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dinates of the extremity of the diameter, but $x'^2 (a^2 - V^2) + y'^2 (b^2 - V^2) + z'^2 (c^2 - V^2) = 0$,

$$\therefore \frac{l^2}{(a^2 - V^2)} + \frac{m^2}{b^2 - V^2} + \frac{n^2}{c^2 - V^2} = 0,$$

which is the equation at which he arrives when we make $l = 1$.

I remain, Gentlemen, yours, &c.,

Trinity College, Dublin,
Jan. 31, 1843.

JOHN WM. STUBBS.

XLIII. On the Calorific Effects of Magneto-Electricity, and on the Mechanical Value of Heat. By J. P. JOULE, Esq.

[Continued from p. 276.]

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

I NOW proceeded to consider the heat evolved by voltaic currents when they are counteracted or assisted by magnetic induction. For this purpose it was only necessary to introduce a battery into the magneto-electrical circuit: then by turning the wheel in one direction I could oppose the voltaic current; or, by turning in the other direction, I could increase the intensity of the voltaic by the assistance of the magneto-electricity. In the former case the apparatus possessed all the properties of the electro-magnetic engine; in the latter it presented the reverse, viz. the *expenditure* of mechanical power.

No. 7.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
May 19. May 20.	Circuits complete.	600	22° 40'	57° 43'	1° 03—	55° 62'	57° 18'	1° 56 gain.
	Circuits broken.	600	0 0	57° 45'	0° 41—	57° 08'	57° 00'	0° 08 loss.
	Circuits complete.	600	20 45	59° 40'	0° 08—	58° 65'	60° 00'	1° 35 gain.
	Circuits broken.	600	0 0	59° 40'	0° 51+	60° 00'	59° 83'	0° 17 loss.
	Circuits complete.	600	23 0	59° 10'	1° 29+	59° 78'	61° 00'	1° 22 gain.
	Mean circuits complete.	600	22 8	.....	0° 06+	.....	.....	1° 38 gain.
	Mean circuits broken.	600	.....	.....	0° 05+	.....	.....	0° 12 loss.
	Corrected Result.	600	22° 8' = 0.864 of current.					1° 50 gain.

In the preceding series I used the steel magnets previously described as the inductive force: and I had two of the large Daniell's cells in series, arranged so as to pass a current of electricity through the revolving electro-magnet and galvanometer. The wheel was turned in the direction which it would have taken had the friction been sufficiently reduced to allow of the motion of the apparatus without assistance. The precaution of interpolating the experiments was again adopted.

I give another series, in which everything else remaining the same, the direction of revolution was reverse, so as to *increase* the intensity of the voltaic electricity by superadding that of the magneto-electricity.

No. 8.

	Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
					Before.	After.	
May 23. May 24. May 26.	Circuits complete. } 600	30 15	60.55	0.19+	59.30	62.18	2.88 gain.
	Circuits broken. } 600	0 0	62.28	0.48+	62.92	62.60	0.32 loss.
	Circuits complete. } 600	29 40	60.90	0.03—	59.50	62.25	2.75 gain.
	Circuits broken. } 600	0 0	59.50	0.0	59.50	59.50	0
	Circuits complete. } 600	29 50	61.85	0.18—	60.33	63.02	2.69 gain.
	Circuits broken. } 600	0 0	60.90	0.49—	60.50	60.33	0.17 loss.
	Mean Circuits complete. } 600	29 55	.....	.....	.....	.....	2.77 gain.
	Mean Circuits broken. } 600	.....	.....	.....	.....	.....	0.16 loss.
	Corrected Result. } 600	29° 55' = 1.346 of current.					2.93 gain.

Dismissing the steel magnets, which did not appear to have lost any of the magnetic virtue which they possessed when newly made, I now substituted for them the large stationary electro-magnet, excited by eight of the Daniell's cells arranged in a series of four double pairs. The revolving electro-magnet completed, as before, a circuit containing the galvanometer and 2 of Daniell's cells in series. The motive power of the apparatus was now so great that it would revolve rapidly in spite of very considerable friction. In order to give the re-

quisite velocity it was necessary however to assist the motion by the hand.

No. 9.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
June 1, May 31, P. M.	Circuits complete.	600	16	62.50	0.11—	62.00	62.78	0.78 gain.
	Circuits broken.	600	0	63.00	0.23—	62.73	62.82	0.09 gain.
	Circuits complete.	600	14	62.65	0.11—	62.18	62.90	0.72 gain.
	Circuits broken.	600	0	63.15	0.20—	62.90	63.00	0.10 gain.
	Mean Circuits complete.	600	15	.....	0.11—	.....	.....	0.75 gain.
	Mean Circuits broken.	600	.....	.....	0.21—	.....	.....	0.095 ga.
Corrected Result.		600 15° = 0.543 of current.						0.68 gain.

The following series of results was obtained with the same apparatus, by turning the wheel in the opposite direction.

No. 10.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
June 3, June 2, A. M.	Circuits complete.	600	35 10	65.38	0.62+	63.25	68.75	5.50 gain.
	Circuits broken.	600	0 0	64.73	0.75+	65.51	65.45	0.06 loss.
	Circuits complete.	600	37 10	65.10	1.40+	63.33	69.66	6.33 gain.
	Circuits broken.	600	0 0	64.93	1.23+	66.28	66.05	0.23 loss.
	Mean Circuits complete.	600	36 10	.....	1.01+	.....	.....	5.915 gain
	Mean Circuits broken.	600	.....	.....	0.99+	.....	.....	0.145 loss
Corrected Result.		600 36° 10' = 1.845 of current.						6.06 gain.

I give two series more, in which only one cell was connected with the revolving electro-magnet, and the revolution was in the direction of the attractive forces. The magneto-electricity

No. 11.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
June 3, P. M.	Circuits complete.	350	0	64.02	0.38—	63.57	63.72	0.15 gain.
	Circuits broken.	350	0	63.75	0.02—	63.73	63.73	0
	Circuits complete.	400	0	63.80	0.02—	63.70	63.86	0.16 gain.
	Circuits broken.	400	0	64.35	0.08—	64.27	64.27	0
	Mean Circuits complete.	375	0	.....	0.20—	.....	.....	0.155 gain
	Mean Circuits broken.	375	0	.....	0.05—	.....	.....	0
	Corrected Result.	375	0					0.12 gain.

No. 12.

		Revolutions of Electro-Magnet per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Loss or Gain.
						Before.	After.	
June 5, A. M.	Circuits complete.	600	9° 40'	60.40	0.16—	60.02	60.47	0.45 gain.
	Circuits broken.	600	0	60.64	0.17—	60.47	60.47	0
	Corrected Result.	600	9° 40' = 0.34	{ current in the opposite direction. }				0.45 gain.

was so intense, at a velocity of 600 per minute, as to overpower the intensity of the single cell, causing the needle to be permanently and steadily deflected to between 9° and 10° in the opposite direction. The command of the magneto-electricity over the voltaic current arising from one cell was beautifully illustrated by the sparks at the commutator. Turning

slowly, they were bright and snapping*; increasing the rapidity of revolution, they decreased in brightness: until at a velocity of about 370 per minute they ceased altogether. They were plainly visible again when the velocity reached 600 per minute.

The results of the preceding series of experiments are collected in the following table along with theoretical results calculated in precisely the same manner as those of Table I. The correction for heat evolved by the iron of the revolving electro-magnet is estimated at $0^{\circ}\cdot 18$, the product of $0^{\circ}\cdot 28$ by $\left(\frac{4}{5}\right)^2$; because in the above experiments the large electro-magnet was excited by $\frac{4}{5}$ of the battery used when $0^{\circ}\cdot 28$ was obtained. No correction is needed for the series in which the steel magnets were used, because they remained in their places during the interpolating experiments.

TABLE II.

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 $\frac{1}{3}$.
No. 7.	0.864	1.50	0	1.50	1.291	0.954	1.272
No. 8.	1.346	2.93	0	2.93	3.133	2.316	3.088
No. 9.	0.543	0.68	0.18	0.50	0.510	0.377	0.503
No. 10.	1.845	6.06	0.18	5.88	5.886	4.351	5.801
No. 11.	0	0.12	0.18	0.06	0	0	0.
No. 12.	0.340	0.45	0.18	0.27	0.200	0.148	0.197
1.	2.	3.	4.	5.	6.	7.	8.

In all these experiments, as well as in those collected in Table I, the time occupied by the platinum wires in crossing the divisions of the commutator was found to be exactly $\frac{1}{4}$ of that occupied by an entire revolution. Hence the multiplication by $\frac{4}{3}$ in order to obtain true theoretical results on the supposition that the current flows uniformly during $\frac{3}{4}$ of a revolution. It will be observed that these theoretical results

* The most splendid sparks are obtained when the voltaic is assisted by the magneto-electricity, by turning an electro-magnetic engine in a direction contrary to the attractive forces,

are not so much inferior to the experimental results of column 5 as they were in Table I. The principal reason of this arises from the mixture of the constant effect of the battery with the variable magneto-electrical current, as will be readily seen on inspecting figs. 6 and 7, the former of which represents the currents in series No. 9; the latter, those in series No. 10. The dotted rectangles *a b c d*, &c., represent the constant effect of the battery of two cells, which is in one instance diminished, in the other increased by the magneto-electricity.

Fig. 6.

Fig. 7.

On comparing columns 6 and 8 with column 5, it is manifest that the law of the square of the electric current still obtains, and is not affected either by the assistance or resistance which the magneto-electricity presents to the voltaic current. Now the increase or diminution of the chemical effects occurring in the battery during a given time is proportional to the magneto-electrical effect, and the heat evolved is always proportional to the square of the current; therefore the heat due to a given chemical action is subject to an increase or to a diminution directly proportional to the intensity of the magneto-electricity assisting or opposing the voltaic current.

We have therefore in magneto-electricity an agent capable by simple mechanical means of destroying or generating heat. In a subsequent part of this paper I shall make an attempt to connect heat with mechanical power in absolute numerical relations. At present we shall turn to a question intimately connected with the previous investigations; and which indeed has already been partly developed.

On the Heat evolved by a Bar of Iron rotating under Magnetic Influence.

Having removed the small electro-magnet from out of the tube of the revolving piece, I fixed in its stead, in the centre of the tube, a solid cylinder of iron 8 inches long and $\frac{3}{4}$ of an inch in diameter. The tube was then, as before, filled with water and rotated for a quarter of an hour between the poles of the large electro-magnet. In the first experiments the electro-magnet was excited by ten cells in a series of five double pairs, a galvanometer being included in the circuit in order to indicate the electric force applied. It was of course placed, as before, so as not to be affected by the powerful attraction of the electro-magnet. The precaution of interpolating the experiments was adopted as usual.

No. 13.

		Revolutions of the Bar per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Gain or Loss.
						Before.	After.	
June 17, P.M.	Electro-magnet in action.	} 600	70 55	67°38	0°35—	66°27	67°80	1°53 gain
	Battery contact broken.	} 600	...	67°60	0°23+	67°77	67°90	0°13 gain
	Electro-magnet in action.	} 600	70 45	67°85	0°67+	67°85	69°20	1°35 gain
	Battery contact broken.	} 600	...	68°92	0°30+	69°18	69°27	0°09 gain
	Mean, Electro-magnet in action.	} 600	70 50	...	0°16+	...	...	1°44 gain
	Mean, Battery contact broken.	} 600	...	...	0°26+	...	...	0°11 gain
	Corrected Result.	} 600	70°50 = 9·85 current.					1°31 gain

Everything else remaining the same, I now used a battery of six cells arranged in a series of three double pairs to excite the electro-magnet.

No. 14.

		Revolutions of the Bar per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Gain or Loss.
						Before.	After.	
June 19, A.M.	Electro-magnet in action.	600	64° 10'	65° 42'	0° 17—	65° 00'	65° 50'	0° 50 gain
	Battery contact broken.	600	...	65° 55'	0° 10—	65° 48'	65° 42'	0° 06 loss
	Electro-magnet in action.	600	64 10	65° 42'	0° 17+	65° 33'	65° 86'	0° 53 gain
	Battery contact broken.	600	...	65° 75'	0° 03+	65° 80'	65° 77'	0° 03 loss
	Mean, Electro-magnet in action.	600	64 10	...	...	...	...	0° 515 gain
	Mean, Battery contact broken.	600	...	...	0° 03—	...	...	0° 045 loss
	Corrected Result.	600	64° 10' = 6° 77 current.					0° 56 gain

I give another series obtained with a battery of two cells in series.

No. 15.

		Revolutions of the Bar per minute.	Deflections of Galvanometer of 1 turn.	Mean Temperature of Room.	Mean Difference.	Temperature of Water.		Gain or Loss.
						Before.	After.	
June 19, P.M.	Electro-magnet in action.	600	54	63° 65'	0° 43—	63° 12'	63° 32'	0° 20 gain
	Battery contact broken.	600	...	63° 80'	0° 38—	63° 40'	63° 45'	0° 05 gain
	Electro-magnet in action.	600	54	63° 75'	0° 20—	63° 45'	63° 65'	0° 20 gain
	Battery contact broken.	600	...	64° 07'	0° 37—	63° 68'	63° 73'	0° 05 gain
	Mean, Electro-magnet in action.	600	54	...	0° 32—	...	...	0° 20 gain
	Mean, Battery contact broken.	600	...	...	0° 38—	...	...	0° 05 gain
	Corrected Result.	600	54° = 4° 17 current.					0° 16 gain

The results of the preceding experiments are collected in the following table :—

TABLE III.

Series of Experiments.	Current employed in exciting the Electro-Magnet.	Heat Evolved.	Square of Numbers proportional to those of Column 2.
No. 13.	9·85	1·31	1·2290
No. 14.	6·77	0·56	0·5807
No. 15.	4·17	0·16	0·2203
1	2	3	4

It was discovered by Prof. Jacobi, and by myself also one or two months afterwards*, that the attraction of electro-magnets, either towards one another or for their armatures, is (below the point of saturation) proportional to the square of the electric force. The *magnetism* in an electro-magnet is therefore simply as the electric force. Consequently the numbers in column 2 are proportional to the magnetic virtue of the electro-magnet. But on comparing columns 3 and 4 together, it will be seen that the heat evolved is as the square of the electricity. Therefore *the heat evolved by a revolving bar of iron is proportional to the square of the magnetic influence to which it is exposed.*

After the preceding experiments there can be no doubt that heat would be evolved by the rotation of non-magnetic substances, in proportion to their conducting power, Dr. Faraday having proved the existence of currents in such circumstances, and that their quantity is proportional, *cæteris paribus*, to the conducting power of the body in which they are excited. I have not made any experiments on this subject, but in the next part we shall have occasion to avail ourselves of the good conducting power of copper, in conjunction with the magnetic virtue of the bar of iron, in order to obtain a maximum result from the revolution of a metallic bar.

[To be continued.†]

* Annals of Electricity, vol. iv. p. 131. Jacobi and Lenz communicated their report to the St. Petersburg Academy in March 1839,—two months previous to the date of my paper.

[† Mr. Joule requests us to insert the following *erratum* in the former portion of his paper: p. 274, for BC, CD, &c., read BC, DE, &c.—EDIT.]