FORM 3542

ALLIS-CHALMERS
MILWAUKEE, WIS.

NEWS

11/14/46

RELEASE ____________

UNIVERSITY OF ILLINOIS

DEVELOPMENT OF THE BETATRON AND ITS PLACE IN SCIENCE

by

Dr. Donald W. Kerst,
Professor of Physics,
University of Illinois

(Delivered before Press Preview at U.S. Army Arsenal, Picatinny, N. J., November 14, 1946).

The betatron, like the airplane, is one of those devices which was claimed to be "impossible." The idea of a device to accelerate electrons by use of a magnetic field is recorded in scientific literature at least as far back as 1922. It promised a way to overcome the increasingly tough problems involved in trying to accelerate electrons to high voltages for the purpose of creating x-rays or other uses. Technical and design difficulties defeated early attempts.

I first became interested in this idea in 1938. The possibilities intrigued me, and the benefits to science, to medicine, and to industry of extremely high voltage x-rays and also of high energy free electrons appeared great. In considering the designs and theory, I felt certain that such an instrument could be made to work, and that it would have great commercial x-ray as well as scientific possibilities.

That these possibilities now are being realized is to be credited to the University of Illinois. The graduate school and the physics department of the university provided the opportunity, funds, and facilities for carrying out the idea, and encouragement for doing it in spite of the difficulties which others had with the idea and in spite of pessimism about the possibility of success.

I joined the university faculty in the fall of 1938, and during the following year, while also teaching classes, completed designs for the first betatron, and in the year after that, built it with the aid of the physics department shop. The machine was completed and put into operation July 15, 1940. It operated without difficulty, producing a beam of x-rays of 2.3 million electron volts energy. This initial instrument is about as large as a good-sized radio cabinet, and weighs between two and three hundred pounds.

Conventional methods of accelerating electrons involve the use of a high potential difference between the electron source and the target. Electrons attracted to the target strike it to produce x-rays of energy equivalent to the force to which the electrons have been accelerated. Because of problems of insulation at high potentials, the maximum practicable energy achieved by conventional methods is in the neighborhood of 4 million volts.

The betatron operates in an entirely different manner. The instrument consists of an electro-magnet, powered by an alternating current, and of a doughnut-shaped vacuum tube placed between the pole faces of the magnet. The operation of the betatron is analagous to that of an alternating-current transformer; the circular vacuum tube being in the same position as would be the secondary on a transformer.

During the quarter-cycle in which current flows, through the primary, rising from zero to full value in one direction, the magnetic flux is also rising. In a transformer, the result is circulation of electrons in the coils of the secondary, the total voltage being proportional to the number of turns in this coil.

In the betatron, a supply of electrons is released inside the vacuum tube from a glowing filament, and under influence of the magnetic flux, spin around inside the doughnut-shaped tube. Through design of the magnet pole faces, the magnetic field is so shaped that it holds the electrons into a narrow path, or orbit, inside the tube. Though receiving only a relatively small amount of energy in each revolution, the total energy gained by the electrons in thousands of revolutions produces the high energy output of the betatron.

At the peak of the cycle, when the electrons have reached their maximum energy, an auxiliary turn on the magnet is energized, upsetting the magnetic field, and allowing the electrons to circle outward. They either strike a platinum target to produce x-rays, or through use of a "peeler" are brought out of the tube in a free beam.

The 20 million volt betatron operates with a current alternating at a frequency of 180 cycles per second. The electrons are accelerated in one 1/720 second, a quarter-cycle of each alternation. During that time, they spin around 350,000 times in the vacuum tube and travel a total distance of 250 miles, reaching a velocity of 186,000 miles per second, just a fraction of a per cent below the speed of light. This is the greatest velocity ever produced by any machine. At each revolution the electrons gain up to 70 volts, although nowhere in the instrument is there any voltage greater than 1/400 that final energy. In producing this 20 million volt output, the instrument uses a 25 kilowatt power input.

The betatron is not to be confused with the cyclotron, another instrument for accelerating atomic particles to high energies. Aside from the fact that both work with atomic particles, the two instruments have little in common, and in fact, for certain research work, are complementary. They differ in what they do, what they do it with, how they do it, in size, and in many other respects.

The betatron works with electrons, the light satellite particles of the atom, while the cyclotron works with protons, the heavy nuclear parts of the atom. The two particles carry opposite electrical charges: The electron is negative and the proton positive. The proton also is 1,800 times as heavy as an electron.

The cyclotron is an immense machine. At the University of Illinois we have a 10 million volt cyclotron. It has a 60 ton magnet, wound with 10 tons of copper wire, and is mounted on a 37 ton concrete base. That makes a machine as big as a truck, and around it are ray-stopping water tanks with outside dimensions the size of a garage. The auxiliary equipment to operate the cyclotron is enough to fill another good-sized garage.

Our 22 million volt betatron, parent instrument of the commercial 20 million volt betatrons, has a $3\frac{1}{2}$ ton magnet, and complete weighs about 4 tons. It is 5 feet long and 3 feet high, and has to be mounted on a pedestal to come up to convenient working height. The 10 million volt cyclotron uses 150 kilowatts of power for operation, and the 22 million volt betatron, one-fifth as much.

The way in which the two machines operate is as different as their sizes. The betatron uses alternating current, and the cyclotron direct current. The betatron operates by giving electrons one spinning push, like a self-starter spinning an engine faster and faster, until the electrons reach a speed very close to that of light. The cyclotron gives protons or deuterons repeated kicks as they circle in a spiral. The radio frequency oscillator gives the particles a push twice in each revolution, and the final speed of cyclotron particles is about one tenth that of light. Energy output of the betatron can be easily changed while that of the cyclotron cannot. This close control is an important feature of the betatron for research purposes.

The cyclotron does have the advantage of a considerably larger beam. It is capable of producing intense artificial radioactivities, while the radioactivities produced around the betatron are very weak. But the x-ray intensity from the betatron, while it is running is great, it is equivalent in ionizing power to the gamma rays from 3,000 grams of radium--more than all the radium ever mined throughout the world.

The industrial application of the betatron, as a source of high energy x-rays, was developed during the war under auspices of the Office of Scientific Research and Development. Calculations had demonstrated that the 20 million volt size betatron, of which the only existing unit then was that at the University of Illinois, furnishes the ideal voltage for industrial radiography. An important reason is that while penetration of x-rays through heavy metals increases with increasing betatron voltage up to about 20 million volts, at voltages beyond that point the penetration decreases. The reason for this decrease at higher energies is a phenomena known as "pair-production," which briefly is a turning of energy into matter--the reverse of the action of the atom bomb. The x-ray protons actually disappear while matter, positrons and electrons, appear if the proton has a high enough energy.

Wartime development of the betatron was carried on under the direction of Prof. Gerald M. Almy of the University of Illinois, while I was away for 28 months working for the Manhattan District Project at Los Alamos. Because of the wartime cloak of secrecy over all work or devices associated with nuclear physics, little was known about OSRD development of the betatron while it was going on. The University of Illinois and the Allis-Chalmers Co. worked together during the war. Several betatrons were built. The rugged 20 million push-button controlled betatron, such as the unit you will see today at Picatinny Arsenal, and which now is ready for general industrial use is the outgrowth of this wartime development.

An important phase of this project was the making of a sealed vacuum tube. The first vacuum tubes for the betatron were made of glass pieces, sealed together with wax. To maintain a vacuum, a pump had to be attached and running all the time the betatron was operated. Such an arrangement was impractical for a betatron for industrial use.

Prof. Ralph K. Hursh of the University of Illinois ceramic department solved the problem with a vacuum tube made of ceramic materials. He developed a glazed porcelain tube which has a coefficient of expansion matching that of the glass into which the injector and other connections for within the tube are built. The glass is fused to the ceramic body of the tube, and the tube is evacuated and sealed off. The vacuum is retained indefinitely.

From its conception, I have considered the betatron to have three important possibilities: (1) for industry, a powerful source of x-rays of 20- to 30-million volts energy; (2) for medicine, a source of x-rays or of an electron beam of 20-to 35-millions volts energy for use against cancer; (3) for science, a powerful x-ray and electron source with precision control, and a laboratory source of cosmic rays, produced at energies of 250-million volts or more. Others on today's program are going to speak of industry and medicine. I shall speak briefly on the physics research.

X-rays from the betatron can be used to study the nucleus. They have special value to science in this work not only because of their great energy, but because of the precise control possible with the betatron. They can be controlled by small steps.

The free stream of electrons which has just recently been produced from the betatron at the University of Illinois is equally important. The beam is produced by replacing the conventional tube, having a target from which x-rays are produced, with a tube containing a "peeler" to bring the electron stream out through a window. These electrons can be used to study the inside of the atom, to study the behaviour of electrons, and to create artificially radioactive substances.

The beam of high-energy negative electrons has greatly different properties and possibilities from the high-energy beams of the much heavier positive ions such as come from a cyclotron. The previous highest energy of a free electron stream was 4 million volts. The University of Illinois betatron produces a 22 million volt beam. It can be used to study the photo disintegration of the nucleus, in a way that never before was possible. Another subject for study is whether high-energy electrons produce effects similar to high-energy x-rays. Experiments at lower energies indicate that they do, even though electrons are charged particles, while x-rays are waves. The problem is most interesting. Another subject to be investigated is artificial radioactivity. There may be new processes found which lead to radioactivity when the electron beam is employed directly.

But the most spectacular scientific possibilities of the betatron lie in creating even greater energies than any yet produced. While 20 to 35 million volts is the optimum energy desirable for industrial or medical use, for scientific research we want energies far beyond that. At the University of Illinois we now are building a betatron to have an output energy of more than 250 million volts. That the output will be more than 250 million volts I can say. At this energy we should be within the field of cosmic ray phenomena. We will actually produce cosmic ray effects in the laboratory, and this will open entirely new doors to research. It will enable us to make fundamental studies which may provide clues to the nature of nuclear energy and nuclear forces, and actually to learn what holds the atom together. We expect to produce mesotrons, those mysterious parts of cosmic ray phenomena.

Right now the only source of cosmic rays is from outer space. Because the rays are dispersed by the earth's atmosphere, scientists who want to study cosmic rays must carry their instruments to the tops of mountains, or send them up in airplanes or stratosphere balloons to get to where the rays are most plentiful. Though cosmic rays have been much talked about, actually very little is known about them. We cannot even imagine what may be developed when we can have cosmic rays in the laboratory, produced by a betatron, operating at the push of a button.

The State of Illinois is providing one and one half million dollars to build this betatron and the laboratory in which it will be used. In doing this, the University of Illinois is opening an entirely new field of science, and we are very excited about the possibilities.

rlg