

Effect of Pressure on the Electron Mobility in Solid Helium[†]

V. E. Dionne,* R. A. Young,† and C. T. Tomizuka

Department of Physics, University of Arizona, Tucson, Arizona 85721

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The effect of pressure on the mobility of the cavity-localized electron in solid helium has been studied to a pressure of 6660 atm. No delocalized electron state has been detected at this pressure below the melting point of the solid. It is shown that the results are consistent with the presence of electron bubbles at the highest pressures investigated. The nature of possible charge-trapping mechanisms that might account for the results is discussed.

INTRODUCTION

The study of properties of excess electrons in liquid¹⁻³ and gaseous^{4,5} helium has received much attention during the past decade. The localized nature of the excess electron has been demonstrated both experimentally and theoretically. Its configuration as a bubble has been well established. With several exceptions, relatively little has been investigated in solid helium in which the electron is also localized. Keshishev, Mezhev-Deglin, and Shal'nikov⁶ made preliminary measurements which have

established a lower limit for the mobility of electrons in ⁴He crystals. Cohen and Jortner⁷ have extended theoretical considerations initially made for the liquid and gas phases to the problem of excess electrons in solid helium.

Within a broad range of helium densities the excess electron is self-trapped in a cavity whose radius is several times the interatomic distance. The cavity is the minimum free-energy configuration in helium associated with a weakly attractive long-range electron-helium-atom polarization potential and a strong short-range electron-atom re-

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TABLE I. Electron mobility in four rare-gas solids. T_c is the critical temperature and T is the temperature at which the measurement was made. Pressure was 1 atm, except for helium which was measured at 38 atm.

Species	T_c (°K)	T/T_c	μ (cm ² /V sec)
Xe ^a	289.8	0.54	4.5×10^3
Kr ^a	209.4	0.54	3.7×10^3
Ar ^a	150.7	0.54	1.0×10^3
He ^{1 b}	5.20	0.47	$\geq 10^{-5}$

^aReference 9.

^bReference 6.

pulsion.⁸ Among solids, this mode of electron localization is unique to helium. In a comparison of the electron mobility in solid helium to other rare-gas solids, the cavity-localized electron of helium is at least 10^5 times less mobile than the free electrons of argon, krypton, or xenon (Table I).

In their theoretical treatment of the localized electron in solid helium, Cohen and Jortner⁷ proposed an experiment to increase the helium density in an attempt to raise the localized electron energy level above that of a free-electron state. The energetically favored delocalized electrons would be expected to behave in a manner similar to electrons in other rare-gas solids. In particular, their mobility should increase several orders of magnitude. This transition is expected to take place at about 4000 atm according to their calculation. This paper reports on the search for the delocalized electron state in helium.

EXPERIMENTAL METHOD

The experiment consists of a series of electron-mobility measurements at low temperatures and high pressures. A null current method, after Cunsolo,¹⁰ is used to monitor any pressure-induced mobility change. A glass or other nonconducting sample vessel has an extremely limited capacity for pressure containment and is not suitable for the present purpose. A fully hardened beryllium-copper vessel is used. The simple linear array of electrodes commonly used with the null current measurement of carrier mobility is not practical with a metal vessel. A cylindrical electrode configuration in which the pressure vessel becomes a guard electrode is successfully employed.

The gas pressure generating apparatus of the pressure system, similar to that of Goldsmith and Heard,¹¹ is separated by a high-pressure valve from the sample vessel and pressure gauge (Fig. 1). A 100 000 lb/in.² Heise gauge with rated accuracy of ± 100 lb/in.² is used to measure pressure. The sample vessel, constructed of hardened beryllium copper, (Berylco 25 alloy, The Beryllium Corp., Reading, Pa.) is sealed at its closure plug with a brass Bridgman extrusion ring. The mobility probe

is mounted directly on the closure plug. The high-pressure solid-helium sample is frozen isochorically from pressurized helium gas generated at room temperature. At the highest working pressures less than 10% of the generated pressure is lost in lowering the vessel temperature from 300 to 4.2 °K.

A thin cone of EC 2850 GT Epoxy (Emerson and Cuming, Inc., Canton, Mass.) is used in place of the standard pipestone or lavite cone for electrical lead insulation. This substitution allows all the insulated electrical leads to be sealed in a single cone. No detectable leak is present when the system is isolated by the valve and the vessel is filled with solid helium.

The current probe (Fig. 2) consists of three concentric cylindrical electrodes, the source, grid, and collector. These are mounted concentric with the pressure vessel cavity. The vessel serves as a guard electrode. The electrodes are separated by supports made of Hysol CP2-4289 Epoxy (Hysol Corp., Olean, N. Y.). Both Epoxy insulating materials are chosen for their high volume resistivity. (Hysol CP2-4289: 6×10^{14} ohm cm at 298 °K; EC 2850 GT: 5×10^{16} ohm cm at 298 °K.) The collector electrode is gold-plated copper. The grid and source electrodes are made of brass and copper, respectively. Connections to the electrodes and the entire electrical network are made with low-thermal solder.

The flux of excess electrons is provided by ionization of helium atoms in the vicinity of the source electrode by α -particle radiation from 10 μ Ci of polonium 210 plated on the source electrode. In solid and liquid helium the range of the 5.30-Mev α particles is less than 0.3 mm.¹ This ensures

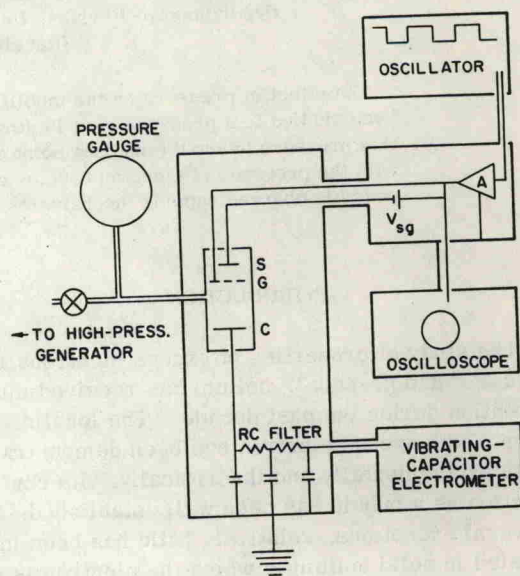


FIG. 1. Schematic diagram of the apparatus.