N_0 is the total vacancy concentration at the beginning of the annealing process and can be calculated from a knowledge of the quenching temperature, divacancy binding energy and solute–vacancy binding energy [7]. The experimental data for annealing at 30° C are also shown in Fig. 4 assuming that the contributions of the defects to resistivity are the same. It is clear that the chromium–vacancy binding energy lies between 0.16 and 0.17 eV. The isothermal data for other temperatures lead to binding energy values in the range 0.13 to 0.17 eV with a mean of 0.15 eV. This is to be compared with the value of 0.10 eV obtained for the manganese–vacancy complex in Al–0.1%Mn alloy [8]. The higher value for chromium is in agreement with theoretical estimates of binding energy based on maximum solid solubility in aluminium [9] and the melting points of chromium and manganese [10].

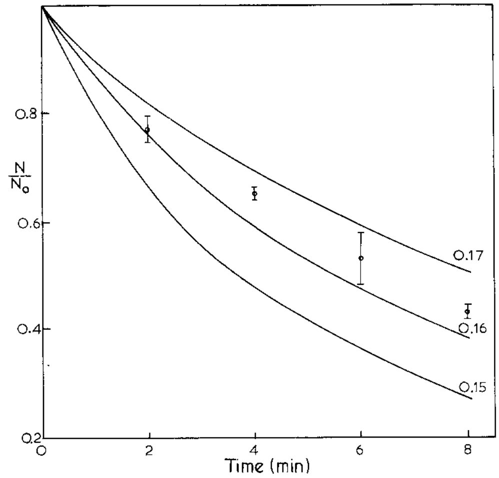

Figure 4 Variation in the total vacancy concentration with time for annealing at 30° C. Quenching temperature 500° C.

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Ion–ion interaction and superconductivity of metals and intermetallic compounds

The application of superconductors to produce very strong magnetic fields, has stimulated investigations with the objective of as high a critical temperature for the superconducting phase transition as possible. Several authors [1–4] have analysed the influence of different physical factors on the critical point of phase transition in superconductors. The influence of phonon spectra, electron–electron indirect interaction as well as the density of states have been taken into account. These efforts brought some important results, for example the explanation of Matthias'rules and raising of the critical temperatures of commercial superconductors.

In this work we wish to analyse the connection between the ion–ion potential and critical temperature. The contribution of ion–ion interaction to the phenomenon of superconductivity is rather important, but in spite of this, it has not been examined up to now.

Ion–ion interaction in metal is described by the general expression:

$$\phi(R) = \frac{\Omega_0}{2}\int_0^\infty F(q)\frac{\sin(qR)}{qR}q^2\,dq \qquad (1)$$

where q is the momentum transfer of conducting electrons, Ω_0 is the atomic volume, R is the interionic distance, and $F(q)$ is the characteristic function:

$$F(q) = \frac{\Omega_0 q^2}{8\pi e^2}V^0(q)\frac{\epsilon(q)-1}{\epsilon(q)} \qquad (2)$$

where $V^0(q)$ is the electron-free ion potential and $\epsilon(q)$ is the dielectric function.

Instead of investigating the very complicated connection between $\phi(R)$ and the critical point (which is realized through the characteristic function $F(q)$, defining one of the basic components of the phonon spectrum), we will analyse the phenomenological correlations between these two quantities. We expect to get some new information in this way, which would be useful in a quantitative analysis of superconducting materials. We will restrict our discussion only to the nearest neighbours interaction $\phi(R_0)$, which is the largest term in the ion–ion interaction. In order to obtain this term we will use the asymptotic expression for ion–ion interaction, the accuracy of which is quite satisfactory in the range of nearest neighbours:

$$\phi(R) = \frac{9\pi Z^*[V(2K_f)]^2}{E_f}\cdot\frac{\cos(2K_fR)}{(2K_fR)^3} \qquad (3)$$

where Z^* is the valence number of a given metal, K_f is the Fermi momentum, E_f is the Fermi energy and $V(2K_f)$ is the formfactor of the pseudopotential for electron–ion interaction, taken at the point $q = 2K_f$. Starting from the pseudopotential [5, 6], the value $V(2K_f)$ takes the following form:

$$V(2K_f) =$$

$$\frac{a_1(Z-Z_0)}{2\pi}\sin[2\pi a_2(Z-Z_0)]\exp(-a_3) \qquad (4)$$

where Z is the atomic number of a given metal, Z_0 is the inert element atomic number that begins the period which includes the given Z, and the coefficients a_1, a_2 and a_3 are taken from [6].

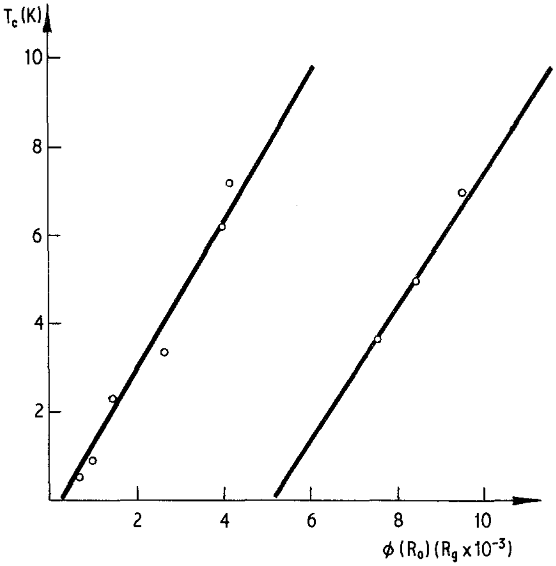

Figure 1 Correlation between the values $\phi(R_0)$ and critical temperature for simple metals.

The values of the ion–ion potential at the potential at the position of the first deep minimum $\phi(R_0)$ (the nearest neighbour interaction) for ten simple metals and their critical temperatures are given in Table I and Fig. 1. Metals of the first and second group of the periodic table have not been considered because of weak electron–electron indirect interaction [4]. Nor was Hg considered, due to its abnormal properties.

The consideration of Si and Ge could lead to some uncertainties due to the fact they are superconductors only under high pressures when they exhibit metallic properties. In this case one can apply the procedure described above. The metals Pb, Ga, In, Tl, Zn and Cd, which have f c c and

TABLE I The values of the ion–ion interaction at the position of the first deep minimum and critical temperatures for simple metals

Metals	$\phi(R_0)$ $(R_y)\times 10^{-3}$	T_c (K)	Structure
Cd	0.70	0.52	h c p
Zn	1.04	0.86	h c p
Tl	1.49	2.40	h c p
In	2.70	3.40	f c c
Ga	3.96	6.20	f c c
Pb	4.16	7.20	f c c
Al	5.50	1.20	f c c
Sn	7.58	3.70	diamond
Ge	8.49	5.00	diamond
Si	9.64	7.00	diamond

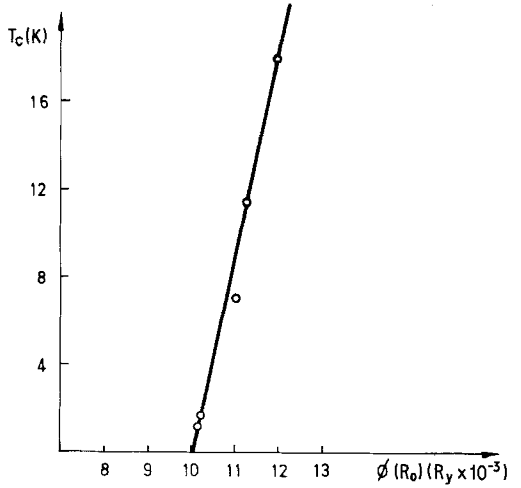

Figure 2 Correlation between the values $\phi(R_0)$ and critical temperature for intermetallic compounds.

TABLE II The values of the ion–ion interaction at the position of the first deep minimum and critical temperatures for intermetallic compounds

Compounds	$\phi(R_0)$ $(R_y) \times 10^{-3}$	T_c (K)	Structure
$GeMo_3$	10.10	1.4	A 15
$IrNb_3$	10.25	1.7	A 15
SnV_3	11.10	7.0	A 15
$AuNb_3$	11.30	11.5	A 15
$SnNb_3$	12.00	18.0	A 15

hcp structure, fall on the same straight line, while Si, Ge and Sn of diamond structure, fall on the other line. These results are probably connected to the fact that fcc and hcp structures have the same packing density. The above relationship does not apply to Al. In Table II and Fig. 2 the results for some intermetallic compounds of the structure type A 15 are given. The results are obtained using Expression 3 in pseudoatomic approximation [7]. As one can see, the linear dependence between $\phi(R_0)$ and T_c is also valid in this case, although with a different coefficient.

If we assume that the same pattern is also valid for alloys, we could conclude that, in principle, it would be possible to raise the critical point of a certain alloy by maintaining its crystal lattice structure in the metastable state in the region of ion–ion interaction potential values in which this structure does not exist under normal conditions. As can be seen from Fig. 1, the increase of $\phi(R_0)$ up to $4 \times 10^{-3} R_y$ results in an increase of T_c, which follows the first straight line. For higher values of $\phi(R_0)$, T_c drops to zero and again rises obeying the same rule. According to Fig. 1, this means that the alloy with $\phi(R_0) > 4 \times 10^{-3} R_y$ must retain the fcc or hcp structure in order to reach T_c. It may be possible that this explains the experimentally established correlation between the instability of metal phases and their critical points.

We can conclude that the interesting connection between the value of the ion–ion interaction potential at the position of the first deep minimum and critical temperature requires more comprehensive theoretical analysis. In practice, the ion–ion interaction, due to its direct influence on critical temperature, is of importance in optimizing the properties of superconducting materials.

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