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INVESTIGATION OF EMPIRICAL LAWS FOR SUPERCONDUCTIVITY OF ALLOY AND COMPOUND SUPERCONDUCTORS*

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By studying the average effect of the electronegativity of alloy and compound superconductors, some empirical laws are found. The average value of the electronegativity of alloy superconductors $\overline{\chi}$ is from 1.3 to 1.9, most of which is concentrated in the region $1.5 < \overline{\chi} < 1.8$. The $\overline{\chi}$ of many higher T_c superconductors is nearly 1.60. All these characteristics are similar to element superconductors. The average value of the electronegativity $\overline{\eta}$ of positive valence elements in oxide superconductors is from 1.3 to 1.6, and the average effect of an electronegativity of zero on every element $\overline{\zeta}$ is from 1.75 to 2.00. The mean of $\overline{\eta}$ and $\overline{\zeta}$ is from 1.5 to 1.8. When both $\overline{\eta}$ and $\overline{\zeta}$ are near the limit value (1.3 or 1.6 and 1.75 or 2.00), the material has a very low T_c, even is non-superconductive. The $\overline{\eta}$ of other compound superconductors is either too high or too low, and the $\overline{\zeta}$ is too low so that the T_c of these superconductors is quite low. Studying the average effect of the electronegativity of non-superconducting compounds further confirms the laws.

Keywords: superconductivity, electronegativity, empirical law
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I. INTRODUCTION

In the history of superconductivity research, many empirical criteria for superconductivity[1−8,10−12] have been found. For example, according to the valence of an element, the volume of the element, Hall effect,[3] Debye temperature,[4−6] the coefficient of specific heat of an electron in the normal state,[7−9] the mean degree of freedom of the free electron,[10] the atomic weight and crystal structure,[11−14] etc., some empirical laws have been produced, such as the Matthias criterion. Many of these are very important for the study of superconductivity and new superconductor discovery, but most have some exceptions which mean they are not final good criteria. In Ref.[1], the authors put all the elements together and analysed the relationship between electronegativity and superconductivity. They found a new criterion for the superconductivity of elements, which can be applied to all the elements in the periodic table. This shows that the values of the electronegativity of all superconducting elements concentrate in a narrow range from 1.3 to 1.9 and that the elements with values outside this region are non-superconductive. Table 1 shows the values of the electronegativity of elements and the T_c of some element superconductors.

The value of electronegativity is adopted from the Pauling formulae[15]

$$\chi_A - \chi_B = 0.208\Delta^{1/2}, \tag{1}$$

$$\chi_A - \chi_B = 0.18\Delta'^{1/2}, \tag{2}$$

and Gordy's empirical formulae[16−18]

$$\chi = \frac{Z_{\rm eff}e}{r}, \tag{3}$$

$$\chi = \frac{0.31(n+1)}{s} + 0.50, \tag{4}$$

$$\kappa = aN\left(\frac{\chi_A\chi_B}{d^2}\right)^{3/4}, \tag{5}$$

$$\chi = 0.44\phi_m - 0.15. \tag{6}$$

Here χ is the value of the electronegativity of the element, Δ is the arithmetic mean of the bond energies of atoms A and B, and Δ' is the geometrical mean of the resonance energy of the extra ion. When the bond energy difference between A and B is too large, formula (2) should be used. $Z_{\rm eff}$ is the effective electric charge of the atomic nucleus, r is the distance between the electron and nucleus, n is the number of electrons in the valence electron shell, s denotes the screen coefficient of the valence electron, κ is the bond stress coefficient, d is the bond length, N is the bond order and ϕ_m is the work function.

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Gordy *et al.* used formulae (1)–(6) and gave out a set of values of electronegativity. Reference [1] adopted this set of values of electronegativity, which is shown in Table 1.

Table 1. The values of electronegativity χ and superconductive critical temperature T_c of the elements.

A	χ	A	χ	T_c/K	A	χ	T_c/K	A	χ
F	3.9	Rh	1.9	325×10^{-6}	Al	1.5	1.196	Pr	1.2
O	3.5	Ir	1.9	0.14	Ga	1.5	1.091	Pm	1.2
Cl	3.0	Os	1.9	0.655			6.2	Sm	1.2
N	3.0	Tc	1.9	8.22			7.62	Gd	1.2
Br	2.8			7.92	Zn	1.5	0.875	Tb	1.2
S	2.6	Fe	1.8		U	1.5	0.58	Dy	1.2
Mn	2.6	Sb	1.8				0.23	Ho	1.2
C	2.5	Si	1.8				1.80	Er	1.2
I	2.4	Bi	1.8		Zr	1.5	0.546	Tm	1.2
Cr	2.2	W	1.8	0.0154			0.65	Lu	1.2
H	2.2	Ru	1.8	0.49	Th	1.4	1.39	Mg	1.2
At	2.2	Re	1.8	1.698	Hf	1.4	0.165	Np	1.1
Pt	2.2	Hg	1.8	4.154	La	1.3	4.9	Ac	1.1
P	2.2			3.949			6.06	Eu	1.1
Ni	2.0	Co	1.7		Pa	1.3	1.4	Yb	1.1
B	2.0	Ti	1.7	0.7	Be	1.3	0.55–2.5	Ca	1.0
Po	2.0	Mo	1.7	0.92	Am	1.3	1.05	Sr	0.98
Pd	2.0	Sn	1.7	3.722	Pu	1.3		Li	0.96
As	2.0	Ta	1.7	4.483	Sc	1.3		Ba	0.93
Cu	2.0	V	1.7	5.30	Cf	1.3		Ra	0.92
Au	1.9	Cd	1.6	0.56	Cm	1.3		Na	0.90
Ag	1.9	Pb	1.6	7.193	Bk	1.3		K	0.82
Te	1.9	Nb	1.6	9.26	Ce	1.2		Rb	0.79
Ge	1.9	In	1.5	3.4035	Nd	1.2		Cs	0.78
Se	1.9	Tl	1.5	2.39	Y	1.2		Fr	0.76

But almost all these criteria of superconductivity can only be used for element superconductivity. For compound superconductors, especially for high T_c superconductors, there are few useful criteria of superconductivity. The reason for this is that the structure of these kinds of materials is complex, and it is not easy to understand their superconductivity clearly. So it is important to carry out high T_c superconductivity research, especially when the mechanism of the high T_c superconductivity is not very well known.

Villars *et al.*[19–24] tried to use the golden coordinates (Villars coordinates) to analyse high T_c (T_c >10K) superconductivity and found that the superconductors mainly concentrate in three certain regions which are concerned with the average of radius difference $\overline{\Delta R}$, average of electronegativity difference $\overline{\Delta\chi}$ and average of valence electrons $\overline{VE}$.

In Ref.[2], the authors also discussed Villars coordinates and drew diagrams of $\overline{\Delta\chi}$ versus $\overline{\Delta R}$, and T_c versus $\overline{VE}$. Over 60 kinds of high T_c superconductors were used, and the result is that these high T_c superconductors mainly concentrate in the regions of $-2.4 < \overline{\Delta\chi} < -1.7$, $0.8 < \overline{\Delta R} < 2.8$, $5.3 < \overline{VE} < 6.7$. Then the concept of average electronegativity $\overline{\chi}$ and average valence $\overline{CV}$ were used to analyse high T_c superconductivity. It was found that these high T_c superconductors mainly concentrate in $-2.4 < \overline{\Delta\chi} < -1.7$, $2.2 < \overline{\chi} < 2.65$, $2.0 < \overline{CV} < 2.45$. Their distribution in the diagram is more concentrated than that in the Villars coordinates system.

All the studies described above show that surely a certain relationship exists between superconductivity and electronegativity. From formula (3), we know that the physical meaning of the electronegativity is the effective potential of the crystal lattice acting on the bonding electrons. So, in alloy or compound materials, the effect of electronegativity can be averaged. In this paper, we concentrate on the study of the relationship between superconductivity and electronegativity in alloys and compounds. But when we adopt the concept of the average effect of electronegativity, we should notice the important difference between alloys and compounds. For alloys, the effect can be simply averaged, but for compounds, it is not so simple. We must analyse these in a different way.

II. THE RELATIONSHIP BETWEEN SUPERCONDUCTIVITY AND THE AVERAGE EFFECT OF ELECTRONEGATIVITY OF ALLOY SUPERCONDUCTORS

By now, many alloy superconductors have been found. Although their T_c is not very high, it is much higher than that of element superconductors. Table 2 lists the T_c and the average values of the electronegativity of some main alloy superconductors. This table also contains those kinds of compounds which are compounded by metals and semiconductors. This does not contradict with the definition of metal or non-metal according to the values of electronegativity. $A_mB_nC_p$ is used to express the general formula of this kind of superconductor, and $\overline{\chi}$ represents the average value of the electronegativity of $A_mB_nC_p$. We have

$$\overline{\chi} = \frac{m\chi_A + n\chi_B + p\chi_C}{m+n+p}. \tag{7}$$

Table 2. The T_c and the average values of the electronegativity $\overline{\chi}$ of some alloy materials.

Material	$\overline{\chi}$	T_c/K
La_3In	1.350	10.4
$Nb_{0.7}Zr_{0.3}$	1.570	10.8
Nb_3Al	1.575	18.67
Nb_3Ga	1.575	20.3
$Nb_3Al_{0.8}Ge_{0.2}$	1.595	20.05
$Nb_3Al_{0.75}Ge_{0.25}$	1.600	20–21
$Nb_{0.79}(Al_{0.75}Ge_{0.25})_{0.21}$	1.600	21
$Nb_3Al_{0.8}Ge_{0.4}$	1.610	20.7
Nb_3Sn	1.625	18.1
NbZrTi	1.600	9.8
Nb_xTi_{1-x}	1.6–1.7	0.6–9.8
Nb_3Ge	1.675	23.2
Nb_3Au	1.675	11.5
$Nb_3Au_{0.95}Rh_{0.05}$	1.600	11.0
$NbTc_3$	1.825	10.5
$(Ce,Gd)Ru_2$	1.600	—
$V_2Hf_{0.5}Zr_{0.5}$	1.617	10.1
V_3Ga	1.650	16.8
V_3Si	1.752	17.1
Pb_xBi_{1-x}	1.6–1.8	7.35–8.4
$Ce_{1-x}Ga_xRu_2$	1.6–1.7	3.2–5.2
$Y_{1-x}Gd_xOs_2$	1.667	1.4–4.7
TiNbTa	1.667	—
$Mo_{0.61}Ru_{0.39}$	1.739	7.2
$Mo_{0.57}Re_{0.43}$	1.743	14
Mo_3Ir	1.750	—
$Mo_{0.3}Tc_{0.7}$	1.840	12
Au_2Bi	1.867	—
$Ge_{0.976}Te$	1.900	0.07

From Table 2, we find that the average value of the electronegativity $\overline{\chi}$ is in the range of 1.3–1.9. Most of these values are distributed in the region $1.5 < \overline{\chi} < 1.8$, and the value of $\overline{\chi}$ of many higher T_c superconductors is nearly 1.60. All these values are quite similar to element superconductors.

Ⅲ. THE RELATIONSHIP BETWEEN SUPERCONDUCTIVITY AND THE AVERAGE EFFECT OF THE ELECTRONEGATIVITY OF OXIDE SUPERCONDUCTORS

Previously, some types of oxide superconductor, such as NbO, $SrTiO_{3-y}$ and $BaPbO_3$, have been found, but due to a low T_c these did not attract much attention. Until the La–Ba–Cu–O oxide superconductors were found in 1986, the study of superconductivity did not develop very quickly. Since then, a new high T_c superconducting field has been found, which has attracted the attention of many scientists. Up to now, four kinds of high T_c oxide superconductor have been found. Here we take some of these as representatives.

1) $La_{2-x}Ba_xCuO_{4-y}$ (Ba can be substituted by Sr),

2) $YBa_2Cu_3O_{7-y}$ (Y can be replaced by Eu, Lu, ...),

3) $Bi_2Sr_2Ca_{x-1}Cu_xO_{2x+4}$ [Bi-22(x–1)x phase],
$Tl_2Ba_2Ca_{x-1}Cu_xO_{2x+4}$ [Tl-22(x–1)x phase],
$TlBa_2Ca_{x-1}Cu_xO_{2x+3}$ [Tl-12(x–1)x phase],
$HgBa_2Ca_{x-1}Cu_xO_{2x+3-y}$ [Tl-12(x–1)x phase],

4) $Nd_{2-x}Ce_xCuO_{4-y}$.

For convenience, we use $A_mB_nC_pD_qO_z$ as the general formula of these kinds of superconductor. Firstly we can obtain the average effect of electronegativity among the positive valence elements (the average value of electronegativity of $A_mB_nC_pD_q$); $\overline{\eta}$ is used. Then we have

$$\overline{\eta} = \frac{m\chi_A + n\chi_B + p\chi_C + q\chi_D}{m+n+p+q}, \tag{8}$$

and we can gain the average effect of the negative valence element (O) on every element (A, B, C, D and O), as O has an action on every element. This is the key point. Thus the average value of the electronegativity of O on every element $\overline{\zeta}$ is

$$\overline{\zeta} = \frac{z\chi_O}{m+n+p+q+z}. \tag{9}$$

Table 3 presents the $\overline{\eta}$, $\overline{\zeta}$ and T_c of some typical high T_c oxide superconductors.

From Table 3, we can find that the $\overline{\eta}$ of high T_c oxide superconductors lies between 1.30 and 1.60, and $\overline{\zeta}$ is from 1.75 to 2.00. If both $\overline{\eta}$ and $\overline{\zeta}$ are on the limit side (1.30 or 1.60 and 1.75 or 2.00), the T_c is very low, and the materials are even non-superconductive. Furthermore, if we take the average of $\overline{\eta}$ and $\overline{\zeta}$ (we use $\overline{\chi}$ to denote this and the value is also shown in Table 3), then

$$\overline{\chi} = \frac{\overline{\eta} + \overline{\zeta}}{2}. \tag{10}$$

We find that amazingly $\overline{\chi}$ is between 1.5 and 1.8. Also, in different superconducting systems, there are different $\overline{\chi}$ which match the maximal T_c. For example, in the Bi system, $\overline{\chi}$=1.674 and $T_{c\ max}$=110K, in the Tl system, $\overline{\chi}$=1.635 and $T_{c\ max}$=125K, in the Hg system, $\overline{\chi}$=1.604 and $T_{c\ max}$=133K. Most values of $\overline{\chi}$ are from nearly 1.60 to 1.70 to match higher T_c. The highest T_c of all these superconductors corresponds to $\overline{\chi}$ being near 1.60. When $\overline{\chi}$ is over 1.70, T_c is not so high, and when $\overline{\chi}$ is close to 1.80, non-superconductivity appears.

Table 3. The $\overline{\eta}$, $\overline{\zeta}$, T_c and $\overline{\chi}$ of the main high T_c oxide superconductive systems.

Material	$\overline{\eta}$	$\overline{\zeta}$	T_c/K	$\overline{\chi}$
La_2CuO_{4-y}	1.533	$2.00-o(y)$	non-sup	1.766
$LaBaCuO_{4-y}$	1.410	$2.00-o(y)$	30–40	1.705
$LaSrCuO_{4-y}$	1.427	$2.00-o(y)$	30–40	1.714
$La_{1.5}Sr_{0.5}CuO_{7-y}$	1.480	$2.00-o(y)$	40	1.740
$YBa_2Cu_3O_5$	1.510	1.750	non-sup	1.630
$YBa_2Cu_3O_7$	1.510	1.885	90	1.698
$GdBa_2Cu_3O_7$	1.510	1.885	90	1.698
$HoBa_2Cu_3O_{7-y}$	1.510	1.885	90	1.698
$Bi_2Sr_2CuO_{6+y}$	1.512	1.909	10–20	1.710
$Bi_2Sr_2CaCu_2O_{8+y}$	1.508	1.860	85	1.684
$Bi_2Sr_2Ca_2Cu_3O_{10+y}$	1.507	1.840	110	1.674
$Bi_{2.2}Sr_2Ca_{0.8}Cu_2O_{8+y}$	1.531	1.867	81	1.699
$Bi_{2.1}Sr_{1.9}CuO_{6+y}$	1.528	1.909	10	1.718
$Bi_{1.9}Pb_{0.2}Sr_{1.9}CuO_{6+y}$	1.520	1.909	5	1.714
$Bi_2Sr_{1.6}La_{0.4}CuO_{6+y}$	1.538	1.909	25	1.724
$TlBa_2CuO_5$	1.340	1.944	20–50	1.642
$TlBa_2CaCu_2O_7$	1.393	1.885	80–90	1.639
$TlBa_2Ca_2Cu_3O_9$	1.420	1.853	110	1.636
$TlBa_2Ca_3Cu_4O_{11-y}$	1.436	1.833	125	1.635
$TlBa_2Ca_4Cu_5O_{13-y}$	1.447	1.820	117	1.633
$Tl_2Ba_2CuO_{6+y}$	1.372	1.909	20–95	1.640
$Tl_2Ba_2CaCu_2O_8$	1.408	1.867	105	1.638
$Tl_2Ba_2Ca_2Cu_3O_{10}$	1.429	1.842	125	1.635
$Tl_2Ba_2Ca_3Cu_4O_{12}$	1.442	1.826	113	1.634
$HgBa_2CuO_{4+y}$	1.415	$1.750+o(y)$	94	1.582
$HgBa_2CaCu_2O_{6+y}$	1.443	$1.750+o(y)$	110	1.596
$HgBa_2Ca_2Cu_3O_{8+y}$	1.458	$1.750+o(y)$	133	1.604
$R_{2-x}Ce_xCuO_{4-y}$	1.467	$2.000-o(y)$	≈20	1.734
$R_{2-x}Th_xCuO_{4-y}$	1.477	$2.000-o(y)$	≈20	1.738
(R=Pr, Nd, Sm; x ≈0.15)				
$NdThCuO_{4-y}$	1.533	$2.00-o(y)$	non-sup	1.766
Th_2CuO_{4-y}	1.600	$2.00-o(y)$	non-sup	1.800

The average effect of the electronegativity of other main oxide superconductors has also been studied, and the results are shown in Table 4.

Table 4. The $\overline{\eta}$, $\overline{\zeta}$ and T_c of some low T_c oxide superconductors.

Material	$\overline{\eta}$	$\overline{\zeta}$	T_c/K
NbO	1.600	1.750	12
$SrTiO_{3-y}$	1.340	$2.1-o(y)$	1.2
$BaPbO_{3-y}$	1.265	$2.1-o(y)$	0.4
$Ba_{1-x}K_xBi_xO_3$			30
$BaPb_{0.5}Bi_{0.5}O_{3-y}$	1.315	$2.1-o(y)$	13
$Li_{1+x}Ti_{2-x}O_{4-y}$		$2.1-o(y)$	12

From Table 4, we find that both $\overline{\eta}$ and $\overline{\zeta}$ of these kinds of superconductor are near the limit value (1.30 or 1.60 and 1.75 or 2.00). All the T_c values are low.

IV. THE RELATIONSHIP BETWEEN SUPERCONDUCTIVITY AND THE AVERAGE EFFECT OF ELECTRONEGATIVITY OF OTHER COMPOUND SUPERCONDUCTORS

In the course of superconductivity study, many other compound superconductors have been found, such as NbN, CuS and Na_xWC_3, but these all have very low T_c. Table 5 shows the $\overline{\eta}$, $\overline{\zeta}$, T_c and $\overline{\chi}$ of some main superconductors.

Table 5. The $\overline{\eta}$, $\overline{\zeta}$, T_c and $\overline{\chi}$ of some non-oxide compound superconductors.

Material	$\overline{\eta}$	$\overline{\zeta}$	T_c/K	$\overline{\chi}$
NbN	1.60	1.50	16.1	1.55
$NbN_{0.72}C_{0.28}$	1.60	1.43	17.9	1.52
CuS	2.00	1.30		1.65
MoC	1.70	1.25	14	1.48
NbC	1.60	1.25	9	1.42
$YThC_3$	1.30	1.50	17	1.40
CoS_2	1.70	1.733		1.72
Y_2C_3	1.20	1.50	14	1.35
Na_xWC_3	1.35–1.8	1.5–1.88	6	
$PbMo_6S_8$	1.686	1.387	14.7	1.54
$PbMo_{5.1}S_6$	1.68	1.29	14.4	1.48
$Mo_{0.56}C_{0.44}$	1.70	1.10	13.0	1.40
$Mo_{0.95}Hf_{0.05}C_{0.75}$	1.68	1.071	14.2	1.376
$Li_{0.3}Ti_{1.1}S_2$	1.54	1.53	13	1.54
$ErRh_4B_4$	1.76	0.889	8.5	1.325
$(Pd_{0.55}Cu_{0.45})_{0.3}H_{0.7}$	2.00	1.54	16.6	1.77
K_3C_{60}	0.82	2.38	18	1.60
Rb_3C_{60}	0.79	2.38	30	1.586
$(CN)_x$	2.50	1.50	0.4	2.00

From Table 5, we find that $\overline{\eta}$ of these kinds of superconductor is either too high or too low, and all the values of $\overline{\zeta}$ are quite low, except for that of the the C_{60} system. But all the values of $\overline{\chi}$ lie between 1.30 and 1.80 except that of $(CN)_x$. Although they are superconductors, they have quite low T_c. The $\overline{\chi}$ of $(CN)_x$ is very high, 2.00, and in fact $(CN)_x$ belongs to the polymer group and its T_c is very low, only 0.4K.

We should notice that, in Table 5, there are some superconductors with a very low $\overline{\zeta}$, such as

$Mo_{0.56}C_{0.44}$. In fact, the their compositions do not entirely correspond to alloys or compounds, they are mixed. For example, $Mo_{0.56}C_{0.44} \rightarrow Mo_{0.44}C_{0.44}+Mo_{0.12}$, then η=1.7, $\overline{\zeta}$=1.25, $\overline{\chi}_{Mo_{0.44}C_{0.44}}$ =1.475, and we have

$$\overline{\chi}_{Mo_{0.56}C_{0.44}} = \frac{0.44 \times 1.475 + 0.12 \times 1.7}{0.44 + 0.12} = 1.523.$$

The problem is how to decide on the formula of the compound part, namely, the valence of the element. Taking $PbMo_{5.1}S_6$ for instance, this is different when the valence of Pb is +2 or +4. In this case, it depends on the structure of the formula.

V. THE AVERAGE EFFECT OF ELECTRONEGATIVITY OF COMPOUND NON-SUPERCONDUCTORS

There are so many non-superconductors that it is difficult for us to list all of them. But we can take some oxides of the single element A_mO_z and normal acid, alkali and salt $A_mB_nO_z$ (if B shows valence +1, this formula will include alkali) as examples. The values of $\overline{\zeta}$ of these material are shown in Table 6.

According to the average effect of the electronegativity of oxides A_mO_z, only when the value of the electronegativity of the metal element is between 1.3 and 1.6, the element shows a valence of +2 (AO), $\overline{\eta}$ is from 1.3 to 1.6 and $\overline{\zeta}$ is 1.75, such as NbO, may there be some superconductors.

From Table 6, we also find that usually $\overline{\zeta} \geq 2.00$ or $\overline{\zeta} \leq 1.75$, so the normal acids, alkalis and salts are usually non-superconductive. Although there are some superconductors such as $BaPbO_{3-y}$ and $SrTiO_{3-y}$, all of these are the O-deficient-type oxides, and they have very low values of T_c.

Table 6. The $\overline{\zeta}$ of compound non-superconductors.

Material	$\overline{\zeta}$	Material	$\overline{\zeta}$
$A^{+1}{}_2O$	1.33	$A^{\geq+2}B^{+4}O_3$	$\geq$2.1
AO	1.75	$A^{+1}B^{+3}O_2$	1.75
$A^{\geq+3}{}_2O_3$	$\geq$2.3	$A^{\geq+2}(B^{+3}O_2)_2$	$\geq$2.00
$A^{\geq+1}B^{+7}O_4$	$\geq$2.5	$A^{+1}{}_2B^{+2}O_2$	1.4
$A^{+1}{}_2B^{+6}O_4$	2.0	$A^{+2}B^{+2}O_2$	1.75
$A^{\geq+2}{}_2B^{+6}O_4$	$\geq$2.33	$A^{+3}{}_2(B^{+2}O_2)_3$	1.91
$A^{+1}{}_2B^{+5}O_3$	2.1	$A^{\geq+4}(B^{+2}O_2)_2$	$\geq$2.00
$A^{\geq+2}(B^{+5}O_3)_2$	$\geq$2.3	$A^{+1}B^{+1}O$	1.33
$A^{+1}{}_2B^{+4}O_3$	1.75	$A^{\leq+7}{}_7(B^{+1}O)_7$	$\leq$1.63

VI. DISCUSSION

From all the results of this research, we find that a relationship does exist between electronegativity and superconductivity. Although there are empirical laws, these are meaningful for new superconductor discovery and research. These empirical laws reflect the essence of superconductivity, and it is worth-while to make it more clear. In fact, the electronegativity of a material reflects the action between electrons and the crystal lattice, which shows the effective potential the crystal lattice gives to the bonding electrons. The chemical bond of a superconductor should be a kind of transition bond which is in the mediacy of metallic and covalent bonds, or metallic and ionic bonds.[1] This has been embodied completely from the average effect of the electronegativity of alloy and compound superconductors. On the other hand, although the composition is very important for the characteristics of superconductors, it is not the only factor to consider; it is necessary but not sufficient. In fact, the structure of the superconductor is also very important.[13,14] We can use the technique of heat treatment to change the structure of materials and obtain the best state of superconductivity.

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