RESEARCH FACILITIES AND PROGRAMS

Nuclear structure at BNL

Facilities for nuclear structure research at Brookhaven National Laboratory are being expanded. The existing 60-inch cyclotron will be converted into a spiral-ridge machine with variable energy, and two Model MP Tandem Van de Graaff accelerators will be constructed there by High Voltage Engineering Corporation. The machines are intended to supplement current university facilities by providing increased energy capability and high-energy resolution.

Modifications for the 60-inch cyclotron are already in progress, and the installation is expected to be finished by September 1966. The energy will be smoothly variable by a factor of ten. The maximum energies of the cyclotron will be 40 MeV for protons and ^{4}He particles 20 MeV for deuterons, and 60 MeV for ^{3}He particles. External beam currents of thirty to fifty microamperes with an energy spread of fifty to seventy keV are expected. It will also be possible to accelerate various heavy ions to energies approaching 100 MeV. A switching magnet and multiple-beampipe arrangement will be installed to extend the availability of experimental stations; a small on-line computer will be available for multiparameter experiments involving several particles in coincidence.

The two tandem Van de Graaff machines will be installed in a new building especially designed for them, and will be able to operate separately, each as a two-stage 20-MeV machine, or else as a single three-stage 30-MeV accelerator with the first machine acting as an injector for the second machine. The injection will be done by operating the first machine with a terminal ion source.

The three-stage beam will be switched into any one of three different rooms by a $\pm$70-degree switching magnet, and the rooms may be used independently so that experimental equipment may be installed and tested in two of the rooms while the other is being used for research. The maximum energy will be 30 MeV for three-stage operation with protons, deuterons, or tritons, and 40 MeV for ^{3}He and ^{4}He ions when negative He ions are available. The energy spread is expected to be + 2 keV and the maximum beam current to be ten microamperes. It will also be possible to accelerate heavy ions to several hundred MeV.

It is expected that the machines will be operational as two-stage tandem Van de Graaff accelerators by the spring of 1968. The terminal source and three-stage operation are expected to be ready for research within a year after final acceptance tests for the two standard machines.

A single-gap high-resolution magnetic spectrometer is also planned for the facility in order to take advantage of the high-energy-resolution capability of the three-stage operation. Most of the experimental apparatus in use at either the cyclotron or the Van de Graaffs will be readily exchangeable from one machine to the other. Since the cyclotron and Van de Graaff buildings will adjoin, it will be possible in the future to inject the cyclotron beam into the tandem accelerator or vice persa, if desired.

10-BeV electrons at Cornell

The world's largest electron synchrotron—10 BeV, will be built at Cornell University with a grant of $11.3 million from the National Science Foundation. This is the largest single grant ever given by NSF to a university. Construction is scheduled to begin immediately and expected to take two or three years.

At present the largest electron synchrotrons are the Cambridge Electron Accelerator in the United States, and DESY in Hamburg. Both machines have peak energies of about 6 BeV and may be capable eventually of 7 or 8 BeV. The Cornell machine is designed for 10 BeV and may eventually give 15 BeV.

It will be a strong-focusing machine, taking 250 MeV electrons from a linear accelerator, and injecting them into a ring tunnel whose orbit radius will be about four hundred feet. There will be six straight sections separating the 96 magnets which alternately focus and defocus the electrons.

The magnets will be very small, 11½" by 8" in cross section. The magnetic field will be rather low, about five kilogauss, because of the large orbit radius. The machine will have no vacuum doughnut in the gap; instead the magnet will be covered on the outside by a stainless steel sheath. The accelerator is expected to produce 10^{11} electrons per pulse with a repetition rate of sixty cycles per second.

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CERN rf separator

A radiofrequency beam separator, which produces a beam of 10-BeV/*c* negative kaons, is now operating at CERN in conjunction with the 28-BeV proton synchrotron. The new installation is the first to use radiofrequency electromagnetic fields as a method of separating beams at such high energies. A separator of the same type is under construction at Brookhaven, and related types are being built at Dubna, Stanford, and Orsay.

The simplest kind of particle separator is electrostatic, but it is only convenient for particles with relatively low energy. As the energy is increased, very high voltages are needed to get a reasonable separation between particles; also, as the energy is increased the difference in velocities produced by the electrostatic field becomes smaller due to the relativity effect. At CERN, for example, in order to produce electrostatically a reasonably pure beam of kaons with 6 BeV/*c* momentum, the beam line was 180 m long, and contained some forty separate components, including three separators in series, each with 500 kV across a gap of 10 cm.

The new separator is basically a sensitive timing device: only those particles which cover a particular distance at the correct velocity can pass through—the others are intercepted. Before they reach the separator, all the particles have the same momentum, within one percent. Then the beam, consisting of pions and kaons, enters a loaded waveguide propagating a single mode of an electromagnetic wave. The particles are deflected through an angle α by the field, are then focused by a magnetic lens system, and then enter a second waveguide. Even though all the particles have the same momentum, the pions have greater velocity and so reach the next waveguide first. The system is adjusted so that the pions are in phase with the waves in the second guide. Hence the pions are again deflected through an angle α and emerge along the axis of the system. Meanwhile the kaons arrive out of phase, are deflected through α in the opposite direction, and emerge at an angle 2α with respect to the axis.

Thus a narrow beam of pions is produced. But it is kaons that one really wants, so a beam stopper is used to absorb the pions. The remaining kaons form a fan of angle 4α, which is collected into a kaon beam by a lens system, and the experimenters are then in business.

Each waveguide is fed as much as twenty megawatts of pulsed rf power from a klystron of the type used in radar equipment. It operates at 2855 Mc/sec, with a pulse length of eight microseconds and a repetition rate of one pulse per second. Since the rf system has such a short pulse length, this type of beam is mainly useful for bubble-chamber experiments.

When the separators began operating last winter they produced about a dozen K^- particles per burst, along with about half a dozen muons. Then it was time to use the bubble chamber; the intensity was deliberately reduced, and the photographs taken showed an average of seven kaons per burst, with only five or ten percent contamination from other strongly interacting particles.

If there are improvements in klystrons or if superconducting waveguides are developed, rf separators might prove to be useful in spark chamber or counter experiments as well.

The moon and its orbit

A new calculation of the moon's orbit, completed during the past year by W. J. Eckert, director of the IBM Watson Laboratory and professor of celestial mechanics at Columbia University, and H. F. Smith, Jr., a research associate at Watson Laboratory and a graduate student at Columbia, has predicted lunar positions with such precision that it has corrected a fluctuating error of 3/10 second per eighteen months in the astronomical time standard. The extreme accuracy of the calculation has also yielded a suggestion that the moon may be denser near the surface than it is in the center. The prediction rests on angular-momentum considerations necessary to explain a discrepancy of ten parts in seven million in the motion of the nodes of the lunar orbit.

The new calculation provides a 100-fold increase in the accuracy of the "main problem" of lunar theory, i.e., the description of the motion of the moon in response to gravitational forces of the earth-sun-moon system. (Effects of the other planets, and of the shapes of the earth and the moon, as well as relativistic effects, are added to the main problem as smaller corrections.)

The main problem presents a set of sixth-order nonlinear differential equations. The solution is attempted by substituting four-dimensional harmonic series, which go roughly to the tenth order, into the differential equations. Calculating out the series substitution results in 6000 residuals which must be used to determine corrections to the coefficients. The problem is further complicated by the fact that, of the four frequencies of the harmonic series, only two (angular motions of the sun and moon) are assumed as known, while the other two (precession of perigee and precession of nodes) must be found in the course of the calculation.

Six thousand variation equations with 600 unknowns are formed to connect the residuals with the corrections, and these yield a 6000 by 6000 matrix among whose 36 million elements the corrected coefficients are found. The corrected coefficients are then substituted back, and the calculation is carried forward again to yield a corrected result. The final solution in the Eckert-Smith procedure is accurate to ten significant figures.

The new solution to the main problem has exposed a significant error in the prediction of lunar motion contained in the tables of current ephemerides. One of the many fluctuations in the moon's orbital speed is an oscillation with a three-year cycle. Current lunar tables do not reflect the full effect of this cycle; their predictions were found to be 440 feet ahead of or behind the moon at the extremes of the cycle. Since the lunar orbital motion is used as the astronomical time standard, this circumstance contributed an error of ± 0.135 second in astronomical time determinations.

The suggestion about the distribution of mass within the moon rests on the calculation of the rate of rotation of the moon's orbital plane in space (precession of nodes), which is a sensitive indicator of forces acting on the moon. The nodes make about six revolutions (seven million seconds of arc) per century. After secondary corrections have been added to the contribution from the main problem, there still exists a discrepancy of about 25 seconds of arc between the observed and calculated motion of the nodes. If this contribution is attributed solely to the distribution of mass in the moon, it leads to the conclusion that the moon has a very high moment of inertia about its axis, i.e., that there is a concentration of dense material near the moon's surface. If the moon were homogeneous, 10 of the 25 seconds discrepancy would remain unaccounted for; if it had a heavy core like the earth, twelve seconds would remain unexplained.

Disagreement over the lunar mass distribution has gone on for a long time. In 1908, E. W. Brown, whose lunar computations have been standard for forty years, assumed that the