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 in-
terested, especially in the past decade, in methods
of producing high energy particles, and in con-
trolling 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 elec-
trons by the accelerating effect of a time-varying
magnetic field. The appearance of the betatron
is somewhat like that of a cyclotron since the beta-
tron is a powerful magnet. Also, both the beta-
tron and the cyclotron electrically accelerate at-
omic 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 vac-
uum chamber. The betatron can accelerate par-
ticles 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 veloc-
ities 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 sil-
ered, 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 elec-
trons inside a doughnut-shaped vacuum tube re-
placing the secondary coil. A step-up transform-
er consists of an electro-magnet with two wind-
ings: a primary of a few turns of wire through
which an alternating current passes, and a sec-
ondary of many turns in which magnetic induc-
tion 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 cor-
responds 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 sec-
ondary, the surge of magnetism whirs electrons
around inside the tube, where they have been re-
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 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 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 $r_e$, is acted upon by a magnetic restraining force which is greater than the centrifugal force of the electron. This resultant force, $\Delta F_p$, the difference between $F_m$ and $F_c$, tends to reduce the radius of the electron's orbit to $r_e$. Similarly, when an electron is inside the equili-
brium orbit, it is acted upon by a force, \( \Delta F' \), 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 accelerated.

(Continued on page 28)
TO THE UTTERMOST ENDS OF THE EARTH

And so, the roads lead away to the uttermost ends of the earth . . . to the South Seas of Captain Cook and Admiral Halsey . . . to the Orient of the Great Khan and General Chiang Kai-shek . . . to the England of Wellington and Churchill. Along every mile of those roads you will find American boys reading American newspapers and magazines . . . "including all the ads, three times"; and American books . . . "right out of their covers."

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THAT'S A FACT. During colonial days in America, iron was shaped by running the molten metal from the quaint blast furnace, or forge, into open forms dug out of sand, where the hot iron cooled into sturdy bars, or pigs as they then were and still are called. Purchasers of such iron, refusing to pay iron prices for the sand that stuck to the pigs, demanded that each long ton (2240 lbs.) of pigs include an extra 28 lbs., the estimated tare or weight of the sand adhering to them.

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BETATRON
(Continued from page 25)

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.

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.

The University of Illinois' 20 mev Betatron

The Ohio State Engineer