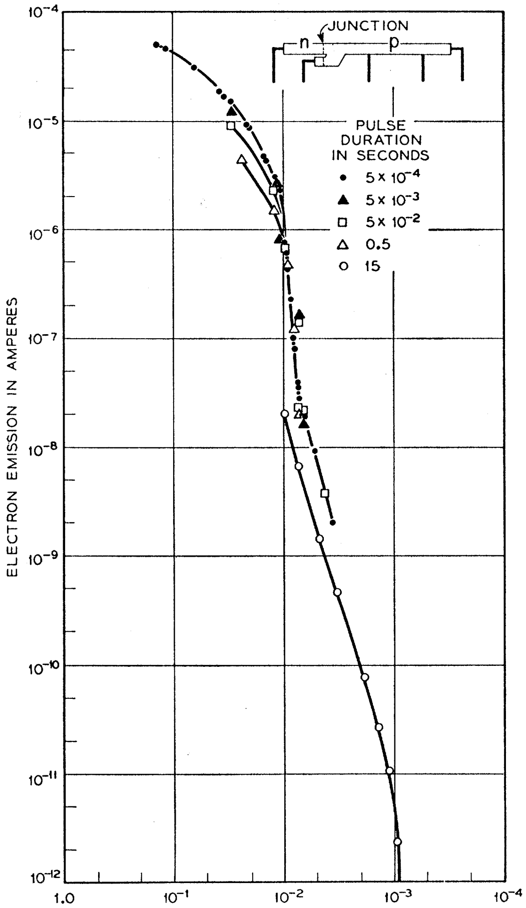

FIG. 1. Electron emission from the Si junction with adsorbed Cs as a function of junction reverse current.

hundred volts is required to saturate the anode current, and only a few percent is collected at an anode potential more negative than that of the n-type region. These effects seem to indicate a shift in the site of origin of the electrons and perhaps the influence of external space charge. Detectable emission currents are observed with as little as 5 volts and 1 milliampere applied to the junction. This emission may arise from electrons accelerated to the n-type surface layer at fields below breakdown. A marked increase in emission current and a sharp change in slope of the junction characteristic occurs at 40 volts and 10 milliamperes, which may be the onset of avalanche breakdown.

For junction reverse currents greater than 15 milliamperes, the emission of white light typical of surface avalanche breakdown[8] was observed with a microscope in a dark room. The light intensity is far less than would be required to account for the electron emission photoelectrically. This light is emitted in a line where the junction intercepts the surface. It fades and recovers like the emission and junction currents. The width of this line of light was too narrow to measure accurately, but it is estimated that the total area of

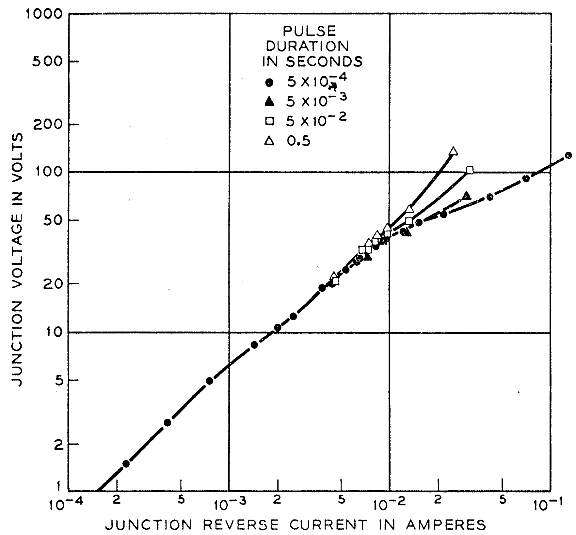

FIG. 2. Reverse current-voltage characteristic for the Si junction with adsorbed Cs.

light emission is less than 10^{-3} cm^2. If the electron emission comes from a similar line, the emission current density is greater than 0.05 ampere/cm^2.

The assistance of A. R. Storm in carrying out this work is gratefully acknowledged.

[1] K. G. McKay and K. B. McAfee, Phys. Rev. **91**, 1079 (1953); K. G. McKay, Phys. Rev. **94**, 877 (1954); P. A. Wolff, Phys. Rev. **95**, 1415 (1954); A. G. Chynoweth and K. G. McKay, Phys. Rev. **106**, 418 (1957); S. L. Miller, Phys. Rev. **105**, 1246 (1957).
[2] D. MacNair (private communication).
[3] F. G. Allen and A. G. Chynoweth (private communication).
[4] C. Garreta (private communication).
[5] C. G. B. Garrett and W. H. Brattain, J. Appl. Phys. **27**, 299 (1956).
[6] I. Langmuir and K. H. Kingdon, Phys. Rev. **24**, 510 (1924); J. A. Becker, Phys. Rev. **28**, 341 (1926).
[7] W. L. Brown, Phys. Rev. **91**, 518 (1953).
[8] Newman, Dash, Hall, and Burch, Phys. Rev. **98**, 1536 (1955); A. G. Chynoweth and K. G. McKay, Phys. Rev. **102**, 369 (1956).

Focusing of Thermal Waves in Superfluid Helium*

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IT is possible to achieve image formation with thermal waves in superfluid helium by means of an ordinary spherical mirror. Small carbon elements serving as thermal source and receiver were placed at conjugate points with respect to a spherical fused quartz surface (50-mm radius). Longitudinal traverse by the source and receiver showed up a sharp focusing of 6-kc thermal waves in a helium bath at 1.8°K.

The phase sensitivity of the signal at the receiver vitiates any role that might be accorded electromagnetic radiation.

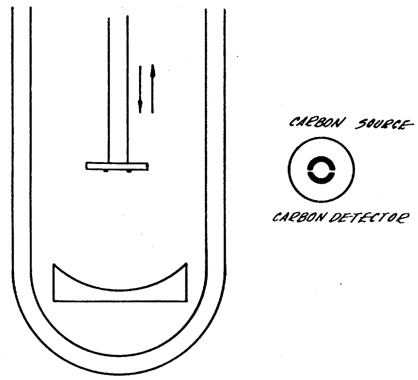

FIG. 1. Diagram of apparatus.

Image formation with thermal waves is no surprise, but its value as an experimental technique should be noted; e.g., Mercereau and Pellam,[1] investigating thermal wave diffraction, ascribe their choice of investigative technique to a lack of Dewar space. "Optical" systems open new avenues for this study.

The importance of thermal wave mirrors for work at lowest temperatures is apparent—energy concentration would minimize the energy input to the helium bath, permitting second sound velocity measurements with continuous wave excitation. With mean free paths of sufficient length one might "focus" phonons.

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[1] J. E. Mercereau and J. R. Pellam, Phys. Rev. **106**, 1113 (1957).

Determination of the Activation Energy of Vacancy Migration in Copper by Ultrasonic Methods*

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THE activation energy for the migration of a vacancy in copper has been estimated theoretically by Huntington[1] to be about 0.9 ev. Because the errors arising from approximations are large, this value serves only as a guide and attempts to find more accurate determinations have been along experimental lines. However, different experiments and assumptions have not led to an unambiguous result, and estimates have ranged between 0.7 and 1.2 ev.[2] This note is to report the results of a determination of the activation energy by use of a new independent method which is based on an analysis of ultrasonic velocity measurements.

The value of the measured elastic modulus is reduced for slightly deformed specimens, since the dislocations which are introduced relieve some of the applied stress by their displacement. The subsequent recovery of the modulus has been interpreted by the writers[3] on the basis of their dislocation theory of internal friction[4] as a pinning of dislocations by deformation-induced point defects which are able to migrate to the dislocations. They derive

$$\Delta E/E = 1/(1+\beta t^{\frac{2}{3}})^2, \tag{1}$$

where ΔE is the difference between the measured modulus and the true elastic modulus E, and t is the recovery time. The parameter β is given by

$$\beta = \frac{C_1}{C_2}\frac{4\alpha}{a^2}\left(\frac{AD}{kT}\right)^{\frac{2}{3}}, \tag{2}$$

where C_1 is the vacancy concentration in the lattice, C_2 is the impurity concentration along the dislocation, a is the lattice spacing, α is a constant with value of about 3, and A is the Cottrell[5] interaction parameter for the interaction between dislocations and the deformation-induced point defects. D is the diffusion constant of the migrating defect, and kT has its usual meaning. The constant β therefore depends exponentially upon the temperature through the diffusion constant D, and the apparent activation energy of β should be $\frac{2}{3}$ of the migration activation energy of the pinning defect.

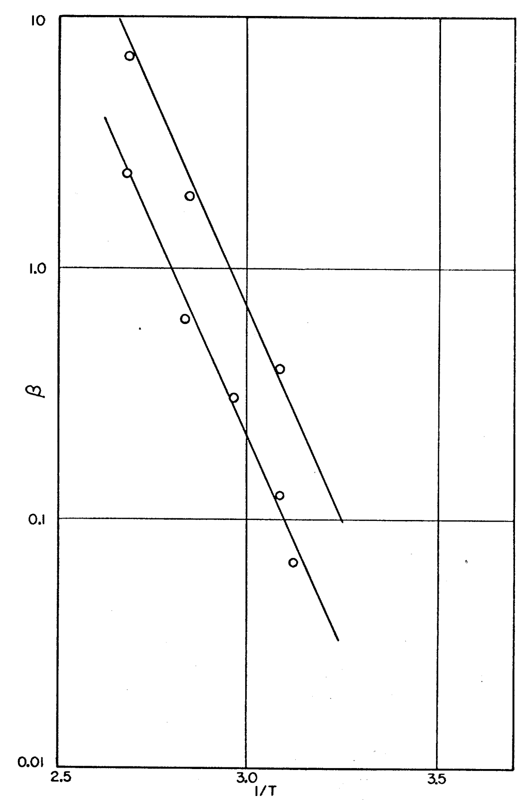

FIG. 1. Parameter β plotted as a function of $1/T$, for two specimens of different purities.