Letters to the Editor

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Influence of an Elastic Strain on the Self-Diffusion of Copper at Low Temperatures

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IN all diffusion processes, the influence of elastic strains seems to be considerable. However, measurement of the effect is difficult. Self-diffusion is generally measured at temperatures directly below the melting point. In this region, the material is very weak. So it is difficult to give a large elastic deformation and at the same time prevent plastic deformation. One has to load the material in compression. This experiment was carried out on sodium and phosphorus by Nachtrieb *et al.*[1,2] The effect measured by these authors is due to two different effects. Firstly, the concentration of the vacancies is altered by the elastic strains. Secondly, the mobility of the vacancies is modified. The first effect is related to the creep which occurs by diffusion.[3] We will call the second effect strain-activated diffusion.

Since the jump probability of a vacancy is very sensitive to a change of the activation energy, it is likely that such a change will be the main reason for an effect. If this is valid, the diffusion coefficient is multiplicated by a factor $e^{-\Delta Q/KT}$ (where ΔQ denotes the change of the activation energy).

In case one wishes to measure only the strain-activated diffusion, it is necessary to work with "injected" vacancies (vacancies which are not in thermal equilibrium). Injected vacancies can be formed by irradiation[4] or by cold working.[5] Measurements on injected vacancies have the advantage that it is possible work at low temperatures. At such temperatures, the material is much stronger, especially when it is cold worked. It is thus possible to load the material in simple extension. Also at low temperatures $|\Delta Q/KT|$ is larger.

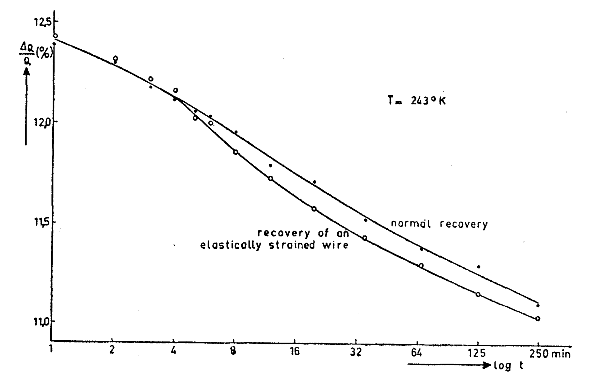

FIG. 1. The influence of an elastic strain on the recovery at $-30°$C. From $t=4$ min, one wire is loaded during recovery.

The experiment was quite simple. Two copper wires were stretched 20% in liquid nitrogen. After the stretching, the recovery of the electrical resistivity was measured at $-30°$C as a function of time. During the first four minutes, the curves coincide for both wires. After four minutes, one wire was loaded with 17 kg/mm^2. The recovery of the resistivity of this wire then speeded up. In Fig. 1, both curves are given.

In case this recovery of the resistivity is due to the diffusion of vacancies, this recovery is a function of $D\times t$ (where D is the diffusion coefficient of the vacancies). When the wire is strained the diffusion coefficient is anisotropic; let D' be the average diffusion coefficient for this case. From our measurements, we calculate $D'/D=1.7$. Calculations of this effect will be published in the near future.

With these calculations, one is able to account for the influence of internal stresses on the recovery of the electrical resistivity after cold working.

[1] N. H. Nachtrieb *et al.*, J. Chem. Phys. **20**, 1189 (1952).
[2] N. H. Nachtrieb and A. W. Lawson, J. Chem. Phys. **23**, 1193 (1955).
[3] C. Herring, J. Appl. Phys. **21**, 437 (1950).
[4] J. W. Glen, Advances in Phys. **4**, 381 (1955).
[5] J. A. Manintveld, Nature **169**, 623 (1952).

Effective Electron Mass in Indium Arsenide and Indium Antimonide

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MEASUREMENTS have been made of Hall coefficient and thermoelectric power for indium arsenide and indium antimonide at room temperature and above. The specimens were prepared from highly purified elements and contained 5×10^{16}/cc extrinsic electrons in the indium arsenide and 7×10^{15}/cc extrinsic holes in the indium antimonide. The values of thermoelectric power indicated that both materials were slightly degenerate at all temperatures within the range considered. Assuming covalent scattering and taking account of the degeneracy present, the effective electron mass ratio has been calculated and is plotted in Fig. 1 as a function of kT which represents the approximate mean energy of the electrons in the conduction band. For energies greater than 0.04 ev above the bottom of

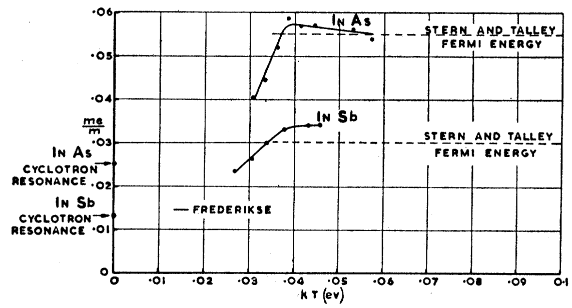

FIG. 1. Variation of effective electron mass with mean electron energy for indium arsenide and indium antimonide.

the band the mass ratio in both materials tends to a constant value, while for lower energies the mass ratio falls towards the cyclotron resonance values[1,2] found for very pure specimens at low temperatures. Frederikse[3] has reported an effective electron mass for indium antimonide between 160°K and 200°K from thermoelectric power measurements on pure specimens at low temperatures, and his values are indicated on the diagram. Hrostowski *et al.*[4] have found $m_e/m=0.015$ from electrical measurements on a pure indium antimonide specimen in a similar temperature range. On the other hand, Stern and Talley[5] have used an overlapping impurity band model to explain the shift of absorption edge with impurity concentration in degenerate specimens of InSb and InAs. Their theory would seem to represent an approximate fit with observation for values of Fermi energy greater than about 0.035 ev taking $m_e/m=0.055$ for InAs and $m_e/m=0.03$ for InSb.

We suggest that the mass found from cyclotron resonance may be best associated with the bottom of the impurity band alone since the bulk of the electrons will have energies below the bottom of the conduction band for very pure samples at low temperatures. For high electron concentrations, the majority of the electrons will have energies above the bottom of the conduction band and will be associated with an effective mass corresponding to the sum of the state densities in both impurity and conduction bands. Our measurements would appear to cover some of the range between these two regions. This explanation can only hold for the *p*-type sample of InSb quoted above if there is some degree of compensation in this sample.

This work is part of an investigation of the electrical properties of InAs and InSb, a full account of which will appear elsewhere.[6] Thanks are due to Dr. Avery (R.R.E., Malvern) for supply of InSb specimens.

[1] Dresselhauss, Kip, Kittel, and Wagoner, Phys. Rev. **98**, 556 (1955).
[2] C. Kittel, Phys. Rev. **98**, 1542 (T) (1955).
[3] H. P. R. Frederikse and E. V. Mielczarek, Phys. Rev. **99**, 1889 (1955).
[4] Hrostowski, Morin, Geballe, and Wheatley, Phys. Rev. **100**, 1672 (1955).
[5] F. Stern and R. M. Talley, Phys. Rev. **100**, 1638 (1955).
[6] Antell, Champness, Cohen, and Chasmar, Report on the Spring Meeting of the British Physical Society (to be published).

Exact Sum Rules in the Fixed-Source Meson Theory

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WE want to report in this letter some exact relations obtained by making use of recent techniques connecting matrix elements of Heisenberg operators and scattering amplitudes[1] and to discuss their implications about the nature of the solution of the fixed-source meson theory. By starting from the relation[2]

$$\langle l\alpha;r|\,\mathrm{Im}T(\omega_p)\,|l'\alpha';r'\rangle = -\tfrac{1}{3}p^3v^2(p)f_0^2(\Psi_r,\,\tau_\alpha\sigma_l\delta(\omega_p-H)\tau_{\alpha'}\sigma_{l'}\Psi_{r'}) \quad (1)$$

connecting the element of the transition matrix T between pion-nucleon states (the subscript r denotes the four single-nucleon states, l and α the angular momentum and isotopic spin components of the meson) with the matrix elements of the source operators between physical single-nucleon states Ψ_r, and adopting the representation in which the total angular momentum J and the total isotopic T are diagonal, the following sum rules can be obtained:

$$4\alpha_3+4\alpha_2+\alpha_1=(1-r_2^2)f_0^2, \quad (2a)$$

$$\alpha_3-2\alpha_2+\alpha_1=(r_2-r_2^2)f_0^2, \quad (2b)$$

$$2\alpha_3-\alpha_2-\alpha_1=(r_2^2-r_1)f_0^2, \quad (2c)$$

where

$$\alpha_i=\frac{1}{3\pi}\int_1^\infty\frac{d\omega_p\,\mathrm{Im}g_i(p)}{p^3v^2(p)}. \quad (3)$$

In Eq. (3), $v(p)$ is the cutoff function; $g_i(p)$ is the eigenvalue of the transition matrix $-\pi T$ in the state $i[i=1(j=\frac{1}{2};\ T=\frac{1}{2});\ i=2(J=\frac{1}{2};\ T=\frac{3}{2})(J=\frac{3}{2};\ T=\frac{1}{2});\ i=3(T=\frac{3}{2};\ J=\frac{3}{2})]$. As is well known, for purely elastic scattering,

$$g_i=e^{i\delta_i}\sin\delta_i.$$

The constant r_2 is the ratio f/f_0 between renormalized and unrenormalized coupling constants. Both r_1 and r_2 can be defined by

$$r_1=(\Psi_1,\sigma_z\Psi_1)=(\Psi_1,\tau_z\Psi_1),$$
$$r_2=(\Psi_1,\sigma_z\tau_z\Psi_1), \quad (4)$$

where Ψ_1 is the physical proton state with spin up.

In Eqs. (2), the expressions for g_i in the one-meson approximation given by Chew and Low for a theory with a square cutoff at ξ can be introduced, and g_1 and g_2 can be neglected with respect to g_3. Then one obtains

$$\frac{1}{6\pi}\int_1^\xi\frac{\sin^2\delta_3}{p^3}d\omega_p=f^2. \quad (5)$$