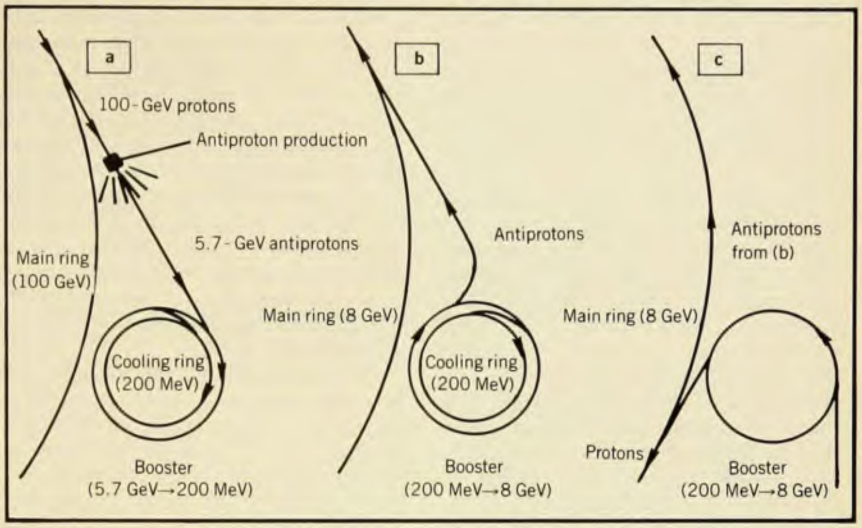
search & discovery

Electron cooling offers high-luminosity antiproton beams

An old idea in accelerator design, called "electron cooling," has been demonstrated to work in experiments over the last two years at the Nuclear Physics Institute in Novosibirsk. The Siberian success has inspired groups at CERN and Fermilab to start experiments on electron cooling with the hope that these might lead to high-energy colliding-beam experiments involving protons and antiprotons.

The electron-cooling idea was first proposed by Lyman Spitzer (Princeton University) about 20 years ago. At that time C. Tsao and Gerard K. O'Neill (Princeton University) did a theoretical analysis, and verified that the idea should work. In 1966 Gersh I. Budker (Novosibirsk) independently developed the electron-cooling idea, reporting on it that year at the Paris particle-accelerator conference. He and Alexander Skrinsky (Novosobirsk) then proposed building a proton–antiproton colliding-beam device using electron cooling (PHYSICS TODAY, August 1969, page 62).



Proposed plan for antiproton–proton colliding beams at Fermilab. In (a) antiprotons are produced, decelerated, cooled (60 millisec) and stored (3 hours). In (b) antiprotons are accelerated and transferred to main ring (60 millisec). In (c) protons are accelerated and transferred to main ring (60 millisec). Then both beams are accelerated to full energy and allowed to collide.

To cool a proton or antiproton beam, one allows an electron beam to travel in the same direction at almost the same velocity. The antiprotons or protons tend to lose their transverse momentum to the electrons by Coulomb scattering, and the entire system tends toward equipartition of energies. Over a large number of turns the oscillation amplitudes and momentum spread of the protons or antiprotons gradually are reduced, and the electron oscillations grow. The net effect is that the volume of phase space occupied by the baryon beam is drastically reduced, making the beam denser and giving it higher luminosity.

Novosibirsk work. Budker's Nuclear Physics Institute has so far done all the experimental work on electron cooling, using a storage ring called NAP-M (Accelerator and Accumulator of Protons). It was designed and built by Skrinsky, Nikolai Dikansky, I. Meshkow, V. Parkhomchuk and their colleagues. First experimental results were reported at the National Particle Accelerator Conference

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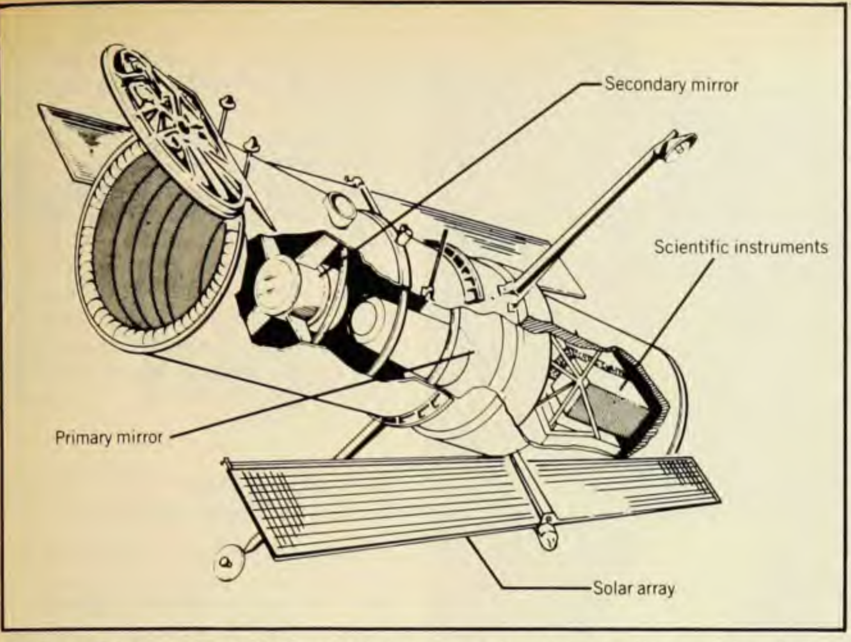
The case of the vanishing superconductivity

A ternary superconductor, $ErRh_4B_4$, does an astonishing thing as its temperature is reduced: Although at 8.6 K it becomes superconducting, as the temperature is reduced further, to 0.9 K, the superconductivity disappears. This discovery was scheduled to be reported by Bernd T. Matthias (University of California, La Jolla and Bell Labs) in a postdeadline paper at the March meeting of The American Physical Society in San Diego. Matthias says that this is the first time an ordered crystal has lost its superconductivity as the temperature is lowered.

Several years ago Matthias decided that the path to higher superconducting transition temperatures was not via the binary compounds. "After all," he said, "Nb_3Ge has been known for the last 22 years." Instead, he decided to look at ternary superconductors. A true ternary superconductor is a compound of three elements whose properties depend on all three. In 1971 Roger Chevrel, M. Sergent and J. J. Prigent (CNRS, Rennes, France) had found[1] a new rhombohedral system, the double molybdenum sulfides, XMo_6S_8, which turned out to be the first system of ternary superconductors. Matthias and his collaborators at La Jolla and Bell Labs began studying both XMo_6S_8 and XMo_6Se_8. They found superconductivity for X being copper, silver, zinc, cadmium, tin, lead and magnesium, first in sulfides, then in selenides.

In 1975 O. Fischer, A. Treyvaud (University of Geneva), Chevrel and Sergent found that X could also be a rare-earth element. Robert N. Shelton and his colleagues at La Jolla showed that some of the rare-earth molybdenum selenides with lanthanides had superconducting transition temperatures as high as 11 K. For all the rare earths, from lanthanum to lutetium, with the exception of cerium and europium, superconductivity has been found in experiments done by M. Brian Maple, Shelton, David C. Johnston and R. William McCallum (La Jolla). Because the transition temperatures of the tin and lead compounds with molybdenum sulfide were somewhat above 15 K, and their critical fields are in the range 500–700 kG, Matthias believes it will be



The Space Telescope is an f/24 Cassegrain instrument whose mirrors will be made from hollow-construction low-expansion fused silica. The device is 46 feet long and weighs 17 000 pounds.

halos. This controversy could be settled by looking at the nearby quasar, 3C273, whose radiation is accordingly not redshifted as much as more distant quasars (if one believes quasars are at cosmological distances), so that it is observable in the ultraviolet. If Bahcall's point of view is correct, those absorption lines should not be present. If the lines are present, Bahcall loses the argument.

A second kind of observation, made possible because the Space Telescope can see much fainter sources than a telescope on Earth can, is to find the distances of galaxies very far away. Thus one can study the cosmological evolution of the universe.

A third kind of observation is synoptic study of planets, in particular, the study of the outer planets such as Uranus and Neptune, which will not be observed by planetary orbiters for decades. The Space Telescope's resolution will be comparable to the early fly-bys of the inner planets.

The scientists involved in planning the Space Telescope expect that it will be used for the most exciting problems of the day, many of which cannot be identified today. In testimony before the House Subcommittee on Space Sciences and Applications in mid-February, Bahcall explained that studies over the last eight years suggest the Space Telescope would allow a better understanding of planetary atmospheres and meteorology, the search for other planetary systems, studies of clouds where stars like our Sun are now being formed, a search for massive black holes and compact white dwarfs inside globular clusters, a measurement of the size of the universe, and the investigation of the nuclei of active galaxies.

The Space Telescope has appeared in the NASA budget in four successive years. For the first two years, it was called the Large Space Telescope, and the design called for a 3.0-meter aperture. O'Dell feels that because the Space Telescope was the first NASA science program to be submitted as a budget item while still in the preliminary design stage, it ran into trouble with Congress. After pressure from Congress and the Office of Management and Budget, NASA redesigned the telescope in Fall, 1974, reducing the aperture to 2.4 meters. In the old scheme, the systems for pointing and communication (support-systems module) had to be placed in the rear because the telescope itself was so wide. This configuration produced a large moment of inertia. With the smaller aperture, the support-system module could be placed in an annular ring around the center of gravity, thus reducing the moment of inertia. So one could have a simpler, more reliable pointing system. The new design has an apparent reduction in cost of about 20% and a greatly increased predictibility of cost. O'Dell is optimistic that the Space Telescope will finally be approved in this go-round. —GBL

Electron cooling

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held in Moscow in 1974. A subsequent report was given at the National Accelerator Conference in Washington the following year.

In recent experiments, protons at 1.5 MeV are injected from a Van de Graaff accelerator into the ring, where they are accelerated to about 65 MeV in a good vacuum. The 100-microamp beam has a lifetime of about eight hours. The ring has four quadrants and long straight sections. After the protons are accelerated, a 35-keV, 1-ampere electron beam is run parallel to the proton beam in one straight section. Only 0.01% of the electrons are lost in the cooling process; the rest are collected at a kinetic energy of 1 keV.

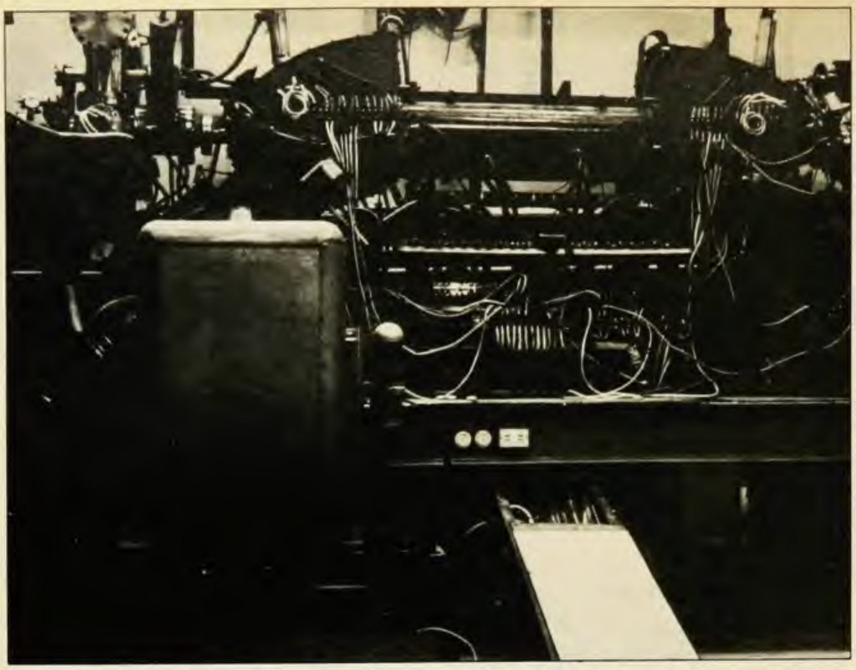
The Novosibirsk group has found that the relative difference in speed between the proton and electron beams must be less than 2×10^{-3} for cooling to occur. When there is cooling, the lifetime of the proton beam in NAP-M is increased from 900 to 5000 seconds. The proton-beam amplitude is reduced from 1 cm initially to 0.5 mm after cooling. The fractional momentum width after cooling is 5×10^{-5}. Thus, the beam is extremely tight. Betatron oscillations are extremely small. (Fields essentially do not penetrate the beam beyond the Debye length. It is so cold that one cannot observe ordinary Schottky noise.)

Based on a naive theory, cooling time was expected to be about one-half second. In fact, the group finds it occurs in 50–60 millisec. It is this rapid cooling rate that has caused much of the enthusiasm at other labs. Two other puzzling features are a skewed electron velocity and the effect of the magnetic field on collisions.

Potentialities. The excitement about the Novosibirsk results is that if electron cooling gives sufficient antiproton densities, it should be possible to build low-cost, high-energy proton-antiproton colliding-beam devices at CERN or Fermilab. The Novosibirsk group is proposing a p-$\bar{p}$ colliding-beam device with 2 TeV in each beam be built at Serpukhov. At the Soviet National Accelerator Conference last year, a detailed analysis was presented by Ya. Derbenev and Skrinsky.

David Cline (University of Wisconsin), Peter McIntyre and Carlo Rubbia (Harvard University) and Frederick Mills (Fermilab) have proposed and are working with Fermilab staff under Russ Huson to implement the following scheme: Protons produced in the main ring at 100 GeV could strike a target, producing 5–6-GeV antiprotons. These would be transported to the booster synchrotron, injected and decelerated to 200 MeV. (This energy is apparently most suitable for electron cooling.) Then the 200-MeV antiprotons could be transferred to a 200-MeV cooling ring, which would, according to calculation, cool the antiprotons in 60 millisec. These antiprotons would then be collected for several hours until 10^{11} antiprotons were obtained, then injected into the booster, accelerated to 8 GeV and injected into the main ring. Then both the proton beam and the antiproton beam would be accelerated to full energy and allowed to collide with each other in a long straight section.

With a high-energy proton–antiproton



Electron-cooling device at the Nuclear Physics Institute in Novosibirsk. The electron gun is at lower left, and the collector at right. The cooling region is in the center. The proton-beam pipe is visible, entering at upper left. The proton-beam amplitude is reduced from 1 cm to 0.5 mm.

colliding-beam device, one would have a unique glimpse of what the future holds for elementary particles. Its proponents argue that the scheme could be operating in a matter of a few years and at a cost in the $10-million ballpark. A comparable energy range will not otherwise be available until Isabelle started operating, at least eight years hence, at a cost of about $200 million. If the p-$\bar{p}$ scheme works, one could start looking for the intermediate vector boson (predicted to be 64–79-GeV/c^2) or for the Higgs boson.

Fermilab is building a 140-meter-circumference race track with dipoles, quadrupoles and cooling features that is designed to study cooling and accumulation of 200-MeV protons. Fermilab expects to have an electron gun with higher current density than has been available at Novosibirsk. Electron energy will be 110 keV. Fermilab has requested partial support for the cooling experiments from NSF. In any case the lab expects to be able to start experiments this fall.

A year later, according to Mills, Fermilab will make a decision on whether to proceed with some scheme to produce p-$\bar{p}$ collisions either in the main ring or the Energy Doubler, which is now under development. The Doubler will share the same tunnel as the main ring and by means of superconducting magnets would produce 1000-GeV protons instead of 500 GeV. If the main-ring cycle were used, Rubbia believes it would be good to operate with each beam at 270 GeV. This is equivalent, Rubbia notes, to a 1-erg cosmic-ray particle, comparable to the jump of a flea. If the Doubler were used for p-$\bar{p}$ collisions, an energy of 2 TeV would be available. To produce that energy by bombarding a fixed target would require an accelerator energy of 2 million GeV.

Mills says that if all goes well, one could achieve a luminosity of at least 10^{29} $cm^{-2}sec^{-1}$ in the main ring, and 10^{30} in the Doubler. By spending additional money, these luminosities could be raised. Using either the main ring or the Doubler, the cost of making a proton-antiproton colliding-beam device is estimated at $5–10 million.

CERN has set up a study group for a proton–antiproton project, headed by Simon Van der Meer. At the same time both electron cooling and stochastic cooling will be studied experimentally. Van der Meer had proposed stochastic cooling in 1975. In this scheme the beam is given a nudge by electric fields to cause the "center of gravity" of the beam to move in a desired orbit. By a statistical process, the beam is cooled in a progressive fashion.

The experimenters will use the (g-2) ring, which was formerly used as a storage ring for 3-GeV muons. Experiments are scheduled to be done over the next year with the expectation of a decision to go ahead with a full-scale proton-antiproton scheme to be made by the end of 1977.

The first CERN project will take protons from the Proton Synchrotron in the range 50 MeV–3 GeV, the low energy being for electron cooling, the high for stochastic cooling. There are four straight sections, each 5 meters long. In one straight section is a 30-ampere electron gun which will produce 100-kV electrons. These will be used in the electron cooling on protons in the range 50–200 MeV. The Novosibirsk studies were done in a 1-cm^2 beam, whereas the (g-2) ring has a 50-cm^2 beam.

Because CERN does not have an Energy Doubler in the works, Rubbia notes, CERN has a special incentive to take advantage of the cooling schemes. Each of the 20 bunches in the Proton Synchrotron carries 10^{11} protons. With just one bunch, Rubbia believes a luminosity of 0.5×10^{30} cm^{-2} sec^{-1} is possible, and if more bunches are used, of course, the luminosity goes up. —GBL

Scyllac expires: And now there are two

Last year ERDA gave Los Alamos Scientific Laboratory a deadline of September 1977 to demonstrate stabilization of plasma in Scyllac, a circular theta-pinch device that had been one of the three major components of the magnetic-fusion program (PHYSICS TODAY, July 1976, page 17). Now ERDA and Los Alamos have decided to terminate operation of Scyllac between 1 July and 30 September.

Edwin Kintner, Director of Magnetic Fusion Energy at ERDA, told us that in the future, tokamaks will continue as the main-line component and magnetic mirrors as the back-up. Los Alamos will pursue a broader physics effort supporting the rest of the fusion program. In this regard, ERDA decided that Los Alamos will build a small Reversed Field Pinch Experiment, ZT-40, and that the lab will submit a proposal for a 15–25-meter linear theta-pinch device to use the existing Scyllac capacitor bank. Los Alamos proposals for other experiments (imploding liners and high-beta tokamak) will be revised, and Los Alamos will continue to work on other, smaller experiments. —GBL

in brief

Sandia Laboratories has begun testing Proto II, an electron-beam accelerator to be used in fusion experiments. It will ultimately produce about 100 kJ in a double diode at a voltage of 1.5 MV and a peak current of 6 megamps. Pulse length will be 24 nanosec.

ERDA has selected a site near Barstow, Calif. in the Mojave Desert for its first solar-electric pilot plant. The 10-MW plant will utilize the central-receiver concept and will be completed in 1980–81. The $23.3-million cost is shared by ERDA and a team of utility companies headed by Southern California Edison. □