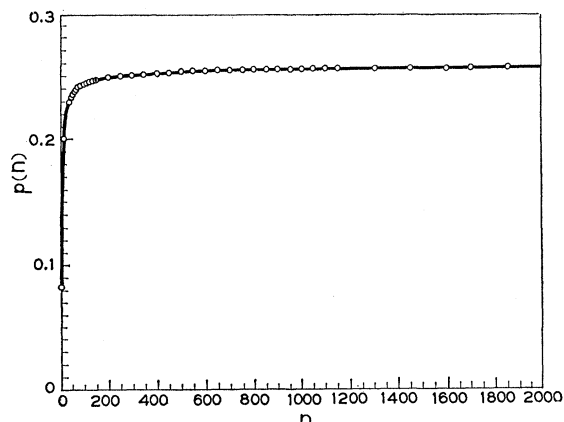


TABLE I. Bond critical probabilities (with  $d$  the number of dimensions and  $z$  the coordination number of the lattice).

Lattice	$d$	$z$	$p_c$	Standard deviation in $p_c$	$p_c$ D.S.	$2/z$	$zp_c/2$
Triangular	2	6	0.341	0.011	0.33	0.33	1.03
Square	2	4	0.493	0.013	0.50	0.50	0.99
Hexagonal	2	3	0.640	0.018	0.66	0.67	0.96
Hexagonal close-packed	3	12	0.124	0.005	...	0.17	0.73
Face-centered cubic	3	12	0.125	0.005	...	0.17	0.74
Simple cubic	3	6	0.254	0.013	0.24	0.33	0.77
Tetrahedral	3	4	0.390	0.011	...	0.50	0.78
Ice (quartz)	3	4	0.388	0.010	...	0.50	0.78

to be comparable to the standard deviation; efforts to evaluate these bias effects more precisely are under way. It is known<sup>5</sup> that the sum of  $p_c$  for the two-dimensional triangular and hexagonal lattices cannot be less than one. Hence the mean value of  $p_c$  for the triangular or hexagonal lattice is too low; although this condition is satisfied within the indicated deviations. For the square lattice it is known that  $p_c \geq \frac{1}{2}$ .<sup>8</sup>

$p_c$  appears to be little affected by differences of lattice type if the number of dimensions and coordination number are the same. Although it appears that for these lattices within the indicated deviations  $zp_c$  is only a function of  $d$  [say  $zp_c = d/(d-1)$ ], a known counter-

FIG. 1. Plot of  $p(n)$  vs  $n$  for the simple cubic lattice. Other lattice structures give a curve analogous to this.

example in two dimensions shows that this is not true in general.<sup>9</sup>

If  $p(n)$  represents the expected probability of bond occupation at which  $n$  vertices have been "wetted," then  $p(n)$  appears to approach  $p_c$  exponentially with  $n$  as shown in Fig. 1. An analogous program for numerically investigating the critical probabilities for the site problem is nearing completion and we expect that numerical results will be available shortly.

<sup>8</sup> T. E. Harris, Proc. Cambridge Phil. Soc. **56**, 13 (1960).]

<sup>9</sup> E. N. Gilbert (private communication).

## Superconductivity of Technetium Alloys and Compounds

V. B. COMPTON, E. CORENZWIT, J. P. MAITA, B. T. MATTHIAS, AND F. J. MORIN  
Bell Telephone Laboratories, Murray Hill, New Jersey

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The superconducting transition temperatures of Mo-Tc alloys are reported. Critical field measurements of a 50 atomic percent alloy indicate that it might be a promising material for superconducting magnets.

The similarity of Tc and Re with respect to alloy and intermetallic compound formation is noted.

The superconducting transition temperatures of the compounds  $ZrTc_6$  and  $NbTc_3$  are 9.7°K and 10.5°K, respectively. X-ray diffraction data suggest that these compounds have the  $\alpha$ -Mn type structure.

THE recent increase in the availability of technetium metal prompted an investigation of the superconducting properties of Mo-Tc alloys and of the compounds  $ZrTc_6$  and  $NbTc_3$ . No alloys or intermetallic compounds of technetium have been reported previously in the literature.

### I. Mo-Tc ALLOYS

The superconducting transition temperature of technetium has been reported by Daunt and Cobble<sup>1</sup> as 11.2°K for powder of  $\geq 99.9\%$  purity. The transition had a range from about 8° to 11°K, which was attributed to the geometrical shape of the specimen.

<sup>1</sup> J. G. Daunt and J. W. Cobble, Phys. Rev. **92**, 507 (1953).

Hulm<sup>2</sup> has reported the superconducting behavior of Mo-Re alloys. He found that the transition temperature approaches 12.5°K for the intermediate range of the solid solution of Re in Mo.

On the basis of the results of these two investigations, it was decided to study superconductivity in the Mo-Tc system assuming that Tc and Re have similar alloying behavior. The Tc metal as received was in the form of chips coated with an oxide layer. Since the melting point of Tc is close to 2200°C, the melts were prepared in an arc furnace in an argon atmosphere. Prior to melting, the Tc lost about 20% of its weight during heating in the furnace. The weight loss of the melted

<sup>2</sup> J. K. Hulm, Phys. Rev. **98**, 1539 (1955), data for  $Mo_3Re$ ; data for Mo-Re system (to be published).

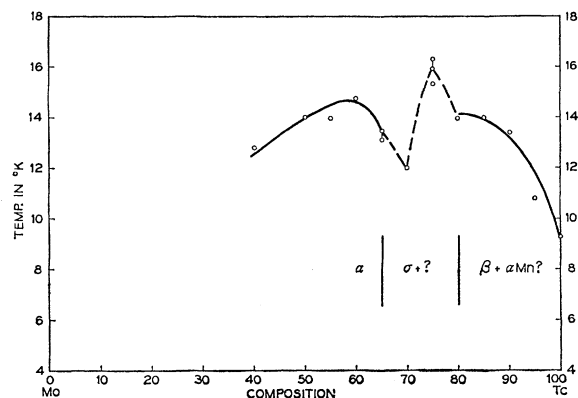


FIG. 1. Superconductivity in the molybdenum-technetium system. The transition temperatures are plotted as a function of composition in atomic percent.

ingot was negligible upon subsequent melting. It is assumed that the loss was due to volatilization of the oxide. As a result, the purity of the metal and its oxygen content are not known. The superconducting transition temperature of the metal chips as received and of the melted material is about 9.3°K, which is somewhat lower than the previously reported value. It is difficult to say at present whether this discrepancy is due to dissolved oxygen or to other factors. It is known, for example, that Re, which is very similar to Tc, shows large variations in its superconducting transition temperature depending on whether it is a finely divided powder or an annealed ingot.

Since the oxide which volatilized in the course of heating the Tc chips was very radioactive in its finely divided state, it was decided to reduce the number of consolidation melts of the chip material. For this reason, three master alloys were prepared containing 5 at. % Mo, 25 at. % Mo, and 50 at. % Mo using high-purity Mo rods and Tc ingots obtained by melting the chips. After their superconducting transition temperatures were measured, enough Mo was added to each alloy to give the next desired composition; followed by melting in the furnace and measurement of the transition temperature. The procedure was repeated until the maximum Mo composition for a given range was reached. The 5 at. % Mo alloy was used for the composition range up to 25 at. % Mo; the 25 at. % Mo alloy for the range up to 50 at. % Mo; and the 50 at. % Mo alloy up to the range 70 at. % Mo.

The transition temperatures vs composition are given in Fig. 1. The superconducting behavior of the Mo-Tc system is very similar to that of the Mo-Re system. The phases present at the various compositions were not determined but were assumed to be similar to those present in the Mo-Re system.<sup>3</sup>

<sup>3</sup> J. M. Dickinson and L. S. Richardson, *Trans. Am. Soc. Metals* **51**, 1055 (1959). A. G. Knapton, *J. Inst. Metals* **87**, 62 (1958).

TABLE I. Lattice constants and transition temperatures.

Compounds	Lattice constant $a$ (Å)	Superconducting transition temperature (°K)
ZrTc <sub>6</sub>	9.636±0.002	9.7
NbTc <sub>3</sub>	9.625±0.002	10.5
ZrRe <sub>6</sub>	9.698±0.002	7.4
Nb <sub>0.18</sub> Re	9.641±0.002	9.7

Critical field measurements with 19 000 gauss of an alloy with an approximate composition near 50 at. % Mo and a transition temperature of 12.6°K would give  $H_0$  value (critical field at 0°K) of 75 000 gauss. A Mo-Re alloy having the same transition temperature gave an  $H_0$  of only 27 000 gauss. From this it would seem that Mo-Tc wire might be a promising material for superconducting magnets, assuming that it is as ductile as the corresponding Mo-Re alloy.

## II. THE COMPOUNDS ZrTc<sub>6</sub> AND NbTc<sub>3</sub>

The similarity of Tc and Re with respect to the formation of intermetallic compounds was investigated very briefly. The compounds ZrTc<sub>6</sub> and NbTc<sub>3</sub> were prepared by melting stoichiometric amounts of the elements in an arc furnace in an argon atmosphere. X-ray diffraction powder photographs were taken of the resulting product using a Norelco camera of 114.6-mm diam and Cu  $K$  radiation ( $\lambda = 1.5405$  Å).

The powder patterns for ZrTc<sub>6</sub> and NbTc<sub>3</sub> were indexed on a body-centered cubic lattice and the intensities are similar to those of ZrRe<sub>6</sub> and Nb<sub>0.18</sub>Re previously determined as the  $\alpha$ -Mn type structure (A12). Data for ZrRe<sub>6</sub> are reported by Savitskii, Tylkina, and Tsyganova<sup>4</sup> and for NbRe<sub>3</sub> by Knapton,<sup>5</sup> Greenfield and Beck,<sup>6</sup> and Niemiec and Trzebiatowski.<sup>7</sup> This structure belongs to space group  $T_d^3$ -I43m and contains 58 atoms per unit cell. The x-ray diffraction data suggest that ZrTc<sub>6</sub> and NbTc<sub>3</sub> have the  $\alpha$ -Mn type structure.

The lattice constant and superconducting transition temperature of ZrTc<sub>6</sub> and NbTc<sub>3</sub> are given in Table I. The transition temperatures of the corresponding rhenium compounds of Zr and Nb have been reported previously and are included in the table for comparison with the Tc compounds.<sup>8</sup>

<sup>4</sup> E. V. Savitskii, M. A. Tylkina, and I. A. Tsyganova, *Atomnaya Energ.* **7**, 231 (1959); *Chem. Abstracts* **54**, 58h (1960).

<sup>5</sup> A. G. Knapton, *J. Inst. Metals* **87**, 28 (1958).

<sup>6</sup> P. Greenfield and P. A. Beck, *Trans. Am. Inst. Mining Met. Engrs.* **206**, 265 (1956).

<sup>7</sup> J. Niemiec and W. Trzebiatowski, *Bull. acad. polon. sci.* **4**, 601 (1956); *Chem. Abstracts* **51**, 7280a (1957).

<sup>8</sup> B. T. Matthias, V. B. Compton, and E. Corenzwit, *J. Phys. Chem. Solids* **19**, 130 (1961).