Superconducting Fusion Reactor

In fusion reactor designs, superconductors (which suffer no resistive power loss) are used to generate the magnetic fields that confine the 100 million degree C plasma. [30]

Hundreds of tiny samples of unconventional superconductors called heavy fermions had to be aligned and glued onto aluminum plates for imaging in inelastic neutron scattering experiments. [29]

In a recent breakthrough, scientists at the Department of Energy's Brookhaven National Laboratory got one step closer to understanding how to make that possible. The research, led by physicist Ivan Bozovic, involves a class of compounds called cuprates, which contain layers of copper and oxygen atoms. [28]

Advanced x-ray technique reveals surprising quantum excitations that persist through materials with or without superconductivity. [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.

Contents

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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

Breakthrough in superconducting materials opens new path to fusion

In fusion reactor designs, superconductors (which suffer no resistive power loss) are used to generate the magnetic fields that confine the 100 million degree C plasma. While increasing magnetic field strength offers potential ways to improve reactor performance, conventional low-temperature superconductors suffer dramatic drops in current carrying ability at high magnetic fields. Now, the emergence of high-temperature superconductors that can also operate at high magnetic fields opens a new, lower-cost path to fusion energy.

A typical measure of fusion plasma performance is called "plasma beta," which is the ratio of plasma pressure to magnetic field pressure. Achieving a very high beta—generating the required plasma pressure with low magnetic field—could help reduce the cost of the superconducting magnets used in a fusion reactor. For this reason, many visions of fusion reactors try to maximize plasma beta at moderate magnetic field strengths. Operation at higher beta, however, pushes the plasma up against many performance limits, making plasma stability a tricky business.

But plasma beta is not the only consideration. Another ratio, the size of the confined plasma compared to the ion gyroradius, also determines overall energy confinement and dictates plasma performance. (The ion gyroradius is the helical path ions are forced to follow in the magnetic field.) Increasing magnetic field strength decreases the ion gyroradius, which allows a reduction in the size of the fusion device with no loss of performance. This approach also lowers beta and the plasma operates farther away from stability limits, in a "safe zone."

While scientists have explored both of these paths to improving performance, the recent development of the so-called "high-temperature superconductors" opens a window for much higher magnetic fields, as the critical currents do not degrade rapidly, even at magnetic field values of 30 Tesla or higher. So these should really be called high-temperature, high-magnetic-field superconductors.

For tokamak design, the field strength limits are primarily determined by the maximum allowable stresses in the structural components holding the magnet together, and not by the intrinsic limits of the superconductors.

Even the most aggressive tokamak designs with conventional superconductor technology are limited to about 6 Tesla on-axis toroidal magnetic fields. By nearly doubling magnetic field strength, to about 10 Tesla on-axis, conceptual designs indicate that a tokamak approximately the physical size of the world's largest currently operating tokamak, JET, would be capable of producing 500 MW of fusion power, and even net electricity. High-temperature, high-magnetic-field superconductors can also make it possible to incorporate jointed magnetic coils into the reactor design, dramatically improving flexibility, and ultimately, maintainability for reactor systems.

While several physics and technology challenges remain to be solved, the world-wide experience from tokamak experiments provides the basis to support a new path of exploration into compact, power producing reactors using the newly available high-temperature, high-magnetic-field superconducting technology. [30]

Neutron-scattering experiments explore origins of high-temp superconductivity

New findings from researchers at Rice University, the University of Illinois at Chicago and the University of California at San Diego (UCSD) suggest that condensed-matter physicists need to rethink how magnetic fluctuations arise in both unconventional and high-temperature superconductors.

"Our results challenge the present understanding of magnetic fluctuations in high-temperature superconductors," said Rice graduate student Yu Song, lead co-author of a study this week in the scientific journal Nature Communications. "Specifically, our findings suggest that magnetic fluctuations similar to those found in magnetically ordered compounds may, in fact, be common to many unconventional superconductors.

Superconductors are materials that lose electrical resistance at a critical temperature. For conventional superconductors, these critical temperatures are impractically low, but high-temperature superconductors tantalize engineers and scientists because their critical behavior comes about at temperatures that are obtainable with relatively affordable industrial processes. In the three decades since high-temperature superconductors were discovered, physicists have found dozens of them but have yet to explain their electronic workings.

All high-temperature superconductors are composite materials. Some contain copper and others have iron. A third class of layered composites called "heavy fermions," which are made of exotic elements like cerium and ytterbium, exhibits the same sort of unconventional superconductivity as high-temperature superconductors, albeit at far colder temperatures.

Most of these unconventional superconductors convey little to no electricity at room temperature, and they continue to be poor conductors until they are cooled to their critical temperature, at which point superconductivity comes about suddenly.

One electronic behavior that's been observed in all classes of unconventional superconductors is neutron spin resonance, a collective magnetic excitation that arises slightly below the critical temperature.

In the new experiments, Song, Rice physicist Pengcheng Dai and colleagues worked for two years to observe resonance behavior in three unconventional superconductors, one made of cerium, cobalt and indium and two others in which ytterbium was substituted for portions of cerium. All three compounds are heavy fermions, so-named because of the tendency of their electrons to behave as if they are far more massive than normal electrons.

"Spin resonance modes are found in both copper- and iron-based high-temperature superconductors, and our results on both doped and undoped cerium-cobalt-indium—prototypical heavy fermions—provide new insights," Song said. "Importantly, superconductivity in all these compounds is believed to be mediated in similar ways by magnetic fluctuations, including those we observe in spin resonance modes, and while it's generally accepted that spin resonance is a signature of unconventional superconductivity, there is no consensus on what causes it to happen."

Song, Dai and colleagues used a technique known as inelastic neutron scattering to examine the resonance behavior of cerium-cobalt-indium and "doped" compounds in which either 5 percent or 30 percent of the cerium was replaced with ytterbium. The experiments were conducted in 2014 at the Heinz Maier-Leibnitz Zentrum at the Technical University of Munich and in 2015 at the National Institute of Standards and Technology's Center for Neutron Research in Gaithersburg, Md.

All samples were created by UCSD physicist Brian Maple and colleagues, and Song spent hours painstakingly aligning hundreds of the tiny samples and gluing them onto aluminum substrates for testing. By cooling the samples to critical temperatures and examining how neutrons scattered from the samples throughout the cooling, Song, Dai and colleagues were able to show how the magnetic resonance of the materials developed and behaved at the critical point where superconductivity arose.

"People have known for years that magnetic order—the alternating alignment of spins that is characteristic of magnetism—actually competes with and suppresses superconductivity," said Dai, professor of physics and astronomy at Rice and the lead scientist on the project. "Intriguingly, magnetic fluctuations in magnetically disordered compounds—fluctuations that resemble what we see in magnetically ordered compounds—appear to be essential for superconductivity."

In one key finding, the behavior of the resonance in both the doped and undoped samples appeared the same; this discovery directly conflicted with behavior that would be expected based on Landau's classical theory governing the electronic behavior of metals. Co-author and theoretical physicist Dirk Morr of the University of Illinois at Chicago said this observation shed new light on a longstanding debate between two theoretical camps that attempts to explain the nature of resonance modes.

"One camp stands for the spin-exciton interpretation, and the other argues that the resonance is a paramagnon, a remnant of the magnetic order," Morr said. "The spin-exciton picture seems to work better for some compounds while the paramagnon interpretation seems to work better for others. Our results fall more within the paramagnon interpretation, and though no theory can unify the two opposing views, these results hint at the possibility that they are, in fact, two ends of a continuum." [29]

Room-temp superconductors could be possible

Superconductors are the holy grail of energy efficiency. These mind-boggling materials allow electric current to flow freely without resistance. But that generally only happens at temperatures within a few degrees of absolute zero (minus 459 degrees Fahrenheit), making them difficult to deploy today. However, if we're able to harness the powers of superconductivity at room temperature, we could transform how energy is produced, stored, distributed and used around the globe.

In a recent breakthrough, scientists at the Department of Energy's Brookhaven National Laboratory got one step closer to understanding how to make that possible.

The research, led by physicist Ivan Bozovic, involves a class of compounds called cuprates, which contain layers of copper and oxygen atoms.

Under the right conditions—which, right now, include ultra-chilly temperatures—electrical current flows freely through these cuprate superconductors without encountering any "roadblocks" along the way. That means none of the electrical energy they're carrying gets converted to heat. If you've ever rested your laptop on your lap, you've felt the heat lost by a non-superconducting material.

Creating the right conditions for superconductivity in cuprates also involves adding other chemical elements such as strontium. Somehow, adding those atoms and chilling the material causes electrons—which normally repel one another—to pair up and effortlessly move together through the material. What makes cuprates so special is that they can achieve this "magical" state of matter at temperatures a hundred degrees or more above those required by standard superconductors. That makes them very promising for real-world, energy-saving applications.

These materials wouldn't require any cooling, so they'd be relatively easy and inexpensive to incorporate into our everyday lives. Picture power grids that never lose energy, more affordable mag-lev train systems, cheaper medical imaging machines like MRI scanners, and smaller yet powerful supercomputers.

To figure out the mystery of "high-temperature" superconductivity in the cuprates, scientists need to understand how the electrons in these materials behave.

Bozovic's team has now solved part of the mystery by determining what exactly controls the temperature at which cuprates become superconducting.

The standard theory of superconductivity says that this temperature is controlled by the strength of the electron-pairing interaction, but Bozovic's team has discovered otherwise. After 10 years of preparing and analyzing more than 2,000 samples of a cuprate with varying amounts of strontium, they found that the number of electron pairs within a given area (say, per cubic centimeter), or the density of electron pairs, controls the superconducting transition temperature. In other words, it's not the forces between objects that matter here, but the density of objects—in this case, electron pairs.

The scientists arrived at this conclusion by measuring how far a magnetic field was able to get through each sample. This distance is directly related to the density of electron pairs, and the distance differs depending on the material's properties. In superconductors, the magnetic field is mostly expelled; in metals, the magnetic field permeates. With too much strontium, the cuprate becomes more conductive because the number of mobile electrons increases. Yet the scientists found that as they added more strontium, the number of electron pairs decreased until absolutely no electrons paired up at all. At the same time, the superconducting transition temperature dropped toward zero. Bozovic and his team were quite surprised at this discovery that only a fraction of the electrons paired up, even though they all should have.

Think of it like this: You're in a dance hall, and at some point, you and the other people—who normally wouldn't be caught arm-in-arm—begin to pair up and move in unison. Some newcomers arrive, and they too pair up and join the harmonious dance. But then something strange happens. No matter how many more people make their way to the dance floor, only a fraction of them pair, even though they are all free to do so. Eventually, nobody pairs up at all.

Why do the dancers, or electrons, pair up in the first place? Answering that question is the next step toward unlocking the mechanism of high-temperature superconductivity in the cuprates—a mystery that's been puzzling physicists for more than 30 years. [28]

Scientists Discover Hidden Magnetic Waves in High-Temperature Superconductors

Advanced x-ray technique reveals surprising quantum excitations that persist through materials with or without superconductivity UPTON, NY—Intrinsic inefficiencies plague current systems for the generation and delivery of electricity, with significant energy lost in transit. High-temperature superconductors (HTS)—uniquely capable of transmitting electricity with zero loss when chilled to subzero temperatures—could revolutionize the planet's aging and imperfect energy infrastructure, but the remarkable materials remain fundamentally puzzling to physicists. To unlock the true potential of HTS technology, scientists must navigate a quantum-scale labyrinth and pin down the phenomenon's source.

Now, scientists at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory and other collaborating institutions have discovered a surprising twist in the magnetic properties of HTS, challenging some of the leading theories. In a new study, published online in the journal Nature Materials on August 4, 2013, scientists found that unexpected magnetic excitations—quantum waves believed by many to regulate HTS—exist in both non-superconducting and superconducting materials.

"This is a major experimental clue about which magnetic excitations are important for high-temperature superconductivity," said Mark Dean, a physicist at Brookhaven Lab and lead author on the new paper. "Cutting-edge x-ray scattering techniques allowed us to see excitations in samples previously thought to be essentially non-magnetic."

On the atomic scale, electron spins—a bit like tiny bar magnets pointed in specific directions—rapidly interact with each other throughout magnetic materials. When one spin rotates, this disturbance can propagate through the material as a wave, tipping and aligning the spins of neighboring electrons. Many researchers believe that this subtle excitation wave may bind electrons together to create the perfect current conveyance of HTS, which operates at slightly warmer temperatures than traditional superconductivity.

The research was funded through Brookhaven Lab's Center for Emergent Superconductivity, an Energy Frontier Research Center funded by the U.S. Department of Energy's Office of Science to seek understanding of the underlying nature of superconductivity in complex materials. [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

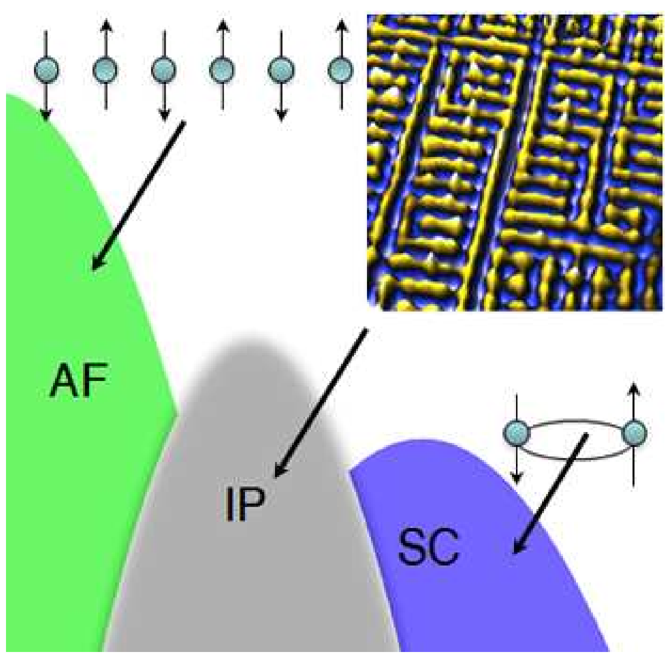
In condensed matter physics, the resonating valence bond theory (RVB) is a theoretical model that attempts to describe high temperature superconductivity, and in particular the superconductivity in cuprate compounds. It was first proposed by American physicist P. W. Anderson and the Indian theoretical 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 $Ba^{0.6}K^{0.4}Fe^2As^2$ 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]

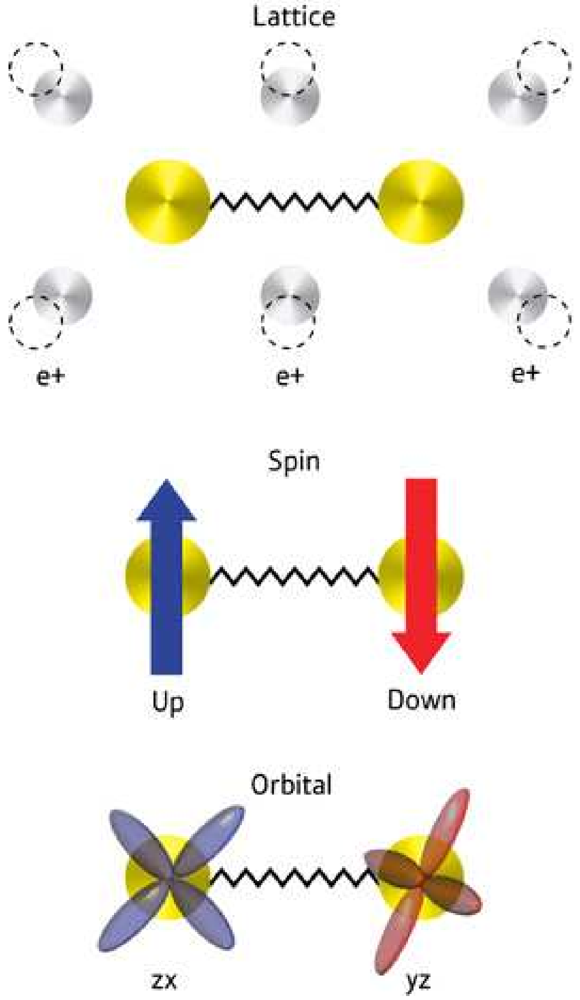
Concepts relating magnetic interactions, intertwined electronic orders, and strongly correlated superconductivity

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, ħ, is set to 1):

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

The operator ψ(*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 ψ(*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:

$$\psi \to e^{iq\phi(x)}\psi$$
$$A \to A + \nabla\phi.$$

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

On the atomic scale, electron spins—a bit like tiny bar magnets pointed in specific directions—rapidly interact with each other throughout magnetic materials. When one spin rotates, this disturbance can propagate through the material as a wave, tipping and aligning the spins of neighboring electrons. Many researchers believe that this subtle excitation wave may bind electrons together to create the perfect current conveyance of HTS, which operates at slightly warmer temperatures than traditional superconductivity. [27]

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]

References:

[1] https://www.academia.edu/3833335/The_Magnetic_field_of_the_Electric_current

[2] https://www.academia.edu/4239860/The_Bridge_between_Classical_and_Quantum_Mechanics

[3] http://en.wikipedia.org/wiki/BCS_theory

[4] http://en.wikipedia.org/wiki/Meissner_effect#cite_note-3

[5] http://en.wikipedia.org/wiki/London_equations

[6] Superconductivity switched on by magnetic field

http://phys.org/news/2013-12-superconductivity-magnetic-field.html#jCp

[7] http://en.wikipedia.org/wiki/Superconductivity

[8] http://en.wikipedia.org/wiki/High-temperature_superconductivity

[9] http://en.wikipedia.org/wiki/Room-temperature_superconductor

[10] http://en.wikipedia.org/wiki/Resonating_valence_bond_theory

[11] http://en.wikipedia.org/wiki/Strongly_correlated_material

[12] http://en.wikipedia.org/wiki/Cooper_pair

[13] https://www.academia.edu/3834454/3_Dimensional_String_Theory

[14] http://en.wikipedia.org/wiki/Color_superconductivity

[15] http://en.wikipedia.org/wiki/Fermi_surface

[16] http://en.wikipedia.org/wiki/Higgs_mechanism

[17] Superconductivity's third side unmasked

http://phys.org/news/2011-06-superconductivity-side-unmasked.html#nRlv

[18] https://www.academia.edu/4158863/Higgs_Field_and_Quantum_Gravity

[19] https://www.academia.edu/4221717/General_Weak_Interaction

[20] Einstein on Superconductivity http://arxiv.org/pdf/physics/0510251/

[21] Conventional Superconductivity http://phys.org/news150729937.html#jCp

[22] http://phys.org/news/2013-12-superconductor-theory-revolutionize-electrical.html#jCp

[23] http://phys.org/news150729937.html#jCp

[24] http://phys.org/news/2013-10-grand-theory-exotic-superconductivity.html#jCp

[25] http://www.pnas.org/content/early/2013/10/09/1316512110.full.pdf+html

[26] The Secret of Quantum Entanglement

https://www.academia.edu/7229968/The_Secret_of_Quantum_Entanglement

[27] Scientists Discover Hidden Magnetic Waves in High-Temperature Superconductors

http://www.bnl.gov/newsroom/news.php?a=11564

[28] Room-temp superconductors could be possible

http://phys.org/news/2016-09-room-temp-superconductors.html

[29] Neutron-scattering experiments explore origins of high-temp superconductivity

http://phys.org/news/2016-09-neutron-scattering-explore-high-temp-superconductivity.html#nRlv

[30] Breakthrough in superconducting materials opens new path to fusion

http://phys.org/news/2015-11-breakthrough-superconducting-materials-path-fusion.html