

An investigation of the temperature and field dependence of T_1 is now being made, together with a study of the effect of impurities and induced color centers on this relaxation time. Audio-frequency spectroscopy is also contemplated.

Resistivity of Dilute Alloys*

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(Received February 15, 1955)

DILUTE substitutional alloys, such as Zn in Cu, have a temperature-independent component to their electrical resistivity which is proportional to the solute concentration. The attempt is usually made¹ to describe the change in resistivity per atomic percent addition, ρ_0 , with the following parameters,

$$\rho_0 = a(\Delta Z)^2 + b, \quad (1)$$

where ΔZ is the valence difference between the host material and the substitutional impurity, and where a and b are quantities determined by properties of the two atoms not involving their valence difference; and are generally treated as being independent of position in a given row of the periodic table. It is sometimes considered that this form is made plausible by the existing simple treatments of the dilute alloy problem,² in which are treated separately the two cases where (1) a valence difference exists, the scattering potential is taken to be a shielded Coulomb potential, and only the first term in Eq. (1) appears, and (2) the valence difference is zero, and only the second term in Eq. (1) occurs. In cases (1) and (2), the parameters a and b , respectively, must of course be positive quantities. Then the argument is made that in general both effects will occur simultaneously, so that one should add the two terms. It seems to have been overlooked that even in the simplest case interference occurs between these two types of scattering, that a linear term in ΔZ will occur in general, and that in fact it may be expected to be sizable unless one of the other terms is also small.

That this is the case may be seen at once from the procedure of calculating a resistivity change, which is proportional to an average of the square of the matrix element of the scattering potential between the initial and final states:

$$\rho_0 = C \langle (i|V|f)^2 \rangle_{Av}. \quad (2)$$

(The averaging process involves some angular weighting factors which need not concern us here.) If the scattering potential V contains a term V_1 proportional to the valence difference, such as $(e\Delta Z/r) \exp(-qr)$, and also another term V_2 independent of ΔZ , determined by inner potentials and lattice strains, the matrix element of V will be equal to the sum of the matrix

elements of V_1 and V_2 . Thus the square of the matrix element of V is not given by the sum of the squares of the two parts, as is implied by Eq. (1), but contains an interference term proportional to ΔZ which may distinguish between atoms of higher and lower valence.

$$(V)^2 = (V_1)^2 + (V_2)^2 + 2(V_1)(V_2). \quad (3)$$

This term [the last in Eq. (3)] has a magnitude at least as great as the smaller of the other two, and may have either sign, so that the interference term may add to or subtract from the resistivity.

Averaging Eq. (3) over angles, we obtain $\langle (V_1)^2 \rangle_{Av}$ and $\langle (V_2)^2 \rangle_{Av}$, which correspond to the first two terms in Eq. (1), plus the linear term $2\langle (V_1)(V_2) \rangle_{Av}$ which may be of either sign. [Since (V_1) and (V_2) will in general have different angular dependences it is possible that the averaging process may tend to decrease the magnitude of the term linear in ΔZ by accidental cancellation, but this effect may only be investigated in specific cases by explicit calculations of the matrix elements involved.] The point made here is that Eq. (1) is not justified by theoretical arguments, and also that it would be surprising to find it capable of interpreting experimental results.

The writer is indebted to Dr. E. I. Salkowitz for a stimulating conversation on this subject.

* Research supported in part by funds from the U. S. Air Force under a contract monitored by Headquarters, Air Research and Development Command, Baltimore, Maryland.

¹ J. Linde, *Ann. Phys.* **15**, 239 (1932).

² N. F. Mott and H. Jones, *The Theory of the Properties of Metals and Alloys* (Oxford University Press, London, 1936), Chap. VII. An extension of these calculations has been performed by D. L. Dexter, *Phys. Rev.* **87**, 768 (1952). Note, however, that J. Friedel [*Phil. Mag.* **43**, 153 (1952)] has shown that additional complications sometimes arise so that these simple theories are not always applicable.

Resistivity of Dilute Magnesium Alloys

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(Received February 15, 1955)

LINDE'S rule¹ states that for dilute substitutional alloys the increase in specific resistivity of a pure metal due to small alloying additions is equal to a term proportional to the square of the difference in valence of the two elements concerned, plus a second term, or

$$\Delta\rho/A = a\Delta Z^2 + b, \quad (1)$$

where $\Delta\rho/A$ is the increase in specific resistivity per atomic percent addition, ΔZ is the difference in valence between the solute and solvent atoms, and a and b are constants. For convenience we define $\gamma = \Delta\rho/A$. In Linde's work, the monovalent face-centered-cubic metals, copper, silver, and gold, were the solvents. In these cases, Linde found that the parameters a and b