HISTORICAL DEVELOPMENT OF THE CYCLOTRON
(SURVEY OF THE LITERATURE)

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A short survey, based on the published literature, is given of the historical development of cyclotron devices. The basic parameters and main features of cyclotrons are given. The paper is illustrated by photographs taken from the literature.

Almost thirty years have passed since the first enunciation of the principle of the magnetic resonance accelerator – the cyclotron, a machine which has played an extremely important role in nuclear research. Because of its universal application, the cyclotron is, at present, one of the most widely used types of accelerators.

Using the published literature, we shall trace the evolution of the cyclotron during this time, a period in which the rapid development of nuclear physics imposed ever-increasing requirements on the cyclotron.

Using the cyclotron it is possible to accelerate ions of virtually all elements from hydrogen to neon and to study a large number of nuclear reactions which occur when charged particles interact with matter. The cyclotron is a source of fast, monochromatic neutrons and, with a sufficiently intense beam of charged particles, allows us to obtain a flux of partially polarized neutrons. By exploiting the discontinuous nature of the ion beam from a cyclotron it is possible to investigate neutron spectra, determining the fast-neutron energy by time-of-flight methods; using a so-called "pulsed beam" we can investigate the interaction of slow neutrons with matter. In certain cases the cyclotron is used as a source of hard $\gamma$-rays. Finally, it can be used to obtain a number of nuclides of high specific radioactivity.

The first paper on the principle of a cyclical resonance accelerator in which a high voltage is not used was that of Lawrence and Edlefsen [1] in 1930. In 1931, using a cyclotron with a pole diameter of 100 mm, Lawrence and M. Livingston were able to accelerate ions of molecular hydrogen to an energy of 80 kev. This primitive, laboratory-built device became the prototype of modern cyclical accelerators.

In that same year, Lawrence and M. Livingston, using an improved machine (Fig. 1), were successful in accelerating protons to an energy of 1.22 Mev. In this work it was noted that a change in the magnetic field of several tenths of a percent was sufficient to disturb the resonance condition. In their basic description the authors indicated the method used for correcting inhomogeneities (the introduction of pieces of iron between the pole pieces of the magnet and the roof of the accelerator chamber). The electric field of a condenser was used to deflect the beam of charged particles. The beam current at the terminal radius was $10^{-9}$ amp, but the authors discussed the possibility of obtaining currents of the order of $10^{-7}$ amp.

In 1932, using an improved machine, these same authors accelerated deuterons to 3.6 Mev. A current of $10^{-9}$ amp was detected with a measuring electrode (Faraday cylinder) which was set up beyond the deflection system. In 1933 ions of molecular hydrogen were accelerated to 4.8 Mev in this same accelerator. In this work an oscillator system consisting of two dees was used.

Using a chamber with a roof diameter of 690 mm, in 1934 the same workers accelerated ions of molecular hydrogen to 5 Mev (Fig. 2) while in 1935 a current of molecular hydrogen ions of $10^{-5}$ amp was obtained beyond the deflection system in this same apparatus.
In 1966 great progress was made. Lawrence and Cooksey [2] built a new chamber with a roof diameter of 700 mm and accelerated deuterons to 5 MeV, moreover, using a deflection system, for the first time it was possible to extract a beam of charged particles with a current strength of 5 μAmp from the chamber through a thin platinum window. The radio-frequency generator, using a self-excited push-pull circuit, delivered radio-frequency power of the order of 25 kW. The potential difference between the dees was 50-100 kV. The magnetic field correction was realized by introducing iron discs between the pole pieces of the magnet and the ends of the accelerator chamber. For the first time attention was paid to the fact that the geometric center of the accelerator chamber does not coincide with the center of the particle orbit and it was shown that this effect can be avoided by additional corrections of the magnetic field. An electrode for measuring the beam current was located in the chamber beyond the deflection system. Provision was made for