Grants from the Foundation:

$1,210,000 to University of California

THE GREAT CYCLOTRON IS READY FOR ACTION

There's a new landmark at the University of California. Crowning the picturesque Charter Hill which rises above the campus to the east, it is visible from many parts of Berkeley and other towns of the San Francisco Bay area: a domed observatory-like building, white walls with a red roof - the House of the Cyclotron. Although the House of the Cyclotron is all that can be seen from below, a visit to the hilltop discloses several auxiliary shops and laboratories among the eucalyptus trees.

Additional structures are planned, including highly original research equipment, but the present dominating interest is the great cyclotron. Had the war not interrupted, it would have been in operation long ago. One thing the war did speed up, however, and that was the construction of the giant magnet, needed in developing the atomic bomb. But the magnet is only part of the cyclotron, and the other parts had to await the end of the emergency. Since V-J Day several hundred men, including scientists, engineers, and mechanics, have been at work here, fitting the drum-shaped vacuum chamber between the poles of the magnet, installing tubes, pumps, electrical tuning devices, and other necessary apparatus.

Now, at last, the job is done. The 184-inch cyclotron stands complete, ready for action. According to present plans the current will be turned on Monday, November 18, and then the world's most powerful instrument for nuclear research will begin to explore the atomic secrets. What it may disclose, scientists can only conjecture. New elements, perhaps; certainly new knowledge of the mysterious nucleus, center and citadel of atomic energy.

Possibly it may crack the riddle of the nuclear forces which seem to contradict the accepted laws of electrical repulsion and attraction. It may even brush aside present conceptions of the nature of matter and give a new picture of the fine structure of the universe.

The Radiation Laboratory

The House of the Cyclotron, the shops and other equipment on the hill, are parts of a more comprehensive organization known as the Radiation Laboratory which has its headquarters down on the campus. This laboratory, now an extensive establishment employing several hundred workers, is a division of the university's department of physics. It grew out of the pioneering work of a young professor, Ernest O. Lawrence, who in 1930 at the age of twenty-nine invented the cyclotron. His first cyclotron was little more than a toy, but it demonstrated that sub-atomic particles could be accelerated to high velocities while spiraling between the poles of a magnet. In 1931 Lawrence built a larger model of 11 inches diameter, and then one of 27½ inches. With this he was able to speed up particles to energies of five million volts; and by discharging these as projectiles against targets of matter he brought about transmutations and induced radioactivity in a variety of substances.

By 1936 the new apparatus had provided such repeated demonstrations of its value as a research tool that the university decided to finance a plan for rebuilding the 27½-inch cyclotron into a more powerful one of 37 inches diameter. With the completion of this instrument, the giant of its day, the Radiation Laboratory started upon its meteoric career as a world center for nuclear research.

The Rockefeller Foundation's first contribution to the Radiation Laboratory came in 1938 when it appropriated $30,000 toward $90,000 needed to build a bigger and better cyclotron. This new instrument, of 60 inches diameter, was intended primarily for the preparation of radioactive materials for medical research, and additional grants by the Foundation totaling $52,000 assisted the research program. William H. Crocker of San Francisco gave $75,000 to provide housing and auxiliary equipment for the 60-inch, and shortly thereafter William H. Donner of Philadelphia gave $165,000 to build and equip a laboratory of medical physics.

Meanwhile, in 1939, the Swedish Academy awarded Lawrence the Nobel Prize in Physics. That was the year in which the momentous news of the fission of the uranium atom reached America. During the next few months, as the whole field of nuclear science opened up with dramatic swiftness, discovery following discovery, a proposal was made to provide the new Nobel Laureate and his brilliant team with an incomparable tool of research. In fact, even earlier than this, while the 60-inch apparatus was still under construction, the young inventor had discussed with an officer of the Foundation his plans for a giant cyclotron of enormously greater energy. He felt encouraged to put his project on paper, and so Lawrence and his associates drew the blueprints for an instrument which would be more than six times as powerful as the 60-inch. The 60-inch weighed 220 tons and produced a beam moving with the energy of 16 million volts; the proposed 184-inch would weigh 4,000 tons and would deliver a beam of 100 million volts. The 60-inch had cost $90,000 - the proposed 184-inch was estimated to cost around $1,400,000. The Rockefeller Foundation voted $1,150,000 of this sum, other foundations and the University of California agreed to raise the remaining $250,000.

These actions were taken in the spring of 1940, and by summer steel, iron, copper, and other materials were moving to Berkeley and the work of construction began. Although Europe and Asia were at war, the United States was technically at peace, and the problem of priorities had not yet raised its head.

The Site on the Hilltop

An important decision was the selection of a site. Both the 37-inch and the 60-inch had to be surrounded by massive shielding to protect workers from the secondary effects of the radiation, and it was recognized that the secondary effects from the 184-inch would be many times more dangerous. In the hills east of the university campus is a steep declivity known as Strawberry Canyon, and there was talk of excavating a site in the canyon, building the new cyclotron there, and then covering the laboratory with the excavated earth. This would provide a natural shielding. However, after weighing the complications, the plan was abandoned. Moving so much earth would cost a pretty penny, and, moreover, once the cyclotron was buried its future would be fixed. There would be little chance for extensions, enlargements, or other modifications. It was decided to build the big machine out in the open with plenty of room for auxiliary buildings and future expansions, provided an isolated site could be found.

The choice finally settled on Charter Hill, which is just above Strawberry Canyon. Indeed, the automobile route to the hilltop passes up Canyon Road to an extension known as Cyclotron Road, which terminates on the peak. Here a wire fence encloses the eight acres set apart for the laboratory. From this height one can see the sea both west and north. It is a beautiful,

a majestic spot, with unobstructed views in every direction. Though conspicuous, the site is isolated, remote from neighbors and traffic, and accessible only by the winding road.

In the center of the eight acres is the circular House of the Cyclotron. Its walls are of transite, a compressed asbestos. The building measures 160 feet in diameter. The domed roof rises to a height of 93 feet. The heart of the cyclotron, the chamber in which the sub-atomic particles whirl, is drum-shaped, but in exterior form the big atom gun is a rectangular mass of metal 56 feet long and 30 feet high with a weight equal to that of ten locomotives. The massive structure has various appendages, pipes and tubes, and to the imagination its sprawling posture suggests that of a vast mechanical octopus. Part of the permanent installation is a 30-ton radial crane which travels a circular track just under the roof. The crane serves to shift parts of the cyclotron. It is also useful in moving the heavy blocks of concrete which are staggered around the room to provide protective shielding.

The Magnet and the Bomb

When the plans were drawn it was estimated that two years would be required to build and install the 184-inch cyclotron, and during the first year progress was rapid. The instrument was about 70 per cent completed when the Japanese struck at Pearl Harbor. By that time the Radiation Laboratory was already much occupied with nuclear research for the National Defense Research Committee, and Dr. Lawrence and his associates had looked forward to the help that the great cyclotron would bring to this effort. Nevertheless,

within a few weeks after Pearl Harbor, it became apparent that at the current rate of progress the cyclotron would be another year or so in building.

One problem was the separation of the fissionable Uranium 235 from the more abundant 238. Various efforts had been made to untangle the mixture, but all to no practical avail. Only microscopic amounts had been obtained. Dr. Lawrence felt sure that if the 4,000-ton magnet which was under construction for the cyclotron were available it would generate a magnetic field strong enough to effect the separation. Accordingly, application was made to the National Defense Research Committee for a special contract which would finance the employment of two additional construction crews, thus putting the work on a 24-hour basis in three shifts. For policy reasons, however, NDRC shrank from allotting government money to build equipment which was the property of an outside agency, the University of California. In this impasse Dr. Lawrence appealed to the Foundation, and a grant of $60,000 was made. As entered in the Trustees minutes (January 16, 1942) the funds were "for expenditure during 1942 for expediting the construction of the giant cyclotron." Actually, it was not the cyclotron as a whole, but only the electro-magnet whose construction was to be expedited.

As a result of this speed-up, the magnet was completed on May 26th, and went into service on June 1st. If the work had continued on the old 8-hour-day basis it would have been late October or early November before the magnet could possibly have been finished.

"This magnet was indispensable to the development of the atomic bomb," declares Dr. Lawrence. "With it we were able to make the desired separation, and then for the first time there were quantities of Uranium 235 sufficient for the experimentation which led to the making of the first bomb.

Without that magnet the whole bomb project would have been seriously delayed. And but for the decision in 1940 to build the cyclotron, there would have been no 184-inch magnet."

Three Types of Atom Smashers

Although the new cyclotron follows the general plan laid down for it in the original design, certain modifications introduced this year have doubled its energy output and made it practically a new instrument. The cyclotron was designed to accelerate streams of particles to energies of 100 million volts, but when it goes into action the beam will move under the urge of 200 million volts or more. How this change was accomplished is a story of outwitting the relativity effect.

Reduced to its simplest terms, the problem posed by the relativity effect is this. As the particles in the vacuum chamber of the cyclotron whirl in ever widening orbits, following the paths ordained by the pull of magnetism, they receive an electrical kick at each half turn of the spiral, and thereby are speeded up. But as their pace quickens, their mass also increases in accordance with Einstein's well-known law of the equivalence of energy and mass. For example, when it is moving at the speed corresponding to 300 million volts, an electron weighs 600 times more than it does at rest. And with increase of mass there is increase of inertia, consequently a tendency to slow down. Since the electrical impulses are precisely timed to give the particles a kick at each half turn, any slowing of the stream gets them out of step, and the kicks occur at the wrong time.

When the 184-inch cyclotron was designed, it was decided to overcome the relativity effect by progressively increasing the power of the electrical

impulses. This was frankly recognized as a measure of brute force, and would require the squandering of much power. But last fall members of the Radiation Laboratory staff began to rethink the problem, analyzed it mathematically, and out of these studies came a simple solution. Why not change the frequency of the electrical impulses? As the accelerated particles grow more massive and tend to slow down, vary the timing of the impulses so that they occur precisely in phase with the lagging motion. Then the kick will be given at the instant when the particle is there to receive it, and to make the most use of it - just as a push on a swing at the right time will send the swing higher. The application of this principle of phase stability made it possible to decrease the input of power to the cyclotron and at the same time double its output of energy.

There is another way to stabilize the phase. Instead of varying the frequency, vary the strength of the magnetic field. This method is more difficult to manage than the other, but Edwin M. McMillan, one of Lawrence's co-workers since 1932, has devised a way to apply it to a stream of light-weight particles - and from these calculations has invented a new type of accelerator which he calls a synchrotron. With the synchrotron Dr. McMillan figures that electrons can be accelerated to velocities corresponding to 300 million volts. Construction of the first 300-million-volt synchrotron is now under way on Charter Hill. The foundations have been laid a couple of hundred feet east of the House of the Cyclotron - and it is expected that the new accelerator will be in operation before the summer of 1947.

Still a third type of apparatus is under development - a device called the linear accelerator, the brain child of another young physicist on the staff, Luis Alvarez. The linear accelerator may be described as an

unrolled cyclotron. Instead of being whirled in a vacuum chamber, the particles here are shot in a straight line like the bullets through the barrel of a machine gun. At intervals along the "barrel" of the accelerator there is a surrounding battery of radar transmitters to supply the accelerating kick, and thus the particles are hustled from one section to the next with increasing velocity. Plans have been drawn for an experimental linear accelerator of 280 feet length, to consist of seven sections of 40 feet, each to be served by sixteen radars. This experimental apparatus should accelerate particles to about 140 million electron volts, and will provide the laboratory with a pilot plant to test the practicability of the idea. The construction of sections has already been begun on Charter Hill, and a site for the pilot plant has been picked north of the House of the Cyclotron.

"Each type of accelerator has advantages and disadvantages," said Dr. Lawrence, "and we want to test them competitively. Having all three available at one time, each working with particles of different mass, will impart extraordinary elasticity to the research program. Machines still more powerful and versatile can be expected as a result of experience with the cyclotron, the synchrotron, and the linear accelerator. It seems probable that within less than a decade, machines will be generating energies of 1,000 million volts and even more."

The Research Team

Perhaps the strongest impression that one brings away from a visit to the Radiation Laboratory is the sense of teamwork which animates the entire place. There are, in fact, four places in which the research is carried on. First is the Old Radiation Laboratory, which houses the 37-inch cyclotron,

still a useful tool of research; next the Crocker Radiation Laboratory, which houses the 60-inch cyclotron; then the Donner Laboratory for Medical Physics, which at present is serving as offices for the administrative staff in addition to providing numerous rooms for research. These three centers are on the university campus. And in addition there is the new area on Charter Hill. Despite the seeming dispersion, there is the closest integration and camaraderie between the campus centers and the hilltop.

Lawrence as director has built up an extraordinary staff. It includes chemists and medical men as well as physicists, mathematicians, and engineers. A whole chapter could be written of the work in medical physics, especially the study of leukemia, polycythemia, and other forms of cancer, which is carried on by John H. Lawrence, M. D., a brother of the director. A broad program of fundamental research in biology with the use of radioactive substances is being pursued by a group under Professor Melvin Calvin, while Professor Glenn T. Seaborg and associates are studying the chemistry of plutonium, americium, and curium.

Chemical research is assuming increasing importance in the triple teamwork of biology, chemistry, and physics which has its home here, and at present a special laboratory for experimenting with plutonium and other "hot" elements is rising on Charter Hill. By arrangement with the Foundation a small part of the money appropriated for the 184-inch cyclotron is being used to finance this building. In addition to the many who are working on construction of the new facilities, the staff of scientists has been greatly increased. In October the laboratory payroll totaled 679 persons, including a research staff of 247 - which compares with a total staff of 35 workers at the beginning of 1940. That's how one nuclear research team has grown in six years.