

of an important determination made by Sir William Thomson*, the preceding figures give a superior limit of the attraction of the coatings, which is as large as one *ninth* of the optically equivalent compressing weight. As to a definite solution of the question, I hope to attempt that, or something equivalent, very soon, in a set of experiments which I have had in view for some time.

Glasgow, 26th August, 1885.

XLV. Sequel to Paper on the Seat of the Electromotive Forces in a Voltaic Cell. Theories of Wiedemann and of Helmholtz. By Professor OLIVER LODGE†.

IN a recent *Beiblätter*‡, Prof. G. Wiedemann points out that in my summary of views and work in connection with the seat of E.M.F. in the pile I have ignored his theory. I had in fact been mainly concerned with possible explanations of the Volta-effect; while Prof. Wiedemann starts with this as a datum, and on the strength of it explains the action of the pile. Moreover, since most of the theoretical opinions held on this subject are summarized at the end of the second volume of his *Elektricität*, while his own theory is given in the first volume, along with the account of Volta-force experiments, I had overlooked it. To make amends for this oversight, for which I beg to express my regret, and because I find it difficult to summarize his opinions briefly, I trust I may be permitted to give a rough semi-literal translation of his most conspicuous passages as a help to other students of the subject.

Theory of G. Wiedemann, 1870. (Wied. Elek. i. p. 251 et seq.)

"We have now to investigate in what way the electrical forces in a closed circuit of two metals and a liquid (*e.g.* Zn, Cu, dilute HCl) are excited. We know that the constituents of the binary compound contained in the liquid separate by the passage of the current in such a way that the one (H) is set free at the copper and an equivalent quantity of the other (Cl) at the zinc, and that the latter combines with an equivalent quantity of zinc to form ZnCl. This process shows that the deportment of the binary body between the metals consists no longer only in a simple overbalancing attraction of its whole mass for one or the other electricity, as in metals, but also in

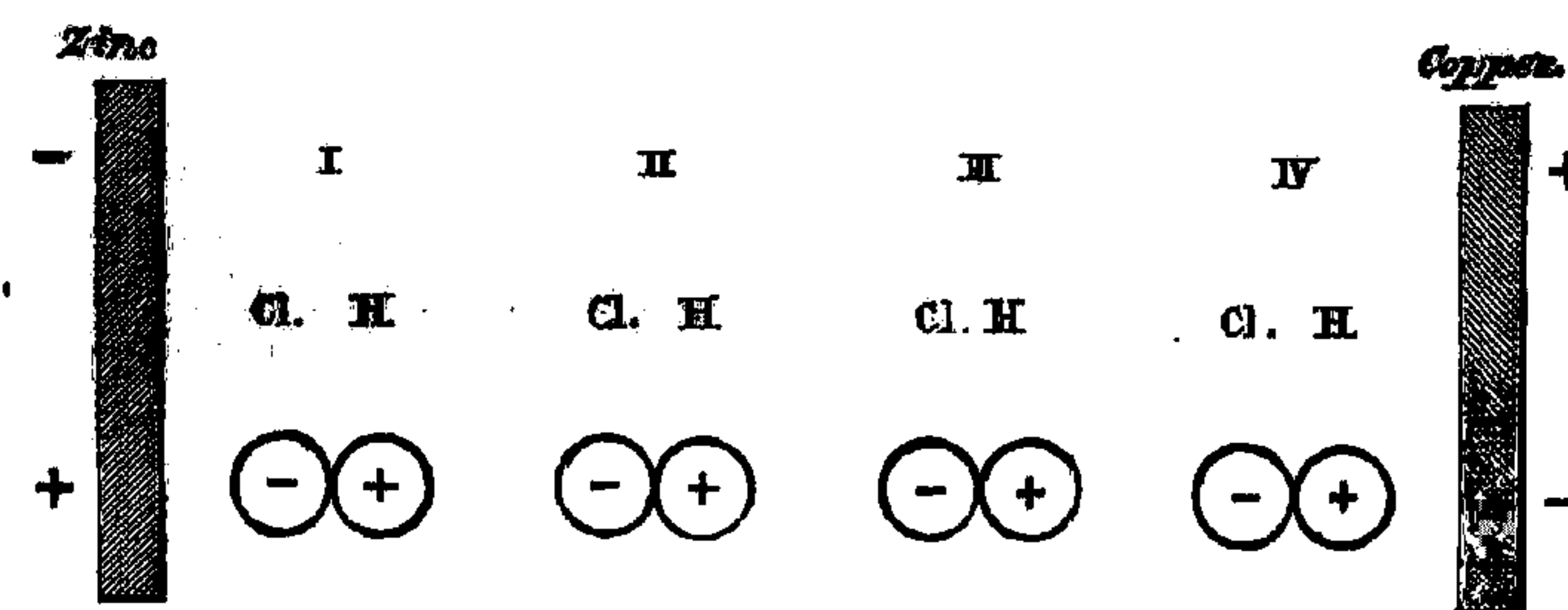
* Reprint of Papers on Electrostatics (§ 340).

† Communicated by the Author, in continuation of paper in *Phil. Mag.* for March, April, May, and June of the current year.

‡ *Beiblätter zu den Annalen der Physik und Chemie*, 1885, No. 7, Band ix. p. 533.

a special action of its constituents. Since the constituent Cl is liberated where the + current enters the liquid, and H where the negative enters, we suppose that each equivalent of Cl in the compound HCl is charged with a definite quantity of negative electricity, which conditions its attraction for the opposite positive electricity. It is the *electro-negative element* of the compound. So also must the equivalent H be charged with + E and form the electro-positive element. These charges could be produced by the combination of H and Cl exactly in the same way as they are produced by the contact of zinc and copper. Since the HCl formed is unelectrified, we must suppose that atoms of the + and - constituents contain equal quantities of + and - E.

"If now we immerse a Zn and a Cu plate into the dilute HCl, we can conjecture that the zinc has a stronger attraction for the electro-negative constituent (Cl) than for the H. In consequence of this the molecule of HCl touching the zinc will so lay itself that its electro-negative element is near the zinc and its electro-positive element near the copper. At the same time the molecules thus polarized act by electrical attraction on the constituents of the successive molecules of HCl, arranging the whole row of molecules between the Zn and the Cu plates as in the figure.



"By induction the negative electricity of the zinc-touching electro-negative constituent, chlorine, would act on the H in the zinc in such a way that the near parts will charge themselves positively, the further parts negatively. In the same way the copper adjacent to the electro-positive element (H) of the HCl atom lying against it will receive negative electricity. The positive will remove itself to the remoter regions.

"Thereupon the positive electricity in the zinc would combine with the negative of the next-lying Cl atom, and this latter with zinc to form unelectrical ZnCl. The electro-positive atom H which was formerly joined to that Cl atom would itself unite with the neighbouring atom of Cl belonging to the second

atom of HCl, at the same time combining with the electricity contained in this atom; in the same way the hydrogen of the second atom—[the welcome letters *u. s. f.* are now not far ahead, and we will let them serve for the next fifteen or sixteen lines].

“It is evident that in this process there occurs a continual loss of *vis viva*, since the elements of the binary compound rushing up to the metal move with a definite velocity to the metal, and then are reduced to rest, either with formation of ZnCl or by being set free (H). This loss of *vis viva* is the equivalent of the heat which is evolved by the obviously occurring chemical process, which essentially is the solution of an equivalent of zinc in the acid. The same value must likewise be the work applied in effecting the redistribution of electricity.

“When, therefore, electricity begins to flow, work must be done, during the solution of Zn and liberation of an eq. of H from the liquid in the whole circuit, whether it be in the form of heat or of external work, which is equivalent to the heat-production attending that chemical process.

“The electrical shearing-force E is an accelerating force, so its work A in unit time is equal to its product with the quantity of electricity moved in unit time, m , and the distance s which the same travels, or

$$A = E \cdot ms.$$

The product ms expresses the quantity of electricity which travels per second through the cross section of the conductor.

“If we have different combinations, as Zn, HCl, Cu; or Mg, H₂SO₄ or NaCl, Cu; or &c., we suppose that the same quantity of E travels per equivalent . . . [a long appeal to the facts underlying Faraday's law is made to prove this]; hence $ms = \text{const.}$,

$$\therefore A = \text{const.} \cdot E;$$

or the E.M.F. is directly proportional to the heat generated by the decomposition of an equivalent of the binary compound and the solution of the zinc.

“For the production of steady currents, that electrical force can alone be active which depends on the unequal attraction and polarization of the atoms of the binary compound in the exciting liquid of the cell; the electrical force at the contact-place of the metals which no mechanical changes can prelude must, on the other hand, be inactive. That this latter, if it perhaps opposed the metal liquid E.M.F. (as by immersion of zinc and lead in KCy solution), is not compensated by a definite part of the tension force, is proved by the afore-

said complete proportionality of the total electrical force (and E.M.F.) in the closed circuit with the ~~total heat-equivalent~~ of the chemical processes. It must then be neutralized in some other way. This would most simply happen on the hypothesis that, by contact of the exciting fluid with the metals, the E.M.F. is excited in a double way: first, by an unequally strong attraction of the masses of fluid and metal *as a whole* for the one or the other electricity; and, secondly, by the unequal attraction of the metals for the oppositely electrified components of the liquid. (This double property would be quite analogous to the following: a metal (*e. g.* zinc) can not only attract to itself by adhesion the whole mass of any given fluid (HCl), but also can exert a much stronger attraction for one constituent of the same (chlorine); just also as a magnet attracts iron, not only by reason of gravitation, but much more because of the magnetic polarization of its individual particles.)

“In consequence of the first unequal (mass) attraction for the electricities, the decomposable liquids would behave exactly according to the metallic law of tension, and in a closed circuit of metals and liquids a complete neutralization of electrical forces (and E.M.F.) would obtain; the second (chemical) action would, on the other hand, alone produce the electrical shearing-force effective in current formation and its accompanying E.M.F.

“We will therefore in the sequel denote the total E.M.F. at the various junctions with strong letters, and that portion of the same of which no part engages in exciting the current by italics in brackets, and by italics without brackets the portion corresponding to the chemical work. In the closed circuit—zinc, sulphuric acid, copper—the whole active E.M.F. would then be

$$Cu/S + S/Zn + Zn/Cu = Cu/S + S/Zn + (Cu/S) + (S/Zn) + (Zn/Cu).$$

“The experiments of Hankel and others give the total E.M.F. between the metal M and water, which we denote by M/Aq , and which is compounded, according to the foregoing hypothesis, of the E.M.F. excited by the mass action of the water (M/Aq), and that excited by reason of its chemical polarization M/Aq . If therefore we put into water a copper and a zinc plate, the total potential difference, or E.M.F. between its ends, is $Cu/Aq + Aq/Zn$. This is the quantity we should directly obtain if we connected the Cu and Zn immersed in water with the same named plate of a zinc-copper condenser, and after breaking the connection determined the charge of the condenser.

"On our hypothesis,

$$\text{Cu/Aq} + \text{Aq/Zn} = (\text{Cu/Aq}) + (\text{Aq/Zn}) + \text{Cu/Aq} + \text{Aq/Zn}.$$

If we close the circuit by connecting the zinc and copper plate by a copper wire, the force Zn/Cu adds itself to these E.M.F.s, and this force removes from the tension series of the metals the following forces, $(\text{Cu/Aq}) + (\text{Aq/Zn})$; wherefore we get

$$\text{Cu/Aq} + \text{Aq/Zn} + \text{Zn/Cu} = \text{Cu/Aq} + \text{Aq/Zn}.$$

But this last is the part of the total E.M.F. applied to the formation of the current. Hence to the directly found contact-forces between different metals and water we must add the electromotive excitation of one metal on the other in order to get the current-forming E.M.F. in the circuit of a closed cell."

So far as I am able to see to the bottom of the foregoing theory its foundation appears to be as follows:—Contact experiments compel us to accept the summation law for the Volta-effects, or total differences of potential,

$$E = \text{Cu/Aq} + \text{Aq/Zn} + \text{Zn/Cu}.$$

The chemical theory constrains us to admit that the E.M.F. of a cell is the equivalent of the chemical action going on, and thus suggests that it equals the sum of some chemical contact forces; or, in Wiedemann's notation, E ought also to equal

$$\text{Cu/Aq} + \text{Aq/Zn}.$$

How are these two requirements to be reconciled?

Assume that at every junction there is a total force made up of two portions—a chemical force, such as Cu/Aq , and a physical force, which may be denoted by (Cu/Aq) , and write the whole E.M.F. of a cell equal to the sum of all these chemical and physical junction-forces,

$$E = \text{Cu/Aq} + (\text{Cu/Aq}) + \text{Aq/Zn} + (\text{Aq/Zn}) + (\text{Zn/Cu}).$$

We have then only to make the physical forces obey Volta's series law; so that

$$(\text{Cu/Aq}) + (\text{Aq/Zn}) + (\text{Zn/Cu}) = 0;$$

and we get the required relation

$$E = \text{Cu/Aq} + \text{Aq/Zn},$$

which harmonizes chemical and contact views.

Prof. Wiedemann's reconciliation of contact and chemical theories would thus seem to be somewhat of the same order as the later and less complete one of Fleeming Jenkin, quoted in my paper, § 6; but I cannot help feeling that the theory

of Prof. Wiedemann is rather fuller of hypotheses than most other contributions to the subject with which I am acquainted; for it postulates

1. An unexplained difference of potential between metals in contact.
2. A similar difference of potential between the elements of a compound.
3. An unequal attraction of bodies for + and - E.
4. An unequal attraction of metals for chemical elements.
5. A chemical contact-force between metals and liquids, depending on No. 4, not obeying Volta's law.
6. A physical contact-force, depending on No. 3, obeying Volta's law.
7. Proportionality of the chemical contact-forces and the heats of combination.
8. A mechanical falling together of atoms accounting for heat-production at electrodes; and
9. That electrical actions go on between the molecules of a liquid, and between those molecules and metals immersed in it, according to the ordinary laws of electrostatics.

Not all of the above hypotheses, however, are to be regarded as independent: the dependence of Nos. 5 and 6 is stated, and it is possible that some of the others are intended to be likewise dependent, though I do not clearly see how.

In some of these hypotheses, for instance Nos. 4 and 5, and, with considerable differences, Nos. 6 and 7, Prof. Wiedemann's theory bears a resemblance to the views set forth by the present writer in the paper to which this communication is a sequel.

One obvious objection may be taken to the theory on a question of fact. According to it, zinc half immersed in water is negative to copper half immersed in water (see diagram above): but experiment has failed to exhibit anything of the kind; and it is well known that Sir W. Thomson, Prof. Clifton, and others have shown that zinc and copper immersed in water or dilute acid are electroscopically at the same, or nearly the same, potential.

Theory of Von Helmholtz, 1847 and later.

There is another theory which I did not indeed ignore, but which I passed over with very insufficient mention, in the paper referred to (see footnote to § 9, *Phil. Mag.* April, p. 258); viz. the theory of Professor von Helmholtz, which he first stated in his great memoir of 1847, *Die Erhaltung der Kraft*, and

which he has improved and elaborated since (see Faraday Lecture of 1881).

This fascinating theory has a small hypothetical basis, viz. Nos. 3 and 9 of the above list; and on this foundation is erected an explanation of the Volta effect, a theory of electrolysis, and a great part of a theory of chemical combination.

Once grant, (1) that every substance has a specific attraction for positive or for negative electricity which can be exerted only through molecular distances, and (2) that the laws of electrostatics may be applied to the charges of atoms in a liquid; and the ease with which a multitude of phenomena are explained is surprising. I do not feel certain that a little too much is not explained; but we can postpone the consideration of possible objections until the theory itself is briefly stated.

Metals, and "electropositive" elements generally, attract positive electricity or positively electrified atoms whenever these come within range, *i. e.* within some molecular distance of the surface. Potassium and zinc attract strongly, copper and gold feebly. Oxygen, chlorine, and other "electronegative" elements, attract negative electricity in a similar manner.

Bring now two metals, say zinc and copper, into contact, and the superior attracting-power of zinc for positive electricity will at once charge it at the expense of the copper, so that the zinc touching-surface becomes strongly positive, and the copper surface strongly negative. Separate the metals, and they mostly discharge into each other; but a feeble charge remains if the surfaces in contact were large, and if they have been neatly separated; and this is the Volta effect.

Moreover since each metal has a definite attracting-power depending on itself only, Volta's series law is an obvious necessity.

If one of the substances had been an insulator much less loss need take place while separating them, and accordingly high charges are then found upon them even after separation ("frictional electricity").

Now consider similarly two atoms in contact, forming, say, a water molecule. The hydrogen will be positively charged, the oxygen negatively. If some atoms should get knocked asunder they retain their charges and therefore tend to unite again, but, while separate, their mutual attractions and repulsions will preserve a uniformity of distribution throughout the liquid—*e. g.* the repulsion of similar charges will prevent a number of oxygen molecules crowding together; and if any cause should remove oxygen atoms from any part of the liquid, the vacancy will be instantly supplied by similar atoms repelled there.

The remarkable thing about the charges of atoms is, however, that they are all equal, and even for different atoms are still the same, or differ only according to simple multiples of some one absolute quantity; so that one atom may have three times as much negative electricity as hydrogen has positive, but not any fractional number. Such an atom may therefore combine with three of hydrogen atoms, and thus be called a triad. Another may be a dyad, &c. A given constant charge belongs to every unit of affinity which the atom possesses; and thus is the fact of chemical equivalence stated, though not accounted for. Faraday's law compels us to believe that atomic charges are thus multiples of one definite electric quantity, but why they should be so we are wholly unable to say. It looks as if electricity were atomic as well as matter; a sufficiently startling idea, as Helmholtz says.

Chemical affinity is thus due to the electrical attraction of oppositely charged atoms; not so much due to the attraction of the atoms themselves. This latter kind of attraction Helmholtz would not indeed deny, and he considers it may account for "molecular" modes of combination; but he regards it as much weaker than the electric forces, and as not effecting definite chemical combination.

We have ideas now concerning the size of atoms, and can calculate roughly what an atomic charge is. The charge of each atom is but small, but the aggregate charge of an appreciable number of them is enormous. It can be easily reckoned that if you take the opposite electricities out of a milligramme of water and give them to two spheres a mile apart, those two spheres will attract each other with a force of ten tons! Or, again, the electrical attraction of two atoms at any distance exceeds their gravitative attraction 71 thousand billion times. Upon such charges as these even very feeble external electrical influence may exert considerable force, and quite overpower any other kind of chemical affinity.

Plunge, therefore, two platinum plates into the liquid and keep them at some slightly different potential, say a volt or two: their surfaces are oppositely charged, and even this feeble charge may be sufficient to tear asunder the atoms of molecules which come close up to it*. If it is not sufficient, it

* It is easy to calculate the surface-density, and the difference of potential, on the above hypothesis, needed to tear asunder oppositely charged atoms attracting each other across molecular distance *x*. Let it be σ , and let the charge of an atom be q ; then

$$2\pi\sigma q = \frac{q^2}{x^2}.$$

Moreover we know that 19,320 electromagnetic units can decompose 18 grammes of water, which allows $536 \times 3 \times 10^{10}$ electrostatic units of each

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will at least hold a layer of oppositely charged atoms facing toward it across molecular distance; so that near each plate we have an excessively thin condenser of enormous capacity; but in the mass of the liquid is no such strain, the slightest E.M.F. being sufficient to redistribute the atoms here and to produce perfect equilibrium. If the atoms are torn asunder by the electrode and liberated, fresh ones are continually supplied by the rest of the liquid, the state of strain being constantly re-formed and instantly broken down.

Thus are the phenomena of polarization and electrolysis explained.

Now insert into the liquid a pair of plates of zinc and copper in contact. By the contact the zinc has become positive and the copper negative, and accordingly the zinc attracts the oxygen (or SO_4 radical) and combines with it: the copper attracts the hydrogen, and does the best it can with it.

This crudely is Helmholtz's view of a voltaic cell.

There is, however, one important detail not yet mentioned. I have spoken as if the work done by an electrode were to tear the atom from its combinations. This is not exactly Helmholtz's view. He adduces arguments to show that the work required to effect decomposition has for its object, not the separation of the atom from the liquid, but the separation of the atom from its electric charge. It is to this that it clings, and this that has to be taken from it. If it be made to give this up

kind of electricity per gramme; so if n be the number of molecules in a gramme of water, the charge of each dyad atom is

$$q = \frac{1.6 \times 10^{13}}{n^2}; \quad \approx 1.6 \times 10^{-11} \text{ probably.}$$

Hence

$$\sigma = \frac{1.6 \times 10^{13}}{2\pi n^2 x^2}; \quad \approx 3 \times 10^{-12} \text{ probably;}$$

and, the difference of potential between either plate and liquid being given by $4\pi x\sigma$, the whole difference of potential between the electrodes is

$$V = 8\pi x\sigma = 6.4 \times \frac{10^{13}}{n^2 x}; \quad \approx .0064 \text{ electrostatic units probably,}$$

or 1.92 volt.

In reckoning the approximate numerical values above, I have assumed that $n=10^8$ and that $nx=1$. The resulting decomposition force comes out, quite accidentally as far as I am concerned, very near that needed to decompose acid-water. But I need hardly point out that *order of magnitude* is all that is really calculated in these figures; and that not only decimals but even numerals, prefixed to the power of 10, have very little meaning. The value of x may perhaps vary somewhat for different substances; and as to the value of n , though that is definite enough, it is very probable that it ought to be something more like 2×10^8 than what I have above assumed it.

It is at any rate satisfactory that the electrostatic hypothesis should give, as a polarization E.M.F., a number so entirely comparable with actual results.

by a sufficient E.M.F., it is of small or no moment whether the ion be really set free, or be dissolved, or otherwise kept in the liquid. But when the electrode is of such a metal that an ion can combine with it, that ion retains its charge, and accordingly very little E.M.F. is sufficient to decompose the liquid under such circumstances.

Without this statement it might be objected, that when a piece of zinc is plunged into acidulated water, since it has a strong attraction for positive electricity, it ought to attract the positively charged hydrogen atoms up to itself, instead of oxygen as commonly supposed. I suppose Helmholtz would admit that it must do this to begin with, when isolated from other metals, on his theory, but that it has no way of separating and liberating atoms because it cannot get rid of their charges. If it be kept at a sufficiently negative potential artificially it can indeed dispose of these charges, and it then does attract and liberate hydrogen. But contact with copper raises it to a positive potential, and it then attracts negatively charged oxygen, rather than hydrogen, and combines with it; while the negatively electrified copper seizes hydrogen atoms, tears their charges away from them, and sets them free.

I must confess, however, that I feel a difficulty here. The natural tendency of zinc is, by hypothesis, to attract positive and repel negative atoms; but, while a very feeble positive electrification applied to it is sufficient to reverse this tendency, a comparatively strong negative electrification is needed to enable it to exert that force which by the hypothesis is supposed to be natural to it.

In considering a Daniell cell, zinc / ZnSO_4 / CuSO_4 / copper, Helmholtz obtains the energy producing the current, by pointing out that electricity is removed from copper, which only attracts it feebly, and given to zinc which attracts it strongly. Zinc goes into solution and becomes positively charged, while an equivalent of equally positive copper comes out; and since this results in a gain of energy, it follows that electricity must do more work in going to zinc, than in going to copper.

But if zinc attracts electricity so much more strongly than copper, why is it so easy to drive electricity across a copper/zinc junction? And why does no energy manifestation result at the junction from such an operation?

The answer probably is, because of the large charge already existing at the junction; the zinc has pulled as much positive electricity out of the copper as it wants, and there exists at the contact an electrical double layer, whose existence makes it quite easy for extraneous electricity to flow either way across the junction.

But, then, if zinc pulls so much electricity out of a piece of

copper with which it is put into contact, where does it all come from? And why does it not leave the copper *strongly* negative instead of only feebly so, as evidenced by Sir W. Thomson's electrified-needle form of experiment? Why, again, does this method of observing the Volta-effect, with the plates permanently in contact, agree so well with the old method of observing it by separation of the plates, if a great but uncertain part of the charge leak back as soon as separation beyond molecular distance is attempted?

These and similar difficulties occur to me in connection with this most interesting theory; and I state them, not with any idea that they are final and unanswerable, but because it is always serviceable to point out the apparent defects of a theory as well as its merits.

It will be seen that, whereas Helmholtz's theory starts with a hypothetical differential attraction of *matter for electricity*, and explains the chemical attraction of matter for matter on the strength of it, my view starts with a differential chemical attraction of *matter for matter* (i. e. zinc attracting oxygen more than copper attracts it), and on this basis works out the theory of the voltaic cell and of the Volta-effect.

In electrolysis proper both views may be at one, because here we are concerned with electrical attractions only; but Prof. Helmholtz's has the advantage, because it explains the fact of atomic charges, which mine has to assume. My view of electrolysis has hitherto been much less electrostatic than Prof. Helmholtz's, but also it has been much more vague. A great deal is to be said for the assumption of ordinary electrostatic attraction over molecular distances, and by adopting such more definite ideas I am in hopes of improving my theory further. And though, after all, none of these views can be really absolute, because they begin and end with action at a distance, still electrostatic attraction is a fact, and we know that it can be accounted for by a strain in a continuous medium. Hence phenomena reduced to electrostatics may be held to be provisionally "explained."

But beyond electrostatic attraction some other primary force is necessary; either *chemical affinity*, the attraction of atom for atom, or *electrical affinity*, so to speak, the attraction of atoms for electricity.

Chemical affinity is a fact, however it be accounted for; but, to enable it to explain everything, the fact of atomic charge must be permitted to likewise go without explanation. These are the necessary data for my view.

"*Electrical affinity*" is not known to be a fact; but if it be granted, everything is explained (barring a few outstanding difficulties), even the fact of atomic charge itself, though not

its numerical exactitude. This is the datum required for Helmholtz's theory.

It may thus be said that while the writer's view rests on two admitted facts which it does not attempt to explain, but, assuming them, explains other things from them; Helmholtz's theory rests on one unverified hypothesis, which, being granted, everything else follows; except indeed the numerical equality of atomic charges, which has to be regarded as experimentally demonstrated in both theories.

According to my view, the zinc of a cell pulls up the negatively charged oxygen atoms (or SO_4 radicals, whatever the real ions may be) to itself, not because they are electrified, but because they are oxygen. The electrical current produced is a secondary result caused by the chemical action.

According to Helmholtz, the zinc pulls the oxygen atoms because it is itself electrified by contact with copper, and because they are oppositely electrified by contact with hydrogen. The chemical action resulting is a secondary result caused by the electric forces.

Helmholtz's is thus a true "contact theory," and is in many respects like Sir W. Thomson's. Sir William postulates an attraction of zinc for copper, and from this explains the Volta-effect and the production of a current. I am unable to picture to myself exactly *how* the attraction of zinc for copper results in a difference of potential when they are put into contact; but undoubtedly such a force, if granted, would put a supply of energy at disposal which could account for the Volta-effect. And a difference of potential thus set up may result in an electrical decomposition of water and maintenance of current, just as in Helmholtz's theory.

I must confess that I am unable to feel quite comfortable about energy considerations with either of these theories of the voltaic cell; because it seems as if the metallic junction were, after all, driving the current, whatever be said about chemical energy. But in this I must certainly be wrong; that is to say, there must be some thorough way of reconciling these, by such men advocated, views with energy considerations, though I am unable satisfactorily to perceive it.

Both these contact-theories, in explaining the Volta-effect, ignore the existence of the oxidizing medium surrounding the metals. My view explains the whole effect as a result of this oxygen bath, and of the chemical strain by it set up. The other theory which likewise took account of the atmosphere is the old chemical one; but this leaves the aspect of the matter exceedingly vague. The strictures applied to it by Prof. Helmholtz (Faraday Lecture, 1881) are well deserved:—

"The so-called chemical theory of Volta's fundamental

experiment was rather indefinite; it scarcely did more than tell us—here is the possibility of a chemical process, here electricity can be produced. But which kind, how much, to what potential, remained indefinite. I have not found in all the papers which have been written for the defence of the chemical theory a clear explanation why zinc opposed to copper in liquids, where zinc really is oxidized and dissolved, becomes negative, and why in air and other gases it becomes positive, if the same cause (*viz.* oxidation) is at work.”

To the chemical *strain* theory, held by me, none of this remark is in the least applicable. This theory *does not say* that zinc opposed to copper in a liquid is negative. It says that, changing the surrounding medium from air to acid-water, makes scarcely any difference; and that accordingly connecting zinc and copper by a drop of water leaves them with the same respective potentials as they had before. The strain of oxygen-atoms towards a metal exists whether in air or water, but it can produce no effect in either case until at some point the oxygen be swept away by contact with another metal. Then instantly the chemical forces are able to do work, and to produce, if in air or other dielectric, the Volta-effect; if in acid or other electrolyte, the voltaic current. The metallic contact equalizes the potential of the two metals in the one case; in the other it perpetually *fails* to equalize their potential. The equalization of an otherwise disturbed potential is its only effect.

And no indefiniteness exists as to either the kind or amount of the Volta-effect as so produced, for I have shown fully that a Volta-effect can be calculated in absolute measure for any pair of clean metals immersed in any medium, from purely thermo-chemical data; but whether this effect is the real one or not is at present a matter of opinion.

These so-calculated effects undoubtedly agree in some cases with experimentally observed ones; but whether they all so agree, and, if not, the extent to which they are erroneous, are matters mainly for future experiment to decide; and upon such agreement or disagreement between calculation and experiment my theory definitely stands or falls.

XLVI. Intelligence and Miscellaneous Articles.

ON A DIFFERENTIAL RESISTANCE THERMOMETER.

BY T. C. MENDENHALL.

THE determination or registration of the temperature at a distant or not easily accessible point is so extremely desirable that many methods for accomplishing this end have been proposed, and

to some extent made use of during the past fifty years. Naturally enough electricity has been utilized in some way or other in the majority of these systems of telethermometry.

The requirements of the problem seem to be that the device or instrument used at the point, the temperature of which is to be ascertained, shall be of the greatest possible simplicity of construction, involving little or no motion in its parts, so that the liability to “get out of order” shall be reduced to the minimum; and that at the observing or registering station, the necessary appliances shall possess a maximum of durability and simplicity—so that a minimum of time and skill will be demanded in making the observations. The whole system must be certain in its indications and correct within a reasonable limit.

The first of these conditions is apparently sufficiently well satisfied by the thermo-electric-junction, which has probably been more extensively made use of than any other form of electric thermometer. It renders necessary, however, the use of a comparatively delicate galvanometer, and as the electromotive force of a single couple is small (it is difficult to use more than one in general practice) the results are subject to considerable errors arising from unknown or neglected sources of electromotive force. This source of error becomes more important as the range of temperature measured becomes smaller, although it may be almost entirely avoided by care and skill on the part of the operator. The well-known resistance method of Siemens satisfies the same condition very perfectly, and is certainly capable of giving good results when skilfully applied, at least throughout moderate ranges.

The desire to possess some form of electric thermometer which might be utilized in the study of certain problems connected with meteorology, especially the observation of soil and earth temperature, and the use of which would not demand greater skill than that of the ordinary meteorological observer, led to the device and construction of the instrument to be described, which may be called a “differential resistance thermometer.” It consists essentially of a mercurial thermometer, not unlike ordinary forms, except that the bulb is greatly enlarged so that the stem may have a diameter of something like a millimetre, and still leave the scale tolerably “open.” In one of the instruments already made 1° C. corresponds to about 5 millim. of the scale. Running down through the stem is a fine platinum wire about .08 millim. in diameter. The lower end may be secured in the bulb so that it is kept straight in the bore of the stem, and at the lower end a heavier wire is sealed in the glass, so that metallic contact can be made with this wire both at the upper end and through the mercury at the lower. It is evident that the resistance between these two points will depend largely (but not entirely) on the length of the platinum wire which is above the mercury in the tube, and this will depend on the temperature to which it is exposed. When this temperature rises the resistance is decreased by an amount equal to the difference between that of the platinum wire which disappears and that of