Unified microscopic mechanism of superconductivity

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Based on real-space localized proton-electron electromagnetic coupling, it is found that there is a unified pairing, coherent and condensate mechanism of superconductivity for all materials. We demonstrate that electric and magnetic fields are intrinsically relevant: an isolated proton or electron creates an electric field, while a proton-electron pair creates a magnetic field. These findings provide new insights into the nature of electron spin, Dirac's magnetic monopoles, and the symmetry of Maxwell's equations. We point out that the superconducting current is the displacement current defined by Maxwell's equation and has nothing to do with the Cooper-pairs. Furthermore, we argue that the electric dipole vector of the proton-electron pair plays the role of the Ginzburg-Landau order parameter in the superconducting phase transition. Under the new theoretical framework, the Meissner effect, the London penetration depth, flux neutralization, vortex lattice, vortex dynamics, and other superconducting phenomena can be consistently explained.

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I. INTRODUCTION

Since the discovery of superconductivity in mercury by Kamerlingh Onnes [1], thousands of superconducting elements and compounds have been discovered [2–11]. As a fundamental point of view in the physics community, these superconducting materials can be divided into two classes: conventional and unconventional. It is widely accepted that conventional superconductors can be well described by BCS electron-phonon theory [12], while unconventional superconductors cannot be understood by BCS theory. The boom in superconductivity research started with Bednorz-Muller's remarkable discovery [4]. Based on Cooper's pairing picture, physicists have spent thirty-six years searching for the pairing glue of high-temperature superconductivity [13]. Despite more than 200,000 published papers and significant efforts have been made to unravel the mystery and hundreds of microscopic mechanisms have been proposed [14–23], none have been considered valid [24]. Why there is no progress in understanding superconductivity? Now is the time for the physics community to seriously consider whether all of these investigations have been misled by some fundamental mistakes. In other words, is it possible that some widely accepted and commonly used theories or models may not capture the essence of the superconducting phenomenon [25, 26]?

The zero resistance in an electric field [1] and the Meissner effect in a magnetic field [27] are two critical phenomena for determining whether a material is a superconductor in an experiment. It should be stressed that all superconductors, whether conventional or not, share these two basic independent properties of the superconducting state. Hence, it is natural to argue that all superconductors share an identical superconductivity mechanism. Today, there are more than 32 different classes of superconductors [28], it is not a good idea to divide superconducting materials into conventional and unconventional superconductors and artificially assume they have different superconducting origins.

As we all know, superconductivity is a very ordinary phenomenon, and nearly all materials and even some insulators can exhibit superconductivity under the right conditions (an appropriate temperature and external pressure). As an intuitive judgment, the more general physical phenomena must obey the most universal laws. On the one hand, according to the Meissner and zero-resistance experiments, it is inevitable that the superconducting phase transition originates from the electromagnetic interaction between an external electric field (or magnetic field) and the internal superconducting carriers. On the other hand, from the perspective of the Landau-Ginzburg phase transition theory [29], symmetry breaking occurs in the order parameter characterizing the superconducting phase transition. Hence, it is evident that the superconducting phase transition is not spontaneous but driven by an external field from a high symmetry in the absence of an external field to a lower symmetry in the presence of an external field. Now the key question is which physical variable qualifies as the superconducting order parameter in Landau-Ginzburg's theory?

If someone asks what is the most extraordinary phenomenon in nature? My answer is positive and negative pairings. In life sciences, the pairing of men and women keeps life going. This paper shows that the essential pairing in the universe occurs between electrons and protons. In addition to the familiar proton-electron pairing of hydrogen atoms and neutrons, the proton-electron pair can be a multifunctional composite particle, which may simultaneously act as capacitance, resistance, current element, displacement current, magnetic needle, magnetic moment, electric dipole, magnetic dipole, quantum magnetic flux, electron spin, etc. It is no exaggeration to say that the proton-electron pair is the "God particle" and the key to unlocking the secrets of superconductivity. Moreover, we find that the proton-electron electric dipole vector is precisely the order parameter of the Ginzburg-Landau theory of superconducting phase transition. It seems pretty encouraging that the new mechanism can qualitatively and self-consistently explain many important superconducting phenomena such as the Meissner effect [27, 30], London penetration depth [31], vortex lattice [32–37], and vortex dynamics [38–43]. Moreover, our hypothesis can successfully achieve the perfect symmetry of Maxwell's equations [44] and reveal the physical nature of electron spin [45] and Dirac's magnetic monopoles [46].

II. ARE FREE ELECTRONS TRULY FREE?

In 1900, Drude constructed a theory to explain the transport properties of electrons in metals [47, 48]. In 1927, Sommerfeld further developed the theory by considering quantum mechanisms [49]. Even though the mathematical forms of the theories look very different, the basic physical concepts have hardly changed. As shown in Fig. 1, the fundamental idea of the theories is based on a simplified model of that lattice of positive immobile ions (for convenience, it can be simplified to protons) and the valence electrons that are free to move about. As shown in Fig. 1(a), without an external electric field, any electron (as the i-th electron in the figure) will never stop colliding with ions and other electrons in random thermal movement inside the metal. As shown in Fig. 1(b), under an applied electric field **E** along $-x$ direction, the free electrons will do random directional motion with a drift velocity v_d in the x direction to conduct an electric current, and the collision of electrons with the lattice and other electrons results in resistance.

Perhaps the simplest question to question Drude's model is : how does a flowing current stop? This is not a trivial problem because it relates to superconducting currents' reliability.

In a high-frequency alternating current (AC) electric field, the Drude's electrons have to swing back and forth rapidly and simultaneously in the wire. Taking 100 kHz AC as an example, all electrons inside the wire must stop and change motion-direction at the same period every 0.01 ms. It is the fact that electrons have inertia and their velocities are different in magnitude and direction, as suggested by Drude. Obviously, the Drude's free electrons cannot instantaneously respond to the change in the external electric field. Therefore, without a mechanism to stop the movement of the electrons momentarily indicates that Drude's free-electron conduction hypothesis is defective. The AC results inspire a question: how can free electrons in metal respond rapidly and synchronously according to the external field?

The basis of Drude's theory is the mean-field approximation, which completely ignores the detailed microstructure of the lattice. In the metal lattice, each stationary positive ion (proton) excites a localized electrostatic field around it, and the electron is a tiny particle with a radius of less than $10^{-15}m$. Clearly, it is the ionic electric field around the electron, not the average field of the entire metal, that directly affects the electron's behavior. Motivated by spring oscillators, we propose a scheme to overcome the abovementioned difficulty of synchronizing electrons' responses to the external AC field in Drude's model. Fig. 2 shows an electron is trapped in a localized electric field U(r) (the dash-dot line in

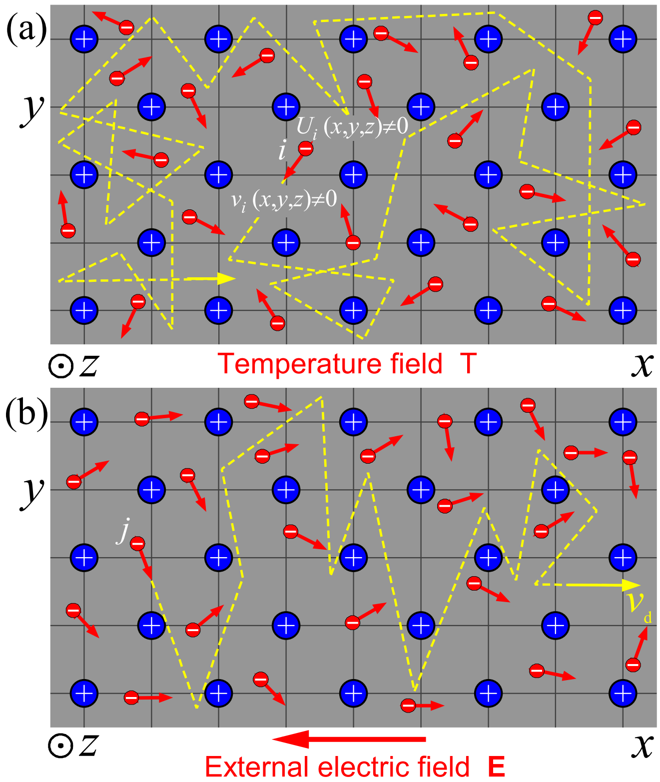


Figure 1: Drude model and conductivity. (a) In a temperature field T, without an external electric field, the electrons make a random thermal motion in a metal, where the i-electron's kinetic energy $m_e v_i^2(x, y, z)/2$ and the potential energy $U_i(x, y, z)$) is not equal to zero; (b) when applied to an external electric field, the electrons (for example, the j-electron in the picture) move directionally with a drift velocity v_d to generate current.

the figure) in the lattice, where O is the equilibrium position of minimum electric potential energy. Without the influence of temperature and external field, the electron tend to stay at the O position with the smallest potential energy. As shown in Fig.2 (a), when the electron absorbs thermal energy, it will leave the equilibrium position O and arrive at A with a displacement $\delta(x, y, z)$. Where the electron will release energy by emitting a photon hv and then return to its equilibrium position O. Figure 2(b) shows the case of applying an DC external electric field **E**, the electron moves from O to B by absorbing electric field energy, and its total displacement is $\Delta(x, y, z) = \delta(x, y, z) + \Delta$, where $\delta(x, y, z)$ is due to thermal motion and Δ is the contribution of the electric field. After reaching B, the electron will emit an electromagnetic wave (current) at the speed of light and return to the equilibrium position. When an AC electric field is applied, the electron is confined to oscillate back and forth in the equilibrium position and periodically simultaneously absorb the electric field and emit a current.

Accordingly, what kind of lattice structure of the metal best fits the given demand points of Fig. 2? To answer this question, we must start with the principle of minimum free en-

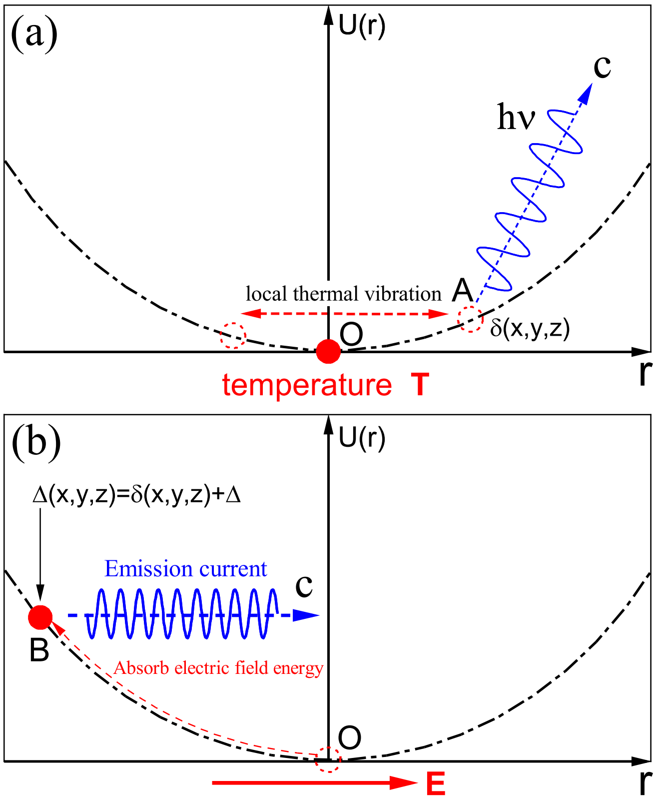


Figure 2: Illustrate how to overcome the AC transfer problem faced by the Drude free electron model. (a) First there must be a local electric field $U(r)$, without an external electric field, an electron is confined to the equilibrium position for random thermal oscillation; and (b) when applied to a DC external electric field, the electron moves from the equilibrium position O of zero potential energy to the B position of high potential energy and then emits direct current; when applied an AC external electric field, the electron will periodically move around the equilibrium position driven by the electric field and emits alternating current.

ergy. As shown in Fig. 1(a), the energy of a free electron in a metal consists of two parts, one kinetic due to the free motion $v_i(x, y, z)$ and the other potential $U_i(x, y, z)$ provided by the positive ion lattice. Hence, we can define the total free energy of electrons:

$$E_{free} = \sum_i \left[\frac{m_e v_i^2(x, y, z)}{2} + |U_i(x, y, z)| \right], \qquad (1)$$

where m_e is the mass of the electron.

It's not hard to see from Eq. (1) that when $v_i(x, y, z) = 0$, and $U_i(x, y, z) = 0$, we immediately have the minimum total free energy $E_{free} = 0$. Fig. 3 shows a possible zero free energy structure, which is a compound lattice of positive ions (protons) and negative electrons (For the three-dimensional case, the electrons and ions will self-organize into the structure of $NaCl$-type lattice with space-group $Fm3m$). Obviously, electrons are no longer free to move and are all confined to an equilibrium position (the resultant external force is zero) of zero potential energy to make tiny thermal vibrations,

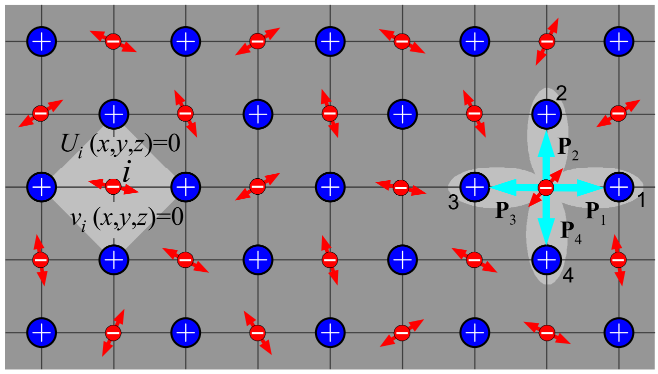


Figure 3: There are no free electrons inside the metal and superconductors, and the electrons are trapped by the electric field of the surrounding ions (protons).

as seen left of Fig. 3. In the absence of an electric field, Fig. 3 represents a normal state, and when there is an external field, it has the potential to undergo a phase transition to a metallic. At the right temperature and pressure, it may also transform into a superconductor or a magnet.

The Drude model is still used extensively in condensed matter physics teaching and research. In addition to the AC issues discussed above, a more severe problem with the Drude model arises when it is extended to describe superconductivity. In the BCS framework, electrons can flow without resistance in superconductors at low temperatures when paired with opposite spins and momentum. This implies that although the paired electrons are in random motion, they can intelligently avoid electron-lattice and electron-electron collisions, which we consider unscientific. One might ignore the physical mechanism that guarantees the Cooper pairs always keep their spin and momentum opposite. However, no one can ignore the fact that electron-ion attractive interactions and electron-electron repulsive interactions still exist, in particular, the coherence radius of the Cooper pair is much larger than that of a single electron, consequently significantly increasing the collision probability between pair-pair and pair-lattice. Therefore, we can conclude that electron pairing based on Drude's free electron hypothesis can not reduce the resistance of the superconductors. On the contrary, it dramatically increases the resistance.

Free electrons are not free, and this is undoubtedly a revolutionary idea that will change many essential concepts in physics. If our immobile-electric-charges hypothesis holds, the new physical mechanism must self-consistently explain several fundamental questions: (i) What is the electric current, and how does it conduct in metals and superconductors? (ii) How is the resistance produced without the collisions between electrons and between electrons and the lattice? (iii) Since electrons cannot flow when driven by an external field, what is the difference between insulators, metals, semiconductors, superconductors, and magnets? The answer lies in the cyan electric dipole on the right side of Fig. 3. In the next chapter, we will discuss how the proton-electron electric dipole can simultaneously play the role of a multifunctional particle.

III. MAGICAL PROTON-ELECTRON PAIRING

What are the elementary particles? This seemingly simple question is difficult to answer. In my opinion, elementary particles are the foundation of everything in the universe. They must satisfy the following points: (i) uniqueness (irreplaceability); (ii) determinism (invariant mass and charge); (iii) stability (long lifetime); (iv) observability (can be discovered by experimental means). It seems to me that there are only protons and electrons can satisfy the above four conditions at the same time. In the following, one would like to find an interesting fact that the same proton-electron pair can show very different physical behaviors in different environments.

For convenience, we could assume that the direction of the electric dipole vector is from proton to electron (the yellow arrow in Figure 4), which is contrary to the provisions of the textbook (the cyan arrow in Figure 1) .

As shown in Fig. 4(a), the independently bound proton-electron pairs can be either hydrogen atoms or neutrons. Figure 4(b) is the most familiar electric dipole, when it is isolated, the electric dipole is a hydrogen atom that can generate a hydrogen atomic spectrum. While they are in the blackbody material, the electric dipoles will produce the quantized thermal electromagnetic radiation discovered by Planck in 1900 [50]. In conductive metallic materials, they can act as resistors that continuously consume electrical energy through radiation. As shown in Fig. 4 (c), surprisingly, a proton-electron pair inside a metal (where proton (ion) is stationary, and electron vibrate around the equilibrium position 0) can transform into the smallest capacitor in nature. If the distance between the proton and the electron is r, then its capacitance is given by

$$C_r = 2\pi\varepsilon_0 r, \tag{2}$$

where ε_0 is the vacuum dielectric constant.

When an external electric field is applied to the metal, the electron will be displaced with a velocity $\mathbf{V}_e$ against the external field, resulting in a change in capacitance and in turn changes its internal electric field. According to Maxwell's equation, this change process can be interpreted by displacement current (Note that only the electric field variation at the center of the proton-electron pair is considered in the following derivation.) [44]:

$$\begin{aligned} \mathbf{J}_D &= \frac{\partial \mathbf{D}}{\partial t} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \\ &= -\frac{e}{2\varepsilon_0 \pi^2 r^3} \frac{\partial C_r}{\partial t} \mathbf{r}_0 \\ &= -\frac{e}{\pi r^3} \frac{\partial r}{\partial t} \mathbf{r}_0 \\ &= -\frac{e}{\pi r^3} \mathbf{V}_e \end{aligned} \tag{3}$$

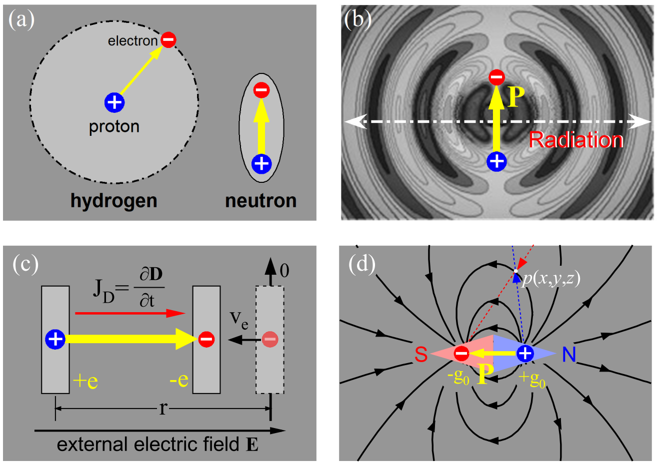


Figure 4: Multifunctional proton-electron pair, (a) hydrogen atom or neutron, (b) electric dipole, (c) capacitance, and (d) magnetic dipole.

where $\mathbf{D}$ is the electric displacement vector, $\mathbf{E}$ electric field intensity, $\mathbf{r}_0$ is the unit vector, and e is the charge of the electron.

From the above equation, it is seen that the magnitude of the displacement current is proportional to the electron's speed $\mathbf{V}_e$, and the current's direction is opposite to the direction of the velocity. One can find that the displacement current is very similar to the traditional conduction current, and its advantage is that the carriers (electrons) do not need to overcome the resistance to traverse the whole metal. Since the electron is confined to vibrations near the equilibrium position, the difficulty of interpreting alternating currents encountered with the Drude model does not exist.

Practically speaking, it is almost impossible for researchers more than 100 years ago to grasp the nature of metal conduction. For them, a metal in front could appear as a "blind box" system. The carrier behavior inside the metal caused by the external electric field is completely based on personal conjecture. From the point of view of modern science, the analogy of electricity flowing like water through a pipe is the wrong approach. Today, numerous physical experiments have shown the observation of the ordered charge-stripe phase in high-T_c superconductors [51, 52, 55], where the charge carriers (electrons) are likely to form a stable lattice as the positive ions rather than freely moving as Drude's model. Results of the above analysis in this paper also indicate that the concept of conduction current, which has been used in teaching and research for over a hundred years, is not physically true. The current measured in the experiment does not represent the flow of the electrons. It reflects the tiny drift as indicated in Fig. 4(c) of the electron from its equilibrium position under the action of the external field.

Figure 4(d) shows the proton-electron electric dipole with fixed electric dipole moment $\mathbf{P}$. Here we raise a question: does the electric dipole excite an electric field or a magnetic field? This question is likely considered "foolish" because it seems logical that electric dipoles generate electric fields. Has anyone argued that this assumption is physically wrong?

We know that a changing electric field produces a magnetic field is the most important contribution of Maxwell. As shown in Fig. 4(d), when the electric field $\mathbf{E}_+$ of positive proton and the electric field $\mathbf{E}_-$ of negative electron appear in $p(x, y, z)$ at the same time, since the two electric fields are of opposite signs, their superposition represents the changing electric field. Hence, according to Maxwell's hypothesis, the vector superposition of electric fields $\mathbf{E}_+$ and $\mathbf{E}_-$ is precisely the magnetic field $\mathbf{B}$ which is given by

$$\mathbf{B} = \frac{\mathbf{E}_+ + \mathbf{E}_-}{c}, \tag{4}$$

where c is the speed of light.

Equation (4) reveals the intrinsic relationship between electric and magnetic fields and indicates that Dirac's hypothetical magnetic monopoles are just the well-known proton and electron. The correctness of this argument can be verified directly from Dirac's theory itself. Dirac believed that electric and magnetic charge could co-exist and satisfy the following quantization condition [46]:

$$eg = \frac{hc}{4\pi}n = \frac{\hbar c}{2}n, \tag{5}$$

where e and g are the electric and magnetic charges, respectively, h is the Plank's constant [50], and n being the integers.

Using the fine structure constant $\alpha = e^2/4\pi\varepsilon_0\hbar c$, the Dirac's formula of Eq. (5) can be reexpressed as:

$$g = (\frac{n}{8\pi\varepsilon_0\alpha})e = \Omega_n e, \tag{6}$$

where $\Omega_{\rm n}$ is an adjustable constant.

The above relation of Eq. (6) makes it not difficult to see that the so-called magnetic monopole is nothing but a dressed electron (or proton). This conclusion perfectly agrees with what we get directly from Fig 4(d). Therefore, the proton-electron pair can also be nature's smallest quantized magnon with a quantized magnetic flux $\Phi_0 = h/2e$, found in type-II superconductors. In addition, it must be pointed out that proton-electron pairings are ubiquitous in all materials and have nothing to do with superconductivity. This conclusion can be verified by the vortex state of the type-II superconductor. The experiments show that the quantized magnetic flux lines appear in the non-superconducting regions of the superconductor rather than the superconducting region where pairing is thought to occur.

The electron spin is considered an intrinsic form of angular momentum [45], which is believed to be a purely quantum mechanical concept, and there is no explaining how spin arises. In fact, there is no direct experimental evidence that electrons have spin because whether it is the atomic fine spectral structure experiments [56], or the Stern-Gerlach silver atom beam experiment [57], it can only show that atoms (silver atom or hydrogen atom), not free electrons, have spin magnetic moments. It is interesting to note that the conclusion that free electrons have no spin is just hidden in Eq. (4). This formula implies that an isolated electron can only generate an electric field, and there is a non-existent so-called intrinsic spin moment. Whereas in atoms, the electrons combine with protons to form magnetic dipoles of Fig. 4(d) with the properties of magnetic moments, which are imagined as electron spins in modern physics.

IV. SYMMETRY OF MAXWELL'S EQUATIONS

The differential form of the Maxwell's equations can be written as:

$$\begin{aligned}
\nabla \cdot \mathbf{E} &= 4\pi\rho_e, \\
\nabla \cdot \mathbf{B} &= 0, \\
\nabla \times \mathbf{E} &= -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}, \\
\nabla \times \mathbf{B} &= \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{J}_e,
\end{aligned} \tag{7}$$

where $\mathbf{E}$ is the electric field, $\mathbf{B}$ is the magnetic field, ρ_e is the electric charge density, $\mathbf{J}_e$ is the electric current density.

Maxwell's equations of Eq. (7) is considered the most beautiful and elegant formula in physics. Because it is not mathematically perfect symmetry, significant efforts have still been made to achieve the exact symmetry of the equations, including Dirac's magnetic monopole hypothesis [46]. We don't think it is the right way to realize the symmetry of the equation through mathematical skills or artificial hypotheses of new particles. In the previous section, we have obtained three significant findings: (i) the physical essence of conduction current is the displacement current of Eq. (3), (ii) the magnetic field is produced by the proton-electron electric dipole of Eq. (4), (iii) the magnetic monopoles are the isolated electrons and protons of Eq. (6).

With the above new findings, we can now reconsider the symmetry of Maxwell's Equations. Maxwell's first equation of Eq. (7) is based on Gauss' law, which describes the electrostatic field. The second equation of Eq. (7) is based on Gauss law on magnetostatics. Here, we will show that these two equations are intrinsically related, and the second equation can be derived from the first equation.

For a proton-electron pair with the electric dipole vector $\mathbf{P}$, according to the first equation of Eq. (7), the electric field generated by the pair satisfies:

$$\nabla \cdot (\mathbf{E}_+ + \mathbf{E}_-) = 4\pi\left[\rho_e(\mathbf{r}_p) + \rho_{-e}(\mathbf{r}_p + \mathbf{P}/e)\right], \tag{8}$$

where e is the electron charge, $\mathbf{r}_p$ is the coordinate position of the proton, $(\mathbf{E}_+, \rho_e)$ and $(\mathbf{E}_-, \rho_{-e})$ are the electric fields and the electric charge densities of proton and electron, respectively.

Substituting Eq. (4) into Eq. (8) , we have

$$\nabla \cdot \mathbf{B} = \frac{4\pi\left[\rho_e(\mathbf{r}_p) + \rho_{-e}(\mathbf{r}_p + \mathbf{P}/e)\right]}{c}. \tag{9}$$

Usually $\mathbf{P}/e$ is an infinitesimal, under a far-field approximation $\mathbf{r}_\mathrm{p} + \mathbf{P}/e \simeq \mathbf{r}_\mathrm{p}$, it is reasonable to assume that proton and electron in close proximity of each other, or $\rho_e(\mathbf{r}_p) + \rho_{-e}(\mathbf{r}_p + \mathbf{P}/e) \simeq 0$, then Eq. (9) will approximately become the second Maxwell's equation.This result means that Maxwell's second equation is not strictly true, or the right-hand side of the equation is not exactly zero. Furthermore, our conjecture has ruled out the existence of conduction currents, this means that $\mathbf{J}_e$ in the fourth Maxwell equation must be equal to zero. So far, we have developed all the tools necessary to rewrite the Maxwell equations. The new equations can be given immediately as:

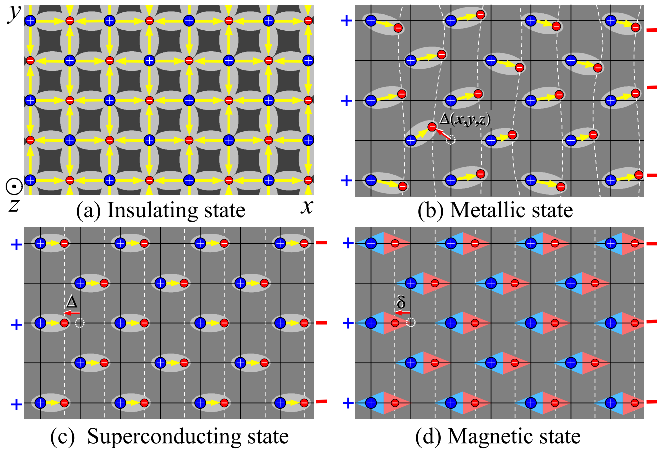
$$\begin{aligned} \nabla\cdot\mathbf{E} &= 4\pi\rho_e, \\ \nabla\cdot\mathbf{B} &\simeq 0, \\ \nabla\times\mathbf{E} &= -\frac{1}{c}\frac{\partial\mathbf{B}}{\partial t}, \\ \nabla\times\mathbf{B} &= \frac{1}{c}\frac{\partial\mathbf{E}}{\partial t}. \end{aligned} \tag{10}$$

Compared with the Maxwell's equations of Eq. (7), the new equation above have two important breakthroughs. First, one can find the original first and second equations of Eqs. (7) are completely independent and uncorrelated, so strictly speaking, Maxwell's equations have not achieved the unification of electrical and magnetic phenomena. The new first and second equations of Eq. (10) are intrinsically closely related. The first equation describes the electric field generated by unpaired charges (protons or electrons) and the second equation describes the magnetic field generated by paired charges. The new equations realize the perfect unification of electromagnetic phenomena. Second, due to the existence of excess conduction current $\mathbf{J}_e$, the original third and fourth equations of Eq. (7) are not perfectly symmetrical. The new third and fourth equations of Eq. (10) show the asymmetry can be naturally resolved under the proton-electron pairing displacement current mechanism.

V. ORDER PARAMETERS AND SYMMETRY BREAKING

It is without a doubt that the Ginzburg-Landau phase transition theory is the most successful theory of superconductivity so far [29]. As a phenomenological theory, it captures the two primary elements of superconducting phase transition: the order parameter and symmetry breaking. Of course, Landau's theory is incomplete because it cannot answer the question on the microscopic level: what is the order parameter with electromagnetic properties? Now, it should be pretty sure that the order parameter in Ginzburg-Landau's theory is the proton-electron electric dipole moment as proposed in our theory.

In condensed matter physics, phase transitions in materials are responsible for the changes in their physical properties, which are described through the evolution of a symmetry-breaking order parameter. Since we believe that the proton-electron electric dipole can play a vital role in the order parameter, as the most basic requirement, it must provide a unified microscopic explanation for the phase transitions of superconductivity, insulation, magnetic, metallic, etc.



(a) Insulating state (b) Metallic state (c) Superconducting state (d) Magnetic state

Figure 5: Symmetry and symmetry-breaking of proton-electron electric dipole crystals, (a) insulating state with the highest symmetry, which ensures the absence of polarized surface charges; (b) metallic state of incomplete symmetry breaking induced by the external field, where the electron's displacement vector $\Delta(x, y, z)$ is random; (c) the external field-induced complete symmetry breaking (the same displacement vector Δ), where all dipoles are identical and become coherent with each other, they can condense into a quantum superconducting state; and (d) the spontaneous symmetry breaking (the same displacement vector δ), where the quantized magnons are coherent and condensed into a magnetic state. In cases (b), (c), and (d), symmetry breaking induces the formation of polarization surface charge distributions along the boundary.

We first discuss the common insulators that do not conduct electricity at all. In our theory, the proton-electron pairs in the insulator will self-organize into a duplex crystal of insulating state with the highest symmetry, as shown in Fig. 5(a). In the insulating state, all valence electrons are trapped in an equilibrium position of zero potential energy without symmetry breaking. For insulating states, including undoped semiconductors and specially doped superconductors (e.g. 1/8 anomaly in cuprates [51]) can be uniformly described in Fig. 5(a). Generally, an insulator is a material whose internal proton-electron electric dipole symmetry cannot be easily disrupted by an external electromagnetic field.

The metallic state is illustrated in Fig. 5(b), where valence electrons in metals are not fully localized at equilibrium positions. In the absence of an external electric field, the orientation of the electric dipole is isotropic due to random thermal motion and the electron's displacement can be expressed as a disorder variable $\delta(x, y, z)$. Under the application of an external electric field oriented in the x-direction, the displacement of the electrons will be superimposed by a constant displacement Δ along the $-x$ direction resulting in an incomplete symmetry breaking with the total displacement: $\Delta(x, y, z) = \delta(x, y, z) + \Delta$ and the indeterminate polarization surface charge distribution, as indicated in the figure. Because the orientation of the electric dipoles is not strictly along the direction of the electric field, which leads to the appearance of displacement currents in the y and z-directions that generate resistance.

By simply lowering the temperature, the random thermal motion of electrons can be effectively suppressed while reducing the electrical resistance. When the temperature falls below the critical temperature, the metallic state will be further symmetrically broken into a superconducting state (here $\delta(x, y, z) = 0$, and $\Delta(x, y, z) = \Delta$). As shown in Fig. 5(c), under the action of the external field, all valence electrons move against the direction of the electric field with the same displacement $\varDelta$, and proton-electron electric dipoles will be strictly aligned into (this is the essence of phase coherence and superconducting condensation) the superconducting state with the displacement current along the external electric field at the temperature below the critical temperature.

Figure 5(d) represents the magnetic state, compared with the superconducting state of Fig. 5(c), there is no essential difference between the two states, both of which form stable polarization surface charge distributions at both ends of the symmetry breaking direction. An external electric field can adjust the surface charge distribution for the superconducting phase while it is fixed and unadjustable for natural magnetic materials. Furthermore, for the magnetic state of Fig. 5(d), there are two possible symmetry breaking. The first is temperature-induced spontaneous symmetry breaking, such as room temperature natural magnet material, and the second is magnetic field-induced symmetry breaking, such as superconducting Meissner effect. So it can be said that the superconductors of the Meissner state are the low-temperature magnets.

It must be pointed out that the key to phase transition in microphysics lies in the correlation of the orientation of the order parameter of a proton-electron electric dipole. A slight change in external electromagnetic fields or temperature may cause a change in the orientation order of the electric dipoles and the phase transitions. Moreover, it is necessary to emphasize that even if a superconductor is below the superconducting transition temperature, it does not mean it is superconducting. Without electric or magnetic fields, the superconductor is insulating state of Fig. 5(a). Only under appropriate electric field and temperature can superconductors exhibit the zero-resistance superconducting state of Fig. 5(c). In the case of a weak magnetic field, it will be magnetized into a magnetic state of Fig. 5(d), which is regarded as the Meissner effect. In the case of a strong magnetic field, it will partially transition into a metallic state of the vortex lattice. In the next section, we will further explain the Meissner effect, the London penetration depth, and the vortex state based on the discussion in this section.

VI. MEISSNER EFFECT PUZZLE

In addition to the property of exactly zero resistivity, superconductors are also characterized by the property of perfect diamagnetism, which is known as the Meissner effect [27]. The effect can be illustrated in Fig. 6, it is generally believed that when a superconductor is placed in a weak external magnetic field **H**, the magnetic field is expelled from the interior if it cooled below its transition temperature.

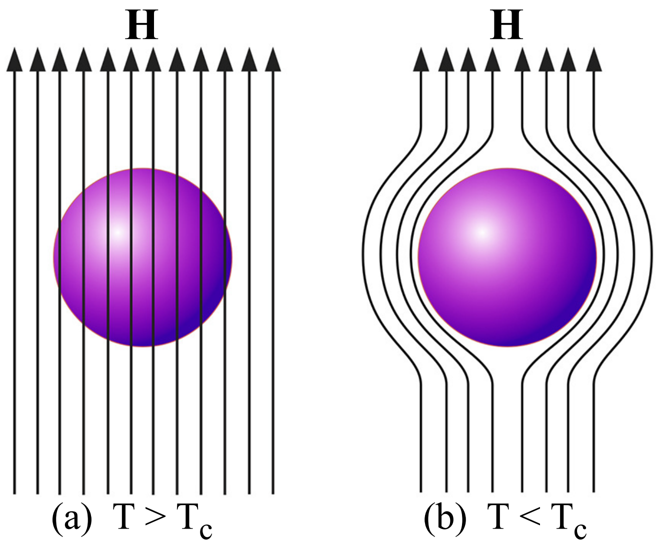


Figure 6: Mainstream explanation of the Meissner effect: (a) above the critical temperature, the magnetic field can pass through the superconductor, (b) below the critical temperature, the magnetic field is excluded from its interior.

From the magnetic field expelled picture of Fig. 6, it is clear that the Meissner effect is a time-dependent dynamic process. Hence, a correct theory of superconductivity must have the physics to explain how the superconductor goes from the normal to the superconducting state by expelling the magnetic field against Faraday's law. Almost ninety years have passed since the experiment in 1933 [27], and many theories and mechanisms have been proposed to explain the Meissner effect. As Hirsch argued [25], none of these mechanisms have consistently described the Meissner experiment. In this study, we will try solving this puzzle using the microscopic mecha-

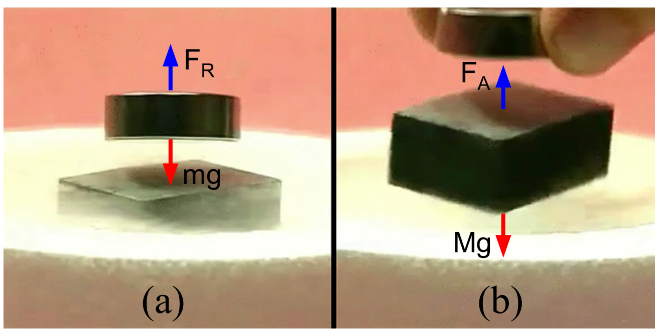


Figure 7: The experiment of Meissner effect: (a) strong repulsion between superconductor and magnet makes the magnet levitate, (b) strong attraction between superconductor and magnet makes superconductor levitate.

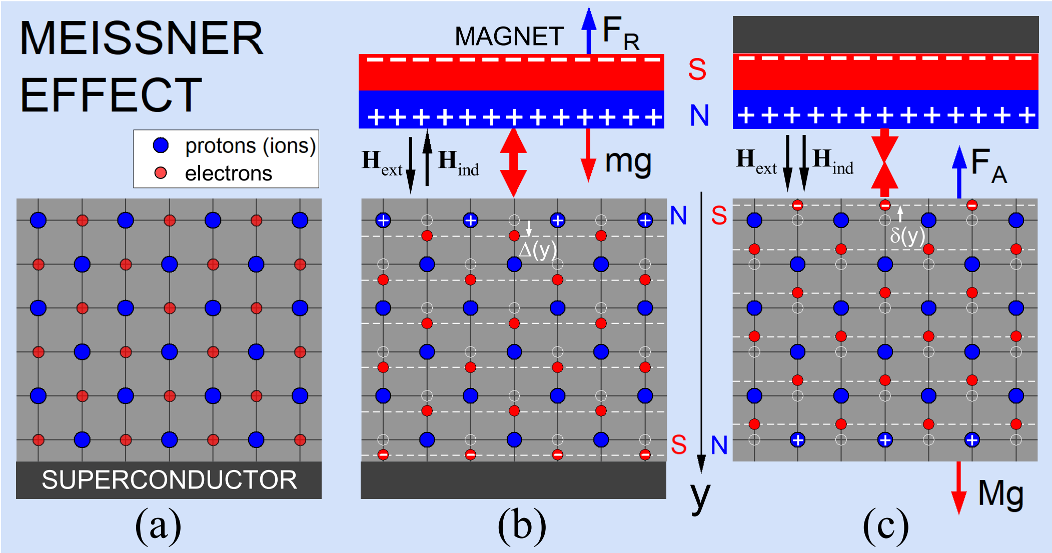


Figure 8: Schematic explanation of Meissner effect experiment of Fig. 7. (a) Without an external magnetic field, the superconductor is insulating with high symmetry; (b) the magnet above causes the collective displacement of electrons $\Delta(y)$ in y direction , then the surface charge on the upper side of the superconductor has the same sign as the lower side of the magnet, resulting in a repulsive interaction; (c) the symmetry breaking occurs due to the collective displacement of electrons $\delta(y)$ in $-y$ direction, in this case, the surface charge on the upper side of the superconductor is of the opposite sign to the lower side of the magnet, resulting in an attractive interaction.

nism of proton-electron electric dipole pairing.

Before starting the following investigation, it is vital to look at the experiment of the Meissner effect [30]. Figure 7 shows two screenshots of the experiment, clearly showing that the superconductor and the magnet can both repel as shown in Fig. 7(a) or attract as shown in Fig. 7(b) each other. Moreover, the repulsion and attraction can be switched instantaneously. One can immediately find that the magnetic field expulsion mechanism of Fig. 6 (b) cannot explain the experimental fact that the superconductor and magnet of Fig. 7(b) are attracted to each other. In order to better explain the Meissner effect, we make a force analysis on the magnetic suspension in Fig. 7 (a) and the superconductor suspension in Fig. 7(b), respectively. By assuming that the masses of the magnet and the superconductor are m and M, respectively, thus the repulsive force F_R and the attractive force F_A satisfy:

$$F_R = mg; \quad F_A = Mg, \tag{11}$$

where g is the acceleration of gravity.

The Eq. (11) seems simple and straightforward, but it contains important information about the Meissner effect. First, the direction of the Meissner effect is automatically adjustable, which can make the magnet and the superconductor attract or repel each other. Second, according to the formula, the Meissner effect can also automatically modulate its strength to balance gravity according to the mass of the magnet or superconductor. From a personal point of view, this experiment result is the biggest challenge for theoretical researchers of superconductivity. From the perspective of energy conservation, maintaining a stable levitation requires stable external energy input. Suppose the magnetic field is expelled from the superconductor, in other words, without the input of external energy. Where does the strong force (repulsive or attractive) come from that can ensure a stable levitation of Fig. 7? In the Meissner effect experiment of Fig. 7, the magnetic field is the only external factor outside the superconductor. Hence, it must also be the only source of the force of the levitation phenomenon.

Our theory as a new mechanism of superconductivity, its reliability and consistency must be strictly tested by the experiment results of Fig. 7. According to our theoretical framework, in the absence of an external magnetic field and a temperature below the superconducting critical temperature, all valence electron will rest at a position with zero potential energy as shown in Fig. 8(a). When a magnet ($\mathbf{H}_{\text{ext}}$) is placed over a superconductor, due to the gravitational field, the magnet tends to fall to increase the strength of the magnetic field within the superconductor, as shown in Fig. 8 (b). Then the electrons will move down from their equilibrium positions, resulting in an induced magnetic field ($\mathbf{H}_{\text{ind}}$) in the opposite direction and a repulsive interaction between the magnet and the superconductor. Thus in the experiment, we could observe the magnet levitating after being repelled by the superconductor, as shown in Fig. 7(a).

As shown in Fig. 8(c), when the magnet is lifted up, gravity will tend to separate the magnet and superconductor, consequently reducing the magnetic field strength inside the superconductor. To resist the process, the electrons in superconductors will will move up from their original positions and simultaneously excite an induced magnetic field ($\mathbf{H}_{\text{ind}}$) in the same direction as $\mathbf{H}_{\text{ext}}$. Naturally, the magnet and superconductor will attract each other to keep the superconductor in suspension, as shown in Fig. 7(b).

From our explanation above, it should be clear that the nature of the Meissner effect is not mysterious. It is merely a simple magnetic interaction between a magnetized superconductor and a magnet. They follow the fundamental principle of "two identical poles repel and two opposite poles attract." Whether the magnet and the superconductor repel or attract can be automatically adjusted by the electrons deviating downward or upward from the equilibrium position. Furthermore, according to formula (11), why is the levitation force (F_R or F_A) automatically adjustable? This question is related to the London penetration depth and will discuss in the next section.

VII. LONDON PENETRATION DEPTH AND LEVITATION

The strength of the Meissner effect is usually described in terms of λ_L, which is according to the following formula [31]:

$$\mathbf{H}(x) = \mathbf{H}_0 e^{-x/\lambda_L}, \quad (12)$$

where $\mathbf{H}_0$ is a weak external magnetic field, $\mathbf{H}(x)$ is the decaying magnetic field inside the superconductor. The London penetration depth is given by

$$\lambda_L = \sqrt{\frac{mc^2\varepsilon_0}{n_s e^2}}, \quad (13)$$

where n_s is the density of superconducting electrons.

In our theory, n_s is equivalent to the proton-electron lattice-determined electron density. Qualitatively, the greater the electron density, the more electrons are within the same penetration depth. Hence, these electrons absorb more magnetic field energy, so the magnetic field decays faster and penetrates shallower into the superconductor.

Since the London theory is only a phenomenological theory, which cannot offer a dynamical explanation for how superconductor expel magnetic fields? Because our present proton-electron electric dipole superconductivity theory is a microscopic theory, thus allowing us to study the dynamic processes of London penetration depth. As shown in Fig. 9(a), when the applied external magnetic field $\mathbf{H}_0$ enters the superconductor, it will interact with the electrons near the surface of the superconductor. During this interaction, the electrons originally at zero potential energy (indicated by the white hollow circles in the figure) will absorb the magnetic field energy and then move to the high potential energy positions of different displacement parameter $\Delta(x)$ determined by the strength of the magnetic field $\mathbf{H}(x)$. In other words, the magnetic field energy is converted into the potential energy of the electrons rather than being expelled from the superconductor through the development of a Meissner surface current as mainstream imagined.

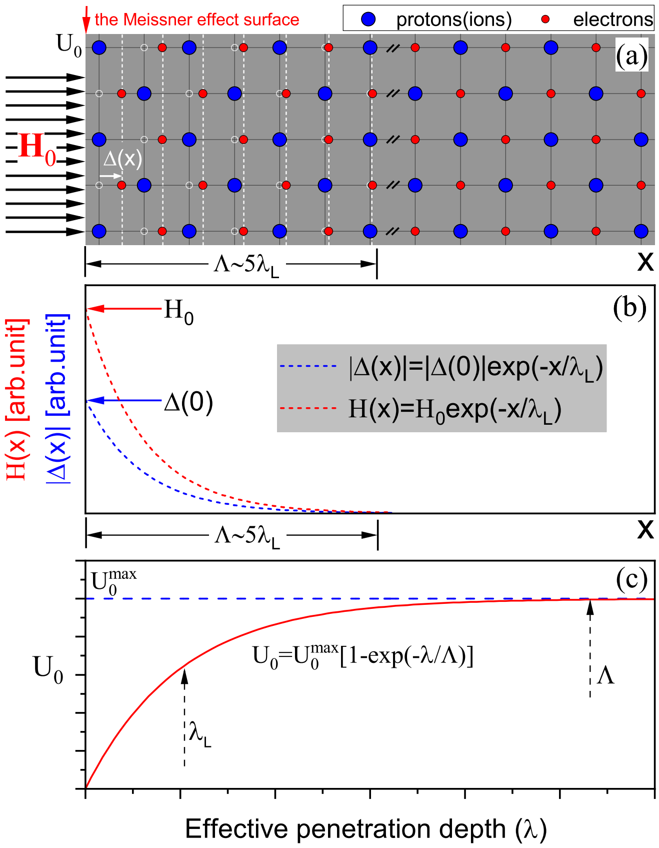


Figure 9: Microscopic explanation of London penetration depth. (a) When the magnetic field $\mathbf{H}_0$ enters the superconductor, the electromagnetic force will cause the electrons near the surface of the superconductor to move from zero-potential-energy positions (the white hollow circles on the left of the picture) to high-potential-energy places (the solid red circles on the left of the picture). As x increases, the magnetic field energy absorbed by the electrons will exponentially decay, and the displacement parameter $\Delta(x)$ decreases simultaneously; (b) the change of the electron displacement $\Delta(x)$ is equivalent to the change of the magnetic field $\mathbf{H}(x)$, when $\Delta(x) = 0$, the magnetic field disappears; (c) the relationship between the effective penetration depth and electrical potential of the Meissner effect surface.

We still see Fig. 9(a), the external magnetic field causes the superconductor to be divided into two regions or two phases. The left of penetration region Λ (In fact, when $\Lambda \simeq 5\lambda_L$, the magnetic field is completely absorbed and disappears.) is symmetrically broken into a non-uniform magnetic state of Fig. 5(d), while the right region remains in the high symmetrical insulating state of Fig. 5(a). Next, we perform a simple qualitative analysis of the London penetration depth. As shown in Fig. 9(a), if a minor displacement of the electron from the equilibrium position is $\Delta(x)$, its potential energy can be expressed as: $E_P \propto |\Delta(x)|^2$, which is the direct conversion from the magnetic-field energy of $E_H \propto |\mathbf{H}(x)|^2$. As the magnetic field penetrates deeper into the superconductor, more and more magnetic field energy is converted to electrons' potential energy until the input energy is completely absorbed. Consequently, the magnetic field $\mathbf{H}(x)$ and the displacement $\Delta(x)$ of the electrons will simultaneously decay exponentially to zero as shown in Fig. 9(b).

The determined London penetration depth of Eq. (13) is only a reference value, and the experimental observed value of penetration depth λ (this paper calls it the "effective penetration depth") is strongly affected by magnetic field and temperature. In the Meissner effect experiment in Fig. 7, the distance between the superconductor and the magnet is constantly changing, so the magnetic field entering the superconductor is not uniform and constant. This results in a constant change in the effective penetration depth λ, which can be verified by measuring the electric potential U_0 on the left surface (the Meissner effect surface) of the superconductor. As shown in Fig. 9(c), they satisfy the following relationship:

$$U_0 = \pm U_0^{max}\left(1 - e^{-\lambda/\Lambda}\right), \tag{14}$$

where the positive and negative signs are determined by the direction of the electron displacement $\Delta(x)$, U_0^{max} and $\Lambda \simeq 5\lambda_L$ are the maximum surface potential and maximum penetration depth, respectively.

From Eq. (14), by changing the effective penetration depth λ through the external magnetic field, the magnitude and sign of the potential energy on the surface of the superconductor can be automatically adjusted, thereby realizing the attraction, repulsion, and suspension of the external magnet. Now, we can provide a better and more intuitive explanation for the suspension experiment in Fig. 7. Figure 10(a) shows a set of springs in a free state. When an object of mass m is placed on the springs, a reaction force N is caused by the compression spring (a proper deformation Δ) to achieve force balance $N = k\Delta = mg$ (where k is the spring coefficient), as shown in Fig. 10(b).

As an analogy, in the absence of an external magnetic field, a superconductor in an insulating state can be simplified to a spring oscillator model, as shown in Fig. 10(c). Here note that the lateral spring oscillators are omitted from the figure. When a magnet of mass m is placed on top of the superconductor, the magnetic field will cause the spring oscillators to be compressed and produce a combined reaction force F_R, as shown in Fig. 10(d). The force balance $F_R = mg$ of Eq. (10) can be achieved by choosing an appropriate effective penetration depth λ. Of course, if the mass of the magnet is too heavy and the effective penetration depth exceeds the limit $\Lambda \sim 5\lambda_L$, the superconductor will undergo a phase transition from the magnetic state to the normal state, and the levitation effect will also be destroyed.

Strictly speaking, the Meissner effect and the London penetration depth are not indeed superconducting phenomena. They are just the low-temperature magnetization effects. By increasing the strength of the external magnetic field, which is equivalent to increasing the temperature, the electrons will gain more magnetic field energy and generate a more significant displacement $\Delta(x)$. When the applied magnetic field is greater than the critical magnetic field $\mathbf{H}_c$ which functions as the Curie temperature of the superconductor, the magnetic state of the Meissner effect will be entirely or partially destroyed to the metallic state of Fig. 5(b) for the type-I and type-II superconductors, respectively. In the next section, we will focus on the vortex state of the type-II superconductor.

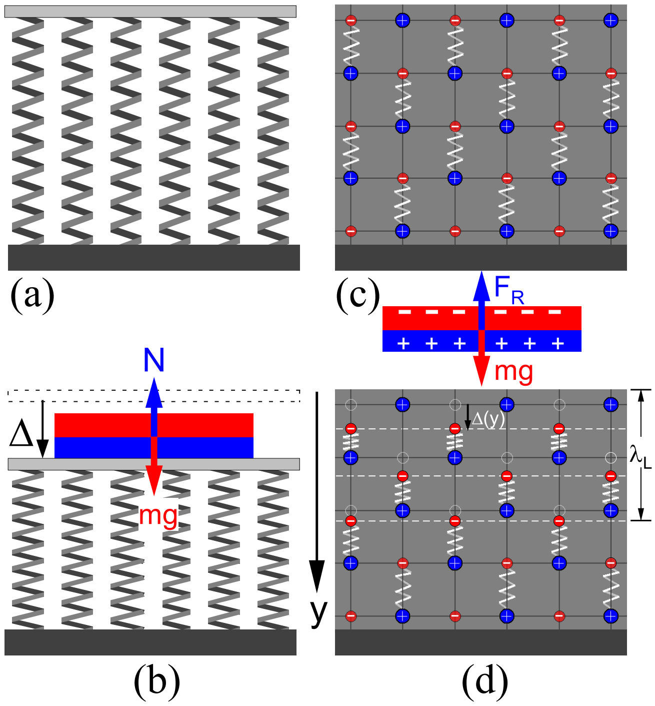


Figure 10: An analogy of superconducting levitation to a classical spring system. (a) A free spring system (assume the mass of the spring is negligible); (b) the object m achieves force balance by compressing the spring; (c) an insulating superconductor described by the "spring oscillators"; (d) similar to the classical spring system of the figure (b), the magnet suspends itself by compressing the "springs" by the magnetic field.

VIII. PHYSICAL ORIGIN OF VORTEX LATTICES

Abrikosov proposed the vortex lattice in type-II superconductors in his pioneering work [32]. Since then, tremendous theoretical and experimental efforts have been directed toward understanding the behavior behind it [34–36, 38–40]. However, to date, everything remains unclear at the macroscopic level. The most fundamental question of how the magnetic field leads to the formation of vortex lattices is still very challenging. What is the physical origin of the vortex state? Our theory provides new insight into the mechanisms by which vortex emerges, and why it disappears is no longer a puzzle.

As shown and interpreted in Fig. 11, when the superconductor is cooled below its critical temperature in an applied magnetic field $\mathbf{H}$, it will undergo a series of phase transitions. Depending on the magnitude of the applied magnetic field, the superconductor can phase transition from an insulating state to

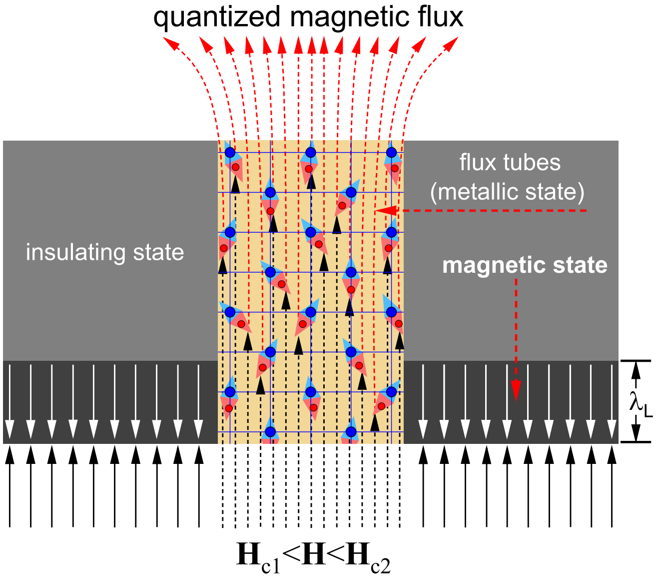


Figure 11: The three-step transition of type-II superconductor below the superconducting phase-transition temperature. When $\mathbf{H} = 0$, the entire superconductor is in the insulating state of Fig. 5(a). In the first-step phase transition, when $\mathbf{H} < \mathbf{H}_{c1}$, the absorption of magnetic field energy by electrons induces the symmetry breaking of the proton-electron electric dipole vector, and the phase transition from the insulating state of Fig. 5 (a) to the magnetic state of Fig. 5(d) occurs near the surface of the superconductor within the London penetration depth λ_L. In the second step, when $\mathbf{H}_{c1} < \mathbf{H} < \mathbf{H}_{c2}$, as the strength of the magnetic field increases, the electrons gain more energy and larger positional perturbations, and the proton-electron electric dipole orientation order is disrupted in some tubes, where the magnetic state to metallic state and insulating state to metallic state phase transitions will occur in London-penetration-depth region and inside the superconductor, respectively. Note inside the tubes, the external magnetic field itself is not quantized. The quantized proton-electron electric dipole absorbs the magnetic field energy and then emits a magnetic flux quantum $\Phi_0 = h/2e$. In the third step, when $\mathbf{H} > \mathbf{H}_{c2}$, all electrons acquire enough potential and vibration energy, the orientation order of the electric dipole is destroyed, and the superconductor becomes a normal metal.

a magnetic state, and then from a magnetic state to a metallic state, or directly from an insulating state to a metallic state. When $\mathbf{H}_{c1} < \mathbf{H} < \mathbf{H}_{c2}$, a vortex state with a mixture of insulating, magnetic, and metallic tri-states is formed.

In our theory, the fundamental reason for these phase transitions is the energy exchange between the magnetic field and the proton-electron electric dipole. The occurrence of the phase transition requires the contribution of magnetic field energy. Maintaining the new phase transition state also requires a continuous energy supply from the magnetic field. Our research shows that the external magnetic field is absorbed by the proton-electron electric dipole inside the superconductor. This explanation is quite different from the conventional picture in that the magnetic field is expelled or penetrates the superconductor in the form of vortices. Furthermore, as shown in the tubes of Fig. 11, the quantized flux observed experimentally does not come from the external magnetic field but the quantized proton-electron pair in the tube. Quantization phenomena can only be manifested in isolated or disordered systems, such as hydrogen atoms, and black body radiation, while quantum condensed matter systems cannot exhibit quantum properties. Therefore, any experiment that claims to confirm the existence of the Cooper pair cannot be related to superconductivity, nor can it be used to prove that the BCS theory is correct.

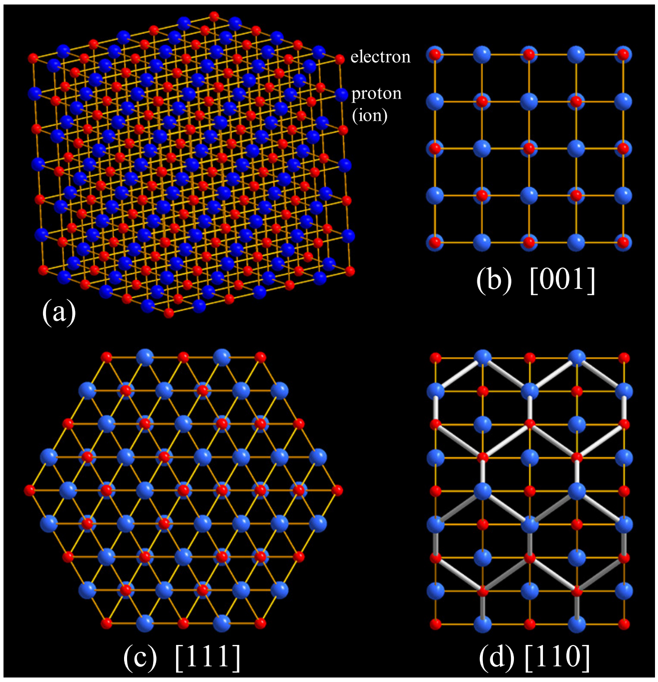


Figure 12: Proton-electron electric dipole crystal and its symmetry, the DNA of vortex lattice. (a) A duplex lattice of proton-electron pairs with space-group $Fm\bar{3}m$; (b) 2 × 2 super-cells of the crystal along the fourfold [001] direction; (c) the threefold [111] direction; and (d) the twofold [110] direction, respectively. For case (d), the rectangle lattice (the thin yellow bonds) can be rearranged as a distorted hexagonal lattice (the thick light gray bonds).

Finally, let us discuss the origin of the vortex patterns in the type-II superconductors and the puzzle of vortex dynamics. There are many experimental results for the vortex lattice structures [34–36], from which two important conclusions have been obtained. First, although the classes and structures of superconductors vary widely, their vortex lattice structures all share very similar symmetries. Second, the vortex symmetry is closely related to the orientation of the applied magnetic field. When the field is applied along the fourfold (the [001] direction), threefold (the [111] direction), or twofold (the [110] direction) symmetric axis of the superconductors, square, triangular, or distorted hexagonal vortex lattices can be observed. To the best of our knowledge, such lattice symmetry exactly matches that of $NaCl$-type lattice, as shown in Fig. 12 of a proton (ion)-electron lattice and symmetry. This figure can be considered as the DNA of the superconducting material, which determines the structure and symmetry of the

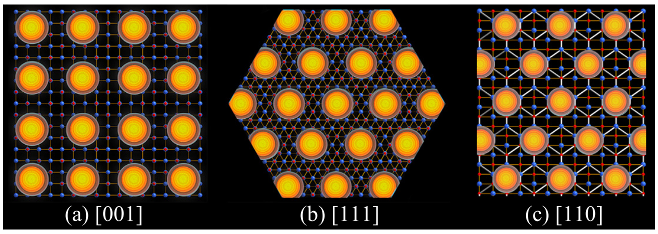


Figure 13: Matching relationship between three typical Abrikosov vortex lattices and the corresponding proton-electron electric dipole lattices. (a) A square vortex lattice in [001] direction; (b) a triangular vortex lattice in [111] direction; and (c) a distorted hexgonal vortex lattice in [110] direction.

vortex lattice.

It should now be apparent that the observed macroscopic perfect symmetry of the vortex lattice originates in the intrinsic microscopic perfect symmetry of the proton (ion)-electron lattice (the lattice's DNA), as shown in Fig. 13. The generation of the vortex structure still follows the principle of minimum free energy. When the vortex's symmetry matches that of the parent lattice of proton-electron pairs, the system's minimum free energy and the vortex lattice's stability can be ensured. As the strength of the magnetic field increases, electrons that gain more magnetic field energy will have a more significant displacement from the equilibrium position, resulting in a strong proton-electron electric dipole interaction. This interaction will cause the orientation order of more electric dipoles to be destroyed. As a result, we can experimentally observe that the diameter and the number of the flux vortices will increase synchronously. Until the upper critical field is reached, the orientation order of the electric dipole is wholly destroyed, and the superconductor enters the normal state.

One of the most complex problems has been the explanation of the vortex dynamics in type-II superconductors [41]. The magnetic flux vortex can form various states inside the superconductor [43], such as solid-state, liquid state, and glass state. Through experiments, we can observe that the magnetic flux vortex will have various forms of movement, such as hopping, creeping, and flowing. In the traditional theoretical framework, to study the movement of a vortex line, it is necessary to know the external force on the vortex line, such as the driving force, friction force, collision force, pinning force, and Magnus force. Obviously, this is a highly complex problem, and no analytical or numerical solution is possible. I wish to point out that the difficulty of this research also arises from Drude's model. The conventional theory of vortex motion is all based on the model of the random motion of carriers (electrons) in the superconductors. Unfortunately, this doesn't seem right.

The generation of vortex lattices in superconductors requires two essential external conditions: first, a sufficiently low temperature; second, and appropriate magnetic field strength. Under low temperature and low external magnetic field, the magnetic flux lines distribute uniformly inside the superconductor. They are frozen to form an ordered lattice, as shown in Fig. 13. A type-II superconductor in a vortex state can be divided into the vortex region and the surrounding non-vortex region. We here raise a question: what is the essential physical difference between the vortex region and the non-vortex region? From the proton-electron pairing mechanism proposed in this paper, the proton-electron electric dipoles inside the vortex region absorb more magnetic field energy and gain higher free energy. As a result, the inner vortex is hotter than the outer vortex. This conclusion means that magnetic field or temperature instability can induce the change in the

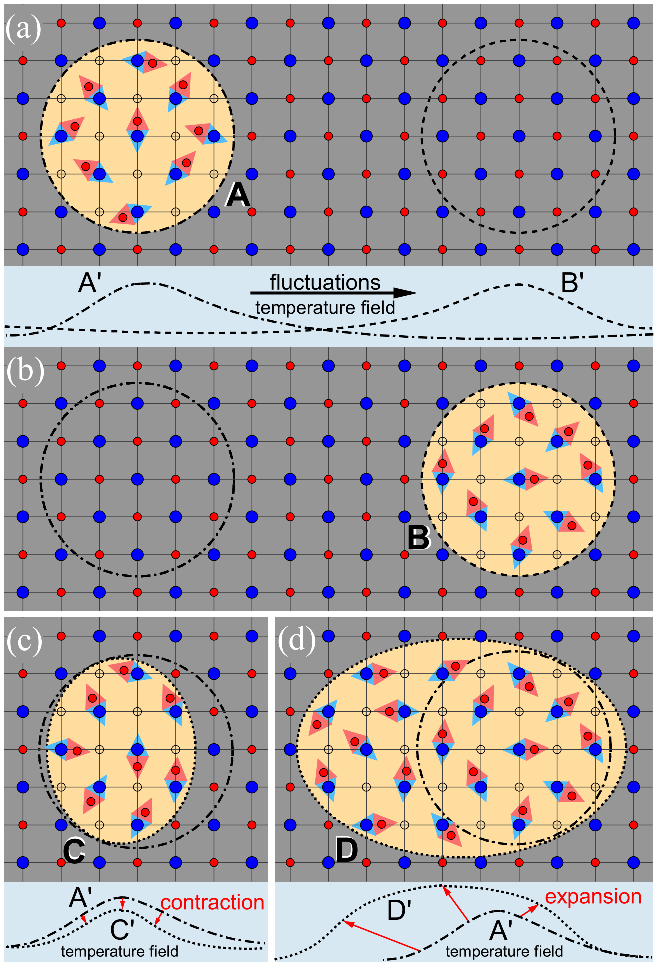


Figure 14: Top view of vortex hopping and creeping, a simple graphical explanation of vortex motion in type-II superconductors. (a) A vortex is formed in the region **A** due to the existence of the temperature field peak A' around the region, see the dot-dash line in the figure below; (b) thermal fluctuations lead to the annihilation of the temperature peak A' and corresponding vortex in region **A**, and at the same time generate new temperature peak B' and corresponding vortex in region **B**, as shown the dashed line in the figure. This process is misinterpreted as the movement (hopping) of the same vortex from **A** to **B**; (c) and (d) the vortex **A** can contract to **C** or expand to **D** in situ based on thermal fluctuations (A' to C', or A' to D'), often interpreted as creeping vortex dynamics.

vortex region, which is the crucial physical reason for the instability and motion of the vortex lattice in the superconductor.

In the following, we will explain the vortex hopping (flowing) and creeping using Fig. 14. Figure 14(a) shows an initial vortex element of area $\mathbf{A}$. Accordingly, there is a temperature field peak A' around the vortex's core, as shown by the dot-dash line in the figure below. As the temperature or magnetic field increases, the temperature and magnetic field's uniformity inside the superconductor will decrease. That is to say, there will be large random fluctuations in temperature and magnetic field inside the superconductor. Due to random fluctuations in temperature, the peak A' of the temperature field around vortex $\mathbf{A}$ may disappear suddenly. All the electrons inside the vortex return to the equilibrium position, and the vortex disappears. As shown in Fig. 14(b), a temperature peak B' may also appear suddenly in the nearby region $\mathbf{B}$ at this time (the dash line in the figure below). The higher temperature intensifies the thermal vibrations of the electrons in the region and causes them to leave their original equilibrium positions, exciting a new vortex $\mathbf{B}$ as shown on the right of Fig. 14(b). The vortex seems to move (or jump) from $\mathbf{A}$ to $\mathbf{B}$ during this process. Moreover, the temperature fluctuations may occur in situ (see the dot lines C' in Figs. 14(c) and D' in Figs. 14(d) below). In this case, the vortex $\mathbf{A}$ may sometimes shrink into a thin vortex $\mathbf{C}$ of Fig. 14(c), alternatively, sometimes expand into a fat vortex $\mathbf{D}$ of Fig. 14(d), which is the experimentally observed vortex creeping.

Under our theoretical framework, the vortex motions are not actual physical processes. It is the temperature field and the magnetic field that is moving (or changing), not the carriers (electrons) inside the vortex core, that researchers have long believed. The fundamental physical process is generating and annihilating vortices by changing the superconductor's external magnetic field and temperature. Microscopically, they merely change the orientation of the proton-electron electric dipole caused by the temperature and magnetic field instability. In addition, the new theory does not require the so-called flux pinning mechanism to prevent "flux creep" in the superconductor. In the proton-electron pairing mechanism, the flux vortices in the superconductors do not move.

IX. CONCLUDING REMARKS

There is a famous proverb in China called "blind people touch an elephant" which means that some people, regardless of objective conditions and constraints of personal subjectivity, make arbitrary guesses and draw conclusions based on only a one-sided understanding of things. Due to the lack of understanding of the nature of magnetism, over a hundred years, researchers have created many artificial physical concepts, such as spin, magnetic monopoles, magnetic moment, electric dipole, and magnetic dipole, which we have shown here that they all originate from the same proton-electron pair. It should now be clear that electric field and magnetic field are intrinsically related. That is, isolated charges (proton or electron) generate electric fields, while paired positive and negative charges (proton-electron pair) generate magnetic fields. Remarkably, the pairing of proton and electron can achieve the perfect symmetry of Maxwell's equations. We have successfully fixed the bug of electric current that has dominated physics for over a hundred years. We have revealed that the current is the Maxwell's displacement current generated by the vibration of localized electrons rather than the Drude's conduction current generated by the long-range free flow of electrons that the academic community has accepted.

To test the proton-electron pairing mechanism, we have argued that the proton-electron electric dipole vector is the order parameter of the Ginzburg-Landau theory of superconducting phase transition. In this theoretical framework, many important superconducting phenomena such as the Meissner effect, the London penetration depth, the vortex lattices and the vortex dynamics have been well explained by the dynamic interaction of the proton-electron electric dipole with the external magnetic field. It is worth pointing out that even below the superconducting transition temperature, a superconductor may be in five different states: an insulating state, a normal state, a metallic state, a magnetic state, or a superconducting state. The Meissner effect is the coexistence of two states (insulating and magnetic states), while the vortex state is the coexistence of three states (insulating, magnetic, and metallic states). Moreover, the proton-electron electric dipoles can be further self-organized into electric dipole crystals with space-group $Fm3m$ through the electromagnetic interaction, which is also the microscopic origin of the vortex lattices of type-II superconductors.

We are aware that the field of theoretical physics has been stagnant for decades. The development of physics requires new and heretic ideas against old-established theories and models which have been proven no longer be valid by modern experiments. We firmly believe that the proton-electron pairing mechanism may shed new insights into all physical problems. In high-temperature superconductors [51–55], the origin of the pseudogap, the charge stripes, the checkerboard phases, the magic doping, the charge density waves (CDW), etc., is controversial and still subject to debate in the condensed matter community. These debates can be perfectly explained in our theoretical framework, and further studies have shown that they are related to the symmetry of the proton-electron electric dipole. Moreover, the quantum Hall effect [58, 59] and the Hall anomaly [60, 61] in superconductors are also caused by the proton-electron pair. These results will be explained in more detail in another article.

Before ending this article, it is necessary to raise an important question: why do identical proton-electron pairs, such as neutrons and hydrogen atoms, exhibit very different physical properties? This is possibly the greatest unresolved puzzle in physics, because it involves the nature of the vacuum. As a reasonable assumption, to bind proton and electron into a stable composite particle, there must be an appropriate externally supplied binding energy, which we believe the contribution comes only from the vacuum. These binding energies can be partially or wholly released under certain conditions, forming characteristic spectra for hydrogen atoms and neutrinos for neutrons. We consider photons and neutrinos to be a quasiparticle mode of vacuum energy. The vacuum is not empty, which contains an infinite amount of energy should be the consensus of the physics community.

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