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By Sir WILLIAM RAMSAY, K.C.B., F.R.S.

The Electron as an Element.

" Nec perit in toto quicquam, mihi credite, mundo,
Sed variat faciemque novat."—OVID.

BEFORE commencing my task, to attempt to show that chemical phenomena
may be represented in a reasonable manner by assigning a symbol to the
electron, considered as an element, it will be advisable to make some
general statements regarding the relations between thinking man and
external nature.

Every one of us (and by " us " I mean to include all things which
have, even in embryo, consciousness both of their own existence and
that of objects external to them) holds certain suppositions, whether by
inheritance or by early teaching, or by virtue of having formed his
own deliberate judgment, to be true ; or if the word true be found
objectionable, to be convenient ; to be necessary as a mode of thought.
Such suppositions we term theories or hypotheses. These words
themselves require definition. To quote Dr. Johnstone Stoney : " The
principal kinds of supposition are : Theories, Hypotheses, and Fictions.
A theory means a supposition which we hope to be true ; a hypothesis
is a supposition which we expect to be useful. Fictions belong to the
realm of art ; when allowed to intrude elsewhere, they become either
Make-believes or Mistakes."

Chemists and physicists deal with the world of phenomena ; with
operations and results of operations which take place in what is called
" nature," that is, in a region exterior to the minds of the observers.
They have agreed, implicitly, to avoid the consideration of the
relationship between such phenomena and the mind of man, a branch
of the subject termed Metaphysics ; they confine their attention
exclusively to the relationships which they observe to exist between
various phenomena external to the workings of consciousness. It is
true that all such phenomena are known to us only in so far as they
impress our consciousness—our own minds, or the minds of other
beings whom each of us regards as constituted more or less nearly like
himself. But inasmuch as there is a consensus of opinion, on the
whole, as to the similarity of impression received by conscious beings, we

agree to ignore the inquiry as to the mode in which such impressions reach our minds and to confine our attention to the relationships which we find to exist among phenomena.

Now, there are two ways of regarding natural phenomena, and these necessarily depend on the fundamental conceptions which all of us hold. We assume, first, that events happen in sequence, and from this we deduce the conception of time. Secondly, we believe that we can change our position relatively to that of other objects, and that they change their relative position to each other; we thus acquire the conception of space. Whether these ideas are engrained from birth, or acquired by experiment or observation, we shall probably never know. Thirdly, we are conscious of sustained muscular effort, and from this consciousness we deduce two ideas, first, that of mass, or that which resists our muscular efforts; and second, that of energy, or, in other words, we learn that to change the position of an object or mass, a sustained muscular effort is necessary. This last conception is of recent introduction; the word, I believe, used in this sense, was due to Professor Macquorne Rankine.

If we assign certain numerical values to these conceptions, if we measure time in seconds, linear space in centimetres, and mass in grams, we arrive at a fundamental equation connecting these with energy, measured in ergs. It is the familiar one:

$$E = \tfrac{1}{2} M L^2 / T^2,$$

where E, L, M, and T may stand for equal number of ergs, grams, centimetres, and seconds respectively.

It will be observed that only three of these fundamental notions are necessary; the fourth can be deduced from the other three. Physicists and chemists have for centuries accepted time, space, and mass as fundamentals, and have agreed to derive the conception of energy from these three. That is, they have accepted a mechanical explanation of the universe; they attempt to explain the invisibly minute in terms of the visible; the nature of objects by the atomic and molecular theories, namely, by the supposition that objects consist of congeries of small masses; that the changes which they observe to occur in these objects are due to the motions and altered positions of the atoms and molecules, and that the nature of these objects depends largely on the relative positions of the atoms, or, as we say, on their structure. It is, of course, acknowledged that the changes that take place in objects are accompanied by gain or loss of energy. To alter the position of a mass, energy must be imparted to it, or, if it spontaneously alter its position, it must part with energy in doing so.

The whole conception of a "material universe" is bound up in this view, which has contributed to a great advance in knowledge; in fact, all progress in chemistry and physics has been made by its aid. The

atomic theory is a "theory," a supposition which is supposed to be true, as well as a "hypothesis," which is known to be useful. By its help we "explain" (that is, render the unknown in terms of the more familiar) such apparently diverse facts as the relations between the volume, temperature, and pressure of gases; the optical properties of certain compounds of carbon, nitrogen, sulphur, tin, and silicon; isomerism; the phenomena of osmotic pressure and vapour pressure; and with an added hypothesis, the behaviour of dissolved salts under electric stress. It is this last part of our conceptions which I propose to discuss in this address.

But before proceeding to do so, it must be noticed that it is possible to explain phenomena by postulating time, space, and energy as the three fundamentals; mass is then a derived conception. To my mind, this method of viewing nature is the more logical, for all that we know through our senses directly, and indirectly by instruments which affect our senses, is due to transfer of energy to or from our nerve-terminals. Such sensations are for us real; in ascribing them to the presence of "matter" as their cause, we make use of a theory which is sanctioned by antiquity, and by all but universal custom. The inconvenience of the hypothesis that energy is the third fundamental entity is that it is difficult to assimilate mentally, and that it results in sets of equations of state, instead of affording a mental picture of the minute unknown in terms of the larger, and better known. Those interested in the subject will find it expounded in various writings of Prof. Mach and of Prof. Ostwald, notably in the latter's "Naturphilosophie."

I should like here to pause, and to note that the words "true" and "false" are inapplicable to such theories as these of which I have spoken. Both are perfectly consistent schemes for the interpretation of the universe. In all probability, neither of these schemes conveys any idea of what constitutes phenomena; one or other may be regarded as more *convenient*. Let me here refer to Dr. Johnstone Stoney's writings for a full discussion of such relations.*

As a matter of convenience, then, like most other chemists and physicists, I choose deliberately the "mechanical" explanation of nature. We assume on what we consider to be good grounds the existence of molecules and of atoms. We believe on reasonable evidence that gases consist of almost innumerable molecules, which may, like argon and its congeners, be single atoms, but which are usually groups of atoms. We hold that, as a rule, liquids consist

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* "On the dependance of what apparently takes place in nature upon what actually occurs in the universe of real existences."—*Amer. Philosoph. Soc.*, Vol. XLII, No. 173. "On the relation between natural science and ontology."—*Sci. Trans. Roy. Dubl. Soc.*, Vol. VI, Part 9.

of molecules of the same order of complexity as gases, but with smaller free path ; the molecules of a liquid are more crowded than those of a gas. Some few liquids, water, the alcohols, the acids, probably salts, and some others, may be regarded as mixtures of polymerides of their gaseous molecules. Of the structure of solids, we are only beginning to have some crude notion.*

We also believe that molecules at the ordinary temperature are in enormously rapid motion ; that they are in frequent collision with each other, and that chemical action is the occasional result of such collisions. I say "occasional" because, as Dr. Stoney has shown, in molecules such as those of the nitrogen and oxygen of air, a collision takes place on the average thirteen billion times every second. Some mixtures of gases, for example, hydrogen and oxygen, or hydrogen and chlorine, at a suitable temperature, combine by virtue of such collisions between the molecules ; but the process of combination is a comparatively slow one, and it is curious to think that a collision which is followed by a combination is a comparatively rare event. " We begin to perceive that chemical reactions, even those that occur with explosive violence, are far from being the sudden events they seem to ordinary human apprehension. What is really occurring in nature is a *protracted* and eventful struggle between the members of two opposing armies, each individual unit of which has his own personal history during the struggle, and is fully occupied with his own acts, which are perhaps, as many, as various, and as different from those of his neighbours as are the thoughts and acts of the individual soldiers during the progress of a battle." †

What is meant by "chemical action"? We can represent it as a loss or gain of energy, but we also regard it as the union or junction of atoms, or, it may be, the dissolution of such union or the re-adjustment of unions, so that bodies with new properties are formed. We may next ask : What mechanism can be devised to give us a picture of the union of two atoms? Do they interpenetrate? Are atoms vortex-rings, and is their union the annular revolution of the two rings? Or is the older conception to be preferred, that they are approximate spheres which come within and stay within the regions of each others' influence? If so, why do they stay near each other? Various chemists have called the mechanism by which it is conceived that atoms remain associated in a compound " affinities " or " bonds," and " valency " is a word used to express the number of such " bonds " which an element can exercise in any particular combination.

I have to bring before you a suggestion which, although not exactly

* " Texture in media."—*Phil. Mag.*, June, 1890.

† Dr. Stoney, "Survey of that part of nature which man is competent to study."
—*Phil. Mag.*, Nov., 1899.

new, admits of definite statement, and affords a mental picture of what
may conceivably takes place.   It is not a "theory"; I do not hope
that it may be true; it is rather a hypothesis, a supposition that I
expect to be useful; it may be a "make-believe"; I trust that it will
not be a "mistake."

The hypothesis admits of short statement.   It is: electrons are
atoms of the chemical element, electricity; they possess mass; they
form compounds with other elements; they are known in the free
state, that is, as molecules; they serve as the "bonds of union" between
atom and atom.   The electron may be assigned the symbol " E."

I might begin the exposition of this subject with a historical sketch
of Davy's and Berzelius's conceptions of the relations of chemical and
electrical phenomena; it will suffice for my purpose to direct your
attention to the Faraday lecture delivered before our Society in 1881.
Professor Helmholtz there stated : ". . . We need not speculate about
the real nature of that which we call a quantity of positive or negative
electricity.   Calling them substances of opposite sign, we imply with
this name nothing else than the fact that a positive quantity never
appears or vanishes without an equal negative quantity appearing or
vanishing at the same time in the immediate neighbourhood.   In
this respect they behave really as if they were two substances,
which cannot be either generated or destroyed, but which can be neu-
tralised and become imperceptible by their union." ". . . I prefer the
dualistic theory. . . . and I keep the well-known supposition that as
much negative electricity enters where positive goes away, because we are
not acquainted with any phenomena which could be interpreted as corre-
sponding with an increase or diminution of the total electricity con-
tained in any body."   Later in his lecture, discussing Faraday's law, he
goes on : "The same definite quantity of either positive or negative
electricity moves always with each univalent ion, or with every unit of
affinity of a multivalent ion, and accompanies it during all its motions
through the interior of the electrolytic fluid.   This quantity we may
call the electric charge of the ion."   It is what Dr. Stoney has named
an "electron."   Helmholtz proceeds : "Now the most startling result
of Faraday's law is perhaps this.   If we accept the hypothesis that
elementary substances are composed of atoms, we cannot avoid con-
cluding that electricity also, positive as well as negative, is divided
into definite elementary portions, which behave like atoms of electricity.
As long as it moves about in the electrolytic liquid, each ion remains
united with its electric equivalent or equivalents.   At the surface of
the electrodes, decomposition can take place if there is sufficient
electromotive force, and then the ions give off their electric charges
and become electrically neutral."   I will make only one more quota-
tion from Helmholtz.   Dealing with "atomic compounds," that is,

molecules consisting of atoms in union with each other, he said : " If
we conclude from the facts that every unit of affinity is charged with
one equivalent either of positive or negative electricity, they can
form compounds only if every unit charged positively unites under the
influence of a mighty electric attraction with another unit charged
negatively. This, as you will immediately see, is the modern chemical
theory of quantivalence, comprising all the saturated compounds."

Just twenty years later, in a lecture delivered at Hamburg in 1901,
Professor Nernst again emphasised Helmholtz's views in the words :
" If, further, the most different elements or radicles invariably com-
bine only with a quite definite quantity of free electricity, or with a
multiple thereof, this can be most simply expressed by the statement :
for compounds between ordinary matter and electricity, exactly the
same fundamental chemical law holds as for compounds with each
other of ordinary chemical substances, namely, the law of constant and
multiple proportions." " For example, if, in common salt, we replace
the sodium atom by a negative electron, we obtain the negative
chlorion ; if we replace the chlorine atom by a positively charged
electron, we obtain the positive sodium ion."

Helmholtz, it will be noticed, declared his assent to the dual
character of electricity ; Nernst has followed his example, and that
view has, until of late years, been universally held. But it is well to
remember that Benjamin Franklin attributed the action of electricity
to a single " electrical fluid " residing in all bodies, and capable of
passing from one to another. The particles of this fluid were supposed
to repel one another, and to be attracted by the particles of ponderable
matter. A positive electrified body was imagined by him to be one
which had a surplus of electric fluid attached to it ; a negatively
electrified one, a deficit. This theory of Franklin's, *mutatis mutandis*,
has gained probability since the investigations of J. J. Thomson, and
since the discovery of radioactive bodies. It has been shown that
electric corpuscles or electrons are capable of detaching themselves
from matter, and inhabiting space unattached to any object. They
pass from one part of space to another, often with enormous velocity.
On certain likely suppositions, the mass of an electron has been
measured by Thomson and his pupils ; it does not differ much from
the thousandth part of that of an atom of hydrogen. The electron
may be termed an atom of negative electricity. The atom which it
has left is generally, and by many supposed to be always, positively
electrified. The mass of an atom from which one or more electrons
have escaped does not differ appreciably from that of the atom of the
element ; it is enormously greater than that of the negative electron.

As may be supposed, such minute corpuscles find ordinary matter
so coarse-grained, that in thin sheets it offers little resistance to

penetration. The β-rays (to give electrons a commonly-used synonym)
pass, when in motion, through a considerable thickness of metals and
of glass. This behaviour is not unknown in the case of helium, which
can traverse thin walls of silica, impervious to other gases, whilst glass
and metals are impervious to it.

We are not here concerned with free electrons and their motions,
but with the mode in which they are associated with matter ; to
render the conceptions clear, I will select a familiar instance.

When the white, opaque, lustrous metal sodium burns in the yellow
gas chlorine, small, white, transparent crystals of common salt are
produced. These crystals are soluble in water, the solution is also
transparent and colourless, and its properties do not materially
differ from those of the mean of salt and water. The power possessed
by the solution of retarding the passage of light is very nearly
proportional to the powers of the salt and the water, taken in the
proportion in which they occur in solution. The specific heat of the
solution, and many other properties, are also mean properties. What
mechanism can we assign to the change which occurs when sodium
burns in chlorine ? When salt is dissolved in water and a " current
of electricity " is passed through the solution, that is, when two
platinum plates, one kept negatively and the other kept positively
charged, are dipped into it, sodium travels towards the negative plate,
and would, were no secondary action to occur, deposit in its original
metallic state ; similarly, chlorine would be liberated at the positive
plate. We say that the salt is " ionised in solution," and we believe
that the sodium ion remains an ion because of the positive charge
which it carries, and, similarly, the properties of the chlorine ion are
due to its negative charge. On removing these charges, the " elements "
as we know them are liberated as such.

Now, I would argue that in the light of modern knowledge we must
suppose that the terms " positive " and " negative " mean merely
" minus electrons " and " plus electrons " ; that the sodium ion or
" sodion " is an element ; that the metal sodium is a compound of the
element " sodion " with an electron ; that the chlorine ion is a
compound of an electron (actually of more than one electron ; see
below) with an atom of chlorine.

It will conduce to clearness of thought here to consider the mechanism
of an electrolytic cell. It consists of two platinum plates, one kept
" positive " and the other " negative," dipping in an electrolyte, say, a
solution of salt. The positive plate may be considered as analogous
to a suction-pump, capable of withdrawing electrons from the solution ;
the negative plate, a species of electrical force-pump, giving electrons
to the solution. The sodium ions move towards the source of electric
pressure ; each combines with an electron, and metallic sodium, or its

equivalent of hydrogen, is liberated. The chlorine ions, ions because each atom of chlorine has separated from the sodium taking with it the electron of the latter, yield up each an electron to the positive plate, and the element chlorine or its equivalent in oxygen is liberated.

The action of a battery is easily pictured on the same general lines. Suppose a simple battery of a copper and a zinc plate dipping in a solution of hydrochloric acid. Electrons can pass through metallic conductors; let us accept that statement for the moment without inquiring into the mechanism. Metals are, however, impervious to ions; they form a species of semipermeable membrane. Both copper and zinc tend to throw off electrons (see Ramsay and Spencer, *Phil. Mag.*, 1906, [vi], **12**, 399), but zinc more readily than copper. So long as the metals are not externally joined, no continuous action takes place; but on making connexion, the result is this: electrons leave the zinc more rapidly and readily than they leave the copper; this induces a flow of electrons from the zinc plate through the connecting wire to the copper; on reaching the surface of the copper, these electrons, or possibly electrons displaced by them, leave the copper plate, combining with ions of hydrogen, which then escapes in the gaseous form, whilst the zinc parts with electrons and enters into solution as zinc ions. It may be asked whence the motive power is derived which causes the current of electrons through the wire; the answer may be stated in two ways: either it is due to the difference of the force with which the copper and the zinc retain their electrons, or, in ordinary language, to the electromotive force of the copper-zinc couple; or it may be attributed to a kind of osmotic pressure, the electrons traversing what to them is a nearly open road, namely, the wire, whilst matter, that is, chlorine ions, is unable to pass. This process goes on so long as there is a difference of electric pressure, so long as any zinc is left, or so long as hydrogen ions are present to take up electrons.

Let us again consider the combination of sodium with chlorine to form common salt. If it be conceded that salt differs from its solution only in so far as the mobility of the solution permits of transfer of ions, the transfer of an electron from the sodium to the chlorine must take place at the moment of combination. Symbolised, if we write E for electron and simplify the reaction, dealing for the moment with an atom and not with a molecule of chlorine, we have

$$ENa + Cl = NaECl.$$
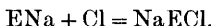
Here the electron serves as the bond of union between the sodium and the chlorine.

If it be desired to form a mental picture of what occurs, let me suggest a fanciful analogy which may serve the purpose: it is that an electron is an amœba-like structure, and that ENa may be con-

ceived as an orange of sodium surrounded by a rind of electron; that on combination, the rind separates from the orange and forms a layer or cushion between the Na and the Cl, and that on solution the electron attaches itself to the chlorine in some similar fashion, forming an ion of chlorine. It will be noticed that the E fills the place usually occupied by a bond, thus: Na–Cl. It happens providentially that the bond and the negative sign are practically the same; Na–Cl may be supposed to ionise thus: Na(–Cl), the negative charge or electron remaining with the chlorine.

Let us next consider a fundamental question, which, however, I do not remember to have seen raised. In ordinary parlance, hydrogen and chlorine are termed monads, and may be represented as each possessing a bond of affinity, thus, H–, Cl–. Now, when they unite, are there two bonds or one? Should we write H–Cl with one bond, or H– –Cl with two? Considering a bond as an electron, the symbol Cl– is wrong for an atom of chlorine; it has, strictly speaking, no bond, that is, no electron, but merely possesses the power of receiving one from the hydrogen. But we know from chemical considerations, as well as from arguments derived from the ratio of the specific heats at constant volume and at constant pressure of monatomic and of diatomic gases, that the hydrogen molecule has the formula H_2, and the chlorine molecule, Cl_2. How can we explain this? Is the formula of hydrogen H–H or H– –H? And is that of chlorine ClCl?

These gases conduct electricity at low pressures, and are therefore ionised. It appears probable that in this state the electric condition of the ions must be different. Several suppositions are conceivable. First, the ions may be H and EHE; second, they may be E and HEH; third, they may be E_2 and H_2. From Wilson's experiments on the separation of the ions in an electric field, and on the slower rate of motion of the positive ions, the second and third of these views are the more probable, and chemical considerations would lead, I think, to the choice of the second. When urged electrically, the electrons can penetrate thin metallic plates, as Lenard as shown. But it is a matter on which we may agree to reserve judgment.
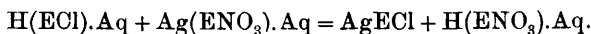
Let us next consider the chlorine molecule. Here we have, apparently, two atoms in juxtaposition, no electron being associated with them. It must, however, be remembered that in the oxygenated compounds of chlorine, that element is a polyad, a triad in KO–Cl=O, a tetrad in O=Cl=O, a pentad in KO–Cl(=O)$_2$, and a heptad in KO–Cl(=O)$_3$. It has therefore a reserve of electrons, and when it combines with itself, forming Cl_2, we have the choice between ClECl, ClE_3Cl, ClE_5Cl, and ClE_7Cl. Were we to write out in full all the electrons, we should have the cumbrous formulæ $E_6ClECLE_7$, $E_4ClE_3ClE_7$, $E_2ClE_5E_7$, and ClE_7ClE_7, or we might draw the mediate electrons partly from
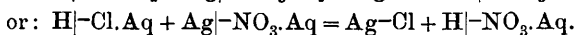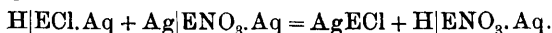
both atoms of chlorine. I am far from suggesting the use of such
formulæ; it is evident that in our ordinary structural or constitutional
formulæ we ignore the " latent " electrons, and make use only of those
which are of service for the moment. We may write for the formula
of chlorine Cl–Cl, or Cl≡Cl, &c., but we gain nothing by indicating that
the two atoms may be trebly bound. In fact, a structural formula
shows by bonds those electrons which we deem it serviceable to
represent. It may be remembered that Frankland in his "Lecture-
notes" (Inorganic, p. 35) suggested that "latent atomicity" (or, as we
now term it, valency) could, if desired, be represented. But he

counselled to write $\overset{\text{H}}{\underset{|}{\text{H–N–H}}}$, and not $\overset{\text{H}}{\underset{\underset{\text{U}}{|}}{\text{H–N–H}}}$.

It will now be convenient to represent some typical formulæ in
terms of electrons, remembering that we are really arguing in favour
of the existence of a new element of which an atom is called an
" electron."

So long as ionisable compounds are considered, this view presents
no real difficulty. Let us examine a few reactions of the usual
"exchange" type first, leaving the question of the disposal of
electrons which are not separable by ionisation until later. As a first
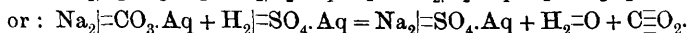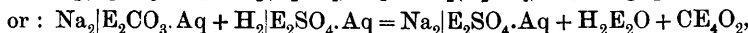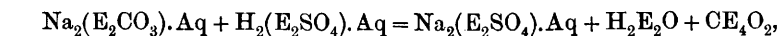example, let us take the action of hydrochloric acid on silver
nitrate:

$$H(ECl).Aq + Ag(ENO_3).Aq = AgECl + H(ENO_3).Aq.$$

We might also write:

$$H|ECl.Aq + Ag|ENO_3.Aq = AgECl + H|ENO_3.Aq.$$
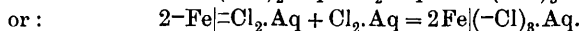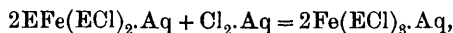$$\text{or:}\ \ H|\text{–}Cl.Aq + Ag|\text{–}NO_3.Aq = Ag\text{–}Cl + H|\text{–}NO_3.Aq.$$

Here the vertical bar denotes ionisation.

Next let us write as an equation the action of an acid on sodium
carbonate:

$$Na_2(E_2CO_3).Aq + H_2(E_2SO_4).Aq = Na_2(E_2SO_4).Aq + H_2E_2O + CE_4O_2,$$
$$\text{or:}\ \ Na_2|E_2CO_3.Aq + H_2|E_2SO_4.Aq = Na_2|E_2SO_4.Aq + H_2E_2O + CE_4O_2,$$
$$\text{or:}\ \ Na_2|{=}CO_3.Aq + H_2|{=}SO_4.Aq = Na_2|{=}SO_4.Aq + H_2{=}O + C{\equiv}O_2.$$
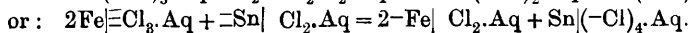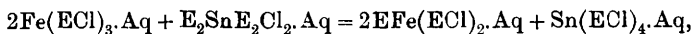
In this instance, nothing is predicated regarding the electrons in
water or in carbon dioxide, except that they serve to unite the
elements. This point will be reserved.

Take next a simple case of oxidation:

$$2EFe(ECl)_2.Aq + Cl_2.Aq = 2Fe(ECl)_3.Aq,$$
$$\text{or:}\ \ 2\text{–}Fe|{=}Cl_2.Aq + Cl_2.Aq = 2Fe|(\text{–}Cl)_3.Aq.$$

Next of reduction:

$$2Fe(ECl)_3.Aq + E_2SnE_2Cl_2.Aq = 2EFe(ECl)_2.Aq + Sn(ECl)_4.Aq,$$
$$\text{or:}\ \ 2Fe|{\equiv}Cl_3.Aq + {\equiv}Sn|\ Cl_2.Aq = 2\text{–}Fe|\ Cl_2.Aq + Sn|(\text{–}Cl)_4.Aq.$$

Such cases give little trouble. It is the formulæ of bodies which are not ionised, or only partially ionised, which require careful consideration.

It will be remembered that Professor Abegg, in a very suggestive memoir on valency (*Zeitsch. anal. Chem.*, 1904, **39**, 330), threw out the suggestion that the total valency of the elements may be taken as eight, which in each group may be taken as " normal " valencies, denoted by the + symbol, and " contra " valencies, denoted by the - symbol. The following table epitomises his suggestion:

Group I.	II.	III.	IV.	V.	VI.	VII.
1 +	2 +	3 +	4 +	- 3	- 2	- 1
7 -	6 -	5 -	4 -	+ 5	+ 6	+ 7

The normal valencies are supposed by Abegg to be " stronger " than the contravalencies.

A somewhat similar hypothesis has been advanced by Arrhenius (*Theorien der Chemie*, Leipzig, 1906) and by Spiegel (*Zeitsch. anorg. Chem.*, 1894, **5**, 29, 365). To take a specific instance: nitrogen in ammonia carries as many pairs of opposite electrical units as corresponds with its maximum capacity for saturation. Thus NH_3 has an additional negative and an additional positive charge when it forms $NH_3(-H)(+Cl)$. The existence of such " neutral " affinities, according to Spiegel, explains the greater content of energy of such bodies as ammonia than their compounds like ammonium chloride.

Let us now consider the question: in compounds containing elements or groups which do not separate as ions, and which therefore do not afford a clue, from which element does the electron come? The answer is best arrived at by considering as an instance such a compound as perchloric acid. When dissolved in water, the hydrogen of $H-OClO_3$ is left as an ion, minus an electron, $H|-OClO_3$. The four atoms of oxygen are capable of receiving electrons; but the chlorine atom, having already seven attached to it, can receive only one more, and that one only when it is ionised, as in a solution of common salt. It then possesses its full complement of eight electrons. Hence it follows that in perchloric acid, the electrons which form the bonds of union of the chlorine with the oxygen must be those previously associated with the chlorine, and not those associated with the oxygen. Expressed in the cumbrous notation in which each electron is denoted by E, we should have

$$HEO(E)_4ECl\{E_2O(E)_4\}_3.$$
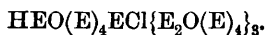
The $(E)_4$ means that the oxygen is normally associated with four electrons besides the two which it receives from the hydrogen and the chlorine; the second $(E)_4$ implies that each oxygen atom is associated with four electrons besides the two which it takes from the chlorine.

In Abegg's phraseology, oxygen possesses two normal valencies which are here latent, and four contravalencies (not six, for oxygen is never known to act as a hexad) which here become operative. If we read Abegg's nomenclature in the sense that a plus sign signifies the ability to part with one or more electrons, whilst a minus sign is the ability to receive one or more electrons, we find in his method of viewing the valency of the elements a close resemblance to the one I am putting forward. This instance will suffice as an indication of how the constitution of such molecules may be elucidated with some probability.

No theory would now be acceptable which did not attempt the explanation of two very remarkable phenomena; first, the extrusion of ionisable groups in such compounds as cobaltammine nitrites by further addition of ammonia, and second, the directive influence of the presence of certain substitutive elements or groups on the position into which further substituents enter. With this last is no doubt bound up the phenomenon of tautomerism, with its attendant absorption spectra. Time fails me to attempt more than to point out the lines of a possible explanation.

Ammonium chloride behaves like the chloride of an alkali metal, inasmuch as it yields chlorine ions when dissolved in water. We must therefore picture its partial constitutional formula as $(NH_4)|-Cl$, the electron, $-$, having become attached to the chlorine atom, converting it into an ion when dissolved in water. It is reasonable to suppose that the nitrogen atom, itself carrying five electrons, may receive three more from the three atoms of hydrogen in ammonia, thus : $H_3|\equiv N$. The total number of electrons now associated with the nitrogen atom is the maximum possible, eight. If an attempt be made to add another, as in NH_4, that proves impossible, but the nitrogen atom may part with one to the chlorine atom, already carrying seven, when it has a vacancy, as it were, which is filled by the electron from the hydrogen atom; it then becomes "saturated." A suggestion resembling this one has been made in terms of positive and negative charges by Arrhenius (*Theorien der Chemie*, p. 73).

Our task is now to consider the compounds investigated by Werner, and a specific case will prove sufficient. The nitrites of the cobalt-ammines have the peculiarity of being non-ionised, partially ionised, or completely ionised, according to the number of ammonia groups present. Thus, if the vertical bar denotes ionisation, we have :
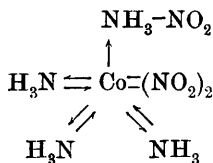
$$Co(NO_2)_3(NH_3)_3,$$
$$Co(NO_2)_2(NH_3)_4|NO_2,\ Co(NO_2)(NH_3)_5|(NO_2)_2,\ \text{and}\ Co(NH_3)_6|(NO_2)_3.$$
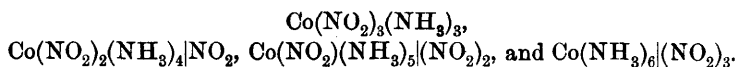
How are these compounds to be represented?

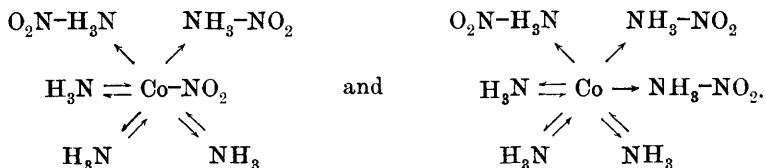Just as the nitrogen atom in NH_4Cl takes one electron from the

hydrogen of the HCl and gives one up to the chlorine, so it appears reasonable to suppose that in these cobaltammines each nitrogen atom of the three ammonia groups takes from the cobalt atom one electron, whilst it gives one at the same time. The formula of the triammino-nitrite would therefore be :

$$\begin{array}{c} NH_3 \\ \Updownarrow \\ H_3N \rightleftharpoons Co{\equiv}(NO_2)_3 \ . \\ \Updownarrow \\ NH_3 \end{array}$$
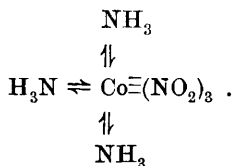
If another molecule of ammonia be added, then the cobalt atom gives to the nitrogen of the ammonia an electron, but does not receive one in return. The nitrogen atom of that ammonia group is then "overloaded," for it has received four electrons in addition to its normal five, making nine in all; now it appears that no element can be associated with more than eight in all. Hence that nitrogen atom must lose an electron. This it imparts to one of the (NO_2)-groups, which parts company with the cobalt atom, and, as a complex ammonium nitrite is now present, it is ionisable on solution in water. A glance at the proposed formula will explain the conception :

$$\begin{array}{c} NH_3{-}NO_2 \\ \uparrow \\ H_3N \rightleftharpoons Co{\equiv}(NO_2)_2 \\ \diagup\!\diagup \quad \diagdown\!\diagdown \\ H_3N \qquad NH_3 \end{array}$$

The remaining formulæ may be written similarly, thus:

$$\begin{array}{cc} O_2N{-}H_3N \quad\quad NH_3{-}NO_2 & \qquad O_2N{-}H_3N \quad\quad NH_3{-}NO_2 \\ \diagdown \quad \diagup & \qquad\qquad \diagdown \quad \diagup \\ H_3N \rightleftharpoons Co{-}NO_2 \qquad\text{and}\qquad & H_3N \rightleftharpoons Co \longrightarrow NH_3{-}NO_2. \\ \diagup\!\diagup \ \diagdown\!\diagdown & \qquad\qquad \diagup\!\diagup \ \diagdown\!\diagdown \\ H_3N \qquad NH_3 & \qquad\qquad H_3N \qquad NH_3 \end{array}$$

Why is the group $Co(NH_3)_3(NO_2)_3$ not ionisable? Let us first inquire : why is cobalt nitrate ionisable? (Cobalt nitrite is unknown.) Because the cobalt atom gives up an electron to each of the three NO_3-groups, remaining itself as an ion. That is, the metal cobalt has three electrons associated with it ; what we call "metallic cobalt" is a "tri-electride" of cobalt. As "cobaltion," it has parted with its three electrons. But, in the last of the three compounds above, the cobalt has not got three electrons at disposal, it has already parted with them to the NH_3NO_2-groups. And we are led to conclude that in the non-ionisable compound the cobalt does not, as in its ordinary

salts, part with three electrons, but that it receives them from the nitro-groups.

This last statement opens the difficult question why the presence of some one substituting element or group in a compound influences the position into which another substituting element or group shall enter. I can only suggest a possible answer in general terms.   Non-metals are bodies which have a strong affinity for electrons ; metals, bodies with but slight affinity.   It is for this reason that " metallic conductors " fulfil their function, whilst non-metals are non-conductors.   In a metallic wire, displacement easily occurs ; whether conduction in a metal consists wholly in displacement or in flow, I do not know. Probably both methods of transit are operative.   Now elements or groups already occupying a position in a compound vary in their affinity for electrons ; some approximate to metals in their feeble affinity, others rather resemble non-metals.   If they have a great affinity, it is likely that they will exert an attractive influence on substituents which are easily disposed to part with electrons, and vice versâ.   I imagine that the phenomenon of " predisposing affinity " is to be explained in some such way.

Lastly, the phenomenon of tautomerism may be conceived as the shifting of an electron, and its accompanying absorption of light of certain parts of the spectrum as due to electronic oscillation.   But it would prolong this address too far were I to enter into such speculations in detail.

I hope that I shall not be accused of presumption if I venture to draw a parallel between the past and the present.   Until nearly the end of the eighteenth century, the phlogistic theory held its sway ; what Lavoisier postulated as oxidation, was regarded as loss of phlogiston.   I will ask you to suppose that certain persons, loth to abandon the theory of phlogiston, took a middle course, and held combustion to consist not only in the loss of phlogiston, but also in combination with oxygen.   Their imaginary case, I venture to think, affords a parallel to the views of those who uphold the dual nature of electricity.   Just as a combustible body may be supposed never to unite with oxygen without at the same time losing phlogiston, so, according to current language, a body never gains positive electricity without at the same time losing negative electricity.   So long as electricity was supposed to be a state of matter, that view was plausible ; now, however, that the substantiality of the electron has been demonstrated in so far as it exhibits inertia and possesses mass, it is surely time to reconsider our position, and, whatever the fate of the hypothesis which I have made the subject of this address, I cherish the hope that it may direct attention to a possible method of " explaining " phenomena.

As regards our Society, it still continues its era of prosperity. Our numbers increase, and our work increases. We welcome the advent of new contributors to our Transactions, and we deplore the loss of some old friends. Many, however, still remain among us, and I wish particularly to congratulate Sir William Crookes on his having attained his fiftieth year of membership, retaining the full vigour of youth. May he be long spared to enrich Science by his admirable researches !