Why can't the Cooper pairing mechanism explain superconductivity?

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High-temperature superconductivity has puzzled researchers for nearly four decades despite intense study. We recently proposed a unified superconducting theory using frozen localized electrons, reframing electron transport in lattices as electromagnetic field energy's lossless transmission via capacitive channels. This theory explains and predicts key results in various superconductors like copper-based, iron-based, nickel-based, and kagome ones. When our manuscript was submitted to Scientific Reports, Reviewer 1 saw its innovation and suggested revisions. Reviewer 2, while recognizing its novelty, criticized the theory as too simple and against the established paradigm, recommending rejection due to reliability concerns. We counter that Cooper's hypothesis in the BCS theory violates three scientific principles despite its Nobel status. Also, the peer review here seems to show a conservative bias, favoring conventional research over innovative work even with flawed existing theories.

INTRODUCTION

It is well-known that all existing superconductivity theories, including the BCS theory [1], are grounded in Drude's free electron gas model [2]. In this model, electric current propagation hinges on electron movement, creating a causal link between current and electron behavior: if electrons stop moving, both normal and superconducting currents would disappear immediately. The concept of free electrons is a fundamental hypothesis, and its validity significantly impacts the reliability of modern physics. However, it remains unclear whether this assumption has adequate scientific backing.

Modern physics reveals that electric current essentially comprises electromagnetic field energy traveling at the speed of light. Phenomena such as natural lightning, displacement currents in capacitors, and wireless and network communications all rely on massless electromagnetic waves (currents) for energy and information transfer. These clearly show that current can propagate independently of electrons.

"Like charges repel, opposite charges attract" is a basic law of nature, explaining why two electrons repel each other inherently. Yet, the BCS theory defies this law with a counterintuitive claim: electron-phonon interactions can produce an effective attraction, forming Cooper pairs where like-charged electrons seemingly attract. The theory posits that these pairs allow electrons to avoid lattice scattering, leading to superconductivity. For decades, guided by the BCS hypothesis, superconductivity research has mainly focused on the difficult task of making repulsive electrons pair up. When a new superconducting material is found, scientists laboriously search for a hard-to-find "pairing glue," only to repeat past theoretical errors. In truth, pairing opposite charges through electromagnetic interaction accords with natural laws. Hence, we propose that the genuine mechanism of superconductivity should stem from universal electromagnetic attraction, without the need for exotic quasiparticles.

It is widely recognized that gold, silver, and copper, despite being excellent conductors, do not exhibit superconductivity. In contrast, ceramic materials, which are insulators in their base state, can show remarkable superconducting performance [3]. Additionally, disorder doping and applied pressure can notably increase the superconducting transition temperature. These experimental findings highlight a strong positive correlation between superconductivity and insulating behavior, but a negative one with metallic properties. This paradox exposes significant flaws in the current definitions and comprehension of metallic, insulating, and superconducting states, this is one of the important reasons why high-temperature superconductivity has not been solved since its discovery 39 years ago.

Moreover, the long-standing enigma of high-temperature superconductivity can be traced back to two flawed assumptions: free electrons and Cooper pairs. Thus, we contend that physics is due for a paradigm revolution. A new theoretical framework should adhere to the following fundamental principles: (1) As the superconducting state represents a zero-resistance, energy-lossless thermodynamic equilibrium of electrons, any viable theory must strictly follow the principle of energy minimization. (2) Thermal motion inherently causes diffusion, dispersion, and energy fluctuations. Hence, all forms of motion-thermal vibrations or directed movement-of both electrons and ions must be fully suppressed. (3) Since electrons and ions have both mass and charge, any non-inertial motion would result in electromagnetic radiation and energy dissipation. Therefore, in the superconducting state, all carrier motion, including those mediated by phonons, must be prohibited.

Based on the above analysis, we recently proposed a novel superconducting mechanism within the framework of polyhedral quantum confinement and symmetry breaking [4]. This mechanism bypasses traditional complexities like electron pairing and coherent condensation. Here, the superconducting phase transition is triggered by symmetry breaking, which results from the collective small-displacement motion of electron Wigner crystals under an applied electric field. Our theoretical framework is robust and highly explanatory. It has successfully accounted for key experimental phenomena in both copper-based and iron-based high-temperature superconductors. Most recently, we've extended this theory to kagome superconductors, achieving outstanding predictive accuracy.

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Our model precisely depicts the 3D charge density wave (CDW) phases, phase shifts, double superconducting domes, star-of-David lattice distortions, and complex Fermi surface structures, all of which align remarkably well with experimental results across various material systems. The reviewers' critical comments are the most effective validation of our new paradigm. Through our detailed responses and counterarguments in this paper, readers will find that the so-called high-temperature superconductivity problem essentially boils down to a rather simple phenomenon: the propagation of lossless electromagnetic waves within superconductors.

RESPONSES TO THE REVIEWERS' COMMENTS

Dear Reviewer,

Thank you for your time and effort in reviewing my manuscript titled **"Visualized high-Tc superconducting mechanism of polyhedral quantum wells confined electrons"**. The feedback provided has been carefully considered and is deeply appreciated. As you are aware, thirty-nine years have passed since the discovery of high-temperature superconductivity. Despite countless theoretical and experimental studies published to date, the mechanism of superconductivity remains unresolved. This persistent uncertainty underscores a fundamental flaw in the existing theoretical paradigm. Authors, reviewers, editors, and readers alike are eagerly anticipating the emergence of a new superconducting theory that transcends the limitations of the current framework. The submitted work represents a bold and innovative step in this direction.

The proposed theory has already demonstrated its effectiveness in explaining the experimental phenomena of copper-based and iron-based superconductors. Recently, it was extended to the kagome superconductor series, and encouragingly, all theoretical predictions align perfectly with the experimental results. This response aims to address and clarify the issues raised, and it is believed that through the exchange and discussion of differing academic perspectives, mutual understanding can be fostered, and research progress in high-temperature superconductivity can be jointly advanced.

Through this response, you may be surprised to discover that the so-called high-temperature superconductivity problem is, in fact, a remarkably simple issue of lossless electromagnetic wave propagation within superconductors. In other words, the entire field of research on strongly correlated high-temperature superconductivity has entered a dead end, and now is the time to choose a new path forward. Below, the comments are addressed point by point.

Reviewer's Question 1: *The paper lacks rigorous theoretical calculations and that the arguments are based on qualitative descriptions and lattice structures alone.*

Response: In the study of strongly correlated high-temperature superconductivity, researchers have published over a hundred thousand papers on theoretical calculations. Despite their apparent rigor, these efforts have failed to resolve the fundamental mechanism of high-temperature superconductivity. This impasse prompts an intriguing question: If a creator exists, how would it design superconductivity? Clearly, such a creator would neither comprehend human-invented theories nor perform theoretical calculations. Instead, it might allow atoms to self-assemble into diverse lattice structures, thereby enabling a variety of superconducting behaviors. In essence, it is the lattice structure that ultimately determines the superconducting properties of materials.

Therefore, I argue that describing superconductivity based on lattice structures-rather than relying solely on theoretical calculations-is scientifically justified. This approach represents the key innovation of this work.

Reviewer's Question 2: *Given that high-T_c superconductors are strongly correlated systems, a simplistic real-space structure that does not take into account strong correlation interactions is insufficient.*

Response: Although high-temperature superconductors are strongly correlated systems, numerous theoretical models, such as the Hubbard model and RVB (resonating valence bond) theory [5], have incorporated strong correlation interactions. However, research to date has demonstrated that introducing strong correlations alone does not resolve the mechanism of high-temperature superconductivity. Clearly, the concept of strong correlation must be reconsidered and redefined. It is well known that the best conductors, such as gold, silver, and copper, are not superconductors, whereas ceramic materials, which are insulators in their parent state, exhibit the highest superconducting performance. Both disorder doping and pressure can enhance the superconducting transition temperature (T_c). These experimental facts suggest that strong correlation is closely linked to electron localization: the stronger the electron localization, the higher the T_c of the material. In this paper [4], we establish the following simple relationship:

$$\triangle \propto T_c = \frac{\lambda}{\xi^2}, \tag{1}$$

This equation explicitly illustrates the relationship between quantum well localization ξ, strong correlation coefficients λ, and T_c. It is remarkable that such a simple formula can accurately predict the highest superconducting transition temperatures for nearly all copper-based and iron-based superconducting materials. As you are well aware, no existing theory of superconductivity has been able to achieve this until now. These findings strongly support the inference that strong electron correlations are closely linked to strong electron localization. Consequently, the research presented here inherently incorporates strong correlation interactions.

Reviewer's Question 3: *Omitting consideration of the Fermi surfaces specific to the materials under discussion is a significant oversight.*

Response: In Chapter 4 (Fermi surface Sheets, abnormal T_c and d-wave symmetry in Bi2223) of my paper, I present a detailed investigation into the relationship between the Fermi surface and superconductivity within the Bi2223 system. Numerical calculations (Fig. 4b in the paper) reveal the existence of two distinct electronic states in the octahedral quantum wells of copper-based superconductors: a strongly correlated electronic state at the center, which facilitates super-

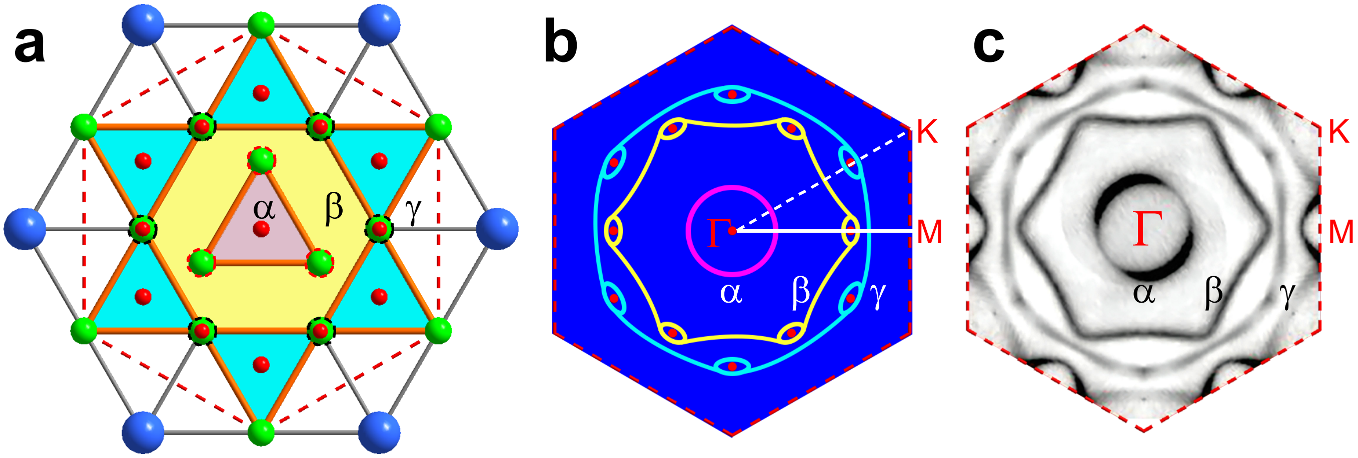

Figure 1. Local electronic states and Fermi surfaces of kagome superconductors. **a**, Holographic superposition of three kinds of local electronic states, which are the pink triangular state, the yellow hexagonal state and the cyan Star of David. **b**, The corresponding three sets of Fermi surface structures, **c**, The Fermi structure obtained through experiments in $CsTi_3Bi_5$ [6].

conductivity, and a normal electronic state along the diagonal direction of the copper-oxygen unit cell, which governs the Fermi surface structure and d-wave symmetry.

Within the proposed theoretical framework, the Fermi surface structures of copper-based, iron-based, and kagome superconductors can be directly and qualitatively derived from the symmetry of polyhedral quantum wells. Figure 1 shows the qualitative analysis results of the Fermi surface structure of the kagome superconductor. Based on the crystal structure, we have discovered that there are three types of polyhedral quantum well structures and corresponding localized electronic states in the kagome superconducting material. Fig. 1**a** presents the holographic superposition of these three localized electronic states, which are the triangular α-state, the hexagonal β-state, and the Star of David γ-state, respectively. Since each holographic electron contributes a segment of the Fermi arc or a Fermi pocket, we can qualitatively obtain the triple Fermi surface structure as shown in Fig. 1**b**, which agrees well with experimental observations (Fig. 1**c**).

It must be emphasized that the Fermi surface is not directly related to the superconducting mechanism; it merely reflects the intrinsic symmetry of the crystal structure. Attempting to discover the mechanism of high-T_c superconductivity through extensive and complex theories and experiments aimed at fermi surface has proven to be futile. This is one of the key conclusions reached in this study.

Reviewer's Question 4: *The depiction of insulating and metallic electrons localized within the octahedral quantum wells lacks both experimental backing and rigorous theoretical support.*

Response: I believe any superconductivity theory must adhere to the following **three fundamental principles**. Firstly, superconductivity represents a coherent quantum condensate state that incurs no energy loss, and thus, any theory of superconductivity must satisfy the principle of energy minimization. Secondly, as a thermodynamic system, superconductivity must abide by the fundamental tenets of thermodynamics. Thirdly, superconducting electrons, bearing the attribute of charge, must conform to the basic laws of electromagnetism. These three principles form the foundation and framework upon which the new theory of superconductivity is constructed.

To validate the reliability of the hypothesis regarding localized electrons in superconductivity, a comparison between the conventional and new paradigms is presented in Figure 2. As shown in Figure 2**a**, under the traditional electronic theory framework, current transport must rely on the directional movement of electrons, making the avoidance of electron-lattice collisions the core issue in superconductivity research. As shown in Figure 2**b**, the old theory posits that when $T < T_c$, electrons with opposite spins and momenta can form Cooper pairs through lattice vibrations (or other mediators) to achieve a superconducting condensate (with resistance $R = 0$). Figures 2**a-b** depict a dynamic scenario where electrons and ions are perpetually in motion. On one hand, from a thermodynamic perspective, the random motion of Cooper pairs inevitably results in diffusion and dispersion within the electronic system, rendering it inherently unstable and susceptible to energy dissipation. On the other hand, fundamental electromagnetic principles dictate that the non-inertial motion of electrons and ions must continuously radiate and lose electromagnetic energy. Clearly, the assumption that current I_e must be bound to moving electrons is fundamentally incompatible with the concept of lossless superconductivity.

Figures 2**c-d** illustrate the proposed static paradigm. Owing to the confinement effect of polyhedral quantum wells, when the temperature T is below the critical temperature T_c and in the absence of an external electric field, the immobilized electrons form a Wigner crystal, depicted by white circles in the figure. Under these conditions, the total capacitance ($C_x = C_{yz} = 0$) of the superconductor is zero, and the superconductor exhibits an insulating state. Fig. 2**c** portrays the metallic state, where an external electric field induces a collective displacement of electrons from their equilibrium

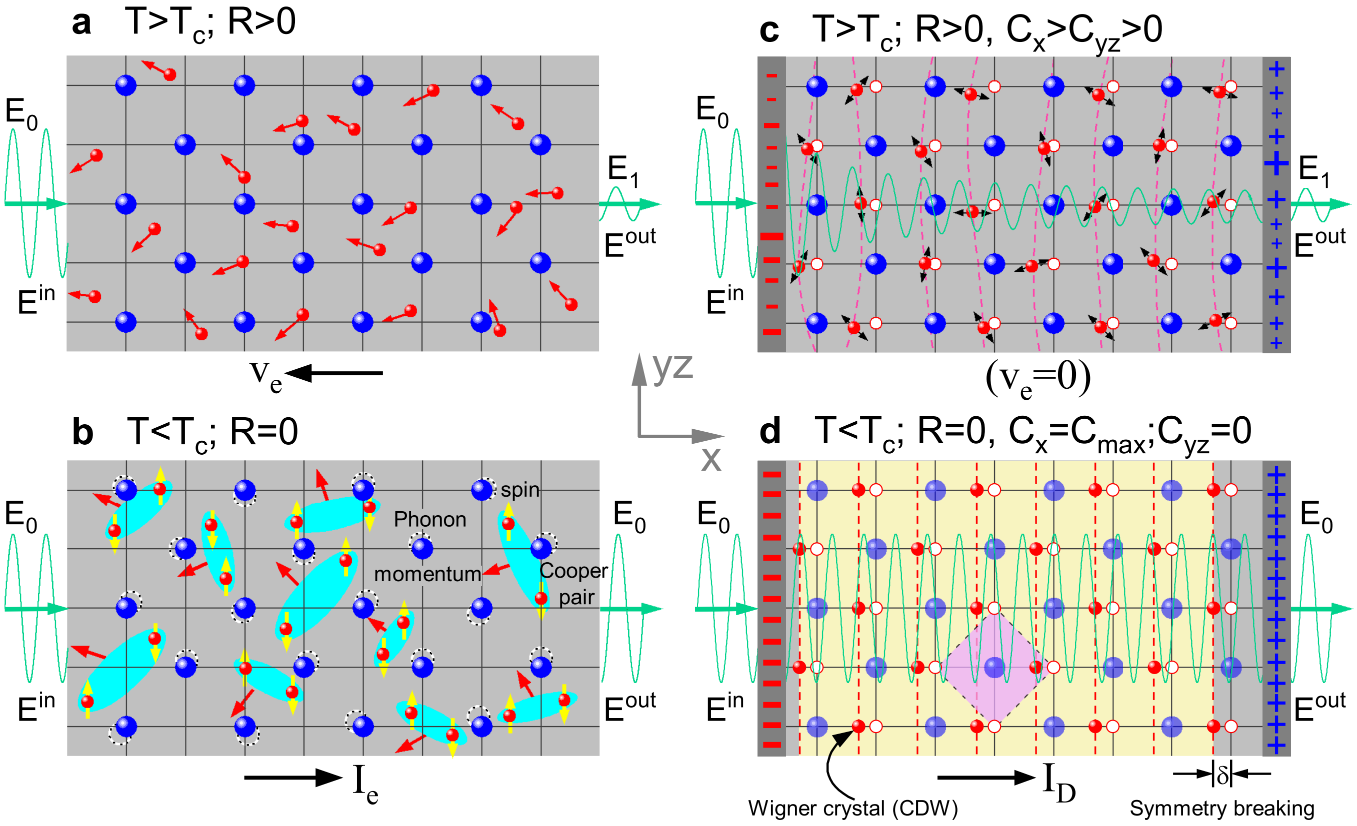

Figure 2. Comparison between the old paradigm and the new paradigm: Which one is more conducive to achieving superconductivity? **a-b**, Dynamic Paradigm (old): Whether in the metallic state of **a** or the superconducting state of **b**, electrons or Cooper pairs are required to perform perpetual long-range directional motion ($v_e > 0$). In Figure **b**, two electrons with disordered motion that repel each other due to like charges are required to pair up to achieve superconductivity. **c-d**, Static Paradigm (new): Whether it is the electric current of **c** or the superconducting current of **d**, there is no need for directional motion of electrons ($v_e = 0$). **c**, When $T > T_c$, the directional collective displacement caused by the electric field, superimposed with random thermal vibrations, results in temperature-dependent polarized charges at the ends of the superconductor, which is equivalent to forming a variable capacitor. **d**, When $T < T_c$, random thermal vibrations are completely suppressed, and the external field causes the collective displacement (δ) of electrons and the transition from the insulating state to the superconducting state due to symmetry breaking. Stable polarized charges and capacitance are formed at the ends of the superconductor, ensuring the lossless propagation of electromagnetic field energy. Note the magenta unit cell: Unlike the electron-electron pairing mediated by phonons or other quasiparticles in **b**, here it can be considered that electrons and ions pair through Coulomb attraction without the need for any additional quasiparticles.

positions, generating capacitance C_x and displacement current I_D. Simultaneously, thermal perturbations cause random electron displacements in the perpendicular direction, represented by capacitance C_{yz}, which introduces resistance R and I_D, in this case, the output electric field strength E^{out} is less than the input electric field strength E^{in}, indicating energy loss due to resistance. When $T < T_c$, the thermal motion of electrons is entirely suppressed, leading to $C_{yz} = 0$ and $R = 0$. At this point, the directional capacitance C_x reaches its maximum value, and the output electric field strength E^{out} is equal to the input electric field strength E^{in}, signifying a lossless transmission process within the superconductor.

The fundamental distinction between the old and new paradigms lies in the definition of current. The old paradigm necessitates continuous directional movement (v_e) of charge carriers (electrons), whereas the new paradigm requires only a minute displacement δ of electrons to establish directional capacitance and open an electromagnetic channel. As illustrated by the magenta unit cell in Fig. 2**d**, the essence of superconducting coherent condensation lies in the indistinguishability of electronic states, which similarly necessitates that electrons remain static.

In the era of ubiquitous wireless communication, it is an incontrovertible fact that current (electromagnetic field energy) can propagate independently at the speed of light without relying on electron movement, a phenomenon fundamentally elucidated by Maxwell's displacement current. This provides robust experimental and theoretical support for the new paradigm.

CONCLUSION

The BCS theory of superconductivity and the Cooper pair hypothesis, which start from free electrons, are incorrect. This is because they violate the principle of minimum energy, as well as the fundamental laws of thermodynamics and electromagnetism. A new theory centered around localized electrons in quantum wells has been established. Through a simple mechanism of symmetry breaking induced by an external field, this theory has successfully explained and predicted almost all the key experimental phenomena of unconventional superconducting materials. We have elucidated that the issue of superconductivity is not a complex problem of electron transport, but rather a simple matter of the lossless propagation of electromagnetic waves. The essence of the supercurrent is Maxwell's displacement current, rendering the concepts of perpetual electron motion, electron pairing, and the so-called quasiparticle "glue" unnecessary. The research on high-temperature superconductivity has been stagnant for decades. The crux of the matter lies in the academic community's blind trust in authorities and its superstition about Nobel Prize-winning achievements. From the examples presented in this paper, it is evident that peer review has become the greatest obstacle to scientific progress. As the author, I hope that editors and reviewers will adopt a more open attitude to foster and support scientific innovation.

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