Previous theoretical proposals[9-11] to account for the general minimum phenomenon appear to be inadequate when considered in the light of these results.

I am grateful to Dr. W. B. Pearson for much help in the preparation of the copper alloys.

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## Residual Resistance in Dilute Copper Alloys

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EXAMINATION of the resistance minimum occurring at $\sim 10°$K in dilute alloys of copper (reported above[1]) demanded as a check on alloy purity and concentration the detailed investigation of the resistance ratios $R_{4.2°K}/R_{273.2°K}$, and further of $R_{77.7°K}/R_{273.2°K}$ and $R_{90.2°K}/R_{273.2°K}$ for comparison with the classical results of Linde.[2] In general such data are of fundamental value when interpreted as cross sections,[3] for electron scattering and prominent deviations found from Linde's results forced us to undertake a systematic investigation. It is significant that all differences found so far are in the direction of lower cross section.

After extensive tests, alumina crucibles for high vacuum melting were chosen which caused no measurable contamination. Control spectrographic and chemical analyses were conducted during the experiments.

Linde's scattering determinations were based on measurements between liquid oxygen and room temperature, dependent on an assumed validity of Matthiessen's rule. Departures from this law, however, are now well known, particularly in the case of copper, and further confirmed by our experiments.

We find the following:

(1) In order to avoid serious errors due almost certainly to oxygen contamination, the final strain-relieving anneal after rolling or drawing must be carried out in a very high continuous vacuum, the specimen being freely suspended in a glass vessel. Following this technique in our work, pure (H.S.) Hilger copper (lab. No. 11,184) always yielded $R_{4.2°K}/R_{273.2°K}=2.9(\pm0.3)\times10^{-3}$ over a wide range of annealing temperatures and times. On the other hand, when a rolled strip received the final anneal in a fresh crucible sealed in an evacuated silica tube, a residual resistance some fortyfold greater was found, agreeing in magnitude with the range of specific resistance variation found by Linde using his annealing technique.

(2) Present results on dilute Cu—Sn alloys with oxygen contamination suggest that the absorbed atoms provide additional scattering centers approximately proportional to the number of already present (Sn) scattering centers. Apart from the general importance of such behavior, it follows that such experiments can yield an artificially high (but approximately constant) scattering cross section. We suggest that this explains the consistent but high cross sections which follow from Linde's work in certain cases.

(3) The figure illustrates some results obtained with dilute Cu—Ni $(A)$, Cu—Sn $(B)$, Cu—Ag $(C)$, and Cu—C—Sn $(D)$, alloys. The cross sections deduced for Ni and Ag call for little comment here; in particular, the scattering by Ni agrees very well with that of Linde. However, in the case of Sn (also Sb, not shown), which differs strongly in chemical valency from copper, the scattering as discussed above is much lower than found by Linde.

The major theoretical interest involved leads us to extend the work to the solute series: Zn→As and Cd→Sb.

(4) Investigation of carbon as an impurity led to curve $D$ in Fig. 1 obtained for Sn alloys melted in spec-pure graphite cru-
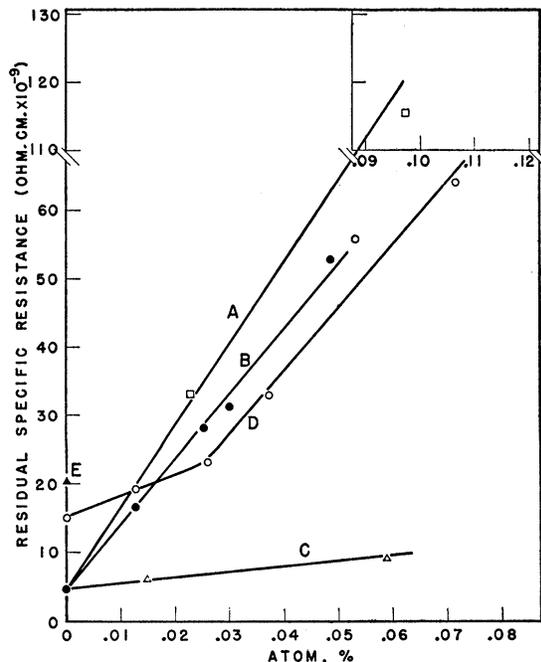


FIG. 1. Residual resistance of dilute alloys. $A$: Cu—Ni alloys; $B$: Cu—Sn alloys; $C$: Cu—Ag alloys; $D$: Cu—Sn alloys melted in spec-pure graphite crucibles; $E$: pure Cu melted with excess powdered graphite. (Specific resistances calculated on basis of $1.58 \times 10^{-6}$ ohm cm for pure Cu at 0°C.)

cibles. That the initial additional scattering was indeed the result of carbon was confirmed by the inclusion of powdered graphite in a pure Cu melt $(E)$. The remarkable fact emerges that, particularly for very low Sn concentrations, the scattering is far from additive. Excluding the virtually untenable hypothesis at these very low concentrations of a mutually ordered lattice structure, one is led to consider the possibility of some novel electron-ion interaction additional to the screened electrostatic potential $(e^2 e^{-qr}/r)$ normally postulated in the theory of metallic resistance.[3] In view of the associated anomaly in the resistance minimum remarked above it appears possible that some type of "resonant" interaction is involved, perhaps analogous to that proposed by Gerritsen and Korringa[4] as a special case in Ag—Mn alloys.

We thank Mr. F. W. Richardson for able technical assistance in the above experiments.

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## The Quenching-in of Lattice Vacancies in Pure Gold*

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ALTHOUGH diffusion in close-packed lattices probably occurs as a result of the migration of vacancies, direct experimental evidence is meager. At present the main support for the theory stems from the Kirkendall effect[1] and from the agreement with

experiment obtained by Huntington and Seitz[2] who calculated the activation energy for self-diffusion in copper on basis of a vacancy mechanism. The following experimental measurements provide preliminary data on the disorder produced at elevated temperature, presumably vacancies, in pure gold.

Gold wires, 99.999 percent pure, of 16-mil diameter were quenched in a blast of gaseous helium to room temperature. The wires were then immediately immersed in liquid nitrogen. The time required for the quench from the high temperature was $7\pm3$ milliseconds. About a third of a second was required to get the wire from room temperature to liquid nitrogen temperature.

After quenching, an increase in the residual electrical resistivity at liquid nitrogen temperature was detected. Measurements were made on the annealing of the quenched-in resistance. About one-third of the resistance increase can be annealed at temperatures in the vicinity of room temperature. The resistance at liquid nitrogen temperature was measured as a function of the annealing time at $-21.7°C$ and also at $-2.7°C$. From these data the energy required to move a vacancy is $0.4$ ev$\pm0.14$ ev.

The remaining two-thirds of the resistance anneals out at some temperature between $100°C$ and $500°C$.

Quenches were made from five different high temperatures, from $920°C$ to $690°C$ and the increment in resistance quenched in from these temperatures varied, respectively, from $0.82$ percent to $0.065$ percent. The large change in the amount of resistance quenched-in with the temperature from which the quench was made indicates that stresses arising from thermal gradients are not the source of the resistance increase. Further, these data may be used to determine the energy required for the production of a vacancy. However, errors in measuring the temperature from which the quenches are made give rise to large errors for the energy to form a vacancy, and with this difficulty we can at present only estimate this energy as lying between 1 ev and 2 ev. More accurate measurements are in progress.

We would like to thank Professor F. Seitz for valuable discussions and Mr. D. Magnuson for aid in making the measurements.

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## Some Experiments on Ge[75] and Ge[75m]†

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GE[75] has not been investigated by spectroscopic means. The half-life is known[1-3] to be 80 min and the beta-ray end point has been measured by aluminum absorption and found to be[1,2] 1.3 Mev.

In the present investigation germanium enriched in Ge[74] was bombarded by neutrons, and measurements were made with the help of a magnetic lens spectrometer, scintillation spectrometer, and coincidence counting techniques. In all of the work the activity was quite weak.

The beta-ray spectrum was measured in the lens spectrometer and two beta-ray groups were found having end-point energies, relative abundances, and $\log ft$ values of 1.137 Mev, 85 percent, $\log ft = 5.2$; 0.614, 15 percent, $\log ft = 4.5$. In addition, two internal conversion lines were seen. There was a well-resolved line at 0.408 Mev and an unresolved group at about 0.520 Mev.

The gamma-rays were measured from observations of photoelectrons from a uranium radiator. A line at 0.265 Mev was found and also a Compton distribution for a line around 0.600 Mev. The line at 0.265 Mev was confirmed with the help of a scintillation spectrometer. In addition, weak lines at 0.418 and 0.572 Mev were seen on the scintillation spectrometer.

Beta-gamma coincidence experiments were performed using ordinary counters. No coincidences were found between the high

energy group of beta-rays and gamma-rays showing that the high energy group leads to the ground state.

Some of the gamma-rays seen in Ge[75] are also seen in the transition[4-7] Se[75]→As[75]. Those which appear in both are the ones at 0.265 and 0.408 Mev. Although a careful search for internal conversion lines of low energy was made, none was seen.

Since the ground state of As[75] has a configuration $p_{3/2}$, and the transition from the ground state of Ge[75] to the ground state of As[75] is allowed, the configuration of the ground state of Ge[75] is probably $p_{1/2}$. The fact that the higher states of As[75] are excited by the K-capture transitions from Se[75] infers that the ground state of Se[75] has the configuration $g_{9/2}$. It is interesting to note that both beta-ray groups of Ge[75] have $\log ft$ values corresponding to allowed transitions.

We have produced a metastable state of Ge[75]. This state was produced both by a Ge[74] (separated) $(n, \gamma)$ reaction and As[75]$(n, p)$ reaction. The energy of the gamma-ray was measured photographically on a scintillation spectrometer and was found to be 0.175 Mev. The half-life of the state was found by setting on the line with a scintillation spectrometer connected to a differential pulse-height selector. The half-life is $48\pm2$ sec. While this experiment was in progress a similar experiment was reported by Flammersfeld.[8]

Assuming the radiation to be $E3$, using the empirical lifetime formula of Goldhaber and Sunyar,[9] and the expected conversion coefficient and $K/L$ ratio, the half-life comes out 88 sec compared with the measured half-life of 48. If, on the other hand, this radiation has been assumed to be $M4$, the half-life would have been of the order of $10^6$ sec.

† Supported by the joint program of the ONR and AEC.
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## K[40] Radioactive Decay: Its Branching Ratio and Its Use in Geological Age Determinations*

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THE ratio of K-capture to beta-emission for the naturally occurring radioactive isotope K[40] has been determined. For this purpose argon was extracted from four different samples of microcline and purified. The volume of the extracted argon was measured by means of a McLeod gauge built into the apparatus, and the amount of radiogenic A[40] was ascertained by mass spectrometric analysis of the isotopic abundances in the extracted argon. The potassium contents of the samples of microcline were determined by chemical analysis and the amount of K[40] has been estimated using the recent value[1] of Nier, $0.0119\pm0.0001$ percent, as the isotopic abundance of K[40] in potassium.

Previous determinations of the branching ratio by direct measurements have used counting techniques,[2-9] whereas those based on indirect measurements have used age data couplied with either Ca[40] or A[40] extraction data to get the branching ratio,[10-12] except Inghram *et al.*,[13] who measured both A[40] and Ca[40] to get the branching ratio.

The argon was extracted by heating a sample of known weight of powdered microcline (75 g in each case) with metallic sodium in vacuum to about $600°C$, and it was purified by treating the gas in a calcium furnace to constant volume. The results of the isotopic analysis of argon thus obtained are shown in Table I. All