THE BETATRON

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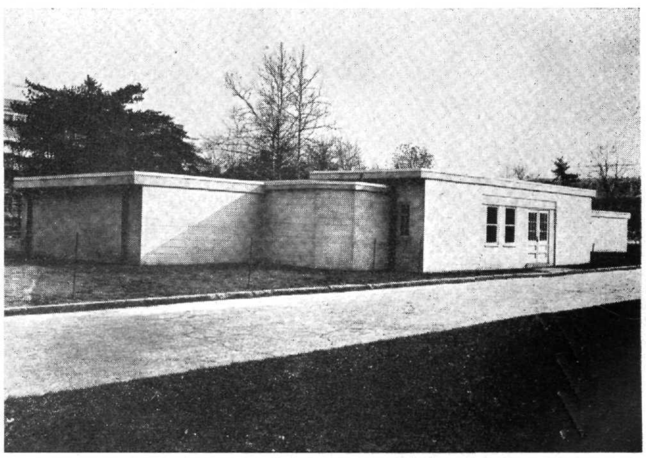
A BETATRON, a machine which is causing a great deal of interest and discussion among scientists is now being constructed in the newest unit of the Radiation Laboratories of the Ohio State University. Scientists have been much interested, especially in the past decade, in methods of producing high energy particles, and in controlling these high energy particles. To Dr. D. W. Kerst of the University of Illinois goes credit for first successfully constructing and operating a machine for accelerating electrons by a varying magnetic field. This new scientific instrument he called the betatron, and the name is now in general use among physicists. The name was selected because it seems probable that the most useful applications of the betatron will involve the production of high-speed electrons or beta rays, as they are known in nuclear physics. When the Greek suffix-*tron,* is attached to the word beta, the name means the agency for producing high-energy electrons.

In the betatron, energy is transferred to electrons by the accelerating effect of a time-varying magnetic field. The appearance of the betatron is somewhat like that of a cyclotron since the betatron is a powerful magnet. Also, both the betatron and the cyclotron electrically accelerate atomic particles. But the similarity ends there. The betatron operates with alternating current instead of direct current. The betatron gives one continued "push" to the electrons spinning in its vacuum tube. The cyclotron accelerates protons or other heavy charged particles by giving them repeated "kicks" as they spiral around in a vacuum chamber. The betatron can accelerate particles to speeds in excess of 184,000 miles per second, only a small fraction of a percent less than the velocity of light, which is the highest velocity attainable by any material particle. Particles accelerated in a cyclotron can at best have velocities of the order of magnitude of a tenth the velocity of light, and therefore only heavy ions can be accelerated in it to appreciable energies. The two machines, the betatron and cyclotron, differ greatly in size and power used. A betatron producing 20-million volt electrons has a magnet which weighs less than four tons. The Ohio State cyclotron has a magnet which weighs eighty-five tons and can accelerate deuterons to 12-million volts.

The betatron, in simple terms, consists of two parts, an electro-magnet and a doughnut-shaped vacuum tube. The magnet is laminated from thousands of pieces of silicon steel. The inside wall of the doughnut-shaped vacuum tube is silvered, and a stem projects from the tube at one side. Through seals in this stem wires lead to a filament, focusing cup, and shield, which form the injector unit located just inside the outer radius of the tube. The shield, incidentally, serves as the electron target wherein X-rays are formed.

The action of the betatron is somewhat similar to that of a step-up transformer, with the electrons inside a doughnut-shaped vacuum tube replacing the secondary coil. A step-up transformer consists of an electro-magnet with two windings: a primary of a few turns of wire through which an alternating current passes, and a secondary of many turns in which magnetic induction from the iron transformer core builds up a voltage proportional to the turns ratio between secondary and primary. The space path of a spinning electron within the vacuum chamber corresponds to the conducting path of the wire of the secondary coil on a transformer. The energy gained by an electron in each revolution in the betatron is about the same as the voltage that would be induced in a coil of one turn of wire placed in the same position as the doughnut.

In the betatron, where the circular vacuum tube is between the magnet poles in the place of a secondary, the surge of magnetism whirls electrons around inside the tube, where they have been re-



The Electrostatic Generator Station which will house the Ohio State University Betatron

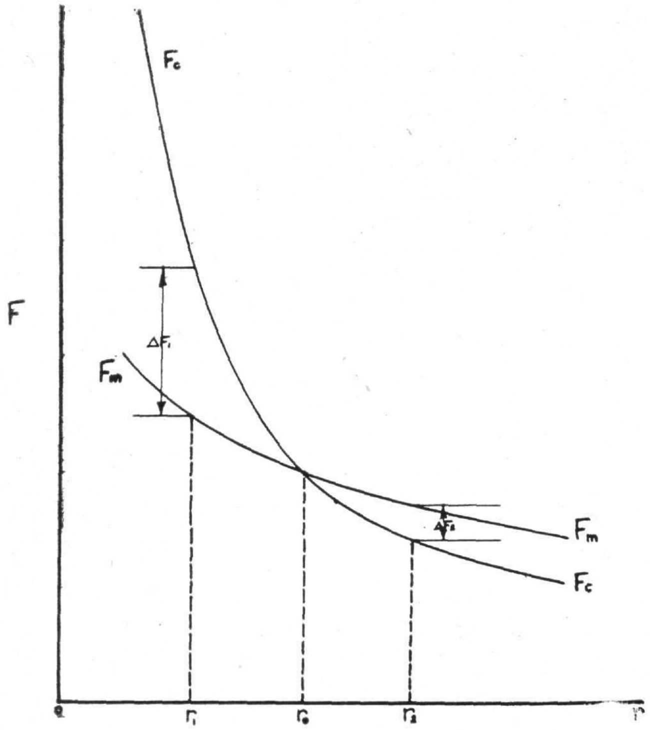


Fig. 1. Radial Variation of Forces Acting on the Electron Beam.

leased by a heated filament, just as electrons are released by the glowing filament in a radio tube. A pulsating voltage on the injector propels the electrons into the tube in pulses or "bursts", a few hundred bursts occurring per second. The current through the coil of the magnet is alternating at the same frequency as the pulsating voltage in the injector.

Each burst of electrons is released while the magnetic field intensity is small, that is, when the current in the coil is at zero and about to begin

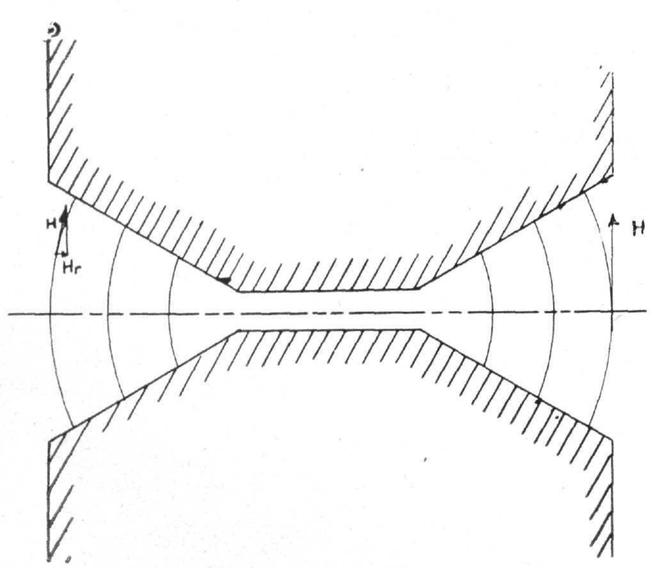
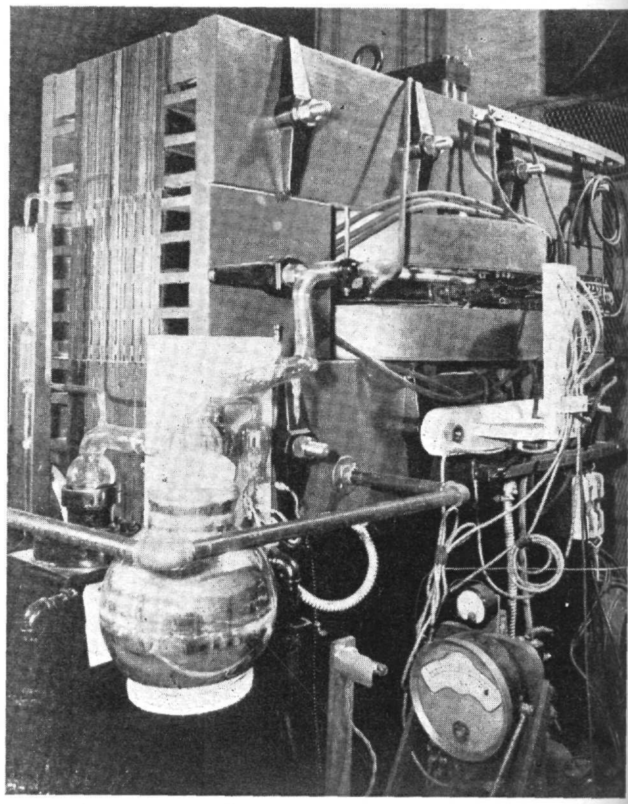


Fig. 2. The Magnetic Field Between the Pole Faces of a Betatron

a cycle. As the flow of this current increases, the strength of the magnet also increases, and the electrons are whirled about inside the vacuum tube by the increasing magnetic field. The field is circular in cross-section, corresponding to the pole faces of the magnet, and the electrons follow a circular path within the vacuum tube just as they would follow the wires of a coil.

The magnetic field pattern is appropriately proportioned to hold the electrons in a stable orbit.



The Twenty Million Electron Volt Betatron at the University of Illinois Showing the Vacuum System and Ventilation Ducts

The focusing effect of the field may be intuitively appreciated by considering Figure 1. F_c, the centrifugal force acting on the electron, and F_m, the restraining force exerted by the magnetic field on the electron, are plotted against r, the distance of the electron beam from the center of the pole face of the magnet. The intersection of the two curves corresponds to the radius of the equilibrium orbit of the electron beam. An electron at a distance r_2 from the center, whenever r_2 is greater than r_o, is acted upon by a magnetic restraining force which is greater than the centrifugal force of the electron. This resultant force, ΔF_2, the difference between F_m and F_c, tends to reduce the radius of the electron's orbit to r_o. Similarly, when an electron is inside the equili-

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brium orbit, it is acted upon by a force, ΔF_1, which pushes the electron out toward the equilibrium orbit.

The electron beam is kept from spreading in a vertical direction by the spatial characteristics of the magnetic field in the neighborhood of the equilibrium orbit. Because an electron traveling through a magnetic field is acted upon by a force which is perpendicular to the path of the electron, it can be seen from Figure 2 that any individual electron which has been displaced vertically from the equilibrium plane is acted upon by a force which moves the electron back toward the main beam in the equilibrium plane.

Correct operation of the machine requires that the magnetic flux enclosed by the equilibrium orbit be just twice what it would be if the flux density were everywhere equal to the flux density at the equilibrium orbit. In order to fulfill this condition, the centers of the pole faces must be spaced closer together than the rest of the surface of the magnet in order that the electron beam be properly confined as it is simultaneously acelerated.

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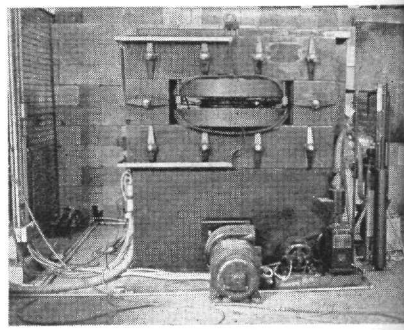
The scientific importance and practical possibilities of the betatron in medicine, in industry, and in research have been shown. Medical tests indicate that the electron-produced X-rays would have the advantage of concentrating more treatment upon deep tissues with less effect to the skin and fatty tissues just under the skin. Sending the accelerated electrons directly into the patient is one promising way to use the betatron for therapy, and may be even more valuable than the use of the X-rays, although clinical tests have not yet been made in this respect, and the electron beam has not been made sufficiently compact for such use. The electron beams, unlike the X-rays, would penetrate a certain distance into the body and no farther, and thus, it is thought, the region or maximum effect could be better regulated.



Courtesy Engineering Experiment Station News

The University of Illinois' 20 mev Betatron

In laboratory research, the betatron may open the way for study of cosmic ray effects. The only source of the cosmic rays now is interstellar space, and in order to study them scientists travel to high mountain tops where the layer of air that screens them from the earth is thinnest. What possibilities there might be if cosmic rays could be produced in a laboratory, scientists can only guess, because we know very little about cosmic rays at present.