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Abstract

Full Text

Physics

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On a Possible Criterion of Superconductivity

(Presented by Academician I. K. Kikoin, 1 VI 1961)

Tables 1-4 give the values of the Hall constants* and of the interatomic distances d of the elements, arranged according to types of crystal structure. Of the 21 superconductors with known Hall coefficient R ⁽²⁾, 15 superconductors have $R > 0$, **which indicates the presence of hole conductivity in them. As is seen from Tables 1-4, in these metals d is greater than in nonsuperconductors having $R > 0$ (elements for which R can take positive values are marked with an asterisk). The only exception is Mo*, which will be discussed below.** For all superconductors the condition $2.6 \div 2.9 \text{ kX} > d > 4 \text{ kX}$ is satisfied. A similar regularity apparently also holds for compounds and alloys.

Thus, in ⁽⁵⁾ it was found that, among Bi compounds, for superconductors the value of d lies within the limits $3.1 \text{ kX} \div 4 \text{ kX}$, whereas for nonsuperconductors d lies outside these limits. An analogous phenomenon is observed in Rh-Te and Rh-Se alloys ⁽⁶⁾. If ferromagnets and strong paramagnets (nonsuperconductors ⁽⁷⁾) are excluded, one may verify that all elements obey the same rule, with the exception of metals with electronic conductivity: Ag, Au, Li, Na, Ca, Mg, Y, as well as the semimetals Sb, Bi and the semiconductors α -Sn and Te. In Sb and Bi the number of current carriers is $N \cong 10^{18} - 10^{19} \text{ cm}^{-3}$, while in α -Sn and Te the value of N is still smaller. The contradiction to the established rule is removed if one assumes that, for the occurrence of superconductivity, a sufficient concentration of holes is necessary.

Thus, the criteria for the occurrence of superconductivity are: the presence of a sufficient concentration of holes $N_p > 10^{19} \text{ cm}^{-3}$, a restriction on the minimum interatomic distance $2.6 \div 2.9 \text{ kX} < d < 4 \text{ kX}$, and the absence of ferromagnetism and strong paramagnetism. From this point of view it seems natural to explain the change in T_c under compression ⁽⁸⁾ and tension ⁽⁹⁾ of superconductors. However, a more significant change in T_c occurs with a change in the hole concentration during plastic deformation of the metal, which causes the appearance of structural defects. Deformation leads to a decrease in R ⁽¹⁰⁾ and to an increase of T_c by several tenths of a degree ⁽¹¹⁾. Annealing removes these effects. In superconductors the mobility is usually considerably smaller ⁽¹⁾ (more structural defects) than in nonsupercon-

* I. Kikoin and B. Lazarev ⁽¹⁾ were the first to draw attention to the possibility of a correlation between superconductivity and Hall coefficients.

** The data for the value of R correspond to room temperature. In the metals Al, Sn, In, $R > 0$ at helium temperatures ⁽⁴⁾. The presence of holes in other superconductors (with $R < 0$) is confirmed by the dependence of R on temperature, due to the temperature dependence of the mobility of electrons μ_e and holes μ_p (in the case of mixed conductivity

$$R = (N_e\mu_e^2 - N_p\mu_p^2)/(N_e\mu_e + N_p\mu_p)^2).$$

*** Mo is close to superconductors, as is shown, for example, by the fact that the addition to it of several percent of the nonsuperconductor Rh makes it a superconductor ⁽²⁰⁾.

Table 1

Face-centered cubic type A-1

	Cu	Au	Ag	α - Ca	Sr	β - Rh*	Ir*	Pd	Pt	Al*	Pb*	α - Th	β - La	β - Hf
R , 10^{11} , m^3/C	-5	-7	-9	-18	?	+5	+35	-7	-2	-3	+1	-1	-8	?
d , kX (\AA)	2,550	2,878	2,883	3,939	4,293	2,684	2,709	2,745	2,769	2,857	3,493	3,588	3,737	3
T_c , °K	Electron- con-	Electron- con-	Electron- con-	Electron- con-	Electron- con-	Electronic 2,85	Electronic 2,85	Electronic 2,85	Electronic 2,85	1,2	7,22	1,39	3,9	?
	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity	ductivity
	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Nonsuperconductor	Superconductor

Table 2

Body-centered cubic type A-2

	Li	Na	Ba	Rb	K	Cs	α - Cr*	V*	Mo*	Nb*	Ta*	γ - U	β - Ti
R , 10^{11} , m^3/C	-17	-21	?	-59	-42	-78	+36	+8	+18	+9	+10	+3?	+1?
d , kX (\AA)	3,032	3,383,72	4,338	4,937	4,515	5,253	2,493	12,617	12,719	12,852	12,850	3,052	2,8578

	Li	Na	Ba	Rb	K	Cs	α - Cr*	V*	Mo*	Nb*	Ta*	γ - U	β - Ti
T_c , °K	Electr con- duc- tiv- ity	Electr con- duc- tiv- ity	Electr con- duc- tiv- ity	Electr con- duc- tiv- ity	Electr con- duc- tiv- ity	Electr con- duc- tiv- ity	Electronic 2,6	5,1	Nonsuper- conductors	8,11	11	?	?
	Nonsuperconductors												

Table 3
Hexagonal close packing, type A-3

	Mg	Y	α - Be*	Ru*	Zn*	Os	Tc	Re*	α - Ti*	Cd*	Hf	α - Zr*	α - Tl*	La	α - Lu	
R , 10^{11} , $m^3/coul$	-9	-8	+24	+22	+4	?	?	+31	+1	+5	?	+12	+2	-3	-5	
d , kX ⁽³⁾	3.190	3.543	3.220	3.644	2.659	3.670	2.698	2.735	2.889	2.972	3.121	3.172	3.400	3.731	3.4275	
T_c , °K	Electr con- duc- tion.	Electr con- duc- tion.	Electronic 2.6	0.47	0.91	0.71	11.2	2.42	0.37	0.56	0.35	0.70	2.38	5.4	?	
	Non-superconductors															

Table 4
Other types of structures

caused by lattice disturbances, can be verified by measuring R of superconductors under conditions of low-temperature deformation.* The anomalies in Tl under strong compression ⁽¹⁵⁾ are probably explained by an increase in N_p owing to the appearance of lattice disturbances. By increasing the hole concentration through low-temperature deformation of a massive metal (or in condensed films ⁽¹⁶⁾), it is probably possible to transfer Mo, Ir, and Sb into the superconducting state. For Bi, as is known, superconducting films have already been obtained ⁽²⁾, and R in such films is thousands of times smaller than for the solid metal ⁽¹⁷⁾.

In ⁽¹⁸⁾ it was established that, with the addition of Fe, Cr, and Co impurities to the superconductors Ti and Zr, T_c increases. It would be interesting to investigate the influence of these impurities on the Hall constant. On the other hand, an influence of the state of ordering in alloys on the magnitude and sign of the Hall constant has been found ⁽¹⁹⁾.

Apparently, the state of ordering should also have a substantial influence on the superconducting properties of alloys.**

In addition, it is probably possible to obtain superconductors by creating a high hole concentration ($N_p \sim 10^{21} \text{ cm}^{-3}$) by heavily doping the semiconductor α -Sn with an impurity (Al, In), or by doping semiconductor compounds with a suitable value of the interatomic distance.

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* Another explanation of these facts is also possible: N_p does not change appreciably under low-temperature deformation, but there occurs a decrease in the electronic conductivity (N_e and μ_e), which prevents the onset of superconductivity.

It would be desirable to check the correlation between superconductivity and N_p (the change of T_c and R under the influence of low-temperature deformation, impurities, ordering, etc.) on the same specimens.

Note: Figure translations are in progress. See original paper for figures.

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