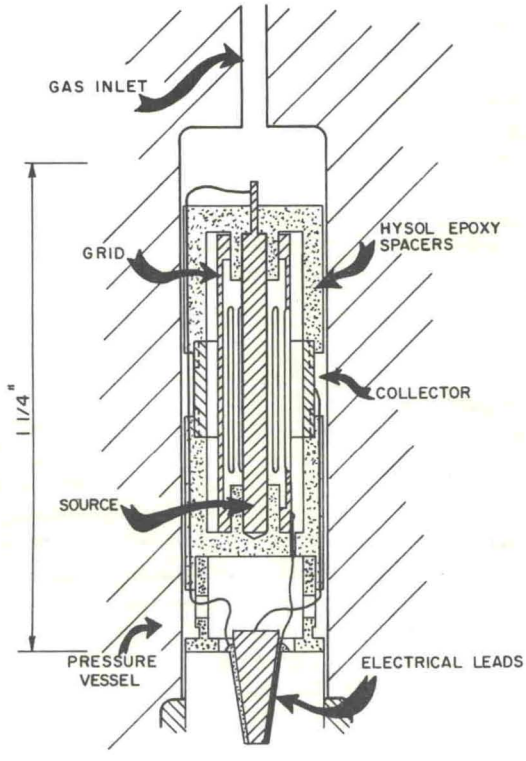

FIG. 2. Cross-sectional view of assembled probe.

that free electrons are not created in the drift space between the grid and collector. Both positive and negative ions can be extracted to the grid depending on the field polarity applied to them.

Temperature is maintained by immersing the high-pressure vessel in a pumped bath of liquid helium which is kept stable to within 0.05 °K during measurement. Temperature regulation is provided simply by controlling the bath vapor pressure with the pumping speed. A calibrated germanium resistance thermometer is used to measure bath temperatures which can be varied between 1.2 and 4.2 °K.

SAMPLE PURITY

The problem of sample purification in this type of measurement has received extensive consideration by many investigators.[9,12] The operation of the gas high-pressure-generating apparatus inevitably introduces impurities and one cannot obtain helium purity as high as that attainable in low-pressure measurements. Precautions are taken to minimize oxygen contamination of the system, primarily by keeping an overpressure of high-purity argon or helium in it at all times. The solid helium is frozen from 99.9999%-pure helium gas as purchased from Matheson Gas Products (East Rutherford, N. J.). To purge contaminants from the pressure system it is alternately filled to tank pressure and bled back to 50–100 lb/in.^{2} six times before it is pumped to working pressure. In the high-pressure runs the gas is pressurized at room temperature and the pressure vessel and gauge are isolated from the rest of the system by the line valve before cooling. Before the sample is cooled to solidification, an electric field of reverse polarity is applied between the source and grid electrodes. This procedure removes charged impurities, such as oxygen molecules which capture electrons, and it generally results in significantly lower background-current levels.

PROBE CALIBRATION

Accurate determination of the electron mobility requires evaluation of the effective probe dimensions as well as determination of the carrier transit time T_0 between the grid and collector in a known field E_g. To maximize the probe sensitivity, the grid-collector separation is minimized. Of the two radii (i.e., grid and collector) which characterize the drift space, only the collector radius r_c can be determined directly. The grid is a thin-walled cylinder with slots along its length; the effective grid radius lies within the thickness of its walls. Two grids have been built and used successfully. The most sensitive probe incorporates a grid whose wall thickness is 0.010 cm. A thinner wall does not offer sufficient structural rigidity. The grid is calibrated by comparing the pressure dependence of the mobility of both positive and negative ions in liquid helium with known results[6] at 4.2 °K. Calibration results for this grid are shown in Fig. 3. With a cylindrical electrode probe the mobility of an ion is given by

$$\mu = \frac{1}{2T_0 V_g}\,(r_c^2 - r_g^2)\ln\left(\frac{r_c}{r_g}\right).$$

This expression can be used to determine r_g and the sensitivity of the equipment. The effective grid radius is determined to be

$$r_g = 0.303 \pm 0.001 \text{ cm}.$$

This gives a drift distance

$$d = 0.015 \pm 0.002 \text{ cm}.$$

In performing the probe-calibration experiments in liquid helium satisfactory pressure can be generated by the helium supply tank. In these experiments the pressure generating equipment is bypassed and the helium tank is connected to the high-pressure gas line entering the vessel. For work in the liquid, the apparatus is limited to detection of transit time T_0 below 0.25 sec by the output RC-filter network and the power supplies. The response time with this equipment configuration is less than 1 min. Alterations to the RC-filter network to increase

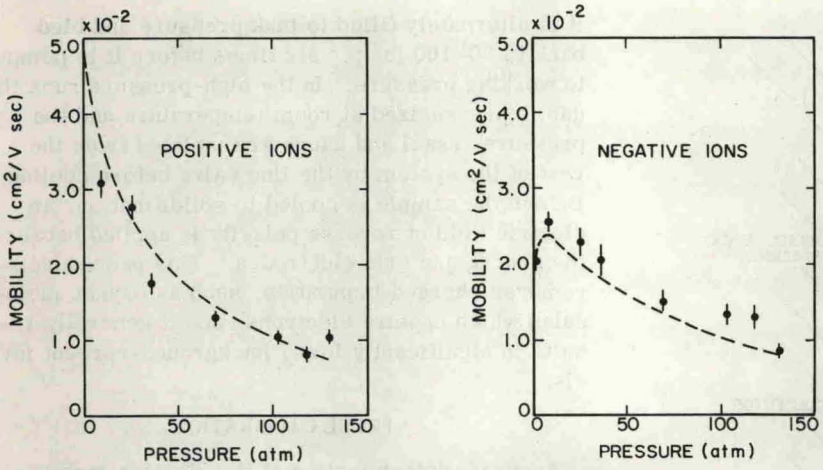

FIG. 3. Calibration results for the most sensitive probe. Ion mobility vs pressure, 4.2 °K. Dashed curves from Keshishev, Mezhov-Deglin, and Shal'nikov (Ref. 6).

the transit-time-detection limit to a maximum of 2.5 sec have resulted in a response time of nearly 30 min. This latter arrangement has been tested in liquid helium to confirm its accuracy and is used in solid helium only with the most sensitive probe.

EXPERIMENTAL RESULTS

Electron-mobility measurements in high-density helium at low temperatures have been performed over a wide pressure range. The measurements in solid helium are supplemented by isolated measurements in the liquid at very low temperatures and in the dense gas at a temperature of approximately 80 °K.

In solid helium the probe sensitivity was 1.6×10^{-6} cm^2/V sec. At 4.2 °K no charge transport was observed at pressures up to 6400 atm in a maximum field of 3300 V/cm. Similar measurements at 1.2 °K and 32 atm yielded the same result. Two experimental runs were performed at high pressure in which the temperature of the helium sample was allowed to rise above the melting temperature from 4.2 °K. In both cases fast probe response was needed to follow the warm-up, thus necessitating use of probe sensitivities an order of magnitude poorer than that attainable with the slow probe. The first run terminated with a pressure of 6270 atm at the melting point of 45 °K, and the second sample melted at 48 °K with a pressure of 6660 atm. Electronic charge transport was not observed in these runs at any temperature below the melting point. The present results, in spite of comparable probe sensitivity, do not agree with the results obtained by Keshishev *et al.*[6] who report the negative-ion mobility value of 9.7×10^{-6} cm^2/V sec in a field of 1.52×10^4 V/cm at 1.96 °K and 38 atm.

Measurements in liquid helium at temperatures below 4.2 °K are in satisfactory agreement with work published by other experimenters. These results are reproducible when the sample phase is cycled from liquid to solid and back to liquid, indicating that no damage has been sustained by the probe during the phase changes.

The results of mobility measurements made in the dense gas at 6760 atm and 80 ± 10 °K of both the positive and negative charge carriers are given below:

$$\mu_- = (3.1 \pm 0.5)\times10^{-3}\ cm^2/V\ sec\ ,$$

$$\mu_+ = (4.9 \pm 0.6)\times10^{-3}\ cm^2/V\ sec\ .$$

The large uncertainty in the temperature results from a lack of sensitivity in the germanium resistance thermometer in this temperature range and from lack of provision for thermal stabilization above liquid-helium bath temperatures.

DISCUSSION

Two explanations may account for the results of the present experiments. First, the localized electron state may not collapse at or below the applied pressure. Second, the electrons may be trapped by imperfections in the solid phase whether they are cavity localized or quasifree.

Let us first assume that no ion-trapping mechanisms of sufficient strength or number are present in the solid-helium sample. Earlier work has confirmed the presence of cavity-localized electrons in the solid phase at low pressures.[6,7] The existence of localized electron states at the maximum pressure applied is indicated by both direct and indirect experimental results. Primary evidence is given by the fact that no high-mobility ion was detected in the solid below its melting temperature. Indirect evidence comes from analysis of the present results in the dense gas. It is shown below that electron bubbles with a radius of approximately 6 Å exist in the gas at densities similar to that in 4000-atm solid helium. Thus, to the extent