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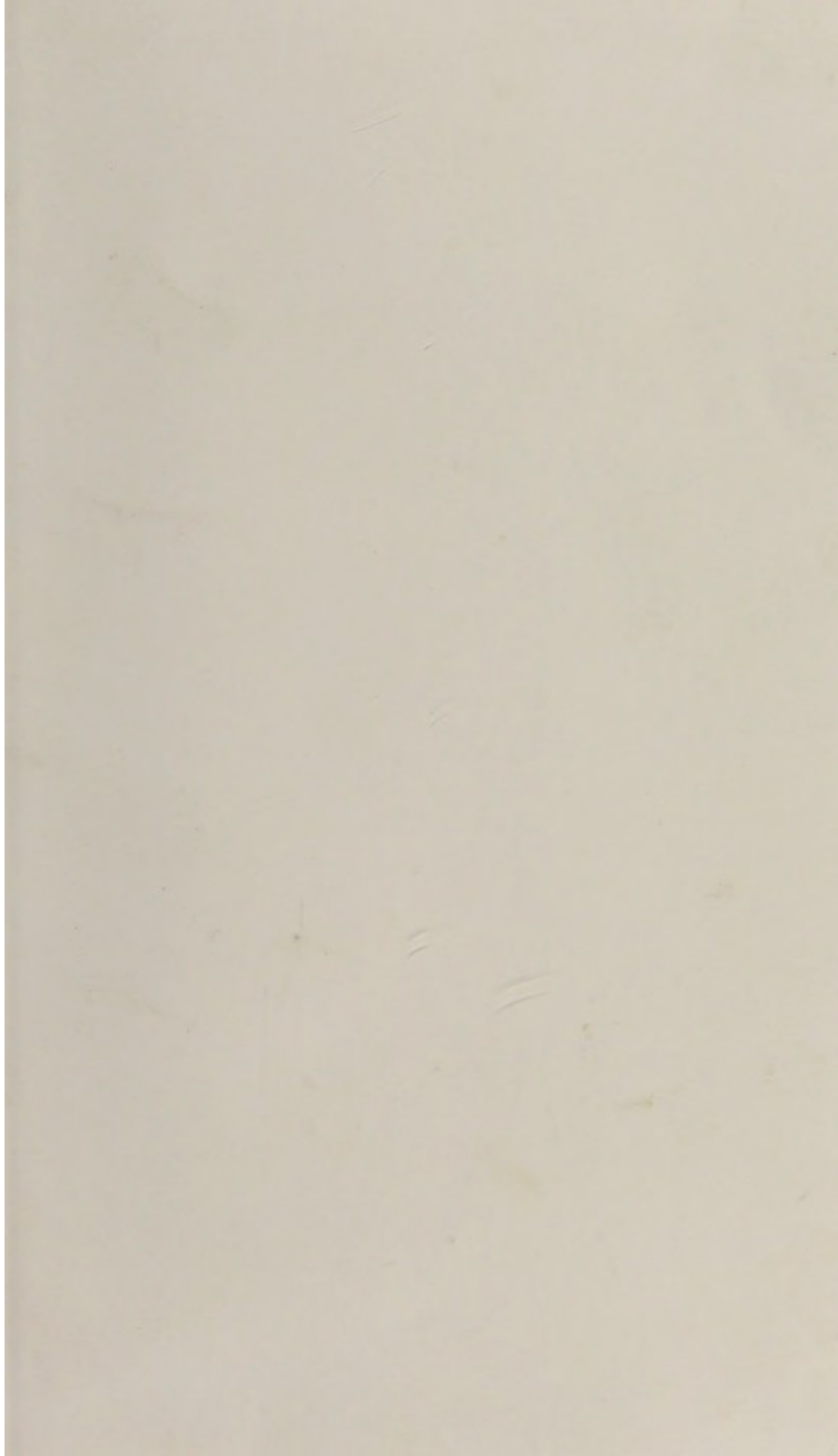
DEFINITION OF THE VOLTAIC CIRCUIT,

WITH

FORMULÆ FOR ASCERTAINING ITS POWER UNDER DIFFERENT CIRCUMSTANCES.

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FROM

" ELEMENTS OF ELECTRO-METALLURGY."

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THEORY OF THE VOLTAIC CIRCUIT.

(191.) In conducting my experiments on the reduction of alloys, certain phenomena and peculiarities were noticed that have so important a bearing on the theory, or rather the rationale of the voltaic current, that it becomes my duty at once to draw up the curtain and expose the conclusions to which they lead, as a knowledge of them will give to the operator great advantages, and enable him, by rightly understanding the force with which he is working, to conduct his various processes to the best possible advantage.

In these experiments I noticed that in various mixed solutions the quantity of voltaic force passing was not at all dependent on the nature of the negative element, but upon the ease with which the hydrogen was removed from it. Thus in a solution of sulphate of zinc very slightly acidulated the hydrogen could not be evolved from smooth copper, but would rather reduce the sulphate of zinc when connected with a small battery. The substitution of smooth platinum in no way added to the power, but the employment of platinized platinum caused an abundant evolution of gas, even to the removal of the zinc already reduced on the smooth platinum. Any metal having but little affinity for hydrogen caused a similar result; thus, iron caused gas to be evolved and increased the force passing, when smooth platinum would not have the effect, and even zinc itself caused a little gas to be evolved, because the adhesion of the gas to it is slighter than the adhesion to smooth platinum.

In the same way I observed that nitric acid allowed far more electricity to pass than sulphate of copper; and that again, than dilute sulphuric acid, simply from the facility with

which hydrogen reduces these substances being greater than the facility of its evolution. I moreover noticed in other cases that the hydrogen would rather be evolved than reduce a metallic salt,—as sulphate of zinc ;—and in every case that the facility of its removal affected the amount of power passing, quite independently of the nature of the negative plate.

Now these facts appeared to me a positive proof of there being no such thing as a negative plate contributing to the production of power, and that this latter is of no value, further than as a means for the removal of the second element of the intervening compound fluid. On the other hand, the multitude of experiments by Faraday all show that the chemical action between one element of a compound fluid and some conducting body appears to be the source of the power, or rather that the power is always dependent on and proportionate to this chemical action. Putting these two series of facts together, an idea presented itself to my mind explanatory of the nature of the voltaic force, for if the force from the experiments of Faraday is proved to depend on chemical action, and the negative pole from my own experiments is proved to be useless, except as affording the means for the removal of the second element of the compound fluid, then it follows as a natural consequence, that if the chemical affinity of any substance for one element of a compound fluid is greater than the resistance offered to the evolution of the second, force is produced. Now it immediately occurred to me that some metals might be made to reduce from a solution of one of their own salts, metal of the same description, by placing the metal partly in a solution for one element of which it has great affinity, and partly in a solution of one of its salts. This was actually found to take place in various cases, by following the facts that were made out respecting the ease with which hydrogen reduces various salts.

Zinc reduces zinc by taking a piece of the metal and doubling it, one half is then to be amalgamated and placed in

dilute muriatic acid, and the unamalgamated into a strong solution of chloride of zinc, made as neutral as possible, when the affinity of the chlorine for the muriatic acid is sufficiently great to cause zinc to be reduced at the other end of the same piece of metal. The use of platinum, palladium, silver, copper, or any other metal appears not to increase the action in the least, which experiment shows most powerfully the utter fallacy of the contact theory, or in other words that the voltaic force is in any degree dependent on the opposition of one substance to another. In this experiment according to the advocates of this now untenable doctrine, the force should have set from the amalgamated zinc to the mercury, the two metals, according to these visionaries, having from simply looking at each other the property of evolving power, but we find that the chemical affinity determined the course of the current.

Copper may by very simple means be made to reduce copper with truly great rapidity ; for if a test tube be half filled with sulphate of copper, and then muriatic acid be poured gently at the top, so that the two fluids do not mix to any great extent, and a copper wire be then placed throughout the whole length of the tube, it will speedily show signs of action. The copper in the acid will rapidly dissolve, whilst copper will be as freely deposited at the lower part of the vessel. Now copper will undergo no action alone, either in muriatic acid or sulphate of copper. This experiment may be varied by the use of different acids or even some salts at the upper part of the vessel, for although muriatic acid shows this experiment most strongly, dilute sulphuric acid or muriate of ammonia will produce the same result.

Silver reduces silver by placing one end of a silver wire in a porous tube containing nitrate of silver, the other in dilute sulphuric acid, though the metal placed in either separately is not affected.

Lead reduces lead by immersing one end of a piece of

lead in a solution of the tris nitrate of lead, the other in dilute nitric acid.

Tin reduces tin by placing one portion of a piece of metal in muriate of tin, the other in muriatic acid.

Gold even reduces gold by immersing one end of a gold wire in the chloride, the other in dilute muriatic acid, the two solutions being separated as in all the former cases by a porous diaphragm.

There is a beautiful experiment detailed by Mr. Grove, which is analogous to those last described, though he attributed the results to a different cause. His experiment is to place two pieces of gold wire in muriatic or nitric acid, separated by a porous diaphragm, when no action will take place on either, but on being connected, that in muriatic acid will rapidly be dissolved, and the nitric acid will at the same time be decomposed by the hydrogen transferred to the other part of the wire.

From the various experiments which I have examined, added to the extensive researches of Faraday on the chemical portion of the voltaic pile, the voltaic force may be defined to be certain effects produced by the chemical action of a body on one element of a compound, and manifested between this point of action and the evolution of the second element. It might in other words also be defined to be peculiar properties evinced between the chemical action of a body on one element of a compound, and the evolution of the second element, the point of abstraction and subsequent combination of the first element being called the positive pole ; the point of evolution or removal of the second element of the compound body, the negative pole. Hence it might be called circular chemical action, because the phenomenon always evinces itself as a circle.

These definitions suit equally every possible case, and there is but one point included in those definitions which is uncertain, though as they now stand, whichever way that doubtful

case be taken, they equally apply. The difficulty, and the only one, that I know concerning the production of the voltaic force, is an uncertainty whether the force is produced by the analysis of the compound body, or the synthesis of the newly-formed salt. This is a point concerning which, perhaps, we shall ever be ignorant, yet analogy would rather lead us to suppose that the combination rather than the analysis is the source of the voltaic force. These definitions show why we cannot obtain the force from the union of two elements; indeed, we can never hope to obtain voltaic power from ordinary combustion, for though the energy of the combination of oxygen with carbon is immense, there is no second element, and therefore no intermediate point at which the effects can be manifested. For the same reason no force can be obtained from the union of liquid sulphur or bromine with metals.

The intensity of chemical action being always proportionate to the voltaic power, and being the only source of power in the pile it follows, that (I) the intensity or the power the voltaic fluid possesses of overcoming obstacles is equal to (F) the affinity which regulates the chemical action. But as we find that this power is lessened under different circumstances, $I = F - O$. O standing for the whole of the obstacles afforded to its passage.

Let us take at once a circle and examine its properties. We find that the intensity of the action (I) is equal to the affinity (F) of the body used to separate one element of the compound fluid (in the galvanic battery this is produced by the zinc and oxygen) lessened by the mechanical resistances afforded by the removal of the newly-formed compound (a) by the

Fig. 28.

obstruction offered to the passage of the force by the compound solution (r), by the imperfection of the conducting
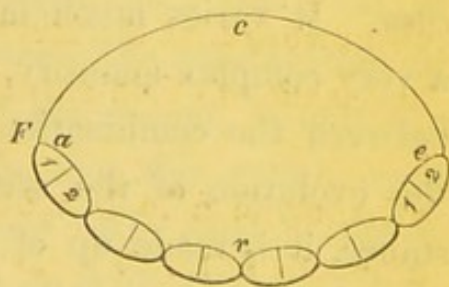
power of the solid parts of the circuit (c), and lastly, by the obstacle which is afforded to the removal of the second element of the compound fluid (e); thus we have algebraically $I = F - \overline{a + c + r + e}$. This circle is supposed to consist of but a single atom of fluid, exposed at one time to the action of the body combining with one of its elements, and all the resistances are supposed to be constant.

Sometimes this circle is exceedingly small, the (r) consisting of but one atom of the compound, and the (c) but of a single atom of the body combining with one element. This might be called properly an atomic circle, a good specimen of which has heretofore been called local action.

We must now consider the different parts of the circle in detail. F the chemical affinity of a body for one element of a compound is immensely strong where zinc is employed, the attraction of that metal for oxygen being most powerful; but if we substitute iron, tin, lead, copper, or gold, for the zinc, the attraction being feeble the value of (F) would be reduced in various proportions, in some cases almost to zero.

(a) the removal of the newly-formed compound affords but little resistance when the new salt is soluble in the fluid and a sufficiency is supplied for that purpose. In batteries generally the removal of sulphate of zinc affords but little obstacle, being quickly dissolved by water.

(r) varies very much from the extent of the interposed fluid, and its conducting power being very different in each case. It varies much in different batteries. Sometimes r is a very complex quantity, as when two or more fluids are used between the combination of one element of a compound and the evolution of the second. In Daniell's battery, for instance, it is made up of three parts, not only the resistance offered by dilute sulphuric acid and solution of sulphate of copper, but also a resistance offered by the interposed diaphragm. It might be made up of a far greater number of

parts, for different parts may be of different temperatures, which alone (if the temperature interferes with the conducting power) would cause r to be complex.

(c) the resistances of the connecting part of the arrangement is generally in batteries very slight, because we select metals which conduct pretty freely ; (c) may be very complex, by being made of a variety of conducting substances, thus, if the connexions are made of wires of different kinds of metal, a different resistance is offered by each. (c) in every battery, is generally made up of three parts, the conducting power of the positive and negative plates, and the intervening connecting wires.

(e) the resistance to the removal of the second element, is generally very great, affording a considerable obstacle in all cases, but the differences in this respect are very remarkable. Ordinarily (e) is a simple quantity, but becomes complex when the hydrogen is removed in a variety of ways at the same moment. It becomes a curious question to ascertain whether (e) might ever be made a plus quantity. If the force proceeds from analysis, then the use of any body having great affinity for the second element might cause the current to be increased. If from synthesis, and this is most probable, if not absolutely certain, (e) can never be a plus quantity, but always a minus. In the removal of the second element by decomposition of another compound body, it is by no means uncommon for a voltaic circuit to be formed. In Grove's battery the hydrogen acts upon nitric acid, forming water, and setting deutoxide of nitrogen, &c., free ; but in this case the intermediate part between the combination of the first element and the removal of the second, is only the atom of hydrogen, it therefore follows, that this action must be regarded as nothing but a series of little local batteries, or atomic circles, having nothing to do with the great battery which we make available for our purposes.

It is absolutely essential, according to our definition of the

voltaic force, that to be enabled to apply this principle for any purpose, however small a quantity of the force may be required, that either (c) or (e) should possess a capability of being so far prolonged as to enable us, with the imperfect powers that nature has furnished us, to handle or deal with these intervening portions of the circuit.

In the principal batteries now in use, their relative powers and attributes may be fully understood by considering each of the above properties in their construction.

	F	a	c	r	$e.$
Grove	large	small	small	medium	little.
Daniell	large	small	small	most	much.
Smee	large	small	small	small	much.
Smooth platinum	large	small	small	small	enormous.

Thus the four batteries may be considered equal in the properties of the F, a, c, the differences being only in (r) and (e). In Grove's the (e) is so small as not only to compensate a slight increase in the (r) over mine, as usually constructed, but to give a great advantage to his form of battery. In Daniell's the (e) is perhaps rather smaller than in mine, but that is more than counterbalanced by (r) being larger in Daniell than in mine. The effect of these properties are, that F in Grove's is diminished but little, F in mine more, in Daniell's more still; and in the smooth platinum battery by far the most. Thus is explained the decomposition of dilute sulphuric acid between platinum plates, by one cell of Grove's battery, and the same result not being obtained by the others. This equation is not only valuable for batteries, but applies to every single case where any substance acts upon a compound fluid in such a way as first to decompose it, then to combine with one of its elements, and set free in some way the other. Thus, if potassium be cast into dilute muriatic acid, (F) is immensely large, potassium having a violent affinity for oxygen; (a) is exceedingly small, potash being readily soluble in water; (r) is almost nothing, only one atom of fluid being traversed by the force; (c) is prac-

tically nothing from the same cause; (e) is very small. The result of such a state of things necessarily causes a vast intensity of action, and an explosion is the result.

Good specimens of contrasts in the magnitude in the several parts of the circuit are to be seen in the relative power of (F), as obtained by zinc and silver; in the relative resistance of (a) in the solubility of sulphate of lead and sulphate of zinc; in the resistance of (r) in the conducting power of pure water and muriatic acid; of the resistance of (c) in a leaden wire a hundred miles long, and a short silver one; in the resistance of (e) in the evolution of hydrogen from smooth platinum, and its removal by nitric acid.
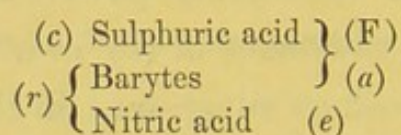
The relative degrees of action evinced by zinc, tin, iron, and lead upon sulphate of copper are easily explained; (F) differs from being larger, (a) in being smaller when zinc is employed, whilst (c), (r), (e), in each case remain nearly the same; (a) indeed is so large when lead is employed as soon to put a stop to the action.

How intelligible is the want of action of dilute sulphuric acid on amalgamated zinc, if examined by our equation for (e); the adhesion of the second element, hydrogen, being increased enormously, counterbalances (F), the affinity of zinc for the first element, or oxygen, and no action takes place. Amalgamated zinc is rapidly dissolved if placed in a solution of salts of copper or silver, for (e) in that case is depressed, the hydrogen rapidly reducing the copper. Nitric acid in the same way does not respect the amalgamation of the zinc, for (e) in that case is also diminished by the removal of hydrogen from the decomposition of the acid. As the adhesion of hydrogen to plumbago is very great, it occurred to me that the simple application of black-lead to zinc would, by preventing the evolution of hydrogen, increase (e), and therefore stop the local action; but although the experiment fully succeeded, the plumbago so quickly came off, that I have not at present made any practical application of the experiment.
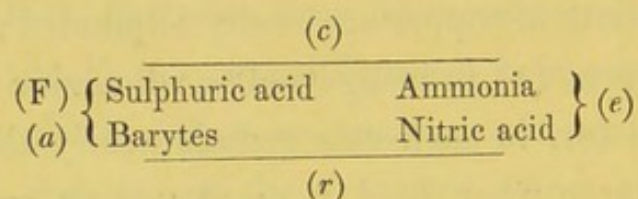
The above cases, with all their analogies, are not the only ones to which the equation applies, for it will account perfectly for the action of bodies on each other.

In cases of single elective affinity, as the action of sulphuric acid on nitrate of barytes, a compound is decomposed, one element enters into another combination, the other is set free ; a voltaic circuit is therefore produced, the parts of which are thus made

$$(r) \begin{cases} (c) \text{ Sulphuric acid} \\ \text{Barytes} \\ \text{Nitric acid} \end{cases} \left.\begin{matrix} \\ \end{matrix}\right\} \begin{matrix} (F) \\ (a) \\ (e) \end{matrix}$$

In cases of double electric affinity, as the action of sulphate of ammonia on nitrate of barytes, a similar circuit is formed thus :—

$$\begin{matrix} & \overline{\quad\quad (c) \quad\quad} \\ (F) \begin{cases} \text{Sulphuric acid} \\ (a) \end{cases} \text{Barytes} & \begin{matrix} \text{Ammonia} \\ \text{Nitric acid} \end{matrix} \left.\begin{matrix} \\ \end{matrix}\right\} (e) \\ & \underline{\quad\quad (r) \quad\quad} \end{matrix}$$

In both these cases, however, we have not the means of increasing the (r) and (c) to a tangible size (at least I have never been able to do it), and at present these actions have been restricted to the formation of atomic circles.

There are some cases where we can extend the intermediate parts (c) and (r), and then our definition of the voltaic force with the formula arising from it enables us to form most extraordinary voltaic circles, which indeed we never could have formed before, unless we happened to light upon them by chance : thus proto-sulphate of iron, placed on one side of a diaphragm, and nitrate of silver on the other, will give a current when connected with a platinum wire, and a beautiful deposit of silver will be reduced on the platinum wire, on the nitrate of silver side of the circuit.

In the same manner circuits may be formed of proto-sulphate of iron and chloride of gold — of proto-nitrate of mercury and chloride of gold—of oxalic acid and chloride of gold, &c. In all of which cases the metal is freely reduced

on that part of the platinum wire inserted in the metallic salt. The reason why a galvanic circuit is formed in these cases is sufficiently obvious; water is the electrolyte or compound decomposed, proto-sulphate of iron is the substance combining with one element, and the metallic salt affords a means for the removal of the second element or hydrogen, and as we have the power of extending the compound (r) and connecting parts (c), not only an atomic circuit, but a working battery may be made. At the diaphragm or the point of juncture of the two liquids, indeed, an atomic or local battery is formed independently of the general or working battery. The following are the parts of the circuit in the above cases.

	(c)	
(F) ⎰	Proto-Sulphate of Iron	Platinum Wire
*(a) ⎱	Oxygen	Hydrogen (e)*
	(r)	

It would be extremely interesting to find every case of decomposition of a compound fluid obedient to the equation, and indeed there is every appearance of that being the fact.

The impossibility of giving a negative tendency to a metal when hydrogen is removed from its surface is also perfectly accounted for by our equation; for hydrogen, as has been already shown, protects the metal; so when a facility is offered for its removal not only is the direct protection removed, but by diminishing the value of (e), (F) the natural affinity of the metal for one element of the fluid, having but little resistance opposed to it, begins to act, and the metal is therefore dissolved.

The superior action of a rough metal in contrast with a smooth one is explainable on the equation most satisfactorily, for in the first case the affinity (F) is opposed by the resistance to the evolution of the hydrogen (e), whilst in the latter case (F) is so strongly opposed by (e) that no action can take

* (a) is the removal of the per-sulphate of iron by solution; (e) is the removal of the hydrogen by the decomposition of the metallic salt.

place.   Zinc shavings, which always have one side bright and
the other rough, show this phenomenon clearly.

Hitherto we have considered (F, a, c, r, e) in every case to
be constant, but in many instances they are subjected to con-
tinual variation.   I do not, indeed, happen to recollect an in-
stance of (F) varying to any amount, but (a) varies frequent-
ly ; in the gradual saturation of a fluid it progressively in-
creases, so much so, as at last to equal (F).   This accounts
for zinc ceasing to be dissolved on the saturation of the fluid
by sulphate of zinc, although still intensely acid. (c) gene-
rally remains constant.   (r) is very unsteady, for as in all vol-
taic arrangements the fluid is always undergoing change, it
is therefore sure to be altered in its conducting power.   (e)
is subject to great variations from alteration of the liquid and
other causes.

In every case of a single battery we have seen that the
intensity is equal to chemical affinity, minus the resistances
to that affinity.   In a compound battery the expression is
equally simple, for the intensity is equal to the sum of the
affinities, minus the sum of the resistances.   In a series of bat-
teries all of the same nature, $I = \overline{F - a + c + r + e} \times n$.   Some-
times (n) is very complex.   For example, if a compound bat-
tery be made up of a Grove's, a Daniell's, and my own,
the values of (I) must be considered separately, and their
sum taken.

Fig. 29.
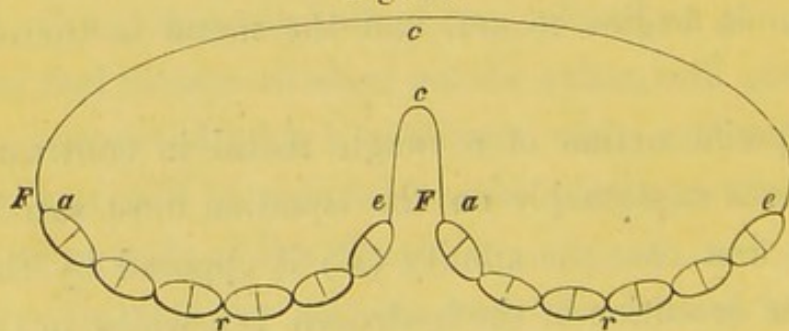
The diagram exhibits well the arrangement and proper-
ties of the compound battery.

A good example of the affinity of (n) is seen in the water

battery, where (I) is exceedingly small from the resistances of (a) and (r) being large, but becomes amplified to such a degree by (n) as to possess prodigious force ; indeed as it possesses a capability of being amplified infinitely by an infinite series completely insulated, a battery might be constructed powerful enough for the force to pass from one electrode, placed in the Thames at London Bridge, and the other in some river in Australia, though the resistances of (r) and (c) in this case, from their extreme length, would be very great. In every water battery, as (a) instead of being constant gradually increases, the power gradually declines, at length to nothing. The curious and wonderfully-multiplying powers of (n), whereby the intensity can be increased, precludes our saying that the galvanic power is unable to effect any particular object ; for, after all, it might turn out that (n) was not magnified sufficiently to attain that end.

When we are turning our power to some application it is very convenient to consider the purpose for which it is applied as a resistance, and call it R. If we have a series of them alike it would be R × n. If, however, the series is not alike, it would be $R + R' + R''$. The intensity of the current here would be also equal to the sum of the intensities, minus the sum of the resistances. $I = \overline{I - R}\, n$. The R is frequently very complex, as in the reduction of metals in a decomposition trough, where it is made up of as many parts as a voltaic battery.

Having amply discussed the power of the force to overcome obstacles, we are led to determine the time in which any given number of equivalents of voltaic power can be obtained. Hitherto we have considered the circuit to be made up of a single atom of the body combining with one element of the compound, and if the affinity exceeds but ever such a trifle its obstacles, then in time any amount of work would be performed provided the current remained constant. A current can easily be conceived so feeble as to take millions

of years to reduce a pound of copper. If the entire circuit of single atoms be increased at every part, in fact if the mathematical voltaic circle be increased to the size of a tunnel, then (W), the amount of work performed in a given time, would be equal to the intensity of the battery, minus the resistance of our working apparatus, multiplied by the number of parts of the tunnel (A) thus : $W = \overline{I - R.} \times A$.

This equation, however, gives us the total amount of chemical actions in the whole series of batteries and decomposition troughs, or, in other words, the sum of the actions evinced in each ; we generally, however, are desirous of estimating the amount done in one particular cell, in which case we divide our equation by the number of cells and troughs (n) thus,

$$W = \frac{\overline{I - R} \times A}{n}.$$

Sometimes this equation is rendered extremely complex by an increase of the circuit at one side but not at another ; in fact, the tunnel is cut away on one side, and this is a case that is perpetually occurring in practice. In this case it is not impossible but that the force is only derived from those parts of the circuit which are complete ; in that case the equation would be $W = \dfrac{\overline{I - R} \times \overline{A - p.}}{n}$ p standing for the incomplete parts. In this view of the question we are supported by the analogy of water running through a pipe of given dimensions from a cistern, for however large this cistern be, provided there be no more pressure, the water running through the pipe would be the same. So far as the voltaic fluid is concerned I feel

Fig. 30.

certain, from numerous observations, that beyond a certain point the increase of a battery does not cause a greater amount of electricity to pass through a given resistance ;
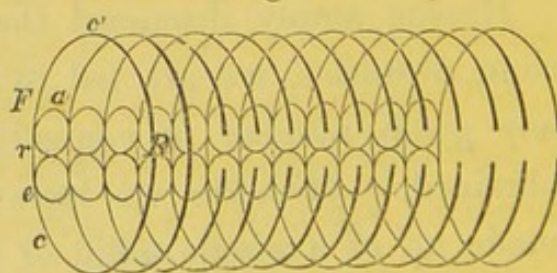
and, perhaps, in those cases, where the enlargement of a battery increases the voltaic force, the battery in the former instance was deficient in size in relation to the size of the resisting part R, the tunnel, in fact, having been defective originally in that part. It is possible that the expression for this condition might be altered; for R, the resistance to the single voltaic circle, might possibly vary in some new manner, for which further experiments are wanted. In that case it would be $W = \dfrac{IA - \mathfrak{R}}{n}$. The old English $\mathfrak{R}$ standing for the new resistance afforded to the whole current. The tunnel might be cut away at any other part besides (R), thus it might be deficient at (F), (a), (c), (r), or (e); but the student will readily perceive the expressions for these cases.

Sometimes W is very small, as in De Luc's columns, where the total amount of chemical action, although (n) is frequently 500 to 1000, is so small that experimenters have even denied its existence; but when we consider that these very persons assert, that as soon as chemical action does become decidedly manifest, the action ceases, how strongly do they favour our views, for, according to our equation, we expect (a) to be gradually increased till all action would be stopped. W indeed, according to our equation, might be so small, as not to be cognizable to our senses for weeks, months, years, or centuries; and yet multiplied by a very large (n) would show enormous intensity or power of overcoming resistances.

The present modifications of the theory of galvanism are perfectly consonant with every practical direction given in the preceding pages, and the only difference in the theory will be found in the uncertainty expressed upon the contact and chemical action theories. Indeed, in page 54 the result is almost given in words though not in letters. By removing the slight difficulties which appeared to envelope the latter theory, by showing the necessity for a negative pole to cause power is unfounded, the beautiful doctrine of Faraday is

placed on the surest foundation, and the extraordinary and dogmatical paradox of a power without a cause is proved to be a fanciful chimera.

With regard to the connexion of the voltaic power with that of electricity produced from other sources, perhaps it might be expected I should say a few words. In the voltaic battery (I) is small, but may be increased to any size by (n), and as we have the power of increasing (A) also unlimitedly, we can perform any amount of work per second, indeed we might throw down hundreds of tons of copper per second, if we were disposed to make our circuit large enough. In frictional electricity (I) is enormous, but (A) is depressed to its utmost limit, so that not having a perfect command over (A) to increase it indefinitely, we cannot at present obtain what work we please in a given time. In animal electricity (I) is great, (A) is moderately large. In thermo-electricity (I) is depressed, perhaps increasingly, so that although (A) and (N) may be multiplied indefinitely, yet, practically, we should never be able thoroughly to overcome the smallness of (I). In that mighty operation of Nature which has just occurred, where the noise accompanying the discharge of the electricity over the metropolis was so awful as to alarm not only delicate females, but the stoutest hearts of men, and even the heretofore un-terrified nervous system of infants—in that terrific storm, when every living creature trembled, and Nature seemed almost alarmed at her own operations, how vast was (I)! how large (A)! O! therefore that I could but have impri-soned that collection of force which in discharging itself com-mitted such devastation on houses, churches, and trees, and, having encased it, been able to have let it loose as it might have been required; then indeed would all batteries be hence-forth discarded as playthings for children—philosophical toys to be admired, still despised, for (I A) being unlimitedly great, we could obtain what work we pleased in any given time, at no expense.

The estimate of the parts of (I) in other cases where force is produced, *i. e.* an electricity not proved to be derived from chemical action, I do not deem it my business now to consider, but great difficulties would attend its accurate investigation, as it is almost impossible to magnify the size of the circle in these cases, in such a way as to make the action in each part cognizable by our senses. It is however quite evident that as in the voltaic and thermo circuits (I) may be magnified to any extent by (N), that the power of (I) in every case might be brought to the same standard in the power overcoming the resistances R' R" R''' &c.

The obstacles to the completion of the voltaic circuit (O), are made up as we have seen of several parts, *a, e, r, c,* but, although they differ in kind, still as they have similar resisting properties, a perfect table might be made, referring them to one given standard, showing the separate value of each. The principle on which it should be constructed, is the law of the completion of the voltaic current, detailed when treating of the reduction of alloys; and as soon as we have this table accurately and numerically drawn up, the principles of the passage of the voltaic circuit, which formerly puzzled the most enlightened experimenters, will be rendered certain, and the difficulties will be also reduced to the facility and certainty of common arithmetic. Having obtained perfect tables of (O) and its several parts, we can readily obtain the relative value of (I), derived from various sources, by finding out what extent of (O) neutralizes each individual (I), and the value of (I), or the force of any battery, will be determined with equal facility. Complete tables of (O) and (I) now become the greatest *desiderata* not only to Electro-metallurgists, but to all who use the voltaic battery.

I now bid adieu to my theory of galvanism and my formulæ, and to those who have neither time nor inclination to dive into these mysteries, remember, in all operations that the sum of the resistances does not exceed the sum of the inten-

sities; and that in increasing the circuit, every part is equally enlarged. To those who have devoted themselves to these properties remember they will be useless if not brought into active operation; thus, if any difficulty occurs in your voltaic circuit, refer it at once to its proper head, and the operator may be sure that a continual practice and habit of using these formulæ will enable him to conduct his proceedings with a certainty never obtainable by blind experiment.

In concluding these formulæ, I herewith leave theory and rationale altogether, for having completed the principles, as far as I am capable, of everything relating to electro-metallurgy, I shall enter at once into the applications of the science for the direct purposes of the Arts, and although, everything that will be contained in the subsequent parts of this work has already been comprised in the parts already finished, yet there are many little practical difficulties to be surmounted — many little circumstances to be pointed out which the operator is likely to overlook or forget in conducting his operations, and these are the circumstances to which the concluding pages will more especially be devoted. Henceforth the work will be entirely practical, as heretofore it has been exclusively theoretical. There is a reproach attached to the very word, theory; the sense in which it is employed means rather rationale than theory, for whilst it has been my constant endeavour to shun theories without facts, I have tried and tried hard to generalize all extensive series of facts, and to give the rationale of every circumstance which is likely to occur to the operator.