THE UNIVERSITY OF BIRMINGHAM CYCLOTRON

THE Nuffield cyclotron in the Physics Department of the University of Birmingham is one of the three cyclotrons in Great Britain which were planned before the outbreak of war in 1939. The construction of a machine for accelerating deuterons to an energy of about 25 MeV. was proposed by M. L. Oliphant, who was appointed to the Poynting chair of physics in the University in 1937, and was responsible for the general planning and guidance of the whole work until 1950. The general design was based largely on that of the 60-in. cyclotron of the Radiation Laboratory of the University of California at Berkeley, and, like the Berkeley machine, the Birmingham cyclotron is of nearly the maximum economic size for fixed-frequency operation. The cost of the initial stages of the undertaking, including the provision of the building which now houses not only the cyclotron but also a large part of the research work of the Department, was met by a generous gift from Lord Nuffield. Financial support has also been given by the Nuffield Foundation and latterly by the Department of Scientific and Industrial Research.

Work on the machine, which started in 1938, was seriously interrupted by the War; but by 1944 the magnet had been assembled, with the view of electromagnetic separation of isotopes for the Atomic Energy Project. The transfer of Prof. Oliphant and his team to the United States ended this particular undertaking; but with the release of many members of the staff of the Department from war work towards the end of 1945 it became possible to continue construction of the cyclotron. An internal beam of 16 μamp. of 25-MeV. molecular hydrogen ions was obtained early in 1950, but sparkover in the deflector system made it difficult to extract beams of this energy, and distortion of the dees also gave trouble. The cyclotron was therefore adjusted to accelerate deuterons to an energy of 20 MeV., and an external beam was obtained in July 1950; since then the machine has operated steadily and well. It represents an important addition to British resources in nuclear physics, and this article has been written to give a brief general account of its main features. Certain specific aspects of the design have already been referred to in a recent review article on cyclic accelerators[1].

The cyclotron stands 15 ft. below ground-level in a pit at one end of the Nuffield Research Laboratory. The magnet pole tip diameter is 61½ in., and the effective air gap is 12 in. The flux density in the magnet gap under present operating conditions is 13,500 lines/cm.^{2}. The magnet yoke weighs 250 tons and the copper windings 40 tons. The magnetizing current is 230 amperes, and the coils dissipate a power of 40 kW. which is removed by an air-cooling system giving a flow of 21,000 cu. ft./min. The magnet can produce a field of 18,000 gauss with a dissipation of 200 kW., so that it is being operated well within its rating. The magnet current is held constant to one part in 10,000 by a stabilizer using a galvanometer and photocell to determine when the current deviates from a fixed standard of reference. The fall-off in magnetic field required for correct focusing properties is obtained by machined steps in the pole faces.

The operating frequency of the cyclotron is at present 10·24 Mc./s. and the peak voltage between the dees is 150 kV. The radio-frequency generator resembles that used in the 60-in. cyclotron at Berkeley; it is a single demountable grounded-grid oscillator using the dee system as a resonant circuit. The oscillator valve is a continuously evacuated tube with a water-cooled anode; the power input is 80 kW. The cathode and anode are coupled to respective dee-stems by a transmission line, coupling loop and terminating stub; the dee-stems are each the inner conductor of a coaxial line of 24 in. diameter which is shorted at one end and enters the main vacuum tank at the other. The radio-frequency system is driven into self-oscillation by a 1-kW. booster oscillator and power amplifier.

The cyclotron tank and dee lines are evacuated by two 14-in. oil diffusion pumps which maintain a pressure of about 2×10^{-5} mm. of mercury under normal operating conditions. When the cyclotron is accelerating deuterons, deuterium is admitted to the ion source at a rate of 35 ml./hr. The ion source is of the hooded arc type; filament life is 30–40 hr. and is ended by erosion of the tungsten under the arc column.

The circulating ion beam of the cyclotron may be partly extracted by electrostatic deflexion into a tangential exit-port, and thence through a 50-μ aluminium window into the air or on to an external target. Alternatively, a further vacuum system may be attached to the exit port, and part of the beam may be deflected by an auxiliary magnet into an observation chamber 16 ft. from the cyclotron. The

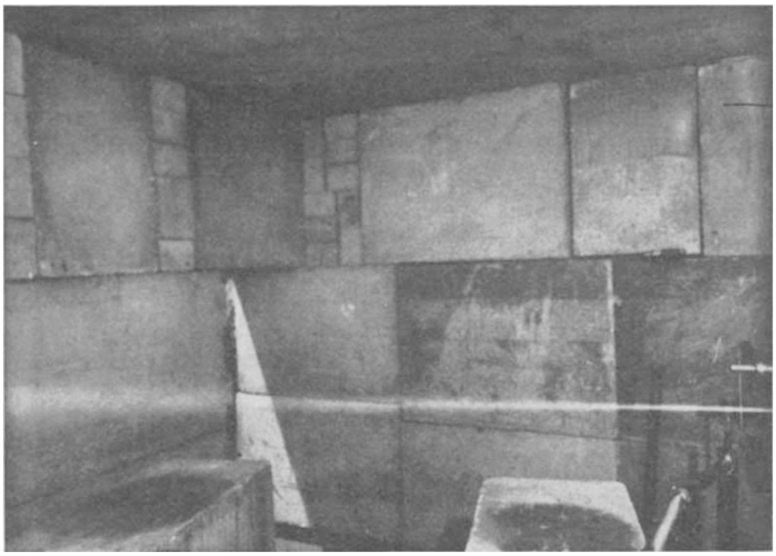
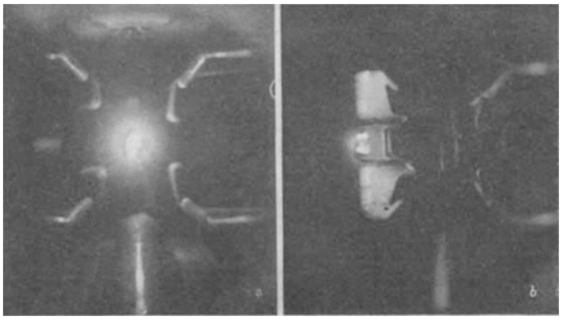


Fig. 1. Analysed beam of 20-MeV. deuterons from the University of Birmingham cyclotron. The angular spread is about 1/10° vertically and 2° horizontally, and the current density is 1 μamp. per cm.^{2}. The track of the beam shown is about 6 ft. long



(a) (b)

Fig. 2. (a) Tip of the ion source at the centre of the cyclotron when the machine is accelerating molecular hydrogen ions. (b) Same as (a), except that the machine is accelerating deuterons. The bright patch on the left-hand side is part of the dee-structure reflecting light from the forked end of the white-hot splitter plate

fringing field of the cyclotron and the field of the deflecting magnet, combined with slit systems in the path of the beam, can be used to provide an analysed beam with an energy spread of less than 1 per cent of its mean energy. The cyclotron is normally used for accelerating deuterons (D^+), molecular hydrogen ions (H_2^+) or alpha particles (He^{++}), for each of which resonance can be obtained at the frequency of 10·24 Mc./s. by relatively small variations of the magnetic field. Each molecular hydrogen ion of energy 20 MeV. is equivalent for transmutation purposes to two protons of 10 MeV. The beam currents normally obtainable are shown in the accompanying table.

Ion accelerated	Energy (MeV.)	Circulating beam (μamp.)	External beam		Analysed beam	
			Current (μamp.)	Energy spread (MeV.)	Current (μamp.)	Energy spread (MeV.)
D^+	20	250–350	40–70	1	4	0·15
H_2^+	20	50–100	10–20	1	1	0·15
He^{++}	40	10–25	1–7	2	0·1	0·3

The photograph (Fig. 1) shows an analysed beam of 20-MeV. deuterons with a density of 1 μamp./cm.^{2} and an angular spread of 1/10° vertically and 2° horizontally emerging into the observation chamber. When molecular hydrogen ions are accelerated, collisions between the ions and gas molecules in the tank during acceleration give rise to protons of half the incident energy, which return to the ion source and rapidly make it white hot. Fig. 2a is a photograph of the tip of the ion source taken through a window in the tank wall under these conditions; Fig. 2b is a similar photograph taken while the machine was accelerating deuterons.

Targets may be given high intensities of bombardment in the circulating beam, in vacuum in the exit port, or in air outside the exit port window, activities of many curies being obtainable with the shorter-lived products. In many cases the intensity of the bombardment is limited by the difficulties of target-cooling rather than by cyclotron performance. Thermocouples in the target-cooling system are convenient for monitoring the beam current in high-intensity bombardments; power inputs of several kilowatts to suitable targets have been used.

Experiments in progress with the cyclotron include studies of nuclear reactions induced by bombardment with helium-3, elastic and inelastic scattering of protons and deuterons by nuclei, angular and energy distributions of products of (dp), ($d\alpha$) and (dt) reactions, and the investigation of short-lived activities. For the latter work the cyclotron ion source may be pulsed by a circuit synchronized with an external time base. Such experiments must all be done on or near the machine; in addition, many long-lived radioisotopes can, of course, be made, and some have already been distributed to users through the Isotope Division of the Atomic Energy Research Establishment, Harwell. Isotopes required by members of the University of Birmingham can be processed chemically in the radiochemical laboratory of the Department. The cost of operating the cyclotron in power alone is at present in the neighbourhood of £2 per hour, and the machine normally runs for 40–60 hr. per week, with one day set aside for routine maintenance.

The background of neutron- and gamma-radiation produced by the cyclotron is very large near the target, a fast neutron flux of about 10^8 neutrons per cm.^{2} per sec. being obtained in the forward direction one metre from a beryllium target bombarded by 30 μamp. of 20-MeV. deuterons. The cyclotron is surrounded by water tanks and concrete blocks to a thickness of 40 in., and in occupied regions in the neighbourhood the radiation intensity does not exceed the maximum permissible level.

The completion and successful operation of the Nuffield Cyclotron was made possible only by the combined efforts of a large number of individuals. Nearly the whole machine was constructed by the workshop and scientific staff of the Physics Department, and the assembly of the major parts of the equipment was also the responsibility of members of the laboratory. By comparison with later cyclotrons some deficiencies in the engineering of the machine are apparent, but the general serviceability and performance since 1950 have been good. The Department has the satisfaction that the time and effort expended on construction have been rewarded not only by the success of the machine, but also by a detailed appreciation of its operating characteristics.

[1] Fremlin, J. H., and Gooden, J. S., "Cyclic Accelerators", Reports on Progress in Physics, 13, 295 (1950).

UNDER-WATER TELEVISION AND MARINE BIOLOGY

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ALTHOUGH in recent years there have been some advances in technique, notably in the use of the echo-sounder and in the development of the Hardy continuous plankton recorder, the marine biologist still relies to a very large extent on old methods for obtaining his 'field' information on the ecology of marine animals. The standard equipment such as nets, grabs and trawls have certainly been improved by various modifications, and their method of working and the results obtained have been subjected to a more critical examination; but such equipment can only give limited information regarding both the detailed distribution and behaviour of the animals in their natural habitats. In this sense progress in marine biology has not kept pace with that in physical oceanography, where there has been considerable technical advance, particularly in respect