[10]A similar Doppler shift in low-energy electron spectra from Ar^+-Ar collisions has recently been demonstrated by M. E. Rudd, T. Jorgensen, and D. J. Volz, Phys. Rev. Letters 16, 929 (1966).

[11]See H. Körber and W. Melhorn, Z. Physik 191, 217 (1966). When the *K* vacancy is caused by electron or photon impact, the *KLL* Anger spectrum has its most intense line at 804 eV with weaker lines down to 730 eV.

MEASUREMENT OF VELOCITY DISTRIBUTIONS OF ATOMS EVAPORATING FROM LIQUID HELIUM II†

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(Received 11 February 1966)

The velocity distribution of atoms evaporating from liquid helium at 0.59-0.7°K has been measured in an atomic-beam apparatus, using a chopped beam and time-of-flight method. The source temperature derived from the time-of-flight data for beams with gas in the source is in satisfactory agreement with the source temperature from vapor-pressure measurements. The source temperature derived from the beam measurements when liquid is used in the source is approximately 1° hotter than that derived from vapor-pressure measurements.

Figure 1 is a schematic view of the apparatus. The source pot, *a*, can be cooled by evaporating liquid ^{3}He supplied to chamber *b* through stainless capillary tubing. The ^{3}He vapor is pumped away through a thin-walled stainless tube which also positions the source. Either liquid or gaseous ^{4}He can be admitted to the source pot through stainless capillary tubing after passing through a heat exchanger in the external helium bath. Beam separation is accomplished by cryosorptive pumping surfaces of molecular sieve Zeolite, *c*. The beam passes through a two-slit, rotary-disk chopper at *d*, and through the drift space *g* to the detector *h*. The detector is a modification of the field-ionization microscope, and has previously been described.[1] Pressures in the detector and chopper chambers were $(2\text{-}4)\times 10^{-10}$ Torr.

A timing signal, coincident with the beam-chopper opening, is derived from a light bulb and photocell arrangement (*e* and *f*). The output from the photomultiplier *k* is routed through appropriate pulse circuitry to a 512-channel memory unit, whose channel advance rate is set by a clock oscillator phase-locked to the beam-opening signal. The memory storage thus yields an intensity versus time-of-flight distribution. Relevant dimensions are source-detector distance, 98 cm; and source-aperture diameter, 3 mm. The rather large (by usual molecular beam standards) source opening was chosen to ensure that the observed beam arose directly from the surface of the evaporating liquid, rather than from a gas cloud just above the liquid surface.

Beams were observed under various conditions as summarized in Table I. Each run corresponds to two hours of running time and resulted in around 80 000 counts of background

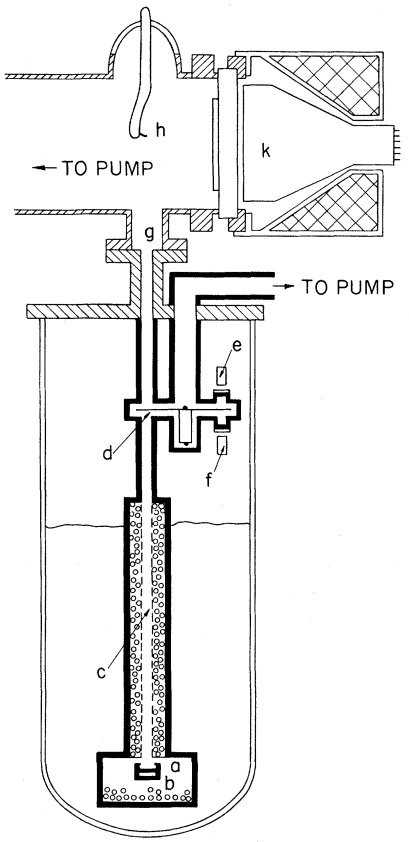

FIG. 1. Atomic-beam apparatus.

Table I. Summary of data.

Run	Gas or liquid	Bath temp (°K)	Source temp (°K)	Source pressure (10^{-3} Torr)	Source temp from beam (°K)
1	G	4.2	4.2	0.4	3.5 ±0.4
2	G	1.60	1.60	2.0	1.65 ±0.1
3	G	1.60	1.60	2.0	1.65 ±0.1
4	G	1.60	1.60	2.0	1.65 ±0.1
5	G	4.2	4.2	1.2	4.0 ±0.4
6	G	4.2	4.2	1.2	4.0 ±0.4
7	L	1.60	0.70	2.3	1.9 ±0.1
8	L	1.60	0.62	0.4	1.65 ±0.1
9	G	1.43	0.60	0.2	0.605 ±0.05
10	G	1.43	0.60	0.07	0.58 ±0.05
11	L	1.43	0.65	0.87	1.55 ±0.1
12	L	1.43	0.59	0.20	1.6 ±0.1

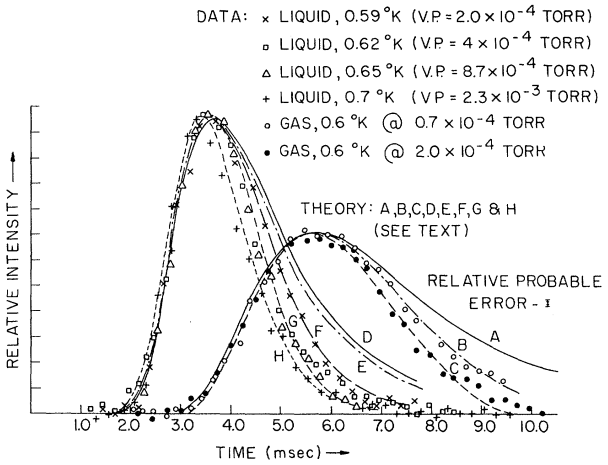

FIG. 2. Results of velocity-distribution measurements (relative intensity versus time of flight).

per velocity interval and 5000-18 000 counts of beam in the peak velocity interval. Typical results of the time-of-flight measurements are shown by the points in Fig. 2. The theoretical curves A, D, and E are based on a Maxwellian distribution in the source at 0.6, 1.6, and 1.65°K, respectively, and include the effect of the time width (0.75 msec) of the input beam pulse. Curves B, C, E, F, and G include a beam-beam scattering correction computed from a straightforward application of the formulas derived by Estermann, Simpson, and Stern[2] using the Massey-Mohr[3] theoretical low-energy He-He cross section (10^{-14} cm^2). The correction was applied for the following temperature and pressure conditions: curve B, 0.6° and 0.7×10^{-4} Torr; curve C, 0.6° and 2.0×10^{-4} Torr; curve F, 1.6° and 2.0×10^{-4} Torr; curve G, 1.65° and 8×10^{-4} Torr; and curve H, 1.7° and 2×10^{-3} Torr. This correction, with a minimum at $v/\alpha=\sqrt{\frac{5}{2}}$, does not shift the most probable arrival time t_m which was used to compute the source temperature (from beam) according to $T=ml^2/5kt_m^2$ where m is the mass of a He atom, l is the drift space length, and k is Boltzmann's constant. Source pressures were deduced from ^{4}He flow rates and pressure outside the apparatus in the gas runs and from the ^{4}He vapor pressure at the source temperature which was determined from the vapor pressure of the liquid in the bath or refrigerator. In all cases the beam intensities at the detector confirm these pressure determinations.

When gas is used in the source, the small dimensions of the inlet pipe and the geometry of the source insure that atoms make many wall bounces before becoming part of the beam, whereas the gas flow is adjusted so that the source pressure is low (cf. especially run 10) and no liquid or superfilm can form. During liquid operations, superfilm creeps out of the source at a rate of $\simeq1.7\times10^{18}$ atoms sec^{-1} at 0.6°K, a result obtained by direct measurement of the time required to empty the pot and in excellent agreement with data on superfilm creep rates. The surface area of the pot-refrigerator assembly allows 3×10^{19} atoms/sec to evaporate at this temperature; hence all creeping atoms evaporate and after a few bounces are trapped by the Zeolite in the source chamber bottom. We have computed the apparent heating of the beam by attenuation of slow atoms[4] in terms of $l/\bar{\lambda}$ where l is some apparatus distance along the beam and $\bar{\lambda}$ is the average mean free path over l. Gas runs 9 and 10 at two pressures enable us to put an upper limit on this heating effect without any assumption about the cross section or the details of the density variations near the source. This limit is such that in liquid run 12, where the film creep increases the helium pressure in the source chamber at most 10 fold, and hence reduces $\bar{\lambda}$ by 10, the apparent beam heating could raise the temperature of the beam by at most 0.24°, compared to the 1° actually observed.

Gas and liquid runs were alternated so that no progressive change in the apparatus seems likely to account for the result. Relative intensities were compared, as these reflect the attenuation introduced by the beam-beam scat-

tering, and were found in reasonable agreement with the assumed cross section for He-He scattering. If the liquid were indeed at the temperature determined by beam measurements and had its usual vapor pressure of 7 Torr, the apparatus would have been overloaded with He. The liquid results do not depend significantly on bath temperature, on changes in the arrangement of heat exchangers and inlet pipe geometry, or on the level of vibration as qualitatively altered by operating a number of extra mechanical pumps. Adequate time to attain equilibrium was allowed.

The data indicate that the Maxwell-Boltzmann distribution is valid for helium gas down to 0.6°K and indirectly confirm the validity of the Massey-Mohr scattering theory in the low-energy limit. The evaporating liquid velocities are similarly distributed in the usual modified Maxwellian way, but are characterized by a velocity that would be associated with a gas warmer by 1.0 ± 0.1°K than the actual source temperature.

It is perhaps premature to try to attribute this result to the well-known quantum properties of He II, but it is interesting that the energy excess per atom is in agreement with that predicted by Toda[5] for the formation of eight-atom microcrystallites (1.05°K per atom). Further development of these techniques will be necessary before beams emitted from liquids can be observed over a wider range of temperatures and with other gases. We feel that the classical molecular-beam method as exemplified by this first experiment can serve as a useful tool in the study of the microscopic properties of liquid helium. Meyer et al.[6] have observed the velocities of atoms evaporated by heat pulses from films of ^{3}He and ^{4}He within a small sealed cavity, and found several anomalous effects. No comparison with our results seems immediately apparent.

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†Work supported by the Joint Services Electronics Program [Contract No. DA36-039-AMC-03200 (E)].

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BAND STRUCTURE AND LASER ACTION IN $Pb_xSn_{1-x}Te$

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(Received 27 May 1966)

This Letter reports the observation of spontaneous and coherent emission in the vicinity of 15 μ from $Pb_xSn_{1-x}Te$ alloys at 12°K optically excited by radiation from a GaAs-diode laser. A model of the band structure of the alloy system is proposed to explain the composition dependence of the band gap and the change in sign of the temperature coefficient of the band gap between PbTe and SnTe.

In the photoluminescence experiments a small crystal sample and the GaAs laser pump were mounted on a copper heat sink which was in contact with liquid helium.[1] The Fabry-Perot cavity was formed by two parallel faces of the sample which were perpendicular to the surface irradiated by the GaAs laser beam. Current pulses of a few microseconds duration were applied to the GaAs diode at the rate of 3000/sec.

Figure 1 shows the emission spectra of a $Pb_{0.81}Sn_{0.19}Te$ laser at 12°K, below and above threshold. The sample was a vapor-grown n-type crystal ($n = 1.7 \times 10^{17}$ cm^{-3} at 77°K) with the as-grown shape of a parallelepiped 550 μ long in the direction of laser emission. The onset of coherent emission, which was evidenced by an abrupt increase in emission intensity as well as by the appearance of mode structure, occurred at a GaAs-diode current of 3.7 A, which corresponds to approximately 1.5 W of 0.84-μ radiation. A single cavity mode at 15.9 μ was excited at currents between 3.7 and 8 A, and multimode operation was observed at higher currents. The mode spacing corresponds