

tion 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 sunspots 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 sunspots 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 nebulae.

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.

[T 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

been more than realised. We stand only at the beginning of what the Röntgen rays promise to accomplish for us.

Knowledge of the main properties of the X-rays grew rapidly under the labours of Röntgen himself and the many investigators who were attracted to the new field. Much was discovered respecting the power of penetrating various substances, the existence of different qualities, hard or penetrating, soft or less penetrating, the dependence of quality on the degree of evacuation, the construction and the applied potential of the X-ray bulb, the action on the photographic plate and on the fluorescent screen, and the power of producing ions in a gas. At the same time, the technique improved rapidly; bulbs, plates and screens, coils and interruptors were all designed afresh to meet the demands of an experiment which grew into an industry.

Notable advances were made by Barkla when he proved the existence of a polarisation which was to be expected on the hypothesis that the rays were ethereal waves or pulses, and when he showed that every element emitted its own special and characteristic X-rays under proper stimulus. The properties of characteristic radiation are most remarkable and instructive. The radiation of any element can excite the corresponding characteristic radiation in elements lighter than itself, but never in any element which is heavier. For example, "zinc rays" can excite the characteristic radiation of magnesium, potassium, or nickel, but not the characteristic radiation of bromine or silver, nor, indeed, of zinc itself. Since energy is necessarily spent in the excitation of radiations, the absorption coefficients of zinc rays by the various elements show a marked discontinuity; they increase steadily from magnesium upwards, but there is a sudden drop at zinc, the coefficient falling to about one-eighth of its previous value. After that the coefficient increases steadily with the atomic weight as before.

X-rays can excite an electron radiation in any substance on which they fall, and this effect has also been the subject of much investigation. The more penetrating the X-rays, the higher the velocity of the electron which it can cause to be emitted. This effect is carried to an extreme in the corresponding emission of very high-speed electrons under the stimulus of the γ -rays of radium, for the parallelism between all the properties of X-rays and γ -rays is an obvious indication of the similarity of their nature. There is a striking correspondence in the two processes—that of the excitation of X-rays by the moving electrons of the X-ray bulb, and that of the emission of electrons under the stimulus of X-rays. The quality of an X-ray depends on the velocity of the electron that excited it, and not at all on the number of electrons in the exciting stream; conversely, the velocity of an electron due to X-rays depends only on the quality of the rays, and not at all on their intensity. Some kind of matter is required to bring about either of the energy transformations, but the atomic weight of

it has no influence on the principle just stated. Anomalies may appear when characteristic radiations are excited, but they can be explained as apparent only.

Many other remarkable properties, which cannot be described in so brief a notice as this, were discovered in the first period of X-ray investigation. All of them were examined with the greatest interest, because it was recognised that if X- and γ -rays were essentially of the same nature as light, their study must contribute to any true theory of light radiation, and, indeed, must be necessary thereto.

A new period of investigation began when von Laue and his collaborators demonstrated in 1912 that X-rays could be diffracted by the ordered array of the atoms of a crystal. From a simple interpretation of von Laue's principle, and from the results of its application to the study of crystals of sodium and potassium chloride, W. Laurence Bragg was able to discover the actual arrangement of the atoms of those crystals and the distances separating the atom-bearing planes. It thus became possible to find the actual length of an X-ray. The older and vaguer methods of defining the quality of an X-ray were at once replaced by a method of great precision. Previous work can now be revised under infinitely better conditions, and much has already been accomplished in that direction.

Moseley, making a careful survey of the wavelengths of the radiations of all the elements available, showed that the wave-length of the characteristic radiation marched in perfectly even step with the increase of the atomic number, and, therefore, that the atomic number of an element defined it more fundamentally than its atomic weight. So all the elements were drawn together by a common tie as they had never been before; anomalies of position in the periodic table were explained, and the number and places of missing elements were made clear.

The examination of the interchange of energy between X-radiation and electron movement can now be made so effectively that it has been possible to use the experimental results for one of the best determinations of Planck's constant.

In another direction the new discoveries have opened out a wide road of advance into crystallography. In the first place, it is possible to determine the crystal lattice—that is to say, to measure the sides and angles of the rhomboid cell which contains the unit pattern of atomic assemblage and is repeated throughout the crystal without change of form or orientation. This is a comparatively easy task. It is a second and more difficult task to determine the arrangement of the atoms within the cell; it has been accomplished in a few single cases only. Lastly, the new researches will give us information concerning the position of the electrons or the diffracting centres within the atoms and about their normal movements. Something has already been done in this direction also.

Moreover, the new knowledge reacts on older information, shaping it for interpretation and making it more valuable. From a knowledge, for example, of the elastic constants of crystals, the forces between the atoms themselves may be calculated as soon as the architecture of the crystal is known. It will be possible to make use of facts concerning cleavage planes, occurrence of certain natural faces and not of others, etching figures, and the like. Light will be thrown on the meaning of valency and on all that lies at the root of chemical action. If the atomic forces can be calculated, an explanation of the form of the wave-surface of light within a crystal will be at hand.

X-rays have been applied with ever-increasing

success to medicine and surgery; their extraordinary power of revealing the interior of a body without disturbing its exterior are beginning to be recognised as a trustworthy aid to industry, as, for example, in the detection of flaws of construction otherwise invisible; and their use in observing the crystalline state is already being considered as a probable and welcome aid to metallurgical problems. But still the richest mode of their employment is by the indirect methods of pure science. Their unique properties help as nothing else can to a knowledge of the relations between radiation and matter, ether-waves and electrons, atoms and the forces that bind them together, which are among the greatest of the fundamental problems of physics.

X-RAYS IN MEDICAL SCIENCE.

BY A. C. JORDAN, M.D., M.R.C.P.

THE discovery of X-rays in 1895 was justly hailed as one of the greatest scientific marvels of any age. Medical men eagerly grasped the possibilities of these rays, which enabled them to see the internal organs of their patients actually at work, hitherto impossible even to surgeons, who in the course of their operations had the organs exposed to view, but only under conditions of anaesthesia.

The first practical uses to which X-rays were applied were: (1) In the detection and localisation of metallic foreign bodies, such as needles and bullets; (2) in the detection and localisation of metallic or other foreign bodies that had been swallowed; (3) in the diagnosis of fractures of bones: this branch of radiology has made enormous strides during the war, and has led to a vast improvement in the treatment of fractures and to the saving of countless limbs; (4) in the diagnosis of calculi in the urinary tract and elsewhere: these foreign bodies throw shadows which have to be distinguished from concretions in the bowel and calcareous deposits: many pitfalls lie in wait for the unwary observer, and the right interpretation of these shadows, even at the present time, calls for skill, patience, and discrimination; (5) in the diagnosis of diseases of the chest: the appearance of the normal movements of respiration and of the beating heart was closely observed, and as a result of these observations upon healthy subjects this branch of physiology has had, to a large extent, to be rewritten. The position of the heart and vessels in the chest—in the midst of the air-filled lungs—rendered accurate diagnosis difficult by the older methods of physical examination, but by means of X-ray examinations with the fluorescent screen the mechanism of the heart has been closely studied and its diseases accurately diagnosed.

In regard to diseases of the lungs, pneumonia, pleurisy, abscess of the lung, tumours, enlarged glands in the chest, and many other con-

ditions produce characteristic shadows on the fluorescent screen, and enable the site, nature, and extent of the disease to be determined. In pulmonary tuberculosis the aid which X-rays have brought to its early diagnosis, and in defining its extent, has proved of such value that this means of diagnosing phthisis is playing an essential part in the campaign in progress for dealing with this scourge. X-ray study has shown that the first changes which occur in the lung in this disease lie so deeply buried in the chest—under cover of a thick layer of healthy lung—that they are quite beyond the reach of the older methods of detection by percussion and auscultation. By the time the stethoscope is able to discover the signs of consumption, the disease is probably so far advanced that the prospects of a cure are remote. The diagnostic utility of X-rays has increased steadily with the continued improvement in the apparatus and the increased skill and experience of those engaged in this branch of science.

The correct estimation of fractures and other injuries to bone and joints necessitated an accurate study of the form and texture of normal bones, as well as the individual variations that occur in the conformation of bones and their joint surfaces. This knowledge led at once to a most important extension of the diagnostic powers of X-rays—the recognition of disease in bone and the differential diagnosis of many diseases of bones and joints.

So far we have considered radio-diagnosis as dependent on differences of density among the tissues. Bone, with its lime salts, is far more opaque to X-rays than muscle: consolidated lung is more opaque than healthy, air-filled lung. At first sight this precludes from the range of radio-diagnosis a very important part of the body—the hollow viscera constituting the digestive tract. Very little information is to be gained from an ordinary X-ray inspection of the stomach and bowels, but the introduction of opaque substances