

Superconductivity of Solid Solutions of Noble Metals

T. H. GEBALLE, B. T. MATTHIAS,* V. B. COMPTON, E. CORENZWIT, AND G. W. HULL, JR.

Bell Telephone Laboratories, Murray Hill, New Jersey

(Received 1 August 1962)

The superconducting properties of Os-Ir and W-Pt solid solutions have been investigated and the transition temperatures have been determined as a function of composition and of valence electron concentration.

Both terminal solid solutions in the Os-Ir system are superconducting. For the same valence electron concentration the face-centered cubic Ir solid solution has a higher transition temperature than the hexagonal close-packed Os solid solution.

Both the body-centered cubic W solid solutions and the face-centered cubic Pt solid solutions are superconducting.

INTRODUCTION

THE superconducting properties of very dilute solutions of Re in Mo suggested that pure Mo would be superconducting. This was subsequently verified and the transition temperature for extremely pure Mo is reported as 0.92°K .¹ Since this type of study proved successful in the case of Mo, the superconducting properties of the solid solutions in the Os-Ir and in the W-Pt systems were investigated to determine whether W, Ir, and Pt could be expected to be superconducting.

The alloys were prepared by reacting the appropriate amounts of the elements in an arc furnace in an argon atmosphere. The alloys were quenched from their melting temperature to room temperature in a matter of seconds by virtue of their being in good contact with the water-cooled copper hearth when the arc was turned off. The wolfram was obtained from the Westinghouse Corporation and was 99.9% W. The noble metals were obtained from Englehard Industries. An analysis of the Os, Ir, and Pt was not available. The superconducting transition temperatures from 0.3 to about 1.0°K were determined in a helium-3 cryostat using an ac method.² Superconductivity above 1°K was observed by mutual inductance measurements.³ The structure of

the phases was determined at room temperature using the x-ray powder diffraction method.

OSMIUM-IRIDIUM SYSTEM

A number of Os-Ir alloys have been investigated by Vacher, Bechtoldt, and Maxwell.⁴ The hexagonal close-packed Os solid solution extends to about 30 at.% Ir and the face-centered cubic Ir solid solution to about 40 at.% Os. There is a miscibility gap from about 30 to 50 at.% Ir. The superconducting transition temperatures for the alloys are plotted as a function of composition and of valence electron concentration in Fig. 1. The transition temperature of the hexagonal close-packed Os is lowered by the addition of Ir in accordance with the variation of valence electron concentration.

The 30 at.% Ir alloy contains both the hexagonal close-packed phase and the face-centered cubic phase and shows two transition temperatures. This is clearly evident in Fig. 2 where the change in frequency of the resonant coil is plotted as a function of temperature. The change in frequency as the sample is placed in and out of the coil is proportional to the change of inductance of the coil. For the alloy in the normal state the change of inductance is essentially zero because the sample is both nonmagnetic and poorly conducting so that the skin depth is much larger than the sample dimension. The frequency shift plotted in Fig. 2, therefore, is a measure of the volume fraction of the sample which becomes superconducting provided that: (1) The penetration depth is small compared to the sample dimensions and (2) there is no multiply connected superconducting phase enclosing nonsuperconducting material. If the latter condition is not satisfied, then the frequency shift is proportional to the volume of material enclosed by the superconducting phase. In the case of the $\text{Os}_{0.70}\text{Ir}_{0.30}$ alloy condition (1) is certainly satisfied and the modified condition (2) applies. Thus, Fig. 2 indicates that slightly more than one-half of the pellet by volume is enclosed by the face-centered cubic Ir solid solution with a transition temperature of 0.97°K and the remainder of the sample is the hexagonal close-packed Os solid solution with a transi-

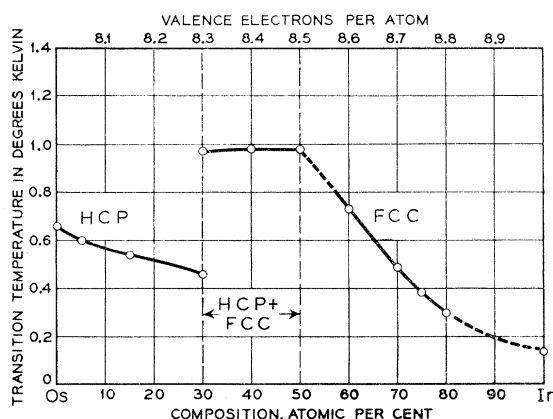


FIG. 1. Superconductivity in the Os-Ir system.

* University of California, La Jolla, California.

¹ T. H. Geballe, B. T. Matthias, E. Corenzwit, and G. W. Hull, Jr., *Phys. Rev. Letters* **8**, 313 (1962); and (to be published).

² A. L. Schawlow and G. E. Devlin, *Phys. Rev.* **113**, 120 (1959).

³ B. T. Matthias and J. K. Hulm, *Phys. Rev.* **87**, 799 (1952).

⁴ H. C. Vacher, C. J. Bechtoldt, and E. Maxwell, *J. Metals* **6**, 80 (1954).

tion temperature of 0.46°K . In an effort to break up any multiply connected regions the pellet was finely powdered and the transition curve was redetermined. The transition temperatures were approximately the same but were no longer sharp which was probably due to strain introduced by powdering. In addition, the frequency shift indicated that about one-fifth of the sample by volume is enclosed by the face-centered cubic Ir solid solution. After annealing the powder at 1000°C for 10 days, a single transition temperature of 0.46°K was obtained which is that of the hexagonal close-packed Os solid solution.

From the data in Fig. 2 it would seem that for the same valence electron concentration the cubic close-packed structure is more favorable for the occurrence of superconductivity than the hexagonal close-packed structure. The superconducting properties of the two forms of La also illustrate this. The face-centered cubic form of La has a transition temperature of 6.3°K whereas that of the hexagonal close-packed form is 4.9°K .⁵

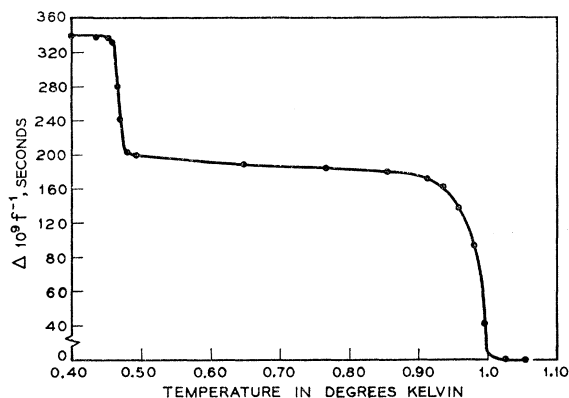


FIG. 2. Change in frequency of resonant coil as a function of temperature for $\text{Os}_{0.70}\text{Ir}_{0.30}$ alloy.

The superconducting properties of the dilute Os solutions in Ir suggested that perhaps Ir would be superconducting if sufficiently pure. Hein *et al.*⁶ verified this and found that highly purified Ir has a transition temperature of 0.14°K . This is the first time that superconductivity has been observed in a face-centered cubic noble metal.

WOLFRAM-PLATINUM SYSTEM

Wolfram and Pt also form a series of solid solutions. The alloys in the system have been investigated by

⁵ K. A. Gschneidner, Jr., and B. T. Matthias, in *Rare Earth Research*, edited by E. V. Kleber (The Macmillan Company, New York, 1961), p. 158.

⁶ R. A. Hein, J. W. Gibson, B. T. Matthias, T. H. Geballe, and E. Corenzwit, *Phys. Rev. Letters* **8**, 408 (1962).

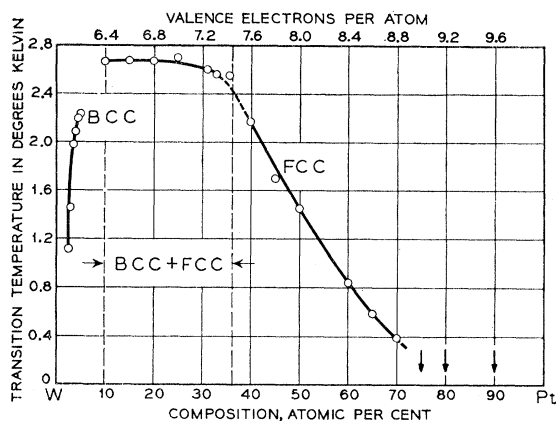


FIG. 3. Superconductivity in the W-Pt system.

Müller,⁷ Hultgren, and Jaffee,⁸ Nemilov and Rudnitskii,⁹ Jaffee and Nielson,¹⁰ and Greenfield and Beck.¹¹ The body-centered cubic W solid solution extends to about 5 at.% Pt and the face-centered cubic Pt to about 60 at.% W. A miscibility gap exists from 10 at.% to about 36 at.% Pt. As expected, these solid solutions are superconducting. Their transition temperatures are plotted as a function of composition and of valence electron concentration in Fig. 3.

Additional data for W-Pt alloys containing larger amounts of Pt are necessary before the question of the possible occurrence of superconductivity in Pt can be answered. These solid solutions are expected to be superconducting below 0.3°K which is the lower limit of our measurement. The superconducting properties of alloys containing 75 at.%, 80 at.%, and 90 at.% are being investigated by R. A. Hein and co-workers.

The transition temperatures of the more dilute solutions of Pt in W are very broad and, therefore, are not too reliable in predicting the possibility of W being a superconductor at very low temperatures. However, if the superconducting properties of the dilute solutions in the W-Pt system are similar to those in the Mo-Re and Os-Ir systems, which correctly suggested that both Mo and Ir would be superconductors, then both W and Pt are expected to become superconducting at extremely low temperatures.

ACKNOWLEDGMENTS

We are indebted to L. D. Longinotti for a great deal of help with the preparation of samples.

⁷ L. Müller, *Ann. Physik* **7**, 9 (1930).

⁸ R. Hultgren and R. I. Jaffee, *J. Appl. Phys.* **12**, 501 (1941).

⁹ V. A. Nemilov and A. A. Rudnitskii, *Izvest. Sektora Platiny (S.S.S.R.)* **21**, 234 (1948); *Chem. Abstracts* **44**, 9904 (1950).

¹⁰ R. I. Jaffee and H. P. Nielsen, *Trans. AIME* **180**, 603 (1949).

¹¹ P. Greenfield and P. A. Beck, *J. Metals* **8**, 265 (1956).