Garden-Variety Iron-Based Superconductor

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Important challenges in creating practical quantum computers have been addressed by two independent teams of physicists in the US. [28]

Physicists have shown that superconducting circuits—circuits that have zero electrical resistance—can function as piston-like mechanical quantum engines. The new perspective may help researchers design quantum computers and other devices with improved efficiencies. [27]

This paper explains the magnetic effect of the superconductive current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories.

The changing acceleration of the electrons explains the created negative electric field of the magnetic induction, the Higgs Field, the changing Relativistic Mass and the Gravitational Force, giving a Unified Theory of the physical forces. Taking into account the Planck Distribution Law of the electromagnetic oscillators also, we can explain the electron/proton mass rate and the Weak and Strong Interactions.

Since the superconductivity is basically a quantum mechanical phenomenon and some entangled particles give this opportunity to specific matters, like Cooper Pairs or other entanglements, as strongly correlated materials and Exciton-mediated electron pairing, we can say that the secret of superconductivity is the quantum entanglement.

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Author: George Rajna

The Quest of Superconductivity

Superconductivity seems to contradict the theory of accelerating charges in the static electric current, caused by the electric force as a result of the electric potential difference, since a closed circle wire no potential difference at all. [1]

On the other hand the electron in the atom also moving in a circle around the proton with a constant velocity and constant impulse momentum with a constant magnetic field. This gives the idea of the centripetal acceleration of the moving charge in the closed circle wire as this is the case in the atomic electron attracted by the proton. Because of this we can think about superconductivity as a quantum phenomenon. [2]

Experiences and Theories

Iron selenide revealed as 'garden-variety iron-based superconductor'

In the pantheon of unconventional superconductors, iron selenide is a rock star. But new experiments by U.S., Chinese and European physicists have found the material's magnetic persona to be unexpectedly mundane.

Rice University physicist Pengcheng Dai, corresponding author of a study of the results published online this week in *Nature Materials*, offered this bottom-line assessment of ironselenide: "It's a garden-variety iron-based superconductor. The fundamental physics of superconductivity are similar to what we find in all the other iron-based superconductors."

That conclusion is based on data from neutron scattering experiments performed over the past year in the U.S., Germany and the United Kingdom. The experiments produced the first measurements of the dynamic magnetic properties of iron selenide crystals that had undergone a characteristic structural shift that occurs as the material is cooled but before it is cooled to the point of superconductivity.

"Iron selenide is completely different from all the other iron-based superconductors in several ways," said Dai, a professor of physics and astronomy at Rice and a member of Rice's Center for Quantum Materials (RCQM). "It has the simplest structure, being composed of only two elements. All the others have at least three elements and much more complicated structure. Iron selenide is also the only one that has no magnetic order and no parent compound."

Dozens of iron-based superconductors have been discovered since 2008. In each, the iron atoms form a 2-D sheet that's sandwiched between top and bottom sheets made up of other elements. In the case of iron selenide, the top and bottom sheets are pure selenium, but in other materials these sheets are made of two or more elements. In iron selenide and other iron-based superconductors, iron atoms in the central 2-D sheet are spaced in checkerboard fashion, exactly the same distance from one another in both the left-right direction and forward-back directions.

As the materials cool, they undergo a slight structural shift. Instead of exact squares, the iron atoms form oblong rhombuses. These are like baseball diamonds, where the distance between home plate and second base is shorter than the distance between first and third base. And this change between iron atoms causes the iron-based superconductors to exhibit directionally-dependent behavior, like increased electrical resistance or conductivity only in the direction of home-to-second or first-to-third.

Graduate student Tong Chen spent weeks creating samples to test in neutron scattering beams. About 20 to 30 1-millimeter squares of iron selenide had to be aligned and glued in place atop each crystal of barium iron arsenide. Credit: Jeff Fitlow/Rice University

Physicists refer to this directionally dependent behavior as anisotropy or nematicity, and while structural nematicity is known to occur in iron selenide, Dai said it has been impossible to measure the exact electronic and magnetic order of the material because of a property known as twinning. Twinning occurs when layers of randomly oriented 2-D crystals are stacked. Imagine 100 baseball diamonds stacked one atop the other, with the line between home plate and second base varying randomly for each.

"Even if there is directionally dependent electronic order in a twinned sample, you cannot measure it because those differences average out and you wind up measuring a net effect of zero," Dai said. "We had to detwin samples of iron selenide to see if there was nematic electronic order."

Study lead author Tong Chen, a third-year Ph.D. student in Dai's research group, solved the twinning problem by cleverly piggybacking on a 2014 study in which Dai and colleagues applied pressure to detwin crystals of barium iron arsenide. It was impossible to apply the same method to iron selenide because the crystals were 100 times smaller, so Chen glued the smaller crystals atop the larger ones, reasoning that the pressure needed to align the larger sample would also cause the layers of iron selenide to snap into alignment.

Chen spent weeks creating several samples to test in neutron scattering beams. About 20 to 30 1-millimeter squares of iron selenide had to be aligned and placed atop each crystal of barium iron arsenide. And applying each of the tiny squares was painstaking work that involved a microscope, tweezers and special, hydrogen-free glue that cost almost $1,000 per ounce.

The work paid off when Chen tested the samples and found the iron selenide was detwinned. Those tests with neutron scattering beams at Oak Ridge National Laboratory, the National Institute of Standards and Technology, the Technical University of Munich and U.K.'s Rutherford-Appleton Laboratory also showed iron selenide's electronic behavior is very similar to that of other iron superconductors.

"The key conclusion is that the magnetic correlations that are associated with superconductivity in iron selenide are highly anisotropic, just as they are in other iron superconductors," Dai said. "That has been a very controversial point, because iron selenide, unlike all other iron-based superconductors, does not have a parent compound that exhibits antiferromagnetic order, which has led some to suggest that superconductivity arose in iron selenide in a completely different way than it arises in these others. Our results suggest that is not the case. You don't need an entirely new method to understand it." [30]

A new iron-based superconductor stabilized by inter-block charger transfer

Iron-based superconductors (IBSCs) have attracted sustained research attention over the past decade, partly because new IBSCs were discovered one after another in the earlier years. At present, however, exploration of IBSCs becomes more and more challenging. A research team from Zhejiang University developed a structural design strategy for exploration from which they succeeded in finding a series of hole-doped IBSCs with double FeAs layers in recent years. Nevertheless, the electron-doped analogue has not been realized until now.

The newly discovered electron-doped IBSC is $BaTh_2Fe_4As_4(N_{0.7}O_{0.3})_2$, an intergrowth compound of un-doped $BaFe_2As_2$ and electron-doped $ThFeAsN_{0.7}O_{0.3}$ (see the inset of Figure 1). The new superconductor could be synthesized only when nitrogen is partially replaced with oxygen as in the case of $BaTh_2Fe_4As_4(N_{0.7}O_{0.3})_2$.

Namely, the oxygen-free phase, $BaTh_2Fe_4As_4N_2$, could not be prepared due to lattice matching. The realized synthetic process is actually a redox reaction, $BaFe_2As_2 + 2ThFeAsN_{0.7}O_{0.3} = BaTh_2Fe_4As_4(N_{0.7}O_{0.3})_2$, which indicates an essential role of inter-block charge transfer for stabilizing the intergrowth structure. Note that, while both the constituent structural blocks share identical iron atoms, they contain crystallographically different arsenic atoms, as a consequence of the charge transfer.

Although the new superconductor is isostructural to the previous "12442-type" ones, it shows contrasting structural and physical properties. First, the structural details in the FeAs layers are different from those of hole-doped 12442-type IBSCs, but similar to most electron-doped IBSCs. Second, the Hall-effect measurement shows negative Hall coefficient in the whole temperature range, and the Hall coefficient values are consistent with the electron doping level due to the oxygen substitution. Third, the superconducting properties such as the upper critical fields and specific-heat jump are close to most electron-doped IBSCs.

The onset resistive transition temperature of the new double-FeAs-layer IBSC is 30 K, and the zero-resistance temperature is 22 K. Correspondingly, the magnetic susceptibility and specific-heat data suggest two transitions, and the bulk superconductivity appears at 22 K. The result is in contrast with the single-FeAs-layer counterpart, $ThFeAsN_{0.85}O_{0.15}$, with the same doping level. The latter does not show superconductivity above1.8 K.

The essential role of inter-block charge transfer demonstrated seems to be insightful, which could be helpful for the exploration of broader layered materials beyond the layered IBSCs. [29]

Superconducting and diamond qubits get a boost

Important challenges in creating practical quantum computers have been addressed by two independent teams of physicists in the US. One team has created a new way of reading-out superconducting quantum bits (qubits), while the other has come-up with a new way to get spin qubits in diamond to interact with each other.

Any viable quantum computer needs isolated quantum states that can store qubits of information for relatively long periods of time. It must also be possible for these qubits to interact with each other at appropriate times so that the information can be processed and the results read-out. It is these often-conflicting requirements that made it very difficult to create a practical quantum computer

In one of two papers published in *Science*, Robert McDermott of University of Wisconsin-Madison and colleagues in Wisconsin and New York describe a new detector for reading-out superconducting qubits. These qubits are superconducting circuits containing Josephson junctions that are cooled to millikelvin temperatures and function as quantized oscillators. The qubit can be switched between two quantum states by a photon at the oscillator's resonant frequency. The circuits also interact strongly to process information.

Complicated measurement

However, reading a qubit's state is difficult because it involves coupling the oscillator to a resonant cavity. "If the qubit is in the ground state, you've got a cavity resonance at one frequency; if it's in the excited state you've got a cavity resonance at a different frequency," explains McDermott. Reading the state can therefore be done by measuring the cavity resonance, which involves probing the cavity with microwaves and detecting the phase of the reflected or transmitted waves. This requires low noise amplifiers and separate circuitry at both cryogenic and room temperatures – making it impractical for scaling-up in a practical quantum computer.

Instead, the group coupled the qubit's resonant cavity to a second cavity connected to another Josephson junction with two easily-distinguishable states: a metastable state loaded with photons and an empty ground state. If the qubit is in one specific state, the photons remain trapped in the metastable state. However, if the qubit is in the other state, the photons will tunnel immediately to the ground state.

"It's a very simple circuit," says McDermott. The researchers detected the qubit states with a fidelity of 92%. They are confident that, with optimization, they can get to over 99%. While other qubit technologies can also reach this fidelity, McDermott's qubits could be easier to scale-up to create a practical quantum computer.

Diamond vacancies

In a second paper in *Science*, Mikhail Lukin and colleagues at Harvard University used two silicon-vacancy centres (SiVs) in diamond as two qubits. A SiV occurs when two neighbouring carbon atoms in the diamond lattice are replaced by one silicon atom. The spin of the SiV makes a good qubit because it is isolated from electrical noise yet interacts with light at certain frequencies.

The challenge is getting SiVs to interact with each other. The team placed two SiVs in an optical cavity, which dramatically increases the probability that they would interact: "The two SiVs are a bit like two people in a dark room trying to send Morse code signals to each other using dim flashlights," explains Harvard's Ruffin Evans, "If you form a cavity by placing mirrors back-to-back on each wall, the light bounces back and forth and gives the people many more chances to see the signal." When tuned into resonance at the same frequency, states from the two silicon vacancy centre states were mixed by the interaction to form a super-radiant "bright" state and a non-radiant "dark" state.

Creating two interacting qubits is not new and other researchers have gone further and created working quantum-logic gates using different qubit technologies. Evans explains, "The novelty of our work is that, even though the interaction between light and matter is normally very weak, we've still been able to create an interaction between these two silicon vacancy centres using light. The next step is to harness this interaction to create a real quantum gate." Such a device system should lend itself naturally to the creation of a "quantum internet" that uses photon-based qubits sent long distances through fibre optic cables.

"Beautiful scheme"

Barry Sanders of the University of Calgary in Canada told *Physics World* that both teams' research is significant – but for different reasons. He believes the McDermott group's work has clear potential for direct application to quantum computation if the measurement fidelity can be increased. "Superconducting circuits are generally regarded as the most promising direction towards making scaleable quantum computing, but a big drawback has always been the lack of single photon detection," he says. "This is a beautiful scheme and it looks scaleable to me."

The relevance of Lukin group's work to quantum computation is less clear but it may have unforeseen applications. Sanders says, "For a long time, we've got away with treating multi-atom systems as a single atom with an effective background. When we get to phenomena like super- and sub-radiance, we're talking about two-body effects with atoms sharing photons between them. These guys have done everything just right that they're able to tune into and out of this collective behaviour. It's a huge challenge in fabrication and control and their results are convincing and elegant." [28]

Superconducting qubits can function as quantum engines

Physicists have shown that superconducting circuits—circuits that have zero electrical resistance—can function as piston-like mechanical quantum engines. The new perspective may help researchers design quantum computers and other devices with improved efficiencies.

The physicists, Kewin Sachtleben, Kahio T. Mazon, and Luis G. C. Rego at the Federal University of Santa Catarina in Florianópolis, Brazil, have published a paper on their work on superconducting qubits in a recent issue of Physical Review Letters.

In their study, the physicists explain that superconducting circuits are functionally equivalent to quantum systems in which quantum particles tunnel in a double-quantum well. These wells have the ability to oscillate, meaning the width of the well changes repeatedly. When this happens, the system behaves somewhat like a piston that moves up and down in a cylinder, which changes the volume of the cylinder. This oscillatory behavior allows work to be performed on the system. The researchers show that, in the double-quantum well, part of this work comes from quantum coherent dynamics, which creates friction that decreases the work output. These results provide a better understanding of the connection between quantum and classical thermodynamic work.

"The distinction between 'classical' thermodynamic work, responsible for population transfer, and a quantum component, responsible for creating coherences, is an important result," Mazon told Phys.org. "The creation of coherences, in turn, generates a similar effect to friction, causing a notcompletely-reversible operation of the engine. In our work we have been able to calculate the reaction force caused on the quantum piston wall due to the creation of coherences. In principle this force can be measured, thus constituting the experimental possibility of observing the emergence of coherences during the operation of the quantum engine."

One of the potential benefits of viewing superconducting qubits as quantum engines is that it may allow researchers to incorporate quantum coherent dynamics into future technologies, in particular quantum computers. The physicists explain that a similar behavior can be seen in nature, where quantum coherences improve the efficiency of processes such as photosynthesis, light sensing, and other natural processes.

"Quantum machines may have applications in the field of quantum information, where the energy of quantum coherences is used to perform information manipulation in the quantum regime," Mazon said. "It is worth remembering that even photosynthesis can be described according to the working principles of a quantum machine, so unraveling the mysteries of quantum thermodynamics can help us to better understand and interpret various natural processes." [27]

Conventional superconductivity

Conventional superconductivity can be explained by a theory developed by Bardeen, Cooper and Schrieffer (BCS) in 1957. In BCS theory, electrons in a superconductor combine to form pairs, called Cooper pairs, which are able to move through the crystal lattice without resistance when an electric voltage is applied. Even when the voltage is removed, the current continues to flow indefinitely, the most remarkable property of superconductivity, and one that explains the keen interest in their technological potential. [3]

High-temperature superconductivity

In 1986, high-temperature superconductivity was discovered (i.e. superconductivity at temperatures considerably above the previous limit of about 30 K; up to about 130 K). It is believed that BCS theory alone cannot explain this phenomenon and that other effects are at play. These effects are still not yet fully understood; it is possible that they even control superconductivity at low temperatures for some materials. [8]

Superconductivity and magnetic fields

Superconductivity and magnetic fields are normally seen as rivals – very strong magnetic fields normally destroy the superconducting state. Physicists at the Paul Scherer Institute have now demonstrated that a novel superconducting state is only created in the material $CeCoIn_5$ when there are strong external magnetic fields. This state can then be manipulated by modifying the field direction. The material is already superconducting in weaker fields, too. In strong fields, however, an additional second superconducting state is created which means that there are two different superconducting states at the same time in the same material. The new state is coupled with an anti-ferromagnetic order that appears simultaneously with the field. The anti-ferromagnetic order from whose properties the researchers have deduced the existence of the superconducting state was detected with neutrons at PSI and at the Institute Laue-Langevin in Grenoble. [6]

Room-temperature superconductivity

After more than twenty years of intensive research the origin of high-temperature superconductivity is still not clear, but it seems that instead of *electron-phonon* attraction mechanisms, as in conventional superconductivity, one is dealing with genuine *electronic* mechanisms (e.g. by antiferromagnetic correlations), and instead of s-wave pairing, d-waves are substantial. One goal of all this research is room-temperature superconductivity. [9]

Exciton-mediated electron pairing

Theoretical work by Neil Ashcroft predicted that solid metallic hydrogen at extremely high pressure (~500 GPa) should become superconducting at approximately room-temperature because of its extremely high speed of sound and expected strong coupling between the conduction electrons and the lattice vibrations (phonons). This prediction is yet to be experimentally verified, as yet the pressure to achieve metallic hydrogen is not known but may be of the order of 500 GPa. In 1964, William A. Little proposed the possibility of high temperature superconductivity in organic polymers. This proposal is based on the exciton-mediated electron pairing, as opposed to phonon-mediated pairing in BCS theory. [9]

Resonating valence bond theory

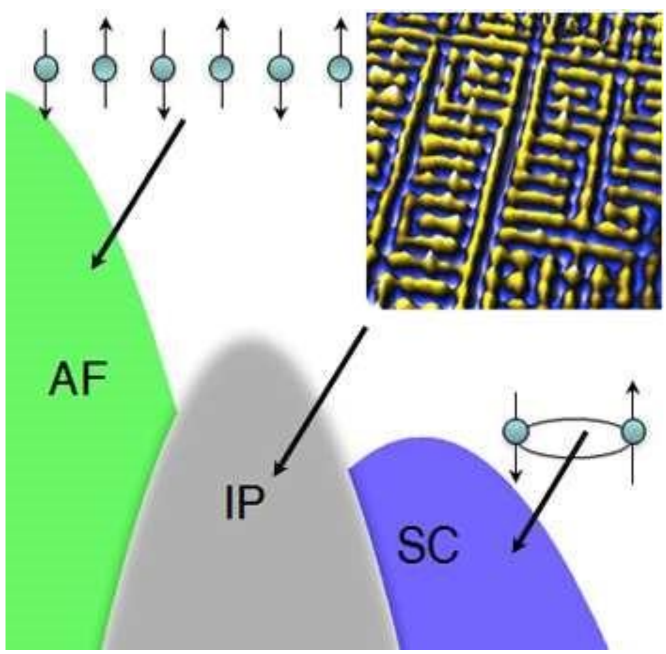
In condensed matter physics, the resonating valence bond theory (RVB) is a theoretical model that attempts to describe high temperature superconductivity, and in particular the superconductivity in cuprate compounds. It was first proposed by American physicist P. W. Anderson and the Indian theoretical physicist Ganapathy Baskaran in 1987. The theory states that in copper oxide lattices, electrons from neighboring copper atoms interact to form a valence bond, which locks them in place. However, with doping, these electrons can act as mobile Cooper pairs and are able to superconduct. Anderson observed in his 1987 paper that the origins of superconductivity in doped cuprates was in the Mott insulator nature of crystalline copper oxide. RVB builds on the Hubbard and t-J models used in the study of strongly correlated materials. [10]

Strongly correlated materials

Strongly correlated materials are a wide class of electronic materials that show unusual (often technologically useful) electronic and magnetic properties, such as metal-insulator transitions or half-metallicity. The essential feature that defines these materials is that the behavior of their electrons cannot be described effectively in terms of non-interacting entities. Theoretical models of the electronic structure of strongly correlated materials must include electronic correlation to be accurate. Many transition metal oxides belong into this class which may be subdivided according to their behavior, *e.g.* high-T_c, spintronic materials, Mott insulators, spin Peierls materials, heavy fermion materials, quasi-low-dimensional materials, etc. The single most intensively studied effect is probably high-temperature superconductivity in doped cuprates, e.g. $La_{2-x}Sr_xCuO_4$. Other ordering or magnetic phenomena and temperature-induced phase transitions in many transition-metal oxides are also gathered under the term "strongly correlated materials." Typically, strongly correlated materials have incompletely filled *d*- or *f*-electron shells with narrow energy bands. One can no longer consider any electron in the material as being in a "sea" of the averaged motion of the others (also known as mean field theory). Each single electron has a complex influence on its neighbors.
[11]

New superconductor theory may revolutionize electrical engineering

High-temperature superconductors exhibit a frustratingly varied catalog of odd behavior, such as electrons that arrange themselves into stripes or refuse to arrange themselves symmetrically around atoms. Now two physicists propose that such behaviors – and superconductivity itself – can all be traced to a single starting point, and they explain why there are so many variations.



An "antiferromagnetic" state, where the magnetic moments of electrons are opposed, can lead to a variety of unexpected arrangements of electrons in a high-temperature superconductor, then finally to the formation of "Cooper pairs" that conduct without resistance, according to a new theory. [22]

Unconventional superconductivity in $Ba^{0.6}K^{0.4}Fe^{2}As^{2}$ from inelastic neutron scattering

In BCS superconductors, the energy gap between the superconducting and normal electronic states is constant, but in unconventional superconductors the gap varies with the direction the electrons are moving. In some directions, the gap may be zero. The puzzle is that the gap does not seem to vary with direction in the iron arsenides. Theorists have argued that, while the size of the gap shows no directional dependence in these new compounds, the sign of the gap is opposite for different electronic states. The standard techniques to measure the gap, such as photoemission, are not sensitive to this change in sign.

But inelastic neutron scattering is sensitive. Osborn, along with Argonne physicist Stephan Rosenkranz, led an international collaboration to perform neutron experiments using samples of the new compounds made in Argonne's Materials Science Division, and discovered a magnetic excitation in the superconducting state that can only exist if the energy gap changes sign from one electron orbital to another.

"Our results suggest that the mechanism that makes electrons pair together could be provided by antiferromagnetic fluctuations rather than lattice vibrations," Rosenkranz said. "It certainly gives direct evidence that the superconductivity is unconventional."

Inelastic neutron scattering continues to be an important tool in identifying unconventional superconductivity, not only in the iron arsenides, but also in new families of superconductors that may be discovered in the future. [23]

A grand unified theory of exotic superconductivity?

The role of magnetism

In all known types of high-Tc superconductors—copper-based (cuprate), iron-based, and so-called heavy fermion compounds—superconductivity emerges from the "extinction" of antiferromagnetism, the ordered arrangement of electrons on adjacent atoms having anti-aligned spin directions. Electrons arrayed like tiny magnets in this alternating spin pattern are at their lowest energy state, but this antiferromagnetic order is not beneficial to superconductivity.

However if the interactions between electrons that cause antiferromagnetic order can be maintained while the actual order itself is prevented, then superconductivity can appear. "In this situation, whenever one electron approaches another electron, it tries to anti-align its magnetic state," Davis said. Even if the electrons never achieve antiferromagnetic order, these antiferromagnetic interactions exert the dominant influence on the behavior of the material. "This antiferromagnetic influence is universal across all these types of materials," Davis said.

Many scientists have proposed that these antiferromagnetic interactions play a role in the ability of electrons to eventually pair up with anti-aligned spins—a condition necessary for them to carry current with no resistance. The complicating factor has been the existence of many different types of "intertwined" electronic phases that also emerge in the different types of high-Tc superconductors—sometimes appearing to compete with superconductivity and sometimes coexisting with it. [24]

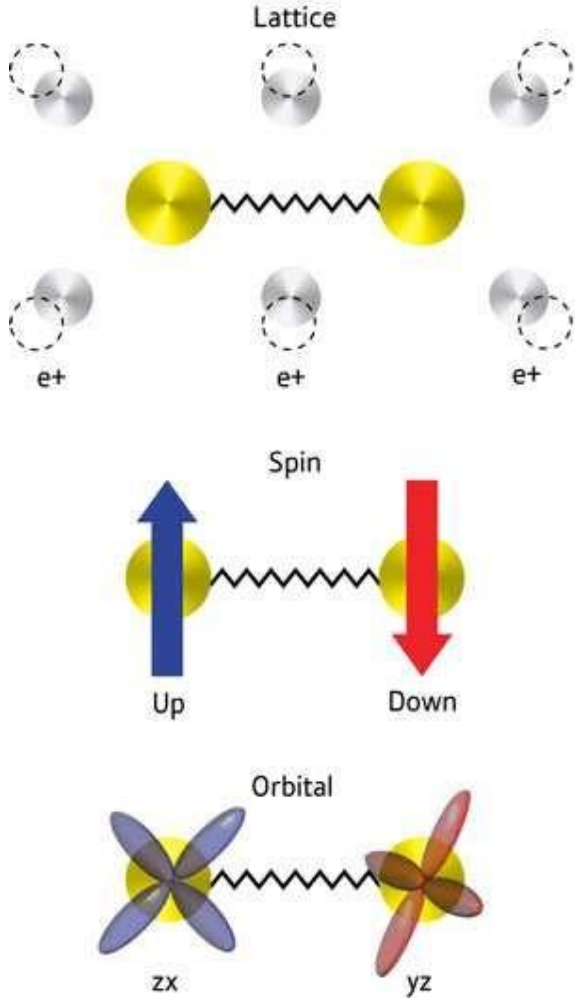
Concepts relating magnetic interactions, intertwined electronic orders, and strongly correlated superconductivity

Unconventional superconductivity (SC) is said to occur when Cooper pair formation is dominated by repulsive electron–electron interactions, so that the symmetry of the pair wave function is other than an isotropic s-wave. The strong, on-site, repulsive electron–electron interactions that are the proximate cause of such SC are more typically drivers of commensurate magnetism. Indeed, it is the suppression of commensurate antiferromagnetism (AF) that usually allows this type of unconventional superconductivity to emerge. Importantly, however, intervening between these AF and SC phases, intertwined electronic ordered phases (IP) of an unexpected nature are frequently discovered. For this reason, it has been extremely difficult to distinguish the microscopic essence of the correlated superconductivity from the often spectacular phenomenology of the IPs. Here we introduce a model conceptual framework within which to understand the relationship between AF electron–electron interactions, IPs, and correlated SC. We demonstrate its effectiveness in simultaneously explaining the consequences of AF interactions for the copper-based, iron-based, and heavy-fermion superconductors, as well as for their quite distinct IPs.

Significance

This study describes a unified theory explaining the rich ordering phenomena, each associated with a different symmetry breaking, that often accompany high-temperature superconductivity. The essence of this theory is an ”antiferromagnetic interaction,” the interaction that favors the development of magnetic order where the magnetic moments reverse direction from one crystal unit cell to the next. We apply this theory to explain the superconductivity, as well as all observed accompanying ordering phenomena in the copper-oxide superconductors, the iron-based superconductors, and the heavy fermion superconductors. [25]

Superconductivity's third side unmasked



Shimojima and colleagues were surprised to discover that interactions between electron spins do not cause the electrons to form Cooper pairs in the pnictides. Instead, the coupling is mediated by the electron clouds surrounding the atomic cores. Some of these so-called orbitals have the same energy, which causes interactions and electron fluctuations that are sufficiently strong to mediate superconductivity.

This could spur the discovery of new superconductors based on this mechanism. “Our work establishes the electron orbitals as a third kind of pairing glue for electron pairs in superconductors, next to lattice vibrations and electron spins,” explains Shimojima. “We believe that this finding is a step towards the dream of achieving room-temperature superconductivity,” he concludes. [17]

Strongly correlated materials

Strongly correlated materials give us the idea of diffraction patterns explaining the electron-proton mass rate. [13]

This explains the theories relating the superconductivity with the strong interaction. [14]

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing. We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. [18] One of these new matter formulas is the superconducting matter.

Higgs Field and Superconductivity

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The specific spontaneous symmetry breaking of the underlying local symmetry, which is similar to that one appearing in the theory of superconductivity, triggers conversion of the longitudinal field component to the Higgs boson, which interacts with itself and (at least of part of) the other fields in the theory, so as to produce mass terms for the above-mentioned three gauge bosons, and also to the above-mentioned fermions (see below). [16]

The Higgs mechanism occurs whenever a charged field has a vacuum expectation value. In the nonrelativistic context, this is the Landau model of a charged Bose–Einstein condensate, also known as a superconductor. In the relativistic condensate, the condensate is a scalar field, and is relativistically invariant.

The Higgs mechanism is a type of superconductivity which occurs in the vacuum. It occurs when all of space is filled with a sea of particles which are charged, or, in field language, when a charged field has a nonzero vacuum expectation value. Interaction with the quantum fluid filling the space prevents certain forces from propagating over long distances (as it does in a superconducting medium; e.g., in the Ginzburg–Landau theory).

A superconductor expels all magnetic fields from its interior, a phenomenon known as the Meissner effect. This was mysterious for a long time, because it implies that electromagnetic forces somehow become short-range inside the superconductor. Contrast this with the behavior of an ordinary metal. In a metal, the conductivity shields electric fields by rearranging charges on the surface until the total field cancels in the interior. But magnetic fields can penetrate to any distance, and if a magnetic monopole (an isolated magnetic pole) is surrounded by a metal the field can escape without collimating into a string. In a superconductor, however, electric charges move with no dissipation, and this allows for permanent surface currents, not just surface charges. When magnetic fields are introduced at the boundary of a superconductor, they produce surface currents which exactly neutralize them. The Meissner effect is due to currents in a thin surface layer, whose thickness, the London penetration depth, can be calculated from a simple model (the Ginzburg–Landau theory).

This simple model treats superconductivity as a charged Bose–Einstein condensate. Suppose that a superconductor contains bosons with charge q. The wavefunction of the bosons can be described by introducing a quantum field, ψ, which obeys the Schrödinger equation as a field equation (in units where the reduced Planck constant, $\hbar$, is set to 1):

$$i\frac{\partial}{\partial t}\psi = \frac{(\nabla - iqA)^2}{2m}\psi.$$

The operator $\psi(x)$ annihilates a boson at the point x, while its adjoint $\psi^\dagger$ creates a new boson at the same point. The wavefunction of the Bose–Einstein condensate is then the expectation value ψ of $\psi(x)$, which is a classical function that obeys the same equation. The interpretation of the expectation value is that it is the phase that one should give to a newly created boson so that it will coherently superpose with all the other bosons already in the condensate.

When there is a charged condensate, the electromagnetic interactions are screened. To see this, consider the effect of a gauge transformation on the field. A gauge transformation rotates the phase of the condensate by an amount which changes from point to point, and shifts the vector potential by a gradient:

$$\psi \rightarrow e^{iq\phi(x)}\psi$$

$$A \rightarrow A + \nabla\phi.$$

When there is no condensate, this transformation only changes the definition of the phase of ψ at every point. But when there is a condensate, the phase of the condensate defines a preferred choice of phase.

The condensate wave function can be written as

$$\psi(x) = \rho(x)\, e^{i\theta(x)},$$

where ρ is real amplitude, which determines the local density of the condensate. If the condensate were neutral, the flow would be along the gradients of θ, the direction in which the phase of the Schrödinger field changes. If the phase θ changes slowly, the flow is slow and has very little energy. But now θ can be made equal to zero just by making a gauge transformation to rotate the phase of the field.

The energy of slow changes of phase can be calculated from the Schrödinger kinetic energy,

$$H = \frac{1}{2m}|(qA + \nabla)\psi|^2,$$

and taking the density of the condensate ρ to be constant,

$$H \approx \frac{\rho^2}{2m}(qA + \nabla\theta)^2.$$

Fixing the choice of gauge so that the condensate has the same phase everywhere, the electromagnetic field energy has an extra term,

$$\frac{q^2\rho^2}{2m}A^2.$$

When this term is present, electromagnetic interactions become short-ranged. Every field mode, no matter how long the wavelength, oscillates with a nonzero frequency. The lowest frequency can be read off from the energy of a long wavelength A mode,

$$E \approx \frac{\dot{A}^2}{2} + \frac{q^2\rho^2}{2m}A^2.$$

This is a harmonic oscillator with frequency

$$\sqrt{\frac{1}{m}q^2\rho^2}.$$

The quantity $|\psi|^2$ ($=\rho^2$) is the density of the condensate of superconducting particles.

In an actual superconductor, the charged particles are electrons, which are fermions not bosons. So in order to have superconductivity, the electrons need to somehow bind into Cooper pairs. [12]

The charge of the condensate *q* is therefore twice the electron charge *e*. The pairing in a normal superconductor is due to lattice vibrations, and is in fact very weak; this means that the pairs are very loosely bound. The description of a Bose–Einstein condensate of loosely bound pairs is actually more difficult than the description of a condensate of elementary particles, and was only worked out in 1957 by Bardeen, Cooper and Schrieffer in the famous BCS theory. [3]

Superconductivity and Quantum Entanglement

We have seen that the superconductivity is basically a quantum mechanical phenomenon and some entangled particles give this opportunity to specific matters, like Cooper Pairs or other entanglements, as strongly correlated materials and Exciton-mediated electron pairing. [26]

Conclusions

Probably in the superconductivity there is no electric current at all, but a permanent magnetic field as the result of the electron's spin in the same direction in the case of the circular wire on a low temperature. [6]

We think that there is an electric current since we measure a magnetic field. Because of this saying that the superconductivity is a quantum mechanical phenomenon.

Since the acceleration of the electrons is centripetal in a circular wire, in the atom or in the spin, there is a steady current and no electromagnetic induction. This way there is no changing in the Higgs field, since it needs a changing acceleration. [18]

The superconductivity is temperature dependent; it means that the General Weak Interaction is very relevant to create this quantum state of the matter. [19]

We have seen that the superconductivity is basically a quantum mechanical phenomenon and some entangled particles give this opportunity to specific matters, like Cooper Pairs or other entanglements. [26]

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