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an influence admit of an easy solution on the sole principle of attraction. On this part of the subject there is, however, one seeming difficulty, which may have suggested itself, in as much as it may be thought to be an inevitable consequence of the minor electrical attraction that the electrical atoms be brought together by it into indissoluble union. In reply, I am prepared to show, that neither such an effect, nor any other which is inconsistent with facts, would follow, if we were entirely to expunge *repulsion*, as a principle of action, from our systems of physics.

65. But what I have more particularly to state here is, that it will be seen in the pages which are immediately to follow, that although the law of Coulomb accurately expresses the *sensible effects* of the action of electricity on common matter in general, we have not on record a single instance of that action that may not be minutely and circumstantially traced to matter at *insensible* distances*. In the same place we shall be able to explain also the particular action by which the electrical state of one body may become compensated by the opposite electrical state induced in some other body at a sensible distance, and which was purposely passed over in an early article as being premature (7.).

London, April 17, 1838.

X. *On some of the Phænomena and Laws of Action of Voltaic Electricity, and on the Construction of Voltaic Batteries, &c. By* Christopher Binks. *A second Communication, addressed to* J. F. Daniell, *Esq. F.R.S., &c. Professor of Chemistry in King's College, London. Part the First.*†

Section I.—*Subjects of Inquiry.*

My dear Sir, Edinburgh, April 9th, 1838.

1. THE paper which I now have the honour to submit to your attention is occupied with the details of an experimental inquiry into subjects which have had their origin as follows:

2. You will remember that in my last paper‡ I stated as the results of certain experiments that any voltaic arrange-

* Since these pages have been in the hands of the printer, I have been favoured by a sight of the forthcoming [Eleventh] series of Dr. Faraday's admirable "Researches;" in which that assiduous and successful philosopher labours to prove by experiment that electrical induction is transmitted to distant bodies by intervening matter. How well this experience accords with the new theory, will more fully appear in the ensuing part of this paper.

† Communicated by Professor Daniell.

‡ Lond. and Edinb. Phil. Mag., July 1837.

ment, whether simple or compound, whose elements were zinc, copper, and dilute sulphuric acid, appeared to be placed in the best circumstances for the exercise of its full power when under either of these two conditions;—first, when the extent of the copper surface was sixteen times greater than that of the zinc; or, secondly, when the surface of the zinc was made the greater of the two in the proportion of about seven to one of copper.

3. To state these results more definitely, let the zinc plate first used have an area, on each surface, of one square inch, and let its associated copper plate be of the same size. The voltaic action resulting from this arrangement being ascertained and taken as unity, and as a standard of comparison, let the zinc and all other conditions remain as at first, but let the copper plate be displaced by others, successively, whose areas increase in a regular progression; when it will be found that with a copper plate of two square inches on each surface, or twice the size of the first, the action will be equal to 1·3; with one of four square inches, equal to 1·6; and so on, by a certain progressive rate of increase till we reach to an area of 16 square inches, when the action will be found to have arrived at its maximum, and to be, in numbers, equal to 4·6.

4. Beyond this point the action will be augmented by no further addition whatever to the size of the copper plate; but, on the contrary, such further additions cause as remarkable a progressive decrease.

5. And, on the other hand, when we retain the copper plate of one square inch first used, but substitute for the small zinc one others of zinc in succession, progressively larger, a corresponding progressive increase of action will likewise follow till the zinc plate becomes of an area of about 7 square inches, at which point the greatest amount of voltaic action will be obtained, being in numbers equal to about 3 compared with the standard amount of 1; and this amount will suffer neither increase nor diminution by any subsequent addition whatever to the dimensions of the zinc plate.

6. The relative proportions of the two plates at which the maximum effect took place as thus determined, were obtained when both surfaces of the zinc, as well as both surfaces of the copper plate, were exposed to the action of the exciting acid; thus making, in the case in which the copper is the larger, a total area of 2 square inches of the zinc and 32 square inches of the copper, and constituting a ratio of 1 to 16.

7. But subsequent experiment (see section 8th) has determined that this same extent of copper surface is needed as well when only one, as when both surfaces of the zinc are

engaged in the operation; provided that if one surface only of zinc be so employed, it be that surface which is directly opposite to the copper. It has been determined that the contrary surface of the zinc serves merely to increase the intensity of action, that is, the quantity in a given time, and in no respect to influence the required area of the copper plate, that being determined solely by the area of that surface of the zinc plate which is opposite to it. These phænomena are more fully entered upon in a subsequent stage of the experiments in this paper; but it is proper to remark here, that the relative proportions of the two plates may be determined under either of the above conditions, either when *both* surfaces of the generating plate or when only *one* is employed; establishing in the former case a ratio of 1 to 16, and in the latter of 1 to 32; but as the latter is the ultimate condition of the experiment, it is that which, in a theoretical point of view, will be considered the more important.

8. Besides some important theoretical considerations which attach to these results, they were immediately serviceable in reconciling the conflicting statements which had previously prevailed respecting the best relative proportions of the two metals; and in showing how, at the will of the inventor, any voltaic battery could be brought to exercise a maximum effect, though different in degree, by having either the zinc or copper plates the larger of the two throughout the series; and also (wherever the same elements are employed) in showing, numerically, the comparative amount of action which can be obtained under any conditions whatever of the proportions of the two metals, and of the strength of the exciting acid.

9. The correctness of these former experiments, so far as they were then carried, is now abundantly confirmed by other experiments differently conducted; and their results will be found ultimately to be deducible from a general law, which will be endeavoured to be established towards the conclusion of this paper.

10. The particular laws formerly arrived at were obtained equally for compound as for single arrangements, and for acid solutions of every strength, or for every degree of activity of the generating agents. But they were sought for under one condition only as regarded the distance of the elementary plates from one another. It was then distinctly stated *, that to preserve uniformity in this respect, the plates were maintained exactly one inch apart throughout the whole inquiry; so that any modification of the results of experiments that

* Page 71, Phil. Mag., July, 1837.

might have occurred by having the mass of interposed fluid of variable dimensions was thus avoided. In only one instance was this deviated from, when the plates were removed from the distance of one inch to that of two inches, which alteration, as will presently appear, was too small materially to affect the results of the experiments as they were then conducted.

11. My first object then is to examine these phænomena (already determined for one such case) when in connexion with every possible condition as regards the distance of the elementary plates from one another; or as they are modified by having the mass of interposed fluid of variable dimensions.

12. Such an inquiry necessarily includes a repetition of my former experiments, since it becomes requisite to find the area of that plate which at any given distance yields the maximum effect, as well as to find the effects abstractedly of differences in the distance, and the influence of acid solutions of different degrees of strength.

13. Until recently, the magnetic needle has usually been employed to detect and estimate comparative quantities of voltaic electricity evolved by ordinary arrangements. When the results brought out by the preceding inquiry had been satisfactorily ascertained, it was made apparent that between them and others previously determined and admitted as correct, there existed a singular disagreement. It became desirable, therefore, to endeavour to reconcile the two methods of observation; and with this view the experiments which occupy the second part of this paper were undertaken; having for their object to determine the relation between the deflections of the magnetic needle and the quantity of zinc and other elements expended in producing those deflections; or, in other words (if the principle of observation here employed be correct), to determine the relation between the quantity of electricity and the deflections it produces.

14. Chemistry has determined the kind of changes which occur among the elements here employed to evolve voltaic electricity; but we know not whether its development be due to the influence of one or more, or all these changes. We have first the resolution of the water into its constituent parts; the appropriation of the oxygen by the zinc, and the appearance of the hydrogen, as gas, upon the copper; the formation of the oxide of zinc, and, subsequently, of the sulphate, and the solution of that salt in the water. The present doctrines of chemistry require that these changes should follow consecutively, but, as far as we can perceive, they are simultaneous.

15. Let some of the attendant phænomena be examined on

the hypothesis, that the development of the electricity, in the present case, is due to the occurrence of a physical change in the condition of the water itself; water is a compound of two measures of hydrogen and one of oxygen. The oxygen being distributed over the whole surface of the zinc, and there combining, it might be presumed that the hydrogen would appear on an extent of surface corresponding to its combining volume, or on a surface of twice the area of that occupied by the other. Or the presumption might be, that the surfaces required would correspond to the difference between the bulks of the metallic zinc expended, and of the liberated hydrogen; or between the bulks of the oxide of zinc produced and of the hydrogen; which latter differences are immense, though not beyond the reach of experiment.

16. But an appeal to experiment at once decides the question, and shows that the relation is none of those just presumed, nor of any other that could have been determined by any *à priori* reasoning. It is found that the relation between the two surfaces upon which the constituents of the water respectively operate or appear, is as one to thirty-two; or directly as the volumes of one quantity by weight of oxygen, and two quantities by weight of hydrogen.

17. So soon as this unexpected relation had been found by actual experiment, it became a matter of interest to inquire whether or not it were an instance of the operation of some general law hitherto unknown, or a mere accidental coincidence. It would have been premature to anticipate the nature of that law on the indications of one instance merely; and it has consequently become the object of the experiments contained in the third part of this paper to examine into as many instances of voltaic action, in connection with the physical and chemical characters of the products resulting from that action, as may be necessary to determine the nature and extent of that law thus suspected to exist.

18. And respecting this part of the present inquiry I may be permitted to add, that whether it be considered with regard to its immediate object, or to the novelty and range of the experiments to which it necessarily leads, to the number of curious relations it serves to detect, or to its bearing upon some others of the collateral sciences, particularly upon chemistry, I know of few others connected with electricity in which an experimentalist can feel a greater interest.

19. The following experiments were begun in the pursuit of these three general objects; but it is almost needless to remark that others have arisen as the inquiry has proceeded, but which will best appear in the order of their occurrence.

The arrangement of the experiments which is here adopted is very nearly the same in the order of succession as that in which they were made, and differs from that order only so far as has appeared desirable, in order the more clearly to show the results actually arrived at, and at the same time to indicate progressively the evidence for other results anticipated, but the completion of which can be reached only at a more advanced stage, or at the conclusion of the whole inquiry. You will permit me also to refer to the circumstance, that occasionally throughout the statements which follow I have thought it desirable to make explicit and repeated references to many minute and well-known details involved in researches of this nature, which in writing to one with whom the subject is so familiar, and to whom each particular would be suggested by the matter in immediate connexion, may appear to be somewhat unnecessary. But as I am aware that my paper may not be confined to your own perusal, I have preferred to aid any demonstrations it may attempt by a recurrence to such details, made explicitly and wherever they might appear useful, rather than, for the sake of inserting only that which is perfectly novel, to omit them, and thus lose the advantage of as much clearness in description as the nature of the subject itself might otherwise admit of.

Section II.—*The Principle of Investigation.*

20. The principle employed throughout the following investigation to detect and estimate effects, has arisen out of the discovery of Faraday of the definite character of voltaic action.

21. The experiments which served chiefly, in the hands of its discoverer, to establish this great principle, were those in which a current of electricity, evolved by a compound arrangement, was passed through water, when it was found, first, that the water which such a current decomposed, bore, in its quantity, a definite relation to the quantity of the elements by whose mutual action that current was produced; and, secondly, that the quantity of any other body than water, which the same current decomposed, was likewise definite, and bore a fixed relation both to the quantity of water first decomposed and to the quantity of elements expended in any one cell of the generating battery itself. And the relations thus presented were found to be exactly the same as the relations between the different respective chemical equivalent numbers of the bodies engaged in the operations. So that, for example, in the instances of the zinc expended in any one cell of the bat-

tery, and of the water or of the muriatic acid which such battery decomposed, the quantities were, for the first, 32, for the second, 9, and for the last 37, or exactly as their equivalent numbers.

22. The distinguished author of this discovery subsequently extended this principle into an inquiry as to the origin and nature of this voltaic action—into an estimate of the absolute quantity of electricity associated with the particles of matter, and also into an estimate of the comparative quantities of electricity evolved by different agencies, &c.; but the general results which I have more particularly in view at this moment are those from which it was deduced that chemical and electrical action, if not identical, are co-existent, and equal in quantity and effect.

23. The application which I make of this principle to the present investigation is exceedingly simple and obvious in its nature: the elements engaged in the phænomena now examined are, water, sulphuric acid, zinc, and copper. Since the last remains unchanged, or subserves its purpose best when unchanged, it may be considered as a mere instrument engaged in aiding the chemical and physical changes which take place among the others, through whose mutual action the electricity itself seems to be evolved. To ascertain the quantity of electricity so evolved, it is only necessary to ascertain (on the principle just stated) the quantity of matter employed in its production; and this can be done by finding the quantity of zinc expended or of sulphuric acid, or of water decomposed, or the quantity of hydrogen evolved, or of sulphate of zinc finally produced. But as chemistry has already determined the relations of these substances one to another, it is only necessary to find the quantity of any one of them, to know the quantity of every other. In the present instance it is most expedient to find the quantity of the zinc so expended by weighing the zinc plate both before and after the operation, or to measure the quantity of the evolved hydrogen; or, if it be the effect of the power of a compound battery which is to be found, then, to measure the quantity of both the gases produced by its action, a contrivance adapted to the last purpose constituting one of the forms of the voltameter of Faraday.

24. The phænomena examined into in the first part of the present paper, are those resulting solely from the action of *single* voltaic arrangements. Let such an elementary arrangement, having its plates of a certain size, and placed at a certain relative distance, be acted on by an acid mixture of a certain degree of strength. The amount of action which will

take place in such an arrangement, under such circumstances, will be altered if the plates be made larger or smaller, or if the strength of the acid or the distance of the plates from one another be altered. But the action resulting from any of these three modifying causes is still of the same kind though different in degree; and it is with the finding of the amount of these differences in degree, in connexion with the circumstances which cause them, that the first part of this paper is chiefly occupied.

25. These degrees of action may either be considered as degrees of chemical or of electrical action. The operations themselves are chemical; and the quantity of chemical action is determined by the quantity of matter which has been employed in it. But this chemical action is induced by a voltaic arrangement; and on the principle stated above, that if not identical, these two kinds of action are co-existent and equal in quantity and effect, the quantities now determined by experiment may be considered as quantities either of chemical or of voltaic action: by whichsoever name they may be called, the experimental results themselves remain unaffected.

26. These explanations are called for to show the connexion which the method I here employ has with the principle discovered by Faraday; and to show also in what respects its results may be wholly dis-associated from any of the mere theoretical considerations which have followed that discovery. The details which follow are confined solely to the progress and results of experiment; or to such general conclusions only as seem to be warranted by a sufficiency of incontestable evidence.

27. The preceding remarks apply equally to the method used in the 2nd and 3rd parts of the following paper, though the ultimate object in each is different.

28. The particular objects of the 1st and 2nd parts have perhaps been already sufficiently adverted to, but this seems to be the proper place, immediately after the preceding remarks, to define the precise object more particularly aimed at in the third.

29. The researches of Faraday have proved that in one great class of its phænomena the action of electricity is definite; and in another class (more particularly examined in the 3rd part of this paper), but entirely different from any examined by Faraday, it will subsequently be shown that the same principle prevails. In the former case the phænomena so examined related chiefly to the influence of quantity of electricity both as regarded its production and its effects. In the latter case the examinations do not regard the production

or effects of electricity abstractedly, but relate chiefly to some of the physical conditions under which its operations take place, and more particularly to the relative spaces occupied by the agents engaged in its operations. The law deduced by Faraday was, that the influence of electricity over bodies subjected to its action was directly as its quantity, and as the equivalent numbers of the bodies themselves. The results which will be attempted here to be established (but of which one instance only has as yet been adduced, in paragraph 16) are, first, that the superficial areas of the spaces within which this electrical action takes place, have a definite relation to the kind of bodies occupied with that action; or, more specifically, that the superficial areas of the electrodes have a definite relation to the kinds of bodies which, by the force of voltaic action, are determined to those electrodes; and second, that the law which expresses these relations is, that the relation between the areas of the two electrodes is inversely as the relation between the specific gravities of the bodies respectively determined to those electrodes, each area being multiplied by the comparative number of volumes of the body determined to it.

30. So that in the instance already referred to (16), wherein the bodies so determined are hydrogen and oxygen gases, we have their relative specific gravities as 1 and 16; but these bodies have resulted from the binary compound water, in which their volumes are not equal, but as two to one. So that when the numbers expressing the specific gravities are used inversely to represent the areas of the two electrodes, we have those areas as 16 and 1; that is, the area of that electrode at which the hydrogen appears being inversely as the sp. gr. of the hydrogen, is equal to 16, and that of the oxygen equal to 1; which numbers, being multiplied respectively by the number of volumes in which these two bodies occur in this case, give 16 (area) $\times$ 2 (vol.) $=$ 32 for the area of the hydrogen electrode; and 1 (area) $\times$ 1 (vol.) $=$ 1 for that of the oxygen; which proportions are exactly those of the copper and zinc plates as found by actual experiment, the surface of the copper plates yielding the maximum effect in any such arrangement requiring to be 32 times greater than that of the zinc.

31. Or, in another view, the expression of the same law may be, that the relative areas of the two electrodes are directly as the relative bulks of equal weights, multiplied by the number of volumes of the two bodies respectively determined to those electrodes: so that in the same instance as above, in which the elements determined to each electrode are hydrogen and oxygen gases, we have the comparative bulks of equal

weights of each as 16 to 1; but there are two volumes of hydrogen and one of oxygen, so that the bulk of the equal weight of hydrogen, being multiplied by its number of combining volumes, gives $16 \times 2 = 32$, and the oxygen gives $1 \times 1 = 1$, which is precisely the relation between the areas of the two electrodes which is found to obtain when the question is submitted to experiment.

32. And it also follows, that if these relations have been determined for the superficies of any such arrangement, they have been determined likewise for every other geometrical relation peculiar to it; and again, that if they have been ascertained for the electrodes, and the bodies determined to the electrodes, they have also been determined for the compound from which these bodies have been derived, or, in other words, for the electrolyte—so that the expressions of the law just stated may be varied so as to include any or all of these relations.

33. The expressions of this law as just stated are framed in accordance with the present theoretical notions of equivalent numbers, volumes, &c., but it is easy to foresee how investigations of the kind now spoken of, when they shall come to be conducted with sufficient nicety, may be used either to confirm or modify the theories at present entertained on some of those points.

34. This general law will not include all the phænomena attendant upon the operations now referred to; but a series of subordinate laws will be needed to express what have already been distinguished as primary and secondary effects:—but not further to anticipate these results, the preceding remarks will perhaps sufficiently indicate the precise nature of the subject with which the third part of this paper is intended to be occupied.

35. It appears, therefore, that the definite character of voltaic action may be proved to extend into other classes of its phænomena, besides that in which its discoverer first detected it; and it seems unquestionable that the same principle prevails throughout all its operations, and that in the end every class of its phænomena will be found to be governed by a law peculiar to itself. The general law of Faraday, and that just stated, are in perfect harmony with the previously well-known physical and chemical properties of the bodies engaged in the phænomena from which they have been deduced; and these two laws themselves will undoubtedly be found in the end equally to harmonize with each other. It seems not to be an unwarranted probability that if the laws peculiar to every such class of voltaic action were accurately determined, we should

then have furnished to us a collection of data more valuable in themselves, and better calculated perhaps than any yet obtained to enable us to approach to the discovery, if not actually to reveal the real nature of this peculiar but still mysterious agent.

Section III.—*The Method of Investigation and preliminary Experiments.*

36. After some preliminary trials the following method was selected for conducting these experiments. A wooden trough, made water-tight by cement, and measuring 50 inches long, 7 wide, and 7 deep, had its upper horizontal edge marked off from one end to the other into divisions of inches and fourths of inches. At the end from which this graduation began, was fixed the zinc-plate to be experimented with, and the first division, marked 1, was exactly one inch from the surface of the plate itself, and the plate was about one inch from the extreme end of the trough, which consequently was divided, beginning from the zinc-plate, into 48 inches and fourths of inches, or in all into 192 parts. At the zinc end was fixed the cup, holding mercury, in which the connexion between the two experimental plates was to be completed. The zinc plate was connected with a short wire, always of the same kind and length, and each copper plate was soldered to a wire 5 feet in length; so that at whatever position the copper plate might be placed within the trough, whether at the distance of $\frac{1}{4}$th of an inch from the zinc, or at 48 inches, or at any position intermediate, the wire completing the circuit was always of the same length; these experimental plates were retained at any required position simply by bending their connecting wires twice or thrice at right angles and thus fixing them over the sides of the trough. It being intended to weigh the zinc-plate before and after each experiment, or to collect the gas evolved from the copper plate during the experiment, the former had its connecting wire so short as not to interfere with its being readily weighed and replaced; and the gas from the latter was collected in a funnel-shaped meter having its open base so large as to gather the whole of the gas sent off from the copper plate of whatever size that might be. The long tubular part of this meter was divided into tenths and fiftieths of a cubic inch, and its entire capacity was about $1\frac{1}{2}$ of a cubic inch. The simple contrivance of a couple of strong glass rods, bent twice at right angles, supported by the sides of the trough and stretching across it, served as supporters for the meter, moveable at pleasure, and by which it could be suspended at any required position above the copper plate. The meter was

readily refilled with liquid by immersion in the trough itself. Another trough and meter of larger dimensions were also provided for such experiments as required the use of larger plates than such as could be introduced into the smaller trough.

37. The zinc used throughout the experiments was always of the same kind and always amalgamated. Its equivalent number was 34·5, requiring in consequence of impurities contained in it 34·5 grains, instead of 32, to yield 1 grain of hydrogen. The connecting wires both of the zinc and copper plates were partly covered, but to the same extent in each, with bee's wax, so as to protect them from the action of the acid, so far as they were at any time immersed in it, and to confine the voltaic action entirely to the surfaces of the plates which were the subject of experiment. The circumstance that the surfaces of the wires, protected by the wax, were of uniform extent in every case, will need afterwards to be remembered.

38. These precautions against error, by preserving uniformity in the kind of metal used, in the kind and lengths of the connecting wires, and in the extent of surfaces to be acted upon, are independent of other precautions requiring equally to be observed. A variety of modifying causes are incessantly operating in experiments of this nature, and producing effects of a most perplexing kind, each of which needs to be fully appreciated and guarded against, or as fully as possible corrected, in order to ensure any satisfactory degree of accuracy in the results of experiment.

39. I. It has been shown by yourself*, that immediately after the first immersion of a zinc plate under voltaic arrangement, its amount of action is greatly impeded by an accumulation upon its surface of minute air-bubbles, which adhering to it interpose a surface of air between the plate and the existing acid; thus preventing the full voltaic action so long as they continue to be attached to the plate. By my own experiments I found that a zinc plate, after such accumulation had taken place, yielded a certain measure of gas in 240 seconds, but by repeatedly clearing its surface from these bubbles, by agitating it or otherwise, the same measure of gas was produced in two-thirds the time, or in 160 seconds. When, however, the copper plate is at its maximum size in any arrangement little or no such accumulation occurs.

40. II. The gas arising from the copper plate will do so more rapidly if the water be agitated than if it remain tranquil during the action: an arrangement yielded voltaic action

* Phil. Trans. 1836.

equal to one measure of gas in 80 seconds, during the agitation of the water occasioned by refilling the meter; but after it had become again tranquil the same measure was produced in 95 seconds, or in a length of time greater by about one-fifth. It is almost needless to remark that this increased action is due solely to the mechanical effect of the water when in motion displacing the air-bubbles as rapidly as formed, and more rapidly than they would otherwise be displaced by reason merely of their superior levity.

41. III. Another mechanical effect of a similar kind, but operating to a much greater extent than in either of the preceding instances, is induced by the mere position of the plate from which the gas is evolved: if the surface of a copper plate be placed in a horizontal plane, the gas which is generated on its under side will remain continually attached to the plate; and should that be the only surface operating, the voltaic action of such an arrangement would be almost completely impeded; but, on the contrary, if it be placed and used in a vertical plane, then the only causes likely to obstruct the ready dismissal of the gas from the surface are the comparatively minute ones just referred to in II.

42. IV. A copper wire which had been stretched in order to straighten it, previously to its being attached to a plate, was found to give a voltaic effect about one-fifth less than another, in all other respects the similar, but which had not been so extended; but the conducting power of the former was again restored by exposing it to heat. And, again, two wires, in all other respects alike, but which had accidentally been heated in different degrees, gave a marked difference in amount of action; but had their uniformity of conducting power restored upon exposure to an equal temperature.

43. V. The same remarks apply equally to plates as to wires; but there is another cause of variation in the action of plates not previously recognised. In an extensive course of experiments connected with the subject of this paper, in which I had completed about 15 tables of results, each table containing, on an average, about 10 observations, I was surprised, on looking these tables over, to observe that there was presented invariably (under whatever conditions the experiments might have been performed) a remarkably increased amount of action opposite to a number representing one particular copper plate. Since no probable cause could be assigned for this recurrence, except that of some property peculiar to the plate itself, another plate was substituted for it, when it was found that throughout the whole inquiry the plate in question had been giving nearly double its amount of

action. It was now remembered that this particular plate had been cut from a piece of copper which had been employed in some former experiments, during which it had been partly amalgamated, and had had one of its sides covered with bee's wax, to remove which and the mercury previously to adopting it to its present use, it had been thrown on the surface of a bright fire, and afterwards, whilst nearly red hot, had been plunged in a trough containing dilute sulphuric acid. The same plate was the agent in another curious phænomenon, to be mentioned subsequently. (See Section VIII.) But confining myself to my present purpose, and without further alluding to this circumstance, or to the suggestion it affords of a means of increasing the power of voltaic arrangements, by some such treatment of the plates, it is necessary here to remark that so soon as this condition of the plate was detected, both the whole of the plates, and the results of the experiments in which they had been engaged, were dismissed as uncertain, and the whole repeated with the use of new plates prepared with every possible regard to uniformity in their condition in every particular.

44. VI. The copper plate of any voltaic arrangement very speedily has its surface so affected as to be greatly diminished in its amount of action; an effect arising in some case from a partial action upon the copper itself, but caused more frequently by a deposition of matter upon its surface, derived from the solution it is acting in; and consequently differing in kind and degree according to the nature of that solution, and to the intensity of the voltaic action itself. If a copper plate be so used through a period of 30 minutes, and its amount of action be examined during every five minutes of that time, it will be found that this diminishing in effect will proceed much more rapidly during the latter than the former portions of that time, as is shown in the following table:

No. 1.

Periods of time of 5 minutes each.	1st.	2nd.	3rd.	4th.	5th.	6th.
Measures of gas in 50ths of a cubic inch yielded in each time.	35.	33.	29.	24.	17.	9.

And when at the end of these periods the surface of the copper was again brightened, its action was restored to the first amount, or to 35 measures in the same time.

45. This table is not unimportant, inasmuch as it might have occurred that the accelerated action which takes place

by continued immersion upon the zinc plate might be compensated for by the retarded action occurring upon its associated copper plate. But the rates at which the one is accelerated and the other diminished are different, as this table serves to show, and consequently any method of correcting such irregularities of action founded upon these opposite properties of the two plates would be futile.

46. VII. The kind of polish also of the copper plate, and the cleanliness of its surface, have likewise a material influence upon its action, and consequently upon the results of experiments conducted with any measure of accuracy. The plate becomes soiled by frequent handling, and particles of the wax from the adjacent wires are liable to be transferred to its surface, and in the end, by their accumulation, almost totally to obstruct its further action.

47. VIII. Again, the action of any voltaic arrangement is greatly affected by the condition of the surface of the zinc plate, as regards its roughness or smoothness. An irregular rough surface of zinc will give a greater amount of action in a given time than one which has a fine polish.

48. IX. And, on the other hand, an exceedingly irregular or rough surface of zinc, over which a profusion of mercury has been spread, will exhibit a less amount of action than another surface which is perfectly smooth, and over which only so much mercury has adhered as has been required to produce a perfect amalgam. These apparently contrary effects under like circumstances are easily explained:—the plate of zinc which is rough and full of cavities, on being suffused with mercury, presents but here and there a point of zinc amalgam to the action of the acid, the other parts of its surface being pure mercury; whereas, in the other case, in which the surface is smoother and its cavities consequently of less extent, a greater number of amalgamated zinc points are exposed to the action of the acid, and the effect of the plate is consequently greater in proportion to the evenness of its surface.

49. These different conditions of the zinc surface, however, are very different in their effects if the zinc be not amalgamated; for in that case an entirely different principle of action is introduced; but as it is amalgamated zinc alone which is used in these experiments, this particular need not be further alluded to.

50. X. The insoluble impurities contained in common zinc accumulate upon the surface of a plate which has been long used, and unless removed from time to time will also serve in the end, and in addition to those causes already mentioned,

to influence the action of such an arrangement. The consequences of this accumulation become strikingly obvious after a plate has been for some hours in use, and without having had its surface cleansed in the interval.

51. XI. The particular position of the zinc plate whilst in action is needed as equally to be attended to as the position of the copper-plate (III.), though the necessity for this has a very different origin in the two cases. A zinc plate whose surfaces are placed in an horizontal plane will have the dissolved sulphate of zinc resting upon its upper side, and hence interposing a stratum of comparatively inactive matter in the place of the existing acid. But when the plate is used in a vertical position, the dissolved sulphate continually subsides, by its superior gravity, from the surface of the plate; thus occasioning a perpetually renewed contact to take place between it and the fresh exciting acid. This effect may be rendered visible when a glass vessel, holding an arrangement so suspended, is interposed between the eye and a strong light, when the varying refractions caused by the commingling of the two fluids of different densities, viz. the dissolved sulphate and the acid mixture, will show that a stream of the dissolved salt falls continuously from the bottom edge of the plate, and is finally diffused through the mass of surrounding liquid.

52. XII. But the continually accelerating action occurring upon the zinc during immersion is the cause of a more frequent and variable kind of interference in these experiments than almost any other. A zinc plate whose surface is perfectly smooth and truly amalgamated (such as are invariably employed in the subsequent experiments), will give a greater amount of action during a second time of immersion than during the first, as appears by the following table:

No. 2.

Equal times of immersion of 10 minutes each . .	1st.	2nd.	3rd.	4th.	5th.	6th.
Measures of gas in 50ths of a cubic inch yielded in each time	34.	36.	38.	42.	50.	59.

Whatever may be the strength of the acid used, or, in other words, whatever may be the total length of time needed to produce the same measure of gas, yet, when the plate has been affected to the same extent, whether that may have taken place in a longer or a shorter time, the difference between the rates of action in the first and last portions of the total time will be the same as exhibited by this table.

53. XIII. Again, the acid solution becomes weakened by

continued use, and deteriorated by the sulphate of zinc dissolved in it; so that the results of any set of comparative experiments will be untrue, unless this source of variation and error shall have been completely avoided by the constant renewal of the acid, or completely provided against by some system of correction adapted to its varied effects.

54. XIV. A voltaic arrangement, at the commencement of a set of experiments, when the apartment in which they were conducted was comparatively of a low temperature, viz. at 53° Fahr., gave $\frac{1}{10}$th of a cubic inch of hydrogen in 45 seconds. But on the room becoming warmer, by means of the fire and lights used in it, the action of the arrangement was as progressively increased, and when arrived at the temperature of 60° the same measure of gas was produced in 30 seconds. Attempts were made to alter this activity of the arrangement by altering the surface of the zinc, by re-amalgamating it and immersing the plates in cold water, but without effect; and the original amount of action was restored only after a free admission into the room of a current of a colder atmosphere, during a few hours, had reduced it to the original temperature. It is worthy of remark here, that whilst the atmosphere in the apartment suffered a change equal to 7 degrees of temperature, the liquid the plates were acting in did not alter by more than two degrees; and I have since had occasion constantly to observe that the changes in question, induced by temperature, in the activity of the arrangements, may be brought about equally when the surrounding atmosphere alone (that is, independently of any alteration in the temperature of the plates or the liquid) is the body which has undergone any perceptible change.

55. These effects of the influence of atmospheric temperature, though ascertained by a different method and independently, are in exact accordance, in general character, with those detailed by yourself, and respecting which you remark that "it is now, however, apparent that in the exact measures of different effects which an invariable current of electricity will enable experimentalists to undertake, the variations of atmospheric temperature even must not be neglected *."

56. XV. There is yet another influence affecting the action of voltaic arrangements which has not, that I am aware of, been previously recognised; namely, the mechanical effects of the pressure of the column of liquid resting upon the plates. If in a trough, holding dilute acid and about 12 inches deep, a small zinc plate be fixed at half its depth or at 6 inches, and the associated copper plate of the same size be fixed, first

* Philosophical Transactions, 1837.

at the depth of one inch from the surface of the liquid, and afterwards at the bottom or at the depth of 12 inches, but still at the same lateral distance from the zinc, the quantity of voltaic action obtained at each of these positions will be found widely different, as will be seen by the following table, in which the copper plate is moved through the same vertical plane to the different depths successively:

No. 3.

Depth in inches of the copper plate from the surface of the liquid .	1.	2.	4.	6.	8.	10.	12.
Time, in seconds, needed at each depth to yield an equal measure of hydrogen	132″	135″	142″	143″	147″	154″	159″

57. When the plate is near the surface of the liquid the hydrogen arises from it in a regular stream of exceedingly minute bubbles; but when at a greater depth they are dismissed from the plate irregularly and of a much greater size, having apparently adhered to it longer and with greater tenacity than when nearer the surface. It is easy to conceive that previously to the dismissal of these larger bubbles from the surface of the plate, they will have prevented the direct contact of the acid and the copper by an interposed stratum of air, proportionate to the size of their bases, and hence have impeded the voltaic action itself. That these differences are due solely to the influence of pressure, in the present case, will be more distinctly shown subsequently (section 7th), when the precise relative positions of the two plates in these trials will need to be remembered.

58. We perceive in the foregoing enumeration a variety of minute influences and effects, incessantly obtruding themselves into examinations of the nature of this present inquiry; all of which, with the utmost care, need to be provided against, or as far as possible to be corrected, to ensure any degree of accuracy in the results of experiments.

59. For the sake of a compendious reference to the methods by which these sources of error are obviated, or their effects otherwise guarded against throughout this inquiry, they may be classified as follows:

60. 1st. Circumstances merely mechanical, affecting the

action of any arrangement, as position of the plates, agitation of the liquid, adherence of the gas to the plates, pressure of the column of liquid, &c., including the particulars stated in Nos. I., II., III., XI. and XV. of the above enumeration.

2nd. Circumstances of a mixed chemical and mechanical kind, affecting the surfaces of the copper plate, as its polish, cleanliness, &c., and stated in Nos. VI. and VII.

3rd. Circumstances of the same kind, affecting the surface of the zinc, and included in Nos. VIII. IX. and X.

4th. The temper, or conducting power of the wires and plates, as explained in Nos. IV. and V.

5th. The influence of the general temperature under which the experiments are performed, as in No. XIV.

6th. The effects of the weakening and deterioration of the acid mixture in No. XIII.

7th. The accelerated action occurring upon the zinc in No. XII.

61. To provide against each and all of these interferences, I adopt the following plans throughout the whole inquiry, and which being once distinctly pointed out, need not again be referred to in the course of the subsequent details upon other points.

62. The zinc plate is removed from the trough at the end of each single experiment, and its surface cleansed by a linen cloth. The copper plate is polished with fine glass paper after each single experiment, washed with a solution of caustic potash, and then well rinsed in acidulated water before its return for the next experiment. The observations of the measure of gas generated in any given time, is not taken till the water has again become tranquil after the motion occasioned by replacing the plates and refilling the meter; nor till after the complete suspension of the local action which generally takes place upon the first immersion of the zinc. (See 39.)

The operating plates (unless where it is distinctly stated to the contrary,) have their central points always in one straight line, passing horizontally through the centre of the mass of liquid they are acting in, that in each set of comparative experiments the pressure upon the plates may be maintained uniform, and the plates themselves be preserved in a vertical position. The plates of either kind, which are here employed, are cut from the same sheet of metal, the wires from the same coil; and the whole, after being adjusted, are exposed for some time to a like temperature, so that the temper and conducting power, as far as that depends upon the texture of the metal, may be the same in each. The temperature of the liquid and of the apartment in which the experiments are conducted is maintained as nearly as possible the same during the performance of any one set of experiments.

63. These regulations sufficiently provide against every contingency that can affect the correctness of the experiments, except those of the gradually diminishing activity of the acid mixture through continued use, and the accelerated action upon the zinc which occurs during its continued immersion.

64. Against the effects of these last, especial provision is made as follows: I prepare ten or a dozen of the kind of zinc plates which are the subject of present experiment, and bring each of those by previous management to yield the same amount of action in a given time. This is accomplished by taking one of them as a standard, and by polishing or roughening as may be needed the surfaces of the others, thus bringing each into precisely the same condition; and a little practice makes this to be done with considerable facility.

65. After any one of such a set has been used twice or thrice, its place is supplied with a fresh plate; and after the whole number may have been so employed, the set is repolished and re-adjusted before their application to any new set of experiments. The extreme nicety which this plan introduces into experiments of this kind will be obvious if it be considered that each plate is employed to produce but at most five-tenths of a cubic inch of hydrogen before it is renewed, and consequently will have expended in that effort but little more than three-tenths of a grain of its entire weight; a quantity much too small to affect the action of the plate in any way likely to interfere with that degree of nicety which these experiments require. And with respect to the effect which so small a quantity of zinc will have upon the acid mixture, either by abstracting its active acid, or by impregnating it with the dissolved sulphate, if it be considered that the quantity of acid mixture here employed is seldom less than eight or ten gallons, and that this too is frequently renewed, it will be obvious that the dissolving in it of even many such minute quantities of zinc will have no effect whatever upon the results of experiment.

66. It will subsequently be seen how essential it is that each and all of the above particulars should be strictly attended to; and preparations being thus made and observed throughout, I know of no other circumstances that can affect the experiments or interfere with their accurate performance; and the whole thus arranged admit of being performed with considerable ease and expedition.

67. It has been thought better to place all these particulars under one view, at an early stage of this paper, as well to

show the precautions which have been observed to ensure accuracy, as to avoid the necessity for a continual reference to such details afterwards.

68. The effects now to be sought for, are estimated generally by the length of time needed to produce a certain measure of gas, or for the expenditure of a certain weight of zinc. But it has been shown in some former experiments that the quantities of zinc expended and of hydrogen produced by it, (under certain conditions of voltaic action,) are not always equivalents of one another. In my former paper* a case of this kind is noticed, in which a small battery when used to decompose water, lost zinc, in quantity one third greater than the equivalent of the hydrogen evolved. In the investigation that now follows no uncertainty will be permitted to remain upon this point; and the labour occasioned by such examinations will be found to have been not altogether without use. (See section 9th.) The measure of gas most commonly used is one tenth of a cubic inch, and the time is taken in seconds. With small plates, this measure will be yielded in a length of time ranging between 30″ and 900″ according to the strength of the acid or the distance of the plates. The moment at which this measure is completed by the meter, may be determined with certainty within two or three seconds of the real time. A closer approximation than this is seldom attempted in the following experiments, nor is it in any respect necessary. The difference between 30 seconds and 900 seconds is an extreme one, and but seldom occurs: most commonly the difference is much less marked, and in some instances is so minute, that no other method, that I am aware of, than that now proposed is adequate to its detection.

69. The capability of this method to detect minute differences in quantity will be apparent upon a little consideration from what has been already said; but the following comparison between it and that afforded by an ordinary magnetic galvanometer, will serve to mark that capability more clearly.

70. The galvanometer here used, though of the common construction, was an exceedingly good one, by Newman; and such an instrument in all respects as would have been employed in the kind of experiments now made had the indications afforded by the needle been desired.

71. The instance selected is an average one of the effects to be estimated. A small arrangement was used at first with its plates one fourth of an inch apart, and afterwards at the distance of thirty-eight inches. At the first position the one

* Phil. Mag., p. 88, July 1837.

tenth cubic inch of hydrogen was yielded in 45″, at the second position in 210″. Testing the same phænomenon by the needle, the first position gave a permanent deflection of 60°, and the second of 45°. By the first method the difference detected was equal to the value of the difference between 45 and 210, or 165. By the second, the difference was equal to that between 60 and 45, or 15. Had the divisions of the needle galvanometer been in seconds, or in thirds, or even in tenths of degrees, its indications would still have been inferior in delicacy to those which the watch and meter thus afforded, with the utmost precision and facility.

72. It will appear subsequently that this superior precision, readiness and certainty, do not constitute the only advantages presented over the magnetic needle, and are not the only reasons why this particular method of experimenting should be preferred.

XI. *Intelligence and Miscellaneous Articles.*

THE HERSCHEL DINNER.

WE deem it proper to record briefly in this Journal the circumstances attendant on the recent festival in honour of Sir John F. W. Herschel, and in commemoration of his return from Southern Africa, after having executed a minute astronomical survey of the Southern Hemisphere, in accordance with the intention and in furtherance of the design of his illustrious father. A meeting of the leading men of science and officers of various scientific institutions in the metropolis having taken place in the apartments of the Geological Society, at a time when the arrival of Sir J. Herschel in his native land was daily expected, to consider and arrange the best means of giving him that welcome with which every lover of knowledge was eager to greet him, it was resolved that a public dinner should be held on the occasion, to which he should be invited, and a vase of silver, to be purchased by the subscriptions of the friends of science, presented to him. Forty-six Stewards were appointed, including several noblemen distinguished by their patronage of science, or their connexion with scientific institutions; His Royal Highness the Duke of Sussex, K.G., P.R.S., having consented to take the Chair, and R. I. Murchison, Esq., F.R.S., V.P.G.S., was appointed Honorary Secretary. The following is a list of the Stewards:

H. R. H. THE DUKE OF SUSSEX, K.G., P.R.S., in the Chair.

STEWARDS.

His Grace the Duke of Northumberland, K.G., F.R.S.
The Marquess of Lansdowne, K.G., F.R.S.
The Marquess of Northampton, V.P.R.S., F.G.S.
The Earl Fitzwilliam, F.R.S., F.S.A.
The Earl of Burlington, V.P.R.S., Chancellor of the Univ. Lond.
The Bishop of Norwich, P.L.S., F.G.S.

Airy, G. B., F.R.S., Astron. Royal.	Baily, F., Treas. R.S., P.R.A.S.
Babbage, C., F.R.S., Luc. Prof. Camb.	Beaufort, Capt., R.N.,F.R.S.,F.R.A.S.