the readings of the bridge ammeter give the strength of the alternating current added to the direct heating current of one valve, and such calibration is valid for all frequencies.

It is made to give full scale deflections for A.C. currents of 5, 10, 20 or 30 milliamperes. Dr. Barlow has also made a useful arrangement of two electrode valves for measuring very small condenser capacities.

A thermionic wattmeter has also been devised by Dr. E. Mallett, in which two thermionic valves and a differential galvanometer are employed. But instruments of this type in which two valves of quite identical characteristics and a differential galvanometer are requisite are not very likely to come into any general use for commercial purposes.

The application shows, however, the extensive possibilities of the thermionic valve as an instrument for scientific research outside of and beyond its technical applications and general employment as an amplifier of voltage.

THE ELECTRONIC THEORIES OF LEWIS AND KOSSEL[1]

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IN March and April of 1916 Kossel in Germany and Lewis in America proposed, quite independently, theories of the function of electrons in chemical combination, which have many ideas in common. Beginners in science and some older persons fail to understand the very complex nature of such theories at the outset and that as the years pass the theory is amplified and changed, slowly approaching, as we believe, the fundamental realities in the material universe. They always remain an imperfect expression for these realities, but those who have watched their development—how the changes are the result of the work of literally hundreds of different persons and how the important ideas of which the theories are made up are constantly checked by experiments of the most varied sorts find it difficult to believe that there is not a rather close correspondence between the ideas of the theory and actual facts.

The two theories had a common background, furnished, at basis, by the idea of Dufay, now two centuries old, that there are two kinds of electricity each having an attraction for its opposite and a repulsion for its own kind. The discovery of the electron, the atom of negative electricity, may be said to have begun with Faraday's experiments on the relation between electricity and chemical atoms a century ago, Helmholtz's interpretation of Faraday's experiments fifty years ago, Crookes's discovery of cathode rays in the late seventies and the determination of the mass of the electron by J. J. Thomson and by Kaufmann in 1897. Fourteen years later, Rutherford, by shooting positive alpha particles through a thin film of gold and noting their deflection, demonstrated that the positive portion of an atom is very small in comparison with the size of the atom. This, together with the known mass of the electron, one eighteen-hundredth of the mass of a hydrogen atom, showed that both the positive charge of an atom and nearly the whole of its mass are concentrated in the small nucleus at its center. Soon after, Moseley based the atomic numbers of the elements on the x-ray spectra from two electrons located close to the nucleus of each atom. The rotation of these electrons about the nucleus is more rapid as the electrons are drawn closer in when the positive charge is increased by one unit in passing from one atom to the next in the periodic system.

These ideas, which I have sketched very briefly and incompletely, gave the background on which Bohr and others based the theory of the structure of atoms as consisting of a central nucleus surrounded by successive groups of 2, 8, 18 and 32 electrons, but always with 8 electrons in the outer shell of a noble gas. These historical facts help us to understand how two men, 7,000 miles apart, should have proposed, independently, theories which have so many items in common.

The theories were proposed in 1916, during the great war, and soon after, Lewis and Kossel were on opposite sides in the world conflict. We may be sure that their theories will soon be fused together into a consistent, generally accepted whole. May we not take this as an omen that Hitler and Eden, who were in trenches just across the battle line, may help to piece the fragments together and build that permanent world peace which we so earnestly desire.

So far as I am aware, the first attempt to connect electrons with chemical phenomena was made by Lewis in March, 1902, when he was teaching elementary chemistry and drew in his notebook the crude figures which developed into his "cubical" atom. He considered the theory too speculative and waited fourteen years before he published it. J. J. Thomson, in 1904, proposed the hypothesis that an atom consists of a

[1] Presented before the Division of Physical Chemistry of the American Chemical Society, April 26, 1935. A comprehensive historical sketch of electronic theories will appear in *Chemical Reviews* for August.

uniform sphere of positive electrification within which electrons move about. He worked it out with elaborate mathematical detail. This will always remain a good illustration of the futility of mathematics when it is based on a false hypothesis. He contributed, however, the very important idea that atoms may be held together by static attraction due to the transfer of an electron from one atom to another. This is still a part of every electronic theory.

Abegg, in 1904, proposed a more qualitative theory in connection with his ideas of "principal" and "contra" valences. Abegg's ideas influenced both Kossel and Lewis.

The most important common idea contributed by both Lewis and Kossel was that every atom has a strong tendency to assume the stable form of a noble gas near it in the periodic system, by the gain or loss of one or more electrons. This led Kossel to a formula for the perchlorate ion in which the chlorine atom had assumed the structure of neon by the loss of seven electrons, and each oxygen atom had also assumed the structure of neon by the gain of two electrons.

While Lewis assumed that atomic ions may be formed in the same manner that was assumed by Kossel he added the thought that the noble gas structure may be formed in compounds by sharing pairs of electrons which belong in common to the atoms held together. Later, Langmuir used the term "covalence" to designate the pair of electrons. According to Lewis, the chlorine of the perchlorate ion has the structure of argon and has four covalences, while each oxygen atom has the structure of neon and has one covalence. Lewis called the portion of the atom within the group of valence electrons the "kernel." The kernel of chlorine has a positive charge of seven units and that of oxygen a positive charge of six units.

The electrons of a covalence are not equally shared by the two atoms, when these are different, but Lewis did not point out clearly that, so far as atoms at a distance are concerned, a covalence balances one positive unit charge in each atom. From this point of view, four of the seven positive charges of the chlorine kernel are balanced by the covalences and three are balanced by the negative electrons associated with the oxygen atoms. Since each oxygen atom with a single covalence has a residual negative charge of one unit the four oxygen atoms give a negative charge of one unit to the perchlorate ion. Reasoning of this sort enables us to select atoms in compounds, which have a residual positive or negative charge when we know their electronic structure. Kossel's theory does not have this advantage.

In 1901 Stieglitz, on the basis of the work of Jakowkin, recognized that the reaction between chlorine and water is ionic in character and assumed that the chlorine molecule separates into positive and negative ions. This is easily explained by assuming that when the atoms of a chlorine molecule separate the covalence electrons remain with one of the atoms. This prepares us to understand that two atoms held by a covalence may separate in three ways: (1) The electrons may go with the first atom, making that negative; (2) they may go with the second atom, leaving the first atom positive; (3) one electron may go with each, which will then be neutral.

Some interpretations of the wave quantum mechanics have replaced Lewis's cubical atoms by the tetrahedral arrangement which had been accepted by organic chemists sixty years ago on the basis of the work of Pasteur, Le Bel and van't Hoff. This has also given a picture of the relation of covalence electrons to the atoms held together which recalls the inclusive orbits suggested in a crude way by the author in 1917 and in a much better form by Campbell, Sidgwick and Knorr in 1923.

The facts that the carbon atoms of a doubled covalence are closer together than those of a single union and that the double bond increases the molecular volume of the compound indicate that the four electrons spread out on the two sides because of the tendency toward a tetrahedral structure. This recalls the old explanation for the cis-trans structure, and Baeyer's treatment of the double union as the limiting case for rings.

It will be seen from the above that Lewis's theory furnishes a simple explanation for many facts which are not so easily reconciled with the theory of Kossel.

OBITUARY

LUCIAN W. CHANEY

LUCIAN W. CHANEY was graduated at Carleton College in the class of 1878. He continued his studies for three years and then joined the faculty of his alma mater in 1882. In the following year he was made professor of biology and geology.

These were years of beginnings for Carleton, and the department to which Professor Chaney was appointed needed to be created by him. He was one of a group of Carleton's earliest faculty members who are known as the "Old Guard," who laid the foundation for high scholarship and character in the young college.