RELATIONSHIPS BETWEEN THE INTRINSIC PROPERTIES OF ELECTRICAL CURRENTS AND TEMPERATURES

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Abstract- The movements of one-ns valence electrons in an alkali metal atom are investigated from a microscopic perspective. The reason that we do not usually observe spontaneous currents without an external applied electric or magnetic field is elucidated from the perspective of the intrinsic features of a single electron rather than from a statistical perspective. Once an ns valence electron starts to move clockwise, a strong magnetic field, which causes the electronic states with clockwise motion to become unstable, is induced; thus, the ns valence electron starts to move counter-clockwise, and vice versa. The spin magnetic moment and the Stern–Gerlach effect in an electron are the main reasons that spontaneous current is suppressed at room temperature. Furthermore, the possible occurrence of spontaneous currents in alkali metal atoms at very low temperatures is suggested. We also show that the two-fluid model, which has been widely considered in the solid state physics, is not necessarily realistic. Furthermore, we reconsider the interpretation of the order parameter in the Ginzburg–Landau theory on the basis of our theory.

Keywords- Ginzburg–Landau Theory; Stern–Gerlach Effect; Spontaneous Currents; Two-Fluid Model.

I. 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.

II. 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.

III. 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 ($\left|\boldsymbol{k}_{ns,\mathrm{X},\mathrm{ground}}\right\rangle$ and $\left|\boldsymbol{k}_{ns,\mathrm{X},\mathrm{excited}}\right\rangle$). 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.

IV. 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 $\left|\boldsymbol{K}_{\text{one},ns,\text{X}}(T)\right\rangle = a_{\boldsymbol{k}_{ns,\text{X,ground}}}(T)\left|\boldsymbol{k}_{ns,\text{X,ground}}\right\rangle + a_{\boldsymbol{k}_{ns,\text{X,excited}}}(T)\left|\boldsymbol{k}_{ns,\text{X,excited}}\right\rangle$ $= \sqrt{1-P_{\boldsymbol{k}_{ns,\text{X,excited}}}(T)}\left|\boldsymbol{k}_{ns,\text{X,ground}}\right\rangle + \sqrt{P_{\boldsymbol{k}_{ns,\text{X,excited}}}(T)}\left|\boldsymbol{k}_{ns,\text{X,excited}}\right\rangle$, where $\left|\boldsymbol{k}_{ns,\text{X,ground}}\right\rangle = c_{+\boldsymbol{k}_{ns,\text{X}}\downarrow}\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle + c_{-\boldsymbol{k}_{ns,\text{X}}\uparrow}\left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|\boldsymbol{k}_{ns,\text{X,excited}}\right\rangle = c_{+\boldsymbol{k}_{ns,\text{X}}\uparrow}\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle + c_{-\boldsymbol{k}_{ns,\text{X}}\downarrow}\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$. If no external electric or magnetic field is applied ($x_{\text{external}} = 0$), the ns valence electron is in one of four electronic states ($\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$, $\left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$, $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$, and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$), and the two electronic states in the ground and excited electronic states rapidly and evenly convert ($c_{+\boldsymbol{k}_{ns,\text{X}}\downarrow} = c_{-\boldsymbol{k}_{ns,\text{X}}\uparrow} = 1/\sqrt{2}$; $c_{+\boldsymbol{k}_{ns,\text{X}}\uparrow} = c_{-\boldsymbol{k}_{ns,\text{X}}\downarrow} = 1/\sqrt{2}$) at relatively high temperatures.

The direction of the spin magnetic moment ($s_{ns,\text{X}}$) in the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ states becomes opposite to that of the induced magnetic field ($B_{\text{ring},ns,\text{X}}$) applied to the ns valence electron. In contrast, the direction of the spin magnetic moment ($s_{ns,\text{X}}$) in the $\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ states becomes the same as that of the induced magnetic field ($B_{\text{ring},ns,\text{X}}$) applied to the ns valence electron. Therefore, the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ states become unstable in energy relative to the $\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ states. Therefore, the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ states are the excited electronic states whereas the $\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ states are the ground electronic states. The energy curve for the excited electronic states at 298 K becomes parabolic. Therefore, the H 1s, Li 2s, Na 3s, and K 4s valence electrons are in the excited electronic states

$\left|\boldsymbol{k}_{ns,\text{X,excited}}\right\rangle \left(= \left(\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle + \left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle\right)/\sqrt{2}\right)$ (approximately 50 %) and in the ground electronic states

$\left|\boldsymbol{k}_{ns,\text{X,ground}}\right\rangle \left(= \left(\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle + \left|-\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle\right)/\sqrt{2}\right)$ 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.

V. 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 $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ state and the ground $\left|+\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ state. The magnetic fields ($B_{\text{ring},ns,\text{X}}$) induced by the ring currents caused by the relative motion of the nucleus around the H 1s, Li 2s, Na 3s, and K 4s valence electron are moderate or strong (in the order of 0.1~1 T). The direction of the spin magnetic moment ($s_{ns,\text{X}}$) in the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ states (up) becomes opposite to the direction of the induced magnetic field ($B_{\text{ring},ns,\text{X}}$) applied to the ns valence electron (down). Therefore, it is reasonable to consider that the excited $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ state with spin up changes to the excited $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ 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 ($s_{ns,\text{X}}$) 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 ($s_{ns,\text{X}}$), 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 $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ states. That is, we must consider that the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ 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 can not 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 $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ states occurs.

VI. INTRINSIC PROPERTIES OF A SINGLE ELECTRON AT LOW TEMPERATURES

Let us next consider the ideal case in which an isolated alkali metal atom exists in vacuum at low temperatures. In this case, even at low temperatures (≈ 0 K), the ns valence electron in an alkali metal atom X only moves around the isolated nucleus. The $P_{\boldsymbol{k}_{ns,\mathrm{X},\mathrm{excited}}}(T)$ value decreases with decreasing temperature, and most of the H 1s, Li 2s, Na 3s, and K 4s valence electrons (more than 99 %) are in the ground states at temperatures on the order of 10^{-1}~10^{-2} K. In these cases, the ns valence electron in the alkali metal atom X is primarily in the ground $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state and is only rarely in the excited $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\uparrow\right\rangle$ state. At very low temperatures, spontaneous symmetry breaking can occur, and the energy curve for the ground state becomes Mexican hat-shaped.

Let us consider the case in which spontaneous symmetry breaking occurs, and the ground state ns electron with spin down starts to move clockwise ($\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$). The $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state is the ground state, and the direction of the magnetic field ($B_{\text{ring},ns,\mathrm{X}}$) induced by the ring current and applied to the ns valence electron (down) becomes the same as that of the spin magnetic moment ($s_{ns,\mathrm{X}}$) of the $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state (down). Therefore, it is reasonable to consider the $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state with spin down to be very stable at low temperatures, and we can expect to observe a spontaneous clockwise current with spin down for a long time even though the $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state is in the Fermi state. Similar arguments can be made for the case in which spontaneous symmetry breaking occurs, and the ground state ns valence electron with spin up starts to move counter-clockwise ($\left|-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow\right\rangle$). The occurrence probability of the spontaneous current $\left|+\boldsymbol{k}_{ns,\mathrm{X}}\downarrow\right\rangle$ state is the same as that of the spontaneous current state $\left|-\boldsymbol{k}_{ns,\mathrm{X}}\uparrow\right\rangle$, which is 0.5000. These results can be also applied to the solid state materials. According to our calculated results, we can expect in this research that, below 10^{-1} ~10^{-2} K, the spontaneous symmetry breaking concerning the electromagnetic forces can occur, and the most stable states are in the nonzero electromagnetic field.

VII. POSSIBILITY OF THE CONVENTIONAL TWO-FLUID MODEL

In the two-fluid model, it has been explained that the ratio of superelectrons with respect to the normal electron decreases with an increase in the external forces such as temperature, applied magnetic field, and applied electric field. On the other hand, we must consider which orbitals these superelectrons and normal electrons occupy. If we consider that the number of electrons promoted from the valence bands to the conduction bands increases with an increase in the external forces, such superelectrons occupying the valence bands change to the normal electrons occupying the conduction bands. That is, the valence and conduction bands are partially occupied by electrons, and thus the electronic states are in the normal metallic states. This can be understood as follows. The number of orbitals forming the valence bands, which are stabilized by the electron–phonon interactions, and that forming the conduction bands, which are destabilized by the electron–phonon interactions, should not change with an increase in the external forces. On the other hand, the number of electrons occupying the valence bands and that occupying the conduction bands, decreases and increases with an increase in the external forces, respectively. This is the reason why the valence and conduction bands are partially occupied by electrons, and thus the electronic states will change from the superconducting states to the normal metallic states. Therefore, superconducting states are destroyed if the number of electrons promoted from the valence bands to the conduction bands increases with an increase in the external forces, and such superelectrons occupying the valence bands change to the normal electrons occupying the conduction bands. That is, we must consider that each orbital forming valence bands are completely occupied by two electrons with opposite momentum and spins, and the electronic structures

should be closed-shell electronic structures with finite energy difference between the occupied and unoccupied orbitals even under the external field in the superconducting states.

Therefore, let us next look into the possibility of the two-fluid model by considering that the electronic structures are the closed-shell electronic structures with the finite energy gaps between the occupied and the unoccupied orbitals. By considering that the electronic structures should be the closed-shell electronic structures with the finite energy gaps between the occupied and the unoccupied orbitals, the superelectrons should change to the normal electrons with an increase in the external forces in the same orbitals forming the valence bands. On the other hand, the Bose–Einstein condensation energy $\Delta E_{\mathrm{BE}}(0)\left(=2V_{\mathrm{kin,Fermi},N}\left(\boldsymbol{k}_{\mathrm{HOMO}}\sigma\right)(0)\right)$ values of about 70 eV are usually very large and the normal fermionic electrons are much more unstable than the bosonic superelectrons [1–3]. Therefore, it would be very difficult to consider that the bosonic superelectrons change to the normal fermionic electrons with an increase in the external forces in the same orbitals forming the valence bands. If two electrons, occupying the HOCO in the closed-shell electronic structures with large valence–conduction band gaps, move independently, each electron can be in the bosonic states with opposite momentum and spins. On the other hand, it would be very difficult for an electron in the orbital completely occupied by two electrons to become bosonic as a consequence of the rapid conversion between two electronic states with opposite momentum and spins because each electron is bound by another electron each other and cannot be independently changed. Furthermore, if such bosonic one electronic state is possible, more than three electrons can occupy an orbital. This clearly contradicts the Pauli exclusion principle. Therefore, we should consider that two electrons, occupying the HOCO in the closed-shell electronic structures with large valence–conduction band gaps, cannot move independently, and a bound state bosonic particle is composed from the two fermionic electrons. Therefore, the conventional two-fluid model is not necessarily realistic.

VIII. PHYSICAL PARAMETERS IN THE GINZBURG–LANDAU THEORY

Let us look into the physical parameters in the Ginzburg–Landau theory. Even though we consider molecular systems as example, for simplicity from the point of view of mathematics, similar discussions can be made in solids. The Ginzburg–Landau theory is established on the basis of the two-fluid model. On the other hand, we show that the two-fluid model is not necessarily realistic. Therefore, we reconsider the Ginzburg–Landau theory by comparing that with our theory.

Let us next look into the stabilization energy for a Cooper pair with respect to the normal metallic two electrons in view of our theory.

The energy difference ($\Delta E_{\mathrm{gap},N}\left(H_{\mathrm{applied}}\right)$) between the normal metallic states ($E_{\mathrm{Bose,two,NM},N}(0)$) and the superconducting states ($E_{\mathrm{Bose,one,SC},N}\left(H_{\mathrm{applied}}\right)$) under the applied magnetic field H_{applied} can be expressed as $\Delta E_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)-\Delta E_{\mathrm{magmetic}}\left(H_{\mathrm{applied}}\right)$ $=\Delta E_{\mathrm{gap},N}(0)\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$, where the $\Delta E_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)$ value denotes $\Delta E_{\mathrm{gap},N,\mathrm{electronic}}(0)f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)$, and the $\Delta E_{\mathrm{magmetic}}\left(H_{\mathrm{applied}}\right)$ value denotes the $\mu_0 H_{\mathrm{applied}}^2 v_{\mathrm{SC}}/2$ value [1–3]. We can see from this equation that the $\Delta E_{\mathrm{gap},N}\left(H_{\mathrm{applied}}\right)$ value significantly decreases with an increase in the H_{applied} value because the $\Delta E_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)$ $\left(=\Delta E_{\mathrm{gap},N,\mathrm{electronic}}(0)\,f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)\right)$ and $\Delta E_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)\left(=\mu_0 H_{\mathrm{applied}}^2 v_{\mathrm{SC}}/2\right)$ values decrease and increase with an increase in the H_{applied} value, respectively. The $\Delta E_{\mathrm{gap},N,\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)$ value decreases with an increase in the H_{applied} value because the $f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)$ value decreases with an increase in the H_{applied} value.

That is, the vibronic stabilization energy decreases with an increase in the H_{applied} value, because the kinetic energy of Cooper pairs increases. At the same time, supercurrent induces the magnetic field, which expels the applied magnetic field. Therefore, the $\Delta E_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$ value increases with an increase in the H_{applied} value. Furthermore, it should be noted that the larger the v_{SC} value, the more significantly the $\Delta E_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$ value increases with an increase in the H_{applied} value. The order parameter in the Ginzburg–Landau theory $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ can be expressed as $f_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)-f_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$, where

$f_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)= f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)$ and $f_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)= \mu_0 H_{\mathrm{applied}}^2 v_{\mathrm{SC}} / \left(2\Delta E_{\mathrm{gap},N}(0)\right)$. When no magnetic field is applied ($H_{\mathrm{applied}} = 0$), these parameters can be expressed as $f_{\mathrm{electronic}}(0) = f_{\mathrm{Bose}}(0) = 1$ and $f_{\mathrm{magnetic}}(0) = 0$, and thus $\psi_{\mathrm{GL}}(0) = f_{\mathrm{electronic}}(0) - f_{\mathrm{magnetic}}(0) = 1$. That is, when no magnetic field is applied ($H_{\mathrm{applied}} = 0$), only vibronic stabilization effect is important, and the $f_{\mathrm{electronic}}(0)\left(= f_{\mathrm{Bose}}(0)\right)$ value is the same with the $\psi_{\mathrm{GL}}(0)$ value.

The $f_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)$ and $f_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$ values decrease and increase with an increase in the H_{applied} value, respectively, and thus the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value decreases with an increase in the H_{applied} value. Finally, at $H_{\mathrm{applied}} = H_{\mathrm{c}}$, the $\Delta E_{\mathrm{gap},N}\left(H_{\mathrm{applied}}\right)$ value should be zero and thus the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value also should be zero, $\psi_{\mathrm{GL}}\left(H_{\mathrm{c}}\right) = f_{\mathrm{electronic}}\left(H_{\mathrm{c}}\right) - f_{\mathrm{magnetic}}\left(H_{\mathrm{c}}\right) = 0$, and therefore, $f_{\mathrm{Bose}}\left(H_{\mathrm{c}}\right) = \mu_0 H_{\mathrm{c}}^2 v_{\mathrm{SC}} / \left(2\Delta E_{\mathrm{gap},N}(0)\right)$.

Let us next reconsider the physical meaning of the order-parameter $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ in the Ginzburg–Landau theory by comparing the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value with the $f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)$ value we have proposed.

The $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ has been considered as ratio of the superelectron (n_{s}) in the two-fluid theory ($n_{\mathrm{s}} + n_{\mathrm{n}} = 1$) in the conventional Ginzburg–Landau theory, where the n_{n} denotes ratio of the normal electron. It has been considered that the ratio of the superelectron becomes 1 ($\psi_{\mathrm{GL}}(0) = 1$) at $H_{\mathrm{applied}} = 0$ and that becomes 0 ($\psi_{\mathrm{GL}}\left(H_{\mathrm{c}}\right) = 0$) at $H_{\mathrm{applied}} = H_{\mathrm{c}}$. On the other hand, according to our theory [1–3], the conventional two-fluid model is not necessarily realistic. Therefore, instead of interpretation of the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value on the basis of the two-fluid model, we may consider that the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value denotes the ratio of the bosonic property (r_{s}) with respect to the fermionic property (r_{n}) of each electron. On the other hand, according to our theory, it should be noted that the ratio of bosonic properties of an electron becomes 1 ($f_{\mathrm{Bose}}(0) = 1$) at $H_{\mathrm{applied}} = 0$ and that does not become 0 ($f_{\mathrm{Bose}}\left(H_{\mathrm{c}}\right) \neq 0$) even at $H_{\mathrm{applied}} = H_{\mathrm{c}}$. This means that even at $H_{\mathrm{applied}} = H_{\mathrm{c}}$, the ratio of the bosonic properties does not become 0 ($f_{\mathrm{electronic}}\left(H_{\mathrm{c}}\right)\left(= f_{\mathrm{Bose}}\left(H_{\mathrm{c}}\right)\right) \neq 0$) even though the $\psi_{\mathrm{GL}}\left(H_{\mathrm{c}}\right)$ value should become 0, according to the Ginzburg–Landau theory. This means that the bosonic properties of each electron should be completely destroyed at H_{c}, according to the Ginzburg–Landau theory. This clearly contradicts the fact that very large energy as a consequence of depairing currents are needed in order to completely destroy the bosonic properties, and this depairing states have not been considered to be realistic [1]. This can be understood from the fact that in the interpretation of the order parameter $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ in the Ginzburg–Landau theory, the magnetic energy $\Delta E_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$ is not considered. That is, the complete disappearances of the superconductivity and the bosonic property are considered to occur in the two-fluid model and the Ginzburg–Landau theory.

That is, the $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ value is conserved to be the same with the $f_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)\left(= f_{\mathrm{Bose}}\left(H_{\mathrm{applied}}\right)\right)$ value in the Ginzburg–Landau theory. On the other hand, according to our theory, the superconducting states can be destroyed at $H_{\mathrm{applied}} = H_{\mathrm{c}}$ before the bosonic properties (r_{s}) in our theory (the number density of superelectron (n_{s}) in the two-fluid theory) completely disappear (the depairing process). This is because the magnetic energy ($f_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$) as well as the electronic energy ($f_{\mathrm{electronic}}\left(H_{\mathrm{applied}}\right)$) should be considered when we consider the energy difference between the superconducting and the normal metallic states at H_{applied}. That is, because of the magnetic destabilization energy ($f_{\mathrm{magnetic}}\left(H_{\mathrm{applied}}\right)$), the superconducting states can be destroyed at $H_{\mathrm{applied}} = H_{\mathrm{c}}$ before the bosonic properties in our theory are completely disappeared (the depairing process $f_{\mathrm{Bose}}(H) = 0$).

The order parameter $\psi_{\mathrm{GL}}\left(H_{\mathrm{applied}}\right)$ in the Ginzburg–Landau theory can be now considered as the ratio of the stabilization energy $\Delta E_{\mathrm{gap},N}\left(H_{\mathrm{applied}}\right)$ of the superconducting states with respect to the normal metallic states at the applied fields H_{applied} to that ($\Delta E_{\mathrm{gap},N}(0)$) at the

zero magnetic field ($H_{\text{applied}} = 0$) ($\psi_{\text{GL}}\left(H_{\text{applied}}\right) = \Delta E_{\text{gap},N}\left(H_{\text{applied}}\right) / \Delta E_{\text{gap},N}(0)$). Furthermore, the ratio of the bosonic properties (r_{s}) (number density of superelectron (n_{s}) in the two-fluid theory) expressed by $\psi_{\text{GL}}\left(H_{\text{applied}}\right)$ in the conventional Ginzburg–Landau theory can be expressed by new parameter $f_{\text{Bose}}\left(H_{\text{applied}}\right)$ (not by $\psi_{\text{GL}}\left(H_{\text{applied}}\right)$) we proposed, $f_{\text{Bose}}\left(H_{\text{applied}}\right) = \Delta E_{\text{electron},N}\left(H_{\text{applied}}\right) / \Delta E_{\text{electron},N}(0)$.

Let us next consider the superconductor at 0 K. According to the two-fluid model, the $\Delta E_{\text{electronic}}\left(H_{\text{applied}}\right)$ value decreases with an increase in the H_{applied} value because the n_{s} value decreases with an increase in the H_{applied} value even though the vibronic stabilization energy $4V_{\text{one}} f_{\text{Bose}}\left(H_{\text{applied}}\right)$ value [1–3] does not change with an increase in the H_{applied} value. On the other hand, according to our theory, by which the two-fluid model is considered to be unrealistic, the $\Delta E_{\text{electronic}}\left(H_{\text{applied}}\right)$ value decreases with an increase in the H_{applied} value because the vibronic stabilization energy $4V_{\text{one}} f_{\text{Bose}}\left(H_{\text{applied}}\right)$ value decreases with an increase in the H_{applied} value even though the n_{s} (= 1) value does not change with an increase in the H_{applied} value.

IX. CONCLUDING REMARKS

In this work, 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 ($s_{ns,\text{X}}$) in the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ and $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ states becomes opposite with respect to that of the induced magnetic field ($B_{\text{ring},ns,\text{X}}$) applying to the ns valence electron. The excited $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ state with up spin is changed to the excited $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ 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 $\left|-\boldsymbol{k}_{ns,\text{X}}\downarrow\right\rangle$ state to the $\left|+\boldsymbol{k}_{ns,\text{X}}\uparrow\right\rangle$ state. The spin magnetic moment ($s_{ns,\text{X}}$) 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 1s, Li 2s, Na 3s, and K 4s 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. Furthermore, we show that the two-fluid model, which has been widely considered in the solid state physics, is not necessarily realistic. Furthermore, we reconsider the interpretation of the order parameter in the Ginzburg–Landau theory on the basis of our theory.

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