accounts for the small number of three- and four-detector coincidences.

The detectors do not appear to be showing seismic or electromagnetic disturbances, Weber believes. He has shown with a seismic array that earthquakes and other earth motions do not generally register on his antennas. Because one of the detectors has an inherent 11-sec time lag for gravitational disturbances, it discriminates against electromagnetic signals.

Weber wants to pin down the directional effects over the next year, improve time resolution and change the frequencies of his detectors. In earlier experiments Weber had used the earth itself as a detector and looked for quadrupole oscillations, using as gravimeter a harmonic oscillator with a very weak spring constant; the period would be 54 min or more. He would like to put such a gravimeter on the moon.

What could be producing the gravity waves? Weber would not hazard a guess. He did note, though, that about 90% of the nearby matter in our galaxy is invisible. "If our intuition is based entirely on the light we see and the radio signals and the x rays, then it's not altogether surprising that there should be some things that we didn't expect."

We asked two of Princeton's gravitation experts what might have caused Weber's observations. John Wheeler explained that in our galaxy alone supernovas occur every 30 to 300 years. If the mass of the collapsing star is less than the Chandrasekhar limit (about two solar masses), a white dwarf or neutron star results, and a pulse of gravitational radiation is emitted. If the mass is bigger, gravitational collapse occurs, and you get a black hole, which produces a pulse with a characteristic spectrum. Then the hole would not be heard from again unless matter floating through space fell into the hole; then another pulse would occur. Another possibility for a pulse is a pulsar "starquake," which some people believe explains the speeding up of the Vela pulsar over the "lost weekend" when nobody observed it.

Wheeler noted that Weber's events just might be due to gravitational waves (which travel at the speed of light) associated with earthquakes, but he doubts it. He would, however, like to see directional measurements to make sure.

Robert H. Dicke commented that the source need not emit only a single pulse. If you had two neutron stars spiraling around each other they would emit gravitational waves, and their frequency would be increasing. These waves would sweep through Weber's detector, which is sensitive to a narrow band of frequencies.

We asked if one could check Brans–Dicke theory with gravitational-wave detectors. Because the theory requires both scalar and tensor fields, one could look for scalar effects. Unlike a tensor wave, which stretches a detector at right angles to the wave direction, a scalar wave produces stretch in all directions. So you could either do a polarization experiment or build a spherical detector and look for purely radial oscillations, which could only be excited by a scalar wave. Dicke and some Princeton colleagues tried such an experiment several years ago, using the earth as the spherical detector. They set up a gravimeter tuned for radial oscillations of the earth, but they did not observe any. —GBL

Matter Meets Antimatter in Akademgorodok

It is worth traveling halfway round the world to visit the antiworld of Andrei Budker. There, at his Nuclear Physics Institute in Akademgorodok, near Novosibirsk, he makes beams of antimatter collide with beams of matter, doing high-energy physics experiments on a low-energy physicist's budget. We spent a week in Akademgorodok, the Siberian science town, and had several pleasant visits with Budker and his wife Ludmilla at their home. At the institute we saw his latest venture, a 25-GeV proton–antiproton device, being built, toured his factory for mass producing accelerators, and looked at beams of positrons and electrons circling in one of his smaller storage rings.

Budker's given name was Gersh Itskovich, but as a boy he chose the name Andrei Mikhailovich, which all his many friends call him. As director of Akademgorodok's largest institute, Budker apparently has the freedom to try bold, new ideas, and he and his group have the imagination and daring to do so. The 25-GeV device is considered an experiment, not guaranteed to work entirely as planned. It is being built out of the institute's annual operating budget, half of which comes from the Siberian branch of the Soviet Academy of Sciences. The other half comes from the sale of high-current electron accelerators, which he sells to customers at home and abroad. The model элит-3, for example, produces 100 amperes of 3-MeV electrons in 100-microsec pulses.

Budker speaks his mind. One evening in his garden we sat on a piece of driftwood from the Ob Sea while he spoke about physicists and their accelerators. Orginally the institute scientific council planned to build both a 25-GeV proton–antiproton machine and a separate 3.5-GeV electron–positron machine. But, he said, "Machines should not rule physicists. We had a big argument when I asked why we should build both a proton and an electron machine when you can build one machine to do both. The answer was, 'It's not comfortable to have only one for both,' as if the main aim of the machine was to be comfortable. When I build a new machine the tunnel won't be big enough for visitors to walk around in."

Accelerators should not have a life of their own, he said. "Otherwise they will become like the pyramids."

When you first think about it, a reliable accelerator seems important, he went on. "You push a button, and it works. It seems nice to have somebody else build the machine for the physicist. It only seems this way. Really, though, the mind of the physicist dies. Because of that, you see the fantastic cost of accelerators now." For research at the frontier of physics, physicists should make their own equipment, he says.

Budker was reminded of a story. "When people tell me that everyone knows accelerators cost a certain amount, and everyone knows that tunnels must be of a certain size, and everyone knows that the customary accelerator is a synchroton, I tell them this story: Two women were talking. One said that England is an island. Her friend replied. 'That's nonsense. If that were so, everyone would know that England is an island.' "

25-GeV machine. What will the 25-GeV machine be like? Budker's group appears to be designing the machine as they go along. We were told of two possible designs. One is for VEPP-3, consisting of a synchroton in-

ANDREI BUDKER AT HOME. At left he stands outside his house. Sign on door says "tavern." In rear are Lev Artsimovich (Kurchatov Institute), Amasa Bishop (USAEC) and his wife Barbara. At right Andrei and Ludmilla Budker sit on a piece of driftwood from the Ob Sea.

jector, a small storage ring and a large storage ring. A more recent design, VAPP-4, will have a 22-GeV ironless synchrotron injector, a small storage ring and a large storage ring.

One day we visited the spacious institute headquarters. Budker introduced us to Vadim Auslander, who then took us over to the construction site for the big machine. The stages are stacked one on top of the other like pancakes; to see the tunnels we kept walking deeper into the Siberian ground. To save money, Budker has built unusually small tunnels. Then to produce the strong bending required with a small-radius synchotron, he uses a high-current magnet with an air core (no iron). We saw the solid-steel magnets being fabricated in the nearby machine shop that serves as an accelerator factory. (Besides the huge machinery you might expect to see, there was a lovely array of potted palms. On second thought, this sight was not so surprising, in a land of nature lovers who must face a long, cold winter. The buildings, for example, are connected by underground passages; so one can avoid donning overcoats more often than necessary.)

In the VEPP-3 design a 200–500-MeV proton synchrotron injects protons into a large racetrack-shaped storage ring. The ring has two semicircles at either end, with a 40-meter average bending radius; between them is a 30-meter straight section. The ring is filled until it contains 10^{13}–10^{14} protons; then the particles are accelerated to 25 GeV.

Electron cooling. The 25-GeV protons are injected onto a target, producing antiprotons with energies of 1–3 GeV with a conversion efficiency of about 10^{-7}. These antiprotons are stored in a second, smaller storage ring where their energy and angular spread are reduced by "electron cooling."

Lyman Spitzer originated the electron-cooling idea about 12 years ago, and C. Tsao and Gerard K. O'Neill followed with a theoretical analysis. Budker has done all the experimental work on electron cooling.

To "cool" an antiproton beam, you let an electron beam travel in the same direction at the same velocity as an ideal average antiproton. The electron beam is very cool in the transverse direction because its light mass gives it a low kinetic energy even at high velocity. The antiprotons tend to lose their transverse momentum to the electrons by Coulomb scattering, the entire system tending toward equipartition of energies. Over a large number of turns the oscillations of the antiprotons gradually damp, and the electron oscillations grow.

Once the cross section of the beam

ALL PHOTOS BY GLORIA LUBKIN

AKADEMGORODOK MACHINE SHOP manufactures accelerators, which are sold in Soviet Union and abroad. Nuclear Physics Institute keeps profit for research.

is reduced, the cycle can be repeated until at least 1000 pulses are stored in the ring. Then the antiprotons are ejected into the large ring, the protons are injected from the original injector into the same ring as the antiprotons, and the two beams are accelerated to 25 GeV. Now at full energy, the two beams are allowed to collide with each other.

The VAPP-4 (A is for antiproton) proposal would be a more efficient producer of antiprotons than VEPP-3. Budker expects the conversion efficiency to be 2×10^{-6}. His injector would be an air-core ironless synchrotron to produce 25-GeV protons. Conventional synchrotrons have fields of 10–20 kG and correspondingly large radii. Budker's ring will have a field of 120 kG and a radius of 6–10 meters.

The 25-GeV protons are injected into a large storage ring, which is filled in 100 pulses. The full beam passes through a "ha-ha" magnetic focusing lens (called a ha-ha because the double-hemispherical shape at either end of the lens resembles the way that the Russians write the letter "X", which is pronounced as "ha"). This megagauss lens focuses the beam onto a target. Antiprotons are produced and stored in a small ring. Once the small ring is filled the antiprotons are accelerated in the ironless synchrotron and tranferred to the big storage ring. Then the beams are allowed to collide. Both the large and small rings would use electron cooling.

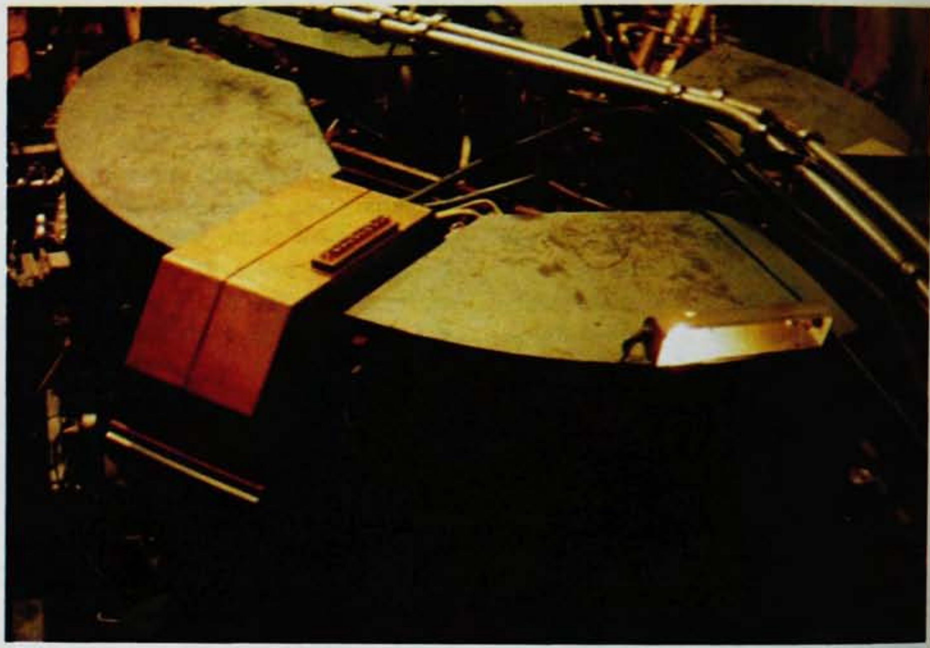
Design and construction appear to move rapidly in Novosibirsk. Budker expects the small ring to be done in 1969 and the big ring to be assembled in 1970. By 1971 or 1972 he hopes to start experiments.

Budker thinks the whole installation will cost between $15 and $20 million, of which $3.5 million will go for the new building and tunnel.

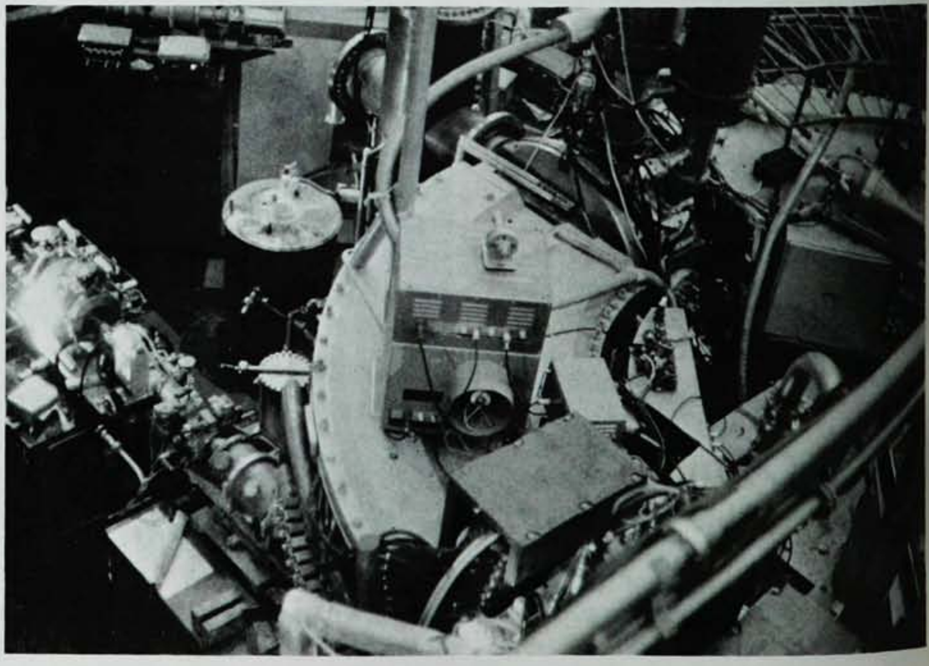
Earlier models. Auslander took us to a huge experimental hall, home for the older storage rings: VEPP-1, a 160-MeV electron–electron machine, and VEPP-2, a 700-MeV electron–positron machine.

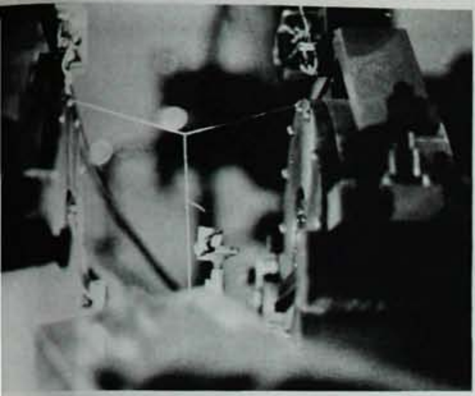
In the VEPP-2 device a 3.5-MeV beam of electrons is injected into a 2-meter-radius synchrotron, which accelerates electrons to 250 MeV in 1 millisec. The electrons are sent to a storage ring, which is filled with 10^{11} electrons in about half an hour. Then

VEPP-2 INJECTOR. 3.5-MeV electrons are injected into a 2-meter-radius synchrotron, which accelerates electrons to 250 MeV in 1 millisec.



VEPP-2. In photo above experimental straight section is at lower left. Electrons are injected from lower right, positrons from upper left; rf is at upper right. Photo below shows ha-ha lens (left), positron injection (bottom); rf (top).





HA-HA LENS with its magnets moved apart. Electron beam is focused onto target by half of the lens. Positrons are emitted, and beam is made parallel by the other half of the lens.

the electron beam is sent through the ha-ha lens, which focuses the beam to a 1-mm diameter onto a tungsten target. A spray of 125-MeV positrons comes off, and the other half of the ha-ha lens creates a parallel beam, which is then sent into storage. Conversion efficiency is about 10^{-4}.

In the storage ring, the positrons are accelerated to 200 MeV. Then one or two pulses of electrons are injected into the ring, both beams are accelerated to 700 MeV and allowed to collide.

We looked into the ring through two ports: One showed the positron beam, the other the electron beam, both glowing brightly with their bluish synchrotron light. The antimatter beam looked just like a matter beam, as far as we could tell. Actually, though, lots more electrons are available for experiments: 50–100 milliamperes of electrons and 30 ma of positrons. The beam lifetime is about one hour. It is limited by two factors: relatively poor vacuum (10^{-9} torr, which they hope to improve to 10^{-10} torr) and transverse motion caused by synchrotron radiation.

Experiments. VEPP-2 has already been used for producing rho mesons, measuring their mass and width. Budker, Auslander, Ju. N. Pestov, Benjamin A. Sidorov, Alexander N. Skrinsky and A. G. Khabakhpashev allowed 380-MeV electrons to collide with positrons, producing a rho (which lasts 10^{-23} sec), which then decays to a positive and a negative pion. Previous rho production experiments had been done with proton–proton interactions, in which the width is much broader. With the better resolution available from VEPP-2, the experimenters found the rho mass to be 764 MeV with a width of 105 ± 20 MeV. Subsequent experiments on rho production, done with the electron–positron storage ring at Orsay, yielded a width of 112 ± 12 MeV.

The next experiment scheduled for VEPP-2 was phi production; the phi decays in 3×10^{-22} sec into positive and negative kaons. Because the lifetime of the phi is longer, the width should be narrower, about 3 MeV.

The really giant step will come when the 25-GeV ring goes into operation, hopefully in 1971. Like the CERN intersecting storage rings (scheduled to start experiments the same year), the interaction energy of the Novosibirsk ring in the laboratory frame of reference is about 1500 GeV. But the CERN rings, fed by the 25-GeV proton synchrotron, will only contain protons. Budker's device will pit proton against antiproton.

BUDKER AND ANTIBUDKER reflect on matter–antimatter interactions.

VADIM AUSLANDER WITH SOLID-STEEL MAGNETS, which are being built for air-core ironless synchrotron, part of the 25-GeV proton-antiproton storage ring.

What kinds of experiments will the Novosibirsk group try? Lev Barkov and his collaborators have been thinking about them. One experiment will be to measure the magnetic moment of the sigma hyperon. (There are only two magnetic moments known for the hyperons.) Locating a pulsed megagauss ha-ha lens near the interaction region, one can measure the precession of the sigma before it decays in 10^{-10} sec.

The round table. Budker sat with us around his famous round table, whose highly polished surface reflected a smiling anti-Budker. The knights of his round table are the 25 members of the institute scientific council, which often meets to discuss policy. The council members are the 16 laboratory chiefs, two deputy directors and the rest, scientists. Rem Solukhin is a deputy director of the institute, and Skrinsky heads the biggest laboratory in the institute, the one that develops storage rings. Sidorov is chief of a lab that prepares experiments for the existing storage rings.

The institute has about 50 physicists, 40 postgraduate students, about 50 engineers doing research and about 100 engineers for the accelerator factory.

Budker says the council members often disagree at their round table. But he is a forceful man, and he usually convinces them to try brave, new ideas. —GBL

Ultrasonic Microscope May Be More Sensitive, Nondestructive

An ultrasonic microscope might be 10 000 times as sensitive to detail as an optical microscope and offer better signal-to-noise ratio. It would not destroy its samples as do the beams of electron microscopes and the staining required with optical microscopes. Thus you could watch effects as you cause them. To test the principle Marvin Chodorow and Bertram A. Auld plan to build one at the Stanford Microwave Laboratory.

They will use 1000-MHz or higher frequencies to produce 3-micron or shorter wavelengths. After scattering from the specimen, sound waves will be converted to visual images by one of two methods that the builders are now exploring. One is modulation of a light beam, which would make an image on film. The other is scanning the object and putting the image on a cathode-ray tube with television techniques.

Although wavelength and resolution will be about the same as in an optical microscope, lower frequencies will offer advantages in detection.

Josephson Effect Permits New Look at Fundamental Constants

Our old friends, the fundamental constants, get a new scrub and polish in the July *Reviews of Modern Physics*.[1] Barry N. Taylor (RCA, Princeton), William H. Parker (University of California, Irvine) and Donald N. Langenberg (University of Pennsylvania) offer best values that have estimated errors about a third as large as those in a 1963 adjustment by E. Richard Cohen and Jesse W. M. DuMond.[2] The values themselves have changed by several standard deviations.

Motivation for the new study came largely from the ac Josephson effect in which an ac supercurrent flows between two weakly coupled superconductors when there is a potential dif-