Recent Researches on the Transmutation of the Elements*

By THE RIGHT HON. LORD RUTHERFORD, O.M., F.R.S.

IT is now well established that the change of one atom into another can only be effected by the addition or subtraction of one of the constituent particles of the atomic nucleus, for example, an electron, proton, neutron or α-particle. Such a transformation was first accomplished in 1919 for the element nitrogen by bombarding it with swift α-particles from radioactive substances. About one α-particle in 100,000 comes so close to the nucleus that it enters and is captured by it. This violent disturbance results in the expulsion of a proton with high speed, and the formation of a new nucleus of mass 17. A number of light elements can be transformed by α-particle bombardment in a similar way, and in most cases a proton is ejected.

A new and strange type of transformation was discovered last year by Chadwick: when α-particles bombard the metal beryllium, uncharged particles of mass 1 called neutrons are expelled. These neutrons, which have remarkable powers of penetrating matter, are themselves very efficient agents for the transformation of atoms. Feather has shown that both nitrogen and oxygen are transformed by the capture of neutrons, with the expulsion of a fast α-particle. The types of transformations produced by the neutron are thus very different from those observed with the α-particle. The capture of an α-particle in general leads to the building up of a new nucleus three units heavier than before, while the capture of a neutron leads to the formation of a nucleus three units lighter.

During the past year, Cockcroft and Walton at Cambridge made the important discovery that comparatively low-speed protons are very effective in causing the transformation of a number of elements. The protons are generated in large numbers by an electric discharge through hydrogen, and then speeded up by passing through an evacuated space to which a high potential of the order of 600,000 volts is applied. Under these conditions the protons acquire high speeds comparable with that of the α-particle from radium. When a stream of these swift protons corresponding to a micro-ampere falls on the element lithium, a large number of α-particles are emitted of energy comparable with that of the swiftest α-particle from radium. It seems that about one in 100 million of the protons enters a lithium nucleus of mass 7, and the resulting nucleus of mass 8 splits up into two α-particles, each of mass 4. Cockcroft and Walton have later found that the α-particles emitted consist of two groups differing widely in speed.

This transformation of lithium can be produced at surprisingly low voltages. With strong proton streams, the emission of α-particles can be observed for 30,000 volts; the number of particles increases rapidly with the voltage, and the variation has been examined by different observers over a very wide range, from 30,000 to 1·5 million volts.

Protons are also remarkably effective in disintegrating the light element boron, and again α-particles are emitted. It is possible in this case that the boron nucleus of mass 11, after capturing a proton, breaks up into three α-particles. The radiation observed is complex, and has not yet been analysed in detail. A number of other elements have been found to be transformed, apparently in all cases with the emission of α-particles.

In a special form of accelerating tube devised by Oliphant in the Cavendish Laboratory, a narrow, intense proton stream can be generated at voltages up to 200,000 volts. The protons, after being bent by a magnetic field, bombard a target of about one square centimetre in area. By special arrangements, it has been found possible to obtain in the detecting chamber at least a thousand times the number of particles observed by Cockcroft and Walton at the same voltage. By this method it is easy to observe the particles from very thin films of lithium and boron at comparatively low voltages, while the variation of number with voltage has been measured. For example, a number of α-particles are emitted from lithium with voltages so low as 30,000 volts. α-Particles from boron have been observed at 60,000 volts, but the number increases much more rapidly with voltage than in the case of lithium.

Special experiments have been made to test by this sensitive method whether the heavy elements thallium, lead, bismuth and uranium show any evidences of transformation for 200,000 volt protons, but no sign of emission of α-particles has been observed for these elements. At first, marked effects were observed, but these were ultimately traced to a minute contamination by boron, probably originating in the discharge tube. It seems not unlikely that the effect observed for uranium and lead in the original experiments of Cockcroft and Walton may have been due to an unsuspected contamination by a minute trace of the very active element boron.

During the last few years, much energy has been devoted throughout the world to developing methods of obtaining streams of very swift charged particles with which to bombard matter and effect its transmutation. In the apparatus of Cockcroft and Walton at Cambridge already referred to, a steady potential of 800,000 volts can be reached. A new and simple type of electrostatic generator has been designed by Van der Graaf and Atta in the Massachusetts Institute of Technology, with which they have obtained a steady potential of

* Substance of the Friday evening discourse delivered at the Royal Institution on March 10.

1·5 million volts, and a larger apparatus is under construction with which they hope to obtain a potential of 15 million volts to apply to a large vacuum tube. Brasch and Lange have applied high momentary voltages to a discharge tube by using an impulse generator.

A new and ingenious method of multiple acceleration has been devised by Lawrence of the University of California with which he has already obtained protons of energy 1·5 million volts by using a potential less than 10,000 volts. The transformation of lithium has been examined at this high energy using a proton current of about a thousandth of a micro-ampere. It is hoped to develop this method so as to obtain protons of energy as high as 10 million volts or more.

Even if these new projects prove successful, the speeds of particles produced by their aid are much smaller than those observed for the very penetrating radiation in our atmosphere, where electrons and protons of energy from 200 million to 2,000 million volts are present. From the experiments of Anderson in Pasadena and Blackett and Occhialini in Cambridge, it seems certain that these very swift particles are very efficient in causing the transformation of nuclei, probably in novel ways. Strong evidence has been obtained of the production of a new type of positively charged particle which has a mass small compared with that of the proton. This may prove to be the positive electron, the counterpart of the well-known negative electron of light mass.

Obituary

DR. C. A. BARBER, C.I.E.

WITH the passing on February 24 of Charles Alfred Barber is severed a link with the past, for he belonged to that old school of scientific investigators who were the first to turn their attention to the problems lying behind development in tropical agriculture. When he gained his first acquaintance with it, there was an awakening to the fact that a harvest does not necessarily follow planting. In the East, Ceylon had gained experience from coffee; in the West, Harrison and Bovell had pointed the way to a healthier growth of cane.

This, as yet dim, appreciation of the need for investigation, led to Barber's first appointment in 1891 as superintendent of agriculture in the Leeward Islands where, however, his stay was brief, for the post was abolished in 1895. In 1898 he was appointed Government botanist, Madras, and, as director of the Botanical Survey of Southern India, commenced to complete the flora of southern India. But here, as in the West Indies, the need for investigation of the economic crops was slowly gaining recognition and his attention was soon diverted to the study of cane and crops in general. These were the days before the Royal Commission of 1896 had led to the establishment of the Imperial Department in the West Indies and before the organisation of an agricultural service in India. It is to Dr. Barber, not least among the pioneers of this period, and to the practical benefits of his work, that the present-day scientific worker in this field largely owes his security in a firmly established service scattered throughout the tropical parts of the British Empire.

During this earlier period, Barber found time to carry out a detailed investigation of the haustoria of sandal and other plants for which he was awarded, in 1908, the degree of Sc.D. of the University of Cambridge. But the earliest economic problem to receive attention was that of the sugar cane disease which was creating anxiety in Madras. In 1912, when the Cane-breeding Station was opened at Coimbatore, the selection fell on him for the post of sugar cane expert, and his field of investigation was extended to cover the whole of India. The problem that faced him was unique. The main cane tract of India lies outside the tropics where, for climatic reasons, the plant forms no viable pollen. Seedlings had to be raised outside the tract and no mean questions of testing and introduction were raised. There was the further fundamental question of the parental type to be used to impart the resistance to frost and drought necessary for success. Through a detailed study of the Northern Indian canes he was attracted to Katha, a hardy Punjab cane, and its similarity to *Saccharum spontaneum*, the wild Kans. He was led to use this wild plant as one parent and, by crossing it with a Noble cane, raised seedlings of which Co.205 remains as testimony to his originality of thought. In its wider aspect his study led him to a classification of the Indian canes, to which he ascribed a dual origin. Again it is a tribute to his insight that this classification, based on a morphological study, has required so little modification from the later Dutch cytological investigations.

Original, too, was Barber's recognition of the importance of the root in the economy of the plant and of the need for a detailed study of the root system. For his services to India he was created a C.I.E. in 1919 on retirement and, in 1931, was awarded the Maynard Ganga Ram prize for Indian research.

Born in 1860 at Wynberg in South Africa, Barber came to England at the age of ten years. After five years' service in the Manchester and Liverpool District Bank, he entered Christ's College, Cambridge, of which he became a scholar. In 1889 he was appointed University demonstrator in botany and, before proceeding to India, served on the staff of the Royal Engineering College, Coopers Hill, where he succeeded the late Prof. H. Marshall Ward.