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 determination of the general magnetic field of the sun by observations of Zeeman effects involving displacements usually amounting to less than one-thousandth of an Ångström unit. Stellar spectroscopes have been improved by the provision of temperature control and other aids to efficiency, so that radial velocities are now measurable in the case of the brighter stars to within a quarter of a kilometre per second. With the exceptional resources of the Mount Wilson observatory, stellar spectra have even been photographed on a scale comparable with that of Rowland's great map of the solar spectrum, providing data for deductions, among other things, on such a delicate matter as that of the pressure in the atmosphere of a star.

Not less important has been the development of experimental researches bearing upon the interpretation of celestial spectra. The study of enhanced lines initiated by Lockyer has been especially productive, not only in relation to stellar temperatures, but also in leading to a satisfactory explanation of most of the lines which are met with in the spectra of the hotter stars, where we might well have expected that the reproduction of the conditions would be outside the range of our laboratory resources. The application to sun-spots of Zeeman's discovery of the effect upon spectrum lines of a strong magnetic field, and Ramsay's discovery of terrestrial helium following its previous detection in the sun's chromosphere, are familiar examples of the close bonds which unite astronomy with other sciences to their mutual advantage.

The spectrum of the sun has naturally been the subject of an immense amount of detailed study, and as the work has progressed it has become less and less probable that there are any substances in the sun which do not also exist on the earth. The spectra of sun-spots and of the chromosphere have also been minutely recorded, and most of their peculiarities have been satisfactorily accounted for. The bright lines of the coronal spectrum, however, have not yet been matched in any terrestrial source, but the precise knowledge of this spectrum which has been obtained during total eclipses has stimulated theoretical investigations, and some extremely suggestive relations have been deduced by Nicholson in his calculations of the spectra of atoms of assumed simple structure. Similar considerations have also been extended to the unidentified lines which occur in nebulæ.

As regards the stars, many of them have been photographed in great detail for minute analysis, and a multitude more for purposes of classification. Secchi's classification, at first merely empirical, soon came to be regarded as indicating the actual sequence of forms assumed by a star in the process of cooling, and the same idea is embodied in the Harvard system of classification, which has been most widely adopted by astronomers in recent years. Lockyer, however, has based a classification on the supposition that there must be stars which are becoming hotter as well as stars which are cooling down, in accordance with the theory of condensing masses of gas or meteorites, and this view has lately been greatly strengthened by the work of H. N. Russell on the densities of stars. In either case the impressive result is that the different types of stars are not to be looked upon as arising from fundamental differences of composition, but as representing successive stages in an orderly evolutionary progression.

The spectroscopic determination of the velocities of stars in the line-of-sight, irrespective of distance, has united the old and the new astronomy in the great task of deciphering the intricacies of structure of the sidereal universe. Besides contributing the velocities and spectral classes of individual stars, the spectroscope has revealed the existence of a large number of close binary systems, and has provided the most trustworthy means of investigating the sun's motion in space, the effect of which is to be eliminated in deducing the movements of the stars themselves.

An entirely new field for the spectroscope has been opened up by the remarkable discovery by Adams of a method of estimating the absolute brightnesses, and thence the distances, of the stars by mere inspection of photographs of their spectra. This novel method is full of promise, and encourages the hope that other equally unexpected applications of the spectroscope may yet be discovered.

Lack of space forbids even the enumeration of many other remarkable achievements, but sufficient may have been said to convey some impression of the enormous extension of the scope of astronomical research which has been brought about by the introduction of the spectroscope. It cannot be doubted that the spectroscope will continue to play a leading part in the advancement of our knowledge of the universe of which we form a part.

X-RAYS IN PHYSICAL SCIENCE.

By PROF. W. H. BRAGG, F.R.S.

IT is twenty-four years since Röntgen made the famous discovery which at once excited such immense and widespread interest. Everyone felt the fascination of the photograph which actually showed the bones of a living human hand. Surgeons seized on its obvious application to their craft; students of physical science realised that a new and most powerful means of investigation had been placed in their hands. And at the present day we see that the first expectations have