

Peculiarities of temperature variation of the superconducting transition under pressure for Mo-Re solid solutions

T. A. Ignat'eva and Yu. A. Cherevan'

Physicotechnical Institute, Ukrainian SSR Academy of Sciences

(Submitted February 21, 1980)

Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 7, 389-392 (5 April 1980)

At present, there is considerable interest in studying the electron spectrum of transition metals and their compounds with high superconducting transition temperatures (T_c) in order to study the nature of the increase in T_c .

PACS numbers: 74.10. + v, 74.70.Lp

This paper examines the peculiarities of the electron spectrum of Mo-Re solid solutions, which are interesting because T_c increases from 0.9 K for pure Mo to 11 K for Mo-30 at.% Re. The studies were performed on $1 \times 0.5 \times 10\text{-mm}^3$ single-crystal specimens with a superconducting transition width of $(0.5 - 1) \times 10^{-2}$ K. The depen-

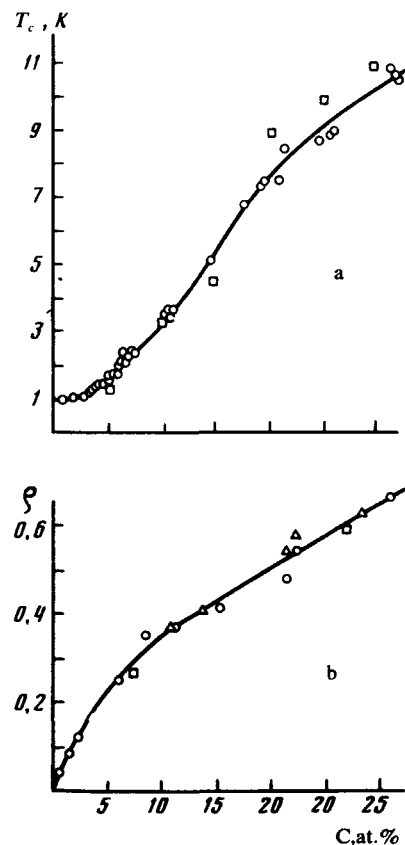


FIG. 1.

dence of T_c on C (at.%) is shown in Fig. 1,a. As can be seen, T increases nonlinearly with increasing concentration of the rhenium impurity. Initially, T_c increases comparatively slowly. Starting with a concentration of 8–10 at.% of rhenium, we observe a steeper increase of T_c with increasing impurity concentration.

Figure 1,b shows the dependence of the relative residual resistance $\rho = R_{4,2} \text{ K} / (R_c - R_{4,2} \text{ K})$ on the rhenium concentration for the investigated Mo–Re solutions. The change in the slope of the ρ vs. C (at.%) curve correlates with the variation in the rate of increase of T_c (C at.%) for 8–10 at.% rhenium.

The results obtained during studies of the Mo–Re solid solutions under pressure (P) were completely unexpected. Figure 2 shows the $T_c(P)$ dependences for Mo–6 at.% Re (2a), Mo–10 at.% Re (2b), and Mo–19.5 at.% and 19.7 at.% Re (2c).

The smooth nonlinear $T_c(P)$ dependence for Mo–6 and 10 at.% Re becomes an "oscillatory" dependence with a further increase in the impurity concentration—to 19.5 at.% and 19.7 at.% Re. This is the first time the oscillatory nature of the $T_c(P)$

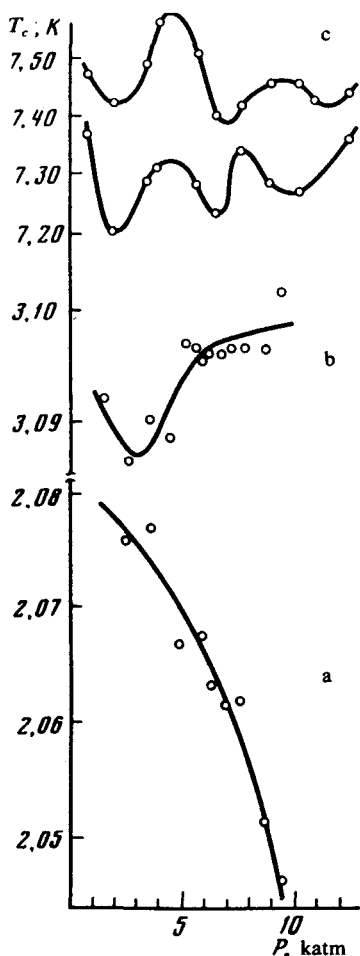


FIG. 2.

dependence was observed. The maximum oscillation amplitude, as seen in the plot, ranges from ≈ 0.1 to ≈ 0.2 K.

Let us note first of all that the $T_c(P)$ dependence reflects peculiarities in the density of electron states and is a delicate "tool" for studying these peculiarities.¹

This possibility of studying the electron spectrum was illustrated experimentally and theoretically in the 2.5-order phase transitions^{1,2} when the peculiarity $\delta\nu \sim (\epsilon_F - \epsilon_c)^{1/2}$ was taken into account in the electron-state density $\nu(\epsilon)$, where $\epsilon_F - \epsilon_c$ is the difference between the Fermi energy ϵ_F and the critical energy ϵ_c at which the topology of the Fermi surface changes. In this case nonlinear $T_c(P)$ dependences, which are attributable to the change in the topology features of the Fermi surface under pressure, were observed.¹ The rather small variation of the Fermi energy due to pressure, in particular $\partial\epsilon_F/\partial P = 6.5 \times 10^{-4}$ eV/katm for Mo,³ makes it possible, by means of pressure (≈ 0.5 katm), to traverse the electron spectrum in "steps" of $\approx 3 \times 10^{-4}$ eV and to probe the fine structure of the electron spectrum of a metal near the Fermi energy. The high energy sensitivity, achievable with an external parameter—pressure, and the fairly high accuracy in the measurements of $T_c \approx 5 \times 10^{-3}$ K make it possible to detect the peculiarities of the electron spectrum from the changes in $T_c(P)$.

The nonlinear $T_c(P)$ dependence for the Mo–6 at.% Re (Fig. 2,a) is attributable to the increase of the electron lenses under pressure; the $T_c(P)$ dependence for the Mo–10 at.% Re (Fig. 2,b) can be explained by the appearance of a hollow in the Fermi surface.

In studying the $T_c(P)$ dependence for the different Mo–Re solid solutions, we can enter each time a new part of the energy spectrum by increasing the Fermi energy with the Re impurity and by increasing the pressure we can traverse this part of the spectrum in a fairly narrow energy range, thereby determining the fine structure of the spectrum near ϵ_F . It can be estimated that ϵ_F is changed by ≈ 0.3 eV as a result of addition of 8–10 at.% Re. For such a change in ϵ_F , according to calculations of the electron dispersion law $\epsilon(P)$ for pure Mo,⁴ we should expect the appearance of an electron group in the NH line of the Brillouin zone. The nonlinear character of the T_c (C at.%) variation can apparently also be explained qualitatively as a phase transition of the 2.5 kind for ≈ 8 –10 at.% Re, due to appearance of a small group of electrons (Fig. 1,a). The experimentally observed "oscillatory" dependence of $T_c(P)$ (Fig. 2,c) cannot be explained within the framework of the change in the Fermi surface topology.

If the relationships of the peculiarities of the $T_c(P)$ dependence to the peculiarities of the electron spectrum of a metal¹ are left within the framework of the discussion, then it must be assumed that, starting with certain Re impurity concentrations (after the 2.5-order phase transition) a quasi-discrete spectrum is formed, in addition to the continuous spectrum in the Mo–Re solutions, with levels having a width $\Delta\epsilon \approx \Delta P (\partial\epsilon/\partial P) \approx 1 \times 10^{-3}$ eV [ΔP is the distance between the extreme points in the $T_c(P)$ dependence in Fig. 2,c], which is also responsible for the oscillatory $T_c(P)$ dependence.

It should be noted that the temperature smearing of this level at $T = T_c \approx 8$ –10 K amounts to $\sim 10^{-3}$ eV, i.e., it is of the order of the level width; therefore, a resonance

mechanism of the observed effect is not too probable.

In principle, the quasi-discrete spectrum can appear because of the presence of impurities⁵ of the dislocation deformation fields.⁶

However, this does not rule out that local configurations of atoms (such as clusters)⁷ can be produced in the Mo-Re systems, starting with certain concentrations, which can lead to the appearance of a pressure-sensitive⁸ stress-field substructure that influences T_c .⁹

The authors wish to thank B. G. Lazarev, V. I. Makarov, A. A. Slutskin, and G. P. Sergeeva for useful discussions of the obtained results.

¹B. G. Lazarev, L. S. Lazareva, V. I. Makarov, and T. A. Ignat'eva, Zh. Eksp. Teor. Fiz. **48**, 1065 (1965) [Sov. Phys. JETP **21**, 711 (1965)]; V. I. Makarov and V. G. Bar'yakhtar, Zh. Eksp. Teor. Fiz. **48**, 1717 (1965) [Sov. Phys. JETP **21**, 1151 (1965)]; T. A. Ignat'eva, V. I. Makarov, and Yu. A. Cherevan', Zh. Eksp. Teor. Fiz. **67**, 994 (1974) [Sov. Phys. JETP **40**, 492 (1974)].

²I. M. Lifshits, Zh. Eksp. Teor. Fiz. **38**, 1569 (1960) [Sov. Phys. JETP **11**, 1130 (1960)].

³M. Posternak and W. B. Waeber, J. Low Temp. Phys. **21**, 47 (1975).

⁴R. J. Iverson and L. Hodges, Phys. Rev. B **8**, 1429 (1973).

⁵I. M. Lifshits, Zh. Eksp. Teor. Fiz. **44**, 1723 (1963) [Sov. Phys. JETP **17**, 1159 (1963)]; N. F. Mott, Perekhody metall-izolyator (Metal-Insulator Transitions), Nauka, Moscow, 1979.

⁶I. M. Lifshits and Kh. I. Pushkarov, Pis'ma Zh. Eksp. Teor. Fiz. **11**, 456 (1970) [JETP Lett. **11**, 310 (1970)].

⁷N. N. Aparov, I. V. Lyasotskiĭ, Yu. D. Tyapkin, and V. E. Panin, Fiz. Met. Metalloved. **40**, 354 (1975).

⁸A. A. Galkin, V. V. Tokiĭ, M. A. Dulin, Yu. P. Paniotov, and B. P. Filatov, Dokl. Akad. Nauk SSSR **235**, 327 (1977) [Sov. Phys. Doklady **22**, 404 (1977)].

⁹V. M. Nabutovskii and B. Ya. Shapiro, Fiz. Nizk. Temp. **5**, 1128 (1979) [Sov. J. Low Temp. Phys. **5**, 532 (1979)].