RELATIONSHIPS BETWEEN THE NORMAL METALLIC AND SUPERCONDUCTING STATES

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Abstract- Relationships between the normal metallic states and superconducting states are investigated. Difference between the magnetic field which is applied to the excited electronic state, and the magnetic field for the ground states to which the electronic state belongs, rather than the changes of the applied magnetic fields, is the origin of the electromotive forces.

Keywords- Cooper pairs; Higgs Mechanism; Lenz'law; Meissner Effects

I. INTRODUCTION

According to the Lenz's law, the magnetic field would penetrate into the sample completely even below T_C when the magnetic field does not change during temperature decreasing process. On the other hand, it has been well known that the magnetic field cannot penetrate into the sample at all well below T_C, according to the Meissner effect. That is, the unified interpretation between the Lenz's law and the Meissner effect has not been completely established. Therefore, we try to establish the unified interpretations between them.

II. ONE ELECTRON SYSTEMS

The $B_{\boldsymbol{k}_{\mathrm{LUCO}}}(B_{\mathrm{out}}, B_{\mathrm{in}})$ value, denoting the magnetic field penetrating into the specimen, under the strengths of the external applied magnetic field of B_{out}, applying to the ground electronic states under the magnetic field B_{in}, can be defined as $\left(1-\delta_{B_{\mathrm{out}},B_{\mathrm{in}}}\right)B_{\mathrm{in}}+\delta_{B_{\mathrm{out}},B_{\mathrm{in}}}B_{\mathrm{out}}$. The energy for induced currents $I_{\boldsymbol{k}_{\mathrm{LUCO}}}(B_{\mathrm{out}}, B_{\mathrm{in}})$ under the $B_{\boldsymbol{k}_{\mathrm{LUCO}}}(B_{\mathrm{out}}, B_{\mathrm{in}})$ value are estimated to be the $2V_{\mathrm{one}}\left(f_{\mathrm{Bose}}(B_{\mathrm{in}})-f_{\mathrm{Bose}}(B_{\mathrm{out}})\right)$ value. The ratio of the bosonic property of an electron in specimen under the internal magnetic field B_{in} can be denoted as $f_{\mathrm{Bose}}(B_{\mathrm{in}})$.

A. Electronic States

Let us next apply the Higgs mechanism in superconductivity to the Lenz's law in the normal metallic states. Let us next consider the superconductor, the critical field of which is B_{c}. Even at 0 K, the one-bosonic normal metallic particle states are in the normal metallic states. We consider that the magnetic field is quantized by $\Delta B_{\mathrm{unit}}(=B_{\mathrm{c}}/n_{\mathrm{c}})$. The n_{c} value is very large and the quantization value of $B_{\mathrm{c}}/n_{\mathrm{c}}$ is very small ($B_{\mathrm{c}}/n_{\mathrm{c}}\approx 0$). That is, the jth quantized magnetic field B_j with respect to the zero magnetic field can be defined as $B_j = j\Delta B_{\mathrm{unit}}$. Even though we consider molecular systems as example, for simplicity from the point of view of mathematics, similar discussions can be made in solids.

Without any external applied magnetic field ($j=0$; $B_{\mathrm{out}}=B_{\mathrm{in}}=0$), the ratio of the bosonic property under the internal magnetic field 0 can be estimated to be $f_{\mathrm{Bose}}(0)=1$. Therefore, one-bosonic normal metallic particle state behaves as a boson. In such a case, there is no induced current and the magnetic fields, as expected, , and $I_{\boldsymbol{k}_{\mathrm{LUCO}}}(0,0)$ $\propto 2V_{\mathrm{one}}\left(f_{\mathrm{Bose}}(0)-f_{\mathrm{Bose}}(0)\right)=0$. This is the bosonic ground normal metallic states for $j=0$ ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(0,0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$). It should be noted that the electronic states are in the ground normal metallic states when both the and $\boldsymbol{v}_{\mathrm{em}}$ values are 0, and are in the excited normal metallic states when the $\boldsymbol{p}_{\mathrm{canonical}}$ or $\boldsymbol{v}_{\mathrm{em}}$ values are not 0.

Let us next consider the case where the applied magnetic field (B_{out}) increases from 0 to ΔB_{unit}. When the B_{out} value changes from 0 to ΔB_{unit}, a Nambu–Goldstone boson formed by the fluctuation of the bosonic electronic state pairing of an electron () is absorbed by a photon. A photon absorbing a Nambu–Goldstone boson interacts with the induced electrical currents. Therefore, a photon has finite mass as a consequence of interaction with the Nambu–Goldstone boson for only very short time. This is the origin of the Lenz's law. The induced electrical current tends to preserve the status quo by

opposing the motion of the change of flux that originally induced it. That is, soon after the external magnetic field is applied, the magnetic momentum of an electron cannot be changed but electrical currents can be induced, because of the Nambu–Goldstone boson. The $B_{\boldsymbol{k}_{\mathrm{LUCO}}}(\Delta B_{\mathrm{unit}},0)$ can be estimated as and the $I_{\boldsymbol{k}_{\mathrm{LUCO}}}(\Delta B_{\mathrm{unit}},0)$ value can be estimated as $2V_{\mathrm{one}}\{1-f_{\mathrm{Bose}}(\Delta B_{\mathrm{unit}})\}$ $\propto\left(1-\delta_{\Delta B_{\mathrm{unit}},0}\right)(\Delta B_{\mathrm{unit}}-0)=\Delta B_{\mathrm{unit}}$. The London penetration depth $\lambda_{\mathrm{L}}(\Delta B_{\mathrm{unit}},0)$ and the mass of a photon $m_{\mathrm{photon}}(\Delta B_{\mathrm{unit}},0)$ values for the excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$ states can be estimated to be nonzero. This is the excited normal metallic states for $j=0$ ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$). It should be noted that the electronic state $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$ is still bosonic because the $\boldsymbol{p}_{\mathrm{canonical}}$ value is 0. In other words, the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$ state is closely related to the diamagnetic current states in the superconducting states in that the supercurrent with $\boldsymbol{p}_{\mathrm{canonical}}=0$ and $\boldsymbol{v}_{\mathrm{em}}\neq 0$ is induced by the electromotive forces as a consequence of the change of the magnetic field. The $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$ state tries not to change the electronic structure ($\boldsymbol{p}_{\mathrm{canonical}}=0$) by induction of the supercurrent ($\boldsymbol{v}_{\mathrm{em}}\neq 0$). This is very similar to the superconducting state.

On the other hand, such excited normal metallic states with supercurrents ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\right\rangle$) can be immediately destroyed because of the unstable opened-shell electronic states subject to the external applied magnetic field, and the induced supercurrent can be immediately destroyed, and the electronic state becomes another excited normal metallic states for $j=0$ ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$). It should be noted that the electronic state $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ is now fermionic because the $\boldsymbol{p}_{\mathrm{canonical}}$ value is not 0. In other words, the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ state is closely related to the normal metallic 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 electromotive forces as a consequence of the change of the magnetic field, as in the conventional solid state physics. The excited fermionic normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},0;\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ state is very unstable and try to become another ground metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ state for $j=1$, and the induced electrical current can be immediately dissipated, and thus the magnetic field can penetrate into the new bosonic ground normal metallic state medium, as $B_{\boldsymbol{k}_{\mathrm{LUCO}}}(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}})=\Delta B_{\mathrm{unit}}$, at the same time, photon is emitted from an electron and this is the origin of the electrical resistivity, $I_{\boldsymbol{k}_{\mathrm{LUCO}}}(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}})$ $\propto\left(1-\delta_{\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}}}\right)(\Delta B_{\mathrm{unit}}-\Delta B_{\mathrm{unit}})=0$. This is very similar to the normal metallic states in the conventional solid state physics.

The ratio of the bosonic property $f_{\mathrm{Bose}}(\Delta B_{\mathrm{unit}})$ value is smaller than the $f_{\mathrm{Bose}}(0)$ value. It should be noted that the $f_{\mathrm{Bose}}(B_{\mathrm{in}})$ value decreases with an increase in the $|B_{\mathrm{in}}|$ value. That is, the bosonic and fermionic properties for an electron decreases and increases with an increase in the $|B_{\mathrm{in}}|$ value, respectively. The $\lambda_{\mathrm{L}}(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}})$ and $m_{\mathrm{photon}}(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}})$ values for the bosonic ground normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(\Delta B_{\mathrm{unit}},\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ can be estimated to be $+\infty$ and 0, respectively, that is, a photon becomes massless at the ground electronic states ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(B_{\mathrm{in}},B_{\mathrm{in}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$), and thus the external applied magnetic field can penetrate into the normal metallic medium.

Similar discussion can be made between another adjacent bosonic normal metallic ground electronic states. When the magnetic field B_{out} changes from B_j to B_k , the bosonic normal metallic ground electronic state $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)(j\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$ changes to the bosonic normal metallic ground electronic state via the bosonic normal metallic excited electronic state $\boldsymbol{k}_{\mathrm{LUCO}}(T)((j+\gamma+1)\Delta B_{\mathrm{unit}},(j+\gamma)\Delta B_{\mathrm{unit}};$

$\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0)\rangle$ and the fermionic normal metallic excited electronic state $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)((j+\gamma+1)\Delta B_{\mathrm{unit}},(j+\gamma)\Delta B_{\mathrm{unit}};\right.$ $\left.\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0)\right\rangle$. In such a case, the total

induced electrical current $I_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_k, B_j\right)$ can be estimated to be proportional to $\sum_{\gamma=0}^{k-j-1}\left(B_{j+\gamma+1}-B_{j+\gamma}\right)$ $= B_k - B_j = k\Delta B_{\mathrm{unit}} - j\Delta B_{\mathrm{unit}} = (k-j)\Delta B_{\mathrm{unit}}$. On the other hand, such induced electrical current can be immediately dissipated. Similar discussions can be made when the magnetic field B_{out} is reduced from B_k to B_j; the induced electrical currents are the same in the strength but opposite in the direction.

We may consider that electromotive forces are observed as a consequence of the fact that the electric current is induced (electrons move) in order that the photon becomes massive by absorbing Nambu–Goldstone boson formed by the fluctuation of the electronic state pairing of an electron.

B. Energy Levels for Various Electronic States

Let us look into the energy levels for various electronic states when the applied magnetic field (B_{out}) increases from 0 to ΔB_{unit} at 0 K. The total energy ($E_{\mathrm{total}}\left(B_{\mathrm{out}}, B_{\mathrm{out}}\right)$) for various electronic states can be expressed as the summation of the electronic $E_{\mathrm{electronic}}\left(B_{\mathrm{out}}, B_{\mathrm{out}}\right)$ and magnetic $\left(1-\delta_{B_{\mathrm{out}}, B_{\mathrm{in}}}\right)E_{\mathrm{magnetic}}\left(B_{\mathrm{out}}, B_{\mathrm{in}}\right)$ energies. The energy level for the bosonic ground normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(B_{\mathrm{in}}, B_{\mathrm{in}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ electronic states can be defined as $-2V_{\mathrm{one}} f_{\mathrm{Bose}}\left(B_{\mathrm{in}}\right)$. The energy level for the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(0,0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state can be expressed as $-2V_{\mathrm{one}} f_{\mathrm{Bose}}(0) = -2V_{\mathrm{one}}$. On the other hand, the magnetic energy level for $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state is expressed as $\left(1-\delta_{0,0}\right)E_{\mathrm{magnetic}}(0,0)=0$. When the B_{out} value changes from 0 to ΔB_{unit}, the energy for the excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state becomes $-2V_{\mathrm{one}}$ with kinetic energy of supercurrent $2V_{\mathrm{one}}\left\{1-f_{\mathrm{Bose}}\left(\Delta B_{\mathrm{unit}}\right)\right\}$, and thus the total energy is $-2V_{\mathrm{one}} f_{\mathrm{Bose}}\left(\Delta B_{\mathrm{unit}}\right)$. The electronic energy level for the bosonic ground normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ is the same with that for the bosonic excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state. On the other hand, it should be noted that even though the electronic energy is conserved between them, the kinds of energies are different. The electronic energy level itself for the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ is $-2f_{\mathrm{Bose}}\left(\Delta B_{\mathrm{unit}}\right)$ with zero kinetic energy for the supercurrent.

On the other hand, the magnetic energy for the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state with respect to the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state can be expressed as $\mu_0 \Delta B_{\mathrm{unit}}^2 v_{\mathrm{SC}}/2$. Therefore, because of the magnetic energy $E_{\mathrm{magnetic}}\left(\Delta B_{\mathrm{unit}}, 0\right)$, such excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state is not stable, and thus the electronic state is converted to the next ground normal metallic ground $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state via the fermionic excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}\neq 0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state. The energy level for the fermionic excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}\neq 0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state can be estimated to be the same with that for the bosonic excited normal metallic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ state even though the potential energy $V_{\mathrm{pootential}}$ for the bosonic states are converted to the kinetic energy $V_{\mathrm{kin,Fermi},\boldsymbol{k}_{\mathrm{LUCO}}\sigma}(0)$ for the fermionic states.

We can consider that the $E_{\mathrm{total}}\left(\Delta B_{\mathrm{unit}}, 0\right)$ values for the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ and $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}\neq 0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ states are larger than that for the $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state by the $E_{\mathrm{magnetic}}\left(\Delta B_{\mathrm{unit}}, 0\right)\left(=\mu_0 \Delta B_{\mathrm{unit}}^2 v_{\mathrm{SC}}/2\right)$ value. Therefore, the conversion from the unstable $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}\neq 0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ state to the stable $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(\Delta B_{\mathrm{unit}}, \Delta B_{\mathrm{unit}};\right.\right.$

$\boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ state occurs by the first-order process of the electron–phonon interactions. In other words, the unstable $|\boldsymbol{k}_{\text{LUCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} \neq 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ state is converted to the stable $|\boldsymbol{k}_{\text{LUCO}}(T)(\Delta B_{\text{unit}}, \Delta B_{\text{unit}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ states as a consequence of the energy conversion from the magnetic energy ($E_{\text{magnetic}}(\Delta B_{\text{unit}}, 0)(= \mu_0 \Delta B_{\text{unit}}^2 v_{\text{SC}} / 2)$) to the photon emission (electrical resistivity (Joule's heats)).

III. TWO ELECTRONS SYSTEMS

A Electronic State

When the B_{out} value changes from 0 to ΔB_{unit}, a Nambu–Goldstone boson formed by the fluctuation of the bosonic Cooper pair $|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ is absorbed by a photon. Therefore, a photon has finite mass as a consequence of interaction with the Nambu–Goldstone boson for a long time. This is the origin of the Meissner effects. The $B_{\boldsymbol{k}_{\text{HOCO}}}(\Delta B_{\text{unit}}, 0)$ can be expressed as $(1 - \delta_{\Delta B_{\text{unit}},0}) 0 + \delta_{\Delta B_{\text{unit}},0} \Delta B_{\text{unit}} = 0$ and $I_{\boldsymbol{k}_{\text{HOCO}}}(\Delta B_{\text{unit}}, 0) \propto (1 - \delta_{\Delta B_{\text{unit}},0})(\Delta B_{\text{unit}} - 0) = \Delta B_{\text{unit}}$

The $\lambda_{\text{L}}(\Delta B_{\text{unit}}, 0)$ and $m_{\text{photon}}(\Delta B_{\text{unit}}, 0)$ values for the excited superconducting $|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ states can be estimated to be nonzero. This is the excited superconducting states for $j = 0$ ($|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$). Such excited superconducting states ($|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$) cannot be destroyed because of the stable closed-shell electronic states, and the induced supercurrent cannot be destroyed, and the electronic state does not become another ground metallic state $|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, \Delta B_{\text{unit}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ for $j = 1$, via the fermionic excited $|\boldsymbol{k}_{\text{HOCO}}(T)(\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} \neq 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ state for $j = 0$. The magnetic field still cannot penetrate into the excited superconducting state medium ($(1 - \delta_{\Delta B_{\text{unit}},0}) 0 + \delta_{\Delta B_{\text{unit}},0} \Delta B_{\text{unit}} = 0$). Similar discussion can be made between another adjacent bosonic superconducting excited electronic states, repeatedly. When the magnetic field B_{out} changes from B_j to B_k, the bosonic superconducting excited electronic state $|\boldsymbol{k}_{\text{HOCO}}(T)(j\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ changes to the bosonic superconducting excited electronic state $|\boldsymbol{k}_{\text{HOCO}}(T)(k\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ via the bosonic superconducting excited electronic state $|\boldsymbol{k}_{\text{HOCO}}(T)((j+\gamma)\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$. In such a case, the total induced electrical current $I_{\boldsymbol{k}_{\text{HOCO}}}(B_k, B_j)$ can be estimated to be proportional to $B_j + \sum_{\gamma=0}^{k-j-1} (B_{j+\gamma+1} - B_{j+\gamma}) = B_j + (B_k - B_j)$ $= j\Delta B_{\text{unit}} + \{k\Delta B_{\text{unit}} - j\Delta B_{\text{unit}}\} = k\Delta B_{\text{unit}}$. Similar discussions can be made when the magnetic field B_{out} is reduced from B_k to B_j; the induced currents are reduced with a decrease in the B_{out} value. The $f_{\text{Bose}}(0)(= 1)$ value does not change with an increase in the $|B_{\text{out}}|$ value. That is, the bosonic properties do not change with an increase in the $|B_{\text{out}}|$ value. The $m_{\text{photon}}(B_{\text{out}}, 0)$ and $\lambda_{\text{L}}(B_{\text{out}}, 0)$ values for the excited superconducting $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{out}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ states ($B_{\text{out}} \neq B_{\text{in}} = 0$) are nonzero under the magnetic field $|B_{\text{in}}|(= 0)$. The $|I_{\boldsymbol{k}_{\text{HOCO}}}(B_{\text{out}}, B_{\text{in}})|$ value for the excited superconducting $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{out}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ states ($B_{\text{out}} \neq B_{\text{in}} = 0$) increases with an increase in the $|B_{\text{out}} - B_{\text{in}}|(= |B_{\text{out}}| < B_{\text{c}})$ value.

At $B_{\text{out}} = B_{\text{c}}$, the bosonic excited superconducting state $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{c}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0)\rangle\rangle$ is converted to the bosonic normal metallic ground state $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{c}}, B_{\text{c}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ via the fermionic normal metallic excited electronic state $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{c}}, 0; \boldsymbol{p}_{\text{canonical}} \neq 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$. The $\lambda_{\text{L}}(B_{\text{c}}, B_{\text{c}})$ and $m_{\text{photon}}(B_{\text{c}}, B_{\text{c}})$ values for the bosonic ground normal metallic $|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{c}}, B_{\text{c}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$ state can be estimated to be $+\infty$ and 0, respectively, that is, a photon becomes massless at the ground electronic states ($|\boldsymbol{k}_{\text{HOCO}}(T)(B_{\text{c}}, B_{\text{c}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0)\rangle\rangle$) under the magnetic field of $B_{\boldsymbol{k}_{\text{HOCO}}}(B_{\text{c}}, B_{\text{c}})$, and thus the external applied magnetic field can penetrate into the normal metallic medium.

B. Energy Levels for Various Electronic States

Let us look into the energy levels for various

electronic states when the applied magnetic field (B_{out}) increases from 0 to ΔB_{unit} at 0 K. At the magnetic field B_{out}, the electronic energy level for the $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(B_{\text{out}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ electronic states can be defined as $E\left(B_{\text{out}},0\right)=-4V_{\text{one}}f_{\text{Bose}}\left(B_{\text{out}}\right)$. The electronic energy level for the $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(0,0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ state can be expressed as $E(0,0)=-4V_{\text{one}}$. On the other hand, the magnetic energy level is expressed as $E_{\text{magnetic}}(0,0)=\left(1-\delta_{0,0}\right)E_{\text{magnetic}}(0,0)=0$. When the B_{out} value changes from 0 to ΔB_{unit}, the energy level for the $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ state can be defined as $E\left(\Delta B_{\text{unit}},0\right)=-4V_{\text{one}}+I_{\text{SC}}\left(\Delta B_{\text{unit}},0\right)$, where the $I_{\text{SC}}\left(\Delta B_{\text{unit}},0\right)$ value denotes the kinetic energy originating from the supercurrents ($\boldsymbol{p}_{\text{canonical}}=0$; $\boldsymbol{v}_{\text{em}}\neq 0$) for the bosonic excited superconducting $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ state, and can be estimated as $I_{\text{SC}}\left(\Delta B_{\text{unit}},0\right)$ $=4V_{\text{one}}\left\{1-f_{\text{Bose}}\left(\Delta B_{\text{unit}}\right)\right\}$. That is, we can consider that the electronic energy for the excited superconducting $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ is $-4V_{\text{one}}$ with the kinetic energy of supercurrent $4V_{\text{one}}\left\{1-f_{\text{Bose}}\left(\Delta B_{\text{unit}}\right)\right\}$, and thus the total electronic energy is $-4V_{\text{one}}f_{\text{Bose}}\left(\Delta B_{\text{unit}}\right)$.

On the other hand, the magnetic energy for the $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ state with respect to the $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},\Delta B_{\text{unit}};\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ state can be expressed as $E_{\text{magnetic}}\left(\Delta B_{\text{unit}},0\right)=\mu_0\Delta B_{\text{unit}}^2 v_{\text{SC}}/2$. Because of the rigid and stable Cooper pair in the closed-shell electronic structure with finite valence–conduction band gap originating from stabilization effect of the electron–phonon interactions, such excited superconducting $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ state is still stable, and thus the electronic state is not converted to the next normal metallic ground $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},\Delta B_{\text{unit}};\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ state via the fermionic $\left|\boldsymbol{k}_{\text{HOCO}}(T)\left(\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}\neq 0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ state. At $B_{\text{out}}=B_{\text{c}}$, the $E_{\text{total}}\left(B_{\text{c}},B_{\text{c}}\right)$ value becomes zero, and thus at $B_{\text{out}}>B_{\text{c}}$, the superconducting state becomes more unstable than the normal metallic state.

IV. COMPARISON OF THE NORMAL METALLIC STATES WITH SUPERCONDUCTING STATES

A. Problems between the Lenz's Law in the Normal Metallic States and the Meissner Effects in the Superconducting States

Let us next compare the normal metallic states with the superconducting states. In superconductivity, two electrons behave only as a Bose particle. On the other hand, in the normal metallic states, an electron behaves as bosonic as well as fermionic under the applied external magnetic field.

Let us consider the experiment at room temperature, in an applied external magnetic field ($B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)\left(=B_j=j\Delta B_{\text{unit}}\right)<B_{\text{c}}$) at the bosonic ground normal metallic state $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}},j\Delta B_{\text{unit}};\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$. Therefore, the magnetic field $B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)$ can completely penetrate into the sample, and the electrical current is not induced ($I_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)=0$). Now cool the specimen in the magnetic field $B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)$ to below the T_{C}. In such a case, the ground normal metallic electronic $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}},j\Delta B_{\text{unit}};\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ states can change and can be in the bosonic excited superconducting states $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ below T_{C}. Therefore, stable Cooper pairs can be formed below T_{C}, and the ground electronic states $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}},j\Delta B_{\text{unit}};\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}=0\right)\right\rangle$ ($B_{\text{out}}=B_{\text{in}}$) in the normal metallic states ($B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)\left(=B_j=j\Delta B_{\text{unit}}\right)$) change to the excited electronic states $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}},0;\boldsymbol{p}_{\text{canonical}}=0;\boldsymbol{v}_{\text{em}}\neq 0\right)\right\rangle$ ($B_{\text{out}}\neq B_{\text{in}}$) in the superconducting states ($B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,0\right)\left(=0\right)$). Therefore, according to the Meissner effects, the magnetic field cannot penetrate into the sample anymore ($B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,0\right)\left(=0\right)$), and the electrical current is induced ($I_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,0\right)\left(\propto B_j=j\Delta B_{\text{unit}}\right)$).

According to the Lenz's law, the magnetic field ($B_{\boldsymbol{k}_{\text{LUCO}}}\left(B_j,B_j\right)\left(=B_j=j\Delta B_{\text{unit}}\right)$) would penetrate into the sample completely even below T_{C} since the

magnetic field ($B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_j, B_j\right)\left(=B_j = j\Delta B_{\mathrm{unit}}\right)$) does not change during temperature decreasing process. On the other hand, it has been well known that the magnetic field cannot penetrate into the sample at all well below T_C, according to the Meissner effect. At this time, this phenomenon does not obey the Lenz's law. That is, even in superconductivity, the electronic properties usually obey the Lenz's law, on the other hand, sometimes do not obey the Lenz's law. This is because the Meissner effect can be always dominantly applied even in the case where the electronic states cannot obey the Lenz's law. That is, since the discovery of the Meissner effect, it has been considered that the superconductivity as well as the normal metallic states basically obey the Lenz's law, on the other hand, if there is discrepancy between the Lenz's law and the Meissner effect, the Meissner effect can be considered to be more dominant than the Lenz's law in superconductivity.

The Meissner effect is independent basic property and cannot be derived from the zero resistivity. This means that the Meissner effect is more essential than the Lenz's law, and the Lenz's law should be explained in terms of more fundamental Meissner effects in the normal metallic states as well as in the superconducting states. In other words, the observation of the Lenz's law is considered as a special case of the Meissner effect in the normal metallic states.

That is, the unified interpretation between the Lenz's law and the Meissner effect, that is, between the normal metallic states and superconducting states has not been completely established.

Therefore, we try to establish the unified interpretations between them.

B. The Meissner Effects in Superconductivity in the Two Electrons Systems

There are only two ground states ($j=0$, n_c) between the magnetic fields 0 ($j=0$) and B_c ($j=n_c$). Conventional Meissner effects in the superconducting states can be considered that the perfect diamagnetism can be applied in the wide range from the ground $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(0,0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ states at the zero magnetic field ($B_{\boldsymbol{k}_{\mathrm{LUCO}}}(0,0)=0$) ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}=0$) to the ground $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(B_c,B_c;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ states at the critical magnetic field ($B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(\pm B_c,\pm B_c\right)=\pm B_c=\pm n_c\Delta B_{\mathrm{unit}}$) ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}=0$). In the various excited superconducting ranges $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(B_j,0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ between $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(0,0;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ and $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(B_c,B_c;\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$, the supercurrent can be induced ($I_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_{\mathrm{out}},0\right)\propto B_{\mathrm{out}}$) because of very stable bosonic electron Cooper pairs formed by two electrons with opposite momentum and spins occupying the same orbitals.

C. The Lenz's Law in the Normal Metals in the One Electron Systems

On the other hand, there are n_c+1 ground superconducting states ($j=0$, 1, 2,..., n_c) between the magnetic fields 0 ($j=0$) and B_c ($j=n_c$) in the normal metallic states. The Lenz's law in the normal metallic states can be considered that the perfect diamagnetism can be applied only from the initial ground state $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ under the magnetic field ($B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_j,B_j\right)\left(=B_j=j\Delta B_{\mathrm{unit}}\right)$) ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}=0$) to the neighboring quantized ground states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm 1)\Delta B_{\mathrm{unit}},(j\pm 1)\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ under the magnetic field ($B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_{j\pm1},B_{j\pm1}\right)\left(=B_{j\pm1}=(j\pm1)\Delta B_{\mathrm{unit}}\right)$) ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}=0$) via the excited bosonic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm1)\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ and fermionic $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm1)\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}\neq 0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ electronic states. In only very small ranges ($\pm\Delta B_{\mathrm{unit}}$) between $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ and $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm1)\Delta B_{\mathrm{unit}},(j\pm1)\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$, the excited supercurrent state ($\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm1)\Delta B_{\mathrm{unit}},j\Delta B_{\mathrm{unit}};\boldsymbol{p}_{\mathrm{canonical}}=0;\boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$) can be induced ($I_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_{j\pm1},B_j\right)$ $\left(\propto B_{j\pm1}-B_j=(j\pm1)\Delta B_{\mathrm{unit}}-j\Delta B_{\mathrm{unit}}=\pm\Delta B_{\mathrm{unit}}\right)$) ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}\neq 0$).

On the other hand, such currents can exist for only very short time and can be immediately dissipated. This is because electronic pairing states in the opened-shell electronic structures are very fragile subject to the external applied field. At the same

time, a photon is emitted from such an electronic state $\boldsymbol{k}_{\mathrm{LUCO}}(T)\left((j\pm1)\Delta B_{\mathrm{unit}}, j\Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}\neq 0; \boldsymbol{v}_{\mathrm{em}}=0\right)\rangle$, and this is the origin of the electrical resistivity in the normal metallic states. That is, we can interpret that the Lenz's law in the normal metallic states are the continuous Meissner effects between each ground ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}=0$) and excited ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}\neq 0$ and $\boldsymbol{p}_{\mathrm{canonical}}\neq 0$; $\boldsymbol{v}_{\mathrm{em}}=0$) superconducting states which appears only on small range of the magnetic field ($\pm\Delta B_{\mathrm{unit}}\left(<< B_{\mathrm{c}}\right)$) between the adjacent quantum ground states $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(B_j, B_j; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ and $\left|\boldsymbol{k}_{\mathrm{HOCO}}(T)\left(B_{j\pm1}, B_{j\pm1}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ for only very short time.

Finite $B_{\mathrm{c,SC}}\left(=n_{\mathrm{c}}\Delta B_{\mathrm{unit}} >> \Delta B_{\mathrm{unit}}\right)$ values in superconducting states originate from the closed-shell electronic structures formed by two electrons with opposite momentum and spins occupying the same orbital by which the Cooper pairs become stable with respect to the small magnetic field. On the other hand, infinitesimal $B_{\mathrm{c,NM}}\left(=\pm\Delta B_{\mathrm{unit}}\right)$ values in the normal metallic states originate from the opened-shell electronic structures formed by only one electron, by which bosonic electronic state pairing of an electron can be easily destroyed by even very small applied magnetic field. Therefore, the Meissner effects can be observed only for a very short time in the normal metallic states. We can consider that the Lenz's law in the normal metallic states is the continuous phenomenon where the Meissner effects in the superconducting states can be observed for a very short time repeatedly.

V. RECONSIDERATION OF THE ELECTROMOTIVE FORCES

A. Conventional Lenz's Law

Let us consider the case where we cool the superconducting specimen in the constant magnetic field $B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_j, B_j\right)$ from room temperature to 0 K. According to the conventional Lenz's law, it has been considered that the electromotive force is induced when the applied magnetic field changes, as $I\propto \mathrm{emf}\propto B_{\mathrm{out}}-B_{\mathrm{intitial}}$. Therefore, when we cool the superconducting specimen in the constant magnetic field $B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_j, B_j\right)$ from room temperature to 0 K, the electromotive force would not be induced, as $I\propto \mathrm{emf}\propto B_{\mathrm{out}}-B_{\mathrm{intitial}}=B_j-B_j=0$. On the other hand, it has been well known for a long time that the perfect diamagnetic supercurrents (and thus electromotive force) can be induced when we cool the superconducting specimen even in the constant magnetic field $B_{\boldsymbol{k}_{\mathrm{LUCO}}}\left(B_j, B_j\right)$ from room temperature to 0 K. That is, this phenomenon cannot be explained by the conventional Lenz's law, and the Lenz's law and Meissner effects contradict each other in this case.

B. New Definition of the Lenz's Law

However, we can consider that during temperature decreasing process even under the constant magnetic field ($B_{\mathrm{out}}=B_j=\mathrm{const.}$), the electronic states have been changed from the two one-bosonic normal metallic particles ground states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, j\Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ (B_j) to the one-bosonic superconducting particle excited states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ (B_j). According to our theory discussed in the previous sections [1–3], the electromotive force can be well explained by considering that the electromotive forces can be induced by the difference between the applied magnetic field (B_{out}) and the magnetic field for the bosonic ground states (B_{ground}), as $I\propto \mathrm{emf}\propto B_{\mathrm{out}}-B_{\mathrm{ground}}$. The magnetic field of the ground states for the two-one-bosonic normal metallic particles ground states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, j\Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ ($B_{\mathrm{out}}=B_j$) is also B_j ($B_{\mathrm{ground}}=B_j$), on the other hand, that for one-bosonic superconducting particle excited states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ ($B_{\mathrm{out}}=B_j$) is 0 ($B_{\mathrm{ground}}=0$). Therefore, the electromotive force for the normal metallic ground states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, j\Delta B_{\mathrm{unit}}; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}=0\right)\right\rangle$ at room temperatures under the constant magnetic field ($B_{\mathrm{out}}=B_j$) can be estimated as $I\propto \mathrm{emf}\propto B_{\mathrm{out}}-B_{\mathrm{ground}}=B_j-B_j=0$ at 300 K . On the other hand, that for the superconducting excited states $\left|\boldsymbol{k}_{\mathrm{LUCO}}(T)\left(j\Delta B_{\mathrm{unit}}, 0; \boldsymbol{p}_{\mathrm{canonical}}=0; \boldsymbol{v}_{\mathrm{em}}\neq 0\right)\right\rangle$ at 0 K under the constant magnetic field ($B_{\mathrm{out}}=B_j$) can be estimated as $I\propto \mathrm{emf}\propto B_{\mathrm{out}}-B_{\mathrm{ground}}=B_j-0=B_j$ at 0 K . In other words, we may consider that the electromotive force is observed as a consequence of the fact that each excited bosonic ($\boldsymbol{p}_{\mathrm{canonical}}=0$; $\boldsymbol{v}_{\mathrm{em}}\neq 0$) electronic states try not to be converted to the another

ground bosonic ($\boldsymbol{p}_{\text{canonical}} = 0;\ \boldsymbol{v}_{\text{em}} = 0$) electronic states.

The electromotive forces have been considered to originate from the changes of the applied magnetic fields. Therefore, according to the conventional interpretation of the electromotive forces, the electromotive forces would not appear and electrical currents cannot be observed during temperature decreasing process under the constant magnetic field ($B_{\text{out}} = B_j = \text{const.}$). On the other hand, during temperature decreasing process even under the constant magnetic field ($B_{\text{out}} = B_j = \text{const.}$), the electrical currents can be observed. This can be understood by considering that the electronic states have been changed from the two one-bosonic normal metallic particles ground states $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}}, j\Delta B_{\text{unit}}; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} = 0\right)\right\rangle$ (B_j) to the one-bosonic superconducting particle excited states $\left|\boldsymbol{k}_{\text{LUCO}}(T)\left(j\Delta B_{\text{unit}}, 0; \boldsymbol{p}_{\text{canonical}} = 0; \boldsymbol{v}_{\text{em}} \neq 0\right)\right\rangle$ (B_j). That is, the applied magnetic field does not change, but the ground states related to the Meissner effect, to which each electronic state belongs, can change during temperature decreasing process under the constant magnetic field ($B_{\text{out}} = B_j = \text{const.}$). In other words, the difference between the magnetic field which is applied to the excited electronic state, and the magnetic field under which the reference electronic state becomes the ground state, appears during temperature decreasing process under the constant magnetic field ($B_{\text{out}} = B_j = \text{const.}$).

Therefore, we can conclude that the difference between the magnetic field which is applied to the excited electronic state (B_{out}), and the magnetic field for the ground states to which the reference electronic state belongs, rather than the changes of the applied magnetic fields ($B_{\text{out}} - B_{\text{intitial}}$), is the origin of the electromotive forces.

VI. THE MECHANISM OF THE FORMING OF COOPER PAIRS IN AROMATIC HYDROCARBONS

In the previous works, we suggested the mechanism of the occurrence of the nondissipative diamagnetic currents in the microscopic sized polyacene molecules such as 6an, 10ac, 14ac, and 18ac. Furthermore, we suggested the unified theory by which the mechanism of the occurrence of the supercurrents in the macroscopic sized conventional superconductivity as well as in the microscopic sized molecules such as 6an, 10ac, 14ac, and 18ac can be explained. According to the previous researches, the electron Cooper pairs in the microscopic sized molecules such as 6an, 10ac, 14ac, and 18ac can be formed by the closed-shell electronic structures with large energy gaps between the occupied and unoccupied orbitals formed by quantization of the orbitals by nature, and large negative 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 previous researches, the electron Cooper pairs in the macroscopic sized conventional superconductivity can be formed by the closed-shell electronic structures with small energy gaps between the occupied and unoccupied orbitals formed by electron–phonon interactions and large negative Coulomb interactions between two electrons.

A photon of sufficient energy can interact with a single electron that is bound in an atom or molecule leading to photoemission of that electron leaving behind a singly charged ion. However, due to electron correlation the emissions of two electrons by a single photon, called double photoionization, is also possible. Many investigations of the double-photoionization process using different techniques have been performed on atoms over several years. A recent double-photoionization experiment on polyacenes found that the ratio of doubly to singly charged parent ions increases with an increase in the molecular size and that the double-photoionization process is dominated by the same mechanism as for atoms for energies up to about 30 eV above the threshold. Furthermore, recently, Wehlitz et al. reported the discovery of the photoemission of Cooper pair in 6an, 10ac, 14ac, and coronene.

In this article, we will try to rationalize the experimental results for the photoemission of Cooper pairs from aromatic hydrocarbons, reported by Wehlitz et al., on the basis of the hypotheses suggested in the previous researches, as described above.

A. The Mechanism of the Forming of Electron Cooper Pairs in the Microscopic Sized Molecules

Let us look into the mechanism of the forming of electron Cooper pairs in the microscopic sized molecules. In our previous researches, we suggested that the Coulomb interactions between two electrons with opposite momentum and spins occupying the same orbitals become attractive via the existence of the Coulomb interactions between all nuclei and electrons. Furthermore, the stable spin singlet electronic states of two electrons with opposite momentum and spins are formed by large HOMO–LUMO gaps ($\Delta E_{\text{HOMO}-\text{LUMO}}$) as a

consequence of the quantization of orbitals formed by nature. That is, because of large attractive Coulomb interactions between all nuclei and electrons, and large HOMO–LUMO gaps as a consequence of the quantization of orbitals formed by nature, two electrons with attractive Coulomb interactions and the stable spin singlet states are in the bound states. Therefore, electron Cooper pairs can be formed.

The total Coulomb interactions for the orbital j occupied by an electron with spin □ in N carrier states ($V_{\text{Coulomb,total},N}(\boldsymbol{k}_j\sigma)$) are caused by the Coulomb interactions between electrons ($V_{\text{Coulomb,e–e},N}(\boldsymbol{k}_j\sigma)>0$), between electrons and nuclei ($V_{\text{Coulomb,e–n},N}(\boldsymbol{k}_j\sigma)<0$), and between nuclei ($V_{\text{Coulomb,n–n},N}(\boldsymbol{k}_j\sigma)>0$). Therefore, the total Coulomb energies can be defined as, $V_{\text{Coulomb,total},N}(\boldsymbol{k}_j\sigma)$ $V_{\text{Coulomb,e–e},N}(\boldsymbol{k}_j\sigma)+V_{\text{Coulomb,e–n},N}(\boldsymbol{k}_j\sigma)$ $+V_{\text{Coulomb,n–n},N}(\boldsymbol{k}_j\sigma)$. Orbital energies for the orbital j with spin □ in N carrier states ($\varepsilon_N(\boldsymbol{k}_j\sigma)$) can be estimated as follows, $\varepsilon_N(\boldsymbol{k}_j\sigma)=V_{\text{kin},N}(\boldsymbol{k}_j\sigma)+V_{\text{Coulomb},N}(\boldsymbol{k}_j\sigma)$, where the $V_{\text{kin},N}(\boldsymbol{k}_j\sigma)$ is the kinetic energy of an electron with spin □ occupying the orbital j in materials with N carriers. From this equation, the $V_{\text{Coulomb},N}(\boldsymbol{k}_j\sigma)$ value can be estimated as, $V_{\text{Coulomb},N}(\boldsymbol{k}_j\sigma)=\varepsilon_N(\boldsymbol{k}_j\sigma)-V_{\text{kin},N}(\boldsymbol{k}_j\sigma)$. Since the $V_{\text{kin},N}(\boldsymbol{k}_j\sigma)$ values are always large positive and the $\varepsilon_N(\boldsymbol{k}_j\sigma)$ values for the occupied orbitals are usually negative or very small positive, the $V_{\text{Coulomb},N}(\boldsymbol{k}_j\sigma)$ values for the occupied orbitals usually become very large negative even in charged materials. The $\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values are estimated to be –6.702, –5.787, and –5.225 eV, the $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values are estimated to be 30.435, 32.217, and 33.345 eV, the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values are estimated to be –37.137, –38.004, and –38.570 eV, and the $\Delta E_{\text{HOMO–LUMO}}$ values are estimated to be 9.22, 7.97, and 6.93 eV in 6an, 10ac, and 14ac, respectively, by using the hybrid Hartree–Fock (HF)/density-functional-theory (DFT) method of Becke, and Lee, Yang, and Parr (B3LYP) and the 6-31G* basis set, as in our previous studies. The Gaussian 03 program package was used for our theoretical analyses

B. Photoionization

Let us look into the photoionization in the neutral 6an, 10ac, and 14ac. We define the thresholds for the single-photoionization as E_{single}, for the double-photoionization as E_{double}, and for the Cooper pair photoionization as $E_{\text{Cooper pair}}$. Furthermore, we define the energy for the peak of the ratio of the occurrence of the direct destruction of the Cooper pair as $E_{\text{Cooper pair,peak}}$.

C. Below Single-Photoionization Threshold

According to the previous researches, there can be electron Cooper pairs and nondissipative diamagnetic supercurrents at room temperatures in the microscopic sized molecules such as the neutral 6an, 10ac, and 14ac. The thresholds for the single photoionization (E_{single}) can be defined as $E_{\text{single}} \approx -\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$ $=-V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma)-V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$, where the $\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$ value is the energy level of the highest occupied molecular orbitals (HOMO), the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ value denotes the Coulomb interactions between an electron occupying the HOMO and another electrons and nuclei, and the $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ value is the kinetic energy for an electron occupying the HOMO with spin □.

When energy of a photon (E_{photon}) is smaller than the E_{single} value, that is, at $E_{\text{photon}} < E_{\text{single}}$, a photon cannot be absorbed by any electron, and thus the Cooper pair and the nondissipative diamagnetic supercurrents cannot be destroyed. This is because any excited energy level of electronic state which is higher than the superconducting ground states, does not exist below the E_{single} value with respect to the superconducting ground state.

D. Single-Photoionization Processes

Let us next consider the single-photoionization processes. The E_{single} values are considered to be similar to the $-\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values.

The $\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values are estimated at the B3LYP/6-31G* level to be –6.702, –5.787, and –5.225 eV, respectively.

At $E_{\text{single}} < E_{\text{photon}} < E_{\text{double}}$, a photon can be absorbed by one of two electrons. Even though it is very difficult for the bosonic electron Cooper pairs formed by strong Coulomb interactions between equivalent two fermionic electrons to be directly destroyed, if a photon with the energies higher than

the E_{single} value is absorbed by one of two electrons occupying the HOMO, such one of two electrons is emitted and removed from the molecule and the electronic states in the molecule are in the excited monocationic states. In such a case, an electron absorbing a photon and emitted from the molecule is not equivalent to another electron anymore, and thus these electrons independently behave as two Fermi particles with large $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values. In general, the threshold energy for the single photoionization ($E_{\text{single}}\left(\approx -\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)\right)$) and the HOMO–LUMO gaps ($\Delta E_{\text{HOMO}-\text{LUMO}}$) are closely related to the superconducting critical temperatures (T_Cs). This means that not the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$ values of –37.137, –38.004, and –38.570 eV but the $\Delta E_{\text{HOMO}-\text{LUMO}}$ values of 9.22, 7.97, and 6.93 eV are closely related to the supercurrent critical temperatures (T_C) in the neutral 6an, 10ac, and 14ac, respectively, as suggested in our previous researches. The E_{single} values are destruction energies of the spin singlet state of a Cooper pair, as discussed in detail later

E. Double-Photoionization Processes

Let us next consider the double-photoionization processes. At $E_{\text{double}} < E_{\text{photon}} < E_{\text{Cooper pair}}$, the single photoionization discussed in the previous section can be observed. On the other hand, due to electron correlation, the emission of two electrons by a single photon, called double-photoionization, is also possible. When a photon of sufficient energy is absorbed by an electron, the electron can leave the molecule, resulting in single ionization, or it can move along the molecule where it has a chance to hit another electron and can cause double ionization. These two electrons are not equivalent, and thus the E_{double} value can be defined as follows,

$E_{\text{double}} = -\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$

$= -V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$

$- V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma') \quad \approx -2\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma)$

$= -2V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma) - 2V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma)$, where the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ value denotes the total Coulomb energy for two electrons occupying the HOMO originating from all nuclei and electrons, and the $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ value denotes the total kinetic energy for two electrons occupying the HOMO. A recent double-photoionization experiment on polyacenes found that the ratio of doubly to singly charged ions increases with an increase in the molecular size from 6an to 14ac. This can be understood as follows.

The $-\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ value decreases with an increase in the molecular size from 6an to 14ac. Furthermore, the dications become more significantly unstable with respect to the monocations with a decrease in molecular size from 14ac to 6an. This is the reason why the ratio of doubly to singly charged ions increases with an increase in the molecular size from 6an to 14ac.

The E_{double} values for 6an, 10ac, and 14ac were reported to be 24.927, 21.391, and 20.072 eV, respectively.

The E_{double} values somewhat similar to the $-\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values are not so large. This can be understood as follows. Two electrons concerning the double photoionization are not equivalent. Therefore, we must consider the $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values as well as the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values.

The $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values are estimated to be –74.274, –76.008, and –77.140 eV, and the $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values are estimated to be 60.870, 64.434, and 66.690 eV in 6an, 10ac, and 14ac, respectively. That is, both the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ and $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values are very large, but opposite in sign, each other.

Therefore, the $V_{\text{Coulomb}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ and $V_{\text{kin}}(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values are compensated by each other, and thus the E_{double} values somewhat similar to the $-\varepsilon(\boldsymbol{k}_{\text{HOMO}}\sigma, \boldsymbol{k}_{\text{HOMO}'}\sigma')$ values do not become very large. This is the reason why the E_{double} values are not so large. In the double- and single-photoionization, the two electrons are not equivalent, and thus the spin singlet states are destroyed. Therefore, the E_{double} as well as the E_{single} values are related to the destruction of the spin singlet state of a Cooper pair.

F. Cooper Pairs Photoemission Processes

At $E_{\text{Cooper pair}} < E_{\text{photon}}$, both the single- and double-photoemission discussed in the previous section can be observed. On the other hand, there is also a possibility that the direct destruction of a Cooper pair, formed by strong attractive Coulomb interactions between two electrons with opposite momentum and spins occupying the HOMO via positively charged nuclei in 6an, 10ac, and 14ac, can be observed. Two electrons forming a Cooper pair are equivalent, and thus the $E_{\text{Cooper pair}}$ value can be defined as follows,

$E_{\text{Cooper pair}}$ = $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ $-V_{\text{kin,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ = $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ >> $E_{\text{double}} \approx -\varepsilon\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$, where the $V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ value denotes the total average Coulomb energy for a Cooper pair occupying the HOMO originating from all nuclei and electrons, and the $V_{\text{kin, Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ value denotes the total kinetic energy for a Cooper pair occupying the HOMO. The $E_{\text{Cooper pair}}$ values were observed to be 51.213, 51.867, and 54.358 eV, and the $E_{\text{Cooper pair,peak}}$ values were observed to be about 70~80 eV in 6an, 10ac, and 14ac, respectively. On the other hand, the $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ values for 6an, 10ac, and 14ac are estimated to be 74.274, 76.008, and 77.140 eV, respectively. That is, the observed $E_{\text{Cooper pair,peak}}$ values are very similar to the estimated $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ values in 6an, 10ac, and 14ac. Considering that two electrons with momentum $+\boldsymbol{k}_{\text{HOMO}}\uparrow$ and $-\boldsymbol{k}_{\text{HOMO}}\downarrow$ rapidly move around a molecule, clockwise and counter-clockwise, respectively, the $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)(r)$ value rapidly changes as a function of the distance (r) between two electrons. The $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)(r)$ value is in the range above the $E_{\text{Cooper pair}}$ values of 51.213, 51.867, and 54.358 eV, and the $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ values of 74.274, 76.008, and 77.140 eV become similar to the $E_{\text{Cooper pair,peak}}$ values of about 70~80 eV in 6an, 10ac, and 14ac, respectively. That is, the observed $E_{\text{Cooper pair,peak}}$ values originate from only the $-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ values. This means that the Cooper pairs can be formed by the attractive Coulomb interactions between two electrons ($-V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$) with opposite momentum and spins occupying the same orbitals via the positive charges of nuclei, as suggested in the previous researches.

G. Comparison of the Cooper Pair Photoionization with the Double Photoionization

The $E_{\text{Cooper pair,peak}}$ values of about 70~80 eV are much larger than the E_{double} values of 24.927, 21.391, and 20.072 eV in 6an, 10ac, and 14ac, respectively. This can be understood as follows. In the case of knockout mechanism, the two electrons are not equivalent, as described above, and these two electrons independently behave as two Fermi particles, and we must consider the $V_{\text{kin}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values as well as the $V_{\text{Coulomb}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values. Both the $V_{\text{Coulomb}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values of –74.274, –76.008, and –77.140 eV and the $V_{\text{kin}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values of 60.870, 64.434, and 66.690 eV in 6an, 10ac, and 14ac, respectively, are very large, but opposite in sign, each other.

That is, the $V_{\text{Coulomb}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ and $V_{\text{kin}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values are compensated by each other, and thus the E_{double} values of 24.927, 21.391, and 20.072 eV somewhat similar to the $-\varepsilon\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$ values of 13.404, 11.574, and 10.450 eV in 6an, 10ac, and 14ac, respectively, do not become very large. In a similar way, the $E_{\text{Cooper pair,peak}}$ can be defined as a summation of the Coulomb interactions ($V_{\text{Coulomb,Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$) and the kinetic energy ($V_{\text{kin, Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$) of a Cooper pair. On the other hand, since there are equivalent two electrons with opposite momentum and spins, the total momentum of a Cooper pair can be zero ($\boldsymbol{k}_{\text{Cooper pair}} = \left(+\boldsymbol{k}_{\text{HOMO}}\uparrow\right)+\left(-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)= 0$), and thus the $V_{\text{kin, Cooper pair}}\left(+\boldsymbol{k}_{\text{HOMO}}\uparrow,-\boldsymbol{k}_{\text{HOMO}}\downarrow\right)$ value can be zero. That is, the kinetic energy, which generally reduces the threshold for the photoemission in the normal fermionic electrons, and is compensated by the Coulomb energy ($V_{\text{Coulomb}}\left(\boldsymbol{k}_{\text{HOMO}}\sigma,\boldsymbol{k}_{\text{HOMO}}'\sigma'\right)$), does not play a role in the decision of the threshold for the photoemission of the bosonic Cooper pairs. The Cooper pair can be formed by the Coulomb interactions between two electrons with opposite momentum and spins occupying the same orbitals via the positive charges of the nuclei. This is the reason why the $E_{\text{Cooper pair}}$ and $E_{\text{Cooper pair,peak}}$ values are much larger than the E_{double} values in 6an, 10ac, and 14ac. The E_{double} as well as the E_{single} values are related to the destruction energy of the spin singlet state of a Cooper pair, on the other hand, the

$E_{\text{Cooper pair}}$ and $E_{\text{Cooper pair, peak}}$ values are related to the destruction of the attractive Coulomb interactions between two electrons of a Cooper pair occupying the HOMO. In other words, observation of the small E_{double} and E_{single} values of about 10~20 eV means observation of just two Fermi particles (not Bose particle), on the other hand, observation of large $E_{\text{Cooper pair, peak}}$ values of about 70~80 eV means that the existence of a bosonic particle with zero kinetic energy (i.e., Cooper pair) can be confirmed in the microscopic sized 6an, 10ac, and 14ac, as suggested in our previous researches.

CONCLUDING REMARKS

Relationships between the normal metallic states and superconducting states are investigated. The electromotive forces have been considered to originate from the changes of the applied magnetic fields. On the other hand, we can conclude that the difference between the magnetic field which is applied to the excited electronic state, and the magnetic field for the ground state to which the electronic state belongs, rather than the changes of the applied magnetic fields, is the origin of the electromotive forces.

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