THE ACCELERATOR CONFERENCE

Many new particle accelerators
are out of the blueprint stage and physicists
are getting down to the brass tacks
of what to do with them.

by ***E. Alfred Burrill***

The extensive building program of presently planned electronuclear machines is, for the most part, completed. It seemed like a good idea to survey existing problems in the particle accelerator field and possible experiments to be conducted in it.

J. G. Trump, associate professor of electrical engineering at the Massachusetts Institute of Technology, with the blessings of President K. T. Compton, conceived the idea of bringing together experimental men who were working with high-energy particle accelerators. The purpose was to get them into one room, where, prodded by each other and a liberal sprinkling of theoretical physicists, some coherent suggestions and plans would evolve in terms of what the machines could and should do. About 150 physicists attended, including G. Breit, K. K. Darrow, E. Fermi, W. A. Fowler, W. W. Hansen,

R. G. Herb, D. W. Kerst, L. Leprince-Ringuet, M. S. Livingston, B. Rossi, J. C. Slater, M. S. Vallarta, R. J. Van de Graaff, and J. H. Williams.

Two distinct fields of experimental endeavor seemed apparent, and the program was so divided when the invitations were sent out. One field concerns itself with investigations in the binding-energy range of the nucleus, and the second with exploration into the binding-energy range of the nuclear particles (nucleons) themselves. To put it another way, one was concerned with high-energy accelerators, and the other with higher-energy accelerators. Several conferees came primed to give short papers summarizing what problems seemed most important to them. They helped keep the discussion going continuously for four solid days.

There was one further division of interest that developed as the conference went on. One group was impatient to push on to new horizons, and the other wished to make more accurate analyses in the energy ranges now prolifically available. The former group was relying heavily on the guidance of the theoretical physicists, whereas the latter was in part guiding the theorists. There could be no better evidence of the need for the interchange of ideas which this conference sponsored.

More Precision

The structure of the nucleus stands today at the frontiers of physical knowledge occupied two decades ago by the configuration of electrons surrounding that selfsame nucleus. Only through experiments which display the character of the nucleus can the basic properties of matter be uncovered, and the character of the nucleus can be revealed only by penetrating or disturbing it and measuring the effects produced. This requires energy several million times that required for atomic spectroscopy, the study of electron configuration, for high energy is needed to push subatomic particles such as electrons, positive ions, neutrons, or gamma photons, through the electron shell and the potential barrier surrounding the nucleus.

Various types of particle accelerators have been developed to accelerate, or to produce, particles in copious and controllable amounts, and their value for different kinds of experiments lies in how copious, how controllable, and how energetic the beams of particles they produce can be. One reason for the variety of accelerators is that no one yet built, or planned, has superior qualifications in all three of these important respects.

In bombarding nuclei with high-energy particles, physicists are able to observe how the particles are deflected by nuclear forces, how much the energy is absorbed by nuclei in the bombarding process, how the nuclei radiate away their increased energy, how the particles are scattered by the stuff of the nucleus itself, how to detect the products of disintegration, and so forth. From these fundamental experiments, theorists can formulate a more coherent explanation of nuclear behavior.

In the energy range from one to ten million electron volts, the electrostatic accelerator emerges as the outstanding research tool for nuclear investigations. The particle beams from this machine are very uniform in their energy and can be controlled over a wide range; they have high intensities, either continuous or modulated, and a low background of competing radiations (which tend to confuse the experimentalist). That the electrostatic, or Van de Graaff, accelerator is considered unique in its field is evidenced by the number of such machines now in use or under construction in research laboratories throughout the world.

This precision in the control of the energy of bombarding particles is essential in the binding-energy range because only through data of very high accuracy can a quantitative theory emerge. The energy levels of excited nuclei are analogous to spectrum lines of excited atoms, but they are much more complex and difficult to interpret. Several different particles are involved in the nucleus, consequently very careful measurements must be made to avoid masking some subtle nuclear states by other more evident states.

Thus the theorists at the conference recommended the investigation of the lighter and more fundamental nuclei because fewer particles are involved and hence nuclear spectra would be simpler to interpret. Their suggestion is not new, of course, but its repetition points up the failure to develop, for a period of several years now, a theory analogous to the one evolved by Rydberg for atomic spectroscopy. The theoretical people have been hampered by the paucity of the data and by insufficient energy resolution. The results of scattering and disintegration experiments, as well as the measurement of energy levels, would permit the theoretical physicists to test the various models of the nucleus which they have devised. Just what takes place at different energies would also serve as guideposts for future experiments with higher-energy accelerators. The deviations of experimental results from present theory might be large and, if the data were precise, a foundation for further investigation could be laid.

It is now possible to control the beam energy from an electrostatic accelerator to about one part in ten thousand by various means which have been tested or which are now in the process of development. Probably this cannot be improved much further because the thermal motion of the atoms in the source, of the order of one hundred electron volts, furnishes particles to the accelerator with initial small differences in energy. One gathered from the conference that the improvement in positive-ion sources, which have been the main limitation of the beam intensity from these accelerators, has culminated in a variety of models which are more dependable than their predecessors.

With more intense beams the need for highly sensitive and hence delicate detection equipment is reduced, and the resolution of data can be improved because of the better statistics involved. Special measuring devices for nuclear spectroscopy are now being put to use, including a large magnetic spectrograph for determining the energies of scattered and disintegration products to an accuracy of one part in a thousand, and a beta-ray spectrograph which converts the gamma-rays emitted from a nuclear process into electrons whose energy can be accurately determined. Apparently, also, the use of electrostatic accelerators as a source of neutrons is gradually increasing. Because the particles from these machines are very uniform in their energy neutrons of comparable uniformity can be produced. Since the neutron is a chargeless particle, it cannot be accelerated to the desired energy and must, therefore, be obtained through a secondary process. Controllable sources of neutrons are of great value in nuclear transmutation work and can be important in the fields of nuclear spectroscopy and scattering.

The energies of particle accelerators are measured by comparison with certain sharply-defined nuclear energy levels of lithium, which are used as standards. The majority of measurements today depend on the absolute calibration of levels in lithium determined ten years ago. R. G. Herb has gone over this ground again, using a proton beam with remarkably uniform energy for his absolute calibration. The variation in energy of the proton beam was only one part in five thousand. Herb found that the absolute values of the lithium energy levels are at slight variance with those accepted up to now.

Although this variation is less than one and one-half percent, the effect of such a discrepancy can be very serious. Certain fundamental relationships, such as the mass difference between neutrons and protons, are very sensitive to the energies used in their determination. A slight variation in measured energy means a much greater discrepancy in the calculations for the mass difference. Herb emphasized the need for similar measurements to be made by other groups in order to establish a more satisfactory value for the particular levels. Surely the uncertainty in this field needs straightening out in order that the theorists have a firmer basis on which to work.

One matter was brought up which illustrated the versatility of the electrostatic accelerator. The excitation of nuclei by electrons and gamma rays in the binding-energy range was championed by B. Waldman. He deplored the fact that there were so few laboratories utilizing electrons and gamma rays as bombarding radiations because he feels that there is a considerable amount of research which should be done not only in the investigation of nuclear levels, but also in the study of the properties of electrons and gamma rays themselves. The electrostatic accelerator lends itself admirably to the production of intense electron and gamma-ray beams, but much of the existing work in this regard has been done with relatively weak radioactive sources.

The present situation with regard to electrostatic accelerator design can be divided into four rough categories. Machines now in service are capable of accelerating electron and positive-ion beams in the range one-half million to three million electron volts, with a few exceptions. The results obtained from these accelerators have pointed the way toward the design and construction of more powerful counterparts. Several generators designed to produce five-million-electron-volt particles are now being built, both in this country and abroad. In addition to being used for nuclear investigation work themselves, some of these newer machines are destined as injectors for particle accelerators of much higher energies.

Representing the present practical upper limit in energies attainable by electrostatic accelerators, two twelve-million-electron-volt units are in the process of construction at the Massachusetts Institute of Technology and Los Alamos. At the other end of the energy (and size) scale, compact proton accelerators for the range one to two million electron volts are now being produced on a commercial basis. From this variety of machines there is hope that one can get results of sufficient accuracy to test the theories now current and to point to others perhaps more fruitful.

New Horizons

Not satisfied with higher precision in lower energy ranges, there were many at the conference who wanted higher energy ranges though it means paying for it with lower precision. Protons and neutrons are held very tightly together in a nucleus by forces which are very powerful. That is known, but what these forces are is not well understood. The magnitude of the forces between neutrons, between protons, and between neutrons and protons has been measured. In character these forces appear to be of an exchange type, similar to the force by which two hydrogen atoms share their electrons in a molecule. A particle, intermediate in mass between the electron and the proton, emerged from theoretical considerations, and shortly thereafter was discovered in cosmic radiation. It is the mesotron. Its presence in the radiation bombarding the earth has tempted physicists to try to extract it from nuclei, something which takes hundreds of millions of electron volts.

The mesotron appears to be a key to the knowledge of intimate nuclear forces and to the character of cosmic radiation. As experimental data has accrued, two basic types of mesotrons seem to emerge, both of which can be positively or negatively charged, or neutral. The heavier mesotron seems to be associated with nuclear forces; the lighter results mainly from the decay of the heavy mesotrons, and infrequently from nuclear bombardment. The Berkeley 184-inch synchrocyclotron has produced both heavy and light mesotrons with alpha-particle energies of about 380 million electron volts. The availability of these virtually unknown particles for investigation has stimulated the activity of high-energy particle accelerator construction.

In addition to the investigation of the properties and production of mesotrons, there is a widespread interest in the interaction of electrons and gamma-rays with the electric field of the nucleus—the 'normal,' or Coulomb electric field which binds the electrons to their atom—to check the new theories of quantum electrodynamics. Besides needing very high energies to observe effects which would shed light on this field, the experimental physicist is required to make very precise measurements because of the very small changes in momentum of the particles of interest in the reaction despite the enormous bombarding energy.

The theoretical physicists present at this conference were fresh from their sessions at the Pocono Conference in the early spring and essentially echoed its conclusions. There was hope of discovery and anticipation of what would happen when the particle energy is increased. The possibility of producing super-heavy mesotrons was introduced, and the potentialities of scattering electrons and neutrons by nuclei were enhanced by the possibility of diffracting these bombarding particles by the nucleons themselves, thus yielding a picture of the nuclear structure in the same sense that x-ray and electron diffraction experiments with available energies today yield information regarding the structures of crystals.

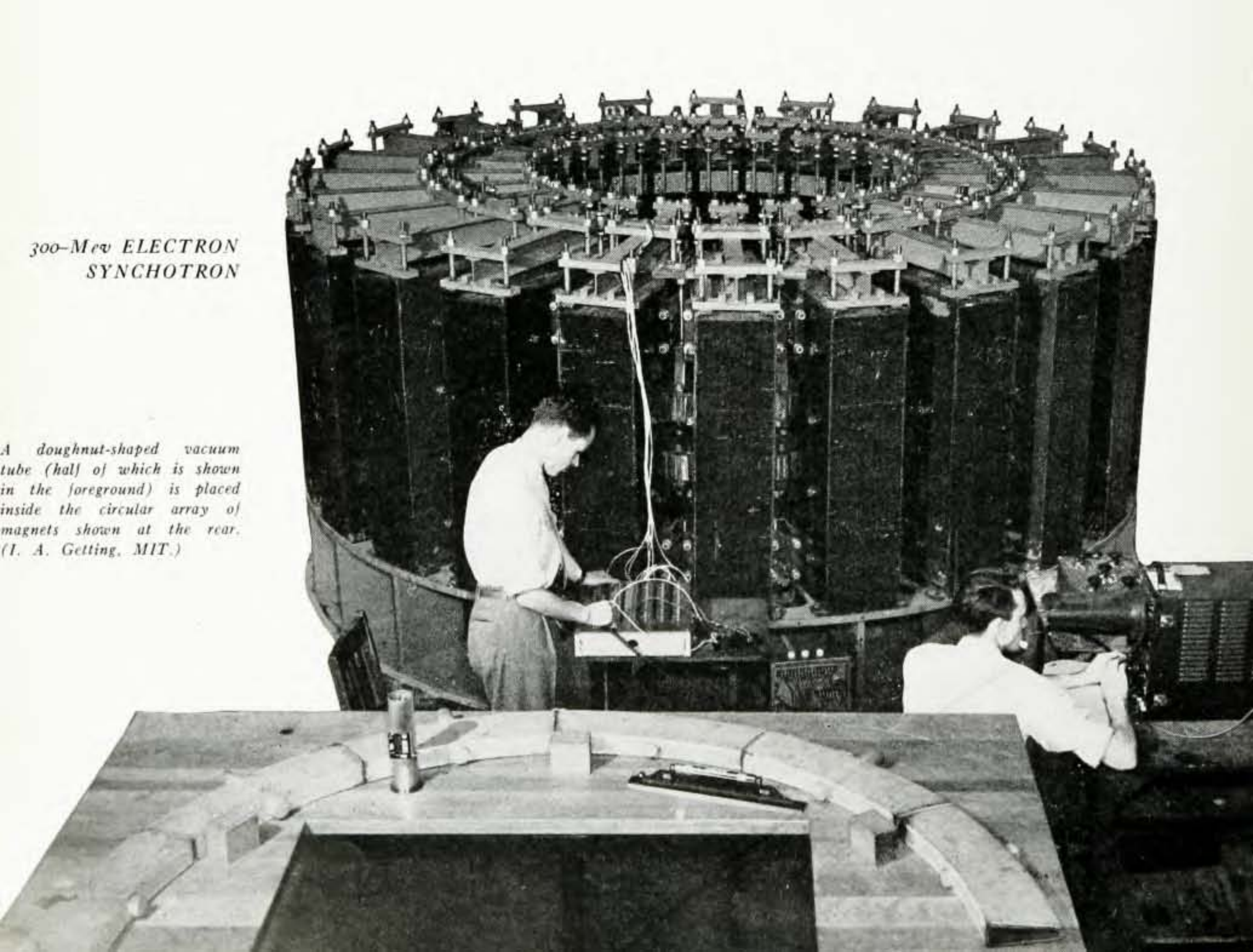
Aside from the more spectacular experiments to be performed in the high-energy range, as some were quick to point out, careful measurements of a more routine nature are important. The production and absorption of x-rays, the absorption and scattering of electrons, and the host of high-energy extrapolations of well-established phenomena, to name but a few, can contribute greatly to the present knowledge of nuclear physics.

In the contest for positive ions of higher energies, the cyclotron and its recent modification, the synchrocyclotron, reach a practical limit at about six hundred million electron volts. The cost and size of such machines for higher energies become prohibitive from the practical viewpoint. The betatron, for electron acceleration, is limited in the region of one hundred million electron volts because the radiation losses of electrons whirling in circular orbits consume an increasing amount of the energy normally imparted to the electron. The electron synchrotron is capable of accelerating particles to about one billion electron volts, beyond which energy radiation losses render this machine impractical. For the production of protons of several billion electron volts, the proton synchrotron seems to be the most economical and practical answer. Two units are being constructed at present, one at Brookhaven for three billion electron volts and one at Berkeley for six billion.

The wave guide linear accelerator appears to be the only answer for obtaining electrons of energies beyond one billion electron volts, but it depends upon the development of radio frequency power tubes capable of handling several times the power that is possible today. At present, small sections of linear accelerators have been constructed with encouraging results. Increasing their energy to the billion-electron-volt range consists essentially in adding on sections and increasing the power at radiofrequencies. At energies lower than one billion electron volts the linear accelerator may surpass the synchrotron because of the greater beam intensities which it can produce. The synchrotron is limited to a few pulses per minute whereas the linear accelerator can operate at much higher repetition rates.

Some types of accelerators have been eliminated in the race for very high energies, for example, the proton linear accelerator, which at present is limited to about 32 million electron volts because of its size and cost. This type of electronuclear machine, together with the betatron, cyclotron, and certain modifications of the electron linear accelerator, will be very valuable in bridging the energy gap between the electrostatic accelerator range and the synchrotron and synchrocyclotron range.

The accelerator conference closed on a high note of optimism and anticipation. There was a regret that there had not been more time for informal discussions of experiments and techniques, but on the other hand there was an appreciation of the opportunity of being able to visualize the grand picture of particle acceleration and bombardment. Up to now has been a period of building. Everyone is anxious to see what new things will be done with the machines that are coming into being.



300–Mev ELECTRON SYNCHOTRON

A doughnut-shaped vacuum tube (half of which is shown in the foreground) is placed inside the circular array of magnets shown at the rear. (I. A. Getting, MIT.)