measurements with a spectrum analyzer show that the signal at $f_p - f_a$ is 30 db larger than the signal at $f_p + f_a$.

We especially wish to thank M. T. Weiss and A. G. Fox for discussions of their work previous to publication; H. J. McSkimin for his acoustical measurements and discussions; J. H. Rowen and R. C. Fletcher for their encouragement and suggestions; and C. S. Porter of the Diamond Ordnance Fuze Laboratories for allowing us to use the same samples on which we have previously reported.

[1] An outwardly similar, but different, effect discovered earlier by M. T. Weiss is described in the preceding Letter [Phys. Rev. Lett. 1, 239 (1958)].

[2] LeCraw, Spencer, and Porter, Phys. Rev. 110, 1311 (1958).

[3] H. J. McSkimin (to be published).

[4] H. Suhl, J. Appl. Phys. 28, 1225 (1957).

DIFFUSION ALONG DISLOCATIONS*

G. P. Williams, Jr.,† and L. Slifkin

Department of Physics,
University of North Carolina,
Chapel Hill, North Carolina

(Received September 10, 1958)

Hart[1] has pointed out that low-temperature diffusion measurements utilizing single crystals should produce values of D elevated a few percent by the effects of dislocations, while exhibiting normal penetration profiles. Indeed, Tomizuka[2] has recently re-analyzed earlier measurements of the diffusion of antimony in silver and has demonstrated the effects discussed by Hart. From a somewhat different point of departure, experiments on the diffusion of rare earth tracers into silver and lead[3] have revealed anomalous penetration profiles, one feature of which is a structure-sensitive tail which appears even in single crystals diffused at temperatures near the melting point. Presumably, this effect involves atomic mobility along dislocations, enhanced in this case by the very small bulk diffusion coefficients and solubilities of rare earths in these metals. It is of interest to inquire if similar dislocation effects could be demonstrated in "well-behaved" systems.

Accordingly, the following rather abnormal type of experiment was performed. Thin layers of Au^{198} were deposited on the ends of cylindrical single crystals of silver and diffusion measurements were made using the standard sectioning procedures, but with these modifications:

(a) greater activity, about 20 microcuries, was deposited on each specimen;

(b) diffusion anneal times were so short that $(Dt)^{\frac{1}{2}}$ was only about 10 microns; and

(c) with a thin-window beta counter with a background of only $4\frac{1}{2}$ counts/min, the tracer concentration after diffusion was followed through a range of several million.

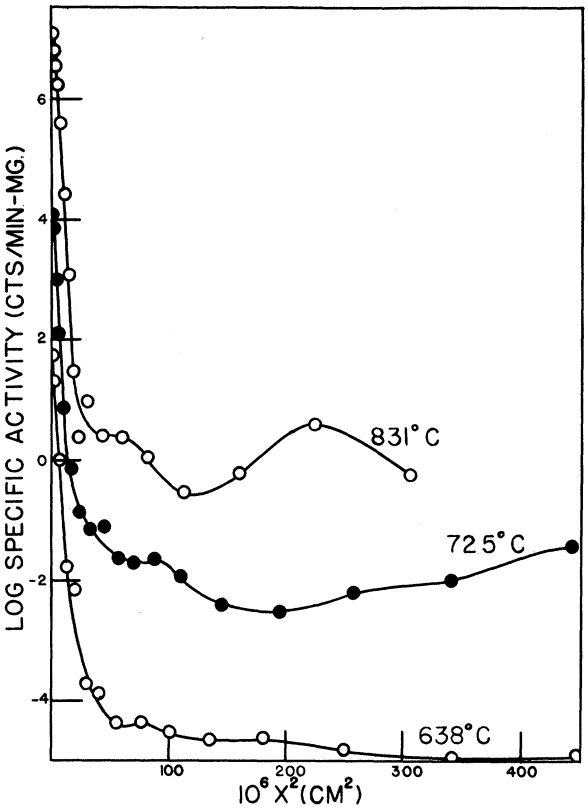

FIG. 1. Penetration plots at three temperatures. For clarity, the upper curve has been shifted upward 3 cycles and the lower curve downward 2 cycles. The statistically predicted counting errors are well within the diameter of the circles.

The results obtained at three different temperatures are shown in Fig. 1. The diffusion coefficients calculated from the steep region agree with values obtained by conventional experiments[4] to within the rather large error imposed by the very small penetration depth employed here. At the lowest tracer concentrations, an unmistakable tail is apparent, being more pronounced the lower the diffusion temperature. It was not practical to follow this tail more deeply into the specimen than as

shown on the figure due to the combination of short half-life and low activities, requiring very long counting periods. It is highly unlikely that this tail is due to carry-over of activity from the active regions to the deep regions since the entire process was thoroughly monitored and extreme care was exercised in all operations to preclude this possibility; for example, in turning the sides of the specimen, the tool motion was toward, rather than away from the active end, and the final turning operation was carried out with a file. It is also quite improbable that the tail is due to a trace of a faster diffusing radioactive impurity for the following reasons:

(a) the tracer was initially deposited on the silver crystal by chemical displacement rather than by electrodeposition, making it unlikely that any but noble-metal impurities would be removed from the solution;

(b) the type of radiation in the tail was qualitatively similar to that of Au^{198}; and finally

(c) the decay of the radioactivity in the tail was measured over two half-lives in one cut from each run and was found to be identical to that of Au^{198}.

It thus appears that these observations represent a real effect. Since the specimens were single crystals, it is proposed that diffusion in dislocations has been observed directly. From the original tracer specific activity (20 000 mC/g when received) and the counting efficiency, one concludes that the atomic fraction of gold in the region of the tail is about 10^{-11}. If there are 10^8 dislocations per cm^2 then less than one atomic site in a thousand along the dislocations need be occupied by a gold atom to account for the observed activity in the tail. Also, it is interesting that the fluctuations shown in the figure are well beyond counting errors. This implies that there exists considerable variation in dislocation density throughout the specimen, even when averaged over distances of the order of 25 microns with a 1-cm^2 cross section.

*Supported in part by the U. S. Atomic Energy Commission.

†Present address: Department of Physics, Wake Forest College, Winston-Salem, North Carolina.

[1]E. W. Hart, Bull. Am. Phys. Soc. Ser. II, 2, 145 (1957).

[2]C. T. Tomizuka (to be published).

[3]G. P. Williams, Jr., and L. Slifkin, Bull. Am. Phys. Soc. Ser. II, 3, 124 (1958).

[4]F. E. Jaumot, Jr., and A. Sawatzky, J. Appl. Phys. 27, 1186 (1956).

EVALUATION OF THE CONTRIBUTION OF THE UMKLAPP-PROCESSES TO THE ELECTRON-PHONON INTERACTION

Pierre Morel*

Ecole Normale Superieure, Paris, France

(Received August 25, 1958)

In a recent paper, Pines[1] has computed the interaction parameter V introduced in Bardeen, Cooper, and Schrieffer's theory of superconductivity.[2] This computation involves the average of a term

$$|I_{kk'}|^2/|q|^2 \qquad (1)$$

over all possible electronic transitions $k \rightarrow k'$. Here $I_{kk'}$ is the Fourier transform of the gradient of the electron-ion potential and is a function of $(k' - k)$ only. q is the momentum of the phonon emitted or absorbed in this process:

$$q = k' - k + K_n \qquad (2)$$

where K_n is a vector of the reciprocal lattice. The domain of integration in computing the average of (1) includes several nodes of the reciprocal lattice in the case of polyvalent metals: the contribution to V of the "Umklapp"-processes ($K_n \neq 0$) is then very significant and even decisive in producing superconductivity, as pointed out by Pines.[1]

In spite of his approximation $q \approx k_D$ (maximum momentum of Debye) for all "Umklapp"-processes, Pines' computed values of V are in fair agreement with experiment. However, a more accurate treatment, using the exact q given by (2), greatly improves this agreement.

As can be easily observed from (2), q approaches zero when $(k'-k)$ approaches any vector of the reciprocal lattice; hence (1) goes to infinity in the vicinity of the nodes of the reciprocal lattice. Taking advantage of this situation, it is possible to divide the domain of integration D into an array of spheres surrounding the poles of the integrand (1) and almost filling D. Within those spheres, the average of (1) can be computed accurately. We could then expect this method to yield a good approximation to the contribution of the "Umklapp"-processes to V.

This method has been tested by computing the high-temperature conductivity of some nontransition metals using Pines' matrix-element for the electron-ion interaction.[1] The results were compared to experimental values compiled by