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Derivation of Neel Temperature and Pressure Expressions for High Temperature Superconductors

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Abstract- Using plasma equations beside Maxwell statistical distribution law a useful expression of the Neel temperature similar to that obtained for high temperature superconductors was derived. This expression was found by obtaining a new expression of energy from the plasma equation. The same procedures were used to find an expression of the pressure and isotope mass in terms of the critical temperature for high temperature superconductors. These expressions resembles the conventional ones.

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I. Introduction

Superconductor (Sc) is one of the most important physical phenomena that attracts attention of physicists. It was found experimentally that beyond a certain critical value of temperature the resistance of the material vanishes [1]. The Sc acts also as a perfect dismagnetic material which expells the external magnetic field be applied when it exceeds a certain critical value [2]. This phenomenon is well explained by the so called Bardeen Shiffer and Cooper (BSC). Recently the so called high temperature superconductors (HTS), which show sc properties at critical temperatures above 130 k were discovered by the researchers [3,4]. These HTS show some very interesting properties [5,6]. For example the critical temperature is highly dependent on the doping process [5,6]. The material can be converted from an insulator to a sc when the concentration of the free carriers changed. The material can also be converted from anti ferromagnetic material to sc above the so called Neel temperature [7]. When some elements are replaced by their isotopes the critical temperature changes also comprising the so called isotope effect [8]. The so called pressure effect shows also that applying external pressure changes also the critical temperature. Different attempts were made to describe HTS phenomena but unfortunately the approaches used are complex and incomplete and unsatisfactory [9]. However recently new promising approaches were tackled by different authors. One of them was proposed by Ghada, et al, where she used Newtonian mechanics to prove that the Sc state is destroyed by the external magnetic field when it exceeds certain critical value for both types 1 and 2 Sc. Despite the success of this model but unfortunately it is based on classical laws that cannot describe other Sc phenomena on the atomic and subatomic scales. Thus this model cannot be promoted further to describe all Sc phenomena [10]. Another seminal paper done by Rasha, et al was published, finding the ordinary expression of the energy gap using tight binding approximation. This expression, however sayes nothing about the other effects, like the pressure and isotope effects [11]. Recently Einas, et al, also used plasma equations to modify Schrodinger equation to explain pressure effect. This model explains why some times the pressure increases critical temperature and why it sometimes decreases the critical temperature. This model however does not give the conventional well known pressure and isotope mass relationships with the critical temperature [12].

In this work one needed to find T_c for high superconducting materials in general and superconducting cuprates with the aid of quantum mechanical treatment in which electrons are considered as harmonic oscillators beside using plasma equations. This work tries to explain the isotope effect and pressure effect. These are done in sections 2&3 respectively. Sections 4&4&5 are devoted for the discussion and conclusion respectively.

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II. Determination the Neel Temperature T_N

To find Neel temperature considers a particle of particles density n_o moving in resistive a medium of density n_r. The resistive force F_r in this case depends on the densities n_o and n_r as well

i.e

$$F_r = \gamma_o n_r v$$

Hence one can write the plasma equation under the effect of the internal field E_i and pressure P in the form

$$nm\frac{dv}{dt} = neE_i - \nabla P - \gamma_o n_r v \quad (1)$$

If the system oscillates as a harmonic oscillator, thus ج

$$F = -nkx = nm\frac{dv}{dt} = neE_i - \gamma k_B T\nabla n - \gamma_o n_r v$$

Using the perturbation solution

$$v = v_o + v_1 e^{i\omega t}$$

$$n = n_o + \tilde{n}_1 e^{i\omega t}$$

$$x = x_o e^{i\omega t} \quad (2)$$

$$E_i = E_{oi} e^{i\omega t}$$

One gets

$$-n_o k x_o = n_o eE_{oi} - \gamma k_B T\nabla\tilde{n}_1 - \gamma_o n_r v_o$$

Thus the frequency

$$m\omega_o^2 = k = \frac{\gamma k_B T\nabla\tilde{n}_1}{n_o x_o} + \frac{\gamma_o n_r v_o}{n_o x_o} - \frac{eE_{oi}}{x_o} \quad (3)$$

$$\omega_o = \sqrt{\frac{1}{mx_o}}\sqrt{\frac{\gamma k_B T\nabla\tilde{n}_1}{n_o} + \frac{\gamma_o n_r v_o}{n_o} - eE_{oi}}$$

This can be satisfied if ω_o is imaginary, where

$$\omega_o = \omega + i\omega_i$$

The real part ω vanishes, when

$$\frac{\gamma k_B T\nabla\tilde{n}_1}{n_o} + \frac{\gamma_o n_r v_o}{n_o} - eE_{oi} < 0$$

$$T < \frac{n_o}{\gamma k_B \nabla\tilde{n}_1}[eE_{oi} - \frac{\gamma_o n_r v_o}{n_o}]$$

Thus Neel temperature is given by

$$T_N = \frac{n_o}{\gamma k_B \nabla\tilde{n}_1}[eE_{oi} - \frac{\gamma_o n_r v_o}{n_o}] \quad (4)$$

According to Maxwell distribution n is given by

$$n_r = Ae^{-\beta E} \quad (5)$$

The electrostatic potential V due to the hole doping which increases positive ions shows the effect of holes on the negative charges in the resistive medium.

$$V = +\frac{ne^2}{4\pi\varepsilon_o r} = -\frac{ne^2}{4\pi\varepsilon_o r} = -V_o$$

where n stands for the hole concentration. The energy E can thus be written as a sum of V blues the rest of energies E_o, i.e

$$E = E_o + V = E_o - V_o$$

Thus

$$n_r = Ae^{-\beta E_o} e^{-\beta V} = A_o e^{+\beta V_o} = A_o e^{C_2 n}$$

The Neel temperature in equation (4) can thus given by

$$T_N = c_4[c_3 - c_1 e^{+c_2 n}] \quad (6)$$

Where c_1, c_2, c_3 and c_4 are constants.

III. Isotope Effect and Pressure Coefficient of T_C

The relation between the pressure and absolute temperature is

$$pv = Nk_B T$$

$$p = \frac{Nk_B T}{v} = n_e k_B T \quad (7)$$

Where $\mathbf{n_e}$ the density of electron (the number of electron in unit volume). The equation of motion of the electrons can be found by treating the medium as a fluid by using Euler equation to get

$$\rho[\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x}] = -\frac{\partial p}{\partial x} - n\gamma v + Bev \quad (8)$$

The density mass of fluid ρ equals the density of electrons n_e multiplied by mass of one electron m is given by expression

$$\rho = m_e n_e$$

The resistive force $n\gamma v$ is assumed to be dependent on the total number of electrons and protons in the medium, n, beside the parameter, γ, since

$$v = v(x,t)\ ;\ dv = \frac{\partial v}{\partial x}dx + \frac{\partial v}{\partial t}dt$$

It follows that

$$\frac{dv}{dt} = \frac{\partial v}{\partial x}\frac{dx}{dt} + \frac{\partial v}{\partial t} = v\frac{\partial v}{\partial x} + \frac{\partial v}{\partial t}$$

$$\rho\frac{dv}{dt} = -\frac{\partial p}{\partial x} - n\gamma v + Bev$$

$$\rho\frac{dv}{dx}\frac{dx}{dt} = \rho v\frac{dv}{dx} = -\frac{\partial p}{\partial x} - n\gamma v + Bev \tag{9}$$

If the pressure is a function of x only it follows that

$$p = p(x)\ ;\ \frac{dp}{dx} = \frac{\partial p}{\partial x} \tag{10}$$

Hence the equation (9) becomes

$$m_e n_e v\frac{dv}{dx} = -\frac{dp}{dx} - n\gamma v + Bev \tag{11}$$

Integrating the equation (11) assuming by B, v, γ, n to be constants one gets

$$m_e n_e\int v dv = \int Bev dx - \int dp - \int n\gamma v dx$$

$$\frac{1}{2}m_e v^2 = \frac{1}{n_e}[Bevx - p - n\gamma vx] \tag{12}$$

The right hand side of this equation represents the kinetic energy of the electron hence

$$E = \frac{1}{2}m_e v^2 = \frac{1}{n_e}[Bevx - p - n\gamma vx] \tag{13}$$

According to Maxwell distribution the number of electrons is given by

$$N_o = C_o e^{-\beta E} \tag{14}$$

Thus using (13) one gets

$$N_o = C_o \exp[-\frac{\beta}{n_e}[Bev - p - n\gamma vx]] \tag{15}$$

where n the total density number of electrons and protons in the sample which is equal to the density of ions multiplied by the total number of electrons and protons $(n_e + n_p)$ in each ion. Hence

$$n = n_i \times (n_e + n_p) = n_i n_e + n_i n_p = n_i n_e + n_i\frac{M}{m_p} \tag{16}$$

Where the mass of electrons is neglected compared to the mass of protons. Hence M=mass of the ions $=n_p M_p$, where M_p is the proton mass.

In view of equation (4) by replacing n by N, Ee by Bev, gamma by 1 and neglecting nr, one gets

$$T_c = \frac{B_a e v_o N_o}{k_B \nabla n} \tag{17}$$

Using equation (15) and (16) one get

$$T_c = \frac{B_a e v_o C_0}{k_B \nabla n_o}\exp[-\frac{\beta}{n_e}[Bev - p - \gamma vx\left(n_i n_e + \frac{n_i M}{m_p}\right)]] \tag{18}$$

Taking the logarithm of both side

$$\ln T_c = \ln[\frac{B_a e v_o C_0}{k_B \nabla n_o}] - \frac{\beta}{n_e}[Bev - p - \gamma vx\left(n_i n_e + \frac{n_i M}{m_p}\right)]$$

Hence by differentiating this equation, one can obtain the isotope effect and coefficient of pressure, respectively.

$$\frac{\partial \ln T_c}{\partial M} = \frac{vxn_i\gamma\beta}{n_e m_p} = -\alpha \tag{19}$$

$$\frac{\partial \ln T_c}{\partial p} = \frac{\beta}{n_e} = \gamma \tag{20}$$

IV. Discussion

Plasma equation (1) together with the fact that the pressure dependent on the temperature for gases in addition to assuming the real part of frequency to vanish, beside Maxwell equation were used to find a useful expression of the Neel temperature. The relation between the absence of the frequency, thus the energy, according to Plank hypothesis, is too vanishes by treating the plasma particles as vibrating strings. The absence of real energy and the dominance of imaginary energy means that the collision is very effective and the thermal energy is very large as pointed out by Dirar et al[10]. This high thermal energy causes random motion of magnetic dipoles due to thermal agitation. This leads to dis appearance of ferro and anti ferro magnetism. Thus it is quite natural to obtain Neel temperature according to this hypothesis in equations (4) and (6) respectively. The emperical expressions of the HTC for pressure and isotope effects were found using gas law in equation (7) and plasma equation (8) to find first a useful expressions for kinetic and total energy in equations (12) & (13) respectively. This leads to a useful expression of the critical temperature in equation (17). Using these relations a theoretical relationship between isotope mass and critical temperature is typical to the conventional emperical one was found in equation (19). A useful expression of the pressure related to the critical temperature is also found in equation (20).This expression is similar to the emperical conventional one.

V. Conclusion

Using plasma equation together with Maxwell equation beside gas laws a useful expression of the Neel temperature, Pressure, isotropic mass for H TS was derived. These relations fortunately conforms with the emperical conventional relations.

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