possible the modern picture of elementary particles and forces, unimaginable in 1900. As Penrose indicated in 1972, twistor theory was intended to change everything, including gravity and its relation to mass.

Here also there are new developments. A preprint[5] from David Skinner, again building on a long sequence of ideas and discoveries, has adapted Witten's 2004 work to get a new practical handle on gravitational scattering amplitudes. These are even more notoriously difficult to calculate from standard theory than those of sub-nuclear particles and forces. Again, this is not a new theory of gravity — it is the standard theory, but in a completely new form. It has an emergent idea: greater simplicity will arise by including the cosmological constant (or 'dark energy') and abandoning Minkowski's flat space-time as the background. There is much interest in this geometry because of the way it now emerges from observations of the early Universe, but this is a new indication that it may also play a fundamental role in describing scattering amplitudes. The cosmological constant has a beautiful and elegant expression in twistor geometry — which will now attract much attention. ❐

Andrew Hodges is at the Mathematical Institute, University of Oxford, Oxford OX1 3LB, UK.
e-mail: andrew.hodges@maths.ox.ac.uk

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ROBERT C. RICHARDSON

Cool new world

Robert Coleman Richardson, who discovered superfluidity in helium-3 together with David M. Lee and Douglas D. Osheroff in 1971, has died at the age of 75. Their work sparked a global effort to characterize and understand superfluid helium-3, and the resulting boom in ultra-low temperature physics laid the groundwork for the study of quantum materials that display macroscopic quantum effects.

These days, commercial dilution refrigerators with base temperatures of 10 mK do not even require (external) cryogens. And starting from these temperatures, nuclear demagnetization refrigerators routinely reach 10 μK and below. But back in 1966, when Richardson first arrived at Cornell University as a research associate, low temperature physics was very much a do-it-yourself enterprise. In fact, Lee convinced Richardson to work on the proposed Pomeranchuk refrigerator to cool to 1 mK with no guarantee that they would ever succeed. At the time, however, there was no other way to get to such temperatures, and they wanted to reach the temperature of the nuclear magnetic ordering transition in solid helium-3.

The basic idea was to cool helium-3 by squeezing it. Zero-point motion of the fermionic helium-3 atoms means that helium-3 remains a liquid at absolute zero. The solid phase only exists under pressure. Given that the entropy of the solid is greater than that of the liquid phase below 0.3 K, a mixture should cool upon compression as the liquid solidifies, theorized Isaak Pomeranchuk in 1950.

Fortunately, the Pomeranchuk principle did work, as demonstrated by Yuri Anufriyev in Moscow and then by John Wheatley's group at the University of California at San Diego, as well as by the Cornell group. Osheroff's design improvements on the first-generation cooling cell soon led to measurements of kinks in the pressure versus time curve of helium-3 near 2 mK. These glitches — first noted as "glitch" and "glitch prime", but now labelled 'A' and 'B' — marked changes in the heat capacity, heralding some kind of phase transition, but in the early days, it was unclear whether those transitions were in the solid or liquid phase.


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In their first publication of the phenomenon, Osheroff, Richardson and Lee interpreted the A transition as being related to the magnetic ordering in the solid (*Phys. Rev. Lett.* **28,** 885–888; 1972). But there was strong skepticism from the community. It became paramount to do NMR measurements, which could discriminate between solid and liquid phases based on the magnitude of the susceptibility. After a number of technical set-backs, Osheroff finally identified the B phase as a superfluid. Then it became clear that the A phase was a different superfluid. There would be yet another superfluid, the C phase, in a magnetic field.

Part of the excitement was because helium-3 follows Fermi–Dirac statistics, so the atoms cannot Bose condense. Instead, the fermions need to first pair up, and the resulting Cooper pairs then condense into a degenerate ground state with no viscosity. These superfluids are highly unconventional, having *p*-wave pairing with non-zero spin and angular momentum.

Even while other experimental groups probed these exotic new phases and theoreticians were trying to explain the results, Richardson resumed his initial path towards measuring the much-anticipated magnetic phase transition in solid helium-3. With his student William Halperin, they finally found the ordering temperature of helium-3 nuclei at 1.17 mK. Richardson would continue his low temperature efforts at Cornell, eventually establishing a micro-Kelvin laboratory, and editing the laboratory bible *Experimental Techniques in Condensed Matter Physics at Low Temperatures*. In 1996, he, Osheroff and Richardson shared the Nobel Prize.

MAY CHIAO