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RESEARCH ARTICLE

THE FORMULATION BETWEEN CRITICAL MAGNETIC FIELD AND CRITICAL TEMPERATURE OF SUPERCONDUCTORS BY THERMAL PHYSICS

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ABSTRACT

Several studies have been investigated in the superconducting materials such as critical magnetic field, magnetic field, critical temperature etc. Here, we will discuss the empirical relation between critical magnetic field and temperature for superconductors. Till today, this empirical relation was obtained on the basis of experimental data of superconducting materials. Therefore, we are deriving this empirical relation theoretically by the use of the concept of BCS theory, thermodynamics and magnetic properties for superconductors.

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INTRODUCTION

The field of superconductivity has emerged as one of the most exciting fields of solid state physics and solid state chemistry during the last decades. Today, many groups have contributed to research on superconductivity. The superconductivity phenomenon was discovered in 1911 by H.K.Onnes in Holland (Onnes, Akad, 1911). The BCS theory was developed in this respect in 1957, which gives the basic concept of cooper pairs and interaction with lattice (Bardeen *et al*., 1957; Kittle, 1996). The Bardeen, Cooper and Schrieffer received the Nobel Prize in 1972 for the BCS theory of superconductivity (Schrieffer and Bardeen, 1973). Basic theory of superconductivity relates to transitions with respect to critical temperature (T_c), critical magnetic field (H_c) and critical current density (J_c) (Anderson *et al*., 2004; Lee *et al*., 2006; Ogata and Fukuyama, 2008). At a critical temperature of the sample undergoes a phase transition from a state of normal electrical resistivity to superconducting state. Currently the mechanism of high temperature superconductivity is also investigated which is ceramics compounds (Gul *et al*., 2005; Singh and Rohitash Kumar, 2014; Singh and Rohitash Kumar, 2016). In this study, we introduce the relation between critical temperature (T_c) and critical magnetic field (H_c), the minimum magnetic field necessary to destroy superconductivity is called the critical magnetic field, which is given in empirical study already.

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Theory

If a superconductor is placed in magnetic field $\vec{H}$ and magnetization $\vec{M}$. Then work done on a superconductor per unit volume is given as

$$dw = -\vec{M}.d\vec{H} \tag{1}$$

Eq (1) shows the energy of the magnetic field.

The thermodynamic identity for the magnetization process is given as

$$dE = TdS - \vec{M}.d\vec{H}$$

Therefore

$$dE = TdS - MdH \tag{2}$$

Since, the energy is the function of entropy (S) and magnetic field. Ie

$$E=E(S,H) \tag{3}$$

Therefore, change in energy is given below

$$dE=\left(\frac{\partial E}{\partial S}\right)_H dS+\left(\frac{\partial E}{\partial H}\right)_S dH \tag{4}$$

Comparing eq. (2) and eq. (4), we have

$$T=\left(\frac{\partial E}{\partial S}\right)_H ; M=-\left(\frac{\partial E}{\partial H}\right)_S \tag{5}$$

But, energy (E) is the state function. So, we have

$$\left(\frac{\partial}{\partial H}\left(\frac{\partial E}{\partial S}\right)_H\right)_S=\left(\frac{\partial}{\partial S}\left(\frac{\partial E}{\partial H}\right)_S\right)_H \tag{6}$$

From eq. (5) and eq.(6), we have

$$\left(\frac{\partial T}{\partial H}\right)_S=-\left(\frac{\partial M}{\partial S}\right)_H \tag{7}$$

$$\left(\frac{\partial T}{\partial H}\right)_S=-\frac{\partial(M,H)}{\partial(S,H)}=-\frac{\partial(M,H)}{\partial(T,H)}\frac{\partial(T,T)}{\partial(S,T)}$$

$$\left(\frac{\partial T}{\partial H}\right)_S=-\frac{T}{T}\left(\frac{\partial M}{\partial T}\right)_H\left(\frac{\partial T}{\partial S}\right)_H$$

$$\left(\frac{\partial T}{\partial H}\right)_S=-\frac{T}{C_H}\left(\frac{\partial M}{\partial T}\right)_H \tag{8}$$

Where, C_H is heat Capacity of superconducting material. Now, from eq. (8) we have

$$dT=-\frac{T}{C_H}\left(\frac{dM}{dT}\right)dH \tag{9}$$

Relation between magnetization **M** and magnetic field **H** with temperature T is given as

$$M=\frac{C}{T}H \tag{10}$$

Where, C is Curie temperature of material.

From eq. (9) and eq. (10), we have

$$dT=-\frac{C}{C_H}\frac{H}{T}dH$$

Now, Rearrange

$$TdT=-\frac{C}{C_H}HdH \tag{11}$$

Eq. (11) integrated from 0 to T_c and $H_c(0)$ to 0 for superconductor, then we have

$$\frac{1}{2}T_C^2=\frac{1}{2}\frac{C}{C_H}H_C^2(0)$$

Where $H_c(0)$ is the critical magnetic field at absolute zero, Now, rearrange

$$\frac{C}{C_H}=\frac{T_C^2}{H_C^2(0)} \tag{12}$$

Again from eq. (11), we have

$$\int_0^T TdT+\int_{T_C}^T TdT=-\frac{C}{C_H}\int_0^{H_C(T)} HdH$$

$$\frac{H_C^2(T)}{H_C^2(0)}=\frac{T_C^2-2T^2}{T_C^2}$$

$$\frac{H_C(T)}{H_C(0)}=\left(1-2\frac{T^2}{T_C^2}\right)^{1/2} \tag{13}$$

By the use of Binomial Theorem in eq. (13), we have

$$\frac{H_C(T)}{H_C(0)}=\left(1-\frac{T^2}{T_C^2}\right)$$

$$H_C(T)=H_C(0)\left(1-\frac{T^2}{T_C^2}\right) \tag{14}$$

The equation (14) is identical empirical formula. This is also called Tuyn's law.

RESULTS AND DISCUSSION

We compare the experimental results with the result of equation (14), which represents the dependence of critical temperature and critical magnetic field and the nature of this variation is parabolic. This equation represents the equation of the phase boundary between the superconducting state and normal state.

Conclusion

A sufficient strong magnetic field will destroy superconductivity. The critical magnetic field is a function of temperature. Experimental threshold curve of critical field versus temperature was parabolic curve and our theoretical expression is also parabolic. This theoretical calculation between temperature and magnetic field is not complex. This result is applicable for both normal superconductor and high temperature superconductor and phase characterization.

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