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In Retrospect

Eighty years of superfluidity

In 1938, two studies demonstrated that liquid helium-4 flows without friction or viscosity at temperatures close to absolute zero. The finding led to major advances in our understanding of low-temperature physics.

WILLIAM P. HALPERIN

In the early twentieth century, scientists discovered the non-intuitive phenomena of superconductivity and superfluidity, in which electrons and atoms, respectively, flow without resistance over great distances. Superfluidity was beautifully demonstrated 80 years ago in two papers published in *Nature* by Allen and Misener[1] and Kapitza[2]. The authors observed the flow of liquid helium-4 through extremely narrow channels and showed that the substance becomes a superfluid at very low temperatures. The studies presaged the firm understanding of the relationship between superfluidity and superconductivity that now exists, and which provides the foundation for investigating unconventional superconductors and superfluid phases.

Allen and Misener observed the flow of liquid helium-4 through long, thin tubes, and found that the fluid's viscosity became immeasurably low at temperatures below 2.17 kelvin. Kapitza obtained similar results by measuring the flow through a small gap between two glass disks (Fig. 1). With foresight, Kapitza noted a possible connection to superconductivity, for which a complete theory was eventually realized[3] in 1957 by Bardeen, Cooper and Schrieffer (BCS). Shortly after the two *Nature* papers were published, an explanation for the superfluidity of liquid helium-4 was offered: Bose–Einstein condensation[4], the process whereby many particles known as bosons 'condense' into a single quantum state.

In the quantum world, particles of the same type are indistinguishable, and there are only two classes of particle: fermions and bosons. However, an even number of interacting fermions can make a composite boson — for example, an atom of helium-4 is a composite boson that comprises six fermions (two protons, two neutrons and two electrons). At sufficiently low temperatures, helium-4 atoms undergo Bose–Einstein condensation and become a superfluid. Similarly, in the BCS theory of superconductivity, electrons that have a suitably attractive interaction can combine into charged composite bosons called Cooper pairs, which condense to form a superconductor.

In the wake of the Second World War, substantial quantities of the light isotope of helium, helium-3, became available through production of the heavy isotope of hydrogen (hydrogen-3 or tritium) for use in the hydrogen bomb. Because helium-3 contains an odd number of fermions (two protons, one neutron and two electrons), it is not a composite boson. It might therefore be considered that Bose–Einstein condensation could not take place and that helium-3 could never be a superfluid. However, the success of the BCS theory suggested another possibility: composite bosons comprising Cooper pairs of helium-3 atoms might condense into a superfluid, much like the electrons of a BCS superconductor.

The properties of this hypothetical superfluid were studied theoretically[5–7] in the 1960s. Research on the subject then exploded following the unexpected discovery[8] in 1972 of this superfluid at temperatures below 0.003 K. At first, the observations were interpreted as spontaneous nuclear magnetic ordering in solid helium-3, but shortly afterwards, they were correctly identified as the transition to a superfluid[9]. Nuclear magnetic ordering in solid helium-3 was discovered[10] two years later at a temperature of 0.001 K.

Cooper pairs have two types of angular momentum, characterized by the orbital quantum number (L) and the spin quantum number (S). Conventional BCS superconductors have $L = 0$ and $S = 0$, whereas superfluid helium-3 has $L = 1$ and $S = 1$. Nevertheless, the superfluid's properties can be understood using a modified version of the BCS theory[11]. The discovery of superfluid helium-3

50 Years Ago

There was an increase in the number of patients discharged from British hospitals in 1964, and a decrease in the average length of stay in hospital compared with 1962 and 1963. Men and boys stayed in hospital an average length of 18.3 days in 1964; women and girls … averaged just under two days less (16.7 days) … These are some of the findings in … the *Report on Hospital In-Patient Enquiry* for the year 1964 … The report contains detailed tables prepared from the 1964 ten per cent sample of discharges and deaths recorded … The tables are a mine of information … Injuries, poisonings and the like are all analysed in great detail according to whether they were caused by road traffic accidents, accidents in the home, or "other" mishaps.
From *Nature* 27 January 1968

100 Years Ago

It was stated officially … that the Admiralty had tested many methods of disguising mercantile shipping. One of these methods is to paint the ship with various quaint combinations of different colours. But this does not appear to have proved much of a success … Mr. Abbott H. Thayer … was one of the first to recognise that a high degree of invisibility is conferred on certain birds by the simple adaptation of being dark above and whitish below. He took two wooden decoy ducks, and placed them against a sandbank. One was coloured like the sand … the other was coloured on its upper parts darker than the surrounding sand, and graded below to pure white. At a short distance the first was still clearly visible, but the second was quite lost against its background … Some modification of this experiment has been tried on ships … but this device has not proved so successful as had been hoped.
From *Nature* 24 January 1918