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Metals and Alloys I, Mössbauer Effect

Superconductivity and Ferromagnetism

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Superconductors fall into three groups; the transition elements and combinations amongst them, the non-transition elements and combinations amongst them, and compounds between transition elements and non-transition elements.

It appears that the mechanism causing superconductivity is somewhat different from one group to the next. The isotope effect illustrates this. The superconducting transition temperature is inversely proportional to the square root of the mass for different isotopes of the non-transition elements as in Hg, Tl, Sn and Pb.[1] On the other hand no effect at all has been found for the transition elements Ru and Os[2], *i. e.*, their transition temperatures are independent of isotopic mass. Only one compound of transition-non-transition elements has been checked, namely Nb_3Sn in which different isotopes of tin were used[3] and there the isotope effect is intermediate between the two just described.

There is, however, another set of experiments showing the different mechanisms: A necessary and frequently sufficient criterion for the occurrence of superconductivity is the average number of valence electrons per atom. The superconducting transition temperature oscillates in the range where metals have from two to eight electrons per atom. Outside this range no superconductivity has ever been found. Inside this range the transition temperature can easily be varied by dissolving one element in another, only: *again* is there a sharp distinction between transition and non-transition elements. The solution of one element in another within the *same* group gives predictable results; *i.e.*, the superconducting temperature is raised or lowered in a manner controlled by the variation of electrons per atom. However, when an element from one group is dissolved in an element of the other one this invariably destroys the superconductivity in an irregular fashion.

While the mechanism causing superconductivity for the non-transition elements is most probably the well known electron-phonon interaction, the mechanism causing superconductivity in the transition elements seems to be much more that of a positive *magnetic* interaction among the conduction electrons. This can be demonstrated by the interaction of ferromagnets with superconductors.

If iron is dissolved in titanium it raises the superconducting transition temperature very rapidly, *i.e.*, about 10 at. % raise it by almost a factor 10. Iron dissolved in niobium lowers the transition according to the change of electron concentration. In both cases the iron has no localized moment (see Clogston[4]). As soon as it does, which is the case in Mo-Re alloys, the superconducting transition temperature is suppressed almost instantaneously; about 0.3 at. % lower the transition temperature by 10°. Again no such effect can be found among the non-transition elements.

The reason why superconductivity cannot coexist with the ferromagnetism of the transition elements is that the *s-d* interaction seems to be too strong. It is, however, different for the *s-f* interaction which one encounters for the ferromagnetic elements of the rare earths. Here the depressing effect on the superconducting transition is an order of magnitude weaker and therefore in these systems superconductivity and ferromagnetism can coexist over a small range.[5]

References

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3 G. E. Devlin and E. Corenzwit: Phys. Rev. **120** (1960) 1964.
4 A. M. Clogston: This conference.
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DISCUSSION

W. Henry: Up to the fields which were used in the susceptibility measurements on ferromagnetic substances with non localized moments (*s* electron ferromagnetism), was there observed any field dependence of the susceptibility?

R. M. Bozorth: Measurements of the magnetization of $ZrZn_2$, made by Matthias and myself, showed definite saturation. At low temperatures extrapolation to $H=\infty$ could be made with reasonable accuracy using the $1/H$ rule.

W. J. Carr: I was under the impression that free electron (Bloch) ferromagnetism does not result when Coulomb correlation is considered. To what extent are you certain localized moments are not present?

B. T. Matthias: Sidney Abrahams checked by neutron diffraction a $ZrZn_2$ single crystal in the ferromagnetic region. With an accuracy of 0.2 Bohr magneton he did not see any localized moment at all, though one expected to see 1.3 Bohr magnetons. This is the number concluded from Bozorth's susceptibility measurements. Second: The improbability of pure electron ferromagnetism is as large as the one of the assumptions made to show that this phenomenon could not exist.