Even in the present year a further significant advance in this direction has been made. For it appears, from the latest results of Sir Ernest Rutherford on the passage of α-particles through nitrogen, as though the nuclei of an exceedingly minute proportion of the nitrogen atoms struck by the α-particle were shattered by the collision. If this is so, artificial transmutation on an infinitesimal scale has already been accomplished, though, it is true, only by the aid of a previous natural transmutation, still impossible artificially to imitate.

IONISATION OF GASES.

By Prof. J. S. Townsend, F.R.S.

DURING the last fifty years many physicists have been occupied in studying problems connected with electric currents in gases. The earlier work was principally confined to experimental investigations of the general outlines of the phenomena which occur in discharges obtained with high potentials. The large number of complicated and surprising properties of gases which were thus discovered naturally attracted much attention, and it is very interesting to read the accounts of the first experiments of the discharges in air and through vacuum tubes which were written before any special investigations of the theory of the conductivity were undertaken.

It would clearly have been extremely difficult to obtain from these experiments any general theory of electricity to explain what was taking place, as such a large number of different phenomena seemed to occur simultaneously. From the first, some physicists maintained that the currents through gases were carried by means of ions, as in liquids, although there were peculiar differences between the two cases, and it was not evident why under a given force a gas might act either as an insulator or as a conductor.

The greatest success in advancing the theory of electricity was obtained from careful studies of the discharges at very low pressures. In this direction some remarkable experiments on the cathode rays were made by Hittorf in 1869. He found that the rays travelled in straight lines from the cathode; when they fell on glass they caused the surface to fluoresce, and an obstacle in the path of the rays cast a shadow on the glass. He also found that the rays were deflected by a magnet into circles, or more generally into spirals, which were described in the direction which would be taken by negatively charged particles moving from the cathode. Notwithstanding these results, and further experiments made by Crookes, the projected particle theory of the rays was not at first universally accepted, and some physicists maintained that the rays were an undulatory motion of the ether. This question was decided by Perrin in 1895. He showed by direct experiment that the rays carried a negative charge, but thus far the origin of the rays, their velocity, and the mass and charge of each particle were unknown.

The question of the ratio of the charge to the mass was studied by Schuster in 1890, and he concluded that in gases it was of the same order as in liquids, but for negative ions it was larger than for positive. This was the first indication of the characteristic difference between positive and negative ions in gases.

A direct method of finding the ratio of the charge e to the mass m of the cathode particles, and the velocity of the particles, was devised by Wiechert, and in 1897 he described the experiments which showed that in some cases the velocity of the rays was about one-tenth of the velocity of light, and that the ratio e/m for the cathode rays was between 4000 and 2000 times as great as the corresponding quantity for a hydrogen atom. Thus, assuming the charges to be the same in the two cases, the experiments showed that the mass of a cathode particle is very small compared with the mass of an atom of hydrogen. This small cathode particle has been called the electron. Further experiments show that currents of negative electricity obtained from metal surfaces by other methods also consist of streams of electrons. Thus Sir J. J. Thomson investigated the charged particles set free from hot wires or from a metallic surface by the action of ultraviolet light, and found that in both cases the ratio e/m was the same as for cathode rays. The values of e/m afterwards found by various methods show that the ratio of the mass of the electron to the mass of an atom of hydrogen is 1 : 1830. This value of e/m is constant provided the velocity is small compared with the velocity of light, but with velocities of this order the effective mass of the electron increases, and Kaufmann found that the value of e/m diminishes in accordance with Lorentz's theory as the velocity approaches the velocity of light.

During the earlier part of this period some investigations were made of the currents that can be obtained with forces smaller than those required to produce discharges. The positive and negative ions produced in air at atmospheric pressure at the surface of incandescent metals, the conductivity of flames, and the charges obtained in newly prepared gases, or by bubbling air through water, were examined. In these cases the mass associated with the ions is comparatively large, and varies rather irregularly over wide ranges, so that it was difficult to formulate precise theories from the results of the experiments. These large ions have the property of condensing water vapour, and in a moist atmosphere small drops are easily obtained which form a visible cloud. This phenomenon led to the method of estimating the charge on each particle. The number of particles in a given volume was found by dividing the weight of the cloud by the weight of each particle estimated from the rate of fall of the cloud. The charge on each particle was then obtained by dividing the total charge by this number. Various corrections and improvements were later introduced by Millikan, and the charge on an ion in a gas has been found to be $4{\cdot}7 \times 10^{-10}$ electrostatic unit.

The remarkable discoveries made by Röntgen and Becquerel, which have led to so many advances in the knowledge of molecular physics, were of invaluable assistance in providing means of studying the properties of ions in gases. It was found that X-rays and the rays from radioactive substances made gases conduct, and it was possible to obtain ionisation at a uniform rate in gases under various conditions, with the advantage that the mass associated with the ions was not liable to irregular change.

Special experiments were devised to determine the rate of recombination of positive and negative ions, the velocity of the ions under electric forces and their rate of diffusion; and various properties of ions in gases were discovered.

The experiments on diffusion, for instance, led to a method of finding the number of molecules per cubic centimetre of a gas and of comparing the charges on ions in liquids and in gases. If N be the number of molecules per cubic centimetre of a gas at atmospheric pressure and 15° C., and e the charge on an ion in a gas, a direct determination of the product $N \times e$ is given by observing the lateral diffusion of a narrow stream of ions. The value of $N \times e$ thus found is $1{\cdot}23 \times 10^{10}$, and as the charge e was also found by other experiments, the value of N is seen to be $2{\cdot}6 \times 10^{19}$.

If E be the charge on a hydrogen ion in a liquid, the total charge $2N \times E$ carried by all the atoms in a cubic centimetre of the gas is equal to the quantity of electricity required to evolve that volume. When expressed in electrostatic units, the latter quantity is $2{\cdot}46 \times 10^{10}$. Thus the two charges E and e are the same.

Another line of investigation was undertaken in order to discover how ions are generated in large numbers, as when small changes of force convert a gas from an insulator to a conductor. It was found that when ions are generated by Röntgen rays or by ultra-violet light a maximum current composed of ions generated by the rays was obtained with small forces, but as the force increased beyond a certain point new ions are generated in the gas by the motion of those produced initially by the rays. At first the new ions are produced by the collisions of negative ions, or electrons, with molecules of the gas, and as the force increases and approaches the value required to produce a discharge, the positive ions also acquire the property of generating others by collision.

The theory of ionisation by collision was found to be in accurate agreement with the experimental determinations of the forces required to produce spark discharges, brush discharges, and the corona discharge which is accompanied by a glow over the surface of a wire or cylinder.

Thus the various properties of ions which have been discovered in the last fifty years have already explained many phenomena connected with electric currents.

SPECTROSCOPIC ASTRONOMY.

BY PROF. A. FOWLER, F.R.S.

THE science of celestial chemistry and physics was brought into existence in 1859, when Kirchhoff's famous experiment on the reversal of spectral lines furnished the key to the interpretation of the dark lines of the solar spectrum, and thence to the determination of the composition of the sun and stars. The new science developed with extraordinary rapidity, and within ten years the spectra of all the different classes of celestial bodies had been carefully observed. The gaseous nature of some of the nebulæ had been discovered by Huggins, and a spectroscopic classification of stars had been made on such sure foundations by Secchi that it still survives as one of the most convenient modes of describing the main features of stellar spectra. The memorable discovery by Lockyer and Janssen of the method of observing solar prominences without waiting for an eclipse of the sun was also made during this fruitful period, and the possible determination of the radial motions of stars by displacements of the spectral lines had been put to a practical test by Huggins. The demonstration that the immensely distant celestial bodies were composed, in part at least, of the same kinds of matter as the earth may well take rank among the greatest triumphs of science.

The half-century which has elapsed since the first issue of this journal has witnessed a progress which must far exceed the highest hopes of the earlier workers. Some of the advances have followed from the increased apertures of the telescopes which collect the light for spectroscopic examination, but many more are to be attributed to the substitution of photographic for visual methods of observation which was made practicable by the introduction of the gelatine dry plate.

Great observatories dedicated to astrophysics have been erected, notably in America, and observational methods have reached a high degree of refinement. In solar investigations, where the great intensity of the light allows of the use of instruments of high resolving power, velocities on the sun's surface can now be measured with a probable error of only a few metres per second; and even more remarkable is Hale's determina-