inium passes back and forth.

This regenerator acts as a thermal flywheel, storing the heat given up by the lattice in one part of the cycle and later giving it back. Thus the entire magnetic effect is available for isothermal heat exchange with the external source and sink. Not only does the regenerative Stirling cycle increase the entropy that can be pumped per cycle for a given magnetic-field and temperature span. It has, according to Brown, an even more important virtue: Because the temperature gradient is built up cumulatively in the regenerator over many cycles, the temperature range between the hot and cold isotherms can be much greater than the maximum 14 kelvins traversed by a single adiabatic (de)magnetization of 7 T.

Brown's magnetic refrigerator consists of an assembly of thin gadolinium plates placed at the center of a solenoidal magnet capable of applying a 7-tesla field to the 0.9 kg of gadolinium refrigerant. The gadolinium assembly remains fixed at the center of the field, but fits and slides freely in a 1-meter-long, 5-cm-diameter hollow cylinder, coaxial with the solenoid. The cylinder is filled with a regenerator liquid of water and ethanol (antifreeze), and is attached to a motor that can move it back and forth along the solenoid axis. The regenerator liquid flows freely between the thin gadolinium plates as the cylinder oscillates along the axis of the solenoid.

The refrigeration cycle begins with the cylinder at its lowest position, so that the gadolinium refrigerant assembly is immersed in regenerator liquid at the top of the cylinder. At this point the magnetic field is raised from 0 to 7 T in a few seconds, heating the gadolinium, which heats the liquid. With the applied field held constant at 7 T, the cylinder is moved upward along the magnet axis until the fixed refrigerant reaches its bottom. At this point the field is reduced to zero in a few seconds, cooling the gadolinium plates and hence the liquid at the bottom of the cylinder. Then with zero field applied, the cylinder is lowered to its starting position, and the cycle recommences.

With each succeeding cycle a thermal gradient is built up in the regenerator liquid as the refrigerant pumps heat from the bottom to the top of the cylinder. After dozens of cycles the system reaches a steady-state equilibrium gradient, whose temperature span depends on the coupling to heat sources and sinks at the ends of the otherwise insulated cylinder, and on the losses in the system. The heat delivered at the top end equals the heat taken up at the cold end plus the magnetic work done in the Stirling cycle, less losses. In principle, the Stirling cycle has Carnot efficiency, to the extent that the specific heat of the refrigerant is independent of its magnetization. For an ideal Carnot refrigerator, the ratio of Q_C, the heat taken out of the cold source, to the work W is $Q_C/W = T_C/(T_H - T_C)$, where T_C and T_H are the source and sink temperatures.

With this laboratory device, whose function, according to Brown, is to demonstrate the principle rather than to serve as an engineering prototype, a maximum 80-kelvin temperature span has been achieved, with cycle time of about a minute and no external heat load attached. The maximum refrigeration power achieved with 0.9 kg of gadolinium was only 34 watts at startup, and 6 watts at the 80-kelvin temperature span. But Brown believes this can be increased to kilowatts by speeding up the cycle by two orders of magnitude and by making the plates thinner than the present 1-mm thickness to improve heat exchange with the liquid.

Brown has calculated that with an optimized version of his magnetic heat pump, one could achieve 60% of the ideal Carnot efficiency, a significant improvement on ordinary heat pumps and refrigerators. The heat energy delivered by a heat pump is not limited by the work done in its cycle. The extra energy comes of course from the cold heat source. Unlike a furnace or electric heater, a heat pump can deliver for space heating many times the number of joules of electrical or chemical energy consumed. A magnetic heat pump can perhaps be made much smaller than conventional pumps of the same power because the heat absorbing capacity per unit volume of the solid gadolinium far exceeds that of a gas.

The Lewis demonstration device used a water-cooled magnet that consumed much more power than the pump delivered. A commercial device would need a superconducting magnet. One must then consider the economics of the power consumption of the magnet's cryogenic system.

The other members of Brown's group are Susan Benford, Willard Coles, Dennis Flood, Erwin Meyn and Stephen Papell.

Steyert's refrigerator, which he and John Barclay are building as a laboratory test device for the Electric Power Research Institute, employs a 2.3-kg gadolinium wheel, six inches in diameter. The porous wheel rotates between high and low-field regions differing by 1.2 tesla, with a cycle time of 5 seconds, exchanging heat with water that is forced to counter-rotate through the wheel on its path between source and sink. In place of Brown's Stirling cycle, Steyert employs a Brayton cycle. This cycle, consisting of two constant-field steps connected by two adiabats, is also borrowed from a 19th-century gas engine, the Brayton "ready motor," the constant-field steps being analogs of constant-pressure lines.

With his small magnetic-field variation, Steyert achieves a maximum temperature span of only 9 kelvins, but when source and sink differ by 7 kelvins he obtains a refrigerating power of 500 watts, with an external heat load. In general, the power achievable in heat pumps decreases as the temperature span increases. Steyert and Barclay have also run their heat pump in reverse, as a heat engine, converting heat flow across a 10-kelvin temperature difference into mechanical energy.

Low-temperature applications. Steyert believes that the refrigerating power of current magnetic-pump designs is limited, presenting an obstacle to their widespread application at room temperature. He feels that in the near future their major application will be in low-temperature refrigeration—2 to 70 K. Brown agrees that cyclic magnetic refrigerators show promise for low-temperature applications, but he is optimistic about their usefulness at room temperature.

In the past, magnetic refrigeration has generally employed "one-shot" devices, in contrast to the continuous, cyclic heat pumps described here. Steyert points out that low-temperature refrigeration is becoming increasingly important for such applications as Josephson computers (PHYSICS TODAY, June 1978, page 17), superconducting electric-power generators, sensing devices on space probes and the production of liquid oxygen for steel mills. An important advantage of magnetic refrigerators over the helium refrigerators that currently dominate the region above 2 K, he told us, is greater reliability, resulting from fewer moving parts. And the parts that do move do so much more slowly than the high-speed turbines required by helium refrigerators. —BMS

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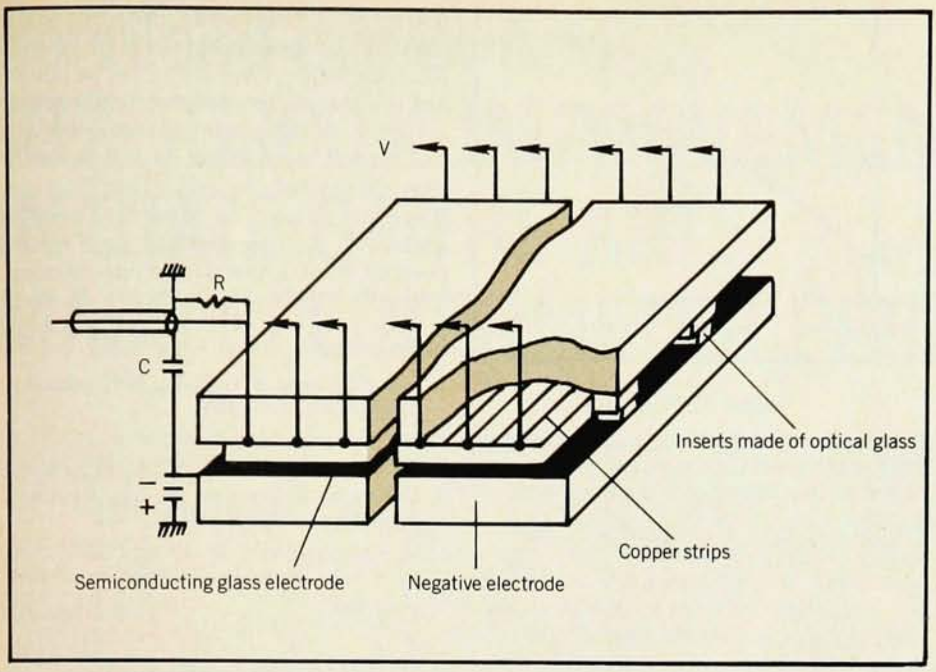
Uri Pestov develops high-resolution spark counter

A new kind of spark counter for high-energy physics is being developed by Uri Pestov and his collaborators at the Institute of Nuclear Physics in Novosibirsk. One model of the Pestov or planar counter was used a year ago as part of a picosecond time-of-flight spectrometer in experiments on the VEPP-2M electron-positron storage ring. Resolution time of the spark counter itself was 30 picosec.

Time resolution is important in time-of-flight systems that are used to separate different kinds of particles. Such a time-of-flight system, employing scintillation counters, was used to detect charmed mesons in a magnetic detector at



Pestov spark detector. At the moment of breakdown, charge on the plates is removed from a limited area of the electrodes around the discharge, while remaining area stays sensitive.

SPEAR. The time resolution in that experiment was 200–300 picosec, a typical value for large scintillator arrays. Pestov believes that a larger version of his counter might improve the time resolution in such detectors by as much as a factor of 10. The range of energy over which separation of particles can be made would then be increased by a factor of three. In addition, Pestov counters can be built with excellent spatial resolution.

During his recent visit to SLAC and elsewhere in the US, Pestov explained to us how his new counter works. It is an improved version of the counter invented by the late Jack Keuffel in 1949. His counter had two parallel planes run at a constant voltage. Although the Keuffel counter had excellent time and spatial resolution, it was not practical for most particle-physics experiments because of its long recovery time and small area. Larger areas proportionately increase the spark-discharge energy, which results in damage to the electrode surfaces.

Pestov's improvement is to make a spark counter with a localized discharge. In such a device, at the moment of breakdown, the charge on the counter plates is removed from a limited area of the electrodes around the discharge. The remaining area is still sensitive to incoming particles. Pestov uses a material with high resistivity (10^9–10^{10} ohm-cm) as one of the counter electrodes. The gap between the electrodes is filled with a specially concocted gas mixture that absorbs spark photons well.

Because the discharge is localized, the size limitation of the Keuffel counter is eliminated. Maximum counting rate also increases significantly, according to Pestov, because his planar counter is equivalent to a large number of independent spark counters.

The negative electrode is made of semiconducting glass (typically 43% SiO_2, 26% BaO, 25% FeO). Its effective resistance has to be large enough to allow the gas to deionize before the full voltage is restored in the gap. Glass thickness must be larger than the spark gap to stop surface propagation of the discharge on the glass. And he says that the glass must conduct electricity by electronic conduction, rather than the ionic conduction typical of window glass.

Some experts in counters are said to use a combination of black magic and alchemy in deciding what gas mixture to use. Pestov told us that in order to get a mixture that will absorb uv photons over a wide range of wavelengths, he uses a mixture of many organic gases. In one case he used 1.7% (1–3) butadiene, 4.2% ethylene, 16.7% propane, 8.4% hydrogen and 69% argon under a total pressure of 6 atmospheres.

Typical spark gaps are 0.1–0.2 mm, and electric-field strength in the gap is 500 kV/cm. The best time resolution achieved at Novosibirsk, using a 0.1-mm gap, has been 28 picosec, measured with two counters in coincidence.

In the first trial of the Pestov detector in a time-of-flight experiment, a counter with 100 cm^2 was used in the measurement of the pion form factor. Now Pestov's group plans to design and construct 200 cm × 10 cm spark counters for use at VEPP-2M for the study of K decays. The experimenters are trying to improve the gas mixture to increase its stability and to improve the surface of the cathode (glass covered with copper) to get a higher work function. They are also designing a counter with thinner semiconducting glass to handle the higher counting rate needed in fixed-target accelerators. Pestov is eager to have physicists outside Novosbirsk try using his detectors.

—GBL

Polymer expands 35% upon uv irradiation

When a collection of long polymeric molecules experiences a change of chemical environment, the system may under certain circumstances exhibit a contraction or dilation, sometimes generating considerable mechanical forces in the process. Such "mechanochemical" forces have in fact been put to work in an isothermal chemical engine invented by Aharon Katchalsky-Katzir[1] and his colleagues at the Weizmann Institute in 1966. The original impetus for the study of mechanochemical phenomena in the early 1950's was an attempt to understand the mechanisms of muscle contraction.

In a union of mechanochemical and photochemical techniques, Avi Aviram of IBM has recently reported the development of a gel that expands to 2½ times its original volume when irradiated with ultraviolet light.[2] This very considerable expansion (35% in each dimension) is strongly suggestive of applications for printing, photocopying and information-storage technology.

Mechanophotochemistry. Aviram has coined the name "mechanophotochemistry" to describe the work in which he attempts to initiate the polymeric deformations characteristic of mechanochemistry by photo-ionization of light-sensitive groups attached to the polymer chains. Light-induced deformations of polymeric systems[3] had been reported by Georges Smets and P. H. Vanderwijer of Louvain University in 1968, and by Gerlof Van Der Veen and Willem Prins[4] at Syracuse in 1971. But these deformations were considerably smaller than the effect reported by Aviram. On the other hand they are reversible, a virtue that has thus far eluded Aviram's deformation process.

The mechanochemical deformation of polymeric systems falls into two basic categories, depending upon whether the system is crystalline or amorphous. In crystalline polymeric fibers that exhibit mechanochemical phenomena, the long molecules are generally linked to neighbors by hydrogen bonds (or other attractive interactions) at intervals along the length of adjacent molecules lying more or less parallel to one another. These cross-linking bonds tend to align neighboring molecules and to stretch them out in a straighter configuration than would be characteristic of an isolated polymer molecule. If one now introduces a chemical change (sometimes simply altering the pH) that melts the polymeric crystals by destroying these cross links, the suddenly separated molecules will