duced monopoles less massive than 2.9 GeV. A cosmic-ray search was made in 1951 by Willem Malkus, who used a solenoid to funnel field lines, and thus monopoles, through nuclear track emulsion; he would have detected one north monopole per cm^2 in 300 years. In 1966, W. C. Carithers, R. Stefanski and Robert Adair, repeating the experiment with a much more powerful Brookhaven bubble-chamber magnet, would have detected one north monopole per cm^2 in 10^6 years. This upper limit may sound very impressive but not if one remembers that meteorites, which are not considered particularly rare, arrive at the rate of one per cm^2 in 10^{16} years.

Ferromagnetic materials. In 1958 Eiichi Goto of Tokyo University pointed out that monopoles would be trapped in ferromagnetic material. Goto, Kenneth Ford and I, collaborating in 1962 at the National Magnet Laboratory, calculated this macroscopic interaction and found that Dirac monopoles would be extracted from magnetite by a 17-kG field and from iron by a 53-kG field. These values are only slightly higher for Schwinger monopoles (18 and 57, respectively).

Using a portable 170-kG pulsed magnet, Goto, Ford and I searched for monopoles to a depth of several centimeters in a magnetite outcrop in the Adirondack Mountains that has been exposed to cosmic radiation since recession of the glacier. We also searched meteoritic material with a continuous magnet.

However monopoles that escaped recombination after their creation in the primordial fireball are destined to acquire ever increasing energies in their travel through the universe. It is therefore likely that prevalent monopoles are too energetic to be thermalized by the atmosphere and would penetrate too deeply to accumulate in surface material or in meteorites.

Goto and Luis Alvarez of Berkeley estimate the present energy of primordial monopoles to be about 10^{20} eV and suggest that they may account for extensive air showers and for the high-energy component of cosmic radiation for which no satisfactory accelerating mechanism has yet been devised.

Ocean sediment. Energetic monopoles would be thermalized by a sufficient depth of ocean water and would then follow the earth's field lines to the bottom so as to accumulate in magnetic components of sediment. Deep-sea sediment thus appears to be the most promising terrestrial source of monopoles, even though 8 km of ocean would stop only monopoles less energetic than 10^{16} eV.

Therefore I have been searching deep-sea sediment (dredged from 2–3-km depths by the Scripps Institution) with the collaboration of Robert Filz and the late Hermann Yagoda. This search has turned up several emulsion tracks that are geometrically compatible with south monopoles, and, strangely, exhibit constant ionization to their termination; unfortunately, however, they are not nearly as heavy as the track of a Dirac monopole should be.

To eliminate the ambiguity of emulsion technique based on speculative track characteristics, Francesco Villa and Allen Odian (SLAC) and I are converting the MIT experiment to a statistical basis by the use of scintillation detectors in a suitable logic array. By trapping monopoles in an iron target system (see figure) and reaccelerating them through the magnet, we can provide positive detection regardless of the nature of the monopole's interaction with matter, or indeed, its charge. The new experiment, improved with Atomic Energy Commission sponsorship, is now ready to begin searching significant quantities of sediment.

In a preliminary search of 800 liters of sediment, we have again found effects similar to our earlier emulsion tracks. Our confidence level has now become so high that it compels us to give serious consideration to a possibility we had previously dismissed: the possibility of a magnetic monopole that has a charge lower than the minimum quantum predicted by Dirac. The energy acquired by a monopole in a given magnetic field is proportional to its charge whereas the rate at which it loses energy (ionizes) in passing through matter is proportional to the square of its charge. The ionization produced in our scintillators is compatible with monopoles that have one third of Dirac's charge. Such monopoles would easily have passed through our target.

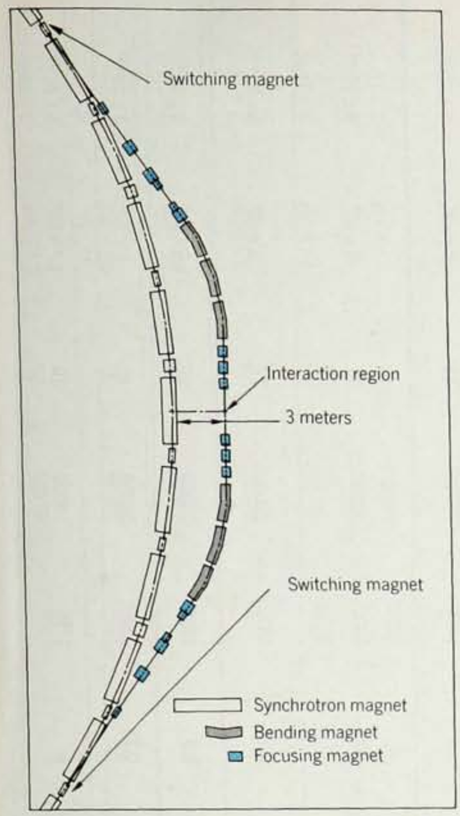
Our new apparatus is designed to investigate this new hypothesis that seems absurd within the framework of Dirac's reasoning and twice as absurd from the viewpoint of Schwinger. However, it appears to be the only hypothesis capable of explaining all of our observations as well as the negative results of all those who have looked for the monopole before us.

Once trapped, a monopole would provide a very useful projectile for high-energy experiments. It could be reëxtracted and accelerated repeatedly to energies several orders of magnitude greater than synchrotron energies now envisaged, and this could be done with only a simple, inexpensive magnet system.

Reversals of the earth's magnetic field, as evidenced by paleomagnetic studies, might be related to monopole showers. An incidence rate of one per cm^2 per second would have canceled the earth's field in one month. Although such a monopole accumulation would eventually have been neutralized by diffusion through the earth, the initial surface charge would constitute a magnetic short circuit that might have initiated a reversal of the earth dynamo. The recent discovery that the latest field reversal coincides with an extensive tektite shower suggests a cosmic event is implicated and lends support to this hypothesis.

Colliding Beams under Way At CEA, Planned for SLAC

The Cambridge Electron Accelerator, a 6-GeV alternating-gradient electron synchrotron, is being modified to produce and store counter-rotating beams of 3–3.5-GeV electrons and positrons in the synchrotron itself. Both beams should be circulating in about two years. At Stanford University, where the first experiments with colliding electron beams of 330 MeV were reported one year ago, an experiment at 550 MeV is under way. Stanford is hoping to build a 3–4-GeV electron-positron colliding-beam facility to be fed by the 20-GeV linac. Although the Weisskopf high-energy advisory



COLLIDING-BEAM EXPERIMENT. Cambridge Electron Accelerator will store counter-rotating beams of 3–3.5-GeV electrons and positrons. Each beam is switched to a bypass sector of dc magnets, is focused and then allowed to collide with opposing beam in the straight section.

committee recently recommended that the ring be built, it has not yet been authorized.

At CEA, rather than build a storage ring from scratch, physicists are performing an experiment to see whether they can use an existing accelerator as a storage ring. According to M. Stanley Livingston, director, CEA is the only laboratory to try such an experiment.

Electrons, preaccelerated to 100 MeV in a linac (in a radial tunnel), are injected into the synchrotron ring, where they orbit in one direction. By injecting electrons 60 times per second, CEA expects to produce in a few cycles a circulating electron beam with an average current of 100 mA.

To produce positrons, the electron linac beam will strike a target, and the positrons produced will be accelerated to 100 MeV in a second linac. The positrons will then be injected into the synchrotron ring, where they will orbit in the opposite direction. Multicycle injection is expected to accumulate a circulating positron beam of 100 mA in less than 30 sec.

The two beams will be separated by vertical electric fields.

Next the ac component of magnetic field will be turned off, and the beams will attain constant energy (half of the peak) in the dc field in a few seconds. This beam storage energy can be adjusted to any desired value up to 3.5 GeV.

Both beams will then be switched into a bypass sector of dc magnets outside the ring (see figure). Here they will be focused, by low-beta insertions, to very small size so that particle density and interaction rate can be much higher than they would be otherwise. Once focused, the beams will be made to collide in an experimental straight section.

Positron and electron beams will circulate through the bypass and the remainder of the synchrotron ring, where the 100-kW rf power supply will compensate for radiation losses. Kenneth Robinson and Gustav-Adolf Voss are the principal designers and planners of the colliding-beam system.

Beam lifetime, which depends on residual gas pressure, is expected to be about 30 min. Livingston notes that the design luminosity is $2 \times 10^{31}/\text{cm}^2/\text{sec}$ at 3.0 GeV, a rate comparable to that planned for other storage rings. He expects that counting rates for electromagnetic interactions of high scientific interest should be 1–1000 per hour.

The Cambridge experimenters have already stored low-intensity beams of electrons at energies up to 3.5 GeV for as long as 30 min. They have also observed the damping of beam oscillation amplitudes due to radiation loss, which is an essential feature of the scheme.

SLAC. The storage ring proposed for Stanford would take advantage of the SLAC linac, which is the most intense high-energy electron source available, to make 3-GeV electrons and positrons. The ring itself is to be located at the two-thirds point on the two-mile linac, so that positrons produced in a target at the one-third point can be accelerated to 3 GeV through one-third the length of the accelerator before being deflected into the ring. Diameter of the ring will be 70 meters.

The circulating beam currents would range from 1 to 25 amperes in each beam, depending on the energy. About 1 MW of rf power will be needed to supply the losses from synchrotron radiation.

At opposite sides of the ring there will be low-beta insertions like the ones developed for the CEA experiment.

The Stanford ring will not only be capable of studying quantum electrodynamics but has been specifically designed for the study of strongly interacting final states, for which cross sections are expected to be small, according to Wolfgang Panofsky, director of SLAC. The design luminosity depends on the operating energy and is greater by a factor 5–300 than that of the CEA project.

Other rings. Three storage rings are now operating: the Stanford electron-electron ring with 550 MeV per particle and two electron-positron rings both now running at 380 MeV per particle; one is at Orsay and the other at Novosibirsk. The electron-electron ring is now being used to extend the limits of quantum electrodynamics to much higher energy than previously investigated. The positron-electron rings are turning out data on the electromagnetic coupling constant of the rho meson.

Within the next few months an electron-positron ring with 1.5 GeV per particle will start operating at Frascati. And at CERN a pair of storage rings is being built to store 28-GeV protons.

With electron-positron storage rings one can study electromagnetic and nuclear processes at interaction energies in the center-of-mass system much larger than are available with existing or planned accelerators.

Wide-Range Device Measures Electron and Proton Energies

Scientists at Rice University, Houston, Tex., have developed a single instrument that can measure electrons and protons over the energy range of 50 to 100 000 eV. Code named SPECS (Switched Proton Electron Channeltron Spectrometer) the device is suit-