An Expression of A in Power Law Equation for Resistivity and Temperature, Resistance or Color and Pressure

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Abstract

We study the power law equation governing the relationship between resistivity and temperature, as well as the pressure-induced resistance and color change of a superconductor, through the generalized relational expression. By assuming a relationship between resistivity, effective mass and temperature, we find a generalized formula without gravitational effect and a generalized expression for the power law coefficient *A*. Through careful selection of the exponent *N* of the speed of light in vacuum, we obtain specific power law equations and a particular expression for *A*. In regards to the relationship between temperature and pressure, it has that the resistance varies inversely with pressure to the power of a third, sixth or half within a specific range. Similarly, in relation to color and pressure, the frequency varies directly with pressure to the power of a quarter, half, linearity, negative half, or inverse proportion. This indicates that the color shifts from blue to purple to blush as the pressure rises within a certain range. It shows that the expansion of the application of generalized relational expression can be achieved by manipulating the exponent of the constants.

1. Introduction

The power law equation [1] describes the relationship between the resistivity of a superconducting material and its temperature. There have been numerous studies on this topic, both theoretical and experimental. One of the most famous models is the Bloch-Grüneisen law [2]; another is Callendar-Van Dusen equation. Holographic method or gauge/gravity duality has made much progress [3] for the linear temperature and resistivity recent years. But they didn’t give the specific expression for the power law coefficient *A* in most cases.

Room temperature superconductivity is a fascinating area of research because the large application prospect. Some materials become superconducting at higher temperatures under high pressure. For instance, C-H-S system becomes superconductor at 287K and 267 Gpa [4], LaH_{10} [5] and YH_9 [6] become superconducting at around 250k under 200 Gpa in recent years. This is a milestone; simultaneously excessive pressures greatly limit their application. Recently room temperature superconductivity at near barometric pressure (about 1 Gpa) was claimed in the nitrogen-doped lutetium hydrides [7]. But several groups couldn’t reproduce except the color changed by the pressure [8, 9, 10, 11]. Also no direct equation described color changing [12].

The paper is organized as follows. In Sec. 2, we find a generalized formula without gravitational effect and a generalized expression for the coefficient *A*. In Sec. 3, we obtain the resistance varying inversely with pressure to the power of a third, sixth or half within a specific range. In Sec. 4, we get that the color varies directly with pressure to the power of a quarter, half, linearity, negative half, or inverse proportion within a certain range. We conclude in Sec. 5.

2. Expression of *A*

The basic relationship [13] is

$$\boldsymbol{A} \sim A_{\mathrm{P}} = [\hbar^{(\delta+\varepsilon+\zeta+\eta)} \mathrm{G}^{(\delta-\varepsilon+\zeta-\eta)} \mathrm{c}^{-(3\delta-\varepsilon+5\zeta-5\eta)} \kappa^{-2\eta} \mathrm{e}^{2\lambda}]^{1/2} \tag{1}$$

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Where $\boldsymbol{A}$ is any physical quantity, $[\boldsymbol{A}] = [\mathrm{L}]^{\delta}[\mathrm{M}]^{\varepsilon}[\mathrm{T}]^{\zeta}[\Theta]^{\eta}[\mathrm{Q}]^{\lambda}$ its dimensions, L, M, T, Θ and Q are the dimensions of length, mass, time, temperature and electric charge separately (here we use the LMTΘQ units [14]), A_{P} the corresponding Planck scale of $\boldsymbol{A}$, δ, ε, ζ, η and λ the real number, ħ, G, c, κ and e the reduced Planck constant, gravitational constant, speed of light in vacuum, Boltzmann constant and elementary charge separately.

The generalized relational expression [13] is

$$\prod_{\mathrm{i}=1}^{\mathrm{n}} \boldsymbol{A}_{\mathrm{i}}^{\alpha_{\mathrm{i}}} \sim \prod_{\mathrm{i}=1}^{\mathrm{n}} A_{\mathrm{iP}}^{\alpha_{\mathrm{i}}},\ \mathrm{i} = 1, 2, 3 \ldots \mathrm{n} \tag{2}$$

where $\boldsymbol{A}_{\mathrm{i}}$ is the physical quantity, α_{i} the real number, and A_{iP} the corresponding Planck scale.

The power law equation for resistivity and temperature [1] is

$$\rho = \rho_0 + AT^n \tag{3}$$

where ρ is the resistivity, ρ_0 the residual resistivity, A the coefficient, n the exponent, and T the temperature. In here we define

$$\rho_n = A_n T^n \tag{4}$$

Consulting the Uemura's law [15], we assume that the resistivity ρ_n has relationship between effective mass m and temperature T, and obtain

$$\rho_n m^{\alpha} T^{\beta} \sim \left(\frac{\hbar^3 \mathrm{G}}{\mathrm{c}^3 \mathrm{e}^4}\right)^{1/2} \left(\frac{\hbar \mathrm{c}}{\mathrm{G}}\right)^{\alpha/2} \left(\frac{\hbar \mathrm{c}^5}{\mathrm{k}^2 \mathrm{G}}\right)^{\beta/2} = \hbar^{(3+\alpha+\beta)/2}\ \mathrm{G}^{(1-\alpha-\beta)/2}\ \mathrm{c}^{-(3-\alpha-5\beta)/2}\ \mathrm{k}^{-\beta}\ \mathrm{e}^{-2} \tag{5}$$

where $\rho_{\mathrm{P}} = \left(\frac{\hbar^3 \mathrm{G}}{\mathrm{c}^3 \mathrm{e}^4}\right)^{1/2}$ is the Planck resistivity (from (1)), $m_{\mathrm{P}} = \left(\frac{\hbar \mathrm{c}}{\mathrm{G}}\right)^{1/2}$ the Planck mass, and $T_{\mathrm{P}} = \left(\frac{\hbar \mathrm{c}^5}{\mathrm{k}^2 \mathrm{G}}\right)^{1/2}$ the Planck temperature. Neglecting the gravitational effect, and ordering $1 - \alpha - \beta = 0$ and $3 - \alpha - 5\beta = N$ → $\alpha = (2+N)/4$ and $\beta = (2-N)/4$, where N is a number, we find

$$\rho_n \sim \frac{\hbar^2 \mathrm{k}^{(N-2)/4} T^{(N-2)/4}}{\mathrm{e}^2 \mathrm{c}^{N/2} m^{(N+2)/4}} \sim A_n T^n,\ N \neq 2 \tag{6}$$

It is the generalized formula for the resistivity, effective mass and temperature without gravitational effect. Therefore

$$A_n \sim \frac{\hbar^2 \mathrm{k}^{(N-2)/4}}{\mathrm{e}^2 \mathrm{c}^{N/2} m^{(N+2)/4}} \tag{7}$$

This is the generalized expression of A.

(1) Ordering N = -2, we obtain

$$\rho_{-1} \sim \frac{\hbar^2 \mathrm{c}}{\mathrm{e}^2 \mathrm{k} T} \sim A_{-1} T^{-1}$$

The resistivity exhibits inversely-proportional temperature dependence [16], but independence the effective mass.

(2) Making N = 0, that is ignoring the relativistic effect, get

$$\rho_{-1/2} \sim \frac{\hbar^2}{\mathrm{e}^2 \mathrm{k}^{1/2} m^{1/2} T^{1/2}} \sim A_{-1/2} T^{-1/2}$$

Resistivity exhibits negative subduplicate temperature dependence.

(3) Ordering N = 4, get

$$\rho_{1/2} \sim \frac{\hbar^2 \mathrm{k}^{1/2} T^{1/2}}{\mathrm{e}^2 \mathrm{c}^2 m^{3/2}} \sim A_{1/2} T^{1/2}$$

Resistivity exhibits subduplicate temperature dependence [17].

(4) Making N = 6, obtain

$$\rho_1 \sim \frac{\hbar^2 \mathrm{k} T}{\mathrm{e}^2 \mathrm{c}^3 m^2} \sim A_1 T$$

Resistivity of metal exhibits linear temperature dependence [4, 18, 19]. Taking it into the formula $\rho = \hbar \mathrm{k} T m / n_{\mathrm{n}} \mathrm{e}^2$ [19], we obtain $m \sim \hbar \sqrt[3]{n_{\mathrm{n}}}/\mathrm{c}$, where n_{n} is the carrier density of quasi-particles.

(5) Ordering N = 8, get

$$\rho_{3/2} \sim \frac{\hbar^2 \mathrm{k}^{3/2} T^{3/2}}{\mathrm{e}^2 \mathrm{c}^4 m^{5/2}} \sim A_{3/2} T^{3/2}$$

Resistivity exhibits temperature dependent on the power of three-half [18, 20].

(6) Making N = 10, obtain

$$\rho_2 \sim \frac{\hbar^2 k^2 T^2}{e^2 c^5 m^3} \sim A_2 T^2$$

Resistivity exhibits quadratic temperature dependence in the low temperature limit for the Fermi liquid like [21].

(7) Ordering N = 12, get

$$\rho_{5/2} \sim \frac{\hbar^2 k^{5/2} T^{5/2}}{e^2 c^6 m^{7/2}} \sim A_{5/2} T^{5/2}$$

Resistivity exhibits temperature dependent on the power of five-half [20].

(8) Making N = 14, obtain

$$\rho_3 \sim \frac{\hbar^2 k^3 T^3}{e^2 c^7 m^4} \sim A_3 T^3$$

Resistivity exhibits cubic temperature dependence [22].

(9) Ordering N = 16, get

$$\rho_{7/2} \sim \frac{\hbar^2 k^{7/2} T^{7/2}}{e^2 c^8 m^{9/2}} \sim A_{7/2} T^{7/2}$$

Resistivity exhibits temperature dependent on the power of seven-half [23].

(10) Making N = 18, obtain

$$\rho_4 \sim \frac{\hbar^2 k^4 T^4}{e^2 c^9 m^5} \sim A_4 T^4$$

Resistivity exhibits biquadratic temperature dependence [24].

(11) Ordering N = 20, get

$$\rho_{9/2} \sim \frac{\hbar^2 k^{9/2} T^{9/2}}{e^2 c^{10} m^{11/2}} \sim A_{9/2} T^{9/2}$$

Resistivity exhibits temperature dependent on the power of nine-half [22, 25].

(12) Making N = 22, obtain

$$\rho_5 \sim \frac{\hbar^2 k^5 T^5}{e^2 c^{11} m^6} \sim A_5 T^5$$

Resistivity exhibits quintic temperature dependence, which is the Bloch-Grüneisen law [2].

And so on.

3. Pressure caused resistance change

Similarly the power law equation for resistance and temperature [11] is

$$R = R_0 + AT^a \tag{8}$$

where R is the resistance, R_0 the residual resistance, and a the exponent.

We define

$$R_a = A_a T^a \tag{9}$$

The relationship between resistance R, temperature T and pressure p is

$$RT^{\alpha} p^{\beta} \sim \left(\frac{\hbar}{e^2}\right)\left(\frac{\hbar c^5}{k^2 G}\right)^{\alpha/2} \left(\frac{c^7}{\hbar G^2}\right)^{\beta} = \hbar^{(2+\alpha-2\beta)/2}\ G^{-(\alpha+4\beta)/2}\ c^{(5\alpha+14\beta)/2}\ k^{-\alpha}\ e^{-2} \tag{10}$$

where $R_P = \frac{\hbar}{e^2}$ is the Planck resistance, and $p_P = \frac{c^7}{\hbar G^2}$ the Planck pressure. Neglecting the gravitational effect, we make $2 + \alpha - 2\beta = N$ and $\alpha + 14\beta = 0 \rightarrow \alpha = 2(N\text{-}2)/3$ and $\beta = (2\text{-}N)/6$, and find

$$R_a \sim \frac{\hbar^{N/2} k^{2(2-N)/3} T^{2(2-N)/3}}{e^2 c^{(2-N)/2} p^{(2-N)/6}} \sim A_a T^a,\ N \neq 2 \tag{11}$$

This is the generalized formula for the resistance, pressure and temperature without gravitational effect also.

(1) Ordering $N = 0$, that is ignoring the quantum effect, we obtain

$$R_{4/3} \sim \frac{\mathrm{k}T}{\mathrm{ce}^2}\sqrt[3]{\frac{\mathrm{k}T}{p}}$$

So the resistance varies inversely with pressure to the power of a third [26].

(2) Making $N = 1$, get

$$R_{2/3} \sim \sqrt[6]{\frac{\hbar^3 \mathrm{k}^4 T^4}{\mathrm{c}^3 p}}/\mathrm{e}^2$$

Resistance varies inversely with pressure to the power of a sixth [26].

(3) Ordering $N = -1$, obtain

$$R_2 \sim \frac{\mathrm{k}^2 T^2}{\mathrm{ce}^2\sqrt{cp}}$$

Resistance varies inversely with pressure to the power of a half within a certain range.

4. Pressure induced color change

Referring to the Birch-Murnaghan equation [27], we consider the frequency ω has relationship between pressure p and volume V, and obtain

$$\omega p^{\alpha} V^{\beta} \sim \left(\frac{\mathrm{c}^5}{\hbar \mathrm{G}}\right)^{1/2} \left(\frac{\mathrm{c}^7}{\hbar \mathrm{G}^2}\right)^{\alpha} \left(\frac{\hbar \mathrm{G}}{\mathrm{c}^3}\right)^{3\beta/2} = \hbar^{-(1+2\alpha-3\beta)/2}\ \mathrm{G}^{-(1+4\alpha-3\beta)/2}\ \mathrm{c}^{(5+14\alpha-9\beta)/2} \quad (12)$$

where $\omega_{\mathrm{P}} = \left(\frac{\mathrm{c}^5}{\hbar \mathrm{G}}\right)^{1/2}$ is the Planck frequency, $V_{\mathrm{P}} = \left(\frac{\hbar \mathrm{G}}{\mathrm{c}^3}\right)^{3/2}$ the Planck volume. Neglecting the gravitational effect, we order $1 + 4\alpha - 3\beta = 0$ and $5 + 14\alpha - 9\beta = N \rightarrow \alpha = (N-2)/2$, $\beta = (2N-3)/3$, and find

$$\omega \sim \hbar^{(2-N)/2} \mathrm{c}^{N/2} p^{(2-N)/2} V^{(3-2N)/3},\ N \neq 2 \quad (13)$$

This is the generalized equation for the frequency, pressure and volume without gravitational effect too.

(1) Ordering $3 - 2N = 0$, $N = 3/2$, we obtain

$$\omega_{1/4} \sim \sqrt[4]{\frac{\mathrm{c}^3 p}{\hbar}}$$

(2) Making $N = 0$, that is ignoring the relativistic effect, get

$$\omega_1 \sim \frac{pV}{\hbar}$$

(3) Ordering $N = 1$, obtain

$$\omega_{1/2} \sim \sqrt[3]{V}\sqrt{\frac{cp}{\hbar}}$$

(4) Making $N = 3$, get

$$\omega_{-1/2} \sim \frac{c}{V}\sqrt{\frac{\hbar \mathrm{c}}{p}}$$

(5) Ordering $N = 4$, obtain

$$\omega_{-1} \sim \frac{\hbar \mathrm{c}^2}{pV^{5/3}}$$

Therefore, the frequency varies directly with pressure to the power of a quarter, half, linearity, negative half, or inverse proportion. This indicates that the color shifts from blue to purple to blush as the pressure rises within a specific range [11].

5. Discussion

In this paper, we study the power law equation governing the relationship between resistivity and temperature, as well as the pressure-induced resistance and color change of a superconductor, by the generalized relational expression. We find the following results.

(1) The resistivity was assumed to have relationship between effective mass and temperature, and was found a generalized formula without gravitational effect and a generalized expression for the power law coefficient *A*.
(2) Through careful selection of the exponent *N* of the speed of light in vacuum, was obtained specific power law equations such as from $A_{-1}T^{-1}$ to A_5T^5, and a particular expression for *A*.
(3) It was discovered a generalized equation neglecting gravitational effect for the resistance, temperature and pressure through selecting exponent *N* of reduced Planck constant correctly. Resistance varied inversely with pressure to the power of a third, sixth or half within a certain range.
(4) Also a generalized equation without gravitational effect for the frequency, pressure and volume was found. Frequency varied directly with pressure to the power of a quarter, half, linearity, negative half, or inverse proportion. It indicates that the color shifts from blue to purple to blush as the pressure rises within a specific range.
(5) The value of exponent *N* isn't arbitrary and requires being determined in conjunction with experiments.
(6) It shows that the expansion of the application of generalized relational expression can be achieved by manipulating the exponent of the constants.

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