UNIVERSITY EXTENSION LECTURES

I

THE ELECTRICAL VIEW OF MATTER

According to Dalton's atomic theory, put forward in 1803, any particular chemical element, for example, iron, is composed of minute particles or atoms, all exactly equal in weight and all other properties. The atoms of different elements have different weights and the relative atomic weights, which play so important a part in chemistry, express the weights of the different atoms on a scale such that the atomic weight of oxygen is 16 and that of hydrogen slightly more than unity. About 90 different elements are known, and it is remarkable that many of them have atomic weights which are very nearly whole numbers, for example carbon 12.00, nitrogen 14.01, sodium 23.00, sulphur 32.06. There are however several elements the atomic weights of which are not whole numbers, such as chlorine 35.46, magnesium 24.32, and hydrogen 1.008.

The fact that many atomic weights are whole numbers naturally suggests that the atoms may be built up out of smaller bodies of atomic weight unity. This idea was suggested by Prout in 1813 but was given up when it was definitely established that some elements have atomic weights which are not exactly integers.

The chemical operations by which atomic weights are determined always involve enormous numbers of atoms, so that what is really found is the average atomic weight for an immense number of atoms; and the assumption that all the atoms of any one element are exactly equal is not really tested by chemical experiments. Sir William Crookes, in 1886, suggested that all the atoms of an element may not be exactly equal and that atomic weights may be merely averages, but these views were not taken very seriously at that time. Recent researches have shown that Prout's hypothesis of 1813 and this suggestion of Crookes are both correct.

Up to about thirty or forty years ago atoms were usually thought of as hard indivisible particles, exciting a field of force in the space around them. We now know that all matter contains electrons which are minute particles of negative electricity all exactly equal. These electrons are emitted by hot bodies and their properties have been carefully studied by Sir J. J. Thomson and many other physicists. They have been shown to be all equal by precise experiments and the weight of one electron is only about one two thousandth of that of one hydrogen atom. Since all kinds of matter contain these electrons it is natural to enquire how many of them go with each atom. We might expect some atoms to have one electron, some two, some three and so on, and we might expect the number per atom to increase with the atomic weight. As a matter of fact, an examination of all the known chemical elements has verified both of these expectations concerning the variation in the number of electrons per atom as we pass from element to element. It is found that hydrogen atoms each contain one electron, helium atoms two, lithium atoms three and so on up to uranium atoms which each contain 92 electrons. If we make a list of the elements in the order of their atomic weights then each element in the list has one more electron per atom than the element preceding it. Thus the first eleven elements in such a list are:

Element	*Atomic Weight*	*Electrons per atom*
Hydrogen	1.008	1
Helium	4	2
Lithium	6.94	3
Beryllium	9.1	4
Boron	10.9	5
Carbon	12.00	6
Nitrogen	14.008	7
Oxygen	16	8
Fluorine	19.00	9
Neon	20.20	10
Sodium	23.00	11

Electrically neutral atoms must contain as much positive electricity as negative, so that, for example, a neutral carbon atom containing six electrons must also contain as much positive electricity as there is negative in six electrons. It has been shown by Sir Ernest Rutherford, the successor of Sir J. J. Thomson in the chair of experimental physics at Cambridge University, that the positive electricity in atoms is in the form of an extremely minute particle or nucleus which has nearly all the weight of the atom. The electrons are believed to move in orbits round this positive nucleus in much the same way that the planets move round the sun. Thus an atom is now thought of as like a minute solar system. The positive nucleus attracts the electrons, but the electrons repel each other; whereas in the solar system the sun and planets all attract each other. The chemical properties of the elements are believed to depend on the number of electrons per atom and especially on the stability of the arrangement of the electrons. Thus an atom which easily loses an electron, so acquiring a positive charge, is an electropositive atom; while an atom which easily takes on an additional electron is an electronegative atom. An atom which easily loses an electron readily combines with an atom which easily gains an electron, and in the compound of the two atoms one has lost and the other gained an electron. The two atoms are then held together by the attraction between the positive charge on one and the negative charge on the other.

The gases helium, neon, argon, krypton and xenon discovered by Rayleigh and Ramsay are remarkable in that they have no chemical properties. They form no compounds with other elements. The atoms of these gases do not easily lose or gain electrons. The electrons in them form very stable systems. Helium has 2 electrons per atom, neon 10, argon 18, krypton 36 and xenon 54. Thus it appears that these numbers of electrons form stable systems in an atom. An atom with one electron less than one of these stable systems, for example, a chlorine atom which has 17 electrons, one less than argon, readily takes on one extra electron, so forming a stable system of 18, like argon but with a negative charge. In the same way an atom with one more electron than one of the inactive gases, for example, a potassium atom which has 19 electrons, readily loses an electron forming a stable system like argon but with a positive charge. Thus, potassium is an electropositive element, and chlorine an electronegative element; and they readily combine into a stable compound, potassium chloride, in which there are 36 electrons per molecule, 18 in the potassium atom and 18 in the chlorine atom.

Atoms with two electrons less than one of the inactive gases readily gain two extra electrons, and atoms with two more readily lose two. Thus, calcium which has 20 electrons, and sulphur, which has 16, readily combine, forming a molecule with 36 electrons, 18 in the calcium atom and 18 in the sulphur atom.

In this way, originally due to Sir J. J. Thomson, many of the chemical properties of the elements have been explained. The chemical properties of an atom depend on the number of electrons it contains in its electrically neutral state when the negative charge on its electrons is equal to the positive charge on its nucleus. The atomic weight of the atom is determined by the weight of its nucleus.

The weight of the nucleus, that is, the atomic weight, does not on this view determine the chemical properties. It is the charge of positive electricity on the nucleus which is important, because this determines the number of electrons in the neutral atom.

A given quantity of a chemical element consists of a large number of atoms all having the same chemical properties, and, therefore, all having the same nuclear charges and the same number of electrons when in the neutral state. It has usually been assumed that all the atoms of a chemical element have equal weights, but we see now that this may not be true, because the chemical properties do not depend on the weight, so that a mixture of atoms of different weights would behave as an element if all the atoms had equal nuclear charges.

The fact that many atomic weights are very nearly whole numbers suggests that the nuclei of these atoms may be built up out of units of atomic weight one, presumably hydrogen atoms. We should expect all atoms to be similarly built up, but some atomic weights are not whole numbers, for example, chlorine 35.45. All the atoms of chlorine have the same chemical properties, but not necessarily equal weights. The atomic weight 35.45 may, therefore, be an average weight of atoms all of which have atomic weights exactly whole numbers. Thus, a mixture of atoms with weights 35 and 36 could have an average weight 35.45. Recent researches by Sir J. J. Thomson and F. W. Aston have shown clearly that this is the true explanation of fractional atomic weights. Chlorine is found to be a mixture of atoms of weights 35, 37 and 39; neon, a mixture of 20 and 22; magnesium, 24, 25 and 26, and so on.

The atomic weight of hydrogen, however, is 1.008, so that when, say, 16 hydrogen nuclei are combined to form an oxygen nucleus we should expect its weight to be 16.128 whereas the atomic weight of oxygen is 16 exactly. It appears that when hydrogen nuclei combine, forming heavier nuclei, there is a loss of weight of 0.008 for each hydrogen nucleus. This is believed to be the weight of the energy which is lost during the combination. One gram of hydrogen according to this must give out an enormous amount of energy on combination into heavier elements. The amount is calculated to be more than 20,000 horse power for one hour.

Thus, if ever it becomes possible to bring about the combination of hydrogen atoms into heavier elements, an inexhaustible supply of energy will be made available. The danger is that such a process once started might proceed with explosive violence and involve all the hydrogen on the earth. If this should happen, the heat involved would be sufficient to volatilize the whole earth and convert it into a new star.

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