*On a New Electrometer, and the Heat excited in Metallic Bodies
by Voltaic Electricity.* By WILLIAM SNOW HARRIS, Esq.
F.R.S.

(Read December 19. 1831.)

1. **I**N the course of some inquiries concerning the power of metallic substances to conduct intense electrical explosions, an account of which was honoured by a place in the Philosophical Transactions for the year 1827, I sought to obtain a comparative measure of the conducting power, in the heat evolved by the metal, at the time of transmitting the charge. The instrument employed for this purpose, was, in principle, that of a common air thermometer, the given metal, the subject of experiment, being drawn into a wire, and passed air-tight across its bulb. This simple contrivance, I have since extended to the general purposes of an electrometer, so as to estimate the force of any ordinary electrical accumulation. The results arrived at with voltaic combinations, seem, for the most part, of much practical utility; and therefore some account of them may, I trust, be found worthy of the attention of the Royal Society of Edinburgh.

2. The electrometer, as prepared for the purposes of voltaic electricity, will be easily understood by the following description:—*abc*, Fig. 1, Plate VIII., is a fine glass-tube, whose interior diameter is about the $\frac{1}{10}$ th of an inch; there is a spherical reservoir blown at *a* for the reception of a coloured fluid; from this

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 5.

Fig. 4.

the tube is bent a little forward, and then perpendicularly, and is finally secured to a correctly divided scale bc , sustained on a convenient base, as seen in the figure. The point o on the scale, corresponding to the level of the coloured fluid in the opposite reservoir a , is marked zero.

A metallic wire mn , Fig. 2, varying from the $\frac{1}{100}$ th to the $\frac{1}{5}$ th of an inch in diameter, according to the circumstances of the experiment, is passed air-tight across the glass ball B by means of small flanges of brass mn , cemented in and round two holes drilled through the sides, and upon these are screwed two brass balls rn in such way as to render the whole air-tight. The method of fixing the wire is extremely simple, the brass parts being made quite clean internally; the wire is passed directly through them; it is put gently on the stretch, and is then compressed in the holes by small pegs of tough wood, so as to insure a good contact: the pegs, and extremities of the wire, are allowed to project a little, for the convenience of removal, and thus different wires may be substituted with great expedition. The ball B, being thus prepared, is screwed air-tight on the spherical reservoir a , Fig. 1, by the ordinary intervention of brass caps, which should be closely cemented with good sealing-wax to the glass; hence, when the wire mn becomes heated by the voltaic action, the fluid will be observed to ascend along the scale bc .

The contact with the battery, as in Figs. 1, 2, 3, &c., is made by means of the small brass cups tt , Fig. 2, screwed in the balls rn , in which is placed a little mercury; and, to adjust the fluid to zero of the scale, there is a small opening drilled through the upper part of the bulb at q , Fig. 2, which, being covered also with a ball and flange, admits of a communication being easily made with the external air at pleasure*.

* The fluid for marking the degrees of action may consist of rectified spirit one part, distilled water three parts, coloured with tincture of cochineal; to which may

3. The indications of this instrument appearing, after a few trials, to be very general and decisive, I endeavoured to ascertain how far it might be relied on as a measure of electrical action, as also the variations to which it might be subject: as these points became satisfactorily determined in the course of the following investigation, I shall give a brief detail of the experiments as they occurred.

4. (a) My first attempts were directed to the law of the action of a single zinc and copper plate *xy*, Fig. 1, placed at various distances from each other in a dilute acid. The plates employed for this purpose were each 7 inches high, 6 inches wide, and about the $\frac{1}{10}$ th of an inch thick, and were secured in a light frame of varnished wood *ff*. The cell A for the acid had bottom and ends of varnished mahogany, and sides of glass; it was internally 10 inches long, 8 inches deep, and 7 inches wide. The wire in the electrometer B was of copper, and about the $\frac{1}{10}$ th of an inch in diameter*. The dilute acid consisted of nitrous acid one part, sulphuric acid one part, water forty-eight parts by measure. The contacts with the plates were effected through small cups *xy* containing mercury; the wires employed to complete the circuit being of copper, and $\frac{1}{4}$ th of an inch in diameter.

The following are the results of this experiment:—

be added as much sulphuric acid as will render the whole pleasantly sour. Mercury also, when the tube is fine, may be used with advantage.

* This experiment was likewise contemplated by my friend Mr WATKINS, the curator of the apparatus, in the London University. In the course of a few trials with the instrument which I had the pleasure of making with him at his house, we succeeded in rendering sensible, the action of a small plate of zinc and copper, of only $\frac{1}{4}$ th of an inch square, when placed in an extremely diluted acid, at upwards of 4 inches apart; the wire in the electrometer was in this instance *extremely* fine.

TABLE I.

Distance of Plates in inches.	Effect on Electro- meter in degrees.
8.0	1.0
6.0	1.5 —
4.0	2.0
2.0	4.0
1.0	8.0
0.5	15.0 —
0.25	25.0

The law in this case seems, therefore, to be that of a simple inverse ratio of the distance between the plates, except in the near approximations, where the numbers are somewhat less than might have been anticipated. In repeating this experiment, however, the effect on the instrument was, for the most part, exactly in the inverse ratio of the distance between the plates.

The plates were removed from the acid before observing the effects due to each respective distance, and carefully wiped, and the acid occasionally changed, from a common stock previously mixed in mass.

5. (b) With a view of ascertaining the law of the action as regarded the quantity of metal immersed, the plates were divided, by horizontal lines drawn across them, into seven portions, each an inch wide, and as much dilute acid poured into the cell as was equivalent to immerse one, two, three, &c. of the divisions successively. In the following Table are given the results of this experiment, the plates being carefully wiped, and the acid renewed as before at such trial.

TABLE II.

Quantity of Metal immersed.	Effect in Degrees.
1	4
2	8
3	12 +
4	16
5	20
6	25
7	28

In this instance, therefore, the resulting effects are exactly as the quantity of metal immersed, or very nearly so, since the instrument appeared to vary with the increased power.

6. The foregoing experiments (5) being repeated with a very fine wire in the electrometer, of about the $\frac{1}{500}$ th of an inch in diameter, the results were no longer regular, being as follows :—

TABLE III.

Quantity of Metal immersed.	Effect in Degrees.
1	6
2	10
3	13
4	15.5
5	18
6	19
7	20

7. The *comparatively* diminishing effects, corresponding to the increased action observable in the above Table, is fairly at-

tributable to some peculiar condition of the fine wire employed in the electrometer, by which it is rendered incapable of transmitting all the increased power; and it may be likewise observed, in comparing the above (Table III.) with the previous results (Table II.), that, when the action was comparatively feeble, then the fine wire (Table III.) was the most heated; but when the action became more considerable, then the larger wire (Table II.) was the most heated.

8. I repeated these experiments in various ways, and found the results very general and invariable. Thus, in employing three separate electro-magnetic batteries with double copper, each exposing about a square foot of zinc, the effects indicated by the electrometer, with extremely fine wires in the bulb, were nearly as great with one battery as with the three combined, whilst, on the contrary, the indications with larger wires were constantly proportionate to the increased power.

9. As the diminished effect on the electrometer, when a very fine wire is employed, with an increased charge, evidently depends on the imperfect conducting power of the wire, it seems reasonable to infer, that imperfect conducting fluids, such as water, or extensive quantities of very fine wire, may become almost insulators to this species of electrical accumulation; and such is found to be the case, since little or no effect is indicated by the instrument, with a given charge, when the circuit *array*, Fig. 1, consists of an extensive spiral of fine wire, covered with silk; and no effect *whatever*, when formed of water contained in glass tubes: hence the accumulation is either insulated, or otherwise transmitted so very imperfectly, as to be quite inappreciable by the heating effect.

10. The foregoing results are very analogous to those arrived at by Sir HUMPHREY DAVY, in the course of his extensive and justly celebrated inquiries into the laws of voltaic action*; who

* Phil. Trans. for the year 1821, p. 435.

states, “ That in a battery where the quantity of electricity is very great, and the intensity very low ; charcoal, made to touch only in a few points, is almost as much an insulating body as water, and cannot be ignited, nor can wires of platinum be heated when their diameters is less than the $\frac{1}{80}$ th of an inch, and their length 3 or 4 feet ; and a foot of platinum-wire is scarcely heated by such a battery ; whilst the same length of silver-wire is made red hot, and the same lengths of *thicker* wires of platinum are intensely heated.” In this case, it is evident that the superior conducting power of the silver allows the quantity of electricity to pass through it, necessary to complete the heating effect ; whilst the inferior conducting power of the platinum impedes the transmission of the charge ; so that the heating effect is only evinced on thicker wires.

11. I endeavoured to find, by a variety of experiments, whether, on increasing the dimensions of the wires in the electrometer, any ratio greater than that of the increased power could be obtained, but I did not arrive at any new result. It is, however, not unlikely, that, provided the times of transmission were inversely proportional to the quantities of electricity transmitted ; that is to say, if, in one-half the time, twice the quantity was discharged, and so on, then the indications of the electrometer might possibly be in a higher ratio, as I have invariably observed in the case of ordinary electrical explosions, by means of coated jars, in which the intensity of the action is such, that the whole accumulation is forcibly transmitted through the wire, in a dense form*.

12. Much care is requisite, in speculating on these curious phenomena, which appear to be intimately connected with the relations subsisting between the causes of heat and electricity ; nevertheless the view taken by the celebrated philosopher above

* Memoirs of Plymouth Institution, p. 68. and 84.

mentioned *, namely, that the excitation of heat occasions the imperfection of the conducting power, seems, to a very great extent, extremely probable, as may be seen in the following experiments :

(c.) Having excited, somewhat powerfully, a large electro-magnetic battery (B. Figs. 3-4), of the cylindrical form, and containing about two square feet of zinc, with double copper ; the voltaic action was transmitted through the electrometer E, as in the previous experiments, by means of large copper-wires connecting the zinc and copper sides. In order to exemplify the influence of heat in decreasing the conducting power, about six inches of the circuit *mn*, Fig. 3, was made up of smaller wire, of about the $\frac{1}{80}$ th of an inch in diameter, and to this wire, the flame of a spirit-lamp was applied, when the fluid in the electrometer E, had attained its greatest height on the scale ; the result was, that the fluid began to descend, as the wire *mn* became heated, and again recovered its former point of elevation on removing the lamp †.

(d) A somewhat similar result was obtained, in substituting for the wire *m n*, another wire of the same dimensions, but of worse conducting power ; in which case, the effect on the electrometer E was considerably diminished.

(e) When the wire *m n* was kept cool by evaporating a little ether from its surface, the effect on the electrometer was greatly increased.

(f) Similar results were obtained, when, instead of allowing the wire *mn* to form a part of the circuit, as in Fig. 3, it was made to connect the contact cups of the battery. In this case,

* Phil. Transactions for 1821, p. 438.

† This experiment with the electrometer had been previously tried by Mr JONATHAN HEARDER, of this place, to whose friendly assistance I have been occasionally much indebted, in the progress of these inquiries.

the electrometer E was only affected by as much of the charge as could not pass immediately in the direction of the small wire. When, therefore, the conducting power of the latter was caused to vary, either by change of temperature, size, or quality, such variation was simultaneously shewn by the elevation or depression of the fluid along the graduated scale of the electrometer, and of these changes the instrument seemed to be most delicately sensible.

13. (*g*) It does not appear to be of any consequence, how the heat is derived by which the conducting power becomes diminished; thus, when the wire mn was caused to transmit the charge of a second battery of sufficient power to heat it somewhat considerably, the same result ensued. This was very pleasingly shewn by the following arrangement: Two electrometers, A and B, Fig. 5, being placed in the circuit $tr'r'n't$, and the elevation of the fluid observed in each: one of them, A, was connected with a second battery C, and in such way, that the wire in the electrometer A might exclusively transmit the charge of this second battery, as well as that of the first*. In this instance, the elevation of the fluid in A was increased, whilst that in B was decreased; so that the two electrometers A and B appeared to vibrate as if delicately balanced, the slightest change in the one being accompanied by an opposite change in the other.

14. It may be inferred from the foregoing experiments, that the indications of the electrometer (2) may be always taken as a measure of the variations in the action of a voltaic combination, provided we employ a wire in the bulb above a certain diameter; and that the limit to the diameter of such a wire, in any given case, may be determined experimentally by observing the action

* This can be readily managed by one particular arrangement of the connecting wires, which admits of the two batteries operating separately.

of the battery, in three or four portions, both when separate and combined. Thus if the points of elevation of the fluid correspond with the respective quantities of metal in action, or very nearly so, supposing the combination arranged as a single pair of plates, we may fairly presume that the instrument will indicate any trifling variation of power upon the whole. It is requisite also to observe, that the steadiness of the fluid at a given point, was found to depend exclusively on the strength of the acid solution and state of the battery. When the zinc is moderately clean, and the action somewhat brisk, the power of the battery to maintain the fluid for a considerable time, at a constant altitude, is very decisive; on the contrary, when a weak acid is employed, or the zinc is loaded with oxide, then the effect is always more or less evanescent, being greatest at the instant of completing the circuit, after which the fluid sinks gradually along the scale, until it reaches some point at which the action of the battery may be considered constant; whilst, in other cases, no stationary point can be obtained, and the fluid sinks gradually to zero. When, however, the battery is in a good state for experiment, and the acid sufficiently strong, the fluid will be observed to rise steadily, and remain stationary at some given point of the scale. The circuit, however, should in all cases be made with very large copper wires, of at least one-fourth of an inch in diameter, and the contacts made good and perfect, in the usual way, by means of mercury.

15. The utility of the instrument, with some of the attendant circumstances, having been thus far investigated, I endeavoured to apply it, in a variety of instances, to the further elucidation of the phenomena of voltaic action, some few of which it may not be unimportant to notice.

(*h*) The zinc and copper plate, already described (4), Fig. 1, being exposed to the action of a dilute acid, and the resulting effect on the electrometer noted; a second and similar plate of

copper, previously placed on the other side of the zinc, was connected with the former, so as to double the quantity of copper. In this case, the effect on the electrometer, as might have been anticipated, was very considerably increased; it was, in almost every instance, at the time of making the contact, at least doubled. That a considerable increase of power is obtained by exposing both surfaces of the zinc to the influence of copper plates is already well known. It is in short the principle of the Wollaston arrangement of the voltaic series. But it is not perhaps so well known, that a further increase of copper, with a single plate of zinc, is also accompanied by a still further increase of power. Thus when the number of plates of copper were quadrupled and connected, the power of the combination was greatly augmented. It appeared, from the few trials made, to be principally limited by the increased distance from the zinc plate at which the external plates of copper were necessarily placed.

16. With a view of investigating the relation of the conducting power to the quantity of metal, as also the conducting powers of different metals, I resorted to an arrangement similar to that represented in Fig. 3, in which the given metal mn , the subject of experiment was drawn into wire, and caused to transmit a given accumulation, in a cool fluid medium, such as water; thus the error arising from an elevation of temperature was, as far as possible, avoided (12), the water itself being inadequate to conduct any portion of the charge (9). The battery employed in these experiments was suspended by balance-weights in a convenient frame, Fig. 4, so as to remove it at pleasure from the acid, the latter being contained in a vessel of wood, having an external glass-tube rt , and a graduated scale, by which the quantity of metal immersed within could be correctly ascertained.

17. Previously to examining the indications on the electrometer E, Fig. 3, with a given wire mn , the force of the battery

was correctly determined by making the circuit with the large copper wires pm , qn , through the electrometer E alone, or otherwise through a second electrometer set apart for that particular purpose. The wire mn being now included in the circuit, the effect on E was again examined, and, finally, the force of the battery again observed as before; any error, therefore, which might arise from a decrease in the power could be detected and corrected by the addition of a small quantity of acid, or by bringing a further portion of the battery into action; the variations, however, in this respect, for a short series of experiments, were inconsiderable, and very easily rectified. The wire in the electrometer E was about the $\frac{1}{80}$ th of an inch in diameter, and was such that the indications on the scale corresponded very nearly with the increased power when successive and equal portions of the battery were immersed. The following are a few of the many interesting facts which seemed to be elicited by the method of investigation.

(i) When four wires, whose diameters varied from the $\frac{1}{100}$ th to the $\frac{1}{25}$ th of an inch, were successively placed in the circuit, as in mn , Fig. 3, the indications of the electrometer A with the less perfect conductors, such as platinum and lead, seemed for the most part in the ratio of these diameters: with the more perfect conductors, such as silver and copper, the wires of the lesser diameters only corresponded to the same ratio, whilst, on the contrary, the smallest wires of the inferior conductors seemed, as already shewn (7) to be in a great degree inaccessible to the influence of the action. The following Table contains the results of some experiments with a given charge on copper, platinum, and lead, three metals which appear to differ materially in their conducting power.

19. This order, with the exception of tin, is about the same as that already observed with the common electrical discharge *, and was invariably shewn when the wires were placed in the circuit, externally, as above described. It is, however, liable to exceptions when deduced from the heating effects observed, by including the metals in the electrometer; hence, in applying the principle arrived at by Mr CHILDREN, in the course of his fine experiments with a battery of large plates, that the heat evolved by the metal, whilst transmitting the charge, is in some inverse ratio of the conducting power, we must take into account the circumstances already noticed (10), from which it appears that the best conductors may appear occasionally to be the most heated; it is therefore only in employing charges within the limit of the transmitting power that the above principle becomes applicable. The following is an experimental illustration of this with the metals, copper and platinum, when *enclosed in the bulb* of the electrometer.

TABLE VI.

Charge of Battery.	Copper.	Platinum.
32°	27°	18°
12°	6°	8°

Thus, when the force is great, the best conductor is the most

sure a good contact, the surfaces being clean and fair. The conducting powers were ascertained according to the method described in section 12, exp. *f*. In this case, the battery was provided with two additional contact cups; with these the forcep-wires above mentioned, were made to connect at pleasure by the intervention of cups containing mercury in which they were secured, and sustained on pillars of glass, as in *m n*, Fig. 3.

* Transactions of the Royal Society of London, for the year 1821, p. 438.

TABLE IV.

Wires.	No. 1.	No. 2.	No. 3.	No. 4.
Ratio of Diameters.	1	0.75	0.50	0.25
Copper, . . .	60°	60°	40°	15°
Platinum, . .	43	30	21	4
Lead,	36	27	18	2

It may be observed, by reference to the above Table, that the smallest copper-wire, No. 4, as compared with the largest, No. 1, indicated a conducting power in the ratio of its diameter. The same is observable on comparing No. 2. and No. 3. together, whilst the conducting power, indicated with the copper-wires, No. 1. and No. 2, seemed for the particular charge employed to be the same ; hence these wires transmitted the force in action equally well,—the differences in the respective quantities of metal, therefore, did not become apparent. On the contrary, the wires of the less perfect conductors, platinum and lead, Nos. 1, 2, and 3, indicated a conducting power exactly in the ratio of their diameters, or very nearly so, whilst the indications with the smallest wires of these metals, No. 4, were inconsiderable.

18. (*k*) The deductions arrived at, on examining in this way the conducting power of various metals, were as follows :

1st, That, for certain and given small forces, the differences in the conducting powers vanish, each metal being equally efficient ; a result quite consistent with that already arrived at in the preceding section (17), with the copper wires, Nos. 1. and 2.

2d, The differences in the conducting powers become more apparent, within a certain limit, as the force of the battery increases, the exact proportions in which the differences increase with the increased power, I could not correctly ascertain.

In the next Table are given the results of some few experiments on wires of platinum and copper, of about the $\frac{1}{50}$ th of an inch in diameter.

TABLE V.

Metals.	Effects.	Force of Battery.
{ Copper, . .	21°	} 28°
{ Platinum, . .	11°	
{ Copper, . .	9°	} 11°
{ Platinum, . .	5°	
{ Copper, . .	5°	} 5°
{ Platinum, . .	3°	

The conducting powers of the above metals, therefore, with the decreasing force of the battery, constantly tended to a ratio of equality ; and it was subsequently found, by employing more delicate electrometers, by which a much less charge became appreciable, that the indicated conducting powers were at last precisely equal.

3d, The order of succession of some of the metals, as regards their conducting power, was observed to be as follow :

Silver, copper, zinc, gold, tin, iron, platinum, lead, antimony, fl. mercury, bismuth *.

* The conducting powers of antimony and bismuth have been determined subsequently to the period at which this paper was read. These metals were cast into bars, and compared with zinc, tin, and lead, treated in a similar way,—a process suggested to me by Mr FORBES, who was so good as to honour me with a communication on this subject. Mercury, in its fluid state, was examined in a somewhat similar way, by causing it to form a fluid bar of like dimensions to the preceding, by means of a groove cut in a support of dry mahogany. The bars were each six inches long, and about the one-eighth of an inch square. They were held securely between stout forcep-wires, having compressing screws, as in *m n*, Fig. 3, so as to in-

heated ; when less, then the inferior conductor is the most heated.

22. These experiments seem calculated to establish many important points connected with voltaic action, nevertheless it is always essential to remember, that, with our present imperfect apprehension of the causes of electricity and heat, an exact knowledge of every observed effect cannot be fairly expected ; the results of these and similar inquiries, therefore, must be considered merely as useful approximations toward a higher degree of theoretical perfection. The instrument resorted to in prosecuting the foregoing researches, although not entirely without the limit of objection, is, nevertheless, convenient, and useful in practice, and sufficiently perfect for the purposes to which it is intended to be applied. In cases where it is thought desirable, mercury, as already observed (2), may be used for indicating the degrees of force instead of the coloured fluid : in this case, however, the tube for regulating the divisions on the scale should be much finer.

PLYMOUTH, *May* 5. 1831.