Optical Experiments with Electrons.*

IT is now seven years since L. de Broglie brought forward the view of the duality between waves and particles which is now almost universally accepted under the name of wave mechanics, and represents one of the greatest advances in physics of this or any other century. The original treatment was a development of the theory of relativity, but this side of his theory can no longer be kept in its original form. It appears, in fact, that the requirements of relativity are closely connected with the magnetic properties of the electron which gave rise on the older theory to the idea of a 'spinning electron' and were not considered by de Broglie. I do not propose to deal with these, and shall give the theory in the approximate form, which is sufficient to explain the experiments I propose to describe.

The basis of the whole is a duality between waves and particles which is common both to matter and radiation. Maxwell made optics a branch of electricity; if de Broglie has not reversed the relation, he has at least shown both as different cases of a common principle, which is more like old-fashioned optics than old-fashioned electricity. The duality takes this form: any observable atomic event is representable as the arrival or departure of a particle at or from a small region of space, but the laws which govern this event involve a quantity which is best thought of as the amplitude of a wave (possibly in multidimensional space). In the case of light, this quantity is indeed the electric or magnetic vector of the Maxwell wave (it is indifferent which).

In the case of electrons, it is the more elusive ψ which obeys also an equation of the type known to mathematicians as a wave equation. In general, ψ is complex, for the equation is complex, so no direct physical meaning can be assigned to it. Its modulus $|\psi|$ is real, and de Broglie gives as his 'principle of interference' the statement that the chance of the presence of an electron at a given place and time is proportional to $|\psi|^2$. The analogous statement in optics is that the chance of a quantum of light appearing at a given place and time is proportional to the square of the amplitude of the Maxwell wave.

According to de Broglie's theory, the wave-length associated with a free electron is $\lambda = h/mv$ where h is Planck's constant and mv the momentum. He enunciates, therefore, a 'law of spectral distribution', according to which the chance of the presence of an electron with a given momentum is proportional to the square of the modulus of the Fourier component of the wave, the wave-length of which corresponds to the given momentum. In optics, the chance of the appearance of a quantum of energy W is proportional to the square of the Fourier component of the Maxwell wave of wave-length hc/W.

This simple correspondence between electron and quantum—ψ wave and Maxwell wave—in the case of the free electron, prepares us for a close experimental analogy. In fact, we can repeat many optical experiments with electrons and get strikingly similar results. The chief differences are due to the smaller wave-length, which is usually less than that of X-rays, and the much smaller penetrating power. Davisson and Germer made experiments with electrons which are analogous to the diffraction of X-rays by a single crystal, as in the Bragg method.

Other experiments have reproduced with cathode rays the diffraction of X-rays by a crystalline powder, and have verified de Broglie's law of wave-length with considerable accuracy. Some recent work with cathode rays and single crystals of copper and silver provides the electron analogy to the optical experiment in which two transmission diffraction gratings

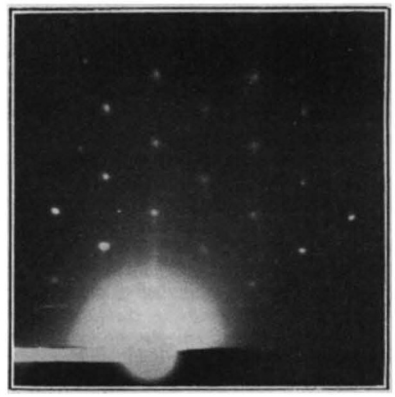

FIG. 1.—Diffraction pattern of cathode rays incident on a cube face of a single crystal of silver.

are superposed with their rulings inclined to each other (Fig. 1). The etched surface of the single crystal is apparently covered with a number of small lumps, probably the material left between etching pits. The cathode rays strike the crystal at a small glancing angle to the main surface, and pass through the lumps, being diffracted by the atoms in them. If the thickness of the lump, in the direction in which the rays traverse it, is less than a certain amount, which for the angles of diffraction and electronic wave-lengths used is of the order 10^{-6} cm., the thickness has no influence on the pattern. The diffracting system is then equivalent to an arrangement of atoms in the plane normal to the rays, and this two-dimensional array is mathematically equivalent to the crossed gratings of the optical experiment, giving rise to an array of spectra which is reciprocally connected with the atomic array producing it.

The spectra, when received on a fluorescent screen, are bright enough to be shown to a small audience.

* From a lecture delivered by Prof. G. P. Thomson, F.R.S., before the Optical Society on May 14.

Indian Fossil Plants.

IN 1928, Prof. Sahni produced the first part of an important work on Indian fossil plants. It dealt with the fossil coniferous plant remains found in the form of impressions and incrustations in rocks of the Gondwana System in India. The majority of the fossils described were of Mesozoic age, but there were also a few Palæozoic species of a doubtful nature.

In the second part of the work, which has recently been published,* Prof. Sahni extends his researches to petrified coniferous plants, providing descriptions of much that is new and interesting, as well as revising earlier work on this subject. The material with which

* Memoirs of the Geological Survey of India. *Palæontologia Indica*, New Series, vol. 11: "Revision of Indian Fossil Plants". Part 2: Coniferales (b. Petrifactions), by Dr. B. Sahni. Pp. 47-124+plates 7-15. (Calcutta: Government of India Central Publication Branch, 1931.) 7.6 rupees; 12s.

he deals has been accumulating for many years in the collections of the Geological Survey of India, and some of the specimens are preserved in the British Museum. As Prof. Sahni remarks, it is unfortunate that the localities and horizons of so many of the specimens are not known with certainty. In spite of this serious disadvantage, Prof. Sahni adds very considerably to our knowledge of the Coniferales.

Most of the petrifactions are of secondary wood and belong to either the Jurassic or Cretaceous age. They include the following form genera: *Mesembrioxylon*, *Cupressinoxylon*, and *Dadoxylon* (*Araucarioxylon*). It is curious that there is no mention of *Dadoxylon indicum* or *Dadoxylon bengalense* Holden, two palæozoic fossil woods which are certainly gymnospermous, while the latter is as likely to be coniferous, in view of its structure, as any of the Mesozoic species of *Dadoxylon* described by Prof. Sahni. These two Indian fossil woods are particularly interesting, since they resemble, in certain important characters, species described from the Karroo formation in South Africa. Prof. Sahni cites this work by Holden in part 1, but does not mention either of these two species.

A new genus of cone, *Indostrobus*, is described. It bears bract and ovuliferous scales as in the living pine, but differs in the ovuliferous scale being forked at its distal end. The seeds are placed on the ovuliferous scale at some distance from the cone axis. Prof. Sahni recognises features reminiscent of the podocarps in the structure of this cone; but at the same time is clear that it is most closely related to the Pinaceæ. He also produces clear evidence of the existence of araucarian conifers in the Jurassic of the Gondwana system. The podocarps, if one may judge not only from the various types of fruits and foliage but also from the numerous examples of secondary wood, were abundant and had a wide geographical distribution in India in the Jurassic and Cretaceous.

The contrast between the present and past distribution of conifers in India is stressed by Prof. Sahni. There is only one native conifer in peninsular India at the present day. There is no native living conifer in Ceylon. The living conifers are restricted, in greater India, to the Himalayas with their connected ranges and to Assam and Burma. In the Tertiary Period there is apparently an almost complete absence of conifers in the India floras so far investigated, and the Indian Tertiary floras would appear to have been almost exclusively angiospermous. There is only one record of Indian Tertiary coniferous wood and that is from Southern India. In the Cretaceous Period the traces of conifers are fairly numerous, but the group appears to have enjoyed its maximum development in the Jurassic. It is a remarkable fact that no fossil conifers are recorded from extra-peninsular India.

On the strength of these facts, Prof. Sahni concludes that the conifers were confined in Mesozoic times to peninsular India. Later they gradually approached extinction, and when the Himalayas were brought into existence in the Tertiary Period the conditions for coniferous growth were reintroduced and an invasion of the modern coniferous flora took place from the landward borders.

From a consideration of their respective floras, Prof. Sahni considers that the Parsora Stage of Dr. Cotter's 1917 classification of the Indian Gondwana System is of Triassic age, and that the Maleri Stage must be referred to the Upper Gondwanas and not, as has been done previously, to the Lower; for the flora suggests an age at least as late as the Rhætic. He considers that while it is clear that Ceylon and the Madras region formed part of the same palæobotanical province in Upper Gondwana times, it is possible that the flora of the Mesozoic plant-beds of the Southern Shan States had a closer connexion with the contemporaneous floras in China than with the Indian Upper Gondwana floras.

Valuable synoptic charts and distribution maps are given. One of the many outstanding good qualities of these memoirs is the excellence of the illustrations, and by means of these the evidence is put before the reader in a manner which leaves little to be desired. All palæobotanists and those geologists who are interested in the stratigraphy of the Indian Gondwana System will look forward to the extension of Prof. Sahni's researches to the other groups of Indian fossil plants.

Physics in Relation to the Internal Combustion Engine.*

THE development of all internal combustion engines using gas or oil as a fuel and for all duties, whether stationary on land or for transport, road, marine, or in the air, owes more to the guidance of physics than any other prime mover.

In the first period, when the engine was nearly always a gas engine, the investigation of the processes which governed its action and the limitation of its cycle of working were carried out by physicists like Sir Dugald Clerk, Prof. Hopkinson, and others. The results assisted and accelerated development, making possible the extended use of the engine for all industrial purposes that followed.

Perhaps the outstanding feature during this time was the growth of the engine in size, until ultimately engines using the waste gases from blast furnaces were built, or are building, for powers so large as 10,000 h.p. per engine. These large-size engines are found usually abroad, operating in the most efficient iron and steel works. As regards the smaller sizes in Great Britain, they would have been used more widely if the gas industry had foreseen the possibilities of a countrywide gas supply with interconnecting trunk mains, as has been done since by the electrical industry.

The War period followed, and led to an intensive and rapid development in the engine for transport, in particular in the air, where special materials and increased accuracy of workmanship were called for. The extraordinary progress made was largely due to the number of highly trained physicists and engineers who concentrated upon every problem and solved it as it arose.

Since the War, development has been in the use of oil, and the wide adoption of the engine for marine propulsion has been due to the high economy of the Diesel motor. The high economic possibilities of this engine were thoroughly discussed in a paper by Diesel before the engine was actually built, and though it took many years to bring this into practice the results have justified all that he had proposed. At the present time, development is being concentrated upon the high-speed oil motor using relatively cheap fuel, with the added advantage of reducing the risk of fire, for road transport and for the air, and very good progress is being made.

The first 'safety first' engines to fly regularly were those supplied to the airship *R101*. Since then one has flown in the United States and one in Germany, and these will shortly be followed by another type in Great Britain.

On the road, extraordinary progress has taken place in the application of the small engine to motor lorries,

* From a lecture delivered by Alan E. L. Chorlton before the Institute of Physics on May 19.