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THE MECHANISM OF THE BOSE–EINSTEIN CONDENSATION AND ITS ROLE IN THE OCCURRENCE OF THE NORMAL CURRENTS AND SUPERCURRENTS

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Abstract

The mechanism of the Bose–Einstein condensation and its role in the occurrence of the normal currents and supercurrents is investigated. In particular, the mechanism of the formation of Cooper pairs and their role in the occurrence of non-dissipative diamagnetic supercurrents is investigated. In the previous works [1–7], we suggested that in the materials with large HOMO-LUMO gaps, the Cooper pairs are formed by the large HOMO-LUMO gaps as a consequence of the quantization of the orbitals by nature, and by the attractive Coulomb interactions between two electrons with opposite momentum and spins occupying the same orbitals via the positively charged nuclei. On the other hand, according to the recent experimental research (Wehlitz et. al; 2012), the Cooper pairs have been observed at room temperatures in the neutral benzene (6an), naphthalene (10ac), anthracene (14ac), and coronene molecules. That is, our prediction in our theoretical researches [1–7] can be well confirmed by the recent experimental research (Wehlitz et. al; 2012), and our previous theory can be reasonably applied to the explanation of the mechanism of the occurrence of the granular high temperature superconductivity in carbon materials. Related to seeking for the room-temperature superconductivity, in this article, we compare the normal metallic states with the superconducting states. Furthermore, in this article, we elucidate the mechanism of the Ampère's law (experimental rule discovered in 1826) in normal metallic and superconducting states, on the basis of the theory suggested in our previous researches.

Keywords

Bose–Einstein Condensation, Ampère's Law, A Bosonic Electron, Stern–Gerlach Effect

1. Introduction

For seventy years, aromatic character and ring currents in aromatic molecules have been of interest [1–7]. The diamagnetic anisotropy of aromatic hydrocarbons can be attributed to the induced ring currents in their-electronic systems [1–7]. The diamagnetic ring currents of aromatic molecules, annulenes such as benzene (6an), and polyacenes such as naphthalene (10ac), anthracene (14ac), and tetracene (18ac) are nondissipative currents similar in many respects to the persistent currents of superconducting rings, and have been often referred to as a form of superconductivity [1–8]. The relationship between the ring current and the virtual superconducting state in these molecular systems has been discussed [1–7]. In the previous work, we discussed the relationships between the electron–phonon interactions and electrical conductivity and provided an explanation of the diamagnetic ring current in aromatic hydrocarbons with small molecular sizes, annulenes and polyacenes [1–7]. For seventy years, aromatic character and ring currents in aromatic molecules have been of interest [1–7]. The diamagnetic anisotropy of aromatic hydrocarbons can be attributed to the induced ring currents in their -electronic systems [1–7]. The diamagnetic ring currents of aromatic molecules, annulenes such as benzene (6an), and polyacenes such as naphthalene (10ac), anthracene (14ac), and tetracene (18ac) are non-dissipative currents similar in many respects to the persistent currents of superconducting rings, and have been often referred to as a form of superconductivity [1–8]. The relationship between the ring current and the virtual superconducting state in these molecular systems has been discussed [1–7]. In the previous work, we discussed the relationships between the electron–phonon interactions and electrical conductivity and provided an explanation of the diamagnetic ring current in aromatic hydrocarbons with small molecular sizes, annulenes and polyacenes [1–7].

On the other hand, even though these small molecules would exhibit non dissipative intramolecular diamagnetic currents, their molecular crystals with macroscopic sizes in bulk system would become insulator. We can expect that if the valence–conduction band gaps are very large in bulk system such as diamonds, non-dissipative diamagnetic currents have a possibility to occur in such bulk systems. As an example, we discussed the neutral sp3 type carbons with macroscopic sizes, very pure diamonds, in which the band gap between valence and conduction bands is very large [1–7]. As discussed in the previous researches [1–7], closed shell electronic structures in the neutral annulenes and polyacenes with large energy difference between the HOMO and the lowest unoccupied molecular orbitals (LUMO) can exhibit

nondissipative intramolecular diamagnetic currents at 298 K in spite of the fact that such closed shell electronic structures should be in insulating states from the point of view of solid state physics. We can consider a bulk diamond as a macro-molecule with very large energy gap between the HOMO and the LUMO. Therefore, it is rational to consider that very pure diamonds with large energy gap between valence and conduction bands, which have been believed to become insulator from the point of view of solid state physics, also have a possibility to exhibit intramolecular diamagnetic currents in bulk systems.

Related to seeking for the room-temperature superconductivity, in this article, we compare the normal metallic states with the superconducting states. In superconductivity, two electrons behave only as a Bose particle. Furthermore, in this article, we elucidate the mechanism of the Ampère's law (experimental rule discovered in 1826) in normal metallic and superconducting states, on the basis of the theory suggested in our previous researches.

I. The Origin of the Ampère's Law

A. Theoretical Background

The wave function for an electron occupying the highest occupied crystal orbital (HOCO) in a material under the external applied field ($x_{in} = B_{in}$ or E_{in}) can be expressed as

$$\begin{aligned}&\left|k_{\mathrm{HOCO}}(T)\left(\left(B_{\mathrm{out}}, B_{\mathrm{in}}\right),\left(E_{\mathrm{out}}, E_{\mathrm{in}}\right), B_{k_{\mathrm{HOCO}}} ; I_{k_{\mathrm{HOCO}}}\right)\right\rangle \\ &=\sqrt{P_{\mathrm{ground}}(T)}\left|k_{\mathrm{HOCO}, \mathrm{ground}, 0}\left(x_{\mathrm{in}}\right)\right\rangle \\ &+\sqrt{P_{\mathrm{excited}}(T)}\left|k_{\mathrm{HOCO}, \mathrm{excited}, 0}\left(x_{\mathrm{in}}\right)\right\rangle, \qquad (1)\end{aligned}$$

where

$$\begin{aligned}&\left|k_{\mathrm{HOCO}, \mathrm{excited}, 0}\left(x_{\mathrm{in}}\right)\right\rangle \\ &=c_{+k_{\mathrm{HOCO}}\uparrow, 0}\left(x_{\mathrm{in}}\right)\left|+k_{\mathrm{HOCO}}\uparrow\right\rangle \\ &+c_{-k_{\mathrm{HOCO}}\downarrow, 0}\left(x_{\mathrm{in}}\right)\left|-k_{\mathrm{HOCO}}\downarrow\right\rangle. \qquad (2)\end{aligned}$$

$$\left|k_{\mathrm{HOCO},\mathrm{ground},0}(x_{\mathrm{in}})\right\rangle$$
$$= c_{-k_{\mathrm{HOCO}}\uparrow,0}(x_{\mathrm{in}})\left|-k_{\mathrm{HOCO}}\uparrow\right\rangle$$
$$+c_{+k_{\mathrm{HOCO}}\downarrow,0}(x_{\mathrm{in}})\left|+k_{\mathrm{HOCO}}\downarrow\right\rangle \qquad (3)$$

$$P_{\mathrm{ground}}(T)+P_{\mathrm{excited}}(T)=1, \qquad (4)$$

$$c^2_{+k_{\mathrm{HOCO}}\downarrow,0}(x_{\mathrm{in}})+c^2_{-k_{\mathrm{HOCO}}\uparrow,0,0}(x_{\mathrm{in}})=1, \qquad (5)$$

$$c^2_{-k_{\mathrm{HOCO}}\downarrow,0}(x_{\mathrm{in}})+c^2_{+k_{\mathrm{HOCO}}\uparrow,0}(x_{\mathrm{in}})=1, \qquad (6)$$

The magnetic field ($B_{k_{HOCO}}(x_{\mathrm{out}}, x_{\mathrm{in}})(=B_{\mathrm{in}})$) at the condition of the external applied field x_{out} and the field felt by an electron x_{in} can be expressed as

$$B_{k_{\mathrm{HOCO}}}(x_{\mathrm{out}},x_{\mathrm{in}})$$
$$=B_{k_{\mathrm{HOCO}}\uparrow}(x_{\mathrm{out}},x_{\mathrm{in}})-B_{k_{\mathrm{HOCO}}\downarrow}(x_{\mathrm{out}},x_{\mathrm{in}}), \qquad (7)$$

where

$$B_{k_{\mathrm{HOCO}}\uparrow}(x_{\mathrm{out}},x_{\mathrm{in}})$$
$$=P_{\mathrm{excited}}(T)c^{2\,+k_{\mathrm{HOCO}}\uparrow,x_{\mathrm{in}}}(x_{\mathrm{out}}-x_{\mathrm{in}})$$
$$+P_{\mathrm{ground}}(T)c^{2\,-k_{\mathrm{HOCO}}\uparrow,x_{\mathrm{in}}}(x_{\mathrm{out}}-x_{\mathrm{in}}), \qquad (8)$$

$$B_{k_{\mathrm{HOCO}}\downarrow}(x_{\mathrm{out}},x_{\mathrm{in}})$$
$$=P_{\mathrm{excited}}(T)c^{2\,-k_{\mathrm{HOCO}}\downarrow,x_{\mathrm{in}}}(x_{\mathrm{out}}-x_{\mathrm{in}})$$
$$+P_{\mathrm{ground}}(T)c^{2\,x_{\mathrm{in}}}_{+k_{\mathrm{HOCO}}\downarrow,}(x_{\mathrm{out}}-x_{\mathrm{in}}). \qquad (9)$$

The electric field ($I_{k_{HOCO}}(x_{out}, x_{in})(= E_{in})$) at the condition of the external applied field x_{out} and the field felt by an electron x_{in} can be expressed as

$$I_{k_{HOCO}}(x_{out}, x_{in}) = I_{+k_{HOCO}}(x_{out}, x_{in}) - I_{-k_{HOCO}}(x_{out}, x_{in}), \quad (10)$$

$$I_{+k_{HOCO}}(x_{out}, x_{in}) = P_{excited}(T) c^2_{+k_{HOCO}\uparrow, x_{in}}(x_{out} - x_{in}) + P_{ground}(T) c^2_{+k_{HOCO}\downarrow, x_{in}}(x_{out} - x_{in}), \quad (11)$$

$$I_{-k_{HOCO}}(x_{out}, x_{in}) \quad (x_{out} - x_{in}) = P_{excited}(T) c^2_{-k_{HOCO}\downarrow, x_{in}} + P_{ground}(T) c^2_{-k_{HOCO}\uparrow, x_{in}}(x_{out} - x_{in}), \quad (12)$$

Let us look into the energy levels for various electronic states when the applied field increases from 0 to x_{out} at 0 K in superconductor, in which the HOCO is partially occupied by an electron. The stabilization energy as a consequence of the electron–phonon interactions can be expressed as

$$E_{SC,electronic}(x_{out}, x_{in}) - E_{NM,electronic}(0,0) = -2V_{one} f_{Bose,0}(x_{in}), \quad (13)$$

where the $-2V_{one}$ denotes the stabilization energy for the electron–phonon coupling interactions between an electron occupying the HOCO and the vibronically active modes [1–7] (Fig. 1).

The $f_{Bose, \Delta E_{unit}}(0)$ denotes the ratio of the bosonic property under the internal field x_{in} ($c_{+k_{HOCO}\downarrow,0}(x_{in}) = c_{+k_{HOCO}\uparrow,0}(x_{in}) = c_{+k_{HOCO},0}(x_{in})$ and $c_{-k_{HOCO}\uparrow,0}(x_{in}) = c_{-k_{HOCO}\downarrow,0}(x_{in}) = c_{-k_{HOCO},0}(x_{in})$), and can be estimated as

$$f_{\text{Bose},0}(x_{\text{in}}) = \frac{1}{2} + c_{-k_{\text{HOCO}},0}(x_{\text{in}})\sqrt{1-c^2_{-k_{\text{HOCO}},0}(x_{\text{in}})}. \quad (14)$$

The $f_{\text{Bose},\Delta B_{\text{unit}}}(0)$ denotes the ratio of the bosonic property under the internal field x_{in} ($c_{+k_{\text{HOCO}}\uparrow,0}(x_{\text{in}}) = c_{-k_{\text{HOCO}}\uparrow,0}(x_{\text{in}}) = c_{k_{\text{HOCO}}\uparrow,0}(x_{\text{in}})$ and $c_{+k_{\text{HOCO}}\downarrow,0}(x_{\text{in}}) = c_{-k_{\text{HOCO}}\downarrow,0}(x_{\text{in}}) = c_{k_{\text{HOCO}}\downarrow,0}(x_{\text{in}})$), and can be estimated as

$$f_{\text{Bose},0}(x_{\text{in}}) = \frac{1}{2} + c_{k_{\text{HOCO}}\downarrow,0}(x_{\text{in}})\sqrt{1-c^2_{k_{\text{HOCO}}\downarrow,0}(x_{\text{in}})}. \quad (15)$$

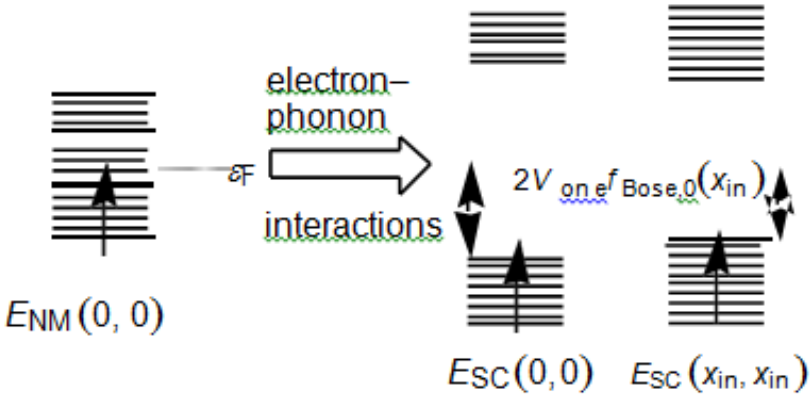

Figure 1: *Stabilization energy as a cons sequence of the electron–phonon interactions as a function of the external applied field*

B. New Interpretation of the Ampère's Law in the Normal Metallic States

Let us next apply the Higgs mechanism to the Ampère's law in the normal metallic states. Let us next consider the superconductor, the critical electric field of which is E_{c}. Below T_{C}, the bosonic Cooper pairs are in the superconducting states. We consider the case where the HOCO is partially occupied by an electron.

We consider that the electric field is quantized by $\Delta E_{\text{unit}}(= E_{\text{c}} / n_{\text{c}})$. The n_{c} value is very large and the quantization value of $E_{\text{c}} / n_{\text{c}}$ is very small ($E_{\text{c}} / n_{\text{c}} \approx 0$). That is, the jth quantized electric field E_j with respect to the zero electric field can be defined as

$$E_j = j\Delta E_{\text{unit}} \tag{16}$$

The ratio of the bosonic property under the internal electric field E_{in} with respect to the ground state for the zero magnetic fields can be denoted as $f_{\text{Bose},0}(E_{\text{in}})$. We define the electronic $\boldsymbol{k}_{\text{HOCO}}(T)\left((B_{\text{out}}, B_{\text{in}}), (E_{\text{out}}, E_{\text{in}}), B_{\boldsymbol{k}_{\text{HOCO}}}; I_{\boldsymbol{k}_{\text{HOCO}}}\right)$ state, where the E_{out} denotes the induced electric field applied to the specimen, the E_{in} the induced electric field felt by the electron, the $B_{\boldsymbol{k}_{\text{HOCO}}}$ the induced magnetic moment from the electron (the induced magnetic field $B_{\text{Induced},\boldsymbol{k}_{\text{HOCO}}}$ or the change of the spin magnetic moment of an electron $\sigma_{\text{spin},\boldsymbol{k}_{\text{HOCO}}}$ from the each ground state), and the $I_{\boldsymbol{k}_{\text{HOCO}}}$ the induced electric moment of an electron (canonical electric momentum $\boldsymbol{p}_{\text{canonical},\boldsymbol{k}_{\text{HOCO}}}$ or the electric momentum of an electron $\boldsymbol{v}_{\text{em},\boldsymbol{k}_{\text{HOCO}}}$). Without any external applied electric field ($j = 0$; $E_{\text{out}} = E_{\text{in}} = 0$), the ratio of the bosonic property under the internal electric field 0 can be estimated to be $f_{\text{Bose},0}(0) = 1$. Therefore, the electronic state pairing of an electron behaves as a boson,

$$f_{\text{Bose},0}(0) = 1 \tag{17}$$

In such a case $(c_{+\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0) = c_{-\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0) = c_{+\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0) = c_{-\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0) = 1/\sqrt{2})$, there is no induced current and the magnetic fields, as expected,

$$\begin{aligned} B_{\boldsymbol{k}_{\text{HOCO}}}(0,0) &= B_{\boldsymbol{k}_{\text{HOCO}}\uparrow}(0,0) - B_{\boldsymbol{k}_{\text{HOCO}}\downarrow}(0,0) \\ &= \left\{P_{\text{excited}}(T)c^2_{+\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0) + P_{\text{ground}}(T)c^2_{\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0)\right. \\ &\quad \left. - \left\{P_{\text{excited}}(T)c^2_{-\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0) + P_{\text{ground}}(T)c^2_{+\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0)\right.\right. \\ &= 0, \end{aligned} \tag{18}$$

$$\begin{aligned} I_{\boldsymbol{k}_{\text{HOCO}}}(0,0) &= I_{+\boldsymbol{k}_{\text{HOCO}}}(0,0) - I_{-\boldsymbol{k}_{\text{HOCO}}}(0,0) \\ &= \left\{P_{\text{excited}}(T)c^2_{+\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0) + P_{\text{ground}}(T)c^2_{+\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0)\right. \\ &\quad \left. - \left\{P_{\text{excited}}(T)c^2_{-\boldsymbol{k}_{\text{HOCO}}\downarrow,0}(0) + P_{\text{ground}}(T)c^2_{-\boldsymbol{k}_{\text{HOCO}}\uparrow,0}(0)\right.\right. \\ &= 0. \end{aligned} \tag{19}$$

This can be in agreement with the fact that charges at rest feel no magnetic forces and create no magnetic fields. This is the bosonic ground normal metallic state for $j = 0$ ($\boldsymbol{k}_{\mathrm{HOCO}}(T)((0,0);(0,0);0;0)$) (Fig. 2 (a)).

It should be noted that the electronic states are in the ground normal metallic states when all the $\boldsymbol{p}_{\mathrm{canonica}}$, $\boldsymbol{v}_{\mathrm{em}}$, σ_{spin}, and B_{induce} values are 0 ($\boldsymbol{p}_{\mathrm{canonical}}= 0$, $\boldsymbol{v}_{\mathrm{em}} = 0$, $\sigma_{\mathrm{spin}} = 0$, and $B_{\mathrm{induced}}= 0$), and the are in the excited normal metallic states when the $\boldsymbol{p}_{\mathrm{canonica}}$, $\boldsymbol{v}_{\mathrm{em}}$, σ_{spin}, or B_{induce} values are not 0 ($\boldsymbol{p}_{\mathrm{canonical}}\neq 0$, $\boldsymbol{v}_{\mathrm{em}} \neq 0$, $\sigma_{\mathrm{spin}} \neq 0$, or $B_{\mathrm{induced}}\neq 0$).

When the electric field ($I_{\boldsymbol{k}_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0)= \Delta E_{\mathrm{unit}}$) is applied, a Nambu–Goldstone boson formed by the fluctuation of the electronic state pairing of an electron $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0,0);(0,0);0;0)$ is absorbed by a photon (electric field) (Fig. 1(b)). Therefore, a photon (electric field) has finite mass as a consequence of interaction with the Nambu–Goldstone boson formed by the fluctuation of the bosonic electronic state pairing of an electron. In such a case, the $I_{\boldsymbol{k}_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0)$ and $B_{\boldsymbol{k}_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0)$ values for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((\Delta B_{\mathrm{unit}},0);(\Delta E_{\mathrm{unit}}, 0); B_{\mathrm{induced}}; 0)$ state (Fig. 2 (b)) can be estimated as

$$
\begin{aligned}
I_{\boldsymbol{k}_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0) = \{ & P_{\mathrm{excited}}(T)c^2_{+\boldsymbol{k}_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
& + P_{\mathrm{ground}}(T)c^2_{+\boldsymbol{k}_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
& - \{P_{\mathrm{excited}}(T)c^2_{-\boldsymbol{k}_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
& + P_{\mathrm{ground}}(T)c^{\leftarrow}_{-\boldsymbol{k}_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}})\} \\
= 0, & \qquad (20)
\end{aligned}
$$

and thus

$$
\begin{aligned}
B_{k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0) = & \{P_{\mathrm{excited}}(T)c^2_{+k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
& + P_{\mathrm{ground}}(T)c^2_{-k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
& - \{P_{\mathrm{excited}}(T)c^2_{-k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
& + P_{\mathrm{ground}}(T)c^2_{+k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
= & \, 2P_{\mathrm{excited}}(T)\{c^2_{+k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
& - c^2_{-k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
= & \, B_{\mathrm{induced},k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0) = -\Delta B_{\mathrm{unit}}. \qquad (21)
\end{aligned}
$$

Soon after the external electric field is applied, the momentum of the bosonic electronic state pairing of an electron cannot be changed but the magnetic field can be induced. It should be noted that the magnetic field $B_{\mathrm{induced},k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0)$ is induced ($B_{\mathrm{induced}} \neq 0$) but the spin magnetic moment of an electron with opened- shell electronic structure is not changed ($\sigma_{\mathrm{spin}} = 0$). This is very similar to the diamagnetic currents in the superconductivity in that the supercurrents are induced ($\boldsymbol{v}_{\mathrm{em}} \neq 0$) but the total canonical momentum is zero ($\boldsymbol{p}_{\mathrm{canonical}} = 0$). The magnetic field is induced not because of the change of the each element of the spin magnetic moment of an electron (similar to the $\boldsymbol{p}_{\mathrm{canonica}}$ in the superconducting states) but because of the change of the total magnetic momentum as a whole (similar to the $\boldsymbol{v}_{\mathrm{em}}$ in the superconducting states).

On the other hand, such excited bosonic electronic state pairing of an electron with the induced magnetic fields $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, 0); B_{\mathrm{induced}}; 0)$ can be immediately destroyed because the initially applied electric field penetrates into the normal metallic specimen, and the electronic state becomes another bosonic excited supercurrent state for $j = 0$ ($\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); B_{\mathrm{induced}}; \boldsymbol{v}_{\mathrm{em}})$) (Fig. 2 (c)). In such a case, the $B_{\boldsymbol{k}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}})$ and

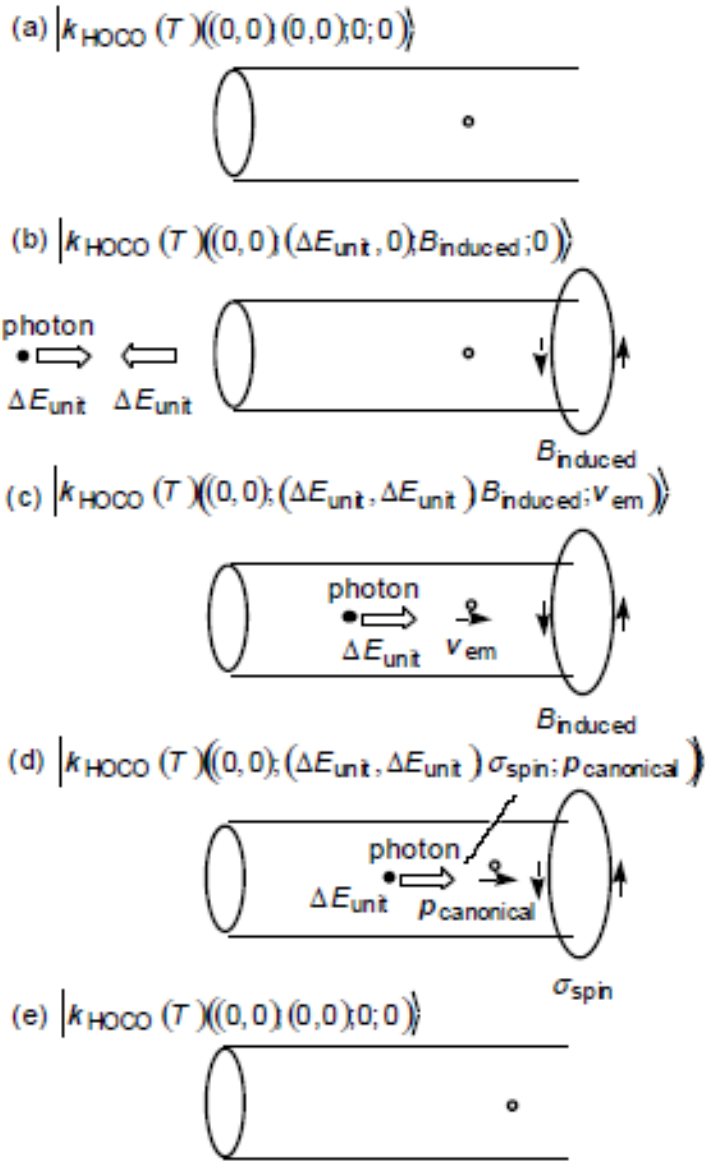

Figure 2: *The electronic states between j =0 and j = 1*

$I_{kHOCO}(\Delta E_{unit}, \Delta E_{unit})$ values for the $k_{HOCO}(T)((\Delta B_{unit},0);(\Delta E_{unit}, \Delta E_{unit}); B_{induced}; v_{em})$ state can be estimated as

$$B_{k_{HOCO}}(\Delta E_{unit}, \Delta E_{unit}) = B_{k_{HOCO}}(\Delta E_{unit}, 0)$$

$$= \{P_{\text{excited}}(T)c^2_{+k_{\text{HOCO}}\uparrow,0}(\Delta E_{\text{unit}})$$

$$+ P_{\text{ground}}(T)c^2_{-k_{\text{HOCO}}\uparrow,0}(\Delta E_{\text{unit}})$$

$$- \{P_{\text{excited}}(T)c^2_{-k_{\text{HOCO}}\downarrow,0}(\Delta E_{\text{unit}})$$

$$+ P_{\text{ground}}(T)c^2_{+k_{\text{HOCO}}\downarrow,0}(\Delta E_{\text{unit}})$$

$$= 2P_{\text{excited}}(T)\{c^2_{+k_{\text{HOCO}}\uparrow,0}(\Delta E_{\text{unit}})$$

$$- c^2_{-k_{\text{HOCO}}\downarrow,0}(\Delta E_{\text{unit}})$$

$$= B_{\text{induced}}\, k_{\text{HOCO}}\ (\Delta E_{\text{unit}}, 0) = \Delta B_{\text{unit}} \qquad (22)$$

$$I_{k_{\text{HOCO}}}(\Delta E_{\text{unit}}, \Delta E_{\text{unit}})$$

$$= v_{\text{em}}\, k_{\text{HOCO}}\ (\Delta E_{\text{unit}}, \Delta E_{\text{unit}}) = \Delta E_{\text{unit}} \qquad (23)$$

In the $k_{\text{HOCO}}(T)((0,0);(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); B_{\text{induced}}; v_{\text{em}})$ state, an electron receives the induced electric field ΔE_{unit}, and thus the superconducting current can be induced as a consequence of the electromotive force, and thus there is kinetic energy ($E_{\text{kineti}}(\Delta E_{\text{unit}}, \Delta E_{\text{unit}})$) of the super current.

That is, the expelling energy of the initially applied electric field ΔE_{unit} for the $k_{\text{HOCO}}(T)((0,0);(\Delta E_{\text{unit}}, 0); B_{\text{induced}}; 0)$ state is converted to the kinetic energy of the super current for the $k_{\text{HOCO}}(T)((0,0);(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); B_{\text{induced}}; v_{\text{em}})$ state. Both the super current ($v_{\text{em},k}(\Delta E_{\text{unit}}, \Delta E_{\text{unit}})$) and the magnetic field ($B_{\text{induced},k_{\text{HOCO}}}(\Delta E_{\text{unit}}, 0)$) can be induced under the condition of the closed-shell electronic structure with zero spin magnetic field and zero canonical momentum ($\sigma_{\text{spin}} = 0$; $p_{\text{canonical}} = 0$). This is the origin of the Ampère's law.

On the other hand, such excited bosonic normal metallic states with super currents($k_{\text{HOCO}}(T)((0,0);(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); B_{\text{induced}}; v_{\text{em}})$) can be immediately destroyed because of the unstable opened-shell electronic states subject to the external applied electric field, and the electronic

state becomes another excited fermionic normal metallic state for $j = 0$ ($\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); \sigma_{\mathrm{spin}}; \boldsymbol{p}_{\mathrm{canonical}})$) (Fig. 2 (d)). It should be noted that the electronic $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); \sigma_{\mathrm{spin}}; \boldsymbol{p}_{\mathrm{canonical}})$ state is now somewhat fermionic because the $\boldsymbol{p}_{\mathrm{canonica}}$ value is not 0. In other words, the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); \sigma_{\mathrm{spin}}; \boldsymbol{p}_{\mathrm{canonical}})$ state is closely related to the normal conducting states in that the normal metallic current with $\boldsymbol{p}_{\mathrm{canonical}} \neq 0$ and $\boldsymbol{v}_{\mathrm{em}} = 0$ is induced by the applied electric field. In such a case, the $B_{\boldsymbol{k}\,\boldsymbol{HOCO}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}})$ and $I_{\boldsymbol{kHOCO}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}})$ values for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); \sigma_{\mathrm{spin}}; \boldsymbol{p}_{\mathrm{canonical}})$ state can be estimated as

$$
\begin{aligned}
B_{k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}) &= B_{k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, 0) \\
&= \{P_{\mathrm{excited}}(T) c^2_{+k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
&\quad + P_{\mathrm{ground}}(T) c^2_{-k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
&\quad - \{P_{\mathrm{excited}}(T) c^2_{-k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
&\quad + P_{\mathrm{ground}}(T) c^2_{+k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
&= 2 P_{\mathrm{excited}}(T) \{c^2_{+k_{\mathrm{HOCO}}\uparrow,0}(\Delta E_{\mathrm{unit}}) \\
&\quad - c^2_{-k_{\mathrm{HOCO}}\downarrow,0}(\Delta E_{\mathrm{unit}}) \\
&= \sigma_{\mathrm{spin}} k_{\mathrm{HOCO}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}) = \Delta B_{\mathrm{unit}}, \qquad (24)
\end{aligned}
$$

$$
\begin{aligned}
&I_{k_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}) \\
&\quad = p_{\mathrm{canonical}} k_{\mathrm{HOCO}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}) = \Delta E_{\mathrm{unit}}, \qquad (25)
\end{aligned}
$$

Such excited fermionic normal metallic states with currents and the induced magnetic field ($\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); \sigma_{\mathrm{spin}}; \boldsymbol{p}_{\mathrm{canonical}})$) can be immediately destroyed because

of the unstable opened-shell electronic states subject to the external applied electric field, and the induced current and the magnetic field can be immediately destroyed. Therefore, the electronic state tries to go back to the original ground bosonic metallic state for $j = 0$ $(\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (0,0); 0; 0))$. In such a case, the $B_{\boldsymbol{kHOCO}}(0, 0)$ and $I_{\boldsymbol{kHOCO}}(0, 0)$ values for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (0,0); 0; 0)$ state can be estimated as Eqs. 18 and 19, respectively.

The ratio of the bosonic property $f_{\mathrm{Bose},\,\Delta E_{\mathrm{unit}}}$ as

$$f_{\mathrm{Bose},\Delta E_{\mathrm{unit}}}(0)$$

$$= \frac{1}{2} + c - k_{\mathrm{HOCO}}(\Delta E_{\mathrm{unit}})\sqrt{\frac{(\Delta E_{\mathrm{unit}})}{1 - c^2 - k_{\mathrm{HOCO}}}}$$

$$< f_{\mathrm{Bose},0}(0) = 1. \qquad (26)$$

The $f_{\mathrm{Bose},\,\Delta E_{\mathrm{unit}}}(0)$ value is smaller than the $f_{\mathrm{Bose},\,0}(0)$ value. It should be noted that the $f_{\mathrm{Bose},\,E_{\mathrm{in}}}(0)$ value decreases with an increase in the E_{in} value. That is, the bosonic and fermionic properties decrease and increase with an increase in the E_{in} value, respectively. In summary, because of the very large stabilization energy ($V_{\mathrm{kin,\,Fermi},\,\boldsymbol{k}_{\mathrm{HOCO}}\,\sigma}(0) \approx 35$ eV) for the Bose-Einstein condensation ($\boldsymbol{p}_{\mathrm{canonical}} = 0$; $V_{\mathrm{kin,\,Bose},\,\boldsymbol{k}_{\mathrm{HOCO}}\,\sigma}(0) = 0$ eV), the electric and magnetic momentum of a bosonic electronic state pairing of an electron cannot be changed but the magnetic field can be induced soon after the electric field is induced. Therefore, the electronic state becomes $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, 0); B_{\mathrm{induced}}; 0)$. On the other hand, such excited bosonic supercurrent states with the induced magnetic fields $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, 0); B_{\mathrm{induced}}; 0)$ can be immediately destroyed because the applied electric field penetrates into the normal metallic specimen, and the electronic state becomes another bosonic excited super current state for $j = 0$ ($\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); B_{\mathrm{induced}}; \boldsymbol{v}_{\mathrm{em}})$). In the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}}); B_{\mathrm{induced}}; \boldsymbol{v}_{\mathrm{em}})$ state, the super current can be induced, and thus there is kinetic energy ($E_{\mathrm{kinetic}}(\Delta E_{\mathrm{unit}}, \Delta E_{\mathrm{unit}})$).That is, the expelling energy of the initially applied electric field ΔE_{unit} for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)((0, 0); (\Delta E_{\mathrm{unit}},$

$0); B_{\text{induced}}; 0)$ state is converted to the kinetic energy of the super current for the $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0);$ $(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); B_{\text{induced}}; \boldsymbol{v}_{\text{em}})$ state. Both the super current ($\boldsymbol{v}_{\text{em},\boldsymbol{k}}(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}) \neq 0$) and the magnetic field ($B_{\text{induced}}, \boldsymbol{k}_{\text{HOCO}}(\Delta E_{\text{unit}}, 0) \neq 0$) can be induced under the condition of the opened-shell electronic structure with zero spin magnetic momentum and zero canonical momentum in a bosonic electronic state pairing of an electron ($\sigma_{\text{spin}} = 0$; $\boldsymbol{p}_{\text{canonical}} = 0$). This is the origin of the Ampère's law. On the other hand, such excited bosonic states with super currents $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}},$ $\Delta E_{\text{unit}}); B_{\text{induced}}; \boldsymbol{v}_{\text{em}})$ can be immediately destroyed because of the unstable opened-shell electronic states, and the electronic state becomes another excited fermionic normal metallic state for $j = 0$. ($\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); \sigma_{\text{spin}}; \boldsymbol{p}_{\text{canonical}})$). The excited fermionic normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)((0,$ $0); (\Delta E_{\text{unit}}, \Delta E_{\text{unit}}); \sigma_{\text{spin}}; \boldsymbol{p}_{\text{canonical}})$ state is very unstable and try to go back to the original ground bosonic metallic state for $j = 0$ ($\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (0,0); 0; 0)$), and the induced electrical current and the induced magnetic field can be immediately dissipated.

II. Energy Levels for Various Electronic States

Let us look into the energy levels for various electronic states when the applied electric field (E_{out}) increases from 0 to ΔE_{unit} at 0 K in superconductor, in which the HOCO is partially occupied by an electron. The total energy $E_{\text{total}}(x_{\text{out}}, x_{\text{in}})$ for various electronic states with respect to the Fermi level before electron-phonon interactions at 0 K and $x_{\text{out}} = x_{\text{in}} = 0$ (Fig. 1) can be expressed as

$$E_{\text{total}}(x_{\text{out}}, x_{\text{in}}) = E_{\text{SC}}(x_{\text{out}}, x_{\text{in}}) - E_{\text{NM}}(0, 0)$$

$$= E_{\text{electronic}}(x_{\text{out}}, x_{\text{in}}) + E_{\text{magnetic}}(x_{\text{out}}, x_{\text{in}}) \quad (27)$$

At $E_{\text{out}} = E_{\text{in}} = 0$, the electronic state is in the ground normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (0, 0);$ $0; 0)$ state for $j = 0$. The electronic and magnetic energies for the $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (0, 0); 0; 0)$ state can be expressed as

$$E_{\text{electronic}}(0, 0) = -2V_{\text{one}} f_{\text{Bose},0}(0) = -2V_{\text{one}} \quad (28)$$

$$E_{\text{magnetic}}(0, 0) = 0. \quad (29)$$

The $E_{\text{electronic}}(\Delta E_{\text{unit}}, 0)$ value for the $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}}, 0); B_{\text{induced}}; 0)$ state can be

estimated as

$$\begin{aligned} & E_{\text{electronic}}(\Delta E_{\text{unit}}, 0) \\ & = -2V_{\text{one}} f_{\text{Bose},0}(0) + E_{I_{k_{\text{HOCO}}}}(\Delta E_{\text{unit}}, 0) \\ & = -2V_{\text{one}} f_{\text{Bose},0}(\Delta E_{\text{unit}}), \end{aligned} \tag{30}$$

where the $E_{IkHOCO}(\Delta E_{\text{unit}}, 0)$ value denotes the expelling energy of the applied electric field, and is estimated

$$\begin{aligned} & E_{I_{k_{\text{HOCO}}}}(\Delta E_{\text{unit}}, 0) = 2V_{\text{one}}\left(f_{\text{Bose},0}(0) - f_{\text{Bose},0}(\Delta E_{\text{unit}})\right) \\ & = 2V_{\text{one}}\left(1 - f_{\text{Bose},0}(\Delta E_{\text{unit}})\right). \end{aligned} \tag{31}$$

Furthermore, we must consider the magnetic energy ($E_{\text{magnetic}}(\Delta E_{\text{unit}}, 0)$) for the induced magnetic field ΔB_{unit} as a consequence of the applied electric field ΔE_{unit},

$$\begin{aligned} E_{\text{magnetic}}(\Delta E_{\text{unit}}, 0) &= E_{B\,induced}(\Delta E_{\text{unit}}, 0) \\ &= \frac{1}{2}\mu_0 \Delta B^2_{\text{unit}} \, v_{SC} \end{aligned} \tag{32}$$

where the μ_0 denotes the magnetic permeability in vacuum, and the v_{SC} denotes the volume of the specimen. The total energy level for the $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}}, 0); B_{\text{induced}}; 0)$ state can be estimated as

$$\begin{aligned} & E_{\text{total}}(\Delta E_{\text{unit}}, 0) \\ & = E_{\text{electronic}}(\Delta E_{\text{unit}}, 0) + E_{\text{magnetic}}(\Delta E_{\text{unit}}, 0) \\ & = -2V_{\text{one}} f_{\text{Bose},0}(\Delta E_{\text{unit}}) + \frac{1}{2}\mu_0 \Delta B^2_{\text{unit}} \, v_{SC} \end{aligned} \tag{33}$$

We can consider from Eqs 30–33 that the energy for the excited normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}}, 0); B_{\text{induced}}; 0)$ state is $-2V_{\text{one}}$ with the expelling energy of the applied electric field $2V_{\text{one}}(f_{\text{Bose},0}(0) - f_{\text{Bose},0}(\Delta E_{\text{unit}}))$ and the energy of the induced magnetic field $E_{\text{magnetic}}(\Delta E_{\text{unit}}, 0)$, and thus the total energy for the bosonic excited normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)((0, 0); (\Delta E_{\text{unit}}, 0); B_{\text{induced}}; 0)$ state is $-2V_{\text{one}} f_{\text{Bose},0}(\Delta E_{\text{unit}}) + E_{Binduced}(\Delta E_{\text{unit}}, 0)$.

In other words, the energy for the initially applied electric field ΔE_{unit} is converted to the energy of the electromotive force $2V_{\text{one}}\left(f_{\text{Bose, 0}}(0) - f_{\text{Bose , 0}}\left(\Delta E_{\text{unit}}\right)\right)$ and the energy of the induced magnetic field $E_{B_{\text{induced}}}\left(\Delta E_{\text{unit}}, 0\right)$.

The $E_{\text{electronic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$ value for the $\boldsymbol{k}_{\text{HOCO}}(T)\left((0, 0); \left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right); B_{\text{induced}}; \boldsymbol{\nu}_{\text{em}}\right)$ state can be estimated as

$$E_{\text{electronic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= -2V_{\text{one}} f_{\text{Bose,0}}(0) + E_{\boldsymbol{\nu}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= -2V_{\text{one}} f_{\text{Bose,0}}\left(\Delta E_{\text{unit}}\right), \qquad (34)$$

where the $E_{\text{vem}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$ value denotes the kinetic energy of the supercurrent, and is estimated as

$$E_{\boldsymbol{\nu}\text{em}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= 2V_{\text{one}}\left(f_{\text{Bose ,0}}(0) - f_{\text{Bose ,0}}\left(\Delta E_{\text{unit}}\right)\right)$$

$$= 2V_{\text{one}}\left(1 - f_{\text{Bose ,0}}\left(\Delta E_{\text{unit}}\right)\right). \qquad (34)$$

Furthermore, we must consider the magnetic energy $\left(E_{\text{magnetic}}\left(\Delta E_{\text{unit}}, 0\right)\left(= E_{\text{magnetic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)\right)\right.$ for the induced magnetic field ΔB_{unit} as a consequence of the applied electric field ΔE_{unit},

$$E_{\text{magnetic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right) = E_{\text{magnetic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= E_{B_{\text{induced}}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= \frac{1}{2}\mu_0 \Delta B^2_{\text{unit}}\, v_{\text{SC}}, \qquad (36)$$

The total energy level for the $\boldsymbol{k}_{\text{HOCO}}(T)\left((0, 0); \left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right); B_{\text{induced}}; \boldsymbol{\nu}_{\text{em}}\right)$ state can be estimated as

$$E_{\text{total}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= E_{\text{electronic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right) + E_{\text{magnetic}}\left(\Delta E_{\text{unit}}, \Delta E_{\text{unit}}\right)$$

$$= -2V_{\text{one}} f_{\text{Bose, 0}}\left(\Delta E_{\text{unit}}\right) + \frac{1}{}\mu_0 \Delta B^2 \quad v$$

$$2 \qquad \text{unit SC} \tag{37}$$

We can consider from Eqs 34–37 that the energy level for the excited normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)\left((0,0);(\Delta E_{\text{unit}},\Delta E_{\text{unit}});B_{\text{induced}};\boldsymbol{\nu}_{\text{em}}\right)$ state is $-2V_{\text{one}}$ with the kinetic energy of the supercurrent $2V_{\text{one}}\left(f_{\text{Bose},0}(0)-f_{\text{Bose},0}(\Delta E_{\text{unit}})\right)$ and the energy of the induced magnetic field $E_{Bk\,HOCO}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$, and thus the total energy for the bosonic excited normal metallic $\boldsymbol{k}_{\text{HOCO}}(T)\left((\Delta B_{\text{unit}},0);(\Delta E_{\text{unit}},\Delta E_{\text{unit}});B_{\text{induced}};\boldsymbol{\nu}_{\text{em}}\right)$ state is $-2V_{\text{one}}f_{\text{Bose},0}(\Delta E_{\text{unit}})+E_{BHOCO}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$. In other words, the energy for the initially applied electric field ΔE_{unit} is converted to the energy of kinetic energy of the supercurrent $2V_{\text{one}}\left(f_{\text{Bose},0}(0)-f_{\text{Bose},0}(\Delta E_{\text{unit}})\right)$ and the energy of the induced magnetic field $E_{B_{\text{induced}}}(\Delta E_{\text{unit}},0)$.

The $E_{\text{electronic}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$ value for the $\boldsymbol{k}_{\text{HOCO}}(T)\left((0,0);(\Delta E_{\text{unit}},\Delta E_{\text{unit}});\sigma_{\text{spin}};\boldsymbol{p}_{\text{canonical}}\right)$ state can be estimated as

$$\begin{aligned}&E_{\text{electronic}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})\\&=-2V_{\text{one}}f_{\text{Bose},0}(0)+E_{\boldsymbol{p}\,\text{canonical}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})\\&=-2V_{\text{one}}f_{\text{Bose},0}(\Delta E_{\text{unit}}),\end{aligned} \tag{38}$$

where the $E_{\boldsymbol{p}\,\text{canonical}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$ value denotes the kinetic energy of the normal current, and is estimated as

$$\begin{aligned}&E_{\boldsymbol{p}\,\text{canonical}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})\\&=2V_{\text{one}}\left(f_{\text{Bose},0}(0)-f_{\text{Bose},0}(\Delta E_{\text{unit}})\right)\\&=2V_{\text{one}}\left(1-f_{\text{Bose},0}(\Delta E_{\text{unit}})\right)\end{aligned} \tag{39}$$

Furthermore, we must consider the magnetic energy ($E_{\text{magnetic}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$) as a consequence of the induced spin magnetic energy $E_{\sigma spinHOMO}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})$,

$$\begin{aligned}&E_{\text{magnetic}}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})\\&=E_{\sigma\,spinHOMO}(\Delta E_{\text{unit}},\Delta E_{\text{unit}})=\frac{1}{2}\mu_0\Delta B^2\quad v\end{aligned} \tag{40}$$

$$\text{unit SC}$$

The total energy level for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});\sigma_{\mathrm{spin}};\boldsymbol{p}_{\mathrm{canonical}}\right)$ state can be estimated as

$$\begin{aligned} & E_{\mathrm{total}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}}) \\ & = E_{\mathrm{electronic}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}}) + E_{\mathrm{magnetic}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}}) \\ & = -2V_{\mathrm{one}} f_{\mathrm{Bose},0}(\Delta E_{\mathrm{unit}}) + \frac{1}{2}\mu_0 \Delta B^2 \quad v_{\mathrm{unit\,SC}} . \end{aligned} \tag{41}$$

We can consider from Eqs 38–41 that the energy level for the excited normal metallic $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});\sigma_{\mathrm{spin}};\boldsymbol{p}_{\mathrm{canonical}}\right)$ state is $-2V_{\mathrm{one}}$ with the kinetic energy of the normal current $2V_{\mathrm{one}}\left(f_{\mathrm{Bose},0}(0) - f_{\mathrm{Bose},0}(\Delta E_{\mathrm{unit}})\right)$ and the energy of the induced magnetic field $E_{B_{\boldsymbol{k}_{\mathrm{HOCO}}}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}})$, and thus the total energy for the bosonic excited normal metallic $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((\Delta B_{\mathrm{unit}},0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});\sigma_{\mathrm{spin}};\boldsymbol{p}_{\mathrm{canonical}}\right)$ state is $-2V_{\mathrm{one}} f_{\mathrm{Bose},0}(\Delta E_{\mathrm{unit}}) + E_{\sigma signHOCO}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}})$. In other words, the energy for the initially applied electric field ΔE_{unit} is converted to the energy of kinetic energy of the normal current $2V_{\mathrm{one}}\left(f_{\mathrm{Bose},0}(0) - f_{\mathrm{Bose},0}(\Delta E_{\mathrm{unit}})\right)$ and the energy of the induced spin magnetic moment $E_{\sigma signHOCO}(\Delta E_{\mathrm{unit}},0)$.

On the other hand, such excited states with currents can be immediately destroyed because of the unstable opened-shell electronic states, and the induced current and magnetic field can be immediately destroyed, and the electronic state goes back to the original ground bosonic metallic state for j = 0. Therefore, we can consider that the energy for the initially applied electric field ΔE_{unit} is converted to photon emission energy and the Joule's heats.

III. Ampère's Law in the Two-Electrons Systems in Superconductivity

Similar discussions can be made in the two- electrons systems in superconductivity. Because of the very large stabilization energy ($2V_{\mathrm{kin,Fermi},\boldsymbol{k}\,\sigma HOCO}(0) \approx 70$ eV) for the Bose–Einstein condensation ($\boldsymbol{p}_{\mathrm{canonical}} = 0$; $V_{\mathrm{kin,\,Bose},\,\boldsymbol{k}_{\mathrm{HOCO}}\,\sigma}(0) = 0$ eV), the electric and magnetic momentum of a bosonic Cooper pair cannot be changed but the magnetic field can be induced soon after the electric field is induced. Therefore, the electronic state becomes $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},0);B_{\mathrm{induced}};0\right)$. On the other hand, such excited bosonic supercurrent states with the induced magnetic fields

$\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},0);B_{\mathrm{induced}};0\right)$ can be immediately destroyed because the applied electric field penetrates into the superconducting specimen, and the electronic state becomes another bosonic excited supercurrent state for $j=0$ ($\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});B_{\mathrm{induced}};\boldsymbol{v}_{\mathrm{em}}\right)$). In the $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});B_{\mathrm{induced}};\boldsymbol{v}_{\mathrm{em}}\right)$ state, the supercurrent can be induced, and thus there is kinetic energy ($E_{\mathrm{kinetic}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}})$). That is, the expelling energy of the initially applied electric field ΔE_{unit} for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},0);B_{\mathrm{induced}};0\right)$ state is converted to the kinetic energy of the supercurrent for the $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});B_{\mathrm{induced}};\boldsymbol{v}_{\mathrm{em}}\right)$ state. Both the supercurrent ($\boldsymbol{v}_{\mathrm{em},\boldsymbol{k}}(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}})\neq 0$) and the magnetic field ($B_{\mathrm{induced},\boldsymbol{k}_{\mathrm{HOCO}}}(\Delta E_{\mathrm{unit}},0)\neq 0$) can be induced under the condition of the closed-shell electronic structure with zero spin magnetic field and zero canonical momentum in a bosonic Cooper pair ($\sigma_{\mathrm{spin}}=0$; $\boldsymbol{p}_{\mathrm{canonical}}=0$). Such excited bosonic states with supercurrents $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});B_{\mathrm{induced}};\boldsymbol{v}_{\mathrm{em}}\right)$ cannot be destroyed because of the stable closed-shell electronic states, and thus the induced supercurrent and magnetic field cannot be dissipated. That is, the excited bosonic superconducting $\boldsymbol{k}_{\mathrm{HOCO}}(T)\left((0,0);(\Delta E_{\mathrm{unit}},\Delta E_{\mathrm{unit}});B_{\mathrm{induced}};\boldsymbol{v}_{\mathrm{em}}\right)$ state is very stable and do not try to go back to the original ground bosonic superconducting state for $j=0$, and the induced electrical current and the induced magnetic field cannot be dissipated. This is the origin of the Ampère's law observed in the superconductivity.

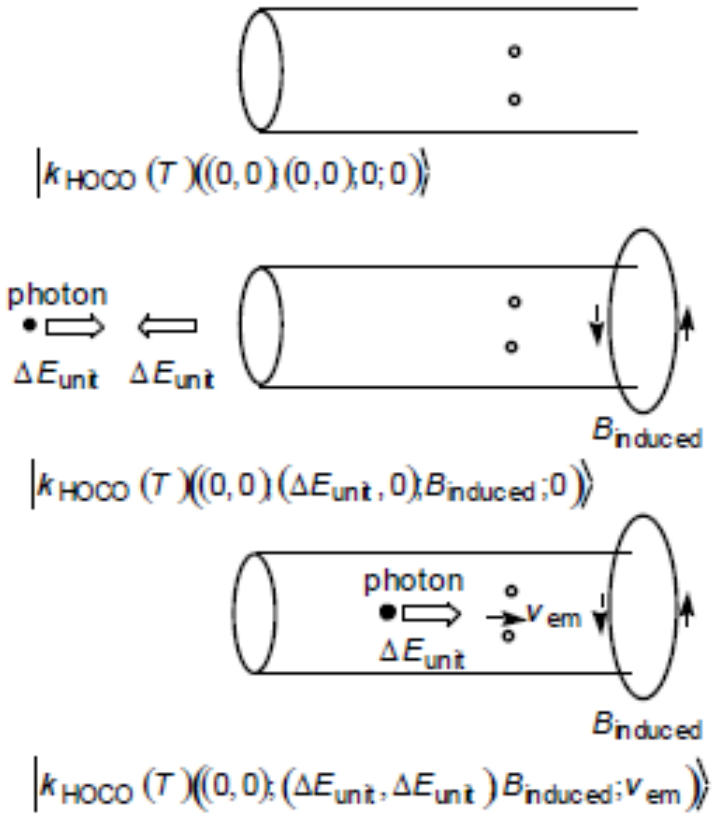

Figure 3: *The electronic states between j =0 and j = 1 in superconductivity*

IV. Ampère's Law in an Electron Traveling in Vacuum

Let us next consider the Ampère's law in vacuum. We consider that there is a reference electron in metal. If very strong electric field is applied to a reference electron, this electron behaves according to the Ampère's law in metal, as discussed in the previous section. On the other hand, once the electron moves away from the metal, and goes into the vacuum, there is no reason (electrical resistivity and Stern–Gerlach effect, etc.) that the electron moving is dissipated. Therefore, the electron moves in vacuum with electrical momentum ($v_{\text{em}} \neq 0$) and the induced magnetic field ($B_{\text{induced}} \neq 0$). This is the Ampère's law observed in the traveling charged particles such as electrons in vacuum.

V. Reconsideration of the Ampère's Law

According to the conventional empirical Ampère's law, it has been considered that any moving charged particle itself creates a magnetic field. On the other hand, according to our theory, the magnetic field originating from the magnetic moment of electron may be induced in order that the photon becomes massive (that is, electric field is expelled from the specimen) by

absorbing Nambu–Goldstone boson formed by the fluctuation of the electronic state pairing of an electron, because of the very large stabilization energy ($V_{\text{kin, Fermi, }\boldsymbol{k}_{\text{LUCO}}\sigma}(0) \approx 35$ eV) for the Bose–Einstein condensation ($\boldsymbol{p}_{\text{canonical}}= 0$; $V_{\text{kin, Bose, }\boldsymbol{k}_{\text{LUCO}}\sigma}(0)= 0$ eV), and the Stern–Gerlach effect. The initial electronic state tries not to change the electronic structure ($\boldsymbol{p}_{\text{canonical}}= 0$) by induction of the magnetic field. After that, the photon becomes massless (electric field can penetrate into the specimen), and thus the electrical current can be induced. Therefore, the induced electrical current as well as the magnetic field can be observed. This is the reason why we can observe that any moving charged particle seems to create a magnetic field, as explained by the Ampère's law. On the other hand, such electrical currents as well as the induced magnetic fields can be immediately disappeared because of the unstable opened-shell electronic states subject to the external applied electric field. And at the same time, photon is emitted from an electron and this is the origin of the electrical resistivity. This process can be continuously repeated while the external applied electric field continues to be applied. That is, according to our theory, the electrical current (i.e., moving charged particle) itself is not directly related to the creation of the magnetic field. The induced magnetic field in the Ampère's law is realized because the bosonic electronic state tries not to change the electronic structure ($\boldsymbol{p}_{\text{canonical}}= 0$ and $\boldsymbol{v}_{\text{em}} = 0$) by inducing the spin magnetic field B_{induce}. If an electron is not in the bosonic state, the applied electric field immediately penetrates into the specimen as soon as the electric field is applied, and any induced magnetic momentum (the induced magnetic field) even in the normal metals, expected from the Ampère's law, would not be observed. This bosonic electron is closely related to the Higgs boson.

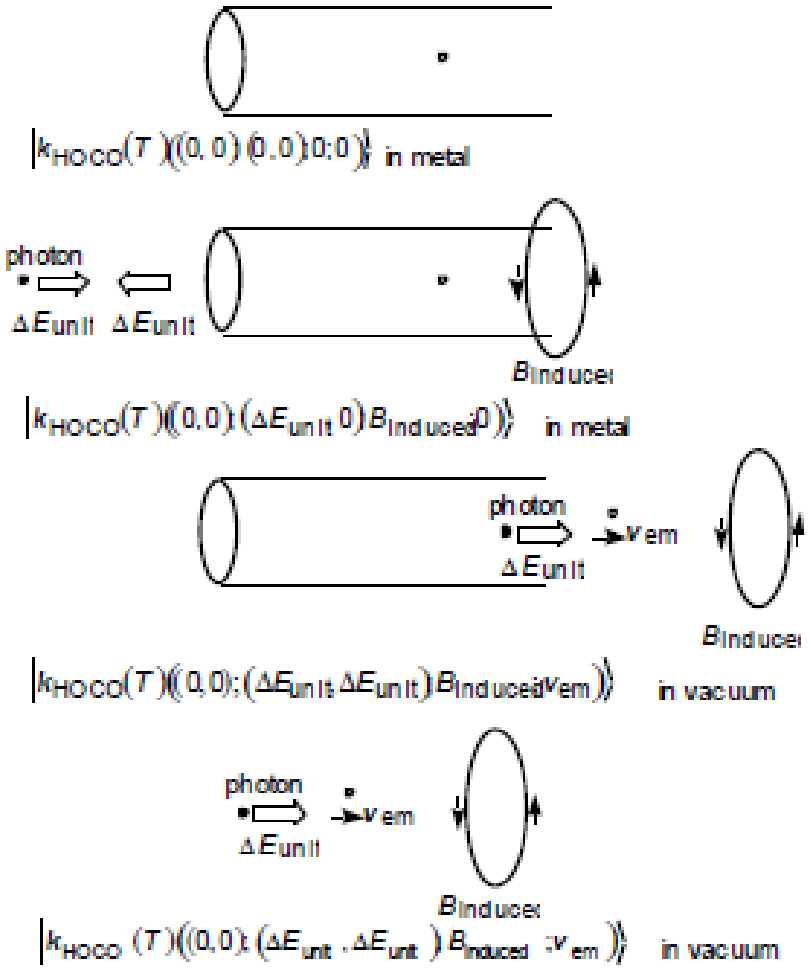

Figure 4: *The electronic states between j =0 and j = 1 in from normal metal to vacuum*

VI. The Role of the Stern-Gerlach Effects in Metals

A. Introduction

In both normal metallic and superconducting states, an electrical current can be induced only when an external electric or magnetic field is applied, and to our knowledge, the possibility of spontaneous currents without the application of an external electric or magnetic field has not been thoroughly investigated. The electrical conductivity of many electrons in a solid has long been discussed from the microscopic perspective. In conventional solid state physics, we cannot expect spontaneous net charge transfer in any direction without the application of an external electric or magnetic field; this understanding does not arise from the perspective of the intrinsic features of an electron, but from the perspective of the statistics of many electrons in a solid. However, we cannot explain why we do not observe spontaneous net charge transfer of *a single electron* in any direction without an applied electric or magnetic field from a statistical

perspective because we consider *only one electron*. That is, the driving force that suppresses the spontaneous current of a single electron has not been elucidated. In this research, we investigate the electrical conductivity of a single electron from a microscopic perspective. We demonstrate why we do not usually observe spontaneous currents without an external applied magnetic or electric field in view of the Stern–Gerlach effect, that is, in view of the interactions between the spin magnetic momentum and the induced magnetic momentum resulting from the movement of an electron. Furthermore, we show that the two-fluid model, which has been widely considered in the solid state physics, is not necessarily realistic. We will consider the theory concerning the Ampère's law discussed in the previous sections.

B. Induced Ring Currents and Magnetic Fields

Let us consider a neutral alkali metal atom in which an electron occupies the *ns* atomic orbital. If the *ns* valence electron goes around the atomic nucleus clockwise or counter-clockwise, we can also consider that the nucleus relatively goes around the *ns* valence electron clockwise or counter-clockwise, respectively. Ring currents ($I_{\mathrm{ring},ns,\,\mathrm{X}}$) arise from such relative movements of the nucleus around the *ns* valence electron. The magnetic field ($B_{\mathrm{ring},ns,\,\mathrm{X}}$) is induced by the relative motion of the nucleus around the *ns* valence electron.

C. Stabilization Energy as a Consequence of the Stern–Gerlach Effect

Because electrons have a spin magnetic moment ($s_{ns,\mathrm{X}}$), there should be an interaction between the spin magnetic moment of an electron occupying the *ns* atomic orbital and the magnetic field ($B_{\mathrm{ring},ns,\,\mathrm{X}}$) induced by the ring currents due to the relative motion of the nucleus around the *ns* electron. This interaction removes some of the energy level degeneracies ($\boldsymbol{k}_{ns,\,\mathrm{X,ground}}$ and $\boldsymbol{k}_{ns,\,\mathrm{X,excited}}$). Because the removal of degeneracies creates new, distinct energy levels, the spectrum of the alkali metal atom should change accordingly. This change can be explained by the Stern–Gerlach effect.

D. Electronic States as a Function of Temperature

Let us next examine the relationship between temperature and the electronic states of the *ns* valence electrons in alkali metal atoms. The electronic states in the *ns* valence electrons in alkali metal atoms at T (given in K) can be expressed by $\boldsymbol{K}_{\mathrm{one},ns\,,\mathrm{X}}(T) = a_{\boldsymbol{k}}(T)\,\boldsymbol{k}_{ns,\,\mathrm{X,ground}} + a_{\boldsymbol{k}}$ (T) $\mathrm{k_{ns,\,X,\,excited}} = 1 - P_{\boldsymbol{k}_{ns,\mathrm{X,excited}}}(T)\,\boldsymbol{k}_{ns\,,\mathrm{X,\,ground}} + P_{\boldsymbol{k}_{ns,\mathrm{X,excited}}}(T)\boldsymbol{k}_{ns,\,\mathrm{X,excited}}$, where $\boldsymbol{k}_{ns,\,\mathrm{X,ground}} = c_{+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow}+\boldsymbol{k}_{ns\,,\mathrm{X}}\downarrow + c_{-\,\boldsymbol{k}_{ns\,,\mathrm{X}}\uparrow}-\boldsymbol{k}_{ns\,,\mathrm{X}}\uparrow$ and $\boldsymbol{k}_{ns,\,\mathrm{X,excited}} = c_{+\boldsymbol{k}_{ns\,,\mathrm{X}}\uparrow}+\boldsymbol{k}_{ns\,,\mathrm{X}}\uparrow + c_{-\,\boldsymbol{k}_{ns,\mathrm{X}}\downarrow}-\boldsymbol{k}_{ns,\,\mathrm{X}}\downarrow$. If no external electric or magnetic field is applied ($x_{\mathrm{external}} = 0$), the *ns* valence electron is in one of four electronic states ($+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$, $-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$, $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$, and $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$), and the two electronic states in the ground and excited electronic states rapidly and evenly convert ($c_{+\boldsymbol{k}_{ns\,,\mathrm{X}}\downarrow} = c_{-\boldsymbol{k}_{ns\,,\mathrm{X}}\uparrow} = 1/\,2$;

$c_{+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow} = c_{-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow} = 1/\sqrt{2}$) at relatively high temperatures.

The direction of the spin magnetic moment ($s_{ns,\mathrm{X}}$) in the $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ states becomes opposite to that of the induced magnetic field ($B_{\mathrm{ring},ns,\mathrm{X}}$) applied to the *ns* valence electron. In contrast, the direction of the spin magnetic moment ($s_{ns,\mathrm{X}}$) in the $+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ states becomes the same as that of the induced magnetic field ($B_{\mathrm{ring},ns,\mathrm{X}}$) applied to the *ns* valence electron. Therefore, the $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ states become unstable in energy relative to the $+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ states. Therefore, the $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ states are the excited electronic states whereas the $+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ and $-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ states are the ground electronic states. The energy curve for the excited electronic states at 298 K becomes parabolic. Therefore, the H 1*s*, Li 2*s*, Na 3*s*, and K 4*s* valence electrons are in the excited electronic states $\boldsymbol{k}_{ns,\mathrm{X,excited}}\left(=\left(+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow + -\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right)/\sqrt{2}\right)$ (approximately 50 %) and in the ground electronic states $\boldsymbol{k}_{ns,\mathrm{X,ground}}$ $\left(=\left(+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow + -\boldsymbol{k}_{ns,\mathrm{X}}\uparrow\right)/\sqrt{2}\right)$ at 298 K. Additionally, at very low temperatures, spontaneous symmetry breaking can occur, and the energy curve for the ground electronic states at very low temperatures becomes Mexican hat-shaped.

E. Intrinsic Properties of a Single Electron at High Temperatures

When an *ns* valence electron in alkali metal atom X moves around the nucleus clockwise at 298 K, the electronic state for the *ns* valence electron in the alkali metal atom X is in the excited $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ state and the ground $+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ state. The magnetic fields ($B_{\mathrm{ring},ns,\mathrm{X}}$) induced by the ring currents caused by the relative motion of the nucleus around the H 1*s*, Li 2*s*, Na 3*s*, and K 4*s* valence electron are moderate or strong (in the order of 0.1~1 T). The direction of the spin magnetic moment ($s_{ns,\mathrm{X}}$) in the $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ states (up) becomes opposite to the direction of the induced magnetic field ($B_{\mathrm{ring},ns,\mathrm{X}}$) applied to the *ns* valence electron (down). Therefore, it is reasonable to consider that the excited $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ state with spin up changes to the excited $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ state with spin down. That is, once the *ns* valence electron starts to move clockwise, a strong magnetic field is induced and causes the excited electronic states with clockwise movement to become unstable, and thus, the *ns* valence electron starts to move counter-clockwise. In a similar way, conversion from counter-clockwise movement to clockwise movement can occur. For this reason, spontaneous currents do not usually exist at room temperature.

Therefore, the spin magnetic moment ($s_{ns,\mathrm{X}}$) in an electron, or more specifically, the Stern-Gerlach effect, is the primary reason that the spontaneous current is suppressed at room temperature. Note that we cannot explain this phenomenon from a statistical perspective but

from the perspective of the intrinsic features (the spin magnetic moment) of an electron. If electrons did not have a spin magnetic moment ($s_{ns,X}$), spontaneous currents would occur even at high temperatures.

On the other hand, it should be also noted that electrons are waves as well as particles. Therefore, we may consider the bosonic resonance effects between the fermionic $+\boldsymbol{k}_{ns,X}\uparrow$ and $-\boldsymbol{k}_{ns,X}\downarrow$ states. That is, we must consider that the $+\boldsymbol{k}_{ns,X}\uparrow$ and $-\boldsymbol{k}_{ns,X}\uparrow$ states occur at the same time as a wave. In such a case, the moderate and strong magnetic fields and ring currents, and photoemission from an accelerated electron cannot be observed even during very short time. That is, the electronic states for an electron is composed of each fermionic electronic states, on the other hand, the two electronic states are resonance states formed by these fermionic electronic states. Therefore, even an electron can be considered to behave as a bosonic particle with zero canonical momentum ($\boldsymbol{p}_{\text{canonical}}= 0$) at the ground states. This is the reason why an electron occupying the *ns* orbital are in the stable ground state, and does not approach the nucleus with photon emission. If an electron occupying the *ns* orbital were fermionic, this electron would approach the nucleus with photon emission when conversion between the $+\boldsymbol{k}_{ns,X}\uparrow$ and $-\boldsymbol{k}_{ns,X}\downarrow$ states occurs.

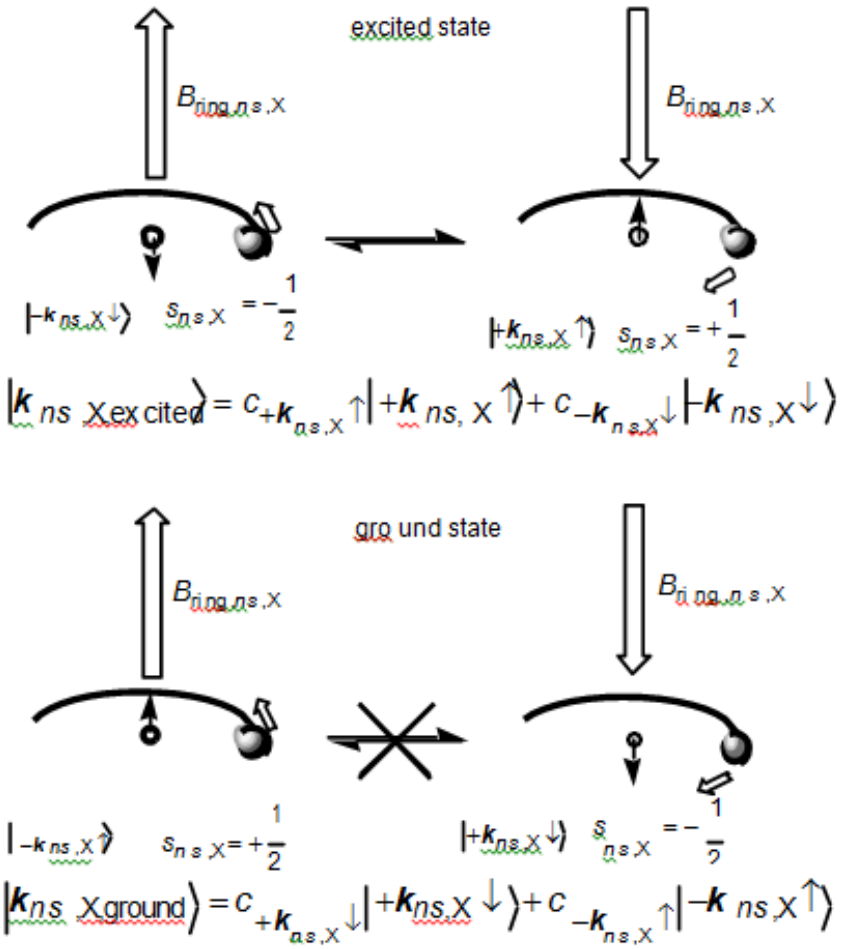

Figure 5: *The Stern-Gerlach effect*

F. Summary

In this section, we looked into the electrical conductivity of one electron from the microscopic point of view. That is, we investigated the reason why we do not usually observe the spontaneous currents without any external applied electric or magnetic field. In particular, as simple examples, we look into the one-*ns* valence electronic states in alkali metal atoms such as H, Li, Na, and K atoms, in which we do not have to consider the vibronic interactions.

The direction of the spin magnetic moment ($s_{ns,X}$) in the $+k_{ns,X}\uparrow$ and $-k_{ns,X}\downarrow$ states becomes opposite with respect to that of the induced magnetic field ($B_{ring,ns,X}$) applying to the *ns* valence electron. The excited $+k_{ns,X}\uparrow$ state with up spin is changed to the excited $-k_{ns,X}\downarrow$ state with down spin. That is, once the *ns* valence electron starts to move clockwise, strong magnetic field, by which the excited electronic states of clockwise movement become unstable, is induced, and thus the *ns* valence electron starts to move counter- clockwise. Similar discussions can be

made in the conversion from the excited $-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow$ state to the $+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow$ state. The spin magnetic moment ($s_{ns,\mathrm{X}}$) in an electron is the main reason why the spontaneous current is suppressed at room temperatures. That is, the Stern–Gerlach effect is the main reason why the spontaneous currents usually do not exist at room temperatures.

Most of H 1*s*, Li 2*s*, Na 3*s*, and K 4*s* valence electrons are in the ground states at the temperatures of the order of 10^{-1} K. The electronic state for the *ns* valence electron in alkali metal atom X is mainly in the ground state, and is only rarely in the excited state at the low temperature regime. At very low temperatures, spontaneous symmetry breaking can occur, spontaneous current can occur.

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