The London, Edinburgh and Dublin philosophical magazine and journal of science

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cover pierced at its centre with an opening destined to receive the thermometer. Five of these apparatus were filled with boiling water and submitted to examination. Here is a result, as an example, for 15° of cooling:—

Nature of the Wood.	Barom.		Inter. Temp.	Exter. humid.	Mean time of cooling 1° C. of the Electrified Surface.	Mean time of cooling 1° C. of the Non-elect. Surface.
Oak .	0m·7113	+	19°·1	100°	71″·60	69″·27
Poplar	0 ·7174	+	19 ·0	90	66 ·86	67 ·73
				Mean . . .	69 ·23	68 ·50

Definitive difference + 0″·73.

I attribute the coincidence of sign of the definitive differences to a fortuitous circumstance which would disappear by combining a greater number of series, although it is in favour of the duration of cooling of the electrified surface, in the examples already mentioned. Moreover, these differences are of so slight a kind that they may be reckoned amongst the possible, nay, I may say probable, errors of observation.

This nullity of influence of the electro-static state of the porous or metallic *parietes* by which a calorific radiation is brought about at the time of its cooling, reminds us of the reciprocal indifference of electricity and of light when one of the two fluids produce a chemical action *. It tends to a conclusion contrary to the opinion of some physiologists, that the electric state, whether of the human body or of the atmosphere, has no influence on the loss of animal heat in a given time, and consequently none on the œconomy of the general state of health, nor on the functions of respiration and of digestion, which are perhaps the only sources of this heat †. In my experiments on organic parietes there has never been any exudation of liquid on the exterior; a change in the chemical nature, and therefore in the temperature of this liquid, is not then to be expected; nor must we look for phænomena of evaporation and of cooling, still less for internal lesions, the probable or certain existence of which had been alleged in more than one case by a skilful physicist ‡.

* Archives of Electricity, vol. ii. p. 596. [*antè*, p. 254.]

† See the remarks of M. Dumas on M. Dulong's researches on Animal Heat, and on the correction to be made of the coefficient of the calorific power of hydrogen.—*Annales de Chimie et de Physique*, 3me Sér. t. viii. p. 180. (June 1843.)

‡ Peltier's memoir on different kinds of fogs, SS. 28–30. *Mém. de l'Acad. de Bruxelles*, t. xv.; *Annales de Chimie et de Physique*, 3me Sér. t. vi. p. 129. (Oct. 1842.)

XXXII. *On the Calorific Effects of Magneto-Electricity, and on the Mechanical Value of Heat.* By J. P. Joule, *Esq.**

IT is pretty generally, I believe, taken for granted that the electric forces which are put into play by the magneto-electrical machine, possess, throughout the whole circuit, the same calorific properties as currents arising from other sources. And indeed when we consider heat not as a *substance*, but as a *state of vibration*, there appears to be no reason why it should not be induced by an action of a simply mechanical character, such, for instance, as is presented in the revolution of a coil of wire before the poles of a permanent magnet. At the same time it must be admitted that hitherto no experiments have been made decisive of this very interesting question; for all of them refer to a particular part of the circuit only, leaving it a matter of doubt whether the heat observed was *generated*, or merely *transferred from the coils* in which the magneto-electricity was induced, the coils themselves becoming cold. The latter view did not seem to me very improbable, considering the facts which I had already succeeded in proving, viz. that the heat evolved by the voltaic battery is *definite*† for the chemical changes taking place at the same time; and 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‡—facts which, among others, seem to prove that *arrangement* only, not *generation* of heat, takes place in the voltaic apparatus; the simply conducting parts of the circuit evolving that which was previously latent in the battery. And Peltier, by his discovery that cold is produced by a current passing from bismuth to antimony, had, I conceived, proved to a great extent that the heat evolved by thermo-electricity is transferred§ from the heated solder, no heat being *generated*. I resolved therefore to endeavour to clear up the uncertainty with respect to magneto-electrical heat. In this attempt I have met with results which will I hope be worthy the attention of the British Association.

* Read before the Section of Mathematical and Physical Science of the British Association, meeting at Cork on the 21st of August 1843; and now communicated by the Author.

† Phil. Mag. S. 3. vol. xix. p. 275.

‡ Memoirs of the Literary and Philosophical Society of Manchester, 2nd series, vol. vii. (part 2.) p. 97.

§ The quantity of heat thus transferred is, I doubt not, proportional to the square of the difference between the temperatures of the two solders. I have attempted an experimental demonstration of this law, but owing to the extreme minuteness of the quantities of heat in question, I have not been able to arrive at any satisfactory result.

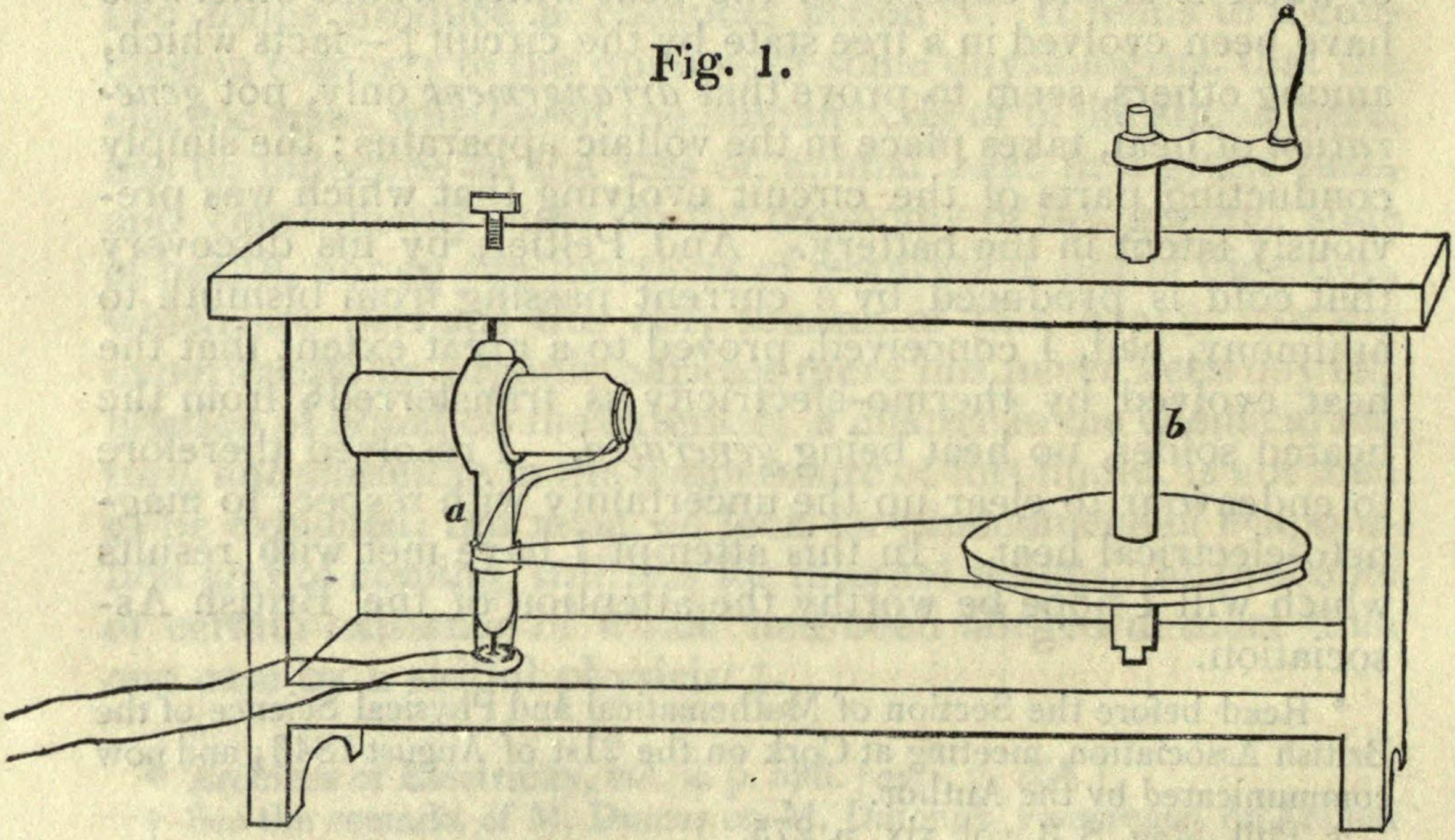
Part I.—*On the Calorific Effects of Magneto-Electricity.*

The general plan which I proposed to adopt in my experiments under this head, was to revolve a small compound electro-magnet, immersed in a glass vessel containing water, between the poles of a powerful magnet; to measure the electricity thence arising by an accurate galvanometer; and to ascertain the calorific effect of the coil of the electro-magnet by the change of temperature in the water surrounding it.

The revolving electro-magnet was constructed in the following manner:—Six plates of annealed hoop-iron, each eight inches long, $1\frac{1}{8}$ inch broad, and $\frac{1}{16}$th of an inch thick, were insulated from each other by slips of oiled paper, and then bound tightly together by a ribbon of oiled silk. Twenty-one yards of copper wire $\frac{1}{18}$th of an inch thick, well covered with silk, were wound on the bundle of insulated iron plates, from one end of it to the other and back again, so that both of the terminals were at the same end.

Having next provided a glass tube sealed at one end, the length of which was $8\frac{3}{4}$ inches, the exterior diameter 2·33 inches, and the thickness 0·2 of an inch, I fastened it in a round hole, cut out of the centre of the wooden revolving piece *a*, fig. 1. The glass was then covered with tinfoil, excepting a

Fig. 1.

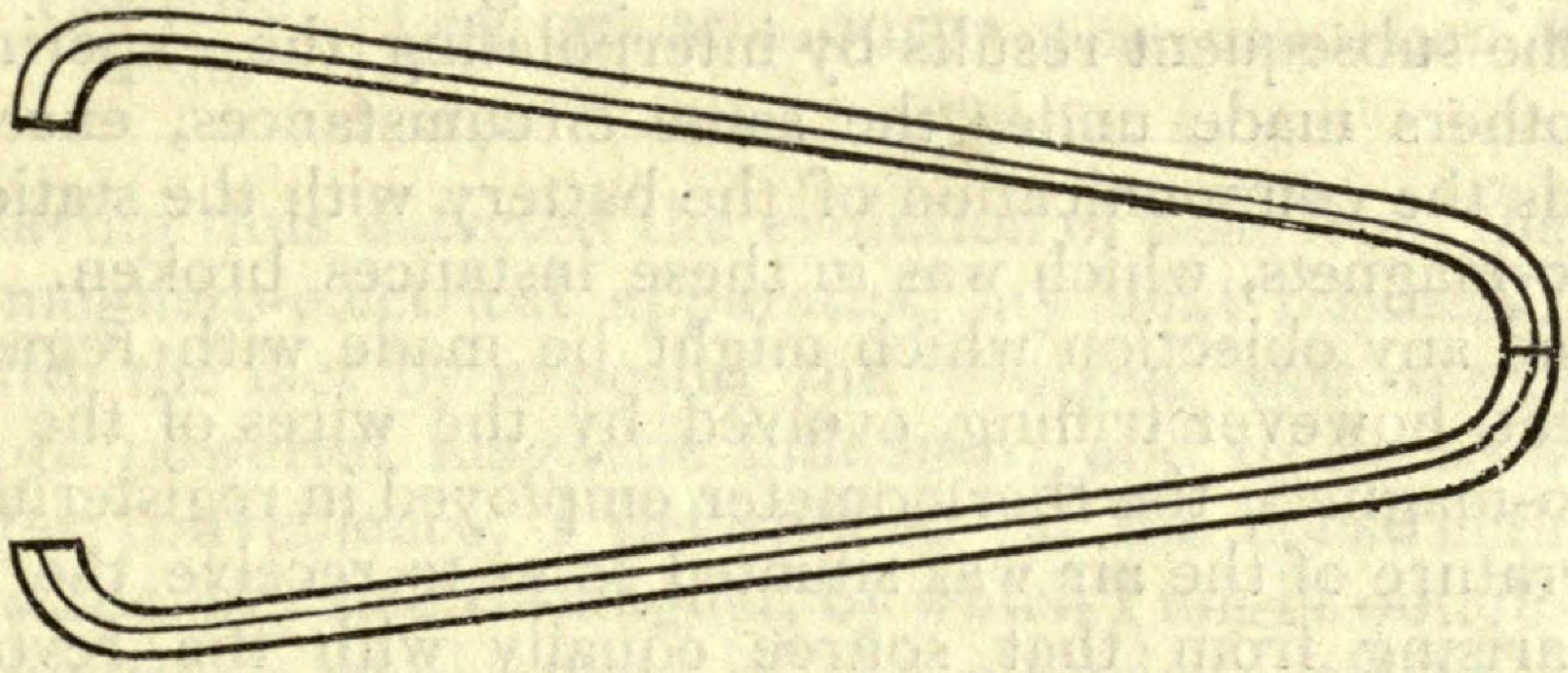


narrow slip in the direction of its length, which was left in order to interrupt magneto-electrical currents in the tinfoil during the experiments. Over the tinfoil small cylindrical sticks of wood were placed at intervals of about an inch, and over these again a strip of flannel was tightly bound, so as to inclose a stratum of air between it and the tinfoil. Lastly, the flannel was well varnished. By these precautions the injurious effects of radiation, and especially of convection of heat in consequence of the impact of air at great velocities of rotation, were obviated to a great extent.

The small compound electro-magnet was now put into the tube, and the terminals of its wire, tipped with platinum, were arranged so as to dip into the mercury of a commutator*, consisting of two semicircular grooves cut out of the base of the frame, fig. 1. By means of wires connected with the mercury of the commutator, I could connect the revolving electro-magnet with a galvanometer or any other apparatus.

In the first experiments I employed two electro-magnets (formerly belonging to an electro-magnetic engine) for the purpose of inducing the magneto-electricity. They were situated with two of their poles on opposite sides of the revolving electro-magnet, and the other two joining each other beneath the frame. I have drawn fig. 2 representing these

Fig. 2.



electro magnets by themselves, to prevent confusing fig. 1. The iron of which they were made was one yard six inches long, three inches broad, and half an inch thick. The wire which was wound upon them was $\frac{1}{20}$th of an inch thick; it was arranged so as to form a sixfold conductor a hundred yards long.

The following is the method in which my experiments were made:—Having removed the revolving piece from its place (which is done with great facility by lifting the top of the frame, and with it the brass socket in which the upper steel pivot of the revolving piece works), I filled the tube containing the small compound electro-magnet with $9\frac{3}{4}$ oz. of water. After

* I had made previous experiments in order to ascertain the best form of commutator, but found none to answer my purpose as well as the above. I found an advantage in covering the mercury with a little water. The steadiness of the needle of the galvanometer during the experiments proved the efficacy of this arrangement.

stirring the water until the heat was equably diffused, its temperature was ascertained by a very delicate thermometer, by which I could estimate a change of temperature equal to about $\frac{1}{50}$th of Fahrenheit's degree. A cork covered with several folds of greased paper was then forced into the mouth of the tube, and kept in its place by a wire passing over the whole, and tightened by means of one or two small wooden wedges. The revolving piece was then restored to its place as quickly as possible, and revolved between the poles of the large electro-magnets for a quarter of an hour, during which time the deflections of the galvanometer and the temperature of the room were carefully noted. Finally, another observation with the thermometer detected any change that had taken place in the temperature of the water.

Notwithstanding the precautions taken against the injurious effects of radiation and convection of heat, I was led into error by my first trials: the water had lost heat, even when the temperature of the room was such as led me to anticipate a contrary result. I did not stop to inquire into the cause of the anomaly, but I provided effectually against its interference with the subsequent results by interpolating the experiments with others made under the same circumstances, except as regards the communication of the battery with the stationary electro-magnets, which was in these instances broken. And to avoid any objection which might be made with regard to the heat, however trifling, evolved by the wires of the large electro-magnets, the thermometer employed in registering the temperature of the air was situated so as to receive the influence arising from that source equally with the revolving piece.

I will now give a series of experiments in which six Daniell's cells, each 25 inches high and $5\frac{1}{2}$ inches in diameter, were alternately connected and disconnected with the large stationary electro-magnets. The galvanometer, connected through the commutator with the revolving electro-magnet, had a coil of a foot in diameter, consisting of five turns of copper wire, and a needle six inches long. Its deflections could be turned into quantities of current by means of a table constructed from previous experiments. The galvanometer was situated so as to be out of the reach of the attractions of the large electro-magnets, and every other precaution was taken to render the experiments worthy of reliance. The rotation was in every instance carried on for exactly a quarter of an hour.

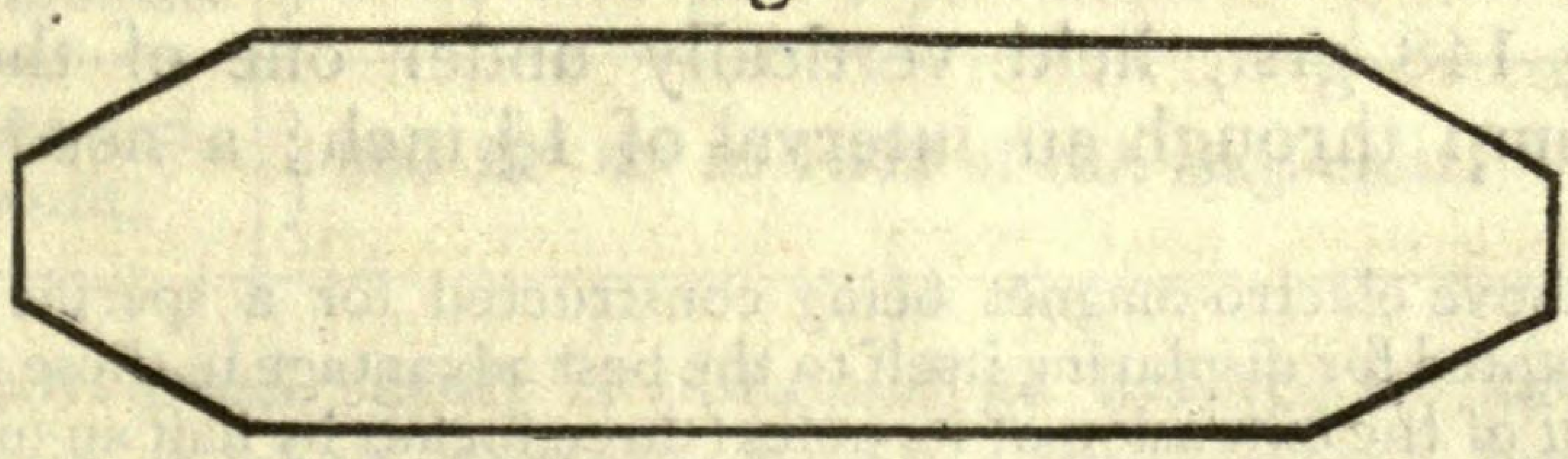
Series No. 1.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 5 turns.		Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
							Before.	After.	
April 15, P.M.	Battery contact broken.	600	0°	0′	54·69°	0·19° +	54·90°	54·85°	0·05° loss
	Battery in connexion.	600	21	0	54·67	0·20 +	54·85	54·88	0·03 gain
	Battery contact broken.	600	0	0	54·61	0·24 +	54·88	54·83	0·05 loss
	Battery in connexion.	600	24	0	54·65	0·23 +	54·85	54·92	0·07 gain
	Mean, Battery in connexion.	600	22	30	...	0·21 +	...	...	0·05 gain
	Mean, Battery contact broken.	600	0	0	...	0·21 +	...	...	0·05 loss
	Corrected Result.	600	22° 30′ = 0·177* of cur. mag.-elect.						0·10 gain

Having thus detected the evolution of heat from the coil of the magneto-electrical apparatus, my next business was to confirm the fact by exposing the revolving electro-magnet to a more powerful magnetic influence; and to do so with the greater convenience, I determined on the construction of a new stationary electro-magnet, by which I might obtain a more advantageous employment of the electricity of the battery. Availing myself of previous experience, I succeeded in producing an electro-magnet possessing greater power of attraction from a distance than any other I believe on record. On this account a description of it in greater detail than is absolutely necessary to the subject of this paper will not I hope be deemed superfluous.

A piece of half-inch boiler plate iron was cut into the shape

Fig. 3.

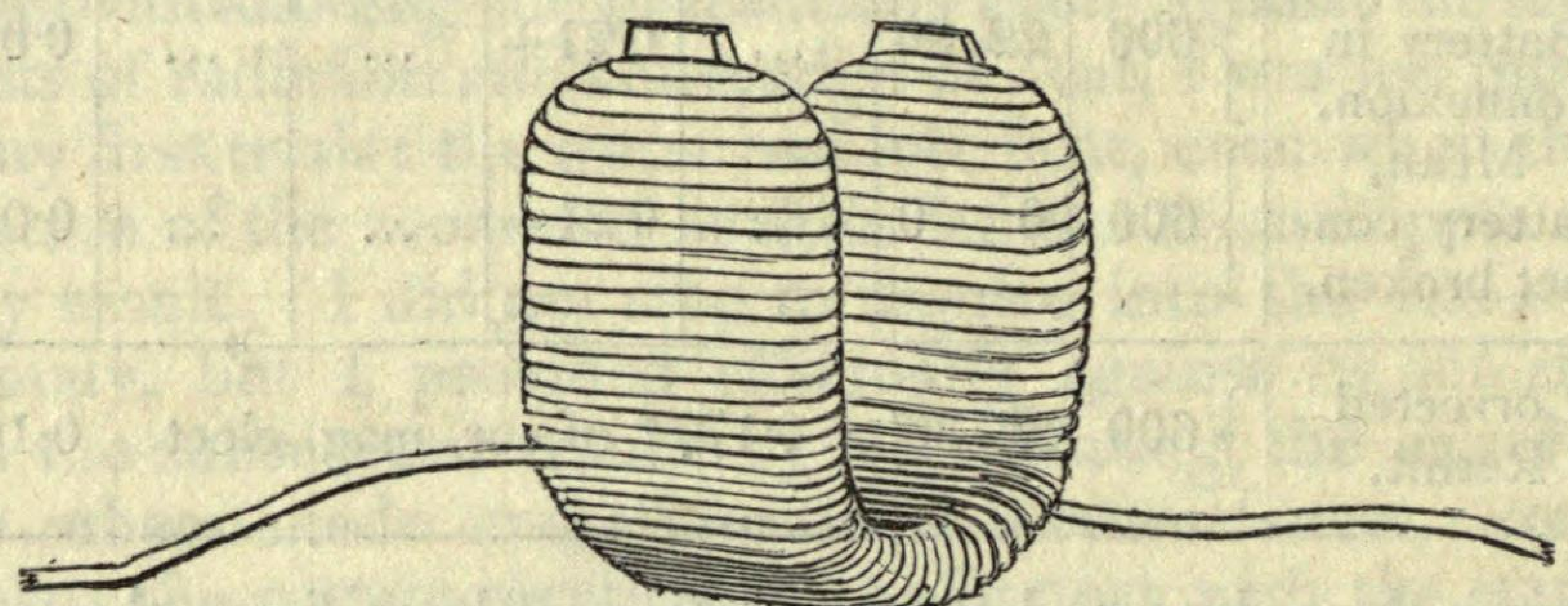


* Throughout the paper I have called that quantity of current *unity*, which, passing equably for an hour of time, can decompose a chemical equivalent expressed in grains.

represented by fig. 3. Its length was thirty-two inches; its breadth in the middle part eight inches; at the ends three inches. It was bent nearly into the shape of the letter U, so that the shortest distance between the poles was slightly more than ten inches.

Twenty-two strands of copper wire, each 106 yards long and about one-twentieth of an inch in diameter, were now bound tightly together with tape. The insulated bundle of wires, weighing more than sixty pounds, was then wrapped upon the iron, which had itself been previously insulated by a fold of calico. Fig. 4 represents, in perspective, the electro-magnet in its completed state.

Fig. 4.



In arranging the voltaic battery for its excitation, care was taken to render the resistance to conduction of the battery equal, as nearly as possible, to that of the coil, Prof. Jacobi having proved that to be the most advantageous arrangement. Ten of my large Daniell's cells, arranged in a series of five double pairs, fulfilled this condition very well, producing a magnetic energy in the iron superior to anything I had previously witnessed. I will mention the results of a few experiments in order to give some definite idea of it.

1st. The force with which a bar of iron three inches broad and half an inch thick was attracted to the poles, was equal, at the distance of $\frac{1}{16}$th of an inch, to 100 lbs; at $\frac{1}{4}$th of an inch to 30 lbs; at half an inch to $10\frac{1}{2}$ lbs.; and at one inch to 4 lbs. 13 oz.* 2nd. A small rod of iron three inches long, weighing 148 grs., held vertically under one of the poles, would jump through an interval of $1\frac{3}{4}$ inch; a needle three

* The above electro-magnet being constructed for a specific purpose, was not adapted for displaying itself to the best advantage in these instances. On account of the extension of its poles (three inches by half an inch) many of the lines of magnetic attraction were necessarily in very oblique directions. Theoretically, circular poles should give the greatest attraction from small distances.

inches long, weighing 4 grains, would jump from a distance of $3\frac{1}{4}$ inches.

Having fixed the electro-magnet just described with its poles upwards, and on opposite sides of the revolving electro-magnet, I arranged to it the battery of ten cells, in a series of five double pairs, and, experimenting as before, I obtained a second series of results. The galvanometer used in the present instance was in every respect similar to that previously described, with the exception of the coil, which now consisted of a single turn of thick copper wire. Great care was taken to prevent, by its distance from, and relative position with the electro-magnet, any interference of the latter with its indications.

No. 2.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of one turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
May 6, A.M.	Battery in connexion.	600	22° 0′	58°·93	0°·17+	58°·20	60°·00	1°·80 gain
	Battery contact broken.	600	0 0	59·60	0·40+	60·02	59·98	0·04 loss
	Battery in connexion.	600	24 0	59·55	1·23+	59·90	61·67	1·77 gain
May 6, P.M.	Battery contact broken.	600	0 0	59·45	0·19+	59·78	59·50	0·28 loss
	Battery in connexion.	600	24 45	58·30	0·05+	57·35	59·35	2·00 gain
May 8, A.M.	Battery in connexion.	600	22 0	57·74	0·32+	57·28	58·83	1·55 gain
	Battery contact broken.	600	0 0	58·35	0·49+	58·83	58·85	0·02 gain
	Battery in connexion.	600	21 20	58·73	0·78+	58·83	60·20	1·37 gain
	Mean, Battery in connexion.	600	22 49	...	0·51+	...	...	1·70 gain
	Mean, Battery contact broken.	600	0 0	...	0·36+	...	...	0·10 loss
	Corrected Result.	600	22° 49′ = 0·902 of cur. mag.-elect.					1·84 gain

The corrected result is obtained as before, by adding the loss sustained when contact with the battery was broken, to the heat gained when the battery was in connexion. I have in the present instance, however, made a further correction of

0°·04 on account of the difference between the *mean differences* 0°·51 and 0°·36. The ground of this correction is the result of a previous experiment, in which, by revolving the apparatus at 94° in an atmosphere of 60°, the water sustained a loss of 7°·6, or about one quarter of the difference between the temperature of the atmosphere and the mean temperature of the water.

With the same electro-magnet, but using a battery of only four cells, arranged in a series of two double pairs, by which I expected to obtain about half as much magnetism in the iron, the following results were obtained:—

No. 3.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 5 turns.	Mean Temperature of Room.	Mean Difference.	Temperature of Water. Before.	Temperature of Water. After.	Loss or Gain.
May 8, P.M.	Battery in connexion.	600	38° 0'	57°·00	0°·02—	56°·73	57°·23	0°·50 gain
May 8, P.M.	Battery contact broken.	600	0 0	57·25	0·0	57·23	57·27	0·04 gain
May 8, P.M.	Battery in connexion.	600	38 30	57·53	0·09+	57·35	57·90	0·55 gain
May 9, P.M.	Battery in connexion.	600	39 45	56·37	0·45—	55·60	56·25	0·65 gain
May 9, P.M.	Battery contact broken.	600	0 0	56·75	0·39—	56·27	56·45	0·18 gain
May 9, P.M.	Battery in connexion.	600	38 45	57·14	0·37—	56·50	57·05	0·55 gain
	Mean, Battery in connexion.	600	38 45	...	0·19—	...	...	0·56 gain
	Mean, Battery contact broken.	600	0 0	...	0·19—	...	...	0·11 gain
	Corrected Result.	600 38° 45′ = 0·418 of cur. mag.-elect.						0·45 gain

In the next experiments a battery of ten cells in a series of five double pairs was used for the purpose of exciting the large stationary electro-magnet. But, dismissing the galvanometer and the other extra parts of the circuit, I connected the terminal wires of the electro-magnet together, so as to obtain the whole effect of the magneto-electricity. The resistance of the coil of the revolving electro-magnet being to that of the whole circuit employed in the experiments No. 2 as 1 : 1·13, and 0·902 of current being obtained in those experiments, I expected to obtain the calorific effect of 1·019 in the new series.

No. 4.

		Revolutions of Electro-Magnet per minute.	Mean Temperature of Room.	Mean Difference.	Temperature of Water. Before.	Temperature of Water. After.	Loss or Gain.
May 10, P.M.	Battery in connexion.	600	56·85	0·61—	54·98	57·50	2·52 gain
	Battery contact broken.	600	57·37	0·12+	57·48	57·50	0·02 gain
	Battery in connexion.	600	57·52	1·08+	57·48	59·73	2·25 gain
	Mean, Battery in connexion.	600	...	0·23+	...	...	2·38 gain
	Mean, Battery contact broken.	600	...	0·12+	...	...	0·02 gain
	Corrected Result.	600	1·019 of cur. mag.-elect.				2·39 gain

It seemed to me very desirable to repeat the experiments, substituting *steel* magnets for the stationary electro-magnets hitherto used. With this intention I constructed two magnets, each consisting of a number of thin plates of hard steel, —an arrangement which we owe to Dr. Scoresby. My metal was, unfortunately, not of very good quality, but nevertheless an attractive force was obtained sufficiently powerful to overcome the gravity of a small key weighing 47 grs., placed at the distance of three-eighths of an inch. The following results were obtained by revolving the small compound electro-magnet between the poles of the steel magnets.

In order to obtain the whole calorific effect of the steel magnets, I now, as in Series No. 4, connected the terminal wires of the revolving electro-magnet, and interpolated the experiments with others in which that connexion was broken. The resistance of the coil of the revolving electro-magnet being to the resistance of the whole circuit used in the experiments marked No. 5 as 1 : 1·44, and 0·236 of current electricity being obtained in those experiments, I expected to obtain in the present series the calorific effect of 0·34 of current magneto-electricity.

No. 5.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 5 turns.	Mean Temperature of Room.	Mean Difference.	Temperature of Water. Before.	Temperature of Water. After.	Loss or Gain.
May 16, A.M.	Circuit complete.	600	26° 0′	59°·72	0°·0	59°·73	59°·70	0°·03 loss
	Circuit broken.	600	0 0	59·82	0·20−	59·70	59·55	0·15 loss
	Circuit complete.	600	29 0	59·95	0·41−	59·55	59·53	0·02 loss
	Circuit broken.	600	0 0	59·58	0·12−	59·52	59·40	0·12 loss
	Circuit complete.	600	27 0	59·65	0·25−	59·40	59·40	0
	Mean, Circuit complete.	600	27 20	...	0·22−	...	...	0·016 loss
	Mean, Circuit broken.	600	0 0	...	0·16−	...	...	0·135 loss
	Corrected Result.	600	27° 20′ = 0·236 of cur. mag.-elect.					0·10 gain

No. 6.

		Revolutions of Electro-Magnet per minute.	Mean Temperature of Room.	Mean Difference.	Temperature of Water. Before.	Temperature of Water. After.	Loss or Gain.
May 17, A.M.	Terminals joined.	600	59°·07	0°·20−	58°·82	58°·92	0°·10 gain
	Terminals separated.	600	59·07	0·22−	58·92	58·78	0·14 loss
	Terminals joined.	600	58·96	0·20−	58·75	58·78	0·03 gain
	Terminals separated.	600	58·88	0·18−	58·78	58·63	0·15 loss
	Mean, Terminals joined.	600	...	0·20−	...	...	0·065 gain
	Mean, Terminals separated.	600	...	0·20−	...	...	0·145 loss
	Corrected Result.	600	0·34 of cur. mag.-elect.				0·21 gain

Although any considerable development of electrical currents in the iron of the revolving electro-magnet was prevented by its disposition in a number of thin plates insulated from each other, I apprehended that they might, under a powerful inductive influence, exist separately in each plate to such an extent as to produce an appreciable quantity of heat. To ascertain the fact, the terminals of the wire of the revolving electro-magnet were insulated from each other, while the latter was subjected to the inductive influence of the large electro-magnet excited by ten cells in a series of five double pairs. The experiments were interpolated with others in which contact with the battery was broken. As we shall hereafter give in detail experiments of the same class, it will not be necessary to do more at present than to state that the mean result of the present series, consisting of eight trials, gave 0°·28 as the quantity of heat evolved by the iron alone.

We are now able to collect the results of the preceding experiments so as to discover the laws by which the development of the heat is regulated. The fourth column of the following table, containing the heat due to the currents circulating in the iron alone, is constructed on the basis of a law which we shall subsequently prove, viz. *the heat evolved by a bar of iron revolving between the poles of a magnet is proportional to the square of the inductive force*. Column 5 gives the heat evolved by the coils of the electro-magnet alone. No elimination is required for the results of series Nos. 5 and 6, because in them the iron of the revolving electro-magnet was subject to the influence of the steel magnets in the interpolating, as well as in the other experiments.

TABLE I.

Series of Experiments.	Current Magneto-Electricity.	Heat actually evolved.	Correction for Currents in the Iron.	Corrected Heat.	Squares of Numbers proportional to those in column 2.	Heat due to Voltaic Currents of the intensities given in col. 2.	The Numbers of column 7 multiplied by $\frac{4}{3}$.
No. 1.	0·177	0°·10	0°·02	0°·08	0°·062	0°·040	0°·053
No. 2.	0·902	1·84	0·28	1·56	1·614	1·040	1·386
No. 3.	0·418	0·45	0·09	0·36	0·346	0·224	0·299
No. 4.	1·019	2·39	0·28	2·11	2·060	1·327	1·769
No. 5.	0·236	0·10	0	0·10	0·109	0·071	0·091
No. 6.	0·340	0·21	0	0·21	0·229	0·148	0·197
1.	2.	3.	4.	5.	6.	7.	8.

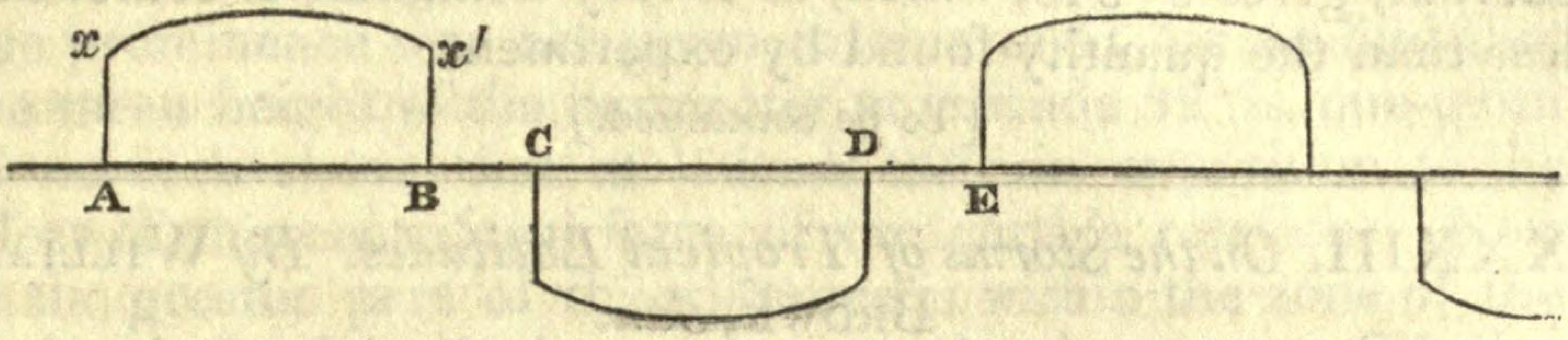
On comparing the corrected results in column 5 with the squares of magneto-electricity given in column 6, it will be abundantly manifest that *the heat evolved by the coil of the magneto-electrical machine is proportional* (*cæteris paribus*) *to the square of the current.*

Column 7, containing the heat due to voltaic currents of the quantities stated in column 2, is constructed on the basis of three very careful experiments on the heat evolved by passing currents through the coil of the small compound electro-magnet. I observed an increase in the temperature of the water equal to 5°·3, 5°·46, and 5°·9 respectively, when 2·028, 2·078, and 2·145 of current voltaic electricity were passed, each during a quarter of an hour, through the coil. Reducing the first and second experiments to the electricity of the third according to the squares of the current, we have 5°·93, 5°·82 and 5°·9 for 2·145 of current. The mean of these is 5°·88, a datum from which the theoretical results of the preceding and subsequent tables are calculated.

But in comparing the heat evolved by magneto-, with that evolved by voltaic electricity, we must remember that the former is propagated by pulsations, the latter uniformly. Now since the square of the mean of unequal numbers is always less than the mean of their squares, it is obvious that the magnetic effect at the galvanometer will bear a greater proportion to the heat evolved by the voltaic, than the magneto-electricity; so that it is impossible to institute a strict comparison without ascertaining previously the intensity of the magneto-electricity at every instant of the revolution of the revolving electro-magnet. I have not been able to devise any very accurate means for attaining this object: but judging from the comparative brilliancy of the sparks when the commutator was arranged so as to break contact with the mercury at different positions of the revolving electro-magnet with respect to the poles of the stationary electro-magnet, there appeared to be but little variation in the intensity of the magneto-electricity during $\frac{3}{4}$ of each revolution. The remaining $\frac{1}{4}$ (during which the revolving electro-magnet passes the poles of the stationary electro-magnet) is occupied in the conversion of the direction of the electricity. In the experiments all flow of electricity during this $\frac{1}{4}$ is cut off by the divisions of the commutator. In illustration of this I have drawn fig. 5, in which the direction and intensity of the magneto-electricity are represented by ordinates A*x*, &c., perpendicular to the straight line A B C D E; the intermediate spaces B C, C D, &c., represent the time during which the electricity is wholly cut off by the divisions of the commutator.

Were A x x' B, &c. perfect rectangles, it is obvious that the heat due to a given deflection of the galvanometer would be

Fig. 5.



$\frac{4}{3}$ of that due to the same deflection and an uniform current, and column 8 of the table would contain exact theoretical results. But as this is not precisely the case, the numbers in that column are somewhat under the truth.

Bearing this in mind in the comparison of columns 5 and 8, it will, I think, be admitted that the experiments afford decisive evidence that *the heat evolved by the coil of the magneto-electrical machine is governed by the same laws as those which regulate the heat evolved by the voltaic apparatus; and exists also in the same quantity under comparable circumstances.*

Although very little doubt could exist with regard to the heating power of magneto-electricity *beyond* the coil, I thought it would nevertheless be well to follow it there, in order to render the investigation more complete: I am not aware of any previous experiments of the kind.

I immersed five or six yards of insulated copper wire of $\frac{1}{40}$th of an inch diameter in a flask holding about 12 oz. of water. The terminals of the wire were connected on one hand with the galvanometer of five turns and on the other with the commutator, and the circuit was completed by a wire extending from the galvanometer to the other compartment of the commutator. The revolving electro-magnet was now subjected to the inductive influence of the large electro-magnet excited by ten cells in a series of five double pairs, and rotated at the rate of 600 revolutions per minute during a quarter of an hour. The needle of the galvanometer, which remained as usual pretty steady, indicated a mean deflection of $32° 40' = 0{\cdot}31$ of current: and the heat evolved was found to be $0°{\cdot}46$, after the correction on account of the temperature of the surrounding air had been applied. Another experiment gave me $0°{\cdot}4$ for $0{\cdot}286$. The mean of the two is $0°{\cdot}43$ for $0{\cdot}298$ current magneto-electricity.

By passing a voltaic current from four cells in series through the wire, I found that $2{\cdot}02$ of current flowing uniformly evolved $12°{\cdot}0$ in a quarter of an hour. Reducing this to $0{\cdot}298$ of current we have $\left(\frac{0\cdot298}{2\cdot02}\right)^2 \times 12^\circ = 0^\circ\cdot261$. The product of this by $\frac{4}{3}$ (on account of the pulsatory character of the magneto-current) gives $0^\circ\cdot348$, which, as theory demands, is somewhat less than the quantity found by experiment.

[To be continued.]

XXXIII. *On the Storms of Tropical Latitudes.* By William Brown, *Jun.*

[Continued from p. 217 and concluded.]

THE storms of the tropics and of temperate regions, though thus referable to the same source, have yet some marked differences. The principal of these are:—the greater violence of the former; the isolation of each individual storm; the less extent of each particular portion of it, and the much greater extent and regularity of its progressive motion; and the more rapid though less depression of the barometer.

It may seem difficult at first to account for the violence of tropical hurricanes, but the difficulty disappears when we cease to compare the force of the upper current with that of the lower which sweeps over the earth, where the friction upon the surface prevents its gaining a great velocity by soon putting a limit to its acceleration. But as at the beginning of the hurricanes which arise in the region of the trade-wind the lower current has not effected the change corresponding to that of the upper one, both therefore flowing in the same direction, the effect of friction must be so slight that we may almost disregard it; as we may do also in other portions of the zone of the tropics, where a permanent reversal of the currents is effected; because it must be supposed that the upper and lower currents of the atmosphere are separated from each other by an interval of calm air; therefore the upper current when confined to the upper strata of the atmosphere, subject as it is from the constant decrease in temperature it meets with to an accelerating force, may attain a very great velocity, more especially in the former regions, before the effect of friction is sufficiently powerful to put a limit to its acceleration.

Thus as it matters little whether the difference of temperature, by which the wind acquires force sufficient to give the velocity of a hurricane notwithstanding the resistance of the air which it must displace, exists between columns of air nearly adjacent, or at the distance of many degrees of latitude, there seems no difficulty in conceiving the difference to be sufficiently great.

The comparative exemption of the upper current from fric-

[Begin Page: Page 262]

cover pierced at its centre with an opening destined to receive

the thermometer. Five of these apparatus were filled with

boiling water and submitted to examination. Here is a re-

sult, as an example, for 15° of cooling: —

Mean time of cooling 1° C. of the

Nature of Inter. Exter. Electrified Non-elect,

the Wood. Barom. Temp. humid. Surface. Surface.

Oak . m *7113 + 19°'l 100° 7l'"60 69'"27

Poplar -7 174 + 19-0 90 66 "86 67*73

Mean ... 69 -23 68 -50

Definitive difference + 0"*73.

I attribute the coincidence of sign of the definitive differ-

ences to a fortuitous circumstance which would disappear by

combining a greater number of series, although it is in

favour of the duration of cooling of the electrified surface, in

the examples already mentioned. Moreover, these differences

are of so slight a kind that they may be reckoned amongst

the possible, nay, I may say probable, errors of observation.

This nullity of influence of the electro- static state of the porous or metallic parietes by which a calorific radiation is brought about at the time of its cooling, reminds us of the reciprocal indifference of electricity and of light when one of the two fluids produce a chemical action *. It tends to a conclusion contrary to the opinion of some physiologists, that the electric state, whether of the human body or of the atmosphere, has no influence on the loss of animal heat in a given time, and consequently none on the ceconomy of the general state of health, nor on the functions of respiration and of digestion, which are perhaps the only sources of this heat f. In my experiments on organic parietes there has never been any exudation of liquid on the exterior ; a change in the chemical nature, and therefore in the temperature of this liquid, is not then to be expected; nor must we look for phaenomena of evaporation and of cooling, still less for internal lesions, the probable or certain existence of which had been alleged in more than one case by a skilful physicist %.

Archives of Electricity, vol. ii. p. 596. [ante, p. 254.]

f See the remarks of M. Dumas on M. Dulong's researches on Animal Heat, and on the correction to be made of the coefficient of the calorific power of hydrogen. — Annates de Chimie et de Physique, 3 me Ser. t. viii. p. 180. (June 1843.)

% Peltier's memoir on different kinds of fogs, SS. 28-30. Mem. de VAcad.

de BruxeUes, t.xv. ; Annates de Chimie et de Physique, 3 me Ser. t. vi. p. 129.

(Oct. 1842.)

[Begin Page: Page 263]

XXXII. On the Calorific Effects of Magneto-Electricity, and
on the Mechanical Value of Heat. By J. P. Joule, Esq.*

"I T is pretty generally, I believe, taken for granted that the -*- electric forces which are put into play by the magneto-electrical machine, possess, throughout the whole circuit, the same calorific properties as currents arising from other sources. And indeed when we consider heat not as a substance, but as a state of vibration, there appears to be no reason why it should not be induced by an action of a simply mechanical character, such, for instance, as is presented in the revolution of a coil of wire before the poles of a permanent magnet. At the same time it must be admitted that hitherto no experiments have been made decisive of this very interesting question ; for all of them refer to a particular part of the circuit only, leaving it a matter of doubt whether the heat observed was generated, or merely transferred from the coils in which the magneto-electricity was induced, the coils themselves becoming cold. The latter view did not seem to me very improbable, considering the facts which I had already succeeded in proving, viz. that the heat evolved by the voltaic battery is definite-^ for the chemical changes taking place at the same time; and 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 % — facts which, among others, seem to prove that arrangement only, not gene* ration of heat, takes place in the voltaic apparatus ; the simply conducting parts of the circuit evolving that which was previously latent in the battery. And Peltier, by his discovery that cold is produced by a current passing from bismuth to antimony, had, I conceived, proved to a great extent that the heat evolved by thermo-electricity is transferred § from the heated solder, no heat being generated. I resolved therefore to endeavour to clear up the uncertainty with respect to magneto-electrical heat. In this attempt I have met with results which will I hope be worthy the attention of the British Association.

* Read before the Section of Mathematical and Physical Science of the British Association, meeting at Cork on the 21st of August 1843; and now communicated by the Author.

f Phil. Mag. S. 3. vol. xix. p. 275.

j Memoirs of the Literary and Philosophical Society of Manchester, 2nd series, vol. vii. (part 2.) p. 97.

§ The quantity of heat thus transferred is, I doubt not, proportional to the square of the difference between the temperatures of the two solders. I have attempted an experimental demonstration of this law, but owing to the extreme minuteness of the quantities of heat in question, I have not been able to arrive at any satisfactory result.

[Begin Page: Page 264]

Part I. — On the Calorific Effects of Magneto-Electricity.

The general plan which I proposed to adopt in my experiments under this head, was to revolve a small compound electro-magnet, immersed in a glass vessel containing water, between the poles of a powerful magnet; to measure the electricity thence arising by an accurate galvanometer ; and to ascertain the calorific effect of the coil of the electro-magnet by the change of temperature in the water surrounding it.

The revolving electro-magnet was constructed in the following manner: — Six plates of annealed hoop-iron, each eight inches long, 1| inch broad, and y^th of an inch thick, were insulated from each other by slips of oiled paper, and then bound tightly together by a ribbon of oiled silk. Twenty-one yards of copper wire y^th of an inch thick, well covered with silk, were wound on the bundle of insulated iron plates, from one end of it to the other and back again, so that both of the terminals were at the same end.

Having next provided a glass tube sealed at one end, the length of which was 8| inches, the exterior diameter 2*33 inches, and the thickness 0*2 of an inch, I fastened it in a round hole, cut out of the centre of the wooden revolving piece a, fig. 1. The glass was then covered with tinfoil, excepting a

narrow slip in the direction of its length, which was left in order to interrupt magneto-electrical currents in the tinfoil during the experiments. Over the tinfoil small cylindrical sticks of wood were placed at intervals of about an inch, and over these again a strip of flannel was tightly bound, so as to

[Begin Page: Page 265]

inclose a stratum of air between it and the tinfoil. Lastly, the flannel was well varnished. By these precautions the injurious effects of radiation, and especially of convection of heat in consequence of the impact of air at great velocities of rotation, were obviated to a great extent.

The small compound electro-magnet was now put into the tube, and the terminals of its wire, tipped with platinum, were arranged so as to dip into the mercury of a commutator*, consisting of two semicircular grooves cut out of the base of the frame, fig. 1. By means of wires connected with the mercury of the commutator, I could connect the revolving electro-magnet with a galvanometer or any other apparatus.

In the first experiments I employed two electro-magnets (formerly belonging to an electro-magnetic engine) for the purpose of inducing the magneto-electricity. They were situated with two of their poles on opposite sides of the revolving electro-magnet, and the other two joining each other beneath the frame. I have drawn fig. 2 representing these

Fig. 2.

electro magnets by themselves, to prevent confusing fig. 1. The iron of which they were made was one yard six inches long, three inches broad, and half an inch thick. The wire which was wound upon them was ^ th of an inch thick ; it was arranged so as to form a sixfold conductor a hundred yards long.

The following is the method in which my experiments were made : — Having removed the revolving piece from its place (which is done with great facility by lifting the top of the frame, and with it the brass socket in which the upper steel pivot of the revolving piece works), I filled the tube containing the small compound electro-magnet with 9| oz. of water. After

* I had matte previous experiments in order to ascertain the hest form of commutator, but found none to answer my purpose as well as the above. I found an advantage in covering the mercury with a little water. The steadiness of the needle of the galvanometer during the experiments proved the efficacy of this arrangement.

[Begin Page: Page 266]

stirring the water until the heat was equably diffused, its temperature was ascertained by a very delicate thermometer, by which I could estimate a change of temperature equal to about j x ^th of Fahrenheit's degree. A cork covered with several folds of greased paper was then forced into the mouth of the tube, and kept in its place by a wire passing over the whole, and tightened by means of one or two small wooden wedges. The revolving piece was then restored to its place as quickly as possible, and revolved between the poles of the large electro-magnets for a quarter of an hour, during which time the deflections of the galvanometer and the temperature of the room were carefully noted. Finally, another observation with the thermometer detected any change that had taken place in the temperature of the water.

Notwithstanding the precautions taken against the injurious effects of radiation and convection of heat, I was led into error by my first trials : the water had lost heat, even when the temperature of the room was such as led me to anticipate a contrary result. I did not stop to inquire into the cause of the anomaly, but I provided effectually against its interference with the subsequent results by interpolating the experiments with others made under the same circumstances, except as regards the communication of the battery with the stationary electro-magnets, which was in these instances broken. And to avoid any objection which might be made with regard to the heat, however trifling, evolved by the wires of the large electro-magnets, the thermometer employed in registering the temperature of the air was situated so as to receive the influence arising from that source equally with the revolving piece.

I will now give a series of experiments in which six Daniell's cells, each 25 inches high and 5| inches in diameter, were alternately connected and disconnected with the large stationary electro-magnets. The galvanometer, connected through the commutator with the revolving electro-magnet, had a coil of a foot in diameter, consisting of five turns of copper wire, and a needle six inches long. Its deflections could be turned into quantities of current by means of a table constructed from previous experiments. The galvanometer was situated so as to be out of the reach of the attractions of the large electro-magnets, and every other precaution was taken to render the experiments worthy of reliance. The rotation was in every instance carried on for exactly a quarter of an hour.

[Begin Page: Page 267]

Having thus detected the evolution of heat from the coil of the magneto-electrical apparatus, my next business was to confirm the fact by exposing the revolving electro-magnet to a more powerful magnetic influence ; and to do so with the greater convenience, I determined on the construction of a new stationary electro-magnet, by which I might obtain a more advantageous employment of the electricity of the battery. Availing myself of previous experience, I succeeded in producing an electro-magnet possessing greater power of attraction from a distance than any other I believe on record. On this account a description of it in greater detail than is absolutely necessary to the subject of this paper will not I hope be deemed superfluous.

A piece of half-inch boiler plate iron was cut into the shape

Fi2. 3.

* Throughout the paper I have called that quantity of current unity,

which, passing equably for an hour of time, can decompose a chemical equivalent expressed in grains.

[Begin Page: Page 268]

represented by fig. 3. Its length was thirty-two inches; its breadth in the middle part eight inches; at the ends three inches. It was bent nearly into the shape of the letter U, so that the shortest distance between the poles was slightly more than ten inches.

Twenty-two strands of copper wire, each 106 yards long and about one-twentieth of an inch in diameter, were now bound tightly together with tape. The insulated bundle of wires, weighing more than sixty pounds, was then wrapped upon the iron, which had itself been previously insulated by a fold of calico. Fig. 4 represents, in perspective, the electro-magnet in its completed state.

Fig. 4.

In arranging the voltaic battery for its excitation, care was taken to render the resistance to conduction of the battery equal, as nearly as possible, to that of the coil, Prof. Jacobi having proved that to be the most advantageous arrangement. Ten of my large Daniell's cells, arranged in a series of five double pairs, fulfilled this condition very well, producing a magnetic energy in the iron superior to anything I had previously witnessed. I will mention the results of a few experiments in order to give some definite idea of it.

1st. The force with which a bar of iron three inches broad and half an inch thick was attracted to the poles, was equal, at the distance of T] ^th of an inch, to 100 lbs; at ^th of an inch to 30 lbs; at half an inch to 10^ lbs. ; and at one inch to 4 lbs. 13 oz.* 2nd. A small rod of iron three inches long, weighing 148 grs., held vertically under one of the poles, would jump through an interval of If inch; a needle three

* The above electro-magnet being constructed for a specific purpose, was not adapted for displaying itself to the best advantage in these instances. On account of the extension of its poles (three inches by half an inch) many of the lines of magnetic attraction were necessarily in very oblique directions. Theoretically, circular poles should give the greatest attraction from small distances.

[Begin Page: Page 269]

inches long, weighing 4 grains, would jump from a distance of 3^ inches.

Having fixed the electro-magnet just described with its poles upwards, and on opposite sides of the revolving electro-magnet, I arranged to it the battery often cells, in a series of five double pairs, and, experimenting as before, I obtained a second series of results. The galvanometer used in the present instance was in every respect similar to that previously described, with the exception of the coil, which now consisted of a single turn of thick copper wire. Great care was taken to prevent, by its distance from, and relative position with the electro-magnet, any interference of the latter with its indications.

No. 2.

Revolu-
tions of
Electro-
Magnet

per
minute.

Deflec-
tions of
Galvano-
meter of
one turn.

Mean

Tempe-

rature of

Room.

Mean

Differ-

ence.

Temperature of

Water.

Before.

After.

Loss or

Gain.

Battery in

connexion.

Battery con-

tact broken.

Battery in

connexion.

Battery con-

tact broken.

Battery in

connexion.

Battery in

connexion.

Battery con-

tact broken.

Battery in

connexion.

J600

J600

1 600

1-600

J600

J600

J600

1-600

22

24

24 45

22

21 20

58-93

59-60

59-55

59-45

58-30

57-74

58-35

58-73

Mean,

Battery in

connexion.

Mean,

Battery con-

tact broken.

600

600

22 49

017+

0-40 +

1-23+

019+

005+

0-32+

0-49+

0-78+

58-20

60-02

59-90

59-78

57-35

57-28

58-83

58-83

60-00

59-98

61-67

59-50

59-35

58-83

58-85

60-20

1-80 gain

0-04 loss

1-77 gain

0-28 loss

2-00 gain

1-55 gain

0-02 gain

1-37 gain

0-51 +

0-36+

1-70 gain

010 loss

Corrected

Result.

1 600 22° 49' = 0-902 of cur.

inag.-elect. 1-84 gain

The corrected result is obtained as before, by adding the

loss sustained when contact with the battery was broken, to the heat gained when the battery was in connexion. I have in the present instance, however, made a further correction of

[Begin Page: Page 270]

o, 04< on account of the difference between the mean differences 0°'51 and 0°'36. The ground of this correction is the result of a previous experiment, in which, by revolving the apparatus at 94° in an atmosphere of 60°, the water sustained a loss of 7 0, 6, or about one quarter of the difference between the temperature of the atmosphere and the mean temperature of the water.

With the same electro-magnet, but using a battery of only four cells, arranged in a series of two double pairs, by which I expected to obtain about half as much magnetism in the iron, the following results were obtained : —

No. 3.

In the next experiments a battery of ten cells in a series of five double pairs was used for the purpose of exciting the large stationary electro-magnet. But, dismissing the galvanometer and the other extra parts of the circuit, I connected the terminal wires of the electro -magnet together, so as to obtain the whole effect of the magneto-electricity. The resistance of the coil of the revolving electro-magnet being to that of the whole circuit employed in the experiments No. 2 as 1 : 1*13, and 0*902 of current being obtained in those experiments, I ex-

[Begin Page: Page 271]

pected

series.

to obtain the calorific effect of 1*019 in the new

No. 4.

It seemed to me very desirable to repeat the experiments, substituting steel magnets for the stationary electro-magnets hitherto used. With this intention I constructed two magnets, each consisting of a number of thin plates of hard steel, — an arrangement which we owe to Dr. Scoresby. My metal was, unfortunately, not of very good quality, but nevertheless an attractive force was obtained sufficiently powerful to overcome the gravity of a small key weighing 47 grs., placed at the distance of three-eighths of an inch. The following results were obtained by revolving the small compound electro-magnet between the poles of the steel magnets.

In order to obtain the whole calorific effect of the steel magnets, I now, as in Series No. 4, connected the terminal wires of the revolving electro-magnet, and interpolated the experiments with others in which that connexion was broken. The resistance of the coil of the revolving electro-magnet being to the resistance of the whole circuit used in the experiments marked No. 5 as 1 : 1*44, and 0-236 of current electricity being obtained in those experiments, I expected to obtain in the present series the calorific effect of 0*34 of current magneto-electricity.

[Begin Page: Page 272]

No. 5.

No. 6.

[Begin Page: Page 273]

m

Although any considerable development of electrical currents in the iron of the revolving electro-magnet was prevented bj f its disposition in a number of thin plates insulated from each other, I apprehended that they might, under a powerful inductive influence, exist separately in each plate to such an extent as to produce an appreciable quantity of heat. To ascertain the fact, the terminals of the wire of the revolving electro-magnet were insulated from each other, while the latter was subjected to the inductive influence of the large electro-magnet excited by ten cells in a series of five double pairs. The experiments were interpolated with others in which contact with the battery was broken. As we shall hereafter give in detail experiments of the same class, it will not be necessary to do more at present than to state that the mean result of the present series, consisting of eight trials, gave o, 28 as the quantity of heat evolved by the iron alone.

We are now able to collect the results of the preceding experiments so as to discover the laws by which the development of the heat is regulated. The fourth column of the following table, containing the heat due to the currents circulating in the iron alone, is constructed on the basis of a law which we shall subsequently prove, viz. the heat evolved by a bar of iron revolving between the poles of a magnet is proportional to the square of the inductive force. Column 5 gives the heat evolved by the coils of the electro-magnet alone. No elimination is required for the results of series Nos. 5 and 6, because in them the iron of the revolving electro-magnet was subject to the influence of the steel magnets in the interpolating, as well as in the other experiments.

Table I.

[Begin Page: Page 274]

On comparing the corrected results in column 5 with the squares of magneto-electricity given in column 6, it will be abundantly manifest that the heat evolved by the coil of the magneto-electrical machine is 'proportional [ceteris paribus) to the square of the current.

Column 7, containing the heat due to voltaic currents of the quantities stated in column 2, is constructed on the basis of three very careful experiments on the heat evolved by passing currents through the coil of the small compound electro-magnet. I observed an increase in the temperature of the water equal to 5 0, 3, 5°*46, and 5°*9 respectively, when 2*028, 2*078, and 2' 145 of current voltaic electricity were passed, each during a quarter of an hour, through the coil. Reducing the first and second experiments to the electricity of the third according to the squares of the current, we have 5°-93, 5°*82 and 5°-9 for 2-145 of current. The mean of these is 5 0, 88, a datum from which the theoretical results of the preceding and subsequent tables are calculated.

But in comparing the heat evolved by magneto-, with that evolved by voltaic electricity, we must remember that the former is propagated by pulsations, the latter uniformly, Now since the square of the mean of unequal numbers is always less than the mean of their squares, it is obvious that the magnetic effect at the galvanometer will bear a greater proportion to the heat evolved by the voltaic, than the magneto-electricity; so that it is impossible to institute a strict comparison without ascertaining previously the intensity of the magneto-electricity at every instant of the revolution of the revolving electro-magnet. I have not been able to devise any very accurate means for attaining this object: but judging from the comparative brilliancy of the sparks when the commutator was arranged so as to break contact with the mercury at different positions of the revolving electro-magnet with respect to the poles of the stationary electro-magnet, there appeared to be but little variation in the intensity of the magneto-electricity during f of each revolution. The remaining ^ (during which the revolving electro-magnet passes the poles of the stationary electro-magnet) is occupied in the conversion of the direction of the electricity. In the experiments all flow of electricity during this 4 is cut off by the divisions of the commutator. In illustration of this I have drawn fig. 5, in which the direction and intensity of the magneto-electricity are represented by ordinates A#, &c, perpendicular to the straight line ABCDE; the intermediate spaces B C, CD, &c, represent the time during which the

electricity is wholly cut off by the divisions of the commutator.

[Begin Page: Page 275]

Were A x x 1 B, &c. perfect rectangles, it is obvious that the heat due to a given deflection of the galvanometer would be

Fig. 5.

K

| of that due to the same deflection and an uniform current, and column 8 of the table would contain exact theoretical results. But as this is not precisely the case, the numbers in that column are somewhat under the truth.

Bearing this in mind in the comparison of columns 5 and 8, it will, I think, be admitted that the experiments afford decisive evidence that the heat evolved by the coil of the magneto- electrical machine is governed by the same laws as those which regulate the heat evolved by the voltaic apparatus ; and exists also in the same quantity under comparable circumstances.

Although very little doubt could exist with regard to the heating power of magneto-electricity beyond the coil, I thought it would nevertheless be well to follow it there, in order to render the investigation more complete : I am not aware of any previous experiments of the kind.

I immersed five or six yards of insulated copper wire of ^ n th of an inch diameter in a flask holding about 12 oz. of water. The terminals of the wire were connected on one hand with the galvanometer of five turns and on the other with the commutator, and the circuit was completed by a wire extending from the galvanometer to the other compartment of the commutator. The revolving electro-magnet was now subjected to the inductive influence of the large electro-magnet excited by ten cells in a series of five double pairs, and rotated at the rate of 600 revolutions per minute during a quarter of an hour. The needle of the galvanometer, which remained as usual pretty steady, indicated a mean deflection of 32° 40' = 0*31 of current: and the heat evolved was found to be 0°*46, after the correction on account of the temperature of the surrounding air had been applied. Another experiment gave me 0°*4 for 0-286. The mean of the two is 0°*43 for 0*298 current magneto-electricity.

By passing a voltaic current from four cells in series through the wire, I found that 2*02 of current flowing uniformly evolved 12 0, in a quarter of an hour. Reducing this to 0*298 of cur-

[Begin Page: Page 276]

fent We have ((t^\ x 12 5 = 0°-2Gl. The product of this

by **|** (on account of the pulsatory character of the magneto-
current) gives o, 34-8, which, as theory demands, is somewhat
less than the quantity found by experiment.
[To be continued.]

XXXIII. 0?i the Storms of Tropical Latitudes. By William

Brown, Jan.

[Continued from p. 217 and concluded.]

''l^HE storms of the tropics and of temperate regions, though
thus referable to the same source, have yet some marked dif-
ferences. The principal of these are : — the greater violence of
the former ; the isolation of each individual storm ; the less
extent of each particular portion of it, and the much greater
extent and regularity of its progressive motion ; and the more
rapid though less depression of the barometer.

It may seem difficult at first to account for the violence of
tropical hurricanes, but the difficulty disappears when we
cease to compare the force of the upper current with that of

the lower which sweeps oyer the earth, where the friction upon the surface prevents its gaining a great velocity by soon putting alimit to its acceleration. But as at the beginning of the hurricanes which arise in the region of the trade-wind the lower current has not effected the change corresponding to that of the upper one, both therefore flowing in the same direction, the effect of friction must be so slight that we may almost disregard it ; as we may do also in other portions of the zone of the tropics, where a permanent reversal of the currents is effected; because it must be supposed that the upper and lower currents of the atmosphere are separated from each other by an interval of calm air; therefore the upper current when confined to the upper strata of the atmosphere, subject as it is from the constant decrease in temperature it meets with to an accelerating force, may attain a very great velocity, more especially in the former regions, before the effect of friction is sufficiently powerful to put a limit to its acceleration.

Thus as it matters little whether the difference of temperature, by which the wind acquires force sufficient to give the velocity of a hurricane notwithstanding the resistance of the air which it must displace, exists between columns of air nearly adjacent, or at the distance of many degrees of latitude, there seems no difficulty in conceiving the difference to be sufficiently great.

The comparative exemption of the upper current from fric-