He^3 *CRYOSTATS*

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Systems are described which permit the attainment and maintenance of temperatures below 1° K through pumping on He^3 vapor. Temperatures down to 0.3° K have been obtained over a volume of approximately 1 cm^3 within a transparent glass system. Temperatures of 0.5° K and higher have been maintained in the presence of a heat influx of 7×10^{-4} W in a continuously-operating metal apparatus containing 140 cm^3 of liquid He^4.

As is well-known, experiments at temperatures between 1 and 4.2° K are carried out in cryostats, Dewars of liquid He^4 subjected to pumping being customarily used for this purpose. At temperatures below T_λ = 2.18° K, however, helium becomes a superfluid, and a film of liquid helium begins to flow rapidly along the Dewar walls to the region of higher temperatures, where it evaporates. This circumstance complicates greatly the attainment of extremely low temperatures by pumping on the helium vapor. The record low temperature for He^4, 0.71° K, was reached by Keesom[1] in 1932, using for removal of the vapor a pump of 675 *l*/sec capacity. Ten years later the same result was obtained by Lazarev and Esel'son,[2] who pumped away the He^4 vapor through a diaphragm having a very small aperture (0.05 mm in diameter), using for this purpose a pump of relatively small capacity, 15 *l*/sec. Temperatures below 0.7° K have not been obtained at all by these means.

The extremely rare helium isotope He^3 does not become superconducting even at the lowest temperatures; its use in systems for the attainment of low temperatures by vapor pumping is therefore highly effective.

At the present time there are, both here and in other countries,[3,4] a number of low-temperature establishments in which He^3 is used as a working substance for obtaining temperatures substantially below 1° K. The present paper is concerned with the description of two such systems in use at the Institute for Physical Problems.

The first of these systems is represented schematically in Figure 1b, together with the apparatus for the production of low temperatures. This same apparatus is illustrated separately in Figure 1a. The system consists of the double Dewar 1 filled with He^4, within which is situated a smaller, transparent glass Dewar 2, containing liquid He^3 and having a volume of approximately 3 cm^3. The He^3 vapor is pumped off through a thin-walled steel tube 3, 15 mm in diameter, which is joined to the inner Dewar by means of the copper seal 4. A screen 5, in contact with the liquid He^4 bath, is placed inside the copper coupling to pro-

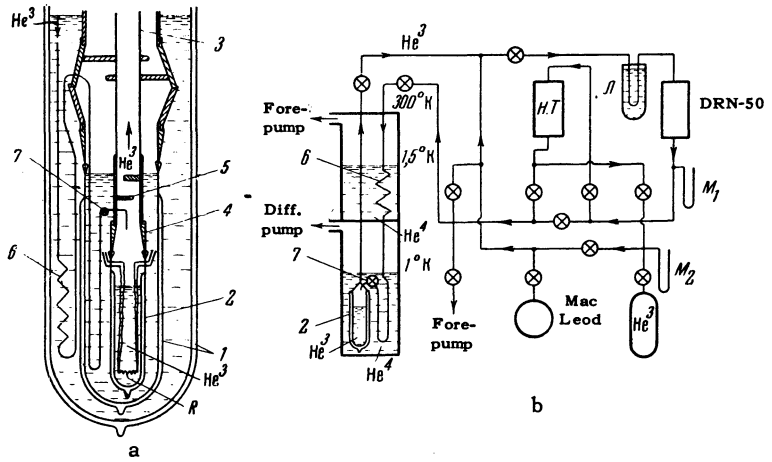

FIG. 1

vide shielding against radiation from above.

Pumping is provided by means of a DRN-50 mercury diffusion pump (Fig. 1b), of 30 *l*/sec capacity, operating with a forepressure of 25 — 30 mm Hg. A cold trap cooled with liquid nitrogen is connected to the input of the DRN-50. The output of the pump is coupled to a coiled tube 6 immersed in the liquid He^4 bath and connected through the valve 7 with the innermost Dewar. The coil passes in succession through the outer and inner He^4 Dewars in which temperatures of 1.5 and 1°K, respectively, are maintained with the aid of separate pumps. Due to the low temperature of the He^4 bath, the DRN-50 mercury pump can be operated without a forepump, having at its output a pressure approximately equal to the vapor pressure of He^3 at 1°K; i.e., 8 — 10 mm Hg. For use in the attainment of limitingly low temperatures, as well as in the event of a high temperature in the surrounding bath, a mechanical mercury Toepler pump NT as developed by Danilov[5] is connected in series following the diffusion pump. A mercury manometer M_1 permitting measurement of the He^3 pressure up to 200 mm Hg is installed at the output side of the DRN-50. The He^3, condensed and cooled to 1°K in the coil, is transferred as needed into the He^3 Dewar 2 through the valve 7. At the end of the experiment the He^3 is pumped into a gas cylinder, the DRN-50 and mechanical mercury Toepler pumps being used for this purpose. Control of the quantity of He^3 collected is accomplished with the aid of a mercury manometer M_2 having a 760 mm Hg scale. The system containing the He^3 is carefully tested for vacuum-tightness.

The lowest temperature reached with this apparatus was 0.3°K (p = 0.002 mm Hg). The temperature of the liquid He^3 was determined by means of a resistance thermometer R of 30 μ phosphor-bronze wire. The thermometer was calibrated in advance against the He^3 vapor pressure as measured with a MacLeod gauge. In the lowest temperature region the resistance thermometer was calibrated against the magnetic susceptibility of potassium chrome alum. For the temperature determinations we employed the scale of Sydoriak and Roberts.[3] The possibility of periodically adding liquid He^3 made it feasible to work uninterruptedly with this system at a low temperature for a period of 8 — 10 hours, using a single charge of gaseous He^3 (approximately 3 *l*). With the pumps shut down, the warm-up of the liquid from 0.3 to 1°K occupied no less than three hours.

The second type of system, used for obtaining low temperatures over a greater volume, is illustrated in Figure 2. The layout of the system is fundamentally similar to that shown in Figure 1b, with the exception that the Toepler pump is replaced by a NVG-2 oil pump[6] developed at NIVI. The gaseous He^3 condenses in a coil 1 (2 × 0.3 mm in diameter, 5 m long) situated in the liquid He^4 bath, and is introduced through an opened valve 2 and a smaller coil 3 into the He^3 collector 4. The coil 3 is formed from a 200 mm length of 0.2 mm i.d. capillary tubing.

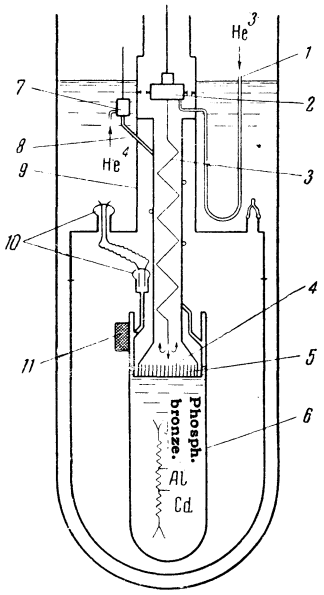

FIG. 2

The He^3 flowing through the smaller coil is further cooled by the vapors from the liquid evaporating below. The valve 2, in contact with the surrounding bath, serves at the same time as a shield for radiation coming from above. The He^3 collector 4 is in the form of a copper vessel soldered to a thin-walled stainless steel tube 12 × 0.2 mm in diameter and 100 mm long. The upper end of the tube is soldered into the body of the apparatus. To the bottom of the He^3 container is soldered a strip 5 of copper 5 mm wide and 0.3 mm thick, in the form of a spiral with a spacing of 0.2 mm between the turns. This increase in the surface area of the collector in contact with the boiling He^3 is needed for better transfer of cold from the coldest surface layer of the He^3 to the walls of the collector. (In the first version of the apparatus, without this increased surface area, sudden increases in the temperature were observed as the He^3 was cooled, due to boiling up of the lower layers of the liquid). The volume of the cylindrical portion of the collector was 2.5 cm^3. A copper bulb 6 of approximately 200 cm^3 capacity was soldered to the He^3 collector. Liquid He^4 was transferred from the bath into the bulb 6

through a valve 7 and a German silver tube 8 (2 × 0.3 mm in diameter and 160 mm long). The He^3 collector and bulb were isolated from the helium bath by means of a vacuum jacket 9. Copper-glass seals 10, with platinum wires (0.3 mm in diameter) sealed into the glass, and connected to each other with 0.1 mm diameter constantan wire, were used to carry twelve electrical leads through the vacuum jacket.

A screen 11 containing activated charcoal (1.5 gm) was fastened to the outer wall of the bulb, within the vacuum jacket. The jacket was filled with He^4 at a pressure p = 0.5 mm Hg, at room temperature, and then sealed off. The presence of He^4 within the jacket reduced the cooling time for the bulb and He^3 collector. At a low temperature the He^4 in the jacket was adsorbed by the charcoal. The time required for cooling the bulb, from the moment pumping was begun on the He^4 bath (T = 4.2°) until a temperature T = 0.5° K was reached, including the filling of the bulb with He^4 and the condensation of the He^3, did not exceed one hour. The time for cooling the He^3 collector and the bulb, with the latter containing liquid He^4, from T = 1.15° K to T = 0.5° K, was 5 — 10 minutes.

Pumping on the He^3 vapor was carried out with the aid of the DRN-50 mercury diffusion pump and an NVG-2 forepump. The temperature of the bulb could be set at 0.5° K or higher by adjusting the rates at which the He^3 was introduced and its vapor pumped away, with the aid of the valve 2. With continuous circulation of the He^3, work could be continued as long as the liquid in the outer bath was not completely boiled away (5 — 10 hr). When the bulb was cooled down without liquid He^4, the temperature could be reduced as far as 0.35° K. The principal leakage of heat into the bulb came from the bath, through the helium in the tube 8. The temperature of the helium bath was maintained at 1.15° K. It should be noted that if an additional valve is installed on the bulb 6 and the tube 8 is evacuated, then for small heat inputs it is possible to obtain a temperature of 0.35° K with the bulb completely filled with liquid He^4. The temperature within the bulb 6 was determined from the He^3 vapor pressure with the pump shut off, and also from the resistance of a thermometer of 30 μ phosphor bronze placed inside it. The resistance thermometer was calibrated in advance against the He^3 vapor pressure and the magnetic susceptibility of potassium chrome alum, and, over the temperature range 0.3 — 1.1° K, had a practically linear temperature dependence. In addition, the superconducting transition points of wires of pure aluminum, 50 μ in diameter, and cadmium, 67 μ in diameter, connected in series with the thermometer, served as standard points with which the temperature measurement could be checked each time.

The systems described above make it possible to experiment conveniently over the temperature region from 0.3 to 2° K.

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