oscillates at about 5 kHz. Johnson noise on the resistor causes the voltage, and consequently the frequency, to fluctuate. You can relate fluctuations in frequency directly to the absolute temperature of the resistor. In fact, if you use a frequency counter, with gate time τ, the variance σ^2 of the fluctuations in the measured frequency is related to the absolute temperature T by

$$\sigma^2 = 2kTR/\tau\phi_0^2$$

where ϕ_0 is the magnetic flux quantum and R may be measured by noting the bias current and the average frequency of oscillation of the Josephson junction.

Recently Robert Soulen and Harvey Marshak (NBS, Washington) have compared Kamper's noise thermometer with other standard reference thermometers —by measuring the magnetic susceptibility of cerium magnesium nitrate, and by measuring the anisotropy of gamma rays coming from radioactive nuclei. These measurements show that the noise thermometer has an error of less than ±1.0 mK for a temperature of 20.0 mK. To achieve this precision at lower temperature, measurements take many minutes, a time which Kamper feels is about as long as is practicable.

Kamper's thermometer has the resistor connected directly to the junction, whereas Wheatley's is coupled by a superconducting transformer. This gives Wheatley the ability to get a bigger signal and to adjust the bandwith. The statistical rms fractional error in measuring temperature is inversely proportional to the square root of the product of the time you're willing to spend and the bandwidth of the system. Because Wheatley's bandwidth is adjustable (Kamper's is not), he can achieve greater precision. On the other hand, Kamper points out, Wheatley has a calibration problem because he must determine the coupling ratio of the transformer and the bandwidth to specify the temperature. Kamper feels his approach is simpler and more direct.

—GBL

References

1. R. P. Gifford, R. A. Webb, J. C. Wheatley, J. Low Temp Phys. 6, 533 (1972).
2. R. A. Kamper in *Symposium on the Physics of Superconducting Devices*, Charlottesville, Va., Office of Naval Research, 1967, page M1; R. A. Kamper, J. E. Zimmerman, J. Appl. Phys. 42, 132 (1971); R. A. Kamper, J. D. Siegwarth, R. Radebaugh, J. E. Zimmerman, Proc. IEEE 59, 1368 (1971); PHYSICS TODAY, August 1971, page 36.

Liquid-xenon proportional counter

Luis Alvarez and his collaborators[1] at Berkeley have built a proportional counter filled with liquid xenon. When we recently discussed the new counter (while flying over the Bay Area in Alvarez's twin-engine Cessna), he told us that the new counter will be useful for cosmic-ray satellite experiments, for ground-based high-energy particle detection and as a medical gamma-ray camera.

The counter works just like any other proportional counter—the ionizing radiation impinges on the filling material, which is normally a gas, but in the Berkeley device is liquid xenon. Because the xenon is liquid its higher density permits the improvement of spatial resolution by a factor of maybe 100 over that of a gas, Alvarez said. At the present time a spatial resolution better than 10 microns has been observed, and that value is limited by the width of the "signal generator." An advantage over solid-state counters is that because there are no grain boundaries in the liquid xenon, you can make as large a volume of liquid xenon as your pocketbook will stand, he went on. Typical condensed counters of germanium or silicon are limited by the size of the furnaces that do the purification, typically 2–3 inches.

The other very high-class, large-volume condensed-state counting material with good gamma-ray detection properties is cesium iodide, and Alvarez says that the liquid xenon is considerably cheaper in the sizes they want.

The Berkeley group has planned to use spark chambers in a cosmic-ray experiment on HEAO (High-Energy Astronomical Observatory)-B, scheduled for launch about 1976. One of the reasons for studying liquid xenon was to improve upon the spatial resolution of the spark chambers (about a fifth of a millimeter). The experiment is primarily designed to measure the very-high-momentum electrons and positrons in cosmic rays to look for evidence of the inverse Compton effect on the 3-K blackbody radiation. The electrons can be identified, but the positrons have to be distinguished from protons. To do that, the experimenters use the fact that positrons make showers in cesium iodide with a much shorter build-up distance than protons. You measure the particle's energy in a magnetic field (produced by a superconducting magnet) and you remeasure it in cesium iodide; if the two numbers agree there's a good change that the particle is a positron. Now Alvarez feels that the liquid xenon is also a promising substitute for the cesium iodide. He would need 10–20 gallons of it to operate a total absorption shower counter.

Alvarez says that many people think of liquid xenon as being too expensive compared with most materials—it's about a dollar per gram, the same as gold. But this cost is less than that of putting the satellite in orbit in the first place, he points out.

Because the liquid-xenon detector can be used as a high spatial-resolution substitute for a spark chamber, it should be quite effective at the energies at which the Batavia accelerator will be running. This ability to detect and measure very small magnetic deflections should lead to great savings in the cost of bending magnets. In such an application, you would use a thickness of only a few thousandths of an inch over a square meter.

In the early development of the liquid-xenon counter the Berkeley group was troubled with some unknown impurities that had an enormous appetite for electrons. To cure the ailment the experimenters use the central wire with potentials reversed as a very copious supply of electrons (produced by field emission from the very thin wire). These electrons are drawn over to the outside cylinder, which is normally a cathode, but in the clean-up mode acts as an anode. The impurities capture the electrons and are then swept out towards the wall by the electric field. Then the potentials are reversed back to normal counter operations. The ionization electrons can then multiply in the intense electric field, producing an avalanche. The clean-up is so effective that no impurities are normally seen for several hours. An unexpected bonus is that the energy resolution of a liquid-xenon counter in the gamma-ray detecting mode is now better than that of a sodium-iodide crystal.

—GBL

Reference

1. Richard A. Muller, Stephen E. Derenzo, Gerald Smadja, Dennis B. Smith, Robert G. Smits, Haim Zaklad, Luis W. Alvarez, Phys. Rev. Lett. 27, 532 (1971).

Batavia accelerator

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and the first 200-MeV beam was achieved two years later. The 7-GeV booster became fully operational in May 1971. On 1 July a 7-GeV beam was injected from the booster into the main ring and made to execute one full turn; by early August the beam was able to execute 10 000 revolutions.

Despite these early achievements it became apparent during the second half of 1971 that many modifications and improvements were needed in the main ring and that even minor changes to