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[Shinichi Ishiguri](#) *

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Article

Discovery of Temperature-Independent Superconductivity with Novel Circuit Integration Properties

Shinichi Ishiguri

Nihon University, 1-2-1 Izumi-Cho, Narashinoshi, Chiba 275-8575 Japan; shinichi.ishiguri@gmail.com

Abstract: This paper describes a new type of superconductivity, which is independent for temperatures and which operates without pressures. Because an appropriate adjustment of the circuit that contains a voltage source, a current source and a load in series results in no electric powers from the two sources, the energy conservation results in no Joule heating of the load (i.e. it is predicted that the load resistance becomes zero.) Then, the method in this paper consists of a pure theory and numerical simulations: As a result of the pure theory, after demonstrating that two electrons combine strongly, the Bose-Einstein condensation of electron pairs and the macroscopic wave function were obtained, and the cancelation of the magnetic flux density i.e., the Meissner effect was confirmed analytically. Moreover, as a result of the numerical simulations, we could derive large negative voltages, i.e., a new electric field at the transient state that differs from the normal Coulomb interactions. Note that energy density of this electric field equals to that of the internal magnetic field in terms of the energy conservation. Considering this energy conservation, because this new electric field disappears up to the steady state numerically, the internal magnetic flux density also vanishes by the steady state. This implies that the Meissner effect achieved in the numerical calculations at the steady state in addition to confirm zero resistance. To conclude, our paper confirmed the Meissner effects from both the pure theory and the numerical simulations at the steady states. Note that this paper has prepared Appendix section, which provides a guide to reproduce actual experiments and preliminary experimental results. These results of the Appendix indicate the zero resistances and the Meissner effects when applying the further magnetic fields after the steady state.

Keywords: circuit-based superconductivity; electron pair; Bose–Einstein condensation; Meissner effect; macroscopic wave function; critical current density; negative voltages

1. Introduction

This paper has two types of backgrounds: The one is about the existing and general superconductors, and the other comes from a novel superconductivity, which was found by us approximately 10 years ago.

First, let us consider a brief history of the existing superconductor studies as the background for this paper. Since the initial discovery of superconductivity, more than a century has passed. During this time, many significant achievements have been made. For example, Bardeen–Cooper–Schrieffer theory [1], which found that the carrier of a superconductor has the combination of a Cooper pair, was established. Then, ceramic cuprates whose critical temperatures [2-6] are beyond that of LN₂ were found. Further, MgB₂ [7-8] and Fe-based superconductors [9-14] appeared. Moreover, recently H-based superconductors with high critical temperatures and with high pressures [15-17] were found. However, the common weak point of the above superconductors is that they require refrigeration or pressures. To overcome this weak point, many previous studies have created some compounds which would be expected to work at higher temperatures. However, most of them did not succeed.

Approximately 10 years ago, we demonstrated a new type of superconductivity using theoretical and experimental techniques [18-20]. That is, it is a circuit-based approach not a compound. This superconductivity is generated when a diffusion current from a current source is supplied to a doped semiconductor and an electrostatic field from a condenser cancels the Ohmic voltage of the semiconductor. As a result, the internal voltages are zero but the current remains without refrigeration, because of the existence of the diffusion current. Accordingly, this new superconductivity bypasses the problem of refrigeration because it is not related to temperatures. However, crucially, this 10-years-ago superconductivity had a very small critical current, which prevented it to the practical applications.

Although the existing superconductors are promoting studies in condensed matter physics [21-25], in the present paper, we describe further new type of superconductivity. Furthermore, the present paper will demonstrate significant progresses compared with the above-mentioned 10-years-ago-superconductivity.

To distinguish the abovementioned two new types of superconductivity, we will refer to the one developed 10 years ago as PNS (referring to the Previous New Superconductivity).

The present superconductivity addresses the following aspects.

1. **The critical current density is much larger.** This fact is important when considering practical applications. In PNS, the critical current was less than 10 μA , which prevents it from being used in practical applications; however, the critical current of the present superconductivity is estimated to be 10^4 A order. This value will pose no problems for practical applications.
2. **It is clear that the mechanism is the Meissner effect.** In PNS, we knew that the superconductor discharged a current as a result of the application of static magnetic fields. However, the details of that mechanism were not clear. In the present study, we were able to demonstrate that the internal magnetic field vanishes and identify the mechanism as the Meissner effect.
3. **Numerical simulations result in clear superconductivity.** In PNS, we could not establish a simulation method; however, the present superconductivity system implies a pure electrical circuit, which enabled us to employ simulation software for electrical circuit calculations (e.g., the PSIM software) by introducing an equivalent circuit. The use of this simulation method enabled us to investigate this system via various approaches.
4. **It is not necessary to prepare the specific setup.** In PNS, we had to produce the setup which is a sandwich of semiconductor, insulator and condenser pole plates. Although this device confirmed the zero resistance, it is hard to produce the setup. However, the present method of this paper does not require the production of the device or materials. This is a new and significant point compared with PNS.

To conclude, the mechanism of our new superconductivity including PNS resulted in a comprehensive understanding.

As relevant fields, superconducting circuits, quantum circuits or micro-circuits are studied by another researcher [26-29]. However, most of them employ the existing, refrigerated superconductors. On the other hand, our superconductivity does not require any refrigeration, which is different from the above.

This paper reviews the characteristics of both the voltage and current sources before detailing the principles of the proposed superconductivity system. The mechanism of pairing and forming the macroscopic wave function is discussed theoretically with obtaining the London equation. Furthermore, the Meissner effect that the internal magnetic field vanishes will be discussed. Moreover, a critical current equation is formulated. The Methods section proposes an equivalent circuit with calculations of the inductance of the internal toroid. In the Results section, we calculate concrete values of the critical currents and use the PSIM software to calculate the time dependences of the voltages and currents in the sample.

Moreover, importantly, we have prepared Appendix A of a guide to reproduce the experiments and of the presentation of preliminary experimental results. We believe that this appendix is significant because it provides a solution of obtaining a superconductor, which enables us to enhance performances of every electrical device. Although it is all right that the results of the experiments in

this appendix are placed in the main body but because they are preliminary tests, we located the descriptions at the end of the paper as an appendix.

In summary, the contents of the theory are simple but novel and thus it provides a new knowledge to the field of condensed matter physics like a new paring system, new forces or a new type of Bose-Einstein condensation. Furthermore, this theory is supported by the numerical results and the preliminary experimental results from the Appendix.

2. Principle

2.1. Review of Voltage and Current Sources

In our proposed system, voltage and current sources are employed, which are elements of a general electrical circuit. Figure 1 shows schematics of these sources. The voltage source generates a constant voltage while its current is varied depending on the connected load. The internal resistance of this voltage source is ideally zero. Conversely, the current source supplies a constant current (not voltage) to the load, which is not related to the electrical resistance of the load. Therefore, its voltage is varied depending on the resistance of the load. In contrast to the voltage source, the internal resistance of the current source is ideally infinite. Moreover, a current from the current source stems from a diffusion current, which is related to a collector current in transistors. This fact will be important later when discussing the theory.

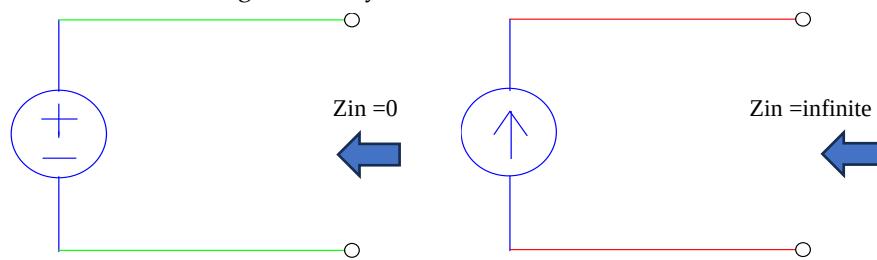


Figure 1. Schematics of the voltage and current sources. The left panel shows the voltage source, which supplies a constant voltage regardless of the value of the connected load. Conversely, the right panel shows the current source, which provides a constant current regardless of the value of the load. This current supply is achieved via the employments of collector currents of transistors. An important point is that their internal resistances, i.e., the input impedances Z_{in} , are opposite to each other. The internal resistance of the voltage source is zero, whereas the internal resistance of the current source is infinite.

2.2. Principle

As shown in Figure 2, a voltage source, a current source, and a load are connected in series. As previously mentioned, the internal resistance of the voltage source is zero, whereas the internal resistance of the current source is infinite. Moreover, the output voltage is equal to the voltage from the load, as derived via Ohm's law. Considering these points, the following can be said:

1. The generating current from the voltage source is zero because of the infinite resistance of the current source. Therefore, this source generates only the voltage V .
2. For the current source, because of the balance of the two voltages of the voltage source and the load, the voltage between the taps of the current source becomes zero. Therefore, this source supplies only the current I to the load.

These characteristics are listed in Table 1.

Considering the above, we see that neither source generates electric power. Therefore, energy conservation requires that the load not receive any energy and that the load not generate Joule heating. Because the current I exists in the load because of the current source, the absence of Joule heating in the load results in zero electric resistance. Therefore, we can predict that this system, in principle, will result in a new type of superconductivity. However, before we reach this conclusion,

it is necessary to theoretically examine the mechanism of the superconductivity in terms of condensed matter physics and demonstrate that the Meissner effect is generated.

Table 1. Comparisons characteristics between voltage and current sources acting our system.

	Voltage (V)	Current (A)	Electric power (W)
Voltage source	Constant V	0	0
Current source	0	Constant I	0

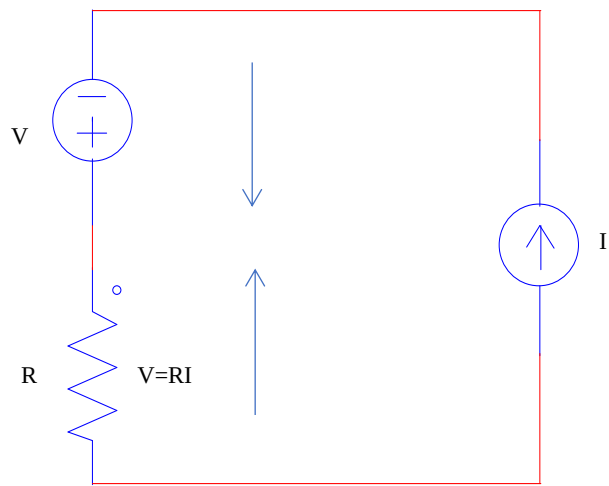


Figure 2. Schematic of the system generating the superconductivity. After setting a current I from the current source, the output of the voltage source is adjusted to balance the Ohmic voltage from the load. In this way, the voltage over the current source becomes zero but the output current I remains, and the current from the voltage source becomes zero because of the infinite internal resistance of the current source but the output voltage is kept constant. Therefore, the electric powers from the two sources are zero, which implies that the load does not generate Joule heating because of energy conservation. Therefore, we can predict that the resistance of the load will become zero.

3. Theory

3.1. Transient State

3.1.1. Spatial Electron Concentration at the Transient State

First, we assume that the voltage of the voltage source and the voltage of the load are equal. Then, the diffusion current of the current source is introduced. Considering the conductivity, introducing a local electric field, and substituting a diffusion constant result in a specific and special electron concentration: The voltage balance is

$$V_E = V = R_0 I, \tag{1-1}$$

$$R_0 = \rho \frac{l}{S_0}, \tag{1-2}$$

where V_E , V , R_0 , and I denote the voltage from the voltage source, the voltage of the load, the resistance of the load, and the current from the current source, respectively. In Eq. (1-2), ρ , S_0 , and l denote the resistivity, the cross-section area of the load, and the length of the load, respectively. The diffusion current I is expressed as [18], [30]

$$I = S_0 q D \frac{dn}{d\xi}, \quad (2)$$

where q , D , and n denote the electron charge, the diffusion constant, and the electron concentration, respectively. Therefore, the Ohmic voltage becomes

$$V = \rho \frac{l}{S_0} S_0 q D \frac{dn}{d\xi} = \frac{l}{\sigma} q D \frac{dn}{d\xi}, \quad (3)$$

where σ denotes the conductivity of the load. Here the following equations are substituted:

$$\sigma = q n \mu, \quad (4-1)$$

$$D = \frac{\mu k_B T}{q}, \quad (4-2)$$

$$V = E_i l, \quad (4-2)$$

where μ , k_B , T , and E_i denote the average mobility, the Boltzmann constant, the temperature, and a local electric field, respectively. Note that i is index at each lattice. Therefore, the local electric field is

$$E_i = \frac{k_B T}{q n} \frac{dn}{d\xi}. \quad (5)$$

Solving this equation gives

$$n = n_0 \exp\left(\frac{q E_i}{k_B T} \xi\right). \quad (6)$$

3.1.2. Attractive Potential and New Electric Field at the Transient State

We employ the Poisson equation to derive the interaction potential between two electrons at the transient state. Equation (6) gives the concentration in terms of the electrons; substituting this concentration into the Poisson equation produces the following attractive interaction potential ($V_\alpha < 0$):

$$V_\alpha = -\frac{n_0 k_B^2 T^2}{\epsilon E_i^2} \exp\left(\frac{q E_i}{k_B T} \xi\right), \quad (7)$$

where ξ is variable and relative macroscopic distance between the two electrons. Hereafter, we refer to this potential as a transient state potential. It is very important to note that the Coulomb repulsive interaction is also determined using Poisson's equation. Accordingly, this repulsive interaction does not appear at a macroscopic scale along ξ -line. Instead, the abovementioned interactive potential V_α works. Note that, at the steady state, the macroscopic relative distance ξ becomes zero but microscopic one is not zero. In this sense, at the steady state, we will consider the Schrodinger equation.

In the process of solving the Poisson equation, we derived the following new electric field at the transient state:

$$E_m = -\frac{n_0 k_B T}{\epsilon E_i} \exp\left(\frac{q E_i}{k_B T} \xi\right). \quad (8)$$

Considering the existence of V_α , the line integral of Eq. (8) must be within a material. Thus, this integral must end up within a material. This implies that, in the material, a coil voltage must be defined. As will be discussed, we will see that, immediately prior to the transition from the normal state to the superconducting state, a negative voltage related to the line integral of Eq. (8) appears in our simulation. That is, this new electric field appears at the transient state and thus an inductor (i.e., a coil) voltage will be essential.

3.1.3. Combination of Two Electrons and Critical Current Density

The transient state attractive interaction potential V_α results in two electrons that approach each other until their distance is only the lattice diameter due to the lack of the Coulomb repulsive interaction at the macroscopic scale. At this moment, the macroscopic relative distance ξ becomes zero. Note that, however, microscopic one is not zero. Therefore, the transient state up to the combination of the two electrons is a macroscopic phenomenon. Instead, after the combination, it is imperative to consider the Hamiltonian for quantum mechanics for the center-of mass motion as described later.

Let us consider the condition of the combination of two electrons, which results in a critical current and superconducting energy gap:

As a result of the transient interaction V_α , the two electrons take the location of a lattice, and at a lattice (i.e., macroscopic variable $\xi = 0$), the total energy E_T of the system is expressed as follows:

$$E_T = |V_\alpha(\xi = 0)| + V + V_p, \text{ and} \\ V_\alpha(\xi = 0) + P = 0. \quad (9)$$

Here, V is the spin magnetic potential [18] expressed as

$$V = -\frac{q^2 \hbar^2}{16\pi m^2 |z_m|^3}, \quad (10)$$

where m and z_m denote the electron mass and the “microscopic” relative coordinate, respectively. In Eq. (9), P and V_p are the kinetic and zero-point energies in terms of the Debye temperature at the lattice, respectively. V_p is expressed as follows:

$$V_p = \frac{1}{2} \hbar \omega_D = \frac{1}{2} k_B \theta_D, \quad (11)$$

where ω_D and θ_D indicate the Debye angular frequency and temperature, respectively. The following conditions should be satisfied for the two-electron combination:

$$|V_\alpha(\xi = 0)| \geq V_p, \quad (12-1)$$

$$|V| \geq P. \quad (12-2)$$

For Eq. (12-1) to be satisfied, both electrons must be located at the zero point of a lattice. This condition, i.e., critical current density, will be considered later. To satisfy Eq. (12-2), the microscopic relative distance z_m (i.e., the coherence) should be

$$z_m \leq 1.0 \times 10^{-9} \text{ m}. \quad (13)$$

If Eq. (12-1) is satisfied, then, Eqs. (12-2) and (13) are also satisfied. The reason is that, by Eq. (12-1), the zero-point energy at a lattice vanishes, which allows that the two electrons locate at the identical lattice and that the relative kinetic energy also vanishes. Note that, of these, each relative kinetic energy is defined by each lattice. Moreover, the identical location of two electrons at a lattice also satisfies Eq. (13), because the average diameter of a lattice is on the order of Å. Therefore, when current density is less than the critical current density, only the spin magnetic potential V remains, and the entire energy takes on a negative value, which implies that the two electrons have a net combination, in which a collision between the two electrons becomes completely inelastic. Consequently, these two electrons combine to form a pair.

Even though the kinetic energy in terms of the relative motions exists in the transient state, as mentioned, in the steady state, only the spin attractive force V remains:

$$V = -\frac{q^2 \hbar^2}{16\pi m^2 a^3}, \quad (10-2)$$

where a denotes the constant coherence of an electron pair.

Therefore, this potential is taken to be the superconducting energy gap of our superconductivity. As mentioned, the two-electron pair combines at the diameter of a lattice, which is typically estimated to be 1 Å, and, therefore, the magnitude of the energy gap is estimated to be approximately 10^{-18} J. The typical room temperature energy $k_B T$ (where the temperature $T \approx 300$ K) is approximately on the

order of 10^{-21} J. Therefore, this superconducting energy gap is much larger than that of room temperature. This implies that the individual electron pair will not be destroyed via normal heating.

Next, let us consider an equation of the critical current density:

At the critical point, i.e., in the case where the inequality of Eq. (12-1) is maximum,

$$\frac{n_0 k_B^2 T^2}{\varepsilon E_i^2} = \frac{1}{2} k_B \theta_D. \quad (14)$$

From this equation, the concentration n_0 can be expressed as

$$n_0 = \frac{\varepsilon E_i^2}{k_B T^2} \frac{1}{2} \theta_D. \quad (15)$$

In Eq. (14), considering the second equation of Eq. (9), the left-hand side of Eq. (14) implies a kinetic energy P . Therefore,

$$\frac{n_0 k_B^2 T^2}{\varepsilon E_i^2} = \frac{1}{2} m v^2, \quad (16)$$

where m and v denote the mass of the electron and the velocity in terms of the relative motions, respectively. Substituting Eq. (15),

$$\frac{\varepsilon E_i^2}{k_B T^2} \frac{1}{2} \theta_D \frac{k_B^2 T^2}{\varepsilon E_i^2} = \frac{1}{2} m v^2. \quad (17)$$

That is,

$$\frac{1}{2} k_B \theta_D = \frac{1}{2} m v^2. \quad (18)$$

Therefore, the relative velocity is derived to be

$$v = \sqrt{\frac{k_B \theta_D}{m}}. \quad (19)$$

Consequently, the critical current density equation is obtained such that

$$j_c = q n_0 v = q \frac{\varepsilon E_i^2}{k_B T^2} \frac{1}{2} \theta_D \sqrt{\frac{k_B \theta_D}{m}}. \quad (20)$$

Note that, in the Results section, we will calculate numerical values of the critical current density using Eq. (20).

3.2. Macroscopic Wave Function and the London Equation at the Steady State

Given that a two-electron pair binds strongly, from the discussion in the previous sections, we now precede to a discussion of Bose–Einstein (BE) condensation and the macroscopic wave function at the steady state.

As described previously, the Hamiltonian equation of an electron pair in terms of the center-of-mass motion is expressed simply as

$$H = -\frac{\hbar^2}{2(2m)} \frac{d^2}{dx^2} + U. \quad (21)$$

The potential U in the above equation indirectly implies the electrostatic potential of the two electrons, i.e., the internal electric field at a lattice:

$$U = -2q \int \vec{E}_i \cdot d\vec{s} \approx -\int_{x_1}^{x_2} 2q E_i dx = -2q E_i (x_2 - x_1), \quad (22)$$

where x_1 and x_2 denote the positions of the two electrons.

In the steady state, we are now considering the combined electron pair at a lattice, without collisions (i.e., the interactions) with another pair, and thus this temperature-independence allows us to consider that the movement of the center-of-mass motion is determined by the local field E_i (i.e., the movement depends on Eq. (22)) Note that, in the above line integral, the other components are relatively small and thus they are approximately neglected. The reason of the absence of interactions between pair and pair will be discussed soon. (However, at the transient state, the existence of the

potential V_α implies that each electron motion depends on temperature T .) Moreover, because there are not net collisions between pair and pair at the steady state, it is potential for a phase transition that is related to temperatures not to exist [25]. The absence of the interactions with another pair guarantees the physical picture of one body.

The local placements at the identical lattice of the two electrons (i.e., the local and strong combination of the two electrons at a lattice) imply that $x_1 = x_2$. Employing the Hamiltonian equation, a wave function from the Schrodinger equation of the pair in terms of the center-of-mass motion can be obtained. Note that, at the moment when the electrons have an identical location at a lattice, the potential U in the Hamiltonian equation converts to an eigenvalue (i.e., the kinetic energy in terms of the center-of-mass motion) that stems from the local electric field E_i . Accordingly, the distribution of the local electric field E_i within the lattice vanishes.

$$\varphi_i = \gamma \exp \left[\frac{2m\mu_i E_i}{\hbar} jx \right], \quad (23)$$

where φ_i and μ_i denote the wave function and the mobility of pair at lattice, respectively. Using the following equations,

$$\frac{J}{\sigma_i} = E_i \quad \text{and} \quad (24-1)$$

$$\sigma_i = \frac{2q}{\Delta V_i/i} \mu_i, \quad (24-2)$$

The wave function of an electron pair can be derived such that

$$\varphi_i = \gamma \exp \left[\frac{2mj}{\hbar} xJ \frac{\Delta V_i/i}{2q} \right], \quad (25)$$

where σ_i , ΔV_i , and J denote the conductivity at the lattice, the variation quantity of the volume with respect to the increase in index i , and the current density, respectively.

Equation (24-1) implies the proportion of Joule electric and applied electric fields at the lattice-scale level. As mentioned, the above wave function of an electron pair is indexed by i , and a wave function at a subsequent lattice does not interact with this wave function because the distance between the two neighboring lattices is much larger than the coherence of the two electrons. Note that, in the previous section, we mentioned that the coherence a of a combined pair is estimated to be approximately 1 Å (i.e., the typical diameter of a lattice). This is the reason why each electron pair does not interact with each other.

Thus, the entire wave function is simply represented in the following equation:

$$\psi = \prod \varphi_i = \gamma^i \exp \left[\frac{2mj}{\hbar} x \sum J \frac{\Delta v_i}{2q} \right]. \quad (26)$$

Assuming that the index i is infinite and that the sample volume of a load is kept constant, the lattice volume $\Delta V_i/i$ converges to the differential dV . Accordingly, the countable lattice concept becomes ineffective, and a macroscopic continuous body appears. That is, we obtain a macroscopic wave function that is mandatory when considering the mechanism of the new superconductivity, and this macroscopic wave function is needed to derive a London equation:

$$\rightarrow \eta \exp \left[\frac{2mj}{\hbar} x \int \frac{J}{2q} dV \right] = \eta \exp \left[\frac{2mj}{\hbar} xa \int \frac{J}{2q} dS \right] = \eta \exp \left[\frac{mI}{\hbar q} a jx \right]. \quad (27)$$

In Eq. (27), the wave number K is

$$K = \frac{mI}{\hbar q} a = \frac{I}{2M} a, \quad (28-1)$$

where M denotes the spin magnetic moment of an electron and a is the constant coherence in terms of our new superconductivity. The spin magnetic moment in this equation can be correlated to the

combination energy (i.e., the spin interaction) from Eq. (10) when the microscopic ordinate z_m is replaced with the constant coherence a .

$$K = \frac{I}{2\sqrt{-4\pi aV}} \quad V \leq 0, \quad (28-2)$$

where V denotes the spin interaction given in Eq. (10-2).

In Eq. (28-2), the macroscopic current I is independent of the collision time and is therefore a superconducting current. Further, the wave number K in this equation is uniform and is not related to space, e.g., it is not related to lattice index i . Therefore, all the quantum states converge to a single state, and Bose–Einstein condensation is derived.

Let us consider the London equation derived from the macroscopic wave function. As mentioned, the macroscopic wave function is

$$\psi = \eta \exp\left(\frac{mIa}{\hbar q} jx\right). \quad (27)$$

In this equation, the macroscopic current I appears. In general, a current needs to be continuous in space and time. In this case, therefore, the current I is continuous for the output current I from the current source. Accordingly, this superconducting current must generate a self-magnetic field in the load sample but, if a new superconductivity is generated, this self-magnetic field must be canceled out. This will be discussed in Sec. 3.3

Considering the above self-magnetic field A , the Aharonov–Bohm (AB) effect [24] can be introduced to the macroscopic wave function, Eq. (27):

$$\psi_A = |\psi| \exp\left[\left(\frac{mIa}{\hbar q} x + \frac{q}{\hbar} \int A ds + \theta\right)j\right], \quad (29)$$

where θ denote arbitrary integral constant.

Based on the property of phases,

$$\frac{mIa}{\hbar q} x + \frac{q}{\hbar} \int A ds + \theta = 2n\pi. \quad (30)$$

Taking the differentials to both sides for variable x ,

$$\frac{mIa}{\hbar q} = -\frac{q}{\hbar} \frac{d}{dx} \int A ds. \quad (31)$$

That is,

$$\frac{mIa}{\hbar q} = -\frac{q}{\hbar} A \frac{\Delta s}{\Delta x}. \quad (32)$$

$$\frac{ma}{\hbar q} \int j_n dS = -\frac{q}{\hbar} A \tau, \quad (33)$$

where $\tau \equiv \frac{\Delta s}{\Delta x}$

Assuming a differential for integrals for the surface is very small, Eq. (33) becomes

$$\frac{ma}{\hbar q} j_n \times a^2 = -\frac{q}{\hbar} A \tau. \quad (34)$$

Therefore, we derive a London equation:

$$j_n = -\frac{q^2 \tau}{ma^3} A. \quad (35)$$

Note that, considering that the parameter τ is dimensionless and when the solution is obtained as $\frac{\Delta s}{\Delta x}$ in Eq. (32), the parameter τ implies that the ratio between wavelength along x -line and wavelength along s -line.

3.3. Consideration of the Meissner Effects

When considering a sample with a cylindrical shape, it is necessary to introduce an internal toroid whose large radius essentially corresponds to that of the cylindrical sample. Then, we consider the renewable coordinate that is basically tangential to the large circumference as corresponding to the z -axis in cylindrical coordinates; see Figure 3. We refer to this type of coordinates as the “specific cylindrical coordinates.”

From the initial time to the transition time, there is a normal self-magnetic field distribution B_0 in the sample along the direction of the z -axis of the specific cylindrical coordinates. However, as mentioned, due to the existence of the new electric field E_m , Eq. (8) at the transient state, internal voltages must be defined within a material. This implies that coils appear at the transient state within the material. During the transient state, a negative voltage appears and, as described later, a current of a locally divided coil that works to cancel the self-magnetic field is produced. Owing to the continuous property of the current, this generated current becomes the persistent one at the steady state. In this process, the generated magnetic field cancels the existing self-magnetic field B_0 whose direction is along the z -axis of the specific cylindrical coordinates. Therefore, the internal net magnetic flux density becomes zero despite the existence of the current I . The more details will be discussed soon.

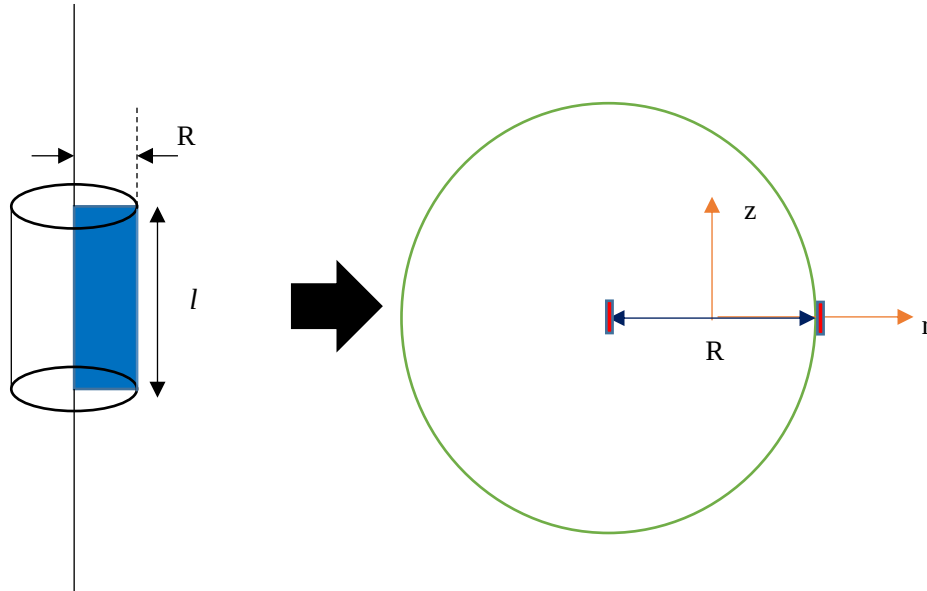


Figure 3. Schematic of the specific coordinates of an internal toroid. The left panel indicates a load whose macroscopic shape is cylindrical, and R is a radius that is essentially identical to the large radius of a toroid. The right panel shows a cross section of an elemental coil as a part of the internal toroid. The red square of right panel is a cross section of the elemental coil, which is located in the z - r -axes of the specific cylindrical coordinates. Note that these elemental coils' cross sections are microscopic and sufficiently small. That is, this is a schematic and therefore an elemental coil is actually very small because its height along the z -axis corresponds to the diameter a of a lattice (it is a so-called two-dimensional elemental coil) and that there is generally a ϕ -axis in cylindrical coordinates but the actual area that the magnetic field vectors cross perpendicularly depends on l , depicted as the blue area in the left panel. Note that, in this paper, the length l is assumed to be Na , where N and a denote arbitrary integer and the diameter of a lattice, respectively. That is, the blue surface of the left panel is divided into many local coils.

At the transient state, an energy conservation holds:

$$\frac{1}{2} \varepsilon_0 E_m^2 = \frac{B_0^2}{2\mu_0}, \quad (36)$$

where ε_0 and μ_0 denote the permittivity and the magnetic permeability constants, respectively.

If the new electric field E_m disappears, then the self-magnetic field B_0 also vanishes. This fact will be confirmed by the results of later simulations in this paper.

Let us consider the above description more concretely. Here, in the right panel of Figure 3, we consider one element coil. Moreover, as discussed soon, this element coil is divided into many local coils. Assuming that the length l in the left panel of Figure 3 is considered to be Na , where N and a denote arbitrary integer and the diameter of a lattice respectively, in the conductor, many locally divided coils and currents whose carriers' momenta are given by Eq. (8) (i.e., the attractive potential V_α) exist. However, considering the analogy of the Stokes' theorem, these internally local currents of each locally divided coil cancel with each other and the net current (i.e., the persistent current) eventually becomes the most outer current of the blue surface in the left panel of Figure 3. These phenomena imply that, as described in the theory section, the cancelation of the local currents implies the perfect inelastic collisions of two electrons and the two electrons bind by the spin magnetic force Eq. (10). That is, two electrons attract each other along each local coil by the new electric field Eq. (8) (i.e., the transient interaction potential V_α), and eventually these electrons bind by the force Eq. (10). (Note that the electric field E_m , Eq. (8), is produced as a result of the many-body effect, which reflects the appearance of the temperature T . Two electrons combine sequentially with reduction of the magnitude of the two-electron interaction E_m . That is, the thermal-equilibrium electron concentration n_0 in Eq. (8) is reduced gradually. Note that the number of the electric field E_m corresponds to the number of two-electrons. Introducing a volume, if the concentration n_0 is replaced to summations, this interaction E_m , i.e., V_α , well expresses the many-body interactions. This is how a local current along the locally divided coil disappears gradually, not suddenly. This implies that there is not a strict phase transition in our system.) After that, these combined electrons result in Eq. (27) (i.e., the Bose-Einstein (BE) condensation). Note that the combined electron-pairs change to a wave front, and thus each created wave front produces the macroscopic wave. However, the superconducting current I in Eq. (27) still generates a self-magnetic field B_0 but AB effect will demonstrate the cancellation of the magnetic fields. Note that, however, forming of BE condensation and AB effect actually occur simultaneously. Thus, the exclusion of the internal magnetic field B_0 is achieved by the steady state:

Let us produce the Meissner effect (i.e., the cancellation of the magnetic fields in this paper) with the combination of the BE condensation and AB effect, in the steady state. Note that a disappearance of the internal magnetic flux density from the initial state to the steady state will be also confirmed in the later simulation, with Eq. (36).

From Eq. (32),

$$\tau \equiv \frac{\lambda_s}{\lambda_x} = -\frac{mIa}{q^2A}, \quad (37)$$

where λ denotes a wavelength.

Using the above equation, Eq. (29) becomes

$$\psi_A = |\psi| \exp \left[\left(-\frac{q}{\hbar} A \tau x + \frac{q}{\hbar} \int A ds + \theta \right) j \right]. \quad (38)$$

Note that

$$\tau x \rightarrow \frac{ds}{dx} x = x \frac{ds}{dx} + s \approx s, \quad (39)$$

where it is assumed that the second term is sufficiently larger than the first term.

Thus,

$$\psi_A = |\psi| \exp \left[\left(-\frac{q}{\hbar} A s + \frac{q}{\hbar} \int A ds + \theta \right) j \right]. \quad (40)$$

When assuming the vector potential A is uniform,

$$\psi_A = |\psi| \exp(j\theta). \quad (41)$$

This is how the self-magnetic field A was cancelled, which implies a Meissner effect. Note that this cancelation (i.e., the balance) in the phase does not necessarily imply each vector potential is zero.

Let us discuss a Meissner effect when applying a further magnetic field after the steady state. Note that, when applying the magnetic field independently for the system, it is necessary to input a further current to create the first term of the phase in Eq. (40), in addition to the application of the

magnetic fields. This fact was confirmed in the Appendix: after confirming the zero voltage of the sample and when a magnetic field was applied, a relatively large voltage appeared steadily.

Let us discuss the reason: As a result of the transport current, Eq. (40) should be considered, based on the logic in terms of the AB effect. However, considering the applied magnetic field, the second term in the phase should change:

$$\psi_A = |\psi| \exp \left[\left(-\frac{q}{h} A s + \frac{q}{h} \int A' ds + \theta \right) j \right], \quad (40-2)$$

where the uniform A' includes one from the applied magnetic field. Therefore, the balance between the first and second terms in the phase breaks. The larger term as a result of the break must form the shield current and then the extra field must be discharged outside. For example, if $A > A'$ is formed, the second term in the phase vanishes by a shield current from the first term of the phase, and the extra field is then discharged outside. Note that the above currents can be defined as the densities of probability flows, considering variable s . This is how the applied magnetic field is excluded. For details, see the Appendix.

4. Method

4.1. Equivalent Circuit

In the previous section, it was found that an internal, local and divided toroid inductance L is produced in the sample. Considering this, we can introduce an equivalent circuit for our system, shown in Figure 4, which has the inductance L . This inductance L is the most important factor in the equivalent circuit but it will be given a concrete value in section 4.2.

The sample has both a resistance R_0 named “R1” and an inductance L named “L2”. Moreover, generally any substance has a small inductor factor (i.e. a flux) when subjected to the transport-current. Thus, in the equivalent circuit, this inductor factor L_0 , which is connected by direct connection with “R1”, is employed. This small inductor factor generates a self-magnetic field. This is because a magnetic flux is generally proportional to both the inductance and the current. Considering herein cross-section area for the magnetic flux density of the sample is arbitrary, this magnetic flux indirectly implies a self-magnetic field. Moreover, the parameter L_0 was given 0.1 mH but this is merely an example value. Moreover, the resistance R_0 of R1 is also example values. Note that the inductances do not give any influences to the voltage balance shown in Figure 2, because Figure 2 implies the steady state and thus sufficiently long time makes the influences of the inductances cease, and we will forecast that the superconductivity appears. That is, in this method, we focus on the transient state.

For the numerical calculations, we employed the PSIM electrical circuit software, which can be purchased from their website.

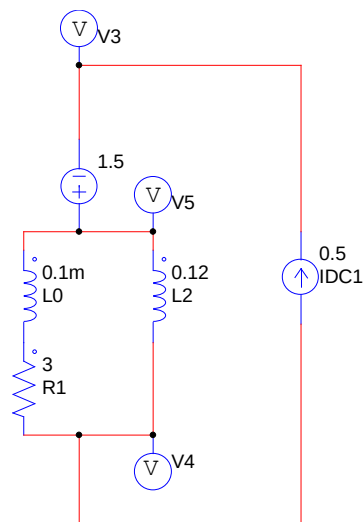


Figure 4. A circuit for numerical calculations. Note that V3, V4 and V5 imply the probes of electrostatic potentials and that parallel of R1 and L2 implies the equivalent circuit of our superconductivity. However, it is necessary to consider that any substance generally has its very small inductor factor L_0 (For example, 0.1 mH). As motioned, this small inductor factor indirectly implies a self-magnetic field. If the value of R1 is varied, then outputs of the voltage source is also varied to maintain the voltage balance. Note that, in this circuit, when considering the voltage of the sample, the probe V5 is defined as the criterion here. Thus, the net voltage of the sample implies the electric potential of the probe V4.

4.2. Calculation of Inductance L

To simulate the equivalent circuit, we need to estimate a concrete value of the inductance L named “L2”, which is determined by the geometrical factors of a locally divided coil. As mentioned, it is necessary to consider the specific cylindrical coordinates, i.e., an internal toroid. The inductance of the toroid is given approximately as,

$$L \approx \mu_0 \frac{N_0^2}{2\pi R} S, \quad (42)$$

where μ_0 , N_0 , S , and R denote the magnetic permeability in a vacuum, the turn number, the area, and the large radius of the toroid, respectively. Note that the area S is indicated in Figure 3 as a blue surface.

In Eq. (42), the turn number is derived from the fact that each element coil of the internal toroid is distributed with a relative distance that is equal to the diameter a of a lattice (see the right panel in Figure 3):

$$N_0 \approx \frac{2\pi R}{a}, \quad (43)$$

where the parameter a is approximated as $1 \text{ \AA}$.

Moreover, because we are now one locally divided coil,

$$S \equiv Ra. \quad (43-2)$$

Assuming $R \equiv 1.23 \times 10^{-3} \text{ m}$, for example, then

$$L \approx 0.12 \text{ H}. \quad (44)$$

This value was incorporated to the inductance of L2 in the equivalent circuit.

4.3. The Discussion of the Uniformity and Independence of Each Locally Divided Coil

The inductance L2 indicates the transient coil and thus we now consider each locally divided coil. Note that each locally divided coil is independent for each other until two electrons complete to combine along ξ -line and their currents are canceled. That is, although at the initial state each locally divided coil coexists within the blue surface in Figure 3, they are not the parallel connections. The reason is that the each locally divided coil is symmetric with each other. That is, considering every locally divided coil within the blue surface in Figure 3, each current does not divert at each node. This implies that every locally divided coil in the left panel of Figure 3 does not form the parallel connections. That is, an independently local current forms along a local coil until two electrons complete to combine. To conclude, the behaviors of every local coil can be represented by an inductance of one local coil.

4.4. Limitations of the Simulation

As mentioned, although we can input a resistance value of the sample through this software, this software does not consider the concrete geometrical shape of the sample and its resistivity. Concerning the limitations, this paper will discuss the future researches in Discussion section.

5. Results

There are two types of results in this paper: the one is analysis of behaviors of the currents and voltages in a sample, and the other is hand calculations of the critical current densities. Let us present them step-by-step

5.1. Circuit Simulations

First let us present results of voltage and current behaviors at the transient state, in the sample. In this analysis, we will vary the value of the resistance to confirm the reproductions of the phenomenon.

Figures 5a–5c indicate the electrical potentials according to Figure 4, when the load is $3\ \Omega$ and the input current is $0.5\ \text{A}$. Figure 6 shows the time dependence of each current that exists in the sample. Note that sampling time is $0.01\ \text{s}$. Moreover, in Figure 4, it is allowed that the criterion of the voltage of the sample is given to the probe V5, and thus the net voltage of the sample implies the electric potential of the probe V4. This is reasonable because the values of the probe V5 are nearly zero consistently. From the initial time, the probe V4 detects very large negative electric potentials up to $0.2\ \text{s}$. However, at $t = 0.2\ \text{s}$, V5 becomes completely zero and V4 also becomes zero.

In addition, in Figure 6, the resistance R1 current reaches zero at $0.2\ \text{s}$, which implies the Joule heating becomes zero and inductor L2 current reaches the steady value at $0.2\ \text{s}$. This implies that the tap voltage between V5 and V4, i.e., the voltage of a sample, becomes zero but the current is retained, which implies net zero resistance. As mentioned, a large negative voltage occurs immediately prior to the time of the transition.

In Figure 7a–c, each electrical potential in the case with $1\ \Omega$ is presented, whereas Figure 8 shows the characteristics of the currents in the sample. Again, the reason for varying the resistance is for confirming a reproduced negative voltage. The behaviors of each electrical potential and the current are the same as in the case with $3\ \Omega$; however, the transition time becomes longer shifting to $0.4\ \text{s}$. As an important result, V4 again exhibits a large negative value similar to that in the case with $3\ \Omega$. Therefore, we can conclude that negative voltages appear immediately prior to the transition time and the disappearance of the new electric field by the steady state implies a demonstration of the Meissner effect, considering the energy conservation, Eq. (36). That is, the self-magnetic field B_0 vanishes.

(Note that each result varies gradually according to time. Thus, as described in the theory section, these results do not define a strict phase transition [25].)

Let us consider a more concrete meaning of the above negative voltages. When considering the criterion of the sample voltage is defined by the probe V5, as mentioned, every locally divided coil within the blue surface in Figure 3 has the same electric potential V4 because every locally divided coil is independent for each other. This is natural when considering that each divided coil is symmetric with each other. However, we consider that the difference between the value of V4 at the initial state and that at the steady state implies the line integral of the new electric field, Eq. (8). That is, a locally divided coil's voltage is represented as

$$\int_0^{\xi_A} E_m d\xi \equiv \varphi_{V4}(t = 0) - \varphi_{V4}(t \rightarrow \infty), \quad (45)$$

where ξ_A and φ denote the maximum ξ along a locally divided coil and the electrostatic potential, respectively.

However, as described, the value of V4 at the steady state (i.e., the second term in Eq. (45)) became zero numerically and thus eventually the value of V4 at the initial state is essentially equal to the line integral of the new electric field.

Note that generally an inductor is shorted for a steady DC current. Thus, the above results claim that initially, the new electric field E_m , Eq. (8), is the maximum but after that this electric field provides the momentum to electrons, which implies that the current in L2 gradually increases. After the transition time, this current becomes the steady DC current, which implies L2 is shorted. This implies that the transient state coils (i.e., locally divided coils) vanish. These descriptions correspond to the fact in Sec. 3.3.

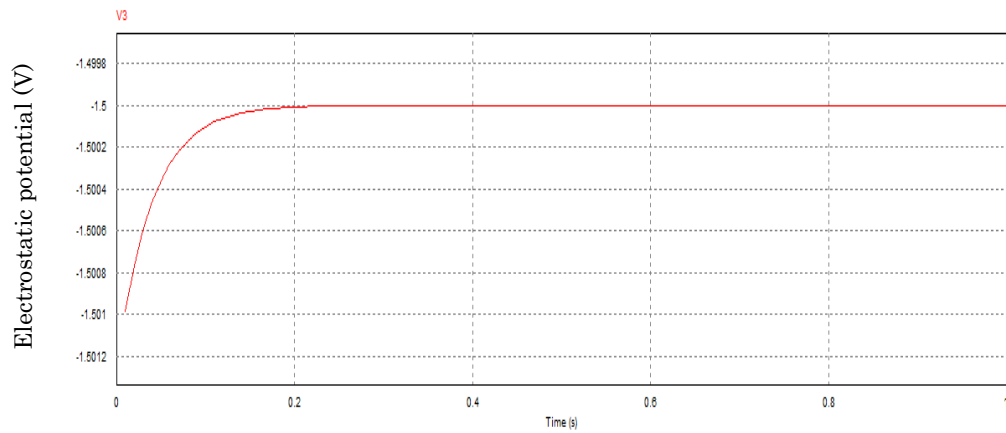
Subsequently, let us consider the meaning of results of the probe V3. At the transition, while the V5 reaches 0.0 [V], the V3 detect the output of the voltage source. Considering that the difference between the V4 and V5 at the steady state implies the zero voltage of the sample, only the V3 detect the output of the voltage source. This fact implies that, although the output of the voltage source does not die, the sample voltage (i.e., the sample resistance) reaches zero. However, in an actual experiment, the voltage of the voltage source was consistently zero as will be described in the Appendix in this paper. Let us consider the reason:

In Figure 4, the Kirchhoff's voltage law provides

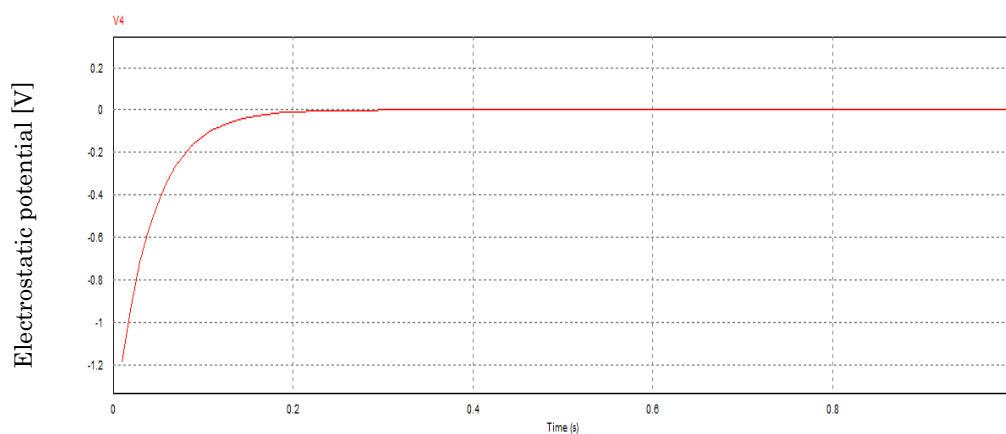
$$(\varphi_{V5} - \varphi_{V3}) - (\varphi_{V5} - \varphi_{V4}) = \varphi_{V4} - \varphi_{V3} \equiv 0, \quad (46)$$

where φ implies each electric potential in Figure 4 and it is assumed that the voltage of the current source becomes zero.

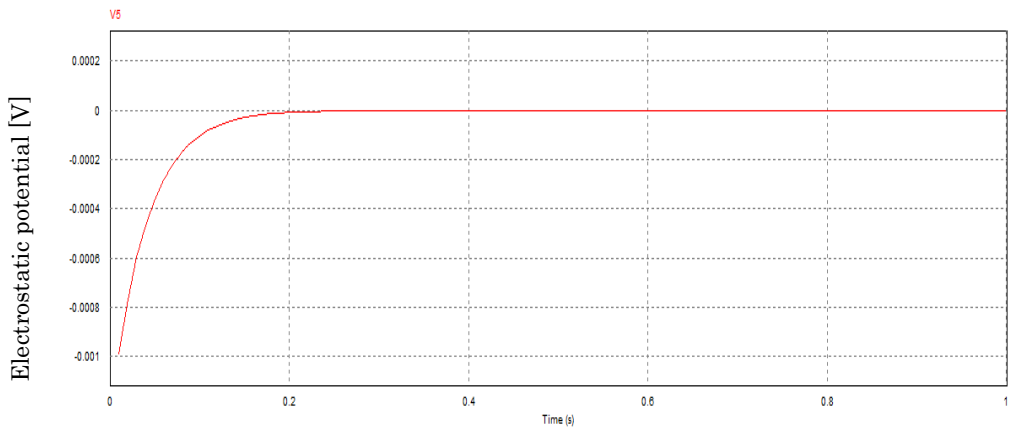
As shown, the common electric potential φ_{V5} vanishes and thus both voltages of the voltage source and the sample cannot be defined and thus we forecast that they must acquire the value 0. This fact will be confirmed in the Appendix in this paper. It is interpreted that the output voltage of the voltage source is consumed to reduce the voltage of the current source and that, at the steady state in the experiment of the Appendix, both the voltages of voltage and current sources become zero, which makes the sample resistance be zero because of non-zero current.



[a]

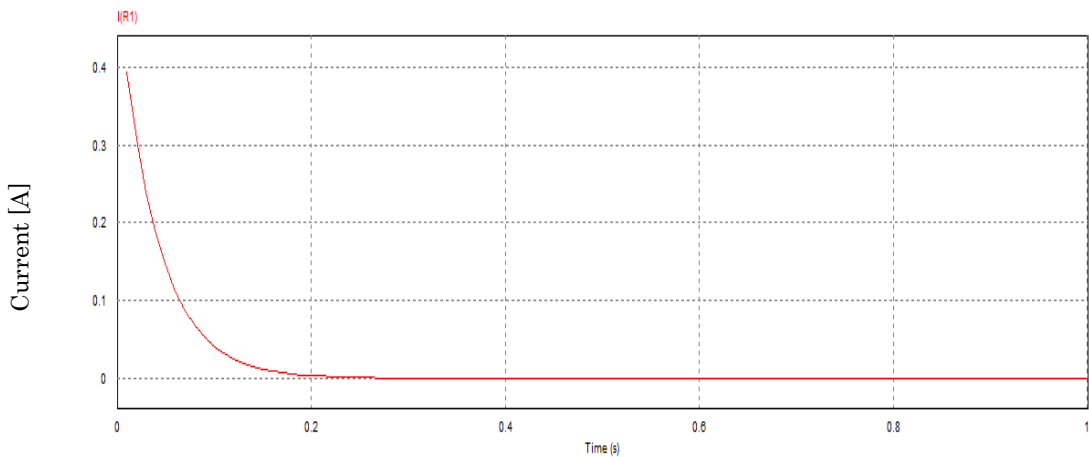


[b]

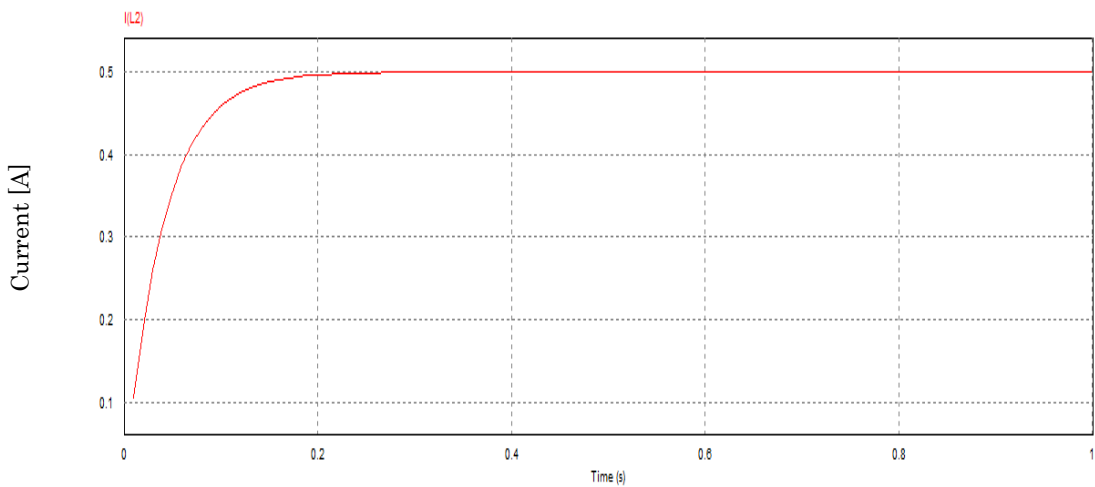


[c]

Figure 5. Time dependences of the electrical potentials. Note that the perpendicular axes indicate the electrostatic potential [V]. The probe names correspond to those in the schematic circuit shown in Figure 4. The V5 is nearly zero, whereas the V4 indicates negative larger electric potential prior to 0.2 s.

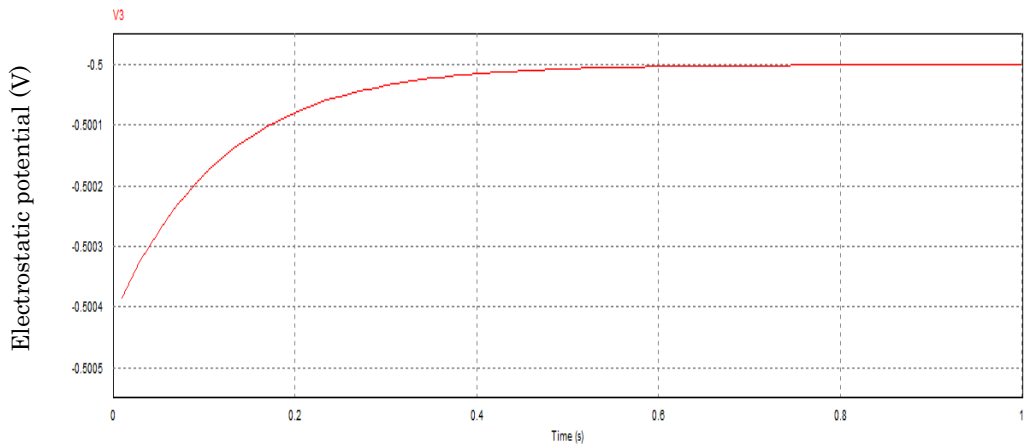


[a]

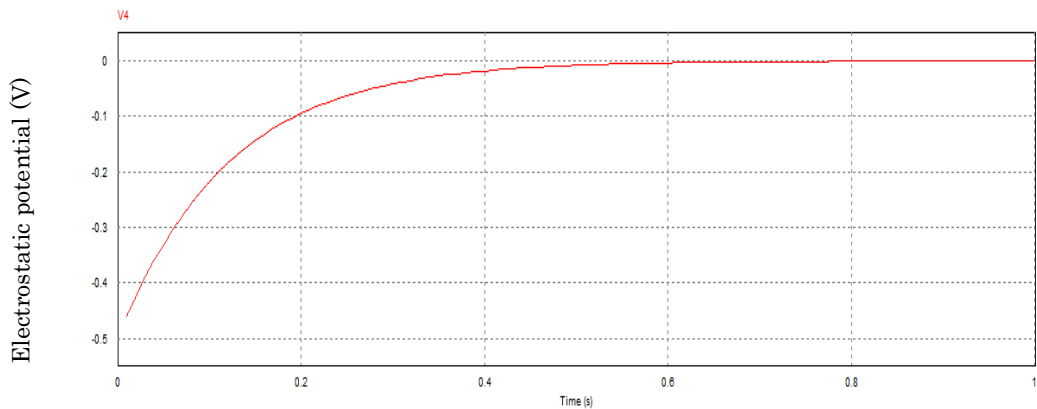


[b]

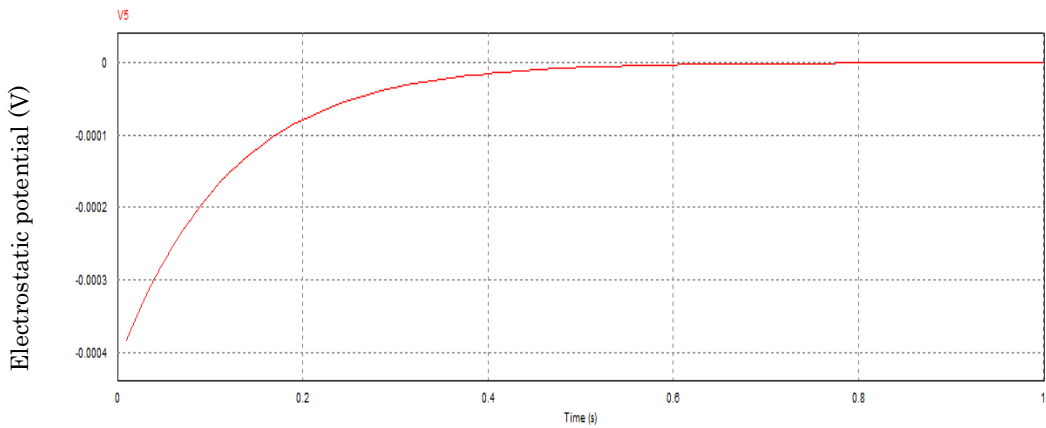
Figure 6. Time dependence of the current in the sample. I (R1) implies the characteristic of current in “R1” and I (L2) is the current of “L2”. Note that the perpendicular axis indicates the current [A]. Corresponding to the behaviors of the electric potentials, the current converges to a steady state after 0.2 s.



[a]



[b]



[c]

Figure 7. Time dependences of each electrical potential in the case where the load is $1\ \Omega$. Note that the input current is kept constant at $0.5\ \text{A}$ but that the input voltage of the voltage source was changed to $0.5\ \text{V}$ to balance the voltage. After $0.4\ \text{s}$, the electrical potential converges to zero, and the difference of the V_4 and V_5 probes indicates negative voltages prior to that time.

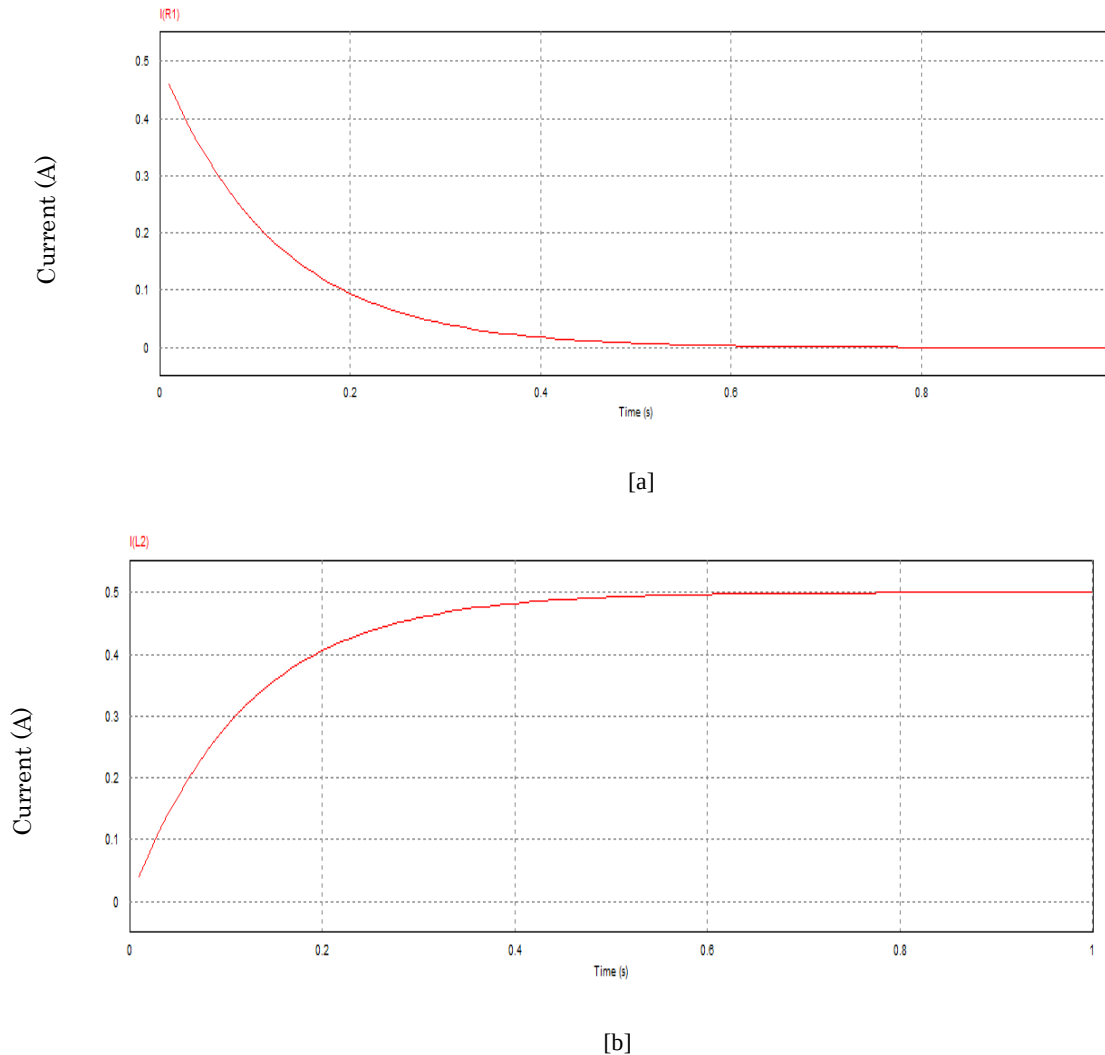


Figure 8. Time dependence of the current in the case where the load is $1\ \Omega$. Except the transition time, the behaviors are almost same as the cases of $3\ \Omega$.

Here, let us summarize Meissner effects in this paper:

- 1) Considering Eq. (36), the numerical calculation indicates that, because the new electric field vanishes up to the steady state, the internal magnetic field also vanishes.
- 2) At the steady state, by the combination of the wave function from the BE condensation and the AB effect, the internal magnetic field is canceled analytically.
- 3) After the steady state, if a further magnetic field is applied, as a result of break of the balance between the two vector potentials in the phase of the macroscopic wave function, a shield current is formed and then the extra field is discharged outside.

5.2. Values of Critical Current and Comparison with That in PNS

Next let us conduct the hand calculations of the critical currents, using Eq. (20). First, let us consider the case of the present paper. When the voltage $V = 1\ \text{V}$, then the local electric field is

$$E_i = \frac{V_E}{a} \approx 1.0 \times 10^{10}\ \text{V/m}, \quad (47)$$

where V_E and a denote the voltage from the voltage source and the coherence of a pair, respectively. As a result of calculation from Eq. (20), the critical current I_c is calculated such that

$$I_c = 8.4 \times 10^4 \text{ A.} \tag{48}$$

In this calculation, the area S_0 of the cross section for the current was assumed as, for example,

$$S_0 \equiv 1.0 \times 10^{-10} \text{ m}^2. \tag{49}$$

Eqs. (48) and (49) imply that, even though a very thin conductor is employed, a sufficiently large current supply is allowed. The value of Eq. (48) is sufficiently large; therefore, we need not to worry about the basic limitation of the transport current. Table 2 lists the physical constants used in these calculations.

Table 2. Physical constants in the calculation of j_c .

Temperature T	300 K
Electron charge q	$1.6 \times 10^{-19} \text{ C}$
Boltzmann constant k_B	$1.38 \times 10^{-23} \text{ J/K}$
Debye temperature θ_D	120 K
Permittivity ε	$8.8 \times 10^{-12} \text{ F/m}$
Coherence a	10^{-10} m
Output voltage of a voltage source V_E	1 V

PNS [18-20] has the same equation, Eq. (20), for the critical current density. In this case, however, the local electric fields do not stem from the voltage from the output of a voltage source but from the electrostatic fields generated by a condenser. Therefore, E_i in Eq. (20) is derived from the surface charge density σ , which arises from the charge Q on the condenser pole plates. However, because of the extremely small capacitance C (approximately 10^{-14} F), even when a relatively large voltage is applied to the condenser pole plates, the charge Q is extremely small; in addition, the area of the pole plates is large. Therefore, the surface charge density σ becomes very small. Considering our previous setup [18-20],

$$E_i = \frac{\sigma}{\varepsilon} \approx 0.11 \text{ V/m.} \tag{50}$$

Considering Eq. (20) and the above small internal electric field E_i , the critical current must be small here.

That is, the critical current in this case is

$$I_{c,PNS} = 2.8 \times 10^{-5} \text{ A.} \tag{51}$$

In Table 3, we indicate the additional constants used to calculate the above value.

Table 3. Additional physical constants in calculating j_c in PNS.

Capacitance C	1.0×10^{-14} F
Applied voltage to condenser V_c	1 V
Permittivity ϵ	8.8×10^{-12} F/m
Surface area of a pole plate of condenser S_0	0.01 m ²
Sored charge of condenser Q	1.0×10^{-14} C
Surface charge density on the pole plates σ	1.0×10^{-12} C/m ²

Comparing the two critical currents, to conclude, it is clear that the case proposed in this paper has sufficient technical merit. This is important when considering superconductivity applications.

6. Discussion

6.1. Important Considerations When Implementing a Superconductor Using This System

Let us consider the time at which the sample load is disconnected from the system after confirming superconductivity. In this case, does the superconductivity remain? We claim that the persistent current remains in the conductor, which implies that the superconductivity is maintained. Note that, as mentioned in the theory section, the created electron pairs are not destroyed by the normal heat energy. For the details, please see results of the Appendix in this paper.

6.2. Consider the Key Finding

Thus far, the researches of superconductors were to provide a compound that would be expected to achieve superconductivity at a higher temperature. However, this method has not been yet succeeded. In this paper, however, altering the viewpoint results in an employment of the specific electric circuit, which is expected to achieve superconductivity. As a result of pure theory and numerical approaches, it was found that both the zero resistance and Meissner effect can be provided with no refrigeration and with no pressure.

More concretely, theory could describe that strong combined two-electrons take the BE condensation and that the cancelation of the internal magnetic field occurs, which implies the Meissner effect. As many elementary textbooks claims, the Meissner effect is equivalent to the zero resistance, which was also confirmed numerically in this paper.

6.3. Summary to Achieve Our Superconductivity

First, the balance of two voltages and a diffusion current result in a specific electron concentration distribution. Using this distribution and the Poisson equation, a new electric field and a transient attractive potential are generated. Because of this solution of the Poisson equation, the Coulomb repulsive potential as the solution of the Poisson equation does not appear at the macroscopic scale, which results in the extreme short-range approach of the two electrons to each other. Under the condition that the kinetic energy in terms of the relative motions dominates the lattice energy (which involves the concept of the critical current density), the two electrons combine via the spin magnetic potential. This spin magnetic potential implies a superconducting energy gap that is much larger than normal heating at room temperature due to the extremely short coherence. Therefore, the combination of two electrons is not destroyed by normal heating. Given that the two electrons bind very strongly, we consider the center-of-mass motion of an electron pair. As a result, the entire wave function of the center-of-mass motion converges to a macroscopic wave function having the single phase. Using the macroscopic wave function and AB effect, the Meissner effect is demonstrated analytically, and the energy conservation of the new electric field's energy density and magnetic field's energy density also resulted in a disappearance of the magnetic flux density numerically.

6.4. Limitations of This Superconductivity

To function this system of the superconductivity, a current source properly must work. In other words, the initial input impedance of a sample must be sufficiently small such that the current from the current source can be input. In this sense, a sample having too large input impedance should be avoided to employ. Moreover, our simulation did not consider the geometrical shape of a sample. This implies that our simulation did not address the length limitation of the sample to achieve superconductivity. This might be an issue when producing an earth scale superconductor line. Probably, it is necessary to connect each superconducting sample but it requires those connections must work as the Josephson effects. This type of the confirmation will be a next follow-up.

6.5. Summary of Significances of This Study

Let us review significances of our proposed superconductivity. Thus far, the history of the existing superconductors was explained by considering the critical temperatures. That is, the research approach was previously to create a compound which was expected to work at higher temperatures. However, presently, this approach has not yet solved the problem that a superconductor requires significant refrigeration or pressures. On the other hand, because our circuit-based superconductivity is independent for temperatures basically, we believe that a new history of superconductors will open. As mentioned in Introduction, there are several researches of superconducting circuit [26-29]. Although these are also circuit-based, all of these employ the existing and refrigerated superconductors, which essentially differs from our present paper.

1) We need not prepare specific substances or setups.

It is not necessary to prepare specific substances or compounds because, if the system is implemented correctly, the load is rendered superconductive. Moreover, in PNS, we needed to prepare a setup, in which a condenser, semiconductor disk, and current leads were included. In particular, attaching the current leads to the semiconductor disk was difficult. In the present system, however, such a setup is not necessary, and therefore, we can very simply obtain superconductivity.

2) The critical current density is sufficiently high.

PNS has an extremely small critical current [18-20], and this fact prevented it from being used in practical applications. In the present superconductivity, however, the critical current is sufficiently high; therefore, we need not be overly concerned by the values of the transport currents.

3) It is not necessary to secure extremely low temperatures and high pressures.

This fact was mentioned with the repetition everywhere in this paper.

4) Global energy problems might be solved, and some technologies are redirected.

Using our proposed system, efficient energy transmissions or performance improvements of electrical devices like motors, electric wires or magnets can be conducted. Moreover, as demonstrated in the later Appendix at the end of this paper, it is possible to make a metal like copper (Cu) be superconductive, which implies that both the running and manufacturing costs will be significantly reduced. This fact is important to the field of developing electrical devices.

5) Theoretical developments in condensed matter physics

In the theory section of the present paper, many new concepts appeared such as the new attractive force, new wave function, new type of BE condensation and so on. We believe that the theory itself is significant in condensed matter physics and expect that the above new concepts will be employed by another researcher.

7. Conclusion

In this paper, we proposed a new type of superconductivity, in which circuit-based and temperature-independent properties exist.

As a result of both analytical and numerical calculations, the Meissner effects as well as the zero resistance were found. Moreover, the hand calculations resulted in much larger critical current than that of PNS. The significance of our superconductivity is that it can be generated very simply with

no refrigeration and with no preparation of specific substances or setups and that it achieves a large critical current density. Moreover, this superconductivity does not require high pressures. These properties have not yet been achieved in conventional superconductor studies.

As mentioned, however, the presented system cannot make too large load be superconductive. Moreover, the simulation did not consider the geometrical shape of the sample, which did not address the issue of considering large scales of our superconductor.

The Appendix in this paper presents preliminary experimental results, which confirms the zero resistance and the Meissner effect. Although it is still necessary to measure a stricter magnetic-field response, accepting the results in this Appendix leads to the future researches that will be productions of the large-scale superconductor, the confirmation of the validities to introduce every electron device, vehicle and energy storage system and so on.

As a remarkable contribution of this paper, it demonstrated a new superconducting theoretical framework, which will promote the knowledges of condensed matter physics. Furthermore, the principle of the present paper challenges the basis of the knowledges of electric and electron technologies, which has a potential to change our societies to better and new states.

Additional information: This paper is not related to any competing interests such as funding, employment and personal financial interesting. Moreover, this paper is not related to non-financial competing interesting

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Appendix A. A Guide to Reproduce the Experiment and Preliminary Experimental Results

Introduction

Let us review the history of discovering the existing superconductors and present the meaning of this Appendix, connecting it with the main body of this paper.

Considering the first superconductor whose critical temperature is around 4 K, the ceramic cuprates have the significantly high critical temperatures [2]. Although the several high-T_c compounds [7,9] were found, these ceramic cuprates have still the highest critical temperature with no pressures. Although H-based superconductors [16] have the relatively high critical temperatures, these materials must receive the significantly high pressures, which implies that it is difficult to employ these materials in practical applications. The weak points of the above-mentioned superconductors are the requirements of refrigeration or pressures.

On the other hand, we had presented the first temperature-independent superconductivity about 10 years ago [18-20]. Although this previous superconductivity overcame the weak points of the refrigeration and pressures, this superconductivity has a small critical current and producing the superconducting device makes it difficult to be applicable in practice. However, the present paper offers the temperature-independent superconductivity with high critical current density and with no setups. Although the main body in this paper mentioned the theoretical aspects, the actual experiments were not described. This main body is still significant because of predicting the new superconductivity. However, we attempted to perform the experiments. As a result, it was found that there is a knack when conducting the experiments. According to this knack, little time is required to achieve superconductivity. Therefore, as an additional but important description, this appendix will describe the knack, and brief results of the experiments will be presented. The importance of this appendix is that, by presenting the knack, it will help every researcher to reproduce our presented new superconductivity. In this sense, this appendix complements the contents of the main body. Note that the obtained results should be considered to be preliminary results and thus further follow-ups will be needed.

Method

In Figure A1, the circuit of the system is shown. As shown, this circuit is the same as that described in the main text. In this case, a toroid coil is employed as a load. Note that this toroid is an example and thus it does not have a special meaning. Moreover, we must not confuse this sample toroid with the internal and microscopic toroid that was described in the main body. The internal toroid is a part of general macroscopic conductor. The photograph of the sample coil is shown in Figure A2. In the experiments of this paper, we purchased an assembly of the identical coils including 20 unit (the cost is approximately less than 1,000 yen by a mail order).

Here, let us consider the method of conducting the experiments. The experiments employ two stabilized power supplies. The one is employed as the voltage source (i.e., the cv mode) and the other is used as the current source (i.e., the cc mode)

Again, as long as relying on the stabilized power supplies, there is a knack when conducting the experiments. Introducing this knack is the aim of this appendix: Figure A3 shows the sequence of conducting the experiment. As shown, when the volume of the voltage source (i.e., the cv mode of the stabilized power supply) is input, then the voltage of the current source (i.e., the cc mode of the stabilized power supply) is reduced, interlocking with the inputs of the volume of the voltage source. This is how we can reduce the voltage of the current source intermittently. As shown in the final panel in Figure A3, we can obtain the state in which both the voltages of voltage source and current source are zero and in which non-zero current still exists. Note that, in this figure, we must not employ a voltmeter, because the above operation potentially affects an internal circuit of the voltmeter.

Moreover, in addition to confirm the zero resistance, we applied static magnetic fields by a ferrite magnet (i.e., a permanent magnet) Note that the zero-resistance measurements and the applications of the static magnetic fields were conducted independently for the system. That is, after manipulating this system, the measurements of load-coil resistances and the magnetic-field applications to the coils were conducted independently for the system. Of these, the 4-terminal method was applied.

In Table A1, specifications of load coil are shown. Note that, if the load impedance is sufficiently low such that the cc mode of the current source of the stabilized power supply can operate, any load is accepted to be applied to the system. That is, we are not able to employ too large loads in terms of the resistivity and the scale. In this experiment of the Appendix, three samples, A, B, and C coils were prepared although these are identical coils, which existed in the assembly package in the time of the purchase. The reason of this preparation is that we would like to confirm reproduction of the experiment by the iterations.

As a very important notation, we must not apply a current higher than that in operating current. For example, considering Table A2 of the sample A (This table will be described soon), a current for measuring the electrical resistance of the sample A must not dominate the value of 0.49 [A]. Moreover, when applying currents to the sample independently for the system, we must provide the currents slowly and gradually. That is, an output of the source is generally sensitive. Moreover, in the process of the experiments, generally we would like to be careful for a disconnection of current lead due to the relatively large current.

Results and Discussion

In this appendix, we described a knack to reproduce the experiments by Figure A3. Based on this knack, let us consider the preliminary results.

Table A2 indicates the result of operating the system. Note that this table implies the final state of cc and cv modes from the initial operation of the system. As shown, although the currents are sufficiently large, the voltages are zero, which implies that the electric resistances are zero on operating the system.

In turn, Table A3 shows results of measurements of the electrical resistances of the load coils. As mentioned, these measurements were conducted independently for the system. As shown, every coil exhibited almost zero electrical resistance, which implies that, after operating the system and even when the loads were separated from the system, the load preserved the zero electrical resistances. This fact is important when considering the application to some technologies. Note that, although the

measuring device's voltages indicated always 0.0 mV, Table A3 indicates the limit of measurements. However, it is clear that the samples exhibit the zero resistance.

Table A4 shows generated voltages when applying the static magnetic fields. In this table, I/V respectively denote the current and the voltage of the stabilized power supply (for the cv mode), and V_0 implies the generated voltage of the other taps of the sample, considering the 4-terminal method. Note that, again, the provided current must not dominate the value of that in operating the system. Moreover, as mentioned, in order that we detect a magnetic field response, the first term in the phase of Eq. (40) or Eq. (29) should be created again. That is, in order that the phase of first term in Eq. (40) should be created again, a further current to create the first term in Eq. (40) must be input to the samples in addition to the application of a magnetic field. However, because of the application of the magnetic field, as mentioned in the main body in Sec. 3.3, Eq. (40-2) is considered here instead of Eq. (40). As a result of the balance break between the two vector potentials in the phase of Eq. (40-2), a shield current is created to vanish the internal field and then the extra field should be discharged.

Let us consider the results: After the confirmations of 0.0 mV of the voltmeter under an input current, a magnetic field was then applied slowly. As shown, the results imply the response for the static magnetic fields; for the samples A and C, a relatively large voltage (i.e., the extra field was discharged) was steadily generated, which implies an exclusion of the applied magnetic fields. On the other hand, however, when the sample B received a static magnetic field and after applying the magnetic field, the sample B still generated the voltage even when the stabilized power supply was removed. This implies that the sample B itself became a small power supply temporally. It is necessary to purist the reason as a follow-up. Moreover, we will need to directly examine whether the net internal magnetic field takes zero as a result of the applications of magnetic field and input current. This is the main reason to require a stricter experiment for responses of a static magnetic field.

To conclude, however, by detecting the generated voltage when applying a static magnetic field, we could confirm the exclusions of the applied magnetic fields.

Let us consider significances of these results.

1. This appendix could indicate a knack to conduct the experiments. By following this, we can obtain higher probability to reproduce the experiments.
2. Because we can now produce a zero-resistance superconductor, without refrigeration, without pressures, and with high currents, it can be applied to various electrical products to enhance their performances. For example, the energy from solar cells in some deserts can be transmitted to every country, which implies that the primitive energy problem might be solved. Moreover, most of electric devices and machines employ motors, and if our superconductivity enhances the motor performances, significant benefits will be provided to our societies. However, as mentioned in the main body, it is necessary to overcome the issue of the scales.
3. Because any substance with a small input-impedance can be accepted and if a metal is employed as a load, the manufacturing costs will become significantly low.

Conclusion

In this Appendix, we described the method to conduct the experiments, relying on the stabilized power supplies. The results indicate superconductivity with no refrigeration and with no pressures. Therefore, we could indicate potential applications like energy transmissions with no energy loss, which will provide a solution of global energy problems. A shortcoming is that the system cannot employ too large load, because the current source can work only to a small input-resistance. Moreover, the scaling issues must be overcome. As a follow-up, it is necessary to conduct experiments with devises that will detect more strictly static magnetic field responses.

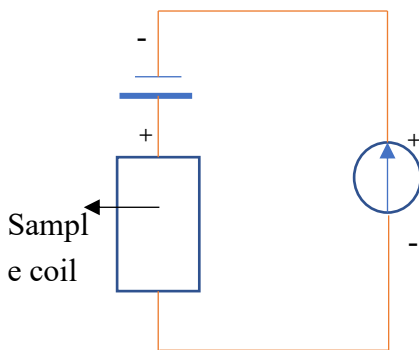
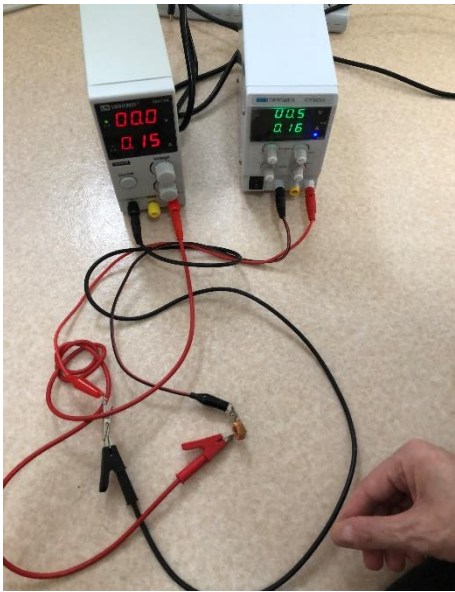


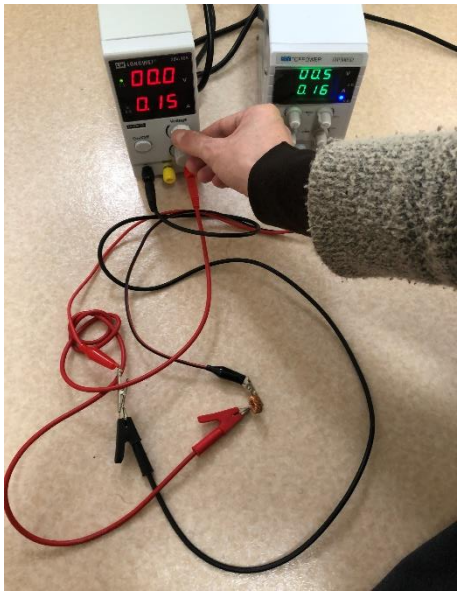
Figure A1. The circuit of the system. This circuit is the same as that in the main body in this paper. However, two stabilized power supplies are employed here. The one is for the current source as cc mode and the other is for the voltage source as cv mode.



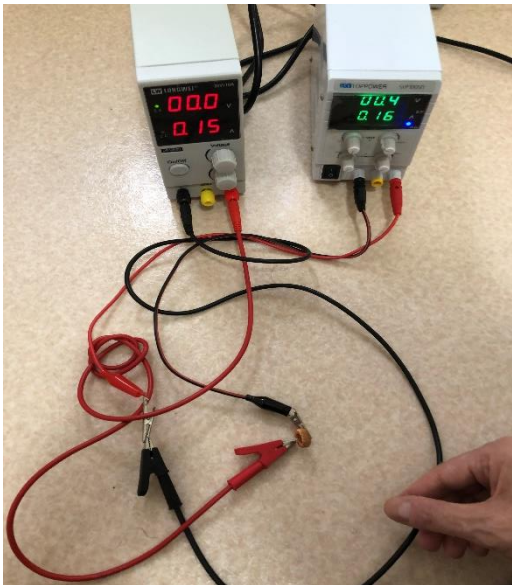
Figure A2. Photo of the sample coil.



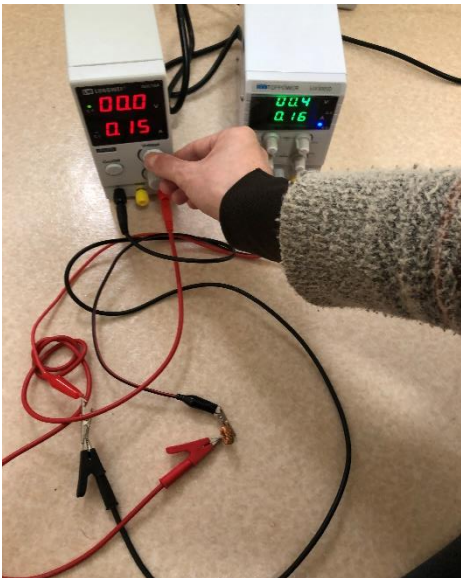
1 (initial state)



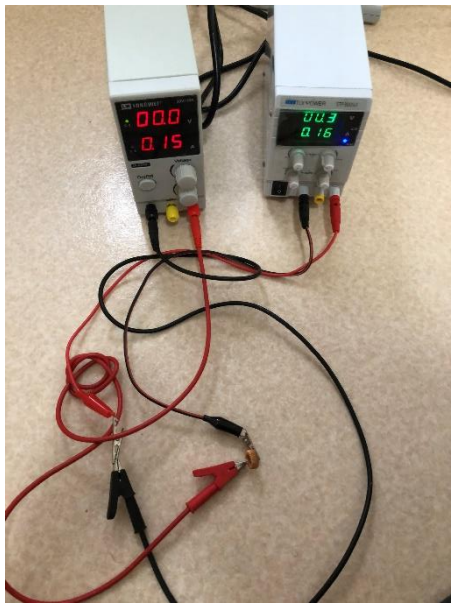
2



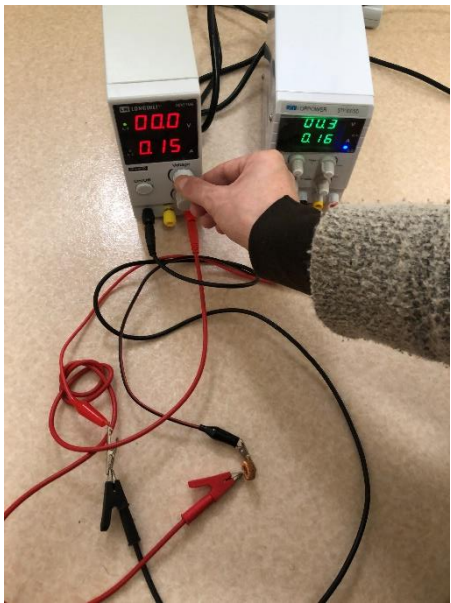
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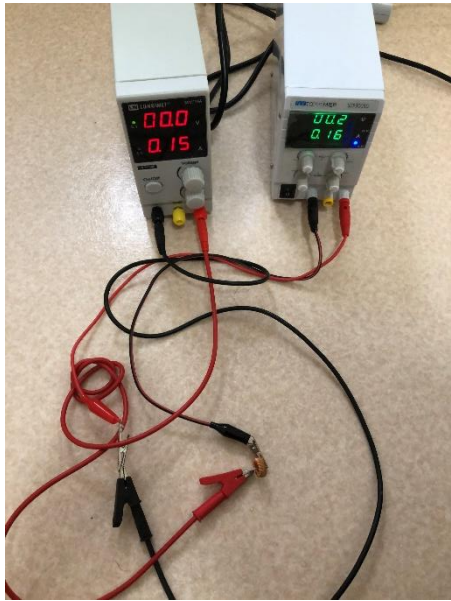
4



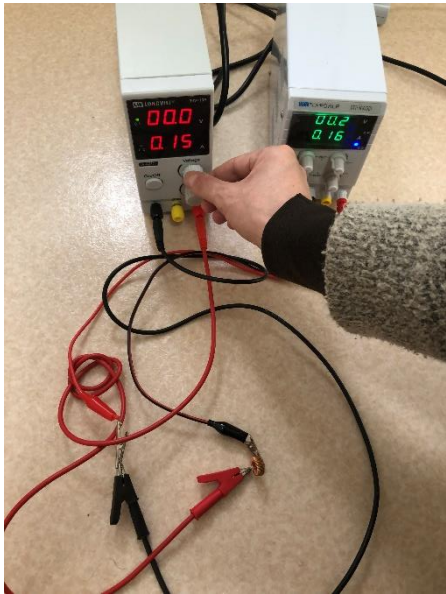
5



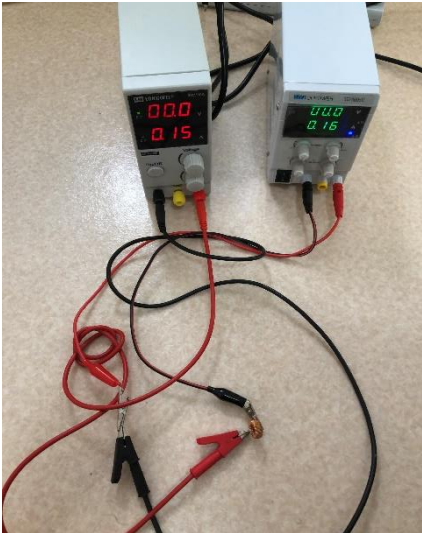
6



7



8



9 (final state)

Figure A3. Experimental sequence when operating the system. The time order is from photo 1 to photo 9. These assembly implies a knack to conduct the experiment to make the sample be superconductive. Two stabilized power supplies are employed. The left one is the voltage source as cv mode and the right one is the current source as cc mode. As shown, when the small volume of the voltage source is input repeatedly, the voltage of the current source can be reduced, interlocking with the input of the voltage source. Thus, the iteration of adding of the small input of the voltage source can make the voltage of the current source be reduced to zero intermittently. Note that the current in the voltage source stems from the output current from the current source.

Table A1. Specifications of samples. Note that, if the input-resistance of a sample is sufficiently small such that the current from a current source can be input, our system could work, which implies that any substance with a small resistance can be accepted and that there are not specific meanings in the sample in this table. In this case, however, a material of the present sample is copper (Cu).

Inductance	100 μ H
Resistance	0.036 Ω

Table A2. The states of the voltage and current sources in operating the system. Note that the voltage V implies the voltage between the taps of the current source. Note that the voltages of the voltage source are the same as that of the current source (see Figure A3). That is, they were consistently 0.0 V.

	Sample A	Sample B	Sample C
V [V]	0.0	0.0	0.0
I [A]	0.49	0.48	0.45

Table A3. The results of the measurements for electrical resistances. Note that the measurements were conducted by 4-terminal method and that these measurements were conducted independently for the system. Moreover, the supplied current must be lower than that in operating the system. Note that the resultant voltages of the samples were always 0.0 mV but we considered the limit of the measuring device.

	Sample A	Sample B	Sample C
Electric resistance [Ω]	Less than 1.8×10^{-4}	Less than 3.9×10^{-4}	Less than 8.0×10^{-4}

Table A4. Voltage generations as a result of the applications of static magnetic fields. Note that V_0 implies the voltage between other taps of the 4-terminal method. Importantly, it is needed to input a further current in addition to the applications of the magnetic fields. After confirming 0.0 mV in the voltmeter, the magnetic fields were then applied slowly. These responses of the static magnetic fields imply discharged currents related to the shield currents to exclude the applied magnetic fields.

	Sample A	Sample B	Sample C
$I[A]/V[V]$	0.084/0.0	0.39/0.0	0.063/0.0
$V_0[mV]$	-1.2	8.9	-1.3

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