, Paris, &c.

After passing in review the experimental researches of Rumford, Davy, Dulong, Faraday, and others who have successively discovered facts tending to prove that heat is not a substance, but a mode of force, the author mentions the papers he has already communicated to the Royal Society, and published in the Philosophical Magazine, in which he has endeavoured to show that in the production of *heat* by the expenditure of *force*, and *vice versâ*, in the production of *force* by the expenditure of *heat*, a constant relation always subsists between the two. This relation he denominates the "Mechanical Equivalent of Heat," and the object of the present paper is to advance fresh proofs of its existence, and to give to it the numerical accuracy requisite to fit it as a starting-point for further inquiries.

In carrying out the above design, the author has determined the relation of *work done* to *heat produced* in the cases of the friction,—1st, of water; 2nd, of mercury; and 3rd, of cast iron.

In the experiments on the friction of the fluids, the liquid was contained in a covered cylindrical vessel of copper or iron, and the agitation was effected by vanes of brass or iron, fixed to a vertical axis revolving in the centre of the vessel, whilst fixed vanes prevented the liquid being whirled in the direction of rotation. In the experiments on the friction of solids, a disc of cast iron was rotated against another disc of cast iron pressed against it; the whole being immersed in a cast-iron vessel filled with mercury.

The *force expended* was measured by the descent of the weights employed in rotating the apparatus; and great care was taken to correct it for the friction of the axes of the pullies employed, &c.

The *heat evolved* by the friction was measured by exact thermometers, and very laborious precautions were taken in order to eliminate the effects of radiation or conduction of heat to and from the surrounding atmosphere. The corrected thermometric effect was then reduced to a known capacity for heat, by means of extensive series of experiments made in order to ascertain the specific heat of the materials in which the thermometric effect was observed.

In this way the number of units of work, estimated in pounds one foot high, required to be done in order to develope one degree Fahr. in one pound of water taken at about 50°, was found to be as follows:—

772·692 from friction of water, a mean of 40 experiments.
774·083 from friction of mercury, a mean of 50 experiments.
774·987 from friction of cast iron, a mean of 20 experiments.

III. *On the Mechanical Equivalent of Heat.* By JAMES PRESCOTT JOULE, *F.C.S., Sec. Lit. and Phil. Society, Manchester, Cor. Mem. R.A., Turin, &c.* Communicated by MICHAEL FARADAY, *D.C.L., F.R.S., Foreign Associate of the Academy of Sciences, Paris, &c. &c. &c.*

Received June 6,—Read June 21, 1849.

"Heat is a very brisk agitation of the insensible parts of the object, which produces in us that sensation from whence we denominate the object hot; so what in our sensation is *heat*, in the object is nothing but *motion*."—LOCKE.

"The *force* of a moving body is proportional to the square of its velocity, or to the height to which it would rise against gravity."—LEIBNITZ.

IN accordance with the pledge I gave the Royal Society some years ago, I have now the honour to present it with the results of the experiments I have made in order to determine the mechanical equivalent of heat with exactness. I will commence with a slight sketch of the progress of the mechanical doctrine, endeavouring to confine myself, for the sake of conciseness, to the notice of such researches as are immediately connected with the subject. I shall not therefore be able to review the valuable labours of Mr. FORBES and other illustrious men, whose researches on radiant heat and other subjects do not come exactly within the scope of the present memoir.

For a long time it had been a favourite hypothesis that heat consists of "a force or power belonging to bodies*," but it was reserved for Count RUMFORD to make the first experiments decidedly in favour of that view. That justly celebrated natural philosopher demonstrated by his ingenious experiments that the very great quantity of heat excited by the boring of cannon could not be ascribed to a change taking place in the calorific capacity of the metal; and he therefore concluded that the motion of the borer was communicated to the particles of metal, thus producing the phenomena of heat:—"It appears to me," he remarks, "extremely difficult, if not quite impossible, to form any distinct idea of anything, capable of being excited and communicated, in the manner the heat was excited and communicated in these experiments, except it be motion†."

One of the most important parts of Count RUMFORD's paper, though one to which

* Crawford on Animal Heat, p. 15.

† "An Inquiry concerning the Source of the Heat which is excited by Friction." Phil. Trans. Abridged, vol. xviii. p. 286.

little attention has hitherto been paid, is that in which he makes an estimate of the quantity of mechanical force required to produce a certain amount of heat. Referring to his third experiment, he remarks that the "total quantity of ice-cold water which, with the heat actually generated by friction, and accumulated in $2^h\ 30^m$, might have been heated 180°, or made to boil,=26·58 lbs."* In the next page he states that "the machinery used in the experiment could easily be carried round by the force of one horse (though, to render the work lighter, two horses were actually employed in doing it)." Now the power of a horse is estimated by WATT at 33,000 foot-pounds per minute, and therefore if continued for two hours and a half will amount to 4,950,000 foot-pounds, which, according to Count RUMFORD's experiment, will be equivalent to 26·58 lbs. of water raised 180°. Hence the heat required to raise a lb. of water 1° will be equivalent to the force represented by 1034 foot-pounds. This result is not very widely different from that which I have deduced from my own experiments related in this paper, viz. 772 foot-pounds; and it must be observed that the excess of Count RUMFORD's equivalent is just such as might have been anticipated from the circumstance, which he himself mentions, that "no estimate was made of the heat accumulated in the wooden box, nor of that dispersed during the experiment."

About the end of the last century Sir HUMPHRY DAVY communicated a paper to Dr. BEDDOES' West Country Contributions, entitled, "Researches on Heat, Light and Respiration," in which he gave ample confirmation to the views of Count RUMFORD. By rubbing two pieces of ice against one another in the vacuum of an air-pump, part of them was melted, although the temperature of the receiver was kept below the freezing-point. This experiment was the more decisively in favour of the doctrine of the immateriality of heat, inasmuch as the capacity of ice for heat is much less than that of water. It was therefore with good reason that DAVY drew the inference that "the immediate cause of the phenomena of heat is motion, and the laws of its communication are precisely the same as the laws of the communication of motion†."

The researches of DULONG on the specific heat of elastic fluids were rewarded by the discovery of the remarkable fact that "equal volumes of all the elastic fluids, taken at the same temperature, and under the same pressure, being compressed or dilated suddenly to the same fraction of their volume, disengage or absorb the same *absolute quantity of heat*‡." This law is of the utmost importance in the development of the theory of heat, inasmuch as it proves that the calorific effect is, under certain conditions, proportional to the force expended.

In 1834 Dr. FARADAY demonstrated the "Identity of the Chemical and Electrical Forces." This law, along with others subsequently discovered by that great man, showing the relations which subsist between magnetism, electricity and light, have

* "An Inquiry concerning the Source of the Heat which is excited by Friction." Phil. Trans. Abridged, vol. xviii. p. 283.

† Elements of Chemical Philosophy, p. 94.

‡ Mémoires de l'Académie des Sciences, t. x. p. 188.

enabled him to advance the idea that the so-called imponderable bodies are merely the exponents of different forms of Force. Mr. GROVE and M. MAYER have also given their powerful advocacy to similar views.

My own experiments in reference to the subject were commenced in 1840, in which year I communicated to the Royal Society my discovery of the law of the heat evolved by voltaic electricity, a law from which the immediate deductions were drawn,—1st, that the heat evolved by any voltaic pair is proportional, *cæteris paribus*, to its intensity or electromotive force*; and 2nd, that the heat evolved by the combustion of a body is proportional to the intensity of its affinity for oxygen†. I thus succeeded in establishing relations between heat and chemical affinity. In 1843 I showed that the heat evolved by magneto-electricity is proportional to the force absorbed; and that the force of the electro-magnetic engine is derived from the force of chemical affinity in the battery, a force which otherwise would be evolved in the form of heat: from these facts I considered myself justified in announcing "that the quantity of heat capable of increasing the temperature of a lb. of water by one degree of FAHRENHEIT's scale, is equal to, and may be converted into, a mechanical force capable of raising 838 lbs. to the perpendicular height of one foot‡."

In a subsequent paper, read before the Royal Society in 1844, I endeavoured to show that the heat absorbed and evolved by the rarefaction and condensation of air is proportional to the force evolved and absorbed in those operations§. The quantitative relation between force and heat deduced from these experiments, is almost identical with that derived from the electro-magnetic experiments just referred to, and is confirmed by the experiments of M. SEGUIN on the dilatation of steam‖.

From the explanation given by Count RUMFORD of the heat arising from the friction of solids, one might have anticipated, as a matter of course, that the evolution of heat would also be detected in the friction of liquid and gaseous bodies. Moreover there were many facts, such as, for instance, the warmth of the sea after a few days of stormy weather, which had long been commonly attributed to fluid friction. Nevertheless the scientific world, preoccupied with the hypothesis that heat is a substance, and following the deductions drawn by PICTET from experiments not sufficiently delicate, have almost unanimously denied the possibility of generating heat in that way. The first mention, so far as I am aware, of experiments in which the evolution of heat from fluid friction is asserted, was in 1842 by M. MAYER¶, who states that he has raised the temperature of water from 12° C. to 13° C., by agitating it, without however indicating the quantity of force employed, or the precautions taken to secure a correct result. In 1843 I announced the fact that "heat is evolved by the passage of water through narrow tubes**," and that each degree of heat per lb. of water required for its evolution in this way a mechanical force represented by

* Phil. Mag. vol. xix. p. 275. † Ibid. vol. xx. p. 111. ‡ Ibid. vol. xxiii. p. 441.
§ Ibid. vol. xxvi. pp. 375. 379. ‖ Comptes Rendus, t. 25, p. 421.
¶ Annalen of WŒHLER and LIEBIG, May 1842. ** Phil. Mag. vol. xxiii. p. 442.

770 foot-pounds. Subsequently, in 1845* and 1847†, I employed a paddle-wheel to produce the fluid friction, and obtained the equivalents 781·5, 782·1 and 787·6, respectively, from the agitation of water, sperm-oil and mercury. Results so closely coinciding with one another, and with those previously derived from experiments with elastic fluids and the electro-magnetic machine, left no doubt on my mind as to the existence of an equivalent relation between force and heat; but still it appeared of the highest importance to obtain that relation with still greater accuracy. This I have attempted in the present paper.

Description of Apparatus.—The thermometers employed had their tubes calibrated and graduated according to the method first indicated by M. Regnault. Two of them, which I shall designate by A and B, were constructed by Mr. Dancer of Manchester; the third, designated by C, was made by M. Fastré of Paris. The graduation of these instruments was so correct, that when compared together their indications coincided to about $\frac{1}{100}$th of a degree Fahr. I also possessed another exact instrument made by Mr. Dancer, the scale of which embraced both the freezing and boiling-points. The latter point in this standard thermometer was obtained, in the usual manner, by immersing the bulb and stem in the steam arising from a considerable quantity of pure water in rapid ebullition. During the trial the barometer stood at 29·94 inches, and the temperature of the air was 50°; so that the observed point required very little correction to reduce it to 0·760 metre and 0° C., the pressure used in France, and I believe the Continent generally, for determining the boiling-point, and which has been employed by me on account of the number of accurate thermometrical researches which have been constructed on that basis‡. The values of the scales of thermometers A and B were ascertained by plunging them along with the standard in large volumes of water kept constantly at various temperatures. The value of the scale of thermometer C was determined by comparison with A. It was thus found that the number of divisions corresponding to 1° Fahr. in the thermometers A, B and C, were 12·951, 9·829 and 11·647, respectively. And since constant practice had enabled me to read off with the naked eye to $\frac{1}{20}$th of a division, it followed that $\frac{1}{200}$th of a degree Fahr. was an appreciable temperature.

Plate VII. fig. 1 represents a vertical, and fig. 2 a horizontal plan of the apparatus employed for producing the friction of water, consisting of a brass paddle-wheel furnished with eight sets of revolving arms, *a*, *a*, &c., working between four sets of stationary vanes,

* Phil. Mag., vol. xxvii. p. 205. † Ibid. vol. xxxi. p. 173, and Comptes Rendus, tome xxv. p. 309.

‡ A barometrical pressure of 30 inches of mercury at 60° is very generally employed in this country, and fortunately agrees almost exactly with the continental standard. In the "Report of the Committee appointed by the Royal Society to consider the best method of adjusting the Fixed Points of Thermometers," Philosophical Transactions, Abridged, xiv. p. 258, the barometrical pressure 29·8 is recommended, but the temperature is not named,—a remarkable omission in a work so exact in other respects.

b, *b*, &c., affixed to a framework also in sheet brass. The brass axis of the paddle-wheel worked freely, but without shaking, on its bearings at *c*, *c*, and at *d* was divided into two parts by a piece of boxwood intervening, so as to prevent the conduction of heat in that direction.

Fig. 3 represents the copper vessel into which the revolving apparatus was firmly fitted: it had a copper lid, the flange of which, furnished with a very thin washer of leather saturated with white-lead, could be screwed perfectly water-tight to the flange of the copper vessel. In the lid there were two necks, *a*, *b*, the former for the axis to revolve in without touching, the latter for the insertion of the thermometer.

Besides the above I had a similar apparatus for experiments on the friction of mercury, which is represented by figs. 4, 5 and 6. It differed from the apparatus already described in its size; number of vanes, of which six were rotary and eight sets stationary; and material, which was wrought iron in the paddle-wheel, and cast iron in the vessel and lid.

Being anxious to extend my experiments to the friction of solids, I also procured the apparatus represented by fig. 7, in which *a a* is the axis revolving along with the beveled cast-iron wheel *b*, the rim of which was turned true. By means of the lever *c*, which had a ring in its centre for the axis to pass through, and two short arms *d*, the bevel turned cast-iron wheel *e* could be pressed against the revolving wheel; the degree of force applied being regulated by hand by means of the wooden lever *f* attached to the perpendicular iron rod *g*. Fig. 8 represents the apparatus in its cast-iron vessel.

Fig. 9 is a perspective view of the machinery employed to set the frictional apparatus just described in motion. *a a* are wooden pulleys, 1 foot in diameter and 2 inches thick, having wooden rollers *bb*, *bb*, 2 inches in diameter, and steel axles *cc*, *cc*, one quarter of an inch in diameter. The pulleys were turned perfectly true and equal to one another. Their axles were supported by brass friction wheels *dddd*, *dddd*, the steel axles of which worked in holes drilled into brass plates attached to a very strong wooden framework firmly fixed into the walls of the apartment*.

The leaden weights *e*, *e*, which in some of the ensuing experiments weighed about 29 lbs., and in others about 10 lbs. a piece, were suspended by string from the rollers *bb*, *b b*; and fine twine attached to the pulleys *a a*, connected them with the central roller *f*, which, by means of a pin, could with facility be attached to, or removed from, the axis of the frictional apparatus.

The wooden stool *g*, upon which the frictional apparatus stood, was perforated by a number of transverse slits, so cut out that only a very few points of wood came in contact with the metal, whilst the air had free access to almost every part of it. In this way the conduction of heat to the substance of the stool was avoided.

* This was a spacious cellar, which had the advantage of possessing an uniformity of temperature far superior to that of any other laboratory I could have used.

A large wooden screen (not represented in the figure) completely obviated the effects of radiant heat from the person of the experimenter.

The method of experimenting was simply as follows:—The temperature of the frictional apparatus having been ascertained and the weights wound up with the assistance of the stand *h*, the roller was refixed to the axis. The precise height of the weights above the ground having then been determined by means of the graduated slips of wood *k*, *k*, the roller was set at liberty and allowed to revolve until the weights reached the flagged floor of the laboratory, after accomplishing a fall of about 63 inches. The roller was then removed to the stand, the weights wound up again, and the friction renewed. After this had been repeated twenty times, the experiment was concluded with another observation of the temperature of the apparatus. The mean temperature of the laboratory was determined by observations made at the commencement, middle and termination of each experiment.

Previously to, or immediately after each of the experiments, I made trial of the effect of radiation and conduction of heat to or from the atmosphere, in depressing or raising the temperature of the frictional apparatus. In these trials, the position of the apparatus, the quantity of water contained by it, the time occupied, the method of observing the thermometers, the position of the experimenter, in short everything, with the exception of the apparatus being at rest, was the same as in the experiments in which the effect of friction was observed.

1*st Series of Experiments.*—Friction of Water. Weight of the leaden weights along with as much of the string in connexion with them as served to increase the pressure, 203066 grs. and 203086 grs. Velocity of the weights in descending, 2·42 inches per second. Time occupied by each experiment, 35 minutes. Thermometer employed for ascertaining the temperature of the water, A. Thermometer for registering the temperature of the air, B.

TABLE I.

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus. Commencement of experiment.	Temperature of apparatus. Termination of experiment.	Gain or loss of heat during experiment.
1 Friction	1256·96	57°·698	2°·252—	55°·118	55°·774	0°·656 gain
1 Radiation ...	0	57·868	2·040—	55·774	55·882	0·108 gain
2 Friction	1255·16	58·085	1·875—	55·882	56·539	0·657 gain
2 Radiation ...	0	58·370	1·789—	56·539	56·624	0·085 gain
3 Friction	1253·66	60·788	1·596—	58·870	59·515	0·645 gain
3 Radiation ...	0	60·926	1·373—	59·515	59·592	0·077 gain
4 Friction	1252·74	61·001	1·110—	59·592	60·191	0·599 gain
4 Radiation ...	0	60·890	0·684—	60·191	60·222	0·031 gain
1	2	3	4	5	6	7

TABLE I. (Continued.)

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus.		Gain or loss of heat during experiment.
				Commencement of experiment.	Termination of experiment.	
5 Friction......	1251·81	60°·940	0°·431 −	60°·222	60°·797	0°·575 gain
5 Radiation ...	0	61·035	0·237 −	60·797	60·799	0·002 gain
6 Radiation ...	0	59·675	0·125 +	59·805	59·795	0·010 loss
6 Friction ...	1254·71	59·919	0·157 +	59·795	60·357	0·562 gain
7 Radiation ...	0	59·888	0·209 −	59·677	59·681	0·004 gain
7 Friction......	1254·02	60·076	0·111 −	59·681	60·249	0·568 gain
8 Radiation ...	0	58·240	0·609 +	58·871	58·828	0·043 loss
8 Friction......	1251·22	58·237	0·842 +	58·828	59·330	0·502 gain
9 Friction......	1253·92	55·328	0·070 +	55·118	55·678	0·560 gain
9 Radiation ...	0	55·528	0·148 +	55·678	55·674	0·004 loss
10 Radiation ...	0	54·941	0·324 −	54·614	54·620	0·006 gain
10 Friction......	1257·96	54·985	0·085 −	54·620	55·180	0·560 gain
11 Radiation ...	0	55·111	0·069 +	55·180	55·180	0·000
11 Friction......	1258·59	55·229	0·227 +	55·180	55·733	0·553 gain
12 Friction......	1258·71	55·433	0·238 +	55·388	55·954	0·566 gain
12 Radiation ...	0	55·687	0·265 +	55·954	55·950	0·004 loss
13 Friction......	1257·91	55·677	0·542 +	55·950	56·488	0·538 gain
13 Radiation ...	0	55·674	0·800 +	56·488	56·461	0·027 loss
14 Radiation ...	0	55·579	0·583 −	54·987	55·006	0·019 gain
14 Friction......	1259·69	55·864	0·568 −	55·006	55·587	0·581 gain
15 Radiation ...	0	56·047	0·448 −	55·587	55·612	0·025 gain
15 Friction......	1259·89	56·182	0·279 −	55·612	56·195	0·583 gain
16 Friction......	1259·64	55·368	0·099 +	55·195	55·739	0·544 gain
16 Radiation ...	0	55·483	0·250 +	55·739	55·728	0·011 loss
17 Friction......	1259·64	55·498	0·499 +	55·728	56·266	0·538 gain
17 Radiation ...	0	55·541	0·709 +	56·266	56·235	0·031 loss
18 Radiation ...	0	56·769	1·512 −	55·230	55·284	0·054 gain
18 Friction......	1260·17	56·966	1·372 −	55·284	55·905	0·621 gain
19 Radiation ...	0	60·058	1·763 −	58·257	58·334	0·077 gain
19 Friction......	1262·24	60·112	1·450 −	58·334	58·990	0·656 gain
20 Radiation ...	0	60·567	1·542 −	58·990	59·060	0·070 gain
20 Friction......	1261·94	60·611	1·239 −	59·060	59·685	0·625 gain
21 Friction......	1264·07	58·654	0·321 −	58·050	58·616	0·566 gain
21 Radiation ...	0	58·627	0·018 −	58·616	58·603	0·013 loss
22 Friction......	1262·97	58·631	0·243 +	58·603	59·145	0·542 gain
22 Radiation ...	0	58·624	0·505 +	59·145	59·114	0·031 loss
23 Friction......	1264·72	59·689	1·100 −	58·284	58·894	0·610 gain
23 Radiation ...	0	59·943	1·027 −	58·894	58·938	0·044 gain
1	2	3	4	5	6	7

TABLE I. (Continued.)

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus. Commencement of experiment.	Temperature of apparatus. Termination of experiment.	Gain or loss of heat during experiment.
24 Radiation ...	0	60·157	1·160 —	58·977	59·017	0·040 gain
24 Friction	1263·94	59·811	0·505 —	59·017	59·595	0·578 gain
25 Radiation ...	0	59·654	0·061 —	59·595	59·591	0·004 loss
25 Friction	1263·49	59·675	0·185 +	59·591	60·129	0·538 gain
26 Radiation ...	0	59·156	0·609 —	58·541	58·554	0·013 gain
26 Friction	1263·49	59·333	0·488 —	58·554	59·137	0·583 gain
27 Friction	1263·99	59·536	0·198 —	59·054	59·623	0·569 gain
27 Radiation ...	0	59·726	0·101 —	59·623	59·627	0·004 gain
28 Friction	1262·99	59·750	0·155 +	59·627	60·183	0·556 gain
28 Radiation ...	0	59·475	0·102 +	59·585	59·569	0·016 loss
29 Friction	1263·31	58·695	0·182 —	58·230	58·796	0·566 gain
29 Radiation ...	0	58·906	0·108 —	58·796	58·801	0·005 gain
30 Radiation ...	0	59·770	1·286 —	58·454	58·515	0·061 gain
30 Friction	1263·99	60·048	1·223 —	58·515	59·135	0·620 gain
31 Friction	1263·49	59·343	0·022 +	59·091	59·639	0·548 gain
31 Radiation ...	0	59·435	0·198 +	59·639	59·627	0·012 loss
32 Radiation ...	0	59·374	0·357 —	59·015	59·020	0·005 gain
32 Friction	1263·49	59·407	0·105 —	59·020	59·585	0·565 gain
33 Radiation ...	0	59·069	0·201 —	58·867	58·870	0·003 gain
33 Friction	1263·49	59·234	0·081 —	58·870	59·436	0·566 gain
34 Friction	1262·99	56·328	0·331 +	56·387	56·932	0·545 gain
34 Radiation ...	0	56·643	0·287 +	56·932	56·929	0·003 loss
35 Friction	1262·99	56·790	0·413 +	56·929	57·477	0·548 gain
35 Radiation ...	0	56·772	0·687 +	57·477	57·442	0·035 loss
36 Radiation ...	0	55·839	0·304 —	55·527	55·543	0·016 gain
36 Friction	1262·99	56·114	0·281 —	55·543	56·124	0·581 gain
37 Radiation ...	0	56·257	0·127 —	56·124	56·137	0·013 gain
37 Friction	1262·99	56·399	0·024 +	56·137	56·709	0·572 gain
38 Radiation ...	0	55·826	0·065 —	55·759	55·764	0·005 gain
38 Friction	1262·99	55·951	0·093 +	55·764	56·325	0·561 gain
39 Radiation ...	0	56·101	0·220 +	56·325	56·317	0·008 loss
39 Friction	1262·99	56·182	0·409 +	56·317	56·865	0·548 gain
40 Friction	1262·99	56·108	0·100 +	55·929	56·488	0·559 gain
40 Radiation ...	0	56·454	0·036 +	56·488	56·492	0·004 gain
Mean Friction...	1260·248	....	0·305075—	....	....	0·575250 gain
Mean Radiation.	0	....	0·322950—	....	....	0·012975 gain
1	2	3	4	5	6	7

From the various experiments in the above Table in which the effect of radiation was observed, it may be readily gathered that the effect of the temperature of the surrounding air upon the apparatus was, for each degree of difference between the mean temperature of the air and that of the apparatus, 0°·04654. Therefore, since the excess of the temperature of the atmosphere over that of the apparatus was 0°·32295 in the mean of the radiation experiments, but only 0°·305075 in the mean of the friction experiments, it follows that 0°·000832 must be added to the difference between 0°·57525 and 0°·012975, and the result, 0°·563107, will be the proximate heating effect of the friction. But to this quantity a small correction must be applied on account of the mean of the temperatures of the apparatus at the commencement and termination of each friction experiment having been taken for the true mean temperature, which was not strictly the case, owing to the somewhat less rapid increase of temperature towards the termination of the experiment when the water had become warmer. The mean temperature of the apparatus in the friction experiments ought therefore to be estimated 0°·002184 higher, which will diminish the heating effect of the atmosphere by 0°·000102. This, added to 0°·563107, gives 0°·563209 as the true mean increase of temperature due to the friction of water*.

In order to ascertain the absolute quantity of heat evolved, it was necessary to find the capacity for heat of the copper vessel and brass paddle-wheel. That of the former was easily deduced from the specific heat of copper according to M. Regnault. Thus, capacity of 25541 grs.† of copper ×0·09515 = capacity of 2430·2 grs. of water. A series of seven very careful experiments with the brass paddle-wheel gave me 1783 grs. of water as its capacity, after making all the requisite corrections for the heat occasioned by the contact of the water with the surface of the metal, &c. But on account of the magnitude of these corrections, amounting to one-thirtieth of the whole capacity, I prefer to avail myself of M. Regnault's law, viz. *that the capacity in metallic alloys is equal to the sum of the capacities of their constituent metals*‡. Analysis of a part of the wheel proved it to consist of a very pure brass containing 3933 grs. of zinc. to 14968 grs. of copper. Hence

Cap. 14968 grs. copper ×0·09515 = cap. 1424·2 grs. water.
Cap. 3933 grs. zinc ×0·09555 = cap. 375·8 grs. water.

Total cap. brass wheel = cap. 1800 grs. water.

* This increase of temperature was, it is necessary to observe, a mixed quantity, depending partly upon the friction of the water, and partly upon the friction of the vertical axis of the apparatus upon its pivot and bearing, *c c*, fig. 1. The latter source of heat was however only equal to about $\frac{1}{80}$th of the former. Similarly also, in the experiments on the friction of solids hereafter detailed, the cast-iron discs revolving in mercury, rendered it impossible to avoid a very small degree of friction among the particles of that fluid. But since it was found that the quantity of heat evolved was the same, for the same quantity of force expended, in both cases, *i. e.* whether a minute quantity of heat arising from friction of solids was mixed with the heat arising from the friction of a fluid, or whether, on the other hand, a minute quantity of heat arising from the friction of a fluid was mingled with the heat developed by the friction of solids, I thought there could be no impropriety in considering the heat as if developed from a simple source,—in the one case entirely from the friction of a fluid, and in the other entirely from the friction of a solid body.

† The washer, weighing only 38 grs., was reckoned as copper in this estimate.

‡ Ann. de Ch. 1841, t. i.

The capacity of a brass stopper which was placed in the neck *b*, fig. 3, for the purpose of preventing the contact of air with the water as much as possible, was equal to that of 10·3 grs. of water: the capacity of the thermometer had not to be estimated, because it was always brought to the expected temperature before immersion. The entire capacity of the apparatus was therefore as follows:—

Water	93229·7
Copper as water. . .	2430·2
Brass as water . . .	1810·3
Total . .	97470·2

So that the total quantity of heat evolved was 0°·563209 in 97470·2 grs. of water, or, in other words, 1° Fahr. in 7·842299 lbs. of water.

The estimate of the force applied in generating this heat may be made as follows: —The weights amounted to 406152 grs., from which must be subtracted the friction arising from the pulleys and the rigidity of the string; which was found by connecting the two pulleys with twine passing round a roller of equal diameter to that employed in the experiments. Under these circumstances, the weight required to be added to one of the leaden weights in order to maintain them in equable motion was found to be 2955 grs. The same result, in the opposite direction, was obtained by adding 3055 grs. to the other leaden weight. Deducting 168 grs., the friction of the roller on its pivots, from 3005, the mean of the above numbers, we have 2837 grs. as the amount of friction in the experiments, which, subtracted from the leaden weights, leaves 403315 grs. as the actual pressure applied.

The velocity with which the leaden weights came to the ground, viz. 2·42 inches per second, is equivalent to an altitude of 0·0076 inch. This, multiplied by 20, the number of times the weights were wound up in each experiment, produces 0·152 inch, which, subtracted from 1260·248, leaves 1260·096 as the corrected mean height from which the weights fell.

This fall, accompanied by the above-mentioned pressure, represents a force equivalent to 6050·186 lbs. through one foot; and $0·8464 \times 20 = 16·928$ foot-lbs. added to it, for the force developed by the elasticity of the string after the weights had touched the ground, gives 6067·114 foot-pounds as the mean corrected force.

Hence $\frac{6067·114}{7·842299} = 773·64$ foot-pounds, will be the force which, according to the above experiments on the friction of water, is equivalent to 1° Fahr. in a lb. of water.

2nd Series of Experiments.—Friction of Mercury. Weight of the leaden weights and string, 203026 grs. and 203073 grs. Velocity of the weights in descending, 2·43 inches per second. Time occupied by each experiment, 30 minutes. Thermometer for ascertaining the temperature of the mercury, C. Thermometer for registering the temperature of the air, B. Weight of cast iron apparatus, 68446 grs. Weight of mercury contained by it, 428292 grs.

Table II.

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus.		Gain or loss of heat during experiment.
				Commencement of experiment.	Termination of experiment.	
1 Friction......	1265·42	58°·491	1°·452 +	58°·780	61°·107	2°·327 gain
1 Radiation ...	0	58·939	2·056 +	61·107	60·884	0·223 loss
2 Radiation ...	0	58·390	0·237 −	58·119	58·188	0·069 gain
2 Friction......	1265·77	58·949	0·467 +	58·188	60·644	2·456 gain
3 Friction......	1265·73	57·322	1·203 +	57·325	59·725	2·400 gain
3 Radiation ...	0	57·942	1·678 +	59·725	59·515	0·210 loss
4 Radiation ...	0	57·545	0·010 −	57·518	57·553	0·035 gain
4 Friction......	1264·72	58·135	0·624 +	57·553	59·965	2·412 gain
5 Friction......	1265·73	57·021	0·907 +	56·715	59·141	2·426 gain
5 Radiation ...	0	57·596	1·474 +	59·141	58·999	0·142 loss
6 Radiation ...	0	56·406	0·174 +	56·565	56·595	0·030 gain
6 Friction......	1265·65	57·057	0·749 +	56·595	59·017	2·422 gain
7 Friction......	1269·55	58·319	0·049 +	57·115	59·622	2·507 gain
7 Radiation ...	0	58·771	0·831 +	59·622	59·583	0·039 loss
8 Radiation ...	0	60·363	0·612 −	59·691	59·811	0·120 gain
8 Friction......	1257·70	60·842	0·209 +	59·811	62·292	2·481 gain
9 Friction......	1255·77	60·282	1·044 +	60·129	62·524	2·395 gain
9 Radiation ...	0	60·862	1·576 +	62·524	62·352	0·172 loss
10 Friction......	1255·33	60·725	0·764 +	60·266	62·713	2·447 gain
10 Radiation ...	0	61·340	1·313 +	62·713	62·593	0·120 loss
11 Radiation ...	0	58·654	0·109 +	58·755	58·772	0·017 gain
11 Friction......	1266·47	59·234	0·746 +	58·772	61·189	2·417 gain
12 Radiation ...	0	56·436	0·247 +	56·673	56·694	0·021 gain
12 Friction......	1265·80	57·240	0·673 +	56·694	59·133	2·439 gain
13 Friction......	1264·70	55·002	1·808 +	55·638	57·982	2·344 gain
13 Radiation ...	0	55·633	2·213 +	57·982	57·711	0·271 loss
14 Friction......	1265·20	54·219	1·273 +	54·290	56·694	2·404 gain
14 Radiation ...	0	54·595	1·972 +	56·694	56·441	0·253 loss
15 Radiation ...	0	53·476	0·174 +	53·633	53·667	0·034 gain
15 Friction......	1265·63	53·995	0·872 +	53·667	56·067	2·400 gain
16 Radiation ...	0	52·082	0·254 +	52·332	52·341	0·009 gain
16 Friction......	1265·45	52·479	1·047 +	52·341	54·711	2·370 gain
17 Friction......	1257·50	50·485	1·453 +	50·772	53·105	2·333 gain
17 Radiation ...	0	50·821	2·164 +	53·105	52·865	0·240 loss
18 Radiation ...	0	48·944	0·450 −	48·434	48·554	0·120 gain
18 Friction......	1257·50	49·330	0·462 +	48·554	51·031	2·477 gain
19 Friction......	1257·50	48·135	1·273 +	48·219	50·598	2·379 gain
19 Radiation ...	0	48·725	1·780 +	50·598	50·413	0·185 loss
20 Radiation ...	0	48·878	0·148 −	48·687	48·773	0·086 gain
20 Friction......	1257·50	49·397	0·597 +	48·773	51·216	2·443 gain
Mean Friction	1262·731	....	0·8836+	....	....	2·41395 gain
Mean Radiation	0	....	0·8279+	....	....	0·06570 loss
1	2	3	4	5	6	7

From the above Table, it appears that the effect of each degree of difference between the temperature of the laboratory and that of the apparatus was 0°·13742. Hence 2°·41395+0°·0657+0°·007654=2°·487304, will be the proximate value of the increase of temperature in the experiments. The further correction on account of the mean temperature of the apparatus in the friction experiments having been in reality 0°·028484 higher than is indicated by the table, will be 0°·003914, which, added to the proximate result, gives 2°·491218 as the true thermometrical effect of the friction of the mercury.

In order to obtain the absolute quantity of heat evolved, it was requisite to ascertain the capacity for heat of the apparatus. I therefore caused it to be suspended by iron wire from a lever so contrived that the apparatus could be moved with rapidity and ease to any required position. The temperature of the apparatus having then been raised about 20°, it was placed in a warm air-bath, in order to keep its temperature uniform for a quarter of an hour, during which time the thermometer C, immersed in the mercury, was from time to time observed. The apparatus was then rapidly immersed into a thin copper vessel containing 141826 grs. of distilled water, the temperature of which was repeatedly observed by thermometer A. During the experiment the water was repeatedly agitated by a copper stirrer; and every precaution was taken to keep the surrounding atmosphere in a uniform state, and also to prevent the disturbing effects of radiation from the person of the experimenter. In this way I obtained the following results:—

	Time of observation.	Temperature of water.	Temperature of apparatus.
Apparatus in air-bath	0′	47°·705	70°·518
	5	47·705	70·492
	10	47·713	70·518
Instant of immersion	11		
Apparatus immersed in water	13½	49·836	57·673
	16	50·493	52·641
	21	50·694	50·941
	26	50·690	50·778
	31	50·667	50·744
	36	50·636	50·709

By applying the correction to the temperature of the water due to its observed increase during the first ten minutes of the experiment, and the still smaller correction due to the rise of the water in the can covering 60 square inches of copper at the temperature of the atmosphere, 47°·714 was found to be the temperature of the water at the instant of immersion. To remove the apparatus from the warm air-bath, and to immerse it into the water, occupied only 10″, during which it must (according to preliminary experiments) have cooled 0°·027. The heating effect of the air-bath during the remaining 50″ (estimated from the rate of increase of temperature between the observations at 5′ and 10′) will be 0°·004. These corrections, applied to 70°·518, leave 70°·495 as the temperature of the apparatus at the moment of immersion.

The temperature of the apparatus at 26′ was 50°·778, indicating a loss of 19°·717. That of the water at the same time of observation, being corrected for the effect of the atmosphere (deduced from the observations of the cooling from 26′ to 36′ and of the heating from 0′ to 10′), will be 50°·777, indicating a gain of 3°·063. Twenty such results, obtained in exactly the same manner, are collected in the following Table.

TABLE III.

No.	Corrected temperature of water.		Gain of heat by the water.	Corrected temperature of apparatus.		Loss of heat by the apparatus.
	Commencement of experiment.	Termination of experiment.		Commencement of experiment.	Termination of experiment.	
1	47°·714	50°·777	3°·063	70°·495	50°·778	19°·717
2	48·127	51·113	2·986	70·518	51·147	19·371
3	48·453	51·430	2·977	70·642	51·452	19·190
4	47·543	50·598	3·055	70·674	50·684	19·990
5	44·981	48·449	3·468	70·901	48·468	22·433
6	45·289	48·701	3·412	70·769	48·657	22·112
7	45·087	48·497	3·410	70·504	48·494	22·010
8	46·375	49·614	3·239	70·678	49·662	21·016
9	47·671	50·832	3·161	71·500	50·873	20·627
10	47·693	50·801	3·108	70·878	50·821	20·057
11	48·728	51·714	2·986	70·947	51·714	19·233
12	47·240	50·414	3·174	71·006	50·392	20·614
13	48·324	51·345	3·021	70·939	51·362	19·577
14	49·079	51·905	2·826	70·332	51·937	18·395
15	49·635	52·490	2·855	71·012	52·504	18·508
16	47·207	50·282	3·075	70·265	50·263	20·002
17	46·227	49·402	3·175	69·877	49·314	20·563
18	46·053	49·296	3·243	70·367	49·258	21·109
19	45·733	48·981	3·248	70·068	49·001	21·067
20	47·170	50·317	3·147	70·741	50·332	20·409
Mean...	....	....	3·13145	....	....	20·300

I did not consider these experiments on the capacity of the apparatus sufficiently complete, until I had ascertained the heat produced by the wetting of the surface of the iron vessel. For this purpose the following trials were made in a similar manner to the above, with the exception that the observations did not require to be extended beyond 26′.

TABLE IV.

No.	Corrected temperature of water.		Gain or loss of heat by water.	Corrected temperature of apparatus.		Gain or loss of heat by apparatus.
	Commencement of experiment.	Termination of experiment.		Commencement of experiment.	Termination of experiment.	
1	50°·558	50°·556	0°·002 loss	50°·565	50°·589	0°·024 gain
2	49·228	49·232	0·004 gain	49·239	49·254	0·015 gain
3	48·095	48·106	0·011 gain	48·034	48·099	0·065 gain
4	47·416	47·425	0·009 gain	47·384	47·429	0·045 gain
5	47·484	47·532	0·048 gain	48·103	47·782	0·321 loss
6	47·429	47·439	0·010 gain	47·703	47·610	0·093 loss
7	47·624	47·637	0·013 gain	47·870	47·790	0·080 loss
8	47·705	47·712	0·007 gain	47·915	47·859	0·056 loss
9	47·685	47·702	0·017 gain	47·891	47·837	0·054 loss
10	48·733	48·793	0·060 gain	49·498	49·112	0·386 loss
11	49·689	49·694	0·005 gain	49·946	49·842	0·104 loss
12	48·191	48·168	0·023 loss	47·972	48·134	0·162 gain
13	48·101	48·119	0·018 gain	48·310	48·254	0·056 loss
14	49·413	49·390	0·023 loss	49·249	49·413	0·164 gain
15	49·243	49·241	0·002 loss	49·343	49·318	0·025 loss
16	49·103	49·103	0	49·172	49·172	0
17	46·991	46·902	0·089 loss	46·204	46·923	0·719 gain
18	46·801	46·814	0·013 gain	47·139	46·953	0·186 loss
19	46·624	46·624	0	46·652	46·652	0
20	46·266	46·158	0·108 loss	45·369	46·167	0·798 gain
Mean...	....	....	0·0016 loss	....	....	0·03155 gain

By adding these results to those of the former table, we have a gain of temperature in the water of 3°·13305, and a loss in the apparatus of 20°·33155. Now the capacity of the can of water was estimated as follows:—

Water	141826 grs.
15622 grs. copper as water . .	1486 grs.
Thermometer and stirrer as water	118 grs.
Total	143430 grs.

Hence $\frac{3·13305}{20·33155} \times 143430 = 22102·27$, the capacity of the apparatus as tried. The addition of 21·41 (the capacity of 643 grs. of mercury which had been removed in order to admit of the expansion of 70°) to, and the substraction of 52 grs. (the capacity of the bulb of thermometer C, and of the iron wire employed in suspending the apparatus) from this result, leaves 22071·68 grs. of water as the capacity of the apparatus employed in the friction of mercury.

The temperature 2°·491218 in the above capacity, equivalent to 1° in 7·85505 lbs. of water, was therefore the absolute mean quantity of heat evolved by the friction of mercury.

The leaden weights amounted to 406099 grs., from which 2857 grs., subtracted for the friction of the pulleys, leaves 403242 grs. The mean height from which they fell, as given in Table II., was 1262·731 inches, from which 0·152 inch, subtracted for the velocity of fall, leaves 1262·579 inches. This height, combined with the above weight, is equivalent to 6061·01 foot-lbs., which, increased by 16·929 foot-lbs. on account of the elasticity of the string, gives 6077·939 foot-lbs. as the mean force employed in the experiments.

$\frac{6077·939}{7·85505}=773·762$; which is therefore the equivalent derived from the above experiments on the friction of mercury. The next series of experiments were made with the same apparatus, using lighter weights.

3rd Series of Experiments.—Friction of Mercury. Weight of the leaden weights and string, 68442 grs. and 68884 grs. Velocity of the weights in descending, 1·4 inch per second. Time occupied by each experiment, 35 minutes. Thermometer for ascertaining the temperature of the mercury, C. Thermometer for registering the temperature of the air, B.

TABLE V.

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus. Commencement of experiment.	Temperature of apparatus. Termination of experiment.	Gain or loss of heat during experiment.
1 Friction.........	1292·12	49°·539	0°·399+	49°·507	50°·370	0°·863 gain
1 Radiation	0	50·165	0·226+	50·370	50·413	0·043 gain
2 Friction.........	1292·00	49·865	0·189+	49·606	50·503	0·897 gain
2 Radiation	0	50·363	0·159+	50·503	50·542	0·039 gain
3 Friction.........	1293·18	50·139	0·460+	50·168	51·030	0·862 gain
3 Radiation	0	50·617	0·408+	51·030	51·021	0·009 loss
4 Radiation	0	50·750	0·146+	50·873	50·920	0·047 gain
4 Friction.........	1293·25	51·401	0·013−	50·920	51·856	0·936 gain
5 Radiation	0	49·936	0·121+	50·031	50·083	0·052 gain
5 Friction.........	1294·92	50·551	0·020−	50·083	50·980	0·897 gain
6 Radiation	0	50·638	0·135+	50·752	50·795	0·043 gain
6 Friction.........	1294·43	51·172	0·065+	50·795	51·680	0·885 gain
7 Radiation	0	51·553	0·260−	51·237	51·349	0·112 gain
7 Friction.........	1294·07	52·194	0·371−	51·349	52·298	0·949 gain
8 Friction.........	1293·30	52·774	0·019−	52·298	53·212	0·914 gain
8 Radiation	0	53·029	0·204+	53·212	53·255	0·043 gain
9 Friction.........	1294·05	51·513	0·306+	51·379	52·259	0·880 gain
9 Radiation	0	52·093	0·177+	52·259	52·281	0·022 gain
10 Friction.........	1293·95	51·197	0·180+	50·907	51·847	0·940 gain
10 Radiation	0	51·960	0·079−	51·847	51·916	0·069 gain
11 Friction.........	1292·80	50·577	0·652+	50·804	51·654	0·850 gain
11 Radiation	0	51·055	0·577+	51·654	51·611	0·043 loss
1	2	3	4	5	6	7

TABLE V. (Continued.)

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus.		Gain or loss of heat during experiment.
				Commencement of experiment.	Termination of experiment.	
12 Radiation	0	51·416	0·483 –	50·860	51·006	0·146 gain
12 Friction.........	1293·25	52·057	0·551 –	51·006	52·006	1·000 gain
13 Radiation	0	51·747	0·246 –	51·456	51·547	0·091 gain
13 Friction.........	1293·25	52·403	0·389 –	51·547	52·482	0·935 gain
14 Friction.........	1293·45	52·703	0·054 +	52·294	53·221	0·927 gain
14 Radiation	0	53·201	0·050 +	53·221	53·281	0·060 gain
15 Friction.........	1293·93	53·644	0·088 +	53·281	54·183	0·902 gain
15 Radiation	0	54·061	0·145 +	54·183	54·230	0·047 gain
16 Radiation	0	51·492	0·318 +	51·821	51·800	0·021 loss
16 Friction.........	1292·83	52·011	0·242 +	51·800	52·706	0·906 gain
17 Radiation	0	51·350	0·055 –	51·272	51·319	0·047 gain
17 Friction.........	1292·83	52·057	0·264 –	51·319	52·268	0·949 gain
18 Friction.........	1292·84	52·576	0·147 +	52·268	53·178	0·910 gain
18 Radiation	0	52·906	0·276 +	53·178	53·187	0·009 gain
19 Radiation	0	50·119	0·142 –	49·928	50·027	0·099 gain
19 Friction.........	1292·33	50·760	0·272 –	50·027	50·950	0·923 gain
20 Friction.........	1293·01	51·004	0·147 –	50·370	51·345	0·975 gain
20 Radiation	0	51·798	0·385 –	51·345	51·482	0·137 gain
21 Radiation	0	52·194	0·646 –	51·482	51·615	0·133 gain
21 Friction.........	1292·83	52·383	0·298 –	51·615	52·555	0·940 gain
22 Friction.........	1292·33	50·389	0·374 +	50·332	51·195	0·863 gain
22 Radiation	0	50·958	0·239 +	51·195	51·199	0·004 gain
23 Radiation	0	51·218	0·498 –	50·636	50·804	0·168 gain
23 Friction.........	1294·69	51·848	0·546 –	50·804	51·800	0·996 gain
24 Friction.........	1294·33	50·582	0·286 +	50·435	51·302	0·867 gain
24 Radiation	0	51·223	0·092 +	51·302	51·328	0·026 gain
25 Radiation	0	51·665	0·406 –	51·190	51·328	0·138 gain
25 Friction.........	1294·33	52·281	0·464 –	51·328	52·306	0·978 gain
26 Friction.........	1294·34	52·652	0·105 +	52·306	53·208	0·902 gain
26 Radiation	0	52·957	0·259 +	53·208	53·225	0·017 gain
27 Friction.........	1293·83	49·463	0·277 +	49·293	50·188	0·895 gain
27 Radiation	0	50·068	0·142 +	50·188	50·233	0·045 gain
28 Radiation	0	48·420	0·145 +	48·537	48·593	0·056 gain
28 Friction.........	1294·33	49·132	0·093 –	48·593	49·486	0·893 gain
29 Friction.........	1294·84	49·142	0·092 +	48·773	49·696	0·923 gain
29 Radiation	0	49·783	0·053 –	49·696	49·765	0·069 gain
30 Radiation	0	50·251	0·422 –	49·765	49·894	0·129 gain
30 Friction.........	1294·33	50·597	0·246 –	49·894	50·808	0·914 gain
Mean Friction ...	1293·532	....	$0·00743\frac{1}{3}$ +	....	....	0·9157 gain
Mean Radiation...	0	....	0·0048 +	....	....	0·0606 gain
1	2	3	4	5	6	7

The effect of each degree of difference between the temperature of the laboratory and that of the apparatus being 0°·18544, 0°·9157−0°·0606+0°·000488=0°·855588, will be the proximate mean increase of temperature in the above series of experiments. The correction, owing to the mean temperature of the mercury in the friction experiments being 0°·013222 higher than appears in the table, will be 0°·002452, which, being added to the proximate result, gives 0°·85804 as the true thermometrical effect. This, in the capacity of 22071·68 grs. of water, is equal to 1° in 2·70548 lbs. of water.

The leaden weights amounted to 137326 grs., from which 1040 grs. must be subtracted for the friction of the pulleys, leaving 136286 grs. as the corrected weight. The mean height of fall was 1293·532 inches, from which 0·047 inch, subtracted on account of the velocity with which the weights came to the ground, leaves 1293·485 inches. This fall, combined with the above corrected weight, is equivalent to 2098·618 foot-lbs., which, with 1·654 foot-lb., the force developed by the elasticity of the string, gives 2100·272 foot lbs. as the mean force employed in the experiments. $\frac{2100·272}{2·70548}=776·303$, will therefore be the equivalent from the above series of experiments, in which the amount of friction of the mercury was moderated by the use of lighter weights.

4th Series of Experiments.—Friction of Cast Iron. Weight of cast iron apparatus, 44000 grs. Weight of mercury contained by it, 204355 grs. Weight of the leaden weights and string attached, 203026 grs. and 203073 grs. Average velocity with which the weights fell, 3·12 inches per second. Time occupied by each experiment, 38 minutes. Thermometer for ascertaining the temperature of the mercury, C. Thermometer for registering the temperature of the air, A.

TABLE VI.

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus.		Gain or loss of heat during experiment.
				Commencement of experiment.	Termination of experiment.	
1 Friction.........	1257·90	46°·362	2°·544 +	46°·837	50°·976	4°·139 gain
1 Radiation	0	46·648	3·950 +	50·976	50·220	0·756 loss
2 Radiation	0	47·296	0·455 −	46·730	46·953	0·223 gain
2 Friction.........	1258·97	47·891	1·247 +	46·953	51·323	4·370 gain
3 Friction.........	1261·80	47·705	1·830 +	47·352	51·718	4·366 gain
3 Radiation	0	48·547	2·950 +	51·718	51·276	0·442 loss
4 Radiation	0	47·825	0·044 −	47·756	47·807	0·051 gain
4 Friction.........	1260·35	48·385	1·598 +	47·807	52·160	4·353 gain
5 Radiation	0	48·323	0·248 −	48·009	48·142	0·133 gain
5 Friction.........	1260·15	48·833	1·494 +	48·142	52·513	4·371 gain
6 Friction.........	1259·95	48·049	1·995 +	47·902	52·186	4·284 gain
6 Radiation	0	48·632	3·283 +	52·186	51·645	0·541 loss
7 Radiation	0	50·385	0·240 −	50·053	50·237	0·184 gain
7 Friction.........	1263·13	51·018	1·408 +	50·237	54·616	4·379 gain
8 Friction.........	1262·12	48·385	1·096 +	47·249	51·714	4·465 gain
8 Radiation	0	49·199	2·343 +	51·714	51·371	0·343 loss
9 Friction.........	1257·20	49·721	2·495 +	50·160	54·273	4·113 gain
9 Radiation	0	50·338	3·643 +	54·273	53·689	0·584 loss
10 Radiation	0	48·439	0·821 +	49·271	49·250	0·021 loss
10 Friction.........	1258·70	49·690	2·282 +	49·877	54·067	4·190 gain
Mean Friction ...	1260·027	....	1·7989+	....	....	4·303 gain
Mean Radiation...	0	....	1·6003+	....	....	0·2096 loss
1	2	3	4	5	6	7

From the above Table, it appears that there was a thermometrical effect of 0°·20101 for each degree of difference between the temperature of the laboratory and that of the apparatus. Hence 4°·303+0°·2096+0°·03992=4°·55252, will be the proximate mean increase of temperature. The correction, owing to the mean temperature of the mercury in the friction experiments appearing 0°·07625 too low in the table, will be 0°·01533, which, added to the proximate result, gives 4°·56785 as the true mean increase of temperature.

The capacity of the apparatus was obtained by experiments made in precisely the same manner that I have already described in the case of the mercurial apparatus for fluid friction. Their results are collected into the following Table.

TABLE VII.

No.	Corrected temperature of water.		Gain of heat by the water.	Corrected temperature of apparatus.		Loss of heat by the apparatus.
	Commencement of experiment.	Termination of experiment.		Commencement of experiment.	Termination of experiment.	
1	45·535	47·305	1·770	71·112	47·421	23·691
2	46·210	47·937	1·727	71·292	48·073	23·219
3	47·334	49·023	1·689	71·454	49·151	22·303
4	49·007	50·555	1·548	71·152	50·632	20·520
5	47·895	49·498	1·603	71·249	49·636	21·613
6	48·784	50·357	1·573	71·445	50·460	20·985
7	50·323	51·757	1·434	70·793	51·808	18·985
8	47·912	49·525	1·613	71·253	49·653	21·600
9	48·449	50·013	1·564	70·798	50·083	20·715
10	49·836	51·337	1·501	71·356	51·375	19·981
11	46·870	48·559	1·689	71·026	48·657	22·369
12	48·562	50·151	1·589	71·291	50·199	21·092
Mean...	....	....	1·60833	....	....	21·42275

By adding 0°·00071 and 0°·0141, the loss and gain of Table IV. reduced to the surface of the solid-friction apparatus, to the above mean results, we have a gain of 1°·60904 by the water and a loss of 21°·43685 by the apparatus. The capacity of the can of water was in this instance as follows:—

Water	155824 grs.
Copper can as water	1486 grs.
Thermometer and stirrer as ditto	118 grs.
Total . . .	157428 grs.

Hence $\frac{1·60904}{21·43685} \times 157428 = 11816·47$, will be the capacity of the apparatus as tried. By applying the two corrections, one additive on account of the absence during the trials of 300 grs. of mercury, the other subtractive on account of the capacity of the thermometer C and suspending wire, we obtain 11796·07 grs. of water as the capacity of the apparatus during the experiments.

The temperature 4°·56785 in the above capacity, equivalent to 1° in 7·69753 lbs. of water, was therefore the mean absolute quantity of heat evolved by the friction of cast iron.

The leaden weights amounted to 406099 grs., from which 2857 grs., subtracted on account of the friction of the pulleys, leaves 403242 grs. as the pressure applied to the apparatus.

Owing to the friction being in the simple ratio of the velocity, it required a good deal of practice to hold the regulating lever so as to cause the weights to descend to the ground with anything like a uniform and moderate velocity. Hence, although the mean velocity was 3·12 inches per second, the force with which the weights struck the ground could not be correctly estimated by that velocity as in the case of fluid friction. However, it was found that the noise produced by the impact was on the average equal to that produced by letting the weights fall from the height of one-eighth of an inch. It generally happened also that in endeavouring to regulate the motion, the weights would stop suddenly before arriving at the ground. This would generally happen once, sometimes twice, during the descent of the weights, and I estimate the force thereby lost as equal to that lost by impact with the ground. Taking therefore the total loss at one-fourth of an inch in each fall, we have twenty times that quantity, or 5 inches, as the entire loss, which, subtracted from 1260·027, leave 1255·027 inches as the corrected height through which the weight of 403242 grs. operated. These numbers are equivalent to 6024·757 foot-lbs., and adding 16·464 foot-lbs. for the effect of the elasticity of the string, we have 6041·221 foot-lbs. as the force employed in the experiments.

The above force was not however entirely employed in generating heat in the apparatus. It will be readily conceived that the friction of a solid body like cast iron must have produced a considerable vibration of the framework upon which the apparatus was placed, as well as a loud sound. The value of the force absorbed by the former was estimated by experiment at 10·266 foot-lbs. The force required to vibrate the string of a violoncello, so as to produce a sound which could be heard at the same distance as that arising from the friction, was estimated by me, with the concurrence of another observer, at 50 foot-lbs. These numbers, subtracted from the previous result, leave 5980·955 foot-lbs. as the force actually converted into heat. $\frac{5980 \cdot 955}{7 \cdot 69753} = 776 \cdot 997$, will therefore be the equivalent derived from the above experiments on the friction of cast iron. The next series of experiments was made with the same apparatus, using lighter weights.

5th Series of Experiments.—Friction of Cast Iron. Weight of leaden weights, 68442 grs. and 68884 grs. Average velocity of fall, 1·9 inch per second. Time occupied by each experiment, 30 minutes. Thermometer for ascertaining the temperature of the mercury, C. Thermometer for registering the temperature of the laboratory, A.

TABLE VIII.

No. of experiment and cause of change of temperature.	Total fall of weights in inches.	Mean temperature of air.	Difference between mean of columns 5 and 6 and column 3.	Temperature of apparatus.		Gain or loss of heat during experiment.
				Commencement of experiment.	Termination of experiment.	
1 Friction.........	1281·07	47°·404	0°·852 +	47°·494	49°·018	1°·524 gain
1 Radiation	0	48·003	0·998 +	49·018	48·984	0·034 loss
2 Radiation	0	48·269	0·702 +	48·984	48·958	0·026 loss
2 Friction.........	1280·74	48·516	1·189 +	48·958	50·452	1·494 gain
3 Radiation	0	49·003	0·133 −	48·812	48·928	0·116 gain
3 Friction.........	1285·10	49·728	0·022 +	48·928	50·572	1·644 gain
4 Friction.........	1283·89	50·138	1·172 +	50·572	52·049	1·477 gain
4 Radiation	0	50·408	1·581 +	52·049	51·929	0·120 loss
5 Friction.........	1282·45	46·798	0·558 +	46·554	48·159	1·605 gain
6 Friction.........	1281·29	47·296	1·571 +	48·159	49·576	1·417 gain
5 Radiation	0	47·535	1·929 +	49·576	49·353	0·223 loss
6 Radiation	0	47·651	1·607 +	49·353	49·164	0·189 loss
7 Radiation	0	46·261	0·298 −	45·880	46·047	0·167 gain
8 Radiation	0	46·748	0·617 −	46·047	46·215	0·168 gain
7 Friction.........	1276·07	46·810	0·978 +	47·022	48·554	1·532 gain
8 Friction.........	1275·17	47·366	1·883 +	48·554	49·945	1·391 gain
9 Radiation	0	46·771	0·271 −	46·425	46·575	0·150 gain
9 Friction.........	1276·95	47·126	0·258 +	46·575	48·194	1·619 gain
10 Friction.........	1276·84	47·238	1·655 +	48·194	49·593	1·399 gain
10 Radiation	0	47·335	2·142 +	49·593	49·361	0·232 loss
Mean Friction ...	1279·957	....	1·0138+	....	....	1·5102 gain
Mean Radiation...	0	....	0·764 +	....	....	0·0223 loss
1	2	3	4	5	6	7

From the above Table, it appears that the effect of each degree of difference between the temperature of the laboratory and that of the apparatus was 0°·1591. Hence 1°·5102+0°·0223+0°·03974=1°·57224, will be the proximate heating effect. To this the addition of 0°·00331, on account of the mean temperature of the apparatus in the friction experiments having been in reality 0°·02084 higher than appears in the Table, gives the real increase of temperature in the experiments at 1°·57555, which, in the capacity of 11796·07 grs. of water, is equivalent to 1° in 2·65504 lbs. of water.

The leaden weights amounted to 137326 grs., from which 1040 grs., subtracted for the friction of the pulleys, leaves 136286 grs. The velocity of descent, which was in this case much more easily regulated than when the heavier weights were used, was 1·9 inch per second. Twenty impacts with this velocity indicate a loss of fall of 0·094 inch, which, subtracted from 1279·957, leaves 1279·863 inches as the corrected height from which the weights fell.

The above height and weight are equivalent to 2076·517 foot-lbs., to which the addition of 1·189 foot-lb. for the elasticity of the string, gives 2077·706 foot-lbs. as the total force applied. The corrections for vibration and sound (deduced from the data obtained in the last series, on the hypothesis that they were proportional to the friction by which they were produced) will be 3·47 and 16·9 foot-lbs. These quantities, subtracted from the previous result, leave 2057·336 foot-lbs. as the quantity of force converted into heat in the apparatus.

$\frac{2057 \cdot 336}{2 \cdot 65504}=774 \cdot 88$, will therefore be the equivalent as derived from this last series of experiments.

The following Table contains a summary of the equivalents derived from the experiments above detailed. In its fourth column I have supplied the results with the correction necessary to reduce them to a vacuum.

TABLE IX.

No. of series.	Material employed.	Equivalent in air.	Equivalent *in vacuo*.	Mean.
1	Water	773·640	772·692	772·692
2	Mercury	773·762	772·814	774·083
3	Mercury	776·303	775·352	
4	Cast iron......	776·997	776·045	774·987
5	Cast iron......	774·880	773·930	

It is highly probable that the equivalent from cast iron was somewhat increased by the abrasion of particles of the metal during friction, which could not occur without the absorption of a certain quantity of force in overcoming the attraction of cohesion. But since the quantity abraded was not considerable enough to be weighed after the experiments were completed, the error from this source cannot be of much moment. I consider that 772·692, the equivalent derived from the friction of water, is the most correct, both on account of the number of experiments tried, and the great capacity of the apparatus for heat. And since, even in the friction of fluids, it was impossible entirely to avoid vibration and the production of a slight sound, it is probable that the above number is slightly in excess. I will therefore conclude by considering it as demonstrated by the experiments contained in this paper,—

1st. *That the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended.* And,

2nd. *That the quantity of heat capable of increasing the temperature of a pound of water (weighed* in vacuo, *and taken at between* 55° *and* 60°) *by* 1° FAHR., *requires for its evolution the expenditure of a mechanical force represented by the fall of* 772 *lbs. through the space of one foot.*

Oak Field, near Manchester,
June 4th, 1849.

XI. "On the Thermal Effects of Fluids in Motion."—No. II. By J. P. JOULE, Esq., F.R.S. and Professor W. THOMSON, F.R.S. Received June 15, 1854.

The first experiments described in this paper show that the anomalies exhibited in the last table of experiments, in the paper preceding it*, are due to fluctuations of temperature in the issuing stream, consequent on a change of the pressure with which the entering air is forced into the plug. It appears from these experiments, that when a considerable alteration is suddenly made in the pressure of the entering stream, the issuing stream experiences remarkable successions of augmentations and diminutions of temperature, which are sometimes perceptible for half an hour after the pressure of the entering stream has ceased to vary.

Several series of experiments are next described in which air is forced (by means of the large pump and other apparatus described in the first paper) through a plug of cotton wool, or unspun silk pressed together, at pressures varying in their excess above the atmospheric pressure, from five or six up to fifty or sixty pounds on the square inch. By these it appears that the cooling effect which the air, as found in the authors' previous experiments, always experiences in passing through the porous plug, varies proportionally to the excess of the pressure of the air on entering the plug above that with which it is allowed to escape. Seven series of experiments, in each of which the air entered the plug at a temperature of about 16° Cent., gave a mean cooling effect of about ·0175° Cent., per pound on the square inch, or ·27° Cent. per atmosphere, of difference of pressure. Experiments made at lower and at higher temperatures showed that the cooling effect is very sensibly less for high than for low temperatures, but have not yet led to sufficiently exact results at other temperatures than that stated (16° Cent.) to indicate the law according to which it varies with the temperature.

Experiments on carbonic acid at different temperatures are also described, which show that at about 16° Cent., this gas experiences $4\frac{1}{2}$ times as great a cooling effect as air. They agree well at all the

* Communicated to the Royal Society, June 1853, and published in the Transactions.

different temperatures with a theoretical result derived according to the general dynamical theory from an empirical formula for the pressure of carbonic acid in terms of its temperature and density, which was kindly communicated by Mr. Rankine to the authors, having been investigated by him upon no other experimental data than those of Regnault on the expansion of the gas by heat and its compressibility.

Experiments were also made on hydrogen gas, which, although not such as to lead to accurate determinations, appeared to indicate very decidedly a cooling effect amounting to a small fraction, perhaps about $\frac{1}{13}$, of that which air would experience in the same circumstances.

The following theoretical deductions from these experiments are made :—

I. The relations between the heat generated and the work spent in compressing carbonic acid, air and hydrogen, are investigated from the experimental results. In each case the relation is nearly that of equivalence, but the heat developed exceeds the equivalent of the work spent, by a very small amount for hydrogen, considerably more for air, and still more for carbonic acid. For slight compressions with the gases kept about the temperature 16°, this excess amounts to about $\frac{1}{77}$ of the whole heat emitted in the case of carbonic acid, and $\frac{1}{420}$ in the case of air.

II. It is shown by the general dynamical theory, that the air experiments, taken in connexion with Regnault's experimental results on the latent heat and pressure of saturated steam, make it certain that the density of saturated steam increases very much more with the pressure than according to Boyle's and Gay-Lussac's gaseous laws, and numbers are given expressing the theoretical densities of saturated steam at different temperatures, which it is desired should be verified by direct experiments.

III. Carnot's function in the "Theory of the Motive Power of Heat" is shown to be very nearly equal to the mechanical equivalent of the thermal unit divided by the temperature from the zero of the air-thermometer (that is, temperature Centigrade with a number equal to the reciprocal of the coefficient of expansion added), and corrections, depending on the amount of the observed cooling effects in the new air experiments, and the deviations from the gaseous laws of expansion and compression determined by Regnault, are applied to give a more precise evaluation.

IV. An absolute scale of temperature, that is, a scale not founded on reference to any particular thermometric substance or to any special qualities of any class of bodies, is founded on the following definition:—

If a physical system be subjected to cycles of perfectly reversible operations and be not allowed to take in or to emit heat except in localities, at two fixed temperatures, these temperatures are proportional to the whole quantities of heat taken in or emitted at them respectively during a complete cycle of the operations.

The principles upon which the unit or degree of temperature is to be chosen, so as to make the difference of temperatures on the absolute scale, agree with that on any other scale for a particular range of temperatures. If the difference of temperatures between the freezing and the boiling-points of water be made 100° on the new scale, the absolute temperature of the freezing-point is shown to be about 273·7; and it is demonstrated that the temperatures from the freezing-point on the new scale will agree very closely with Centigrade temperature by the standard air-thermometer; quite within the limits of the most accurate practical thermometry when the temperature is between 0° and 100° Cent., and very nearly if not quite within these limits for temperatures up to 300° Cent.

V. An empirical formula for the pressure of air in terms of its density, and its temperature on the absolute scale, is investigated, by using forms such as those first proposed and used by Mr. Rankine, and determining the constants so as to fulfil the conditions (1) of giving the observed cooling effects, (2) of agreeing with Regnault's observations on expansion by heat, and (3) of agreeing with Regnault's experimental results on compressibility at a particular temperature.

A table of comparison of temperature by the air-thermometer under varied conditions of temperature and pressure with the absolute scale, is deduced from this formula.

Expressions for the specific heats of any fluid in terms of the absolute temperature, the density, and the pressure, derived from the general dynamical theory, are worked out for the case of air according to the empirical formula; and tables of numerical results derived exclusively from these expressions and the ratio of the specific heats as determined by the theory of sound, are given. These tables show the mechanical values of the specific heats of air at different constant pressures, and at different constant densities. Taking 1390 as the mechanical equivalent of the thermal unit as determined by Mr. Joule's experiment on the friction of fluids, the authors find, as the mean specific heat of air under constant pressure,

·2390, from 0° to 100° Cent.

·2384, from 0° to 300° Cent.

XII. "Note on Nitro-glycerine." By A. W. Williamson, Ph.D., F.C.S., Professor of Practical Chemistry in University College. Communicated by Dr. Sharpey, Sec. R.S. Received June 15, 1854.

This compound is formed by acting upon glycerine with a mixture, in equal volumes, of concentrated nitric and sulphuric acids, the glycerine being added by a few drops at a time.

It is heavier than water, in which it is slightly soluble, and is soluble in alcohol and in ether.

From its proneness to decomposition in drying, even by the air-pump, a complete analysis could not be made, but a qualitative examination of the relative amounts of carbon and nitrogen gave the following results:—

	1.	2.	3.	4.
Volumes of mixed gases	101	91·5	99	97
Volumes of nitrogen not absorbed by potash	32	30·5	34	33
Carbonic acid absorbed by potash	69	61	65	64

	1.	2.	3.	4.	5.
Mixed gases	178	194	173	194	192
Nitrogen	61	66	58	65	65
CO_2	117	128	115	129	127

From these results the following formula was deduced:—

$$C_6 H_8 O_6 + 3NO_5 = C_6 {}^{H_5}_{3NO_4} O_6 + 3HO.$$

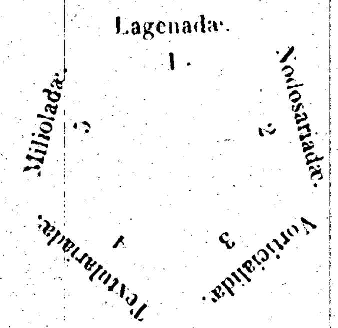
It would therefore appear that 3H are replaced by $3NO_4$.

On boiling this compound with concentrated solution of potash, it is decomposed into glycerine and nitrate of potash.

Having examined thousands (I may say myriads) of these elegant organisms, I am induced to suggest the following arrangement:—

1. *Lagena* (Walker) and *Entosolenia* (Williamson).
2. *Nodosaria* and *Marginulina* (D'Orb.), &c.
3. *Vorticialis* (D'Orb.), *Rotalia* (Lam.), *Lobatula* (Flem.), *Globigerina* (D'Orb.), &c.
4. *Textularia* (Defrance), *Uvigerina* (D'Orb.), &c.
5. *Miliola* (Lam.), *Biloculina* (D'Orb.), &c.

This division must, however, be modified by a more extended and cosmopolitan view of the subject, as I only profess to treat of the British species. To illustrate MacLeay's theory of a quinary and circular arrangement, the case may be put thus.



The first family is connected by the typical genus *Lagena* with the second, and by *Entosolina* with the fifth; the second is united with the third through *Marginulina*; the third with the fourth through *Globigerina*; and the fourth with the last through *Uvigerina*.

Whether these singular and little-known animals are Rhizopodes, or belong to the Amœba, remains yet to be satisfactorily made out.

London, June 18, 1855.

XVI. "Preliminary Research on the Magnetism developed in Iron Bars by Electrical Currents." By J. P. Joule, F.R.S. Received June 21, 1855.

The author had, many years ago, found that the magnetism developed by electro-magnetic coils in bars of upward of $\frac{1}{3}$rd of an inch diameter, was nearly proportional to the strength of the current and the length of the wire, any alteration, within certain limits, of the diameter of a bar being attended with only trifling effects, so long as the point of saturation was not nearly approached. The Russian philosophers Lenz and Jacobi had, however, stated that the magnetism developed was, *cæteris paribus*, proportional to the diameter of the bar. The discrepancy between the above results is considered by the author to be owing rather to the different circumstances under which the experiments were tried than to any inaccuracies in the experiments themselves. Further, it appeared to him that in any case of induction by electric currents, careful distinction should be made between the several effects, which, compounded together, constitute the total magnetic action. Especially should a distinction be made between the magnetism existing under the inductive influence of the current and that permanently developed so as to remain after the electrical circuit is broken, and therefore the first efforts of the author were directed to ascertain the laws which regulate this permanent effect, or, as he thinks it may be conveniently termed, the *magnetic set*.

In his experiments the magnetism of any bar was ascertained, by placing it vertically with its lower end near a delicately suspended magnetic needle. This was a piece of sewing-needle $\frac{3}{16}$ths of an inch long, furnished with an index of fine drawn glass tube traversing over a graduated circle six inches in diameter. It was suspended by a filament of silk. The tangent of the deflection of the needle was found to be the exact measure of the attraction of a bar. In working with this instrument, it was found that the resistance of the air prevented the needle from swinging even once beyond the point of equilibrium to which it always arrived in less than ten seconds. This resistance of the air, so useful for bringing the needle rapidly to a state of rest, rendered it necessary to keep the entire instrument at a uniform temperature, for the slightest local application of heat produced currents of air within the glass case of sufficient strength to occasion considerable deflections. The circumstance points to the possibility of constructing a new and very sensitive thermometer which might be useful, particularly in experiments on the conduction of heat.

The method of experimenting consisted in observing,—1st. the magnetic attraction of any bar when a current circulated through its spiral; 2nd. the attraction still subsisting after the circuit was broken; 3rd. the attraction of the other pole of the needle on the reversal of the current; and 4th. the attraction remaining after this reverse current was cut off. The sum of the 1st and 3rd observations gives the total change in the magnetism of a bar by the reversal of the current. The sum of the 2nd and 4th gives the total permanent change of magnetism, or the *magnetic set*.

The experiments were made with iron bars of the several diameters, $\frac{1}{25\cdot6}$, $\frac{1}{17\cdot2}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, and one inch, the length being in each case one yard; and also with iron bars $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ and one inch diameter, of the length of two yards. In all the bars of small diameter up to $\frac{1}{4}$ of an inch, the magnetic set obtained by the use of feeble currents was found to be proportional to the square of the current employed in producing them. This law was found to subsist through a long series of electric intensities; but when the current was increased to a certain amount, the *set*, as observed in the bars of $\frac{1}{25\cdot6}$ and $\frac{1}{17\cdot2}$ of an inch diameter, increased in a much higher ratio, so as to vary, in some instances, with the 4th and 6th powers of the current. The point at which this phenomenon takes place is called the *magnetic breaking point*. A further increase of the current was attended with a rapid decrease of this ratio as the saturation of the bar was approached.

The total change of magnetic condition by reversal of the current, minus the magnetic set, is found to be nearly proportional to the intensity of the current.

Results of exactly similar character were obtained by the use of an electro-magnet, consisting of a bar of hard steel $\frac{1}{4}$ of an inch in diameter and $7\frac{3}{4}$ inches long.

In conclusion, the author points out the striking and instructive analogy which exists between the above phenomena and those of the set of materials as exhibited by Professor Hodgkinson, who, in his admirable researches, has proved that the *set*, or permanent change of figure, in any beam is proportional to the square of the pressure to which it has been exposed.

Communications were read also from the ASTRONOMER ROYAL and Mr. MACQUORN RANKINE*.

* Notices of these will appear in the next Number.

XIII. *Introductory Research on the Induction of Magnetism by Electrical Currents.*

By J. P. JOULE, *F.R.S., Corr. Mem. R.A., Turin, Hon. Mem. of the Philosophical Society, Cambridge, &c.*

Received June 21,—Read June 21, 1855.

THE researches of JACOBI and LENZ led them some years ago to the announcement as a law, that when two bars of iron of different diameters but equal to one another in length and surrounded with coils of wire of the same length carry equal streams of electricity, the magnetism developed in the bars is proportional to their respective diameters. Experiments which I made about the same time threw doubts on my mind as to the general accuracy of the above proposition, for I found that the magnetism induced in straight bars of a variety of dimensions varying from $\frac{1}{3}$ to 1 inch in diameter, and from 7 inches to one yard in length, was nearly proportional to the length of the wire and the intensity of the current it conveyed, irrespectively of the shape or magnitude of the bars. The valuable experimental researches which have recently been made by WEBER, ROBINSON, MÜLLER, DUB and others, refer chiefly to the attraction of the keeper or submagnet, and are not calculated to confirm or disprove either of the above propositions; and the correct view is probably that of Professor THOMSON, who considers both of them as corollaries (applying to the particular conditions under which the experiments were made) of the general law, that "similar bars of different dimensions, similarly rolled with lengths of wire proportional to the squares of their linear dimensions and carrying equal currents, cause equal forces at points similarly situated with reference to them*." I have been induced to undertake some further experiments with an endeavour to elucidate the subject, and also to open the way to the investigation of the molecular changes which occur during magnetization.

I procured four iron bars one yard long and of the respective diameters $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{2}$ and 1 inch, their weights being 1736, 3802, 14560, and 55060 grs. Each bar was wound with 56 feet of copper wire $\frac{1}{40}$th of an inch in diameter covered with silk, the number of convolutions being 1020, 712, 388, and 207 respectively. The smallest bar was closely covered throughout its entire length, but on account of the larger surface of the other bars the coils had to be distributed upon them as evenly as possible. Four other bars were also procured of the same diameters as the above. They were however twice as long, weighing 3500, 7624, 29944, and 108574 grs., and were wrapped with double the length of wire, forming 2060, 1435, 768, and 418 convolutions respectively.

* Letter to the author.

To measure the electrical currents, I employed a galvanometer of tangents, the needle of which, half an inch long, carried a glass index over a divided circle 6 inches in diameter. This instrument was furnished with a coil of sixteen circumvolutions of 1 foot diameter, which could be exchanged for a single circle of 1 foot diameter when the intensities to be measured were very considerable. It was ascertained by experiment that the tangent of deflection by the former coil was exactly sixteen times that of the latter when the same intensity of current was employed. For convenience sake I have reduced all the observations to the latter standard; the unit current being therefore that which, passing through a circle 1 foot in diameter, is able to deflect the needle through 45°.

The amount of magnetism induced in a bar was ascertained by placing it vertically with its lower end at a distance of 6 or 12 inches from a magnetized needle $\frac{3}{16}$ths of an inch long and $\frac{1}{40}$th of an inch in diameter, suspended by a filament of silk, and having a fine glass index traversing over a graduated circle 6 inches in diameter. The force of torsion of the filament was found to be so trifling, that the tangents of the deflections of the needle could be taken as representing, without sensible error, the magnetism of the bar. Observations with so small a needle were made with great facility, the pointer moving steadily up to and attaining a new angle of deflection in eight or ten seconds after the electrical circuit was completed, the resistance of the air to the motion of the pointer being such as to prevent the smallest degree of oscillation. This resistance, however, of the air, so useful in bringing the needle speedily to rest, renders it necessary to guard carefully against any irregularity of the temperature of the case in which it is enclosed. A ray of sun-light would speedily occasion a deflection of several degrees*; and I found that the heat of the hand held over a part of the thick glass case 45° in advance of the pointer was sufficient, after penetration through the glass, to produce a current of air causing a steady deflection of no less than 30°, a deflection which subsided with extreme regularity and great slowness after the hand was removed. I would suggest that this circumstance points to the means of constructing a new and exceedingly sensible thermometer which would be valuable in many researches, particularly those on the conduction of heat.

Previously to employing electric currents, I made some experiments simply with a view to ascertain the inductive power of the earth's magnetism on the bars; and in which the action on the suspended needle was observed both at the distance of 12 and 6 inches, in order to determine the influence of distance for the convenience of future reductions. Having noticed the deflection produced by any bar, it was reversed and the observation repeated, the sum of the tangents of deflection showing the total effect produced on the magnetism of the bar by its reversion. I may here remark, that both ends of the pointer of the needle were invariably observed, though to save unnecessary detail the tangent of the mean is only given.

* Dr. TYNDALL has drawn attention to the importance of guarding against these effects of heat on a delicately poised needle. Philosophical Magazine, 4th series, vol. iii. p. 127.

Effect of Reversal of Bars two yards long.

Diameter of bar.	Sum of tangents of deflection. At 6 inches distance.	At 12 inches distance.
$\frac{1}{6}$ inch	·0450	·0088
$\frac{1}{4}$ inch	·0850	·0300
$\frac{1}{2}$ inch	·5912	·1922
1 inch	1·3910	·4598

The magnetism induced in the smaller bars appears to be nearly proportional to the square of the diameter, as might have been anticipated. The ratio of the attraction at 6 inches to that at 12 inches is 2·98.

Effect of Reversal of Bars one yard long.

Diameter of bar.	Sum of tangents of deflection. At 6 inches distance.	At 12 inches distance.
$\frac{1}{6}$ inch	·0480	·0138
$\frac{1}{4}$ inch	·1260	·0384
$\frac{1}{2}$ inch	·4926	·1430
1 inch	1·0380	·3084

The magnetism induced in the smaller bars of the above set is nearly proportional to the square of the diameter; the greater amount of discrepancy arising in all probability from the inferior length of the bars compared with those of the last set. The ratio of the attractions at the two distances is as 3·39 to unity.

In the following experiments on the induction of magnetism in the above bars by electrical currents, the method employed was,—1st, to observe the magnetism of a bar under the influence of the current; 2nd, that left permanently developed; 3rd, to observe the magnetism when the current was reversed; and 4th, the magnetism remaining after the current was the second time cut off. The difference between the first and third observations gives the entire change in the magnetism of the bar consequent on the reversal of the current; the difference between the second and fourth gives the entire permanent change, or as I may term it for convenience, the *magnetic set.*

The results were obtained by using currents of four degrees of intensity, in the first two of which the needle was at 6 inches distance, in the last two at 12 inches. The latter results are reduced to the action at 6 inches distance by employing the data arrived at from the foregoing experiments.

Table I.

Attraction, at 6 inches, of bars one yard long wrapped with 56 feet of wire.

Diameter of bar.	Intensity of current.	Total change of magnetism by reversal of current.	Magnetic set.	Total change minus magnetic set.	Set divided by square of current.	Total change minus set, divided by current.
$\frac{1}{6}$ inch	·0044	·0164	·0014	·0150	72·31	3·409
	·0197	·1012	·0266	·0746	68·54	3·787
	·0417	·3020	·1085	·1935	62·40	4·640
	·1450	2·7747	1·7036	1·0711	81·03	7·387
$\frac{1}{4}$ inch	·0041	·0364	·0038	·0326	226·05	7·951
	·0197	·2336	·0628	·1708	161·82	8·670
	·0414	·8798	·4085	·4713	238·34	11·384
	·1446	8·2871	4·9179	3·3692	235·20	23·300
$\frac{1}{2}$ inch	·0045	·0857	·0113	·0744	558·02	16·533
	·0194	·4573	·0882	·3691	234·35	19·026
	·0419	1·2162	·3207	·8955	182·67	21·372
	·1460	8·6948	2·7628	5·9320	129·61	40·630
inch	·0045	·1017	·0128	·0889	632·10	19·755
	·0195	·5089	·0817	·4272	214·86	21·908
	·0416	1·0935	·1377	·9558	79·57	22·976
	·1404	5·6858	1·0248	4·6610	51·99	33·198
1	2	3	4	5	6	7

Although the covered wire was fine and wound close to the iron, it could not be expected to act with exactly equal advantage in the bars of small as of large diameter, chiefly on account of the circuit taken by the wire being, relatively to the circumference of the bar, greater in the small than in the large bars. In comparing the results together, it should therefore be borne in mind, that those obtained with the bar of $\frac{1}{6}$th of an inch diameter are somewhat diminished from the above circumstance.

A very cursory inspection of the results convinced me that the *magnetic set* followed a very different law from that which regulated the magnetic action under the influence of the current. I have therefore subtracted the former from the latter in the 5th column of the Table. Even after this separation has been effected, it will be seen from column 7 that the magnetic action over and above the set increases with considerably greater rapidity than the intensity of the current, a result which is I believe owing to a portion of the set actually existing during the action of the current being destroyed on the breaking of the circuit. It will be remarked, on inspecting column 6, that the set of the bars of $\frac{1}{6}$ and $\frac{1}{4}$ of an inch diameter increases nearly in proportion to the square of the current, but that with the thicker bars the ratio is diminished; so that, although the set of the bars of small diameter is greater than that of the large bars when a current of powerful intensity is employed, the reverse takes place when a weak stream is used. From the 7th column it may be gathered that the magnetism induced by an equal current, increasing at first nearly with the section of the bars, becomes ultimately almost independent of their thickness, the attractions of the half-inch and inch bars being almost exactly equal to one another.

Table II.

Attraction, at 6 inches, of bars two yards long wrapped with 112 feet of wire.

Diameter of bar.	Intensity of current.	Total change of magnetism by reversal of current.	Magnetic set.	Total change minus magnetic set.	Set divided by square of current.	Total change minus set, divided by current.
$\frac{1}{8}$ inch	·0042	·0150	·0009	·0141	51·02	3·357
	·0160	·0826	·0190	·0636	74·22	3·975
	·0281	·1440	·0410	·1030	51·92	3·665
	·0988	1·6531	1·0030	·6501	102·75	6·580
$\frac{1}{4}$ inch	·0042	·0451	·0037	·0414	209·75	9·857
	·0167	·2555	·0513	·2042	183·94	12·227
	·0297	·6227	·2392	·3835	271·17	12·912
	·1048	6·5007	4·3887	2·1120	399·59	20·152
$\frac{1}{2}$ inch	·0044	·0937	·0095	·0842	490·70	19·136
	·0192	·5275	·0870	·4405	236·00	22·943
	·0386	1·2243	·2597	·9646	174·30	24·990
	·1338	10·6557	4·9784	5·6773	278·08	42·429
inch	·0043	·1280	·0128	·1152	692·27	26·791
	·0178	·6088	·0822	·5266	259·44	29·584
	·0316	1·0440	·1833	·8607	183·56	27·237
	·1154	6·1017	1·6200	4·4817	121·65	38·836
1	2	3	4	5	6	7

An inspection of the above results, obtained from bars of double length wrapped with twice the length of wire, leads to conclusions similar to those we drew from Table I.

It appeared to me a matter of very great importance to investigate more closely the laws which regulate the *magnetic set*, and to determine with certainty whether the proportionality between the set and the square of the current, leading as it inevitably would to the better understanding of the nature of the molecular changes which occur in a magnetized bar, existed, and to what modifications it was subject. Seeing, therefore, that the supposed law began to fail when the thicker bars were employed, in which the mutual action of the particles distributed over a large section would naturally tend to counteract the magnetic induction developed on the exterior surface, I constructed two straight electro-magnets, one of an iron wire one yard long and $\frac{1}{25\cdot6}$ of an inch in diameter, the other of an iron wire one yard long and $\frac{1}{17\cdot2}$ of an inch in diameter. The former was wrapped with a single layer of covered copper wire $\frac{1}{40}$th of an inch in diameter and 21 feet long, the latter similarly with wire 27 feet long. The attractions of these wire electro-magnets were ascertained at distances of 2 and 6 inches. They are all however reduced to the latter distance by means of the data derived from the comparison of the action of the wire electro-magnets at the respective distances.

In the adjoining Table, all the results except the last six were obtained at 2 inches distance, and the observations are divided by 8·96, the relative attraction at 2 inches to that at 6 inches, called unity: the first recorded magnetic set was deduced from the mean of thirty-six experiments on the attraction at 2 inches distance. The mean deflection amounted to no more than ·247 of a minute of a degree, and as the error incident to any single observation is from 1 to 2 minutes of a degree, it follows that no great reliance can be placed on this first result.

Table III.

Attraction, at 6 inches, of wire electro-magnet, $\frac{1}{25 \cdot 6}$ inch diameter, wrapped with 21 feet of wire.

No. of experiments forming the mean result.	Intensity of current.	Total change of magnetism by reversal of current.	Magnetic set.	Total change minus magnetic set.	Set divided by square of current.	Total change minus set, divided by current.
36	·0044 } ·0065	·00072	·00001	·00071	·516 } ·934	·161 } ·159
32	·0086	·00145	·00010	·00135	1·352	·157
18	·0195	·00377	·00029	·00348	·763	·178
20	·0391	·00929	·00152	·00777	·994	·198
9	·0568	·01528	·00330	·01198	1·023	·211
8	·0787	·02657	·00782	·01875	1·263	·238
8	·0806	·02798	·00855	·01943	1·316	·241
8	·0848 } ·0841	·02998	·00939	·02059	1·306 } 1·315	·243 } ·246
8	·0870	·03220	·01001	·02219	1·323	·255
8	·0908	·03529	·01228	·02301	1·489	·253
8	·0961 } ·6963	·03976	·01488	·02488	1·611 } 1·765	·259 } ·256
8	·0992	·04570	·02090	·02480	2·124	·250
8	·0992	·04413	·01809	·02604	1·838	·262
8	·1019	·04573	·01904	·02669	1·834	·262
8	·1046 } ·1060	·04838	·02047	·02791	1·871 } 2·742	·267 } ·287
8	·1085	·05338	·02355	·02983	2·000	·275
8	·1089	·09969	·06240	·03729	5·262	·342
8	·1134	·05972	·02835	·03137	2·205	·277
8	·1151 } ·1156	·10190	·06580	·03610	4·967 } 3·168	·314 } ·291
8	·1184	·06622	·03269	·03353	2·332	·283
8	·1653 } ·1703	·14570	·09900	·04670	3·623 } 4·125	·283 } ·287
8	·1753	·19320	·14220	·05100	4·628	·291
8	·3041 } ·3043	·29710	·21420	·08290	2·316 } 2·393	·272 } ·298
8	·3045	·32810	·22900	·09910	2·470	·325
8	·4372	·38750	·24760	·13990	1·295	·320
6	1·2919	·52980	·26400	·26580	·158	·206
1	2	3	4	5	6	7

From the results of the above Table, it appears that, through the range of electrical intensities from ·0065 to ·0841, the *set* of the wire electro-magnet is proportional to the square of the current; that from the latter intensity to ·1060 the set increases with much greater rapidity, varying at one point with the 6th or 7th power of the current; and that from the intensity ·1060 the rate of increase rapidly declines as the limit of magnetization is approached. From the last column of the Table, it will be seen that the magnetic effect of the current, separated from the set, increases very uniformly with the current, though a little more rapidly. Similar conclusions may be drawn from the results of experiments with the electro-magnet of thicker wire contained in the next Table, in which all the observations but the last four were made at 2 inches distance, and are reduced to the standard of the rest by dividing by 6·668, the observed action on the needle at the distance of 2 inches compared with that at 6 inches.

Table IV.

Attraction, at 6 inches, of wire electro-magnet, $\frac{1}{17\cdot2}$ inch diameter, 1 yard long, wrapped with 27 feet of wire.

Number of experiments forming the mean result.	Intensity of current.	Total change of magnetism by reversal of current.	Magnetic set.	Total change minus magnetic set.	Set divided by square of current.	Total change minus set, divided by current.
44	·0043	·00213	·00007	·00206	3·786	·479
20	·0089	·00443	·00027	·00416	3·408	·469
20	·0248	·01498	·00180	·01318	2·927	·531
10	·0493	·03835	·00719	·03116	2·958	·632
10	·0900	·10720	·03611	·07109	4·458	·790
10	·1171 } ·1188	·18702	·08508	·10194	6·205 } 6·739	·871 } ·802
10	·1205 }	·19404	·10560	·08844	7·273 }	·734 }
10	·1998	·45360	·31840	·13520	7·976	·677
10	·3448	·68450	·43310	·25140	3·643	·729
6	1·1633	1·07320	·48640	·58680	·359	·504
1	2	3	4	5	6	7

My next experiments, recorded in the following Table, were made with a bar of hard steel, 7¾ inches long, ¼ of an inch in diameter, wound with 34 feet of silked copper wire $\frac{1}{40}$th of an inch in diameter, distributed in two layers. The first five observations were obtained at the distance of 3 inches, and are reduced to the standard of the remaining observations at 9 inches by dividing by 22·762, the number of times that the attraction at 3 inches was observed to surpass that at 9 inches.

Table V.

Attraction, at 9 inches, of steel electro-magnet, $7\frac{3}{4}$ inches long, $\frac{1}{4}$ inch diameter, wound with 34 feet of wire.

Number of experiments forming the mean result.	Intensity of current.	Total change of magnetism on reversing the current.	Magnetic set.	Total change minus magnetic set.	Set divided by square of current.	Total change minus set, divided by current.
40	·0045	·00281	·0000092	·00280	·454	·622
40	·0089	·00543	·0000448	·00539	·566	·606
20	·0263	·01663	·0002157	·01641	·312	·624
10	·0489	·03132	·0008769	·03044	·367	·622
8	·0921	·06046	·0032278	·05723	·381	·621
20	·1594	·22992	·02356	·20636	·927	1·294
8	·3201	·65241	·17791	·47450	1·736	1·482
6	·4582	1·09119	·39722	·69397	1·892	1·514
6	·5688	1·45540	·58421	·87119	1·806	1·531
6	·8381	2·22020	1·03410	1·18610	1·472	1·415
2	1·5108	2·96510	1·29880	1·66630	·569	1·103
1	2	3	4	5	6	7

From the preceding Table it appears that the *set* of the steel bar increases almost exactly with the square of the current from the intensity ·0045 to ·0921; that thence to ·1594 it increases more rapidly than the cube of the current; and that from that point it increases in a gradually diminishing ratio as the point of saturation is approached. It will be remarked that the first five numbers of column 7 are nearly equal to one another; but that when the set begins to increase more rapidly than with the square of the current, the magnetism of the bar over and above the *set* increases more rapidly than the current.

There is a striking and instructive analogy between the phenomena above pointed out and those relating to the set and elasticity of materials. Professor Hodgkinson has pointed out that the set or permanent change of figure in any beam is proportional to the square of the force which has been applied, a law which of course is transgressed near the breaking-point. May we not with propriety term the point at which, in the foregoing experiments, the set increases so abruptly, the *magnetic breaking-point*? Mr. Thomson has propounded the view, that the elasticity of all bodies is perfect when abstraction is made of the effect of set. The foregoing Tables indicate approximately the same law respecting what might be termed the *magnetic elasticity*. The analogy thus established between magnetic and ordinary molecular actions, when viewed in connexion with those changes of dimension which take place in iron bars by magnetization, and which I propose to study more deeply, promises to afford a point of view whence a more perfect insight into the nature of magnetism than we at present possess, may ultimately be attained.

Oak Field, Moss Side, Manchester,
June 20, 1855.

COMPTES RENDUS

HEBDOMADAIRES

DES SÉANCES

DE L'ACADÉMIE DES SCIENCES.

» Afin d'obtenir des résultats d'une utilité pratique, il m'a fallu entreprendre un très-grand nombre d'expériences sur la vapeur surchauffée, sur les métaux portés à de très-hautes températures, sur l'action respiratoire ou *pulmonaire*, etc., etc., que je me propose de faire connaître prochainement à l'Académie.

» Cependant on pourrait voir des extraits de mes recherches dans un Mémoire présenté à l'Institut des Ingénieurs civils de Londres, dans ses séances de 1852-1853, et récompensé par la médaille de Telford. Le titre de ce travail est : *On the conversion of heat into mechanical effect.*

» J'ai présenté, en outre, à l'Institut des Ingénieurs-Mécaniciens d'Angleterre, un Mémoire sur un condensateur-régulateur (1850).

» Enfin, j'ai des brevets pris en France et en Angleterre depuis 1847 et 1851, dans lesquels mes idées se trouvent exposées et appliquées aux machines.

» Un de mes appareils fonctionnera, je l'espère, à la prochaine Exposition. L'Académie sera alors mise en état de juger, par expérience, de la valeur réelle des idées théoriques d'où je suis parti. »

PHYSIQUE. — *Note sur l'équivalent mécanique de la chaleur; par* J.-P. JOULE.

« Dans un article de M. Person, publié dans les *Comptes rendus* le 11 décembre 1854, on a donné plusieurs valeurs de l'équivalent mécanique de la chaleur qui diffèrent tellement les unes des autres, qu'elles pourraient contribuer à jeter des doutes sur la rigueur des méthodes qu'on a employées pour y parvenir et sur la doctrine même à laquelle elles se rattachent. Cependant aucune théorie physique n'est appuyée sur des fondements plus solides, et ne permet une plus grande exactitude dans la détermination des coefficients numériques. Je rappellerai d'abord qu'après la découverte du principe de la convertibilité réciproque de la chaleur en travail, à laquelle je fus conduit, en 1843, par mes expériences sur l'électro-magnétisme (1), j'entrepris des expériences sur les effets thermiques produits par la dilatation et la compression de l'air, dans le but d'établir leur rapport avec la convertibilité mutuelle du travail en chaleur. Ces expériences, communiquées, en 1844, à la Société royale, étaient de trois espèces. Dans les premières, la quantité de chaleur qui résulte de la compression de l'air était comparée au travail de cette compression : leur rapport se trouva très-approché du rap-

(1) *Philosophical Magazine*, 1843.

port d'équivalence, auquel j'étais déjà arrivé précédemment. Dans la deuxième série d'expériences, un vase rempli d'air comprimé et un vase semblable où le vide était fait se trouvaient réunis par un tuyau muni d'un robinet; le tout était plongé dans un réservoir rempli d'eau. Quand le robinet était ouvert et que l'air pouvait se répandre dans l'espace additionnel que lui présentait le deuxième vase, on n'observait aucun changement sensible dans la température. Dans la troisième catégorie d'expériences, on comprimait de l'air dans un réservoir, et on le laissait s'échapper par un serpentin plongé avec le réservoir dans de l'eau. La diminution de température observée dans l'eau était comparée au travail nécessaire pour élever une colonne d'air atmosphérique d'une certaine hauteur, et cette comparaison servit à montrer l'équivalence très-approchée de ces deux quantités.

» Les expériences de la deuxième série, que j'ai décrites plus haut, ont été récemment répétées par M. Regnault, et le célèbre physicien est arrivé aux mêmes conclusions que moi-même; c'est-à-dire que, dans les circonstances de ces expériences, où tout effet thermique se distribue à travers une masse d'eau considérable, on ne reconnaît aucune diminution sensible de température quand l'air dans l'acte de la dilatation se restitue à lui-même, sous forme de chaleur, tout le travail produit par l'expansion. Il est pourtant important d'observer que cette conclusion n'est qu'une approximation, et que, dans la réalité, il se produit un peu de froid quand de l'air se dilate sans produire aucun travail extérieur.

» Le professeur Thomson, qui le premier avait soupçonné ce fait, proposa, dans le but d'en vérifier l'exactitude, de faire des expériences où la température d'un fluide élastique confiné sous pression constante est observée immédiatement avant et après son passage à travers un corps poreux non conducteur, en se répandant dans l'atmosphère. Par cette méthode (1), dont la sensibilité est 900 fois plus grande que celle que M. Regnault et moi-même avons employée, il a été établi avec évidence qu'il se produit, dans l'air et les gaz, un très-léger refroidissement quand leur volume augmente sans aucune production de travail. Plus récemment, ces expériences, conduites sur une vaste échelle par M. Thomson et moi-même, ont fait voir qu'aux températures ordinaires ce refroidissement s'élève pour l'air atmosphérique à $0^{\circ},26$ seulement; mais dans l'acide carbonique il s'élève à $1^{\circ},14$ par chaque atmosphère de différence de pression (2).

(1) *Philosophical Magazine,* 1852.

(2) *Philosophical Transactions,* 1855.

» L'équivalent mécanique, tel que M. Person l'a déduit de la vitesse du son, et de la détermination de la chaleur spécifique de l'air sous pression constante, faite par M. Regnault, est donc une valeur très-approchée; et je ferai observer qu'elle est presque identique avec celle à laquelle j'ai été amené par mes expériences sur la chaleur produite par la friction des fluides et dont le résultat est indépendant de toute hypothèse.

» L'équivalent mécanique indiqué par M. Mayer dans un Mémoire très-remarquable, publié dès 1852, fut estimé d'une manière analogue, mais il s'éloigne considérablement de la vérité à cause de l'incorrection du nombre qu'il avait admis pour la chaleur spécifique de l'air. A cette époque, la véritable cause du développement de chaleur produit par la compression de l'air n'avait pas été établie. Aussi le résultat obtenu par cet éminent physicien, quelle que soit la sagacité dont il a fait preuve, ne pouvait être regardé que comme hypothétique.

» Dans un Mémoire sur une machine à air (1), le professeur Thomson et moi avons calculé la chaleur spécifique de l'air au moyen de la vitesse du son et de l'équivalent mécanique déduit de mes expériences sur la friction des fluides. Le résultat auquel nous sommes arrivés s'est trouvé très-conforme avec mes propres déterminations expérimentales, et presque identique avec les plus exactes de toutes celles de M. Regnault. Récemment (2) nous avons corrigé les calculs relatifs à la chaleur spécifique et aux autres propriétés de l'air, en tenant compte des écarts que présentent ces éléments, relativement aux lois ordinaires des gaz, ainsi que M. Regnault les a établis, et en introduisant les corrections qui résultent du faible refroidissement de l'air dilaté, dont j'ai déjà parlé plus haut.

» En terminant, je crois pouvoir établir que la série nombreuse d'expériences sur la friction des fluides que j'ai faites, il y a plusieurs années (3), m'a permis de fixer la valeur de l'équivalent mécanique de la chaleur d'une manière absolue, et indépendammment de toute hypothèse. Ces résultats sont les les suivants :

En pieds anglais et degrés Farenheit..........	772
En pieds anglais et degrés centigrades..........	1389,5
En mètres français et degrés centigrades......	423,5

(1) *Philosophical Transactions*, 1852.

(2) *Philosophical Transactions*, 1855.

(3) *Philosophical Transactions*, 1850.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON.

From January 10, 1856 *to June* 18, 1857 *inclusive.*

(BEING A CONTINUATION OF THE SERIES ENTITLED
"ABSTRACTS OF THE PAPERS COMMUNICATED TO
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VOL. VIII.

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III. Letter from JAMES P. JOULE, Esq. F.R.S. to Prof. STOKES, in reference to the Paper of Dr. WOODS read on the 10th of January 1856. Received February 22, 1856.

Manchester, February 21st, 1856.

In the abstract of Dr. Woods' paper printed in the 'Proceedings' for January 10th, the following remark occurs: "Mr. Joule published in the Philosophical Magazine for June 1852, a memoir proving exactly the same proposition, but giving me the merit of priority in a preliminary remark." In justice to myself I must state that my actual words were—"I observe with pleasure that Dr. Woods has recently arrived at one of the results of the paper, viz. 'that the decomposition of a compound body occasions as much cold as the combination of its elements originally produced heat,' by the use of an elegant experimental process described in this Magazine for October 1851. I ought, however, to remark, that previous to the year 1843 I had demonstrated 'that the heat rendered latent in the electrolysis of water is at the expense of the heat which would otherwise have been evolved in a free state by the circuit.'"

The memoir referred to by Dr. Woods was acknowledged by the French Academy in its 'Comptes Rendus' for Feb. 9, 1846, and according to established rule dates from that period. I may however observe that the law he claims was published by me in the Philosophical Magazine for October 1841, where I pointed out that the heat evolved by the combination of oxygen and hydrogen is equal to that due to the electrical intensity required to separate water into its elements. The same fact was reiterated in various subsequent papers, in which it is also proved that "the quantities of heat which are evolved by the combustion of the chemical equivalents of bodies are proportional to the intensities of their affinities for oxygen" (Phil. Mag. xx. p. 111), a proposition which is given as his own by Dr. Woods, and considered by him as "an original idea."

JAMES P. JOULE.

caused by currents of air of different velocities thus produced, he was enabled to arrive at a measure of the velocities in tubes placed in a still atmosphere, as described in his former paper.

The author in that paper pointed out a correspondence between the variations of force in the upward currents of atmospheric air in the tubes and variations in the humidity of the atmosphere, and expressed his belief that the variations were attributable in great measure to the varying hygrometric conditions of the atmosphere.

In further proof of this position, he has appended two tables, showing that both natural and artificial increase of atmospheric humidity are accompanied by increase in the velocity of the rotations, and that in each case increase of humidity is attended by increase of velocity, independent of temperature.

III. "On the Thermal Effects of Fluids in Motion." By J. P. JOULE, Esq., F.R.S., and Professor W. THOMSON, F.R.S. Received May 23, 1856.

On the Temperature of Solids exposed to Currents of Air.

In examining the thermal effects experienced by air rushing through narrow passages, we have found, in various parts of the stream, very decided indications of a lowering of temperature (see Phil. Trans. June 1853), but never nearly so great as theoretical considerations at first led us to expect, in air forced by its own pressure into so rapid motion as it was in our experiments. The theoretical investigation is simply as follows:—Let P and V denote the pressure and the volume of a pound of the air moving very slowly up a wide pipe towards the narrow passage. Let p and v denote the pressure and the volume per pound in any part of the narrow passage, where the velocity is q. Let also $e-E$ denote the difference of intrinsic energies of the air per pound in the two situations. Then the equation of mechanical effect is

$$\frac{q^2}{2g}=(PV-pv)+(E-e),$$

since the first member is the mechanical value of the motion, per pound of air; the first bracketed term of the second member is the excess of work done in pushing it forward, above the work spent by it in pushing forward the fluid immediately in advance of it in the narrow passage; and the second bracketed term is the amount of intrinsic energy given up by the fluid in passing from one situation to the other.

Now, to the degree of accuracy to which air follows Boyle's and Gay-Lussac's laws, we have

$$pv = \frac{t}{T} PV,$$

if t and T denote the temperatures of the air in the two positions reckoned from the absolute zero of the air-thermometer. Also, to about the same degree of accuracy, our experiments on the temperature of air escaping from a state of high pressure through a porous plug, establish Mayer's hypothesis as the thermo-dynamic law of expansion; and to this degree of accuracy we may assume the intrinsic energy of a mass of air to be independent of its density when its temperature remains unaltered. Lastly, Carnot's principle, as modified in the dynamical theory, shows that a fluid which fulfils those three laws must have its capacity for heat in constant volume constant for all temperatures and pressures,—a result confirmed by Regnault's direct experiments to a corresponding degree of accuracy. Hence the variation of intrinsic energy in a mass of air is, according to those laws, simply the difference of temperatures multiplied by a constant, irrespectively of any expansion or *condensation that may* have been experienced. Hence, if N denote the capacity for heat of a pound of air in constant volume, and J the mechanical value of the thermal unit, we have

$$E - e = JN(T - t).$$

Thus the preceding equation of mechanical effect becomes

$$\frac{q^2}{2g} = PV\left(1 - \frac{t}{T}\right) + JN(T - t).$$

Now (see "Notes on the Air-Engine," Phil. Trans. March 1852, p. 81, or "Thermal Effects of Fluids in Motion," Part 2, Phil. Trans. June 1854, p. 361) we have

$$JN = \frac{1}{k-1}\frac{H}{t_0} = \frac{1}{k-1}\frac{PV}{T},$$

where k denotes the ratio of the specific heat of air under constant pressure to the specific heat of air in constant volume; H, the product of the pressure into the volume of a pound, or the "height of the homogeneous atmosphere" for air at the freezing-point (26,215 feet, according to Regnault's observations on the density of air), and t_0 the absolute temperature of freezing (about 274° Cent.). Hence we have

$$\frac{q^2}{2g} = \mathrm{PV}\left(1 + \frac{1}{k-1}\right)\left(1 - \frac{t}{\mathrm{T}}\right) = \frac{k\,\mathrm{PV}}{k-1}\left(1 - \frac{t}{\mathrm{T}}\right).$$

Now the velocity of sound in air at any temperature is equal to the product of $\sqrt{k}$ into the velocity a body would acquire in falling under the action of a constant force of gravity through half the height of the homogeneous atmosphere; and therefore if we denote by α the velocity of sound in air at the temperature T, we have

$$\alpha^2 = k g \mathrm{PV}.$$

Hence we derive from the preceding equation,

$$\frac{\mathrm{T} - t}{\mathrm{T}} = \frac{k-1}{2}\left(\frac{q}{\alpha}\right)^2,$$

which expresses the lowering of temperature, in any part of the narrow channel, in terms of the ratio of the actual velocity of the air in that place to the velocity of sound in air at the temperature of the stream where it moves slowly up towards the rapids. It is to be observed, that the only hypothesis which has been made is, that in all the states of temperature and pressure through which it passes the air fulfils the three gaseous laws mentioned above; and that whatever frictional resistance, or irregular action from irregularities in the channel, the air may have experienced before coming to the part considered, provided only it has not been allowed either to give out heat or to take in heat from the matter round it, nor to lose any mechanical energy in sound, or in other motions not among its own particles, the preceding formulæ will give the lowering of temperature it experiences in acquiring the velocity q. It is to be observed that this is not the velocity the air would have in issuing in the same quantity at the density which it has in the slow stream approaching the narrow passage. Were no fluid friction operative in the circumstances, the density and pressure would be the same in the slow stream flowing away from, and in the slow stream approaching towards the narrow passage; and each would be got by considering the lowering of temperature from T to t as simply due to expansion, so that we should have

$$\frac{t}{T} = \left(\frac{V}{v}\right)^{k-1}$$

by Poisson's formula. Hence if Q denote what we may call the "reduced velocity" in any part of the narrow channel, as distinguished from q, the actual or true velocity in the same locality, we have

$$Q = \frac{V}{v} q = \left(\frac{t}{T}\right)^{\frac{1}{k-1}} q,$$

and the rate of flow of the air will be, in pounds per second, wQA, if w denote the weight of the unit of volume, under pressure P, and A the area of the section in the part of the channel considered. The preceding equation, expressed in terms of the "reduced velocity," then becomes

$$1 - \frac{t}{T} = \frac{k-1}{2} \left(\frac{T}{t}\right)^{\frac{2}{k-1}} \left(\frac{Q}{\alpha}\right)^2,$$

and therefore we have

$$\frac{Q}{\alpha} = \sqrt{\left\{\frac{2}{k-1} \left(\frac{t}{T}\right)^{\frac{2}{k-1}} \left(1 - \frac{t}{T}\right)\right\}}.$$

The second member, which vanishes when $t = 0$, and when $t = T$, attains a maximum when

$$t = \cdot 83 T,$$

the maximum value being

$$\frac{Q}{\alpha} = \cdot 578.$$

Hence, if there were no fluid friction, the "reduced velocity" could never, in any part of a narrow channel, exceed ·578 of the velocity of sound, in air of the temperature which the air has in the wide parts of the channel, where it is moving slowly. If this temperature be 13° Cent. above the freezing-point, or 287° absolute temperature (being 55° Fahr., an ordinary atmospheric condition), the velocity of sound would be 1115 feet per second, and the maximum reduced velocity of the stream would be 644 feet per second. The cooling effect that air, must, in such circumstances, experience in acquiring such a velocity would be from 287° to 268° absolute temperature, or 19° Cent.

The effects of fluid friction in different parts of the stream would require to be known in order to estimate the reduced velocity in any narrow part, according to either the density on the high-pressure side or the density on the low-pressure side. We have not as yet made any sufficient investigation to allow us to give even a conjectural estimate of what these effects may be in any case. But it appears improbable that the "reduced velocity," according to the density on the high-pressure side, could ever with friction exceed the greatest amount it could possibly have without friction. It therefore seems improbable that the "reduced velocity" in terms of the density on the high-pressure side can ever, in the narrowest part of the channel, exceed 614 feet per second, if the temperature of the high-pressure air moving slowly be about the atmospheric temperature of 13° Cent. used in the preceding estimate.

Experiments in which we have forced air through apertures of $\frac{29}{1000}$, $\frac{53}{1000}$, and $\frac{84}{1000}$ths of an inch in diameter drilled in thin plates of copper, have given us a maximum velocity reduced to the density of the high-pressure side equal to 550 feet per second. But there can be little doubt that the stream of air, after issuing from an orifice in a thin plate, contracts as that of water does under similar circumstances. If the velocity were calculated from the area of the contracted part of the stream, it is highly probable that the maximum velocity reduced to the density on the high-pressure side would be found as near 614 feet as the degree of accuracy of the experiments warrants us to expect.

As an example of the results we have obtained on examining the temperature of the rushing stream by a thermo-electric junction placed $\frac{1}{8}$th of an inch above the orifice, we cite an experiment, in which the total pressure of the air in the receiver being 98 inches of mercury, we found the velocity in the orifice equal to 535 and 1780 feet respectively as reduced to the density on the high-pressure and that on the atmospheric side. The actual velocity in the small aperture must have been greater than either of these, perhaps not much greater than 1780, the velocity reduced to atmospheric density. If it had been only this, the cooling effect would have been exactly $T\frac{k-1}{2}\left(\frac{1780}{1115}\right)^2$, that is, a lowering of temperature amounting to 150° Cent. But the amount of cooling effect observed in the experiment was only 13° Cent.; nor have we ever succeeded in observing (whether with thermometers held in various positions in the stream, or with a thermo-electric arrangement constituted by a narrow tube through which the air flows, or by a straight wire of two different metals in the axis of the stream, with the junction in the place of most rapid motion, and in other positions on each side of it,) a greater cooling effect than 20° Cent; we therefore infer *that a body round which air is flowing rapidly acquires a higher temperature than the average temperature of the air close to it all round.* The explanation of this conclusion probably is, that the surface of contact between the air and the solid is the locality of the most intense frictional generation of heat that takes place, and that consequently a stratum of air round the body has a higher average temperature than the air further off; but whatever the explanation may be, it appears certainly demonstrated that the air does not give its own temperature even to a tube through which it flows, or to a wire or thermometer-bulb completely surrounded by it.

Having been convinced of this conclusion by experiments on rapid motion of air through small passages, we inferred of course that the same phenomenon must take place universally whenever air flows against a solid or a solid is carried through air. If a velocity of 1780 feet per second in the foregoing experiment gave 137° Cent. difference of temperature between the air and the solid, how probable is it that meteors moving at from six to thirty miles per second even through a rarefied atmosphere, really acquire, in accordance with the same law, all the heat which they manifest! On the other hand, it seemed worth while to look for the same kind of effect on a much smaller scale in bodies moving at moderate velocities through the ordinary atmosphere. Accordingly, although it has been a practice in general undoubtingly followed, to whirl a thermometer through the air for the purpose of finding the atmospheric temperature, we have tried and found, with thermometers of different sizes and variously shaped bulbs, whirled through the air at the end of a string, with velocities of from 80 to 120 feet per second, temperatures always higher than when the same thermometers are whirled in exactly the same circumstances at smaller velocities. By alternately whirling the same thermometers for half a minute or so fast, and then for a similar time slow, we have found differences of temperature sometimes little if at all short of a Fahrenheit degree. By whirling a thermo-electric junction alternately fast and slow, the same phenomenon is most satisfactorily and strikingly exhibited by a galvanometer. This last experiment we have performed at night, under a cloudy sky, with the galvanometer within doors, and the testing thermo-electric apparatus whirled in the middle of a field; and thus, with as little as can be conceived of disturbing circumstances, we confirmed the result we had previously found by whirling thermometers.

Velocity of Air escaping through narrow Apertures.*

In the foregoing part of this communication, referring to the circumstances of certain experiments, we have stated our opinion that the velocity of atmospheric air impelled through narrow orifices was, in the narrowest part of the stream, greater than the reduced velocity corresponding to the atmospheric pressure; in other words, that the density of the air, kept at a constant temperature, was, in the narrowest part, less than the atmospheric density. In order to avoid misconception, we now add, that this holds true only when the difference of pressures on the two sides is small, and friction plays but a small part in bringing down the velocity of the exit stream. If there is a great difference between the pressures on the two sides, the reduced velocity will, on the contrary, be *less* than that corresponding with the atmospheric pressure; and even if the pressure in the most rapid part falls short of the atmospheric pressure, the density may, on account of the cooling experienced, exceed the atmospheric density.

We stated that, at 57° Fahr., the greatest velocity of air passing through a small orifice is 550 feet per second, if reduced to the density on the high-pressure side. The experiments from which we obtained this result enable us also to say that this maximum occurs, with the above temperature and a barometric pressure of 30·14 inches, when the pressure of the air is equal to about 50 inches of mercury above the atmospheric pressure. At a higher or lower pressure, a smaller volume of the compressed air escapes in a given time.

* Received June 19, 1856.

Surface Condenser.—A three-horse power high-pressure steam-engine was procured for our experiments. Wishing to give it equal power with a lower pressure, we caused the steam from the eduction port to pass downwards through a perpendicular iron gas-pipe, ten feet long and an inch and a half in diameter, placed within a larger pipe through which water was made to ascend. The lower end of the gas-pipe was connected with the feed-pump of the boiler, a small orifice being contrived in the pump cover in order to allow the escape of air before it could pass, along with the condensed water, into the boiler. This simple arrangement constituted a "surface condenser" of a very efficient kind, giving a vacuum of 23 inches, although considerable leakage of air took place, and the apparatus generally was not so perfect as subsequent experience would have enabled us to make it. Besides the ordinary well-known advantages of the "surface condenser," such as the prevention of incrustation of the boiler, there is one which may be especially remarked as appertaining to the system we have adopted, of causing the current of steam to move in an opposite direction to that of the water employed to condense it. The refrigerating water may thus be made to pass out of the condenser at a high temperature, while the vacuum is that due to a low temperature; and hence the quantity of water used for the purpose of condensation may be materially reduced. We find that our system does not require an amount of surface so great as to involve a cumbrousness or cost which would prevent its general adoption, and have no doubt that it will shortly supersede that at the present time almost universally used.

IV. "On the Stability of Loose Earth." By W. J. Macquorn Rankine, Esq., C.E., F.R.SS. L. & E., Regius Professor of Civil Engineering and Mechanics in the University of Glasgow.

(Abstract.)

The object of this paper is to deduce the mathematical theory of that kind of stability which depends on the mutual friction of the parts of a granular mass devoid of tenacity, from the known laws of friction, unaided by any hypothesis.

III. "On the Thermo-electricity of Ferruginous Metals, and on the Thermal Effects of stretching Solid Bodies." By J. P. JOULE, F.R.S. Received January 29, 1857.

The experiments on the above subjects were made with a thermo-multiplier placed in the vacuum of an air-pump. Its sensibility was such that with the junction antimony and bismuth, a thermometric effect not greater than $\frac{1}{5000}$ of a degree Centigrade could be estimated. In determining the thermo-electric position of the metals, it was necessary to increase the resistance of the instrument a hundred-fold, by placing in the circuit a coil of fine wire. In thermo-electric arrangement *steel* was found to be nearer copper than iron was. By hardening, steel was raised almost to the place of copper. *Cast iron* was found to surpass copper; so that the junction cast iron and copper is reverse to that of wrought iron and copper, and the arrangement cast iron and wrought iron is much more powerful than copper and wrought iron. *A new test of the quality and purity of* ferruginous metals is thus indicated, which will probably be found of value to the arts.

The experiments on the stretching of solids showed, in the case of the metals, a decrease of temperature when the stretching weight was applied, and a heating effect when the weight was removed. An iron wire $\frac{1}{4}$ of an inch in diameter was cooled $\frac{1}{10}$ of a degree Centigrade when stretched by a weight of 775 lbs. Similar results were obtained with cast iron, hard steel, copper, and lead. The thermal effects were in all these cases found to be almost identical with those deduced from Professor Thomson's theoretical investigation, the particular formula applicable to the case in question being $H=\frac{t}{J}\times Pe$, where H is the heat absorbed in a wire one foot long, t the absolute temperature, J the mechanical equivalent of the thermal unit, P the weight applied, and e the coefficient of expansion per 1°. With gutta-percha also a cooling effect on extension was observed; but a reverse action was discovered in the case of vulcanized india-rubber, which became *heated* when the weight is laid on, and *cooled* when the weight was removed. On learning this curious result, Professor Thomson, who had already intimated the probability of a reverse action being observed under certain circumstances with india-rubber, suggested to the author experiments to ascertain whether vulcanized india-rubber stretched by a weight is shortened by increase of temperature. Accordingly, on trial, it was found that this material, when stretched by a weight capable of doubling its length, has that length diminished by one-tenth when its temperature is raised 50° Centigrade. This shortening effect was found to increase rapidly with the stretching weight employed; and, exactly according with the heating effects observed with different stretching weights, entirely to confirm the theory of Professor Thomson.

February 5, 1857.

The LORD WROTTESLEY, President, in the Chair.

THE BAKERIAN LECTURE was delivered by MICHAEL FARADAY, Esq., F.R.S., "On the Relations of Gold and other Metals to Light."

The Lecturer gave an exposition, illustrated by experiments, of the substance of a paper presented by him to the Society under the above title. The following is an abstract:—

The author of this paper hopes that the undulatory theory of light, when more fully and perfectly developed, may aid in comparing local actions with those which take place at a distance, and even help towards the comprehension of the physical means by which the latter are carried on; and with that view he endeavoured, experimentally, to subject a ray of light to the action of particles, so small in size as to have an immediate and near relation, not only to the undulations of light, but even to the far smaller motions of the parts of the ether, which are supposed to produce, by their joint and successive action, the light-wave. His hope was, that by choosing particles of a fitting substance, experimental results might be obtained which, in the hands of the mathematical philosopher, might aid in perfecting the theory; and for this purpose gold was selected, because of its high optical

PROCEEDINGS

OF

THE ROYAL SOCIETY.

January 10, 1856.

ADMIRAL BEECHEY, V.P., in the Chair.

In consequence of there not being a sufficient number of Fellows present, the Ballot for the question of the readmission of Mr. Sievier was postponed to the next Meeting.

The following communications were read:—

I. "On Insolinic Acid." By AUGUSTUS W. HOFMANN, Ph.D., F.R.S. &c. Received December 20, 1855.

(Abstract.)

In attempting to purify cuminic acid by boiling with chromic acid, I observed that this acid experienced, on the part of this reagent, a progressive alteration. By twenty-four hours' ebullition, cuminic acid is completely converted into an acid insoluble in alcohol

XXI. "On the Thermal Effects of Fluids in Motion:—Temperature of a Body moving slowly through Air." By Prof. W. Thomson, F.R.S., and J. P. Joule, Esq., F.R.S. Received June 18, 1857.

The motion of air in the neighbourhood of a body moving very slowly through it, may be approximately determined by treating the problem as if air were an incompressible fluid. The ordinary hydrodynamical equations, so applied, give the velocity and the pressure of the fluid at any point; and the variations of density and temperature actually experienced by the air are approximately determined by using the approximate evaluation of the pressure thus obtained. Now, if a solid of any shape be carried uniformly through a perfect liquid *, it experiences fluid-pressure at different parts of its surface, expressed by the following formula,—

$$p=\Pi+\tfrac{1}{2}\rho\,(V^2-q^2),$$

where Π denotes the fluid-pressure at considerable distances from the solid, ρ the mass of unity of volume of the fluid, V the velocity of translation of the solid, and q the velocity of the fluid relatively to the solid, at the point of its surface in question. The effect of this pressure on the whole is, no resultant force, and only a resultant couple which vanishes in certain cases, including all in which the solid is symmetrical with reference to the direction of motion. If the surface of the body be everywhere convex, there will be an augmentation of pressure in the fore and after parts of it, and a diminution of pressure round a medium zone. There are clearly in every such case just two points of the surface of the solid, one in the fore part, and the other in the after part, at which the velocity of the fluid relatively to it is zero, and which we may call the fore and after pole respectively. The middle region round the body in which the relative velocity exceeds V, and where consequently the fluid pressure is diminished by the motion, may be called the equatorial zone; and where there is a definite middle line, or line of maximum relative volocity, this line will be called the equator.

* That is, as we shall call it for brevity, an ideal fluid, perfectly incompressible and perfectly free from mutual friction among its parts.

If the fluid be air instead of the ideal "perfect liquid," and if the motion be slow enough to admit of the approximation referred to above, there will be a heating effect on the fore and after parts of the body, and a cooling effect on the equatorial zone. If the dimensions and the thermal conductivity of the body be such that there is no sensible loss on these heating and cooling effects by conduction, the temperature maintained at any point of the surface by the air flowing against it, will be given by the equation

$$t=\Theta\left(\frac{p}{\Pi}\right)^{\frac{\cdot 41}{1\cdot 41}},$$

where Θ denotes the temperature of the air as uninfluenced by the motion, and p and Π denote the same as before*. Hence, using for p its value by the preceding equation, we have

$$t=\Theta\left\{1+\frac{\rho}{2\Pi}\left(V^2-q^2\right)\right\}^{\frac{\cdot 41}{1\cdot 41}}.$$

But if H denote the length of a column of homogeneous atmosphere, of which the weight is equal to the pressure on its perpendicular section, and if g denote the dynamical measure of the force of gravity (32·2 in feet per second of velocity generated per second), we have

$$g\rho H=\Pi\,;$$

and if we denote by a the velocity of sound in the air, which is equal to $\sqrt{1\cdot 41\times gH}$, the expression for the temperature becomes

$$t=\Theta\left\{1+\frac{1\cdot 41}{2}\,\frac{V^2-q^2}{a^2}\right\}^{\frac{\cdot 41}{1\cdot 41}}.$$

According to the supposition on which our approximation depends, that the velocity of the motion is small, that is, as we now see, a small fraction of the velocity of sound, the expression becomes

$$t=\Theta\left\{1+\cdot 41\times\frac{V^2-q^2}{2a^2}\right\}.$$

At either the fore or after pole, or generally at every point where the velocity of the air relatively to the solid vanishes (at a re-entrant

* The temperatures are reckoned according to the absolute thermodynamic scale which we have proposed, and may, to a degree of accuracy correspondent with that of the ordinary "gaseous laws," be taken as temperature Centigrade by the air-thermometer, with 273°·7 added in each case. See the author's previous paper "On the Thermal Effects of Fluids in Motion," Part II., Philosophical Transactions, 1854, part 2. p. 353.

angle for instance, if there is such), we have $q=o$, and therefore an elevation of temperature amounting to

$$\cdot41\times\frac{V^2}{2a^2}\Theta.$$

If, for instance, the absolute temperature, Θ, of the air at a distance from the solid be 287° (that is 55° on the Fahr. scale), for which the velocity of sound is 1115 per second, the elevation of temperature at a pole, or at any point of no relative motion, will be, in degrees Centigrade,

$$58^\circ{\cdot}8\times\left(\frac{V}{a}\right)^2,\text{ or }58^\circ{\cdot}8\times\left(\frac{V}{1115}\right)^2,$$

the velocity V being reckoned in feet per second. If, for instance, the velocity of the body through the air be 88 feet per second (60 miles an hour), the elevation of temperature at the points of no relative motion is ·36°, or rather more than $\frac{1}{3}$ of a degree Centigrade.

To find the greatest depression of temperature in any case, it is necessary to take the form of the body into account. If this be spherical, the absolute velocity of the fluid backwards across the equator will be half the velocity of the ball forwards; or the relative velocity (q) of the fluid across the equator will be $\frac{3}{2}$ of the velocity of the solid. *Hence the depression of temperature at the equator of a sphere moving slowly through the air will be just* $\frac{5}{4}$ of the elevation of temperature at each pole. It is obvious from this that a spheroid of revolution, moving in the direction of its axis, would experience at its equator a depression of temperature, greater if it be an oblate spheroid, or less if it be a prolate spheroid, *than* $\frac{5}{4}$ *of* the elevation of temperature at each pole.

It must be borne in mind, that, besides the limitation to velocities of the body small *in comparison* with the velocity of sound, these conclusions involve the supposition that the relative motions of the different parts of the air are unresisted by mutual friction, a supposition which is not even approximately true in most cases that can come under observation. Even in the case of a ball pendulum vibrating in air, Professor Stokes* finds that the motion is seriously influenced

* "On the Effect of the Internal Friction of Fluids on the Motion of Pendulums," read to the Cambridge Philosophical Society, Dec. 9, 1850, and published in vol. ix. part 2 of their Transactions.

by fluid friction. Hence with velocities which could give any effect sensible on even the most delicate of the ether thermometers yet made (330 divisions to a degree), it is not to be expected that anything like a complete verification or even illustration of the preceding theory, involving the assumption of no friction, can be had. It is probable that the forward polar region of heating effect will, in consequence of fluid friction, become gradually larger as the velocity is increased, until it spreads over the whole equatorial region, and does away with all cooling effects.

Our experimental inquiry has hitherto been chiefly directed to ascertain the law of the thermal effect upon a thermometer rapidly whirled in the air. We have also made some experiments on the modifying effects of resisting envelopes, and on the temperatures at different parts of the surface of a whirled globe. The whirling apparatus consisted of a wheel worked by hand, communicating rapid rotation to an axle, at the extremity of which an arm carrying the thermometer with its bulb outwards was fixed. The distance between the centre of the axle and the thermometer bulb was in all the experiments 39 inches. The thermometers made use of were filled with ether or chloroform, and had, the smaller 275, and the larger 330 divisions to the degree Centigrade. The lengths of the cylindrical bulbs were $\frac{9}{10}$ and $1\frac{4}{10}$ inch, their diameters ·26 and ·48 of an inch respectively.

Table I.—Small bulb Thermometer.

Velocity in feet per second.	Rise of temperature in divisions of the scale.	Rise divided by square of velocity.
46·9	$27\frac{1}{2}$	·0125
51·5	32	·0121
68·1	$46\frac{1}{2}$	·0100
72·7	$57\frac{1}{2}$	·0109
78·7	$67\frac{1}{2}$	·0109
84·8	74	·0103
104·5	91	·0083
130·2	151	·0089
133·2	172	·0097
145·4	191	·0090
	Mean..	·01026

The above Table shows an increase of temperature nearly proportional to the square of the velocity.

$V=\sqrt{\frac{275}{\cdot 01026}}=163\cdot 7=$ the velocity in feet per second, which, in air of the same density, would have raised the temperature 1° Centigrade.

Table II.—Larger bulb Thermometer.

Velocity in feet per second.	Rise of temperature in divisions of scale.	Rise divided by square of velocity.
36·3	18	·0125
66·6	42	·0095
84·8	57	·0079
125·6	146	·0093
	Mean	·0098

In this instance $V=\sqrt{\frac{330}{\cdot 0098}}=183\cdot 5$ feet per second for 1° Centigrade. It is however possible that the full thermal effect was not so completely attained in three minutes (the time occupied by each whirling) as with the smaller bulb. On the whole it did not appear to us that the experiments justified the conclusion, that an increase of the dimensions of the bulb was accompanied by an alteration of the thermal effect.

Table III.—Larger bulb Thermometer covered with five folds of writing-paper.

Velocity in feet per second.	Rise of temperature in divisions of scale.	Rise divided by square of velocity.
36·3	20	·0152
51·5	43	·0162
72·6	53	·0101
118	132	·0095

The increased thermal effect at comparatively slow velocities, exhibited in the above Table, appeared to be owing to the friction of the air against the paper surface being greater than against the polished glass surface.

One quarter of the enveloping paper was now removed, and the bulb whirled with its bared part in the rear. The results were as follow :—

TABLE IV.—Paper removed from posterior side.

Velocity in feet per second.	Rise of temperature in divisions of scale.	Rise divided by square of velocity.
75·6	60	·0105
96·8	87	·0093

On whirling in the contrary direction, so that the naked part of the bulb went first, we got,—

TABLE V.—Paper removed from anterior side.

Velocity in feet per second.	Rise of temperature in divisions of scale.	Rise divided by square of velocity.
81·7	56	·0084
93·8	72	·0082

On rotating with the bare part, posterior and anterior in turns, at the constant velocity of 90 feet per second, the mean result did not appear to indicate any decided difference of thermal effect.

Another quarter of paper was now removed from the opposite side. Then on whirling so that the bared parts were anterior and posterior, we obtained a rise of 83 divisions with a velocity of 93·8. But on turning the thermometer on its axis one quarter round, so that the bared parts were on each side, we found the somewhat smaller rise of 62 divisions for a velocity of 90·8 feet per second.

The effect of surface friction having been exhibited at slow velocities with the papered bulb, we were induced to try the effect of increasing it by wrapping iron wire round the bulb.

TABLE VI.—Larger bulb Thermometer wrapped with iron wire.

Velocity in feet per second.	Rise in divisions of scale.	Rise divided by square of velocity.
15·36	10·25	·0434
23·04	33	·0623
30·71*	49·25	·0522
46·08	68·75	·0324
69·12	98	·0206
111·34	185	·0149
126·72	207	·0129
153·55	above 280	above ·0118

* The whirring sound began at this velocity. According to its intensity the

On inspecting the above Table, it will be seen that the thermal effect produced at slow velocities was five times as great as with the bare bulb. This increase is evidently due to friction. In fact, as one layer of wire was employed, and the coils were not so close as to prevent the access of air between them, the surface must have been about four times as great as that of the uncovered bulb. At high velocities, it is probable that a cushion of air which has not time to escape past resisting obstacles makes the actual friction almost independent of variations of surface, which leave the magnitude of the body unaltered. In conformity with this observation, it will be seen that at high velocities the thermal effect was nearly reduced to the quantity observed with the uncovered bulb. Similar remarks apply to the following results obtained after wrapping round the bulb a fine spiral of thin brass wire.

TABLE VII.—Bulb wrapped with a spiral of fine brass wire.

Velocity in feet per second.	Rise in divisions of scale.	Rise divided by square of velocity.
7·68	2·5	·0424
15·36	13·5	·0572
23·04	36·5	·0687
30·71	48	·0509
46·08	64·5	·0304
76·8	103·5	·0175
115·18	224·5	·0169
148·78	264	·0119

The thermal effects on different sides of a sphere moving through air, have been investigated by us experimentally by whirling a thin glass globe of 3·58 inches diameter along with the smaller thermometer, the bulb of which was placed successively in three positions, viz. in front, at one side, and in the rear. In each situation it was placed as near the glass globe as possible without actually touching it.

thermal effect must necessarily suffer diminution; unless indeed it gives rise to increased resistance.

TABLE VIII.—Smaller Thermometer whirled along with glass globe.

Velocity in feet per second.	Rise in divisions of scale.		
	Therm. in front.	Therm. at side.	Therm. in rear.
3·84	·66	10	4
7·68	2·66	40	10·5
15·36	41·9	78	51
23·04	71·2	90	71·7
38·4	78·4	90	68
57·5	99·9	112	76
70·92			107

The effects of fluid friction are strikingly evident in the above results, particularly at the slow velocities of 3 and 7 feet per second. It is clear from these, that the air, after coming in contact with the front of the globe, traverses with friction the equatorial parts, giving out an accumulating thermal effect, a part of which is carried round to the after pole. At higher velocities the effects of friction seem rapidly to diminish, so that at velocities between 23 and 38 feet per second, the mean indication of thermometers placed all round the globe would be nearly constant. Our anticipation (written before these latter experiments were made), that a *complete* verification of the theory propounded at the commencement was impossible with our present means, is thus completely justified.

It may be proper to observe, that in the form of experiment hitherto adopted by us, the results are probably, to a trifling extent, influenced by the vortex of air occasioned by the circular motion.

We have on several occasions noticed the effect of sudden changes in the force of wind on the temperature of a thermometer held in it. Sometimes the thermometer was observed to rise, at other times to fall, when a gust came suddenly on. When a rise occurred, it was seldom equivalent to the effect, as ascertained by the foregoing experiments, due to the increased velocity of the air. Hence we draw the conclusion, that the actual temperature of a gust of wind is lower than that of the subsequent lull. This is probably owing to the air in the latter case having had its *vis viva* converted into heat by collision with material objects. In fact we find that in sheltered situations, such for instance as one or two inches above a wall opposite to the wind, the thermometer indicates a higher temperature than it does when exposed to the blast. The question, which is one of great interest for meteorological science, has hitherto been only partially discussed by us, and for its complete solution will require a careful estimate of the temperature of the earth's surface, of the effects of radiation, &c., and also a knowledge of the causes of gusts in different winds.

XXII. "On the Thermal Effects of Longitudinal Compression of Solids." By J. P. JOULE, Esq., F.R.S.; and "On the Alterations of Temperature accompanying Changes of Pressure in Fluids." By Prof. W. THOMSON, F.R.S. Received June 18, 1857.

In the further prosecution of the experiments of which an outline was given in the 'Proceedings' for January 29, 1857, the author has verified the theory of Professor Thomson, as applied to the thermal effects of laying weights on and taking them off metallic pillars and cylinders of vulcanized india-rubber. Heat is evolved by compression, and absorbed on removing the compressing force in every substance yet experimented on. In the case of metals, the results agree very closely with the formula in which e, the longitudinal expansion by heat under pressure, is considered the same as the expansion without pressure. *It was observed, however, that* all the experimental results were a little in excess of the theoretical, and it became therefore important to inquire whether the force *of elasticity in metals is impaired by heat. In the first arrange*ments for this purpose, the actual expansion of the bars employed in the experiments was ascertained by a micrometric apparatus, 1st, *when there was no tensile force, and 2nd, when a weight of 700 lbs.* was hung to the extremity of the quarter-inch rods. The results, reliable to less than one-hundredth of their whole value, did not exhibit any notable effect *of tensile force on the coefficient of expansion* by heat. An experiment susceptible of greater delicacy was now tried. Steel wire of $\frac{1}{50}$th of an inch in diameter was wound upon a rod of iron $\frac{1}{4}$ of an inch in diameter. This was heated to redness. Then, after plunging in cold water, the spiral was slipped off. The number of convolutions of the spiral was 420, and its weight 58 grains. Its length, when suspended from one end, was 6·35 inches, but on adding to the extremity a weight of 129 grains, it stretched without sensible set to 14·55 inches. The temperature of the spiral thus stretched was raised or lowered at pleasure by putting it in, or removing it out of an oven. After several experiments it was found that between the limits of temperature 84° and 280° Fahr., each degree Centigrade of rising temperature caused the spiral to lengthen as much as ·00337 of an inch, and that a contraction of equal amount took place with each degree Centigrade of descending temperature. Hence, as Mr. James Thomson has shown that the pulling out of a spiral is equivalent to twisting a wire, it follows that the force of torsion in steel wire is decreased ·00011 by each degree of temperature.

An equally decisive result was obtained with copper wire, of which an elastic spiral was formed by stretching out a piece of soft wire, and then rolling it on a rod $\frac{1}{4}$ of an inch in diameter. The spiral thus formed consisted of 255 turns of wire, $\frac{1}{40}$ of an inch in diameter, weighing altogether 230 grains. Unstretched, it measured 6·7 inches, but with a weight of 1251 grains attached to it, it stretched, without set, to 10·05 inches. Experiments made with it showed an elongation of ·00157 of an inch for each degree Centigrade of elevation of temperature, and an equal shortening on lowering the temperature. The diminution of the force of torsion was in this case ·00047 per degree Centigrade*.

* Since writing the above, I have become acquainted with M. Kupffer's researches on the influence of temperature on the elasticity of metals (*Compte-Rendu Annuel*, St. Petersburgh, 1856). He finds by his method of twisting and transverse oscillations, that the decrease of elasticity for steel and copper is ·000471 and ·000478. Very careful experiments recently made by Prof. Thomson, indicate a slight increase of expansibility by heat in wires placed under tension.—August 1. J. P. J.

Professor Thomson has obligingly furnished me with the following investigation :—

On the Alterations of Temperature accompanying Changes of Pressure in Fluids.

Let a mass of fluid, given at a temperature t and under a pressure p, be subjected to the following cycle of four operations in order.

(1) The fluid being protected against gain or loss of heat, let the pressure on it be increased from p to $p+\varpi$.

(2) Let heat be added, and the pressure of the fluid maintained constant at $p+\varpi$, till its temperature rises by dt.

(3) The fluid being again protected against gain or loss of heat, let its pressure be reduced from $p+\varpi$ to p.

(4) Let heat be abstracted, and the pressure maintained at p, till the temperature sinks to t again.

At the end of this cycle of operations, the fluid is again in the same physical condition as it was at the beginning, but, as is shown by the following considerations, a certain transformation of heat into work or the reverse has been effected by means of it.

In two of these four operations the fluid increases in bulk, and in the other two it contracts to an equal extent. If the pressure were uniform during them all, there would be neither gain nor loss of work; but inasmuch as the pressure is greater by ϖ during operation (2) than during operation (1), and rises during (1) by the same amount as it falls during (3), there will, on the whole, be an amount of work equal to $\varpi\, dv$, done by the fluid in expanding, over and above that which is spent on it by pressure from without while it is contracting, if dv denote a certain augmentation of volume which, when ϖ and dt are infinitely small, is infinitely nearly equal to the expansion of the fluid during operation (2), or its contraction during operation (4). Hence, considering the bulk of the fluid primitively operated on as unity, if we take

$$\frac{dv}{dt}=e,$$

to denote an average coefficient of expansion of the fluid under constant pressure of from p to $p+\varpi$, or simply its coefficient of expansion at temperature t and pressure p, when we regard ϖ as infinitely small, we have an amount of work equal to

$$\varpi\, e\, dt$$

gained from the cycle. The case of a fluid such as water below 39°·1 Fahr., which contracts under constant pressure, with an elevation of temperature, is of course included by admitting negative values for e, and making the corresponding changes in statement.

Since the fluid is restored to its primitive physical condition at the end of the cycle, the source from which the work thus gained is drawn, must be heat, and since the operations are each perfectly reversible, Carnot's principle must hold; that is to say, if θ denote the excess of temperature of the body while taking in heat above its temperature while giving out heat, and if μ denote "Carnot's function," the work gained, per unit of heat taken in at the higher temperature, must be equal to

$$\mu\,\theta.$$

But while the fluid is giving out heat, that is to say, during operation (1), its temperature is sinking from $t + dt$ to t, and may be regarded as being on the average $t + \frac{1}{2}dt$; and while it is taking in heat, that is, during operation (2), its temperature is rising from what it was at the end of operation (1) to a temperature higher by dt, or on the average exceeds by $\frac{1}{2}dt$, the temperature at the end of operation (1). The average temperature while heat is taken in consequently exceeds the average temperature while heat is given out, by just as much as the body rises in temperature during operation (1). If, therefore, this be denoted by θ, and if $\mathrm{K}\,dt$ denote the quantity of heat taken in during operation (2), the gain of work from heat in the whole cycle of operations must be equal to $\mu\,\theta\,\mathrm{K}\,dt$, and hence we have

$$\mu\,\theta\,.\,\mathrm{K}\,dt = \varpi\, e\, dt.$$

From this we find

$$\theta = \frac{e}{\mu\mathrm{K}}\varpi,$$

where, according to the notation that has been introduced, θ is the elevation of temperature consequent on a sudden augmentation of pressure from p to $p + \varpi$; e is the coefficient of expansion of the fluid, and K its capacity for heat, under constant pressure; and μ is Carnot's function, being, according to the absolute thermodynamic scale of temperature, simply the reciprocal of the temperature, multiplied by the mechanical equivalent of the thermal unit. If then t denote the absolute temperature, which we have shown by experiment* agrees sensibly with temperature by the air-thermometer Cent. with 274° added, and if J denote the mechanical equivalent of the thermal unit Centigrade, we have

$$\theta=\frac{t\,e}{\mathrm{JK}}\varpi.$$

This expression agrees in reality, but is somewhat more convenient in form, than that first given, Dynamical Theory of Heat, § 19, Trans. R.S.E. 1851.

Thus for water, the value of K, the thermal capacity of a cubic foot under constant pressure, is 63·447, and e varies from 0 to about $\frac{1}{2200}$, for temperatures rising from that of maximum density to 50° Cent., and the elevation of temperature produced by an augmentation of pressure amounting to n times 2117 lbs. per square foot (that is to say, to n atmospheres), is

$$\frac{t\,e\times2117}{1390\times63\cdot447}n.$$

For mercury, we have $\frac{t\,e\times2117}{1390\times28\cdot68}n.$

If, as a rough estimate, we take

$$e=\frac{t-278}{46}\times\frac{1}{2200},$$

this becomes $\frac{t(t-278)}{420000}n.$

If, for instance, the temperature be 300° on the absolute scale (that is, 26° of the Centig. thermometer), we have

$$\frac{n}{636}$$

as the heating effect produced by the sudden compression of water at that temperature: so that ten atmospheres of pressure would give $\frac{1}{64}$ of a degree Cent., or about five divisions on the scale of the most sensitive of the ether thermometers we have as yet had constructed.

Thus if we take $\frac{1}{5300}$ as the value of e, this becomes

$$\frac{t}{103600}n;$$

* See Part II. of our Paper "On the Thermal Effects of Fluids in Motion," Philosophical Transactions, 1854.

and at temperature 26° Cent., the heating effect of ten atmospheres is found to be $\frac{1}{34}$ of a degree Cent.

TABLE giving the thermal effects of a pressure of ten atmospheres on water and mercury*.

Temperature.	Increase or decrease of temperature in water.	Increase of temperature in mercury.
0°	·005 decrease	·026
3°·95	·0	·0261
10°	·006 increase	·027
20°	·015 do.	·028
30°	·022 do.	·029
40°	·029 do.	·030
50°	·035 do.	·031
60	·041 do.	·032
70°	·047 do.	·033
80°	·055 do.	·034
90°	·065 do.	·035
100°	·078 do.	·036

XXIII. "On the Phenomenon of Relief of the Image formed on the Ground Glass of the Camera Obscura." By A. CLAUDET, Esq., F.R.S. Received June 17, 1857.

(Abstract.)

The author having observed that the image formed on the ground glass of the camera obscura appears as much in relief as the natural object when seen with the two eyes, has endeavoured to discover the cause of that phenomenon, and his experiments and researches have disclosed the singular and unexpected fact, that although only one image *seems* depicted on the ground glass, still each eye perceives a different image; that in reality there exist on the ground glass two images, the one visible only to the right eye, and the other visible only to the left eye. That the image seen by the right eye is the representation of the object refracted by the left side of the lens, and the image seen by the left eye is the representation of the object refracted by the right side of the lens. Consequently these two images presenting two different perspectives, the

* Added August 1.

PROCEEDINGS

OF

THE ROYAL SOCIETY.

November 19, 1857.

Dr. W. A. MILLER, V.P., in the Chair.

In accordance with the Statutes, notice was given of the ensuing Anniversary Meeting for the election of Council and Officers.

Mr. Thomas Davidson, Mr. George Bowdler Buckton, and Mr. Joseph Whitworth, were admitted into the Society.

Mr. Gassiot, Mr. Hardwick, Mr. Horner, Dr. Percy, and Mr. Archibald Smith, were elected by ballot as Auditors of the Treasurer's Accounts, on the part of the Society.

The following communications were read:—

I. "On the Anatomy of *Tridacna*." By J. D. MACDONALD, Esq.

(For Abstract, see vol. viii. p. 589.)

II. "Summary of a paper on the Spinal Cord as a leader for Sensibility and Voluntary Movements." By E. BROWN-SÉQUARD, M.D.

(See vol. viii. p. 591.)

III. "Summary of a paper on the resemblance between the effects of the section of the Sympathetic Nerve in the Neck and of a transverse section of a lateral half of the Spinal Cord." By E. BROWN-SÉQUARD, M.D.

(See vol. viii. p. 594.)

IV. "Experimental Researches on the Influence of Efforts of Inspiration on the Movements of the Heart." By E. BROWN-SÉQUARD, M.D.

(See vol. viii. p. 596.)

LL.D.; John Percy, M.D.; Lyon Playfair, Ph.D.; The Rev. Bartholomew Price, M.A.; Archibald Smith, Esq., M.A.; Charles Wheatstone, Esq.

Mr. Henry Clifton Sorby was admitted into the Society.

The following communications were read:—

I. "On the Expansion of Wood by Heat." By J. P. Joule, LL.D., F.R.S. &c. Received November 5, 1857.

In pursuing the researches of which abstracts have been given in the 'Proceedings' for January 29 and June 18, the author found that the heat evolved by compressing wood, cut either in or across the direction of the grain, was nearly that due to the application to the particular case of Professor Thomson's formula. Exact agreement could not be expected, on account of the discordant results arrived at by different experimenters on the expansion of wood. On investigating the subject, the author finds that the expansion of wood cut in the direction of the grain, is greatly influenced by the tension to which it is exposed, as well as by its humidity. A rod of well-seasoned and dried bay-wood, $\frac{3}{8}$ths of an inch in diameter, and exposed to the tension of 26 lbs., gave an expansion of ·00000461 per degree Centigrade, but when a weight of 426 lbs. was hung to it, its coefficient of expansion was increased to ·00000566. In conformity with this result, it was found that the elasticity of the rod was considerably diminished by an increase of its temperature. On investigating the effect of humidity, the author found that it occasioned a diminution in the expansibility by heat. After the rod of bay-wood with which the above experiments were made had been immersed in water until it had taken up 150 grains, making its total weight 882 grs., its expansion with a tension of 26 lbs. was found to be only ·000000436. Experiments with a rod of deal 33 inches long, and weighing when dried 425 grs., gave similar results. Its expansion when dry, with 26 lbs. tension, was ·00000428, and with 226 lbs. ·00000138; but when made to absorb water, its coefficient of expansion gradually decreased, until, when it weighed 874 grs., indicating an absorption of 449 grs. of water, expansion by heat ceased altogether, and, on the contrary, a *contraction* by heat equal to ·000000636 was experienced.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON.

From November 19, 1857 *to April* 14, 1859 *inclusive.*

(BEING A CONTINUATION OF THE SERIES ENTITLED "ABSTRACTS OF THE PAPERS COMMUNICATED TO THE ROYAL SOCIETY OF LONDON.")

VOL. IX.

LONDON:
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MDCCCLIX.

III. "On the Thermal Effect of drawing out a Film of Liquid." By Professor WILLIAM THOMSON, F.R.S., &c., being extract of two Letters to J. P. JOULE, LL.D., F.R.S., dated February 2 and 3, 1858. Received April 30, 1858.

A very novel application of Carnot's cycle has just occurred to me in consequence of looking this morning into Waterston's paper on Capillary Attraction, in the January Number of the Philosophical Magazine. Let T be the contractile force of the surface (by which in Dr. Thomas Young's theory the resultant effect of cohesion on a liquid mass of varying form is represented), so that, if Π be the atmospheric pressure, the pressure of air within a bubble of the liquid of radius r, shall be $\frac{4T}{r}+\Pi$. Then if a bubble be blown from the end of a tube (as in blowing soap-bubbles), the work spent, per unit of augmentation of the area of one side of the film, will be equal to 2T.

Now since liquids stand to different heights in capillary tubes at different temperatures, and generally to less heights at the higher temperatures, T must vary, and in general decrease, as the temperature rises, for one and the same liquid. If T and T′ denote the values of the capillary tension at temperatures t and t' of our absolute scale, we shall have $2(T-T')$ of mechanical work gained, in allowing a bubble on the end of a tube to collapse so as to lose a unit of area at the temperature t and blowing it up again to its original dimensions after having raised its temperature to t'. If $t'-t$ be infinitely small, and be denoted by $\mathfrak{T}$, the gain of work may be expressed by

$$-\frac{2dT}{dt}\times\mathfrak{T};$$

and by using Carnot's principle as modified for the Dynamical Theory, in the usual manner, we find that there must be an absorption of heat at the high temperature, and an evolution of heat at the low temperature; amounting to quantities differing from one another by

$$\frac{1}{J}\times\frac{-2dT}{dt}\times\mathfrak{T},$$

and each infinitely nearly equal to the mechanical equivalent of this difference, divided by Carnot's function, which is $\frac{J}{t}$, if the temperature is measured on our absolute scale. Hence if a film such as a soap-bubble be enlarged, its area being augmented in the ratio of 1 to m, it experiences a cooling effect, to an amount calculable by finding the lowering of temperature produced by removing a quantity of heat equal to

$$m\frac{t}{J}\times\frac{-dT}{dt},$$

from an equal mass of liquid unchanged in form.

For water T=2·96 gr. per lineal inch.

Work per square inch spent in drawing out a film =5·92, say 6 grains, $\frac{dT}{dt}=\frac{1}{550}T$, or thereabouts.

Suppose $\frac{t'}{J}=\frac{300}{1390\times 12}$, then the quantity of heat to be removed, to produce the cooling effect, per square inch of surface of augmentation of film will be $\frac{1}{5100}$. Suppose, then, 1 grain of water to be drawn out to a film of 16 square inches, the cooling effect will be $\frac{16}{5100}$ of a degree Centigrade, or about $\frac{1°}{320}$. The work spent in drawing it out is $16\times 6=96$ grains and is equivalent to a heating effect of $\frac{96}{12\times 1390}=\frac{1}{174}$. Hence the total energy (reckoned in heat) of the matter is increased $\frac{1}{174}+\frac{1}{320}$ of a degree Centigrade, when it is drawn out to 16 square inches.

IV. "On the Logocyclic curve, and the geometrical origin of Logarithms." By the Rev. J. Booth, LL.D., F.R.S. Received April 15, 1858.

In a paper read before the Mathematical Section of the British Association during its meeting at Cheltenham in 1856, and which was printed among the reports for that year, I developed at some length the geometrical origin of logarithms, and showed that a trigonometry exists as well for the parabola as for the circle, and that every formula in the latter may be translated into another which shall indicate some property of parabolic arcs, analogous to that from which it has been derived. I showed, moreover, that the same formation has been traced together with lithodomous perforations by Dr. Carlo Gemmellaro and Baron v. Waltershausen along the sea-shore as far north as Taormina, beyond the volcanic region of Etna. From these and other data enlarged upon in the memoir, Sir C. Lyell concludes, first, that a very high antiquity must be assigned to the successive eruptions of Etna, each phase of its volcanic energy, as well as the excavation of the Val del Bove, having occupied a lapse of ages compared to which the historical period is brief and insignificant; and secondly, that the growth of the whole mountain must nevertheless be referred, geologically, to the more modern part of the latest Tertiary epoch.

II. "On some Thermo-dynamic Properties of Solids." By J. P. Joule, LL.D., F.R.S. &c. Received April 22, 1858.

(Abstract.)

A *résumé* of the greater part of this paper has already appeared in the 'Proceedings' for January 29, June 18, and November 26, 1857. The author has since examined the expansion by heat of wood cut across the grain, which, as well as that cut in the direction of the fibre, he finds to be increased by tension and decreased by moisture. When a sufficient quantity of water has been absorbed the expansibility by heat ceases, and wood is *contracted* in each direction by rise of temperature. Nevertheless, when wood, saturated with water, is weighed in water of different temperatures, the result shows cubical expansion of the substance of the wood by heat. The inference drawn by the author from these facts is, that the contraction of the dimensions of wet wood is owing to the action of heat in diminishing the force of capillary attraction, and that thus the walls of the minute cells and tubes of the woody structure are partially relieved from a force which thrusts them asunder, a small quantity of water exuding at the same time. In the case of wet wood which contracts by heat, he finds, in accordance with Professor Thomson's formula, that a rise of temperature is produced by the application of tension. In conformity with the deductions of the same philosopher, the author has also been able to detect experimentally the minute quantity of heat absorbed, in bending or twisting an elastic spring, arising from the diminution of the elastic force of metals with a rise of temperature.

If the space be nearer to the station, or if the difference in density be more than 1-100th part, these deflections must be multiplied by a corresponding quantity.

7. The paper is concluded by a revision of some of the calculations in the former communication. The mass of the mountain region above the level of the plains is shown to be somewhat more than four-millionths of the mass of the earth.

III. "On the Thermal Effects of Compressing Fluids." By J. P. Joule, LL.D., F.R.S. &c. Received October 9, 1858.

(Abstract.)

The author in this paper gives an experimental demonstration of the correctness of Professor Thomson's formula, $\theta = \frac{Tep}{JK}$, where θ is the thermal effect, T the temperature from absolute zero, e the expansibility by heat, p the pressure, J the mechanical equivalent of the thermal unit, and K the capacity for heat. The fluids experimented on were water and oil, with the results tabulated below:—

	Temperature of the liquid.	Pressure applied in atmospheres.	Experimental result.	Theoretical result.
Water	1°·2 Cent.	25·34	−0°·0083	−0°·0071
	5	25·34	0·0044	0·0027
	11·69	25·34	0·0205	0·0197
	18·38	25·34	0·0314	0·0340
	30	25·34	0·0544	0·0563
	31·37	15·64	0·0394	0·0353
	40·4	15·64	0·0450	0·0476
Oil	16	7·92	0·0792	0·0886
	17·29	15·64	0·1686	0·1758
	16·27	25·34	0·2663	0·2837

IV. "Note on Archdeacon Pratt's paper on the Effect of Local Attraction on the English Arc." By Captain Clarke, R.E. Communicated by Lieut.-Colonel James, R.E. Received June 30, 1858.

The following letter of Colonel James will explain the nature of this communication; the numerical statements, being not susceptible

PROCEEDINGS

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ROYAL SOCIETY OF LONDON.

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VOL. X.

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MDCCCLX.

III. "On the Thermal Effects of Fluids in Motion." By J. P. JOULE, LL.D., F.R.S., and Professor W. THOMSON, LL.D., F.R.S. Received May 9, 1860.

In our paper published in the Philosophical Transactions for 1854, we explained the object of our experiments to ascertain the difference of temperature between the high- and low-pressure sides of a porous plug through which elastic fluids were forced. Our experiments were then limited to air and carbonic acid. With new apparatus, obtained by an allotment from the Government grant, we have been able to determine the thermal effect with various other elastic fluids. The following is a brief summary of our principal results at a low temperature (about 7° Cent.).

Elastic fluid.	Thermal effect per 100 lbs. pressure on the square inch, in degrees Centigrade.
Air.	1·6 Cold.
3·9 Air +96·1 Hydrogen	0·116 Heat.
7·9 Air +92·1 Nitrogen	1·772 Cold.
5·1 Air +94·9 Oxygen	1·936 Cold.
3·5 Air +96·5 Carbonic acid ..	8·19 Cold.
58·3 Air +41·7 Hydrogen	0·7 Cold.
62·5 Air +37·5 Carbonic acid ..	3·486 Cold.
54·6 Nitrogen +45·4 Oxygen	1·696 Cold.
4·23 Air { +46·47 Hydrogen .. / +49·3 Carbonic acid }	2·848 Cold.

Further experiments are being made at high temperatures, which show, in the gases in which a cooling effect is found, a decrease of this effect, and an increase of the heating effect in hydrogen. The results at present arrived at indicate invariably that a mixture of gases gives a smaller cooling effect than that deduced from the average of the effects of the pure gases.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON.

From March 6, 1862, to June 18, 1863 inclusive.

VOL. XII.

LONDON:
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MDCCCLXIII.

XXIII. "On the Thermal Effects of Fluids in Motion."—Part IV. By J. P. Joule, LL.D., F.R.S., and Professor W. Thomson, F.R.S. Received June 19, 1862.

(Abstract).

A brief notice of some of the experiments contained in this paper has already appeared in the 'Proceedings.' Their object was to ascertain with accuracy the lowering of temperature, in atmospheric air and other gases, which takes place on passing them through a porous plug from a state of high to one of low pressure. Various pressures were employed, with the result (indicated by the authors in their Part II.) that the thermal effect is approximately proportional to the difference of pressure on the two sides of the plug. The experiments were also tried at various temperatures, ranging from 5° to 98° Cent., and have shown that the thermal effect, if one of cooling, is approximately proportional to the inverse square of the absolute temperature. Thus, for example, the refrigeration at the freezing temperature is about twice that at 100° Cent. In the case of hydrogen, the reverse phenomenon of a rise of temperature on passing through the plug was observed, the rise being doubled in quantity when the temperature of the gas was raised to 100°. This result is conformable with the experiments of Regnault, who found that hydrogen, unlike other gases, has its elasticity increased more rapidly than in the inverse ratio of the volume. The authors have also made numerous experiments with mixtures of gases, the remarkable result being that the thermal effect (cooling) of the compound gas is less than it would be if the gases after mixture retained in integrity the physical characters they possessed while in a pure state.

XXIV. "On the Spectra of Electric Light, as modified by the Nature of the Electrodes and the Media of Discharge." By the Rev. T. R. Robinson, D.D., F.R.S. Received June 19, 1862.

(Abstract.)

The author, after referring briefly to the researches of previous inquirers, and the hypothesis now generally adopted, that the bright lines observed in these spectra depend so absolutely on the chemical nature of the substances present that their occurrence is an unerring test of that presence, expresses his belief that it cannot be admitted