

Effect of Pressure on Superconductivity in Transition Metal Alloys*

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Measurements on twelve alloys of the series Zr-Nb-Mo show a close correlation of dT_c/dp with the d -band structure of these alloys and suggest that the d -band is virtually rigid with respect to pressure. The results are not compatible with an empirical observation of McMillan that T_c is governed only by a phonon factor $M\omega^2$.

Introduction

The reaction of superconductivity of transition metals and their alloys to volume changes caused by the application of hydrostatic pressure is complex. Positive and negative signs of dT_c/dp and nonlinearities in $T_c(p)$ have been observed for the various superconductors of this group¹. Attempts to correlate this behaviour with irregularities in the isotope effect of these metals are made increasingly difficult by a growing body of experimental facts². Also, a correlation of dT_c/dp with the band structure could only be seen for a few selected metals and alloys^{3,4}.

In contrast, the situation is much simpler in superconducting non transition metals, in which the transition temperatures decrease nearly

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1 For a compilation of relevant data see: Brandt, N. B., Ginzburg, N. I.: *Soviet Phys. Usp.* **8**, 202 (1965). — More recent work on transition metals: Gardner, W. E., Smith, T. F.: *Phys. Rev.* **138**, A484 (1965); *ibid.* **140**, A1620 (1965); *ibid.* **144**, 233 (1966); *ibid.* **146**, 291 (1966). — Bucher, E., Müller, J., Olsen, J. L., Palmy, C.: *Cryogenics* **5**, 283 (1965). — Gey, W., Heyden, G. v.: *Z. Physik* **193**, 65 (1966). — Köhnlein, D.: *Z. Physik* **208**, 142 (1968). — Andres, K.: *Phys. Rev.* **168**, 708 (1968). — Chu, C. W., Smith, T. F., Gardner, W. E.: *Phys. Rev. Letters* **20**, 198 (1968). — Chu, C. W., Gardner, W. E., Smith, T. F.: *Phys. Letters* **26A**, 627 (1968).

2 Bucher, E., Müller, J., Olsen, J. L., Palmy, C.: *Cryogenics* **5**, 283 (1965).

3 Brandt, N. B., Ginzburg, N. I.: *Soviet Phys. Usp.* **8**, 202 (1965).

4 Brandt, N. B., Ginzburg, N. I.: *Soviet Phys. JETP* **24**, 40 (1967).

linearly with pressure^{1,5}. An empirical rule has been established for these metals⁶ which more recently has received semiquantitative justification^{7,8} by use of a simplification of McMillan's theoretical formula for T_c ⁹. Although not yet fully satisfactory, because use of the full expression for T_c makes the agreement worse⁸, this approach certainly indicates the direction in which the solution for the simple metals is to be found.

In an attempt to detect similarly a unifying principle for the divergent behaviour of transition metals under pressure, the alloy series Zr-Nb-Mo was chosen on the following grounds:

1. The series is homologous in structure (*bcc*) from Zr₈₀Nb₂₀ to molybdenum¹⁰. 2. Only 4-*d* elements are involved. The rigid-band-model has been shown to be valid¹¹. 3. Data on the electronic specific heat coefficient γ and on the Debye characteristic temperature θ exist for almost the whole composition range¹². 4. Data on dT_c/dp for Zr, Nb, and Nb₇₅Mo₂₅ were already available. Those on Nb from different authors were not in complete accord^{13,14}. 5. Presumably no effects of electron-magnon interactions obscure the situation¹⁵. Our main result is that for all alloys the variation of T_c with pressure is governed by the shape of the *d*-band.

Experiment

Pressure

The apparatus used for generation of high pressure has been described earlier¹⁶. The linear dimensions of the pressure tongs have been increased by a factor of approximately 1.5 which permits the use of a piston-

5 At first sight Tl appears to be an exception since in this case T_c passes through a flat maximum. It seems to be confirmed, however, that this maximum is due to a superposition of two monotonic functions. After subtraction of the one, which stems from a pressure dependent gap anisotropy, Tl also shows a nearly linear decrease of T_c with *p*. Gey, W.: Phys. Rev. **153**, 422 (1967).

6 Rohrer, H.: Helv. Phys. Acta **33**, 675 (1960).

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12 Heiniger, F., Bucher, E., Muller, J.: Phys. kondens. Materie **5**, 243 (1966).

13 Brandt, N. B., Ginzburg, N. I.: Soviet Physics JETP **19**, 823 (1964); *ibid.* **24**, 40 (1967).

14 Gardner, W. E., Smith, T. F.: Phys. Rev. **144**, 233 (1966). In this paper the slope dT_c/dp for niobium was reported to be zero, in contrast to the findings of Ref. ¹⁷. More recently Smith has also obtained a positive value (private communication).

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16 Buckel, W., Gey, W.: Z. Physik **176**, 336 (1963).

17 Gey, W., Heyden, G. v.: Z. Physik **193**, 65 (1966). — Köhnlein, D.: Z. Physik **208**, 142 (1968).