

SPECIAL ISSUE Helium-3 and helium-4

Low-temperature physics has traditionally been associated with the subjects of superconductivity and liquid and solid helium. While a glance at the program of any current meeting will reveal many other fascinating activities under the rubric of low-temperature physics, these two subjects have continued to be pursued with vigor and striking success for three quarters of a century. Readers of *PHYSICS TODAY* were given a view of modern research on superconductivity in the March 1986 issue. This special issue is devoted to modern investigations in He^3 and He^4 .

Helium-4 was first liquefied in 1908 by Heike Kamerlingh Onnes. Twenty years later the existence of the two different phases of the liquid, helium I and helium II, was recognized by Willem Keesom and Mieczyslaw Wolfke. Superfluidity was not observed until 1939, when it was found by Jack Allen and Donald Misener and by Peter Kapitza, who named it by analogy to superconductivity. He^3 first became available in usable quantities after World War II, and its superfluidity was discovered in 1972 by Douglas Osheroff, Robert Richardson and David Lee.

The development in the 1950s of the helium expansion engine system together with the widespread availability of liquid nitrogen and gaseous helium (from natural gas wells) led to major cost reductions and to the widespread use of liquid helium throughout the world.

Liquid helium has long been used not only in fundamental studies of its own properties, but also as a tool in other areas of science and technology. Most obviously it has been used in the production of low temperatures. With liquid He^4 under reduced pressure one can reach about 1 K and with liquid He^3 temperatures to about 0.3 K can be achieved. The special properties of liquid mixtures of He^3 in He^4 have made possible the development of the dilution refrigerator, which can be used to cool materials to temperatures near 2 mK. More recently a class of experiments has arisen where liquid helium is used as a means to a result not directly related to its own properties. These include studies of Bénard convection, of turbulence, and of the motions of ions and electrons at a free surface.

It is impossible to present the vast

subject matter on liquid and solid helium in five articles. Instead I have selected topics representative of current research in both liquid and solid He^3 and He^4 and included one article describing a system that is a tool rather than an end in itself.

For more complete accounts of current research on liquid and solid helium, see, for example, the series *Progress in Low Temperature Physics*, edited by Douglas Brewer, and the proceedings of the triennial IUPAP Conferences on Low Temperature Physics.

In their article (page 25), Humphrey Maris and Aleksander F. Andreev show that at the He^4 solid-liquid interface the freezing pressure is practically independent of temperature. Freezing then becomes a primarily mechanical rather than thermal process, and the kinetics of growth become easy to study.

Michael Cross and Douglas Osheroff show in their article on solid He^3 (page 34) how atom-atom exchange leads to nuclear antiferromagnetism in the ultralow-temperature solid, and suggest that the field is still wide open for improving our understanding of this elegant, simple quantum spin system.

The article by W. F. Vinen and Arnold J. Dahm (page 43) is a good example of the use of liquid helium in another scientific context mentioned above. They describe the trapping of charged particles at the free surface of superfluid He^4 . This technique has made possible the study of two-dimensional fluids and solids formed on a nearly ideal interface.

Quantized vortices in liquid He^4 were first discussed by Lars Onsager and Richard Feynman in the 1940s and 1950s. Since then much has been written on their properties, even though some very fundamental problems, such as the core structure in He^4 vortices, remain unresolved. Klaus W. Schwarz and William Glaberson (page 54) discuss vorticity in two and three dimensions. They show how important the mechanics of classical ideal fluids has become in this study, and how one can understand even turbulent flows with relatively simple rules.

Vortices in superfluid He^3 have only recently come under study. Pertti Hakonen and Olli Lounasmaa (page 70) discuss the remarkable properties of vorticity in superfluid He^3 -A and He^3 -B, including the latest results with the dramatic rotating millidegree facility at the Low Temperature Laboratory in Helsinki.

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Copper nuclear demagnetization cryostat built by Douglas D. Osheroff (Bell Labs) for studies of spin-ordered solid He^3 . (See the article on page 34.)