of a pearly lustre. When sublimed, its crystals resemble those of naphthaline, and when formed by spontaneous evaporation from æther they are deposited in large, very regular rhombohedrons. I formerly stated that alkalies do not evolve ammonia from nitro-theine; I find that in this I was mistaken, for when boiled with solution of potash it gives off abundance of ammonia.

When subjected to analysis,—

I. 0·2628 gr. of the substance dried at 212° gave 0·398 carbonic acid and 0·1005 of the water.

II. 0·2529 gr. gave 0·3855 carbonic acid and 0·0975 water.

When burnt with oxide of copper, ten tubes gave carbonic acid and nitrogen in the proportion of five to one.

	I.	II.
Carbon	41·87	42·15
Hydrogen	4·24	4·28
Nitrogen	19·39	19·56
Oxygen	34·50	34·01
	100·00	100·00

Nitro-theine appears to be a neutral body, and as I have not been able to determine its atomic weight, I have not thought it worth while to attempt to deduce any formula from these analyses. Theine does not yield more of this substance than from 5 to 6 per cent.

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

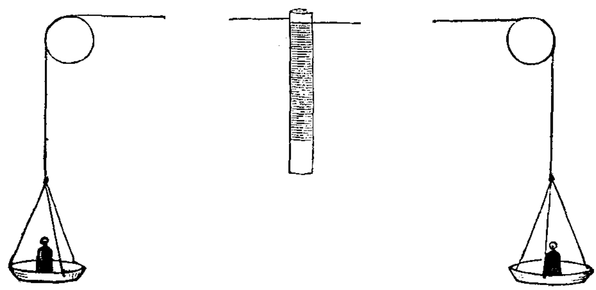
[Continued from p. 355 and concluded.]

Part II.—*On the Mechanical Value of Heat.*

HAVING proved that *heat* is *generated* by the magneto-electrical machine, and that by means of the inductive power of magnetism we can *destroy* or *increase* at pleasure the *heat* due to chemical changes, it became an object of great interest to inquire whether a constant ratio existed between it and the mechanical power gained or lost. For this purpose it was only necessary to repeat some of the previous experiments, and to ascertain, at the same time, the mechanical force necessary in order to turn the apparatus.

To accomplish the latter purpose, I resorted to a very simple device, yet one peculiarly free from error. The axle *b*, fig. 1, (p. 264) was wound with a double strand of fine twine, and the strings (as represented in fig. 8) were carried over very easily-working pullies, placed on opposite sides of the axle, at a distance from each other of about 30 yards. By means of weights placed in the scales attached to the ends of the strings, I could easily ascertain the force necessary to move the apparatus at any given velocity; for, having given in the first instance the required velocity with the hand, it was easily observed, in the course of about 40 revolutions of the axle, corresponding to

Fig. 8.



about 270 revolutions of the revolving piece, whether the weights placed in the scales were just able to maintain that velocity.

The experiments selected for repetition first were those of series No. 2. Ten cells, in a series of five double pairs, were connected with the large electro-magnet; and the small compound electro-magnet (restored to its place in the centre of the revolving tube) was connected, through the commutator, with the galvanometer. Under these circumstances a velocity of 600 revolutions per minute was found to produce a steady deflection of the needle to 24° 15′, indicating 0·983 of current magneto-electricity.

To maintain the velocity of 600 per minute, 5 lbs. 3 oz. had to be placed in each scale; but when the battery was thrown out of communication with the electro-magnet, and the motion was opposed solely by friction and the resistance of the air, only 2 lbs. 13 oz. were required for the same purpose. The difference, 2 lbs. 6 oz., represents the force spent during the connexion of the battery with the electro-magnet in overcoming magnetic attractions and repulsions. The perpendicular descent of the weights was at the rate of 517 feet per 15 minutes.

According to series No. 2, Table I., the heat due to 0·983 of current magneto-electricity is $\left(\frac{983}{902}\right)^2 \times 1^\circ{\cdot}56 = 1^\circ{\cdot}85$. But as the resistance of the coil of the revolving electro-magnet was to that of the whole circuit as 1 : 1·13, the heat evolved by the whole conducting circuit was $1^\circ{\cdot}85 \times 1{\cdot}13 = 2^\circ{\cdot}09$. Adding to this $0^\circ{\cdot}33$ on account of the heat evolved by the iron of the revolving electro-magnet, and $0^\circ{\cdot}04$ on account of the sparks* at the commutator, we have a total of $2^{\circ}{\cdot}46$. Now in order to refer this to the capacity of a lb. of water, I found—

	lbs.		lbs.
Weight of glass tube	= 1·65 =	capacity for heat of	0·300 of water.
Weight of water	= 0·61 =	... ...	0·610 ...
Weight of electro-magnet	= 1·67 =	... ...	0·204 ...
Total weight ...	= 3·93 =	... ...	1·114 ...

$2^{\circ}{\cdot}46 \times 1{\cdot}114 = 2^{\circ}{\cdot}74$; and this has been obtained by the power which can raise 4 lbs. 12 oz. to the perpendicular height of 517 feet.

1° of heat per lb. of water is therefore equivalent to a mechanical force capable of raising a weight of 896 lbs. to the perpendicular height of one foot.

Two other experiments, conducted precisely in the same manner, gave a degree of heat to mechanical forces represented respectively by 1001 lbs. and 1040 lbs.

I now made an experiment similar to those of series No. 10. Eight cells in a series of four double pairs were connected with the large electro-magnet, and two in series with the small revolving electro-magnet. The velocity of revolution was at the rate of 640 per minute, contrary to the direction of the attractive forces, causing the needle to be deflected to $37^{\circ}\ 20'$, which indicates a current of 1·955.

A weight of 6 lbs. 4 oz. placed in each scale was just able to maintain the above velocity when the circuits were complete; but when they were broken, and friction alone opposed the motion, a weight of 2 lbs. 8 oz. only was required, which is less than the former by 3 lbs. 12 oz. The fall of the weights was in this instance 551 feet per 15 minutes.

According to series 10, Table II., the heat due to the current observed in the present instance is $\left(\frac{1{\cdot}955}{1{\cdot}845}\right)^2 \times 5^{\circ}{\cdot}88 = 6^{\circ}{\cdot}6$. But I had found by calculations, based as usual upon the laws of Ohm, that, in the present experiment, the resistance of the coil of the revolving electro-magnet was to that of the whole circuit, including the two cells, as 1 : 1·303. Therefore the heat evolved by the whole circuit, including $0^{\circ}{\cdot}18$ on account of the iron of the revolving electro-magnet, and $0^{\circ}{\cdot}12$ on account of sparks at the commutator, was $8^{\circ}{\cdot}9$, or $9^{\circ}{\cdot}92$ per capacity of a lb. of water.

Now when the revolving electro-magnet was stationary, the two cells could pass through it an uniform current of 1·483.

* The heat evolved by sparks in the above and subsequent instances had been determined by previous experiments.

The heat evolved from the whole circuit by such a current is $\left(\frac{1\cdot483}{2\cdot145}\right)^2 \times 5^\circ\cdot88 \times 1\cdot303 \times 1\cdot114 = 4^\circ\cdot08$ per lb. of water per 15 minutes, according to data previously given. Hence the quantity of heat due to the chemical reactions in the experiment is $\frac{1\cdot955}{1\cdot483} \times 4^\circ\cdot08 = 5^\circ\cdot38$, instead of $9^\circ\cdot92$, the quantity actually evolved.

Hence $4^\circ\ 54'$ were evolved in the experiment over and above the heat due to the chemical changes taking place in the battery, by the agency of a mechanical power capable of raising 7 lbs. 8 oz. to the height of 551 feet. In other words, one degree is equivalent to 910 lbs. raised to the height of one foot.

An experiment was now made, using the same apparatus as an electro-magnetic engine. The power of the magnetic attractions and repulsions alone, without the assistance of any weights, was able to maintain a velocity of 320 revolutions per minute. But when the circuits were broken, a weight of 1 lb. 2 oz. had to be placed in each scale in order to obtain the same velocity. The deflection of the needle was in this instance $17^\circ\ 15' = 0\cdot63$ of current electricity. The perpendicular descent of the weights was 275 feet per 15 minutes.

Now, calculating in a similar manner to that adopted in the last experiment, we have, from series 9, Table II., and other data previously given, $\left(\frac{630}{543}\right)^2 \times 0^\circ\cdot50 \times 1\cdot303 = 0^\circ\cdot877$, which, on applying a correction of $0^\circ\cdot012$ on account of sparks at the commutator, and $0^\circ\cdot18$ on account of the iron of the revolving electro-magnet, and then reducing to the capacity of a pound of water, gives $1^\circ\cdot191$ as the quantity of heat evolved by the whole circuit in 15 minutes.

The quantity of current which the two cells could pass through the revolving electro-magnet when the latter was stationary, was in this instance 1·538; and $\left(\frac{1\cdot538}{2\cdot145}\right)^2 \times 5^\circ\cdot88 \times 1\cdot303 \times 1\cdot114 = 4^\circ\cdot38$. Hence, as before, the quantity of heat due to the chemical reactions during the experiment is $\frac{0\cdot63}{1\cdot538} \times 4^\circ\cdot38 = 1^\circ\cdot794$, which is $0^\circ\cdot603$ more than was obtained during the revolution of the electro-magnet.

Hence $0^\circ\cdot603$ has been converted into a mechanical power equal to raise 2 lbs. 4 oz. to the height of 275 feet. In other words, one degree per lb. of water may be converted into the mechanical power which can raise 1026 lbs. to the height of one foot.

Another experiment, conducted in precisely the same manner as the above, gave, per degree of heat, a mechanical power capable of raising 587 lbs. to the height of one foot.

As the preceding experiments are somewhat complicated, and therefore subject to the accumulation of small errors of observation, I thought it would be desirable to execute some of a more simple character. For this purpose I determined upon an arrangement in which the whole of the heat would be evolved in the revolving tube.

The iron cylinder used in previous experiments was placed in an electrotype apparatus constructed in such a manner as to render every part of it equally exposed to the voltaic action. In four days 11 oz. of copper were deposited in a hard compact stratum. The ends of the cylinder were then filed until the iron just appeared. Thus I had a cylinder of iron immediately surrounded by a hollow cylinder of pure copper nearly one-eighth of an inch thick. This was placed in the centre of a new revolving tube fitted up in precisely the same manner as the former one, which had been accidentally broken, and surrounded with $11\frac{1}{4}$ oz. of water. I give the following series of experiments in which the above was rotated between the poles of the large electro-magnet excited by ten cells arranged in a series of five double pairs, a galvanometer being included in the circuit to indicate the electric force to which the electro-magnet was exposed.

No. 16.

		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.	
July 5, A.M.	Battery contact broken.	600	° ...	67°·50	0°·15−	67°·37	67°·33	00°·4 loss
	Electro-magnet in action.	600	72 35	69·32	0·42−	67·50	70·30	2·80 gain
July 4, P.M.	Battery contact broken.	600	...	68·80	0·16+	69·00	68·93	0·07 loss
	Electro-magnet in action.	600	72 25	69·70	0·56+	69·00	71·52	2·52 gain
	Mean, Electro-magnet in action.	600	72 30	...	0·07+	...	...	2·66 gain
	Mean, Battery contact broken.	600	...	...	...	...	...	0·05 loss
	Corrected Result.	600	72° 30′ = 10·93 current.					2·73 gain

I now proceeded to ascertain, by means already described, the mechanical power by which the above effects were produced. First, I ascertained the current passing through the coil of the electro-magnet; then the weights necessary to maintain the velocity of 600 revolutions per minute, both when the magnet was in action and when contact with the battery was broken. I have collected the results of my experiments on this subject in the following table. The first five were obtained with a battery of ten cells in a series of five; the last two with a battery of five pairs in series.

TABLE IV.

	Deflections of the Galvanometer of one turn completing the circuit of the Electro-Magnet.	Weight in each scale, the Electro-Magnet being in action.	Weight in each scale, the Electro-Magnet being not in action.	Difference.
	° ′	lb. oz.	lb. oz.	lb. oz.
	72 30	4 4	2 5	1 15
	72 30	4 4	2 3	2 1
	72 25	4 2	2 0	2 2
	72 15	5 0	2 10	2 6
	72 5	4 0	2 0	2 0
	68 0	3 14	2 8	1 6
	66 10	3 0	2 0	1 0
Mean of the first 5 experiments	72° 21′ = 10·82 current.			2·1 lbs.
Mean of the last 2 experiments	67° 5′ = 7·91 current.			1·19 lb.

Referring to series 16, we see that 2°·73 were obtained when the bar was revolved between the poles of the electro-magnet excited by a current of 10·93. Therefore the quantity of heat due to the mean current in the first five experiments of the above table is $\left(\frac{10{\cdot}82}{10{\cdot}93}\right)^2 \times 2^\circ{\cdot}73 = 2^\circ{\cdot}675$. To reduce this to the capacity of a pound of water, I had in the present instance the following data:—

	lbs.		lb.	
Weight of glass tube .	= 1·125 =	capacity for heat of	0·205	of water.
Weight of water . .	= 0·687 =	... ...	0·687	...
Weight of metallic bar	= 1·688 =	... ...	0·202	...
Total Weight	= 3·500 =	... ...	1·094	...

2°·926, the product of 1·094 and 2°·675, is therefore the heat generated by a mechanical force capable of raising 4·2 lbs. to the height of 517 feet.

In other words, one degree of heat per lb. of water may be generated by the expenditure of a mechanical power capable of raising 742 lbs. to the height of one foot.

By a similar calculation, I find the result of the last two experiments of the table to be 860 lbs.

The foregoing are all the experiments I have hitherto made on the mechanical value of heat. I admit that there is a considerable difference between some of the results, but not, I think, greater than may be referred with propriety to mere errors of experiment. I intend to repeat the experiments with a more powerful and more delicate apparatus. At present we shall adopt the mean result of the thirteen experiments given in this paper, and state generally that,—

The quantity of heat capable of increasing the temperature of a pound 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.*

Among the practical conclusions which may be drawn from the convertibility of heat and mechanical power into one another, according to the above absolute numerical relations, I will content myself with selecting two of the more important. The former of these is in reference to the duty of steam-engines; the latter, to the practicability of employing electro-magnetism as an œconomical motive force.

1. In his excellent treatise on the Steam-engine, Mr. Russell has given a statistical table*, containing, among other important matter, the number of pounds of fuel evaporating one cubic foot of water, from the initial temperature of the water, and likewise from the temperature of 212°. From these facts it appears that in the Cornish boilers at Huel Towan, and the United Mines, the combustion of a lb. of Welsh coal gives 183° to a cubic foot of water, or otherwise 11,437° to a lb. of water. But we have shown that one degree is equal to 838 lbs. raised to the height of one foot. Therefore the heat evolved by the combustion of a lb. of coal is equivalent to the mechanical force capable of raising 9,584,206 lbs. to the height of one foot, or to about ten times the duty of the best Cornish engines.

2. From my own experiments, I find that a lb. of zinc consumed in Daniell's battery produces a current evolving about 1320°; in Grove's battery, about 2200° per lb. of water. Therefore *the mechanical forces of the chemical affinities which produce the voltaic currents in these arrangements, are, per lb. of zinc, equal respectively to* 1,106,160 *lbs. and* 1,843,600 *lbs. raised to the height of one foot.* But since it will be practically impossible to convert more than about one half of the heat of

* Enc. Brit., 7th Edition, vol. xx. part 2. p. 685.

the voltaic circuit into useful mechanical power, it is evident that the electro-magnetic engine, worked by the voltaic batteries at present used, will never supersede steam in an œconomical point of view.

Broom Hill, Pendlebury,
near Manchester, July 1843.

P.S.—We shall be obliged, after all, to admit that Count Rumford was right in attributing the heat evolved by boring cannon to friction, and not (in any considerable degree) to any change in the capacity of the metal. I have myself proved experimentally that *heat is evolved by the passage of water through narrow tubes.* My apparatus consisted of a piston perforated by a number of small holes, working in a cylindrical glass jar containing about 7 lbs. of water. I thus obtained one degree of heat per lb. of water from a mechanical force capable of raising about 770 lbs. to the height of one foot,—a result which will be allowed to be very strongly confirmatory of our previous deductions. I shall lose no time in repeating and extending these experiments, being satisfied that the grand agents of nature are, by the Creator's fiat, *indestructible*; and that wherever mechanical force is expended, an exact equivalent of heat is *always* obtained.

On conversing a few days ago with my friend Mr. John Davies, he told me that he had himself, a few years ago, attempted to account for that part of animal heat which Crawford's theory had left unexplained, by the friction of the blood in the veins and arteries, but that, finding a similar hypothesis in Haller's 'Physiology*,' he had not pursued the subject further. It is unquestionable that heat is produced by such friction, but it must be understood that the mechanical force expended in the friction is a part of the force of affinity which causes the venous blood to unite with oxygen; so that the whole heat of the system must still be referred to the chemical changes. But if the animal were engaged in turning a piece of machinery, or in ascending a mountain, I apprehend that in proportion to the muscular effort put forth for the purpose, a *diminution* of the heat evolved in the system by a given chemical action would be experienced.

I will observe in conclusion, that the experiments detailed in the present paper do not militate against, though they certainly somewhat modify the views I had previously entertained with respect to the electrical origin of chemical heat. I had before endeavoured to prove that when two atoms combine together, the heat evolved is exactly that which would have been evolved by the electrical current due to the chemical action taking place, and is therefore proportional to the intensity of the

* Haller's Physiology, vol. ii. p. 304.

chemical force causing the atoms to combine. I now venture to state more explicitly, that it is not precisely the attraction of affinity, but rather the mechanical force expended by the atoms in falling towards one another, which determines the intensity of the current, and consequently the quantity of heat evolved; so that we have a simple hypothesis by which we may explain why heat is evolved so freely in the combination of gases, and by which indeed we may account "latent heat" as a mechanical power prepared for action as a watch spring is when wound up. Suppose, for the sake of illustration, that 8 lbs. of oxygen and 1 lb. of hydrogen were presented to one another in the gaseous state, and then exploded, the heat evolved would be about one degree Fahr. in 60,000 lbs. of water, indicating a mechanical force expended in the combination equal to a weight of about 50,000,000 of lbs. raised to the height of one foot. Now if the oxygen and hydrogen could be presented to each other in a liquid state, the heat of combination would be less than before, because the atoms, in combining, would fall through less space. The hypothesis is, I confess, sufficiently crude at present, but I conceive that ultimately we shall be able to represent the whole phænomena of chemistry by exact numerical expressions, so as to be enabled to predict the existence and properties of new compounds.

August, 1843. J. P. J.

LIII. *Experiments on Voltaic Reaction. By* W. R. Grove, *Esq., M.A., F.R.S., Professor of Experimental Philosophy in the London Institution**.

On the weekly evening meeting of the Royal Institution for March 13, 1840†, I communicated some experiments and observations on certain phænomena which I collated under the general term Voltaic Reaction. I then stated, that in certain (probably in all) cases of the development of a voltaic current a reaction was induced by the voltaic force itself, and that upon the cessation of the initial force the reacting force was apparent in an opposed direction. I showed, moreover, that the diminution or removal of this reaction was one means of increasing the power of the initial current. This reaction in electrolytes (though it is by no means confined to electrolytes) is what has been generally called polarization, and would be one of the resistances to be taken into account in calculating the resulting power of a voltaic current upon Ohm's theory.

It recently occurred to me, that as one method of increasing the power of the initial current was to diminish (or, as it were,

* Communicated by the Author.

† A report is published in the Phil. Mag., S. 3., vol. xvi. p. 338.