

A Simple Mechanism For Superconductivity

Abstract: Based on the statistical thermodynamics and quantum mechanics, a simple mechanism for superconductivity has been proposed. With the method described in this paper, the transition temperatures can be easily determined, as a result, the efficiency in searching new superconductivity material is greatly improved.

Key words: superconductivity; transition temperature; cooper pair.

I.Introduction.

The topics regarding the mechanism of the material conductivity becomes hot due to the discovery of the high temperature superconductivity¹. Till now, several Nobel Prizes are awarded to the researchers in this field². The most famous theory about the superconductivity is the BCS theory³, named by the abbreviation of the names of founders, who are awarded Nobel Prize for their theoretical contribution to science. However, with new superconductivity materials being discovered, the more and more experimental results can't be explained by the BCS theory, therefore, the different mechanisms about the superconductivity are proposed and the new theories are developed. The most recent ones are the resonating-valence-band theory⁴ and the spin fluctuation theory⁵. Our question is which one is correct? Maybe most of these superconductivity theories just catch a part of the facts about the superconductivity? For example, the BCS theory demonstrates the cooper pairs are formed in the superconductivity materials but no direct evidence shows that the cooper pairs take response for the superconductivity, not mention to assign the formation of the cooper pairs as unique mechanism for the super-conductivity of materials. The question is whether there exists a general mechanism for the superconductivity? In this paper, based on the statistical dynamics and quantum theory, we would like to try toward a general mechanism for the superconductivity.

II.Theory

Fig.1 Illustrates the basic situation in the materials. The electron density in the potential well is $n(e)$. If the electron moves out of the potential well, then the electron makes contribution to the conductivity of materials, otherwise, the contribution of electron to the conductivity of materials is zero. In order for electron to move out of the potential well, the electron must overcome the energy barrier. If the electron is bounced back or scattered back by the energy barrier, the electron makes no contribution to the conductivity of materials. It is obvious that if this energy barrier in some way is reduced, the conductivity of materials will increase; if this energy barrier

totally disappeared, then the electron can move freely in the materials and the materials become superconductivity, therefore, the energy barrier is the key factor which determines the material behavior as insulator, semiconductor, conductor or superconductor.

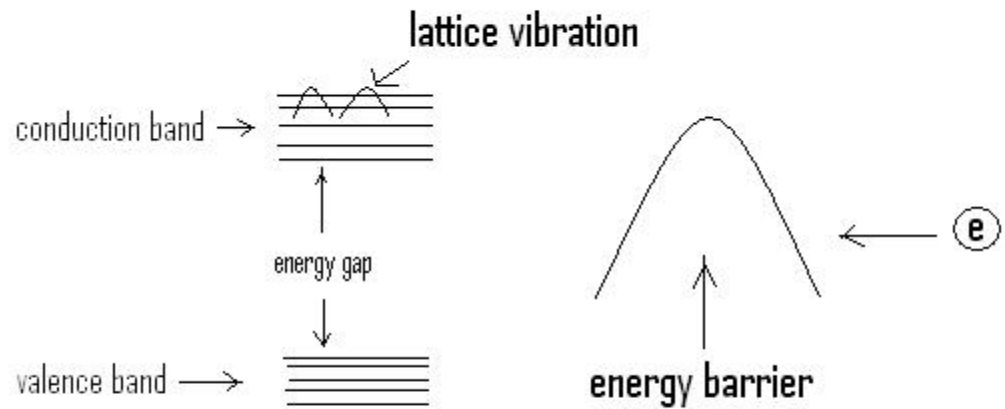


Fig.1 Illustration of electron moving in the metal.

From the statistical thermal dynamics and quantum mechanics⁶, there are four main factors responsible for the formation of the energy barrier. One is the lattice vibration, called phonon. The stronger the lattice vibration, the higher the energy barrier and therefore, the more chance for the electron being scattered back by the energy barrier; Second is the coulomb attraction from the nuclei, the stronger the attraction, the higher the energy barrier becomes and the more difficult for the electron to move in the materials; Third is the energy level of electron in the materials. The higher the energy level of electron, the lower the energy barrier becomes and easier for the electron to move in the materials; Fourth is the magnetic interaction which makes the movement of electron in the materials more difficult, therefore, increases the energy barrier. In fact, the last three factors are included in the binding energy term (E_e).

Based on these understandings, the probability for the electron to pass the energy barrier or tunnelling through the energy barrier can be written as:

$$P = A \exp \frac{-(E_{vib} - E_e)}{RT} n_e \quad (1)$$

$$\text{Where } E_{vib} = 9N \left(\frac{k_b T}{h \nu_D} \right)^3 k_b T \int_0^{x_m} \frac{x^3}{e^x - 1} dx / 3N$$

$$x = \frac{h \nu}{k_b T} \text{ and } x_m = \frac{h \nu_D}{k_b T}$$

$$E_e = \gamma T^2 \quad \gamma = \frac{R k_b \pi^2}{4 E_f} n_e = \text{density of electron}$$

There are four cases.

Case 1. $E_{vib} \gg E_e$, then the materials will show as insulator. The electron tunnelling probability is too small to be accounted. Most of insulators belong to this category.

Case 2. $E_{vib} > E_e$, then the materials will show certain conductivity but not good conductor. The temperature has great influence on the conductivity of these materials. Increasing the temperature, the conductivity of materials increases.

Case 3. $E_{vib} - E_e = \varepsilon$, where ε is the smallness, then the materials will show good conductivity. Most of metal belong to this category. Since E_{vib} and E_e are temperature dependent, therefore, the conductivity of materials also depends on the temperature. How the conductivity of materials changes with temperature depends on the temperature coefficient of E_{vib} and E_e . For metal, increasing the temperature, contrarily to the situation in case 2, the conductivity of materials decreases.

Case 4. $E_{vib} \ll E_e$, then the materials will show the superconductivity. That means the electron in the materials can move freely like free electron. Here we don't need the concept of the cooper pair formation.

To our knowledge, no materials show the superconductivity at room temperature. From the discussion above, E_{vib} and E_e are all temperature dependent, which offers the possibility for the materials to meet the requirement of superconductivity by changing the temperature. In fact, till now, the discovered superconductors are always realized experimentally by reducing the temperature of materials to extremely low temperature, then the condition in case 4 above is met. That is to say, with decreasing the temperature, the E_{vib} decreases faster than E_e . This result opens a new way for us to synthesize the new superconductivity materials and determine what kinds of materials are the potential candidate for the superconductivity materials. Furthermore, from $C_{vib} \sim T$ and $C_e \sim T$, we also can determine the critical temperature of materials for superconductivity (Fig.2).

Normally, E_{vib} always increases with temperature, but this temperature dependence of E_{vib} is not linear, therefore, it is possible in certain range of temperature, the E_e will increase faster than E_{vib} , then principally, we can also observe the superconductivity of materials by increasing the temperature of materials. An extremely case is to increase the temperature of materials so high that the materials become plasma. Nobody doubt the superconductivity of plasma but also nobody believe the superconductivity of plasma coming from the formation of the cooper pair in plasma. Obviously, the superconductivity of materials doesn't need the cooper pair concept here.

From Fig.1, we see that compared to E_{vib} , the position of valence band is too low to make the condition in case 4 to be met. Whereas the conduction band is at right position which can meet the condition in case 4 by changing the temperature of materials.

From the discussion above, $E_{vib}=E_e$ is the requirement for the transition of the normal material to superconductor. Based on the expressions of E_{vib} and E_e , principally, we can determine at least two transition temperature for most of materials. One is at extremely low temperature as most of researchers focused on at present; another is at very high temperature at which most of materials will become plasma (Fig.2).

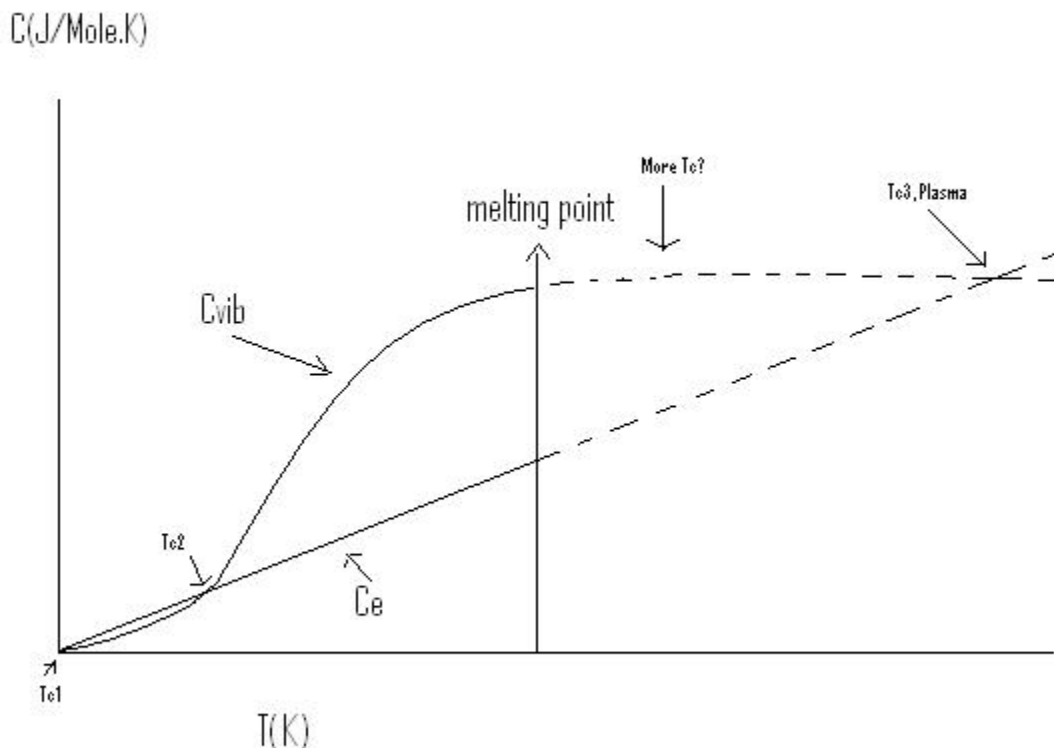


Fig.2 Illustration for determining the transition temperature.

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104 **Table 1. transition temperature**

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107	Element	T _{c1} (k)	T _{c2} (k)	T _{c3} (k)	T _c (k) in reference ⁷⁻⁹
108	Li	0	5.7	15552	
109	Na	0	1.6	18190	
110	K	0	0.9	12058	
111	Rb	0	0.5	10390	
112	Cs	0	0.2	7822	
113	Cu	0	3.3	36122	
114	Ag	0	3.8	38772	
115	Au	0	2.6	34335	
116	Al	0	7.1	18785	1.175
117	Be	0	18.0	119841	0.026
118	Mg	0	6.6	19483	
119	Ca	0	4.2	8769	
120	Sr	0	2.4	7036	
121	Ba	0	1.4	9320	
122	Nb	0	9.2	3396	9.25
123	Fe	0	16.3	5339	
124	Mn	0	18.0	2989	
125	Zn	0	3.3	39215	0.85
126	Cd	0	1.8	36303	0.517
127	Hg(β)	0	0.7	18275	3.949
128	Ga	0	3.3	20810	1.083

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129	In	0	1.0	14998	3.408
130	Tl	0	0.6	17025	2.38
131	Sn	0	2.6	14157	3.722
132	Pb	0	1.1	8117	7.196
133	Bi	0	0.1	3117839	
134	Sb	0	0.7	226910	
135	Sc	0	15.0	2566	
136	Ti	0	10.1	8221	0.4
137	V	0	17.0	2965	5.4
138	Cr	0	13.4	18276	
139	Ni	0	18.1	3863	
140	Co	0	15.4	5598	
141	As	0	1.0	249631	
142	Y	0	8.9	2618	
143	Zr	0	5.9	9120	0.61
144	Mo	0	8.8	12780	0.915
145	Ru	0	15.7	9306	0.49
146	Rh	0	18.4	5448	
147	Pd	0	9.8	2837	
148	La(α)	0	4.2	2602	4.88
149	(β)	0	3.8	2595	6.0
150	Hf	0	4.2	11733	0.128
151	Ta	0	6.5	4400	4.47
152	W	0	6.5	19481	0.0154
153	Re	0	9.2	11147	1.697
154	Os	0	11.2	10731	0.66
155	Ir	0	10.9	4049	0.1125
156	Pt	0	6.9	3839	

Table 1 listed the T_c determined with method described above and Fig.2 illustrates how to determine the T_c from $C_{vib} \sim T$ and $C_e \sim T$. In fact, we can get at least three T_c s. Two of them is at low temperature; one at high temperature. For $T_c=0K$, there is no practical meanings because the absolute zero temperature can't be realized. But theoretically we can say there exists another superconductivity phase at $T=0K$, which is different from the $T_c \approx 0.1 \sim 140K$ superconductivity phase. For the high temperature T_c , it is far beyond the melting temperature of element listed in the table 1. This gives us a hint, that is, at high temperature, there may exist one or more superconductivity phases. To my knowledge, one superconductivity phase definitely exists, that is the plasma. Whether there exists other superconductivity phase or not, we still need doing experiment to verify but the equation we developed above should be modified before applying to the high temperature phase because the material is not solid under such high temperature. However, following our work here, it should be easier to setup new equations for $C_{vib} \sim T$ and $C_e \sim T$, then the concept developed here is still valid.

From the table 1, we noticed that the transition temperatures are far from the room temperature, therefore, the wide applications of the superconductors are prohibited. The task of the researchers is to find the materials of which the transition temperatures are not too far from the room temperature. Our work here offers an easy way to find the material meeting the requirement of transition temperature for superconductivity, that is, by drawing $C_{vib} \sim T$ and $C_e \sim T$ to determine the possible transition temperature of materials for superconductivity. This kind of research can be done by the cooperation between synthetic scientist and the theoretical scientist. For example, the theoretical scientist can design the materials which have certain crystal structure and determine what kind of material is possible to have the adequate transition temperature for superconductor, the synthetic scientist can synthesize the material in Lab. and measure the $C_{vib} \sim T$ and $C_e \sim T$. In this way, we can greatly save the time and reduce the cost in searching new superconductivity materials.

Changing the temperature of materials is a conventional but not the best way to change the properties of materials, such as electric and heat conductivity. For example, when we reduce the temperature of materials, E_{vib} decreases but at the same time, E_e also decreases. The decrease of E_{vib} , as discussed above, is good for the movement of the electron in the materials but the decrease of E_e is not good for the electron movement in the materials. If we increase the temperature of materials, E_e will increase, which is good for the electron movement in the materials but E_{vib} will also increase in this case, which is not good for the electron movement in the materials. These two factors have counter influence on the conductivity of materials. This is one of the reasons why the superconductivity of materials only can be observed at extremely low or high temperature.

From the expressions of E_{vib} and E_e and Fig.1, we also think the possibility to find a way just to promote the electron to high energy level but has no or minor influence on the E_{vib} , or reduce the E_{vib}

effectively but has no or minor influence on E_e , then the energy barrier for the electron moving in the materials will be greatly reduced. In fact, we find the microwave is a potential method for this purpose, that is, the microwave can promote the electron to high energy level quicker but has less influence on E_{vib} for metal. The experimental result will be presented soon later. Another possible way is to change the pressure applied onto the materials, which we will explore in the future.

Here we would like to make some comment on the current superconductivity theory. The famous one is the BCS theory which supposes the superconductivity of material coming from the formation of the cooper pair of electron in the materials. In fact, no evidence shows that the paired electron can move faster or smother than a single electron or unpaired electron. In metal, all electrons in valence band are paired but they make almost no contribution to the conductivity of material, not mention to the superconductivity of materials (based on the quantum mechanics, the inner electrons still can make minor contribution to the conductivity of materials through tunnelling mechanism, but this contribution is too small to be accounted.). Our work here also reveals that the superconductivity of materials mainly contributed by outer electron or conduction band electron because the requirement of $E_{vib} \leq E_e$ is easier to meet, whereas for inner electron or valence band electron, the requirement of $E_{vib} \leq E_e$ is difficult to meet.

III.Summary

We setup a simple physical picture to show how the transition from the normal materials to superconductor happens and offer an easy way to determine the transition temperatures of materials for the superconductivity. Our work also point out there are three ways to reduce the energy barrier to meet the requirement of $E_{vib} \leq E_e$. One is to reduce the temperature of material, which is to reduce E_{vib} , just as most of researchers are doing currently; second is to increase the temperature of materials. If E_e increase faster than E_{vib} , then the energy barrier also can be effectively reduced, therefore, $E_{vib} \leq E_e$ can be met; third is to find a way to promote the electron in materials to high energy level but has no or minor influence on E_{vib} , then $E_{vib} \leq E_e$ also can be realized. For some materials, the microwave can be applied for this purpose. Finally, our work also gives a clue for both synthetic scientist and theoretical scientist. For synthetic scientist, they can synthesize the materials which has certain crystal structure to meet the requirement of $E_{vib} \leq E_e$, whereas for theoretical scientist, they can design or predict the materials which has certain crystal structure to meet the requirement of $E_{vib} \leq E_e$. Our work makes the research much easier than before for scientist in searching the new superconductivity materials and avoiding randomly trying and error, therefore, improving efficiency and reducing the cost in searching the new superconductivity materials.

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