

RESEARCH FACILITIES AND PROGRAMS

Nuclear-structure Emperor operating at Yale

The A. W. Wright Nuclear Structure Laboratory at Yale University, which houses the first Emperor Van de Graaff accelerator, is being dedicated this month. Its two-stage tandem machine produces the most energetic protons yet obtained with an electrostatic accelerator—23.50 MeV; this energy could eventually go as high as 30 MeV, according to D. Allan Bromley, director of the laboratory. Beam currents are also high. During acceptance tests in July the Emperor put out 25 microamperes at 15 MeV and 10 μ A at 20 MeV.

Like all Van de Graaffs, the Emperor produces a narrow beam whose energy is precisely controllable, easily varied and continuous. It can accelerate ions of any nucleus from hydrogen to uranium, provided that a negative ion can be formed. The characteristics of electrostatic accelerators, combined with the newly available energy, make the Emperor an exciting new tool for nuclear-structure physics.

To learn more about the new accelerator and the research that can be done with it, we recently visited the laboratory, located near the edge of the New Haven Campus. Yale architecture is noted for its diversity, and its nuclear physicists wanted to continue the tradition. Noting that only one style was conspicuously absent, they built themselves a Mayan temple. (Bromley complains, however, that both Yale and AEC have taken a discouragingly narrow view regarding provision of sacrificial maidens.) The Mayan contours also help shield the accelerator by covering it with many meters of earth.

Inside the earth shield the Emperor—46 meters long and 180 000 kg—stands in a spacious room majestically alone and clearly visible when its beam is off (otherwise it can be viewed by strategically placed television cameras). It is the first in a new line of tandem Van de Graaffs. A second, at the University of Rochester, just had its first beam last month; 8 MeV protons came out. Other Emperors will go into serv-

ice at the University of Minnesota and the Chalk River Laboratory.

Tandems. All tandem machines essentially trick a singly ionized particle into seeing twice the actual dc electrode potential by accelerating negative ions, converting them into positive ions and accelerating them again; if the particle has higher charge the effective voltage gain is higher.

To produce negative ions, the machine allows positive ions to enter a gas-filled electron-adding canal, where a small percentage become neutral and then acquire a negative charge. An analyzing magnet then directs negative ions to the accelerator structure, where they are accelerated by the positive electrode and acquire an energy that is the product of voltage and ionic charge. Then the ions enter a gas filled stripping canal and, because of their high velocity, lose some of their electrons. The newly positive ions are further accelerated back to ground potential, acquiring additional energy, proportional to their acquired charge.

More than 30 tandems have been installed by High Voltage Engineering

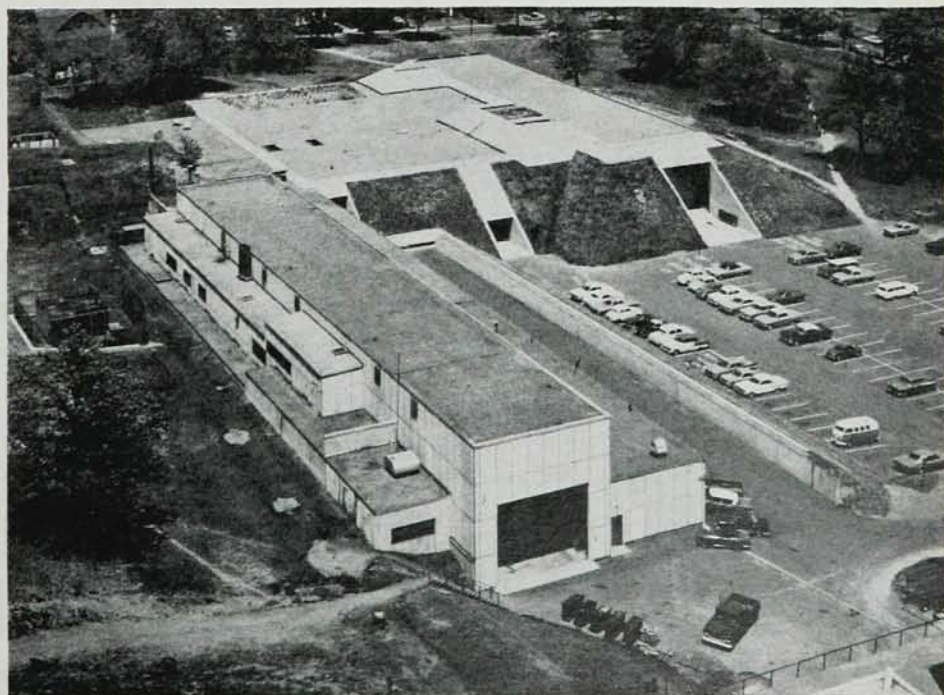
Corp. since 1959, many of which produce 15-MeV proton beams.

What is an Emperor? Six years ago Bromley convinced HVEC to build a new tandem—the Emperor—a 10-MV terminal, high-current version. Yale and HVEC research staff collaborated on design, and construction was started in 1963. Originally the plans were to build the Emperor at HVEC and then float it from Boston harbor to New Haven. Unfortunately transporting it from the harbor to Yale's campus would have required more urban renewal than the city was prepared for; so the accelerator was built in pieces and then assembled on site.

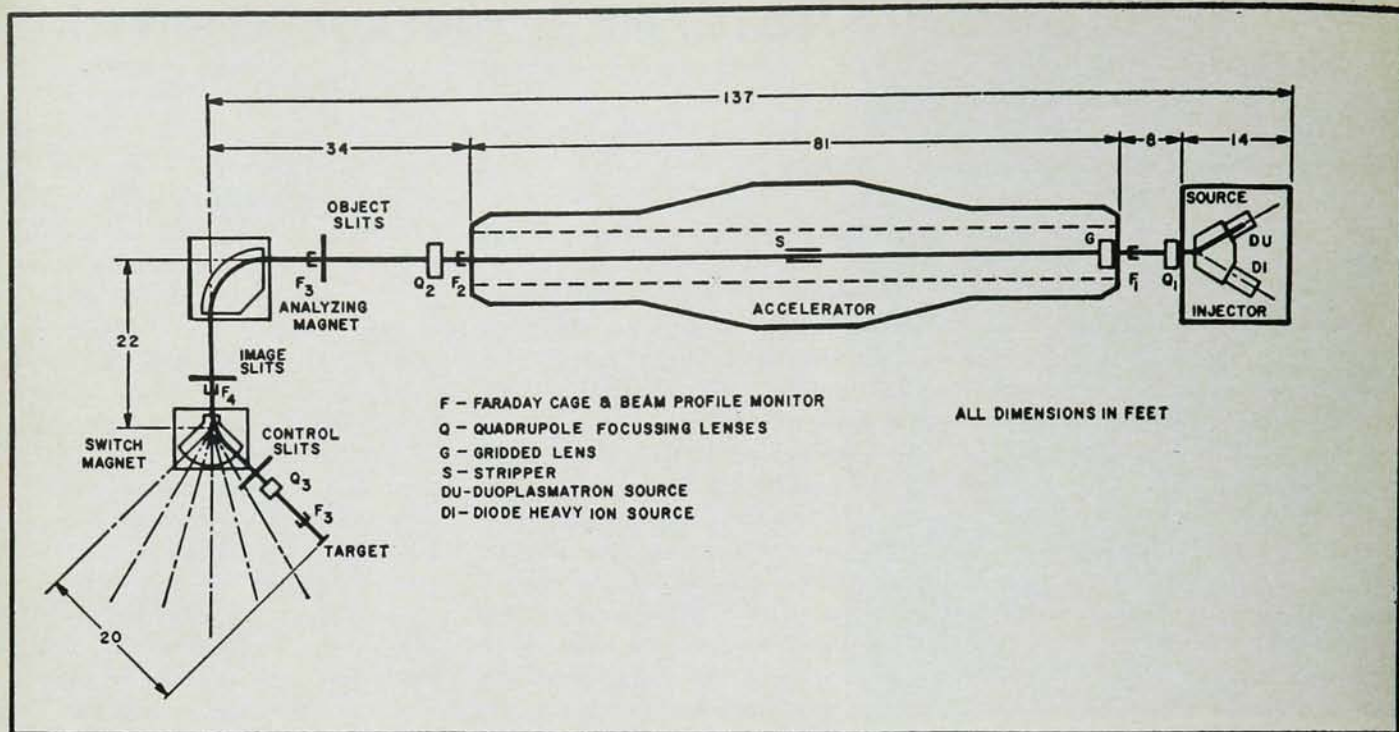
Sections were welded together; then the entire tank was heated to a cherry red to anneal it. To check its seaworthiness it was filled with water and a J.-Arthur-Rank type hammered on it.

The accelerator is supported by a horizontal insulating structure, 21 meters long and 25 tons heavy, and made primarily of glass. In the center of the truss-type structure is the high-voltage terminal.

Two major factors contribute to the Emperor's unique capabilities. First, it uses a "tilted-gradient" acceleration



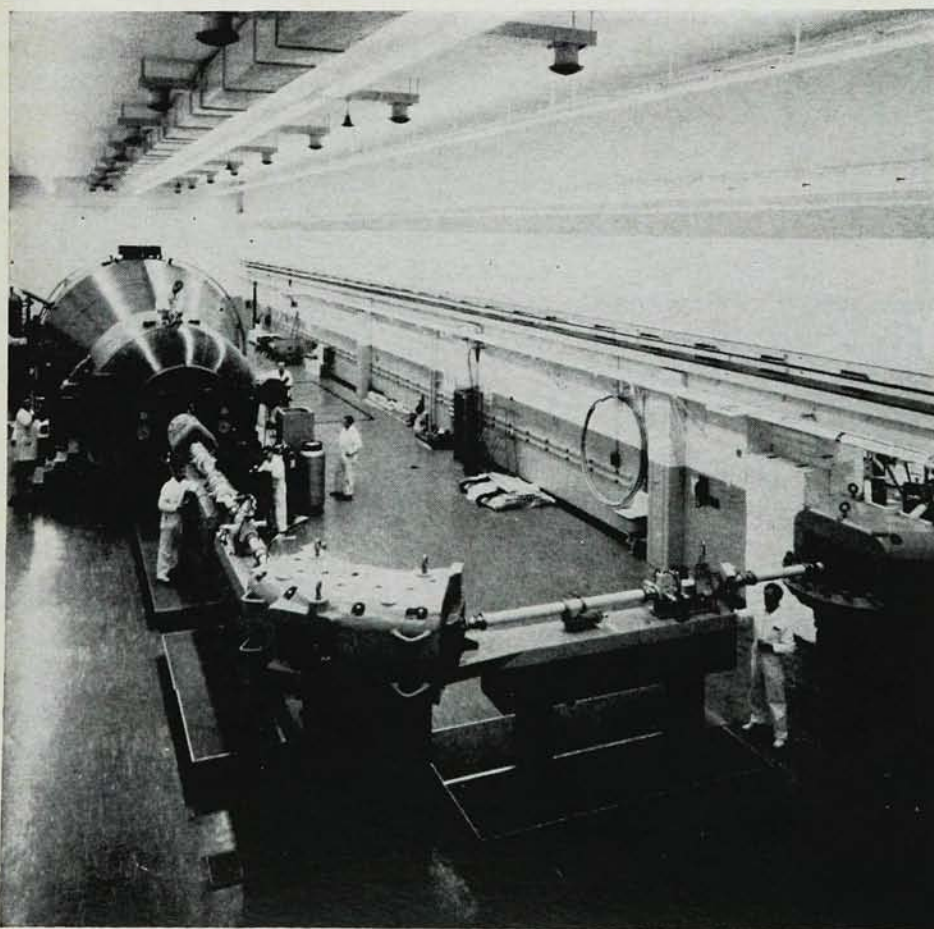
"MAYAN TEMPLE" on Yale campus houses and shields Emperor Van de Graaff.



EMPEROR VAN DE GRAAFF LAYOUT. Ions enter accelerator "tank" from sources

at right. At S their electrical polarity is reversed, and they get a second kick in

the second half of the tank. Accelerated particles leave tank at left.



THE EMPEROR CONSTRUCTED. Accelerator tank is at upper left: Accelerated particles come down the thin tube, make

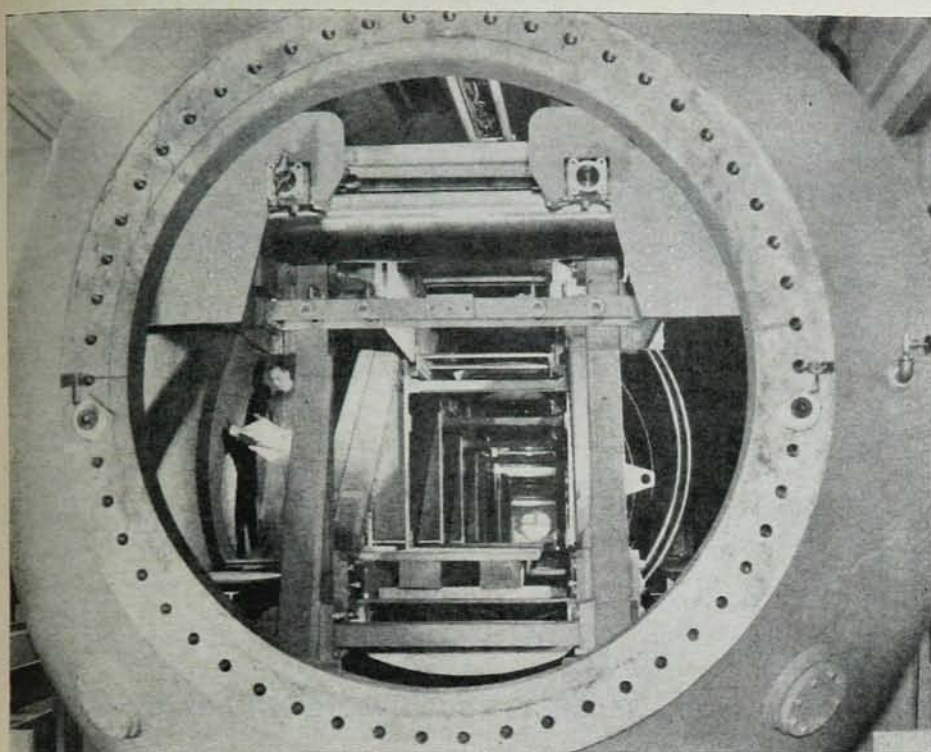
a 90-degree turn in the analyzing magnet at lower left and proceed to targets through switch magnet at lower right.

tube, to remove unwanted particles and prevent radiation from lowering the breakdown potential in the insulating gas. Second, adding sulfur hexafluoride to the conventional insulating mixture of carbon dioxide and nitrogen is expected to make the breakdown potential much higher.

Ions can be supplied by two different sources simultaneously; a duoplasmatron source is being used now. Once a diode ion source is installed for beams of heavy ions and protons, the duoplasmatron will be reserved for helium.

Originally designers expected that the beam being accelerated would produce enough background radiation to provide the slight ionization of the insulating gas required for proper operation. The inclined field tubes now turned out to be so clean, however, that the ionization is produced by inserting an 8-curie source into the tank.

Apparatus. Four major target areas are planned; right now one target room and a gamma cave are being used. The cave, which houses a goniometer for angular correlation studies, is built entirely of ilmenite concrete to reduce background; during opera-



EMPEROR TANK INTERIOR. With the end plate of the accelerating tank

removed, members of the Yale staff can walk inside to check components.

tion people are excluded from the cave because the normal radioactivity their bodies emit would mask the radiation being measured.

A 24-gap magnetic spectrograph being built at the Atomic Weapons Research Laboratory, Aldermaston, England, is expected early next year. The spectrograph will occupy a vacuum sphere 5.2 meters in diameter. The entering beam strikes a target placed in the spectrograph's center, and emitted particles are detected simultaneously by 24 nuclear emulsions at 7.5-deg intervals around the circumference. The entire magnet (80-cm pole radius) can be rotated to cover all intermediate angular ranges. Each exposure will yield 12 meters of film, which must then be scanned; it is hoped to automate this scanning in the near future.

A data-acquisition and control system, jointly developed by Yale and IBM, will be installed late this year. It is based on an IBM 360/44 central processor with extremely flexible input-output capabilities. The gamma-cave goniometer will be the first candidate for on-line control, followed by some particle angular-distribution chambers that are being built. Eventu-

ally Bromley hopes the accelerator itself will be controlled on line.

Kinds of experiments. Since the Emperor can produce a high-energy (for Van de Graaffs), precisely controllable beam of almost any particle you can name, Yale physicists are eagerly preparing a large and varied assortment of experiments for it.

The first experiment reported from the Emperor appeared in *Phys. Rev. Letters* for 28 Sept. Bromley, Jack C. Overley and P. D. Parker made precision mass measurements of several neutron-deficient isotopes (^{12}N , ^{24}Al , ^{28}P and ^{40}Sc), using a p,n reaction to produce each of the unstable isotopes and observing the threshold energy. Such precise mass determinations will provide stringent comparisons of masses in a variety of isobaric multiplets, a subject that is once again of great interest to nuclear physicists. Yale also plans to do p,2n reactions, which since they have high negative Q (more than 8 or 10 MeV) have not been examined in much detail previously.

Heavy ions will figure in many of the Emperor's experiments, since they have the following advantages: (a) Their short mean free path localizes the interaction in the nuclear sur-

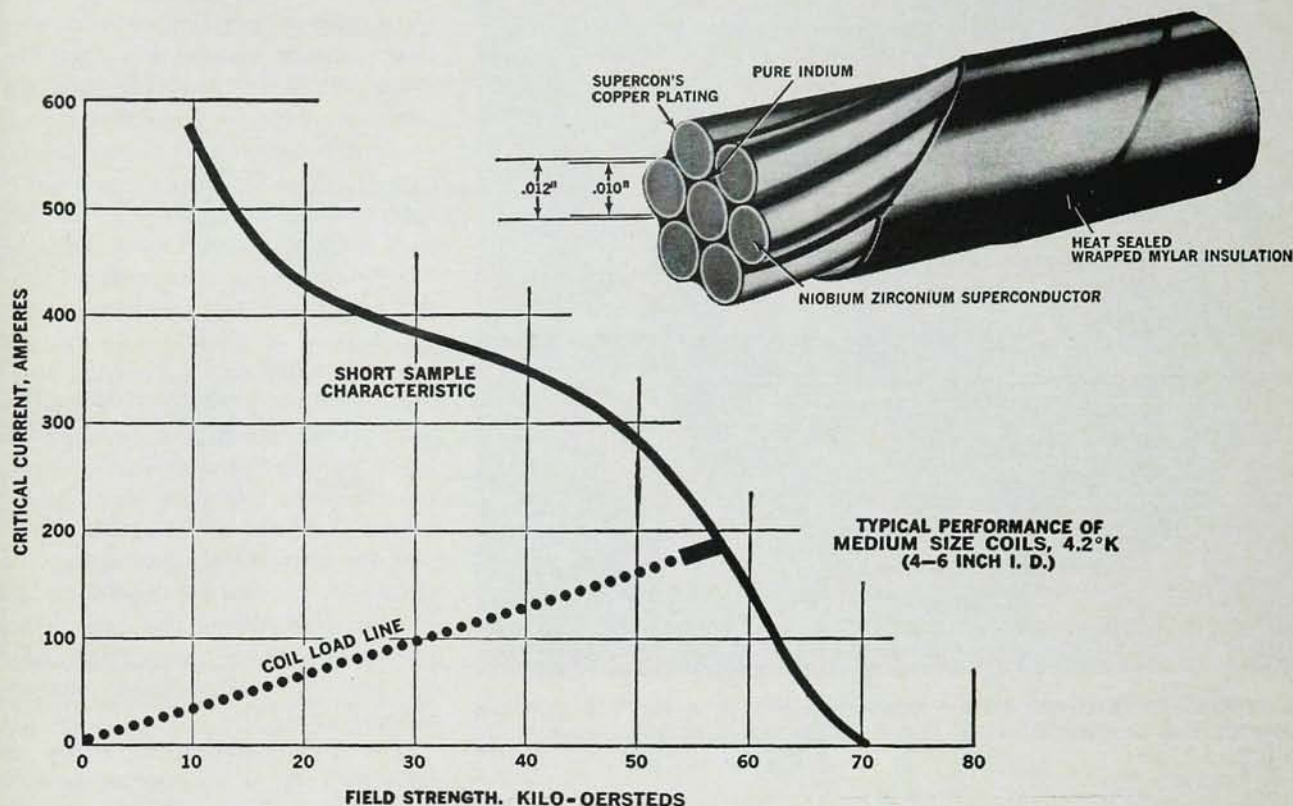
face, so that collective excitations are isolated and enhanced. (b) For a given energy heavy projectiles carry large angular momenta so one can study relatively low-lying high-spin states. (c) They provide direct access to cluster-reaction mechanisms. (d) The complexity of the heavy ions often removes ambiguities in the actual reaction mechanisms. (e) One can study the simultaneous excitation of both the target and the incident particle. (f) Because of their high charge they are well suited to the study of single and multiple Coulomb excitation. Since it is difficult to separate the heavy particles produced in heavy-ion experiments, Yale has developed a system that provides isotopic separation for elements at least as heavy as oxygen; it is based on the $dE/dx \times E$ identification system and uses a gas-ionization-chamber-transmission counter and a semiconductor stopping counter.

The Yale experimental group has embarked on a diverse program of study of nuclear behavior. Experiments on isobaric analog states in both light and heavy nuclei are underway. Measurements have begun on heavy-ion-induced Coulomb excitation of rare-earth elements. These are designed to investigate previously ignored perturbations of nuclear vibrations and rotations. A study of the neutron-neutron interaction has been initiated through study of the p,2p reaction on a tritium target. A comprehensive study of the spectroscopy of complex nuclei, throughout the periodic table, has been undertaken to provide new insight into nuclear structure and the relevance of currently fashionable nuclear models. Wherever possible the research program has been designed to exploit the unique beam species, energy and current characteristics of the Emperor.

Many other experiments are in the works, now that Yale's six-year wait for the Emperor is over.

Time and money. First discussions with HVEC started in October 1960. Laboratory construction began in May 1963. By December 1964 voltage testing began on the electrostatic column structure. There was a full year's wait before voltage testing on the finished accelerator structure could begin, how-

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ever, mainly because of unavailability of parts. Last February the accelerator produced its first beam, and in May Yale physicists took their first experimental data.

Money for the accelerator and associated research instrumentation—\$3.1 million and \$2 million respectively, came from AEC. The building to house the equipment was paid for by the Yale Alumni Development Fund (\$1.5 million) and NSF (0.5 million).—CBL

Slow electrons—not relativistic?

Two recent publications have cast doubt on the importance of relativistic effects in the scattering of slow electrons (2 to 200 eV). The claim that relativistic factors played an important part in such reactions was made by H. N. Browne and Ernst Bauer [*Phys. Rev. Letters* **16**, 495 (1966)] and reported in *PHYSICS TODAY*, May 1966, page 82. Objections have been entered by Manuel Rotenberg [*Phys. Rev. Letters* **16**, 969 (1966)] and by Larry Spruch [*Phys. Rev. Letters* **16**, 1137 (1966)].

Rotenberg bases his doubts on what he claims is an improper mixture of potentials and wave equations in Browne and Bauer's calculations. Browne and Bauer had calculated phase shifts for the scattered electrons from the Schrödinger and Dirac equations and obtained a difference that they put down to relativistic effects. In both equations, however, they used the same potential, obtained from Hartree-Fock or a similar approximation. Rotenberg contends that they should have used different potentials, which Rotenberg calculates by using expressions that reproduce experimental level structures. One of the parameters in the expression varies depending on whether a relativistic or nonrelativistic potential is being studied. The variation in this parameter seems to be enough to compensate for the effect reported by Browne and Bauer.

Spruch endorses Rotenberg's argument but goes on to present one of his own that he says is broader and not dependent on details of the potential. He assumes that the atom and the impinging electron can form a bound state with very small binding energy and calculates phase shifts for

relativistic and nonrelativistic cases. He calls his argument "very specialized . . . and . . . not conclusive." He says that "It proves only that regions of strong interaction need not lead to significant R[elativistic] effects, not that they cannot." Nevertheless since Browne and Bauer's reported calculations for a given element and incident energy differ among the various models by amounts sometimes far larger than that claimed for the difference between relativistic and nonrelativistic treatments, Spruch ends his paper with the remark: "In fact, one suspects that R[elativistic] effects are probably much smaller in general, than present uncertainties in NR [nonrelativistic] calculations."

Neither Rotenberg nor Spruch makes a strong claim for the importance or unimportance of relativistic effects on the scattering of slow electrons. They argue only that Browne and Bauer provide no real basis for their claim that relativistic effects are large.

Star-pointing space telescope

Early in August the NASA Goddard Space Flight Center at Greenbelt, Md. reported that on 15 July it had successfully operated a telescope with a star-pointing device above the earth's atmosphere. NASA claims that this is the first time such a feat has been accomplished.

The device, called the "STRAP" (Star Tracking Rocket Attitude Positioning) system was flown to an altitude of 144 km by an Aerobee 150 rocket at the White Sands Missile range. It was recovered undamaged about 90 km from the launch site and will be flown again in the fall.

During the flight STRAP pointed its 32.8-cm telescope at three different stars: Vega, ζ Scorpionis and ζ Ophiuchi. (Almost 80 sec of ultraviolet data were obtained from the three stars.)

STRAP operates with a star-tracking device that seeks a star and points the telescope at it (with an accuracy of about 20 sec of arc) for a specific time. At a predetermined time gas jets are turned on to maneuver the rocket toward the next star to be observed. On the 15 July flight STRAP accomplished turns up to 85 deg.

Current plans call for launching two or three STRAP payloads a year. Future flights will observe up to five different stars each. More than 200 stars are being considered for observation with the STRAP system.

Matter-antimatter asymmetry

New experiments on the decay of an η^0 meson into π^+ , π^- and π^0 find no statistically significant asymmetry between matter and antimatter. An earlier experiment by Paolo Franzini and his collaborators at Columbia and Stony Brook (*PHYSICS TODAY*, August, page 71) found an asymmetry of $7.2\% \pm 2.8\%$, implying a violation of charge-conjugation invariance in intermediate-strength interactions.

At the Berkeley High-Energy Physics conference last month three groups reported on their observations of eta decay. G. Finocchiaro discussed a CERN experiment that found 10 665 decays of η^0 into three pions. Calculating N^+ , the number of events for which the positive pion had more energy than the negative pion, and N^- , the number of events for which the negative pion had more energy than the positive pion, the group

Asymmetry in Eta Decay		
Experiment	Number of events	Asymmetry (%)
CERN	10 665	$+ 0.3 \pm 1.0$
Saclay-Rutherford	705	$- 6.0 \pm 4.0$
Duke	565	$+ 4.1 \pm 4.1$
Columbia-Stony Brook	1 351	$+ 7.2 \pm 2.8$
Total of other results	1 300	$+ 5.8 \pm 3.4$

found an asymmetry $A = 0.3\% \pm 1.0\%$, where $A = (N^+ - N^-) / (N^+ + N^-)$. To produce the π^0 , the group used $\pi^- + p \rightarrow n + \pi^0$; the energy of η^0 was inferred by measuring the neutron time of flight. Pion energies were obtained by an array of spark chambers, rather than the bubble-chamber photographs used by Franzini.

A Saclay-Rutherford group reported