covered during the last sixty years are merely details included in the general system developed between 1860 and 1870 by de Chancourtois, Newlands, Mendeléeff, and Mayer. The periodic relationship between the abundance of the elements (or their evolution) and the atomic numbers, as presented in this paper, is entirely independent of the other system.

14. Since the theory here presented establishes to some extent a "normal" average composition for material it should have an important bearing on the history of the differentiative processes which have taken place on the earth. Its applications to geology will be considered in a later paper.

CHICAGO, ILL.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF ILLINOIS.]

A KINETIC HYPOTHESIS TO EXPLAIN THE FUNCTION OF ELECTRONS IN THE CHEMICAL COMBINATION OF ATOMS.[1]

BY WILLIAM A. NOYES.

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Beginning with Davy[2] and Berzelius, during the first part of the nineteenth century chemists generally accepted the theory that chemical combination is due to electrical forces but when Dumas discovered the chloroacetic acids in which chlorine atoms, supposedly negative, replace positive hydrogen atoms it was believed that the theory had been shown to be false and it was practically abandoned. Following this, for fifty years or more, a theory of valence which took no account of electrical forces was developed and while occasional reference was made to positive and negative atoms and groups, no definite meaning in an electrical sense was attached to these expressions. Helmholtz in his Faraday lecture in 1881[3] drew the attention of chemists once more to the very close connection between chemical forces and electrical phenomena and spoke for the first time of "atoms of electricity." He also pointed out that the "sulfur of sulfuric acid must be charged with positive equivalents of electricity." In 1887, Arrhenius proposed his theory of electrolytic dissociation and with the help of Ostwald and van't Hoff the belief in a separation of molecules into electrically charged parts in solutions was rapidly accepted. J. J. Thompson[4] gave precision to the atomic character of electricity in 1897 when he demonstrated the material character of cathode rays and the very minute mass of the corpuscles carrying negative charges. Van't Hoff[5] seems to have suggested for the first time that electrically charged atoms may play a part in reactions not usually considered as

[1] Presented before a meeting of the National Academy of Sciences in Washington, April 16, 1917.

[2] *Phil. Trans.*, **1807**, 1.

[3] *J. Chem. Soc.*, **24**, 291 (1881).

[4] *Phil. Mag.*, **44**, 296 (1897).

[5] *Z. physik. Chem.*, 16, 411 (1895).

ionic. The same idea was proposed by the author[1] and by Stieglitz,[2] a little later. J. J. Thompson[3] seems to have been the first to suggest that two atoms may be held together by the electrical forces resulting from the transfer of an electron from one to the other. He assumed a shell of electrically positive matter within which there was a static arrangement of electrons. Abegg[4] in an entirely independent paper published the same year, discussed the relation between electrons and ionization and the connection with older theories of Helmholtz and others. He also raises, I think for the first time, the question of polar and non-polar valences but seems to have decided that the former are more probable.[5] Rutherford[6] has advanced strong reasons for considering that atoms contain a positive nucleus, around which electrons are rotating and this hypothesis has been further developed by Bohr,[7] Nicholson,[8] Moseley[9] and others.

Physicists in general have directed their attention to rotating or rapidly moving electrons and to the relation between these and spectral lines, the disintegration of atoms and other phenomena involving individual atoms. Chemists, on the other hand, following the suggestion of J. J. Thompson have considered chiefly the role which the valence electrons probably play in the combination of atoms. Sir William Ramsay[10] in his address on "The Electron as an Element," considered that the electron takes a position between the two atoms which are held in combination. In a very recent paper, probably the last which he wrote,[11] he elaborates this thought further and describes models to illustrate the magnetic attractions which would result from electrons rotating in contiguous parts of two molecules. The magneton theory of the structure of the atom has also been developed elaborately by Parson.[12] It cannot account for ionization, where, if we accept the electron theory at all, electrons must be transferred completely from the positive atom or group to the negative.

[1] THIS JOURNAL, **23**, 463 (1901).

[2] *Ibid.*, **23** 797 (1901).

[3] *Phil. Mag.*, **7**, 237 (1904).

[4] *Z. anorg. Chem.*, **39**, 330 (1904).

[5] *Loc. cit.*, p. 347.

[6] *Phil. Mag.*, **21**, 669 (1911).

[7] *Phil. Mag.*, **26**, 1, 476, 857 (1913). On p. 862 Bohr discusses the hypothesis that atoms may be held in combination by electrons rotating about the line joining the positive nuclei of two atoms. This is similar to Ramsay's view, mentioned below.

[8] *Ibid.*, **27**, 54 (1914).

[9] *Ibid.*, **26**, 1024 (1913).

[10] *J. Chem. Soc.*, **93**, 774 (1908).

[11] *Proc. Roy. Soc.*, (*A*) **92**, 451 (1916).

[12] "A Magneton Theory of the Structure of the Atom," Smithsonian Miscellaneous Collections, **65**, No. 11 (1915).

Falk and Nelson,[1] Fry,[2] L. W. Jones,[3] Stieglitz,[4] Bray and Branch,[5] G. N. Lewis,[6] and others have discussed the phenomena connected with the transfer of valence electrons from one atom to another but, with the exception of the magneton theories referred to above, no one, so far as I can discover, has suggested a possible connection between the motion of the valence electrons and chemical combination between atoms.

In the hypothesis here proposed the following assumptions, now more or less current among physicists and chemists, are made:

1. The atoms are of a complex structure made up of positive nuclei and electrons, of which the latter, at least, are in very rapid motion. If we assume that the electrons are 1/1800 the mass of hydrogen atoms and that they obey the same laws of motion as other atoms, their average velocity would be about 60 times the velocity of molecules of hydrogen (H_2). I will not attempt to discuss here the question whether the law of equipartition of energy actually holds for electrons.

2. That the electrons are of two kinds in their relation to the structure of the atom. Some of them are so involved in their orbits or motions among the positive nuclei that they can never escape from the atom. Others, called valence electrons, may be transferred to other atoms.

Let us suppose that two atoms, which have an affinity for each other are brought close together. A valence electron which is rotating around a positive nucleus in the first atom may find a positive nucleus in the second atom sufficiently close so that it will include the latter in its orbit and it may then continue to describe an orbit about the positive nuclei of the two atoms. During that portion of the orbit within the second atom that atom would become, on the whole, negative while the first atom would be positive. During the other part of the orbit each atom would be electrically neutral, and the atoms might fall apart. When we remember, however, the tremendous velocity of the electrons and the relatively sluggish motions of the atoms it seems evident that the motion of an electron in such an orbit might hold two atoms together. In ionization the electron would, of course, revolve about the nucleus of the negative atom leaving the other atom positive. It seems impossible to explain ionization otherwise than on the supposition of the complete transfer of the electron. This complete transfer in ionization is one of the strongest arguments against the magneton theory as the only explanation of chemical combination.

An interesting feature of the hypothesis proposed is that it may be

[1] *School of Mines Quarterly*, **30**, 179 (1909); THIS JOURNAL, **32**, 1637 (1910).

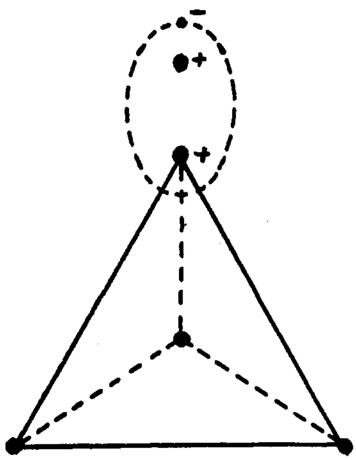
[2] THIS JOURNAL, **34**, 664 (1912); *Z. physik. Chem.*, **76**, 385, 398, 591 (1911).

[3] THIS JOURNAL, **36**, 1268 (1914).

[4] *Ibid.*, **36**, 272 (1914); **38**, 2046 (1916).

[5] *Ibid.*, **35**, 1440 (1913).

[6] *Ibid.*, **35**, 1448 (1914).



used to account for that localization of the affinities in particular parts of atoms which is indicated by many of the properties of organic compounds. Thus if we suppose that there are four (or eight) positive nuclei in a carbon atom, around which valence electrons may rotate, an atom of hydrogen may be held to the neighborhood of one of these nuclei as indicated in the figure.

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URBANA, ILL.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF CALIFORNIA.]

THE ELECTRICAL CONDUCTIVITIES OF DILUTE SODIUM, POTASSIUM AND LITHIUM AMALGAMS.

BY THOMAS B. HINE.

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According to the current electron theory of metallic conduction as developed by Riecke, Drude, J. J. Thomson, Lorentz and others, the atoms of the metal are dissociated into positive ions and free electrons. These particles are supposed to be in disordered thermal motion. When an electromotive force is applied, a velocity of drift is superimposed upon the thermal motion and it is this drift of electrons that constitutes the electric current. The positively charged ions are in general assumed not to move, or at most to carry a negligible fraction of the current. In terms of this theory, therefore, the resistance of a metal depends upon the concentration and mobility of the free electrons. The changes in resistance of a metal under different conditions are variously ascribed by different investigators to one or the other of these factors, since the conductivity is the product of the two. A more precise conception of what is meant by a free electron seems desirable, and it may be that a closer examination will show that degree of ionization and mobility are two aspects of the same physical process. Before any definite mechanistic concept of the electric conduction can be obtained it will be necessary to study the phenomena in the simpler cases more thoroughly. With this idea in view the present investigation was undertaken. In a liquid conductor such as mercury and the dilute amalgams there are none of the crystalline forces