

Carbon Quantum Effects

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A team of scientists has used microwaves to unravel the exact structure of a tiny molecular motor. The nano-machine consists of just a single molecule, made up of 27 carbon and 20 hydrogen atoms (C₂₇H₂₀). [31]

Skyrmions are swirling spin structures with spiral shapes described in 2009. They have attracted attention in academia as representing a possible basic unit of ultra-high-density next-generation memory devices due to their unique topological stability, small size, and efficient movement. [30]

That could lead to new devices such as polariton transistors, Fei said. And that could one day lead to breakthroughs in photonic and quantum technologies. [29]

The future of nano-electronics is here. A team of researchers from the Air Force Research Laboratory, Colorado School of Mines, and the Argonne National Laboratory in Illinois have developed a novel method for the synthesis of a composite material that has the potential of vastly improving the electronics used by the Air Force. [28]

Physicists have theoretically shown that a superconducting current of electrons can be induced to flow by a new kind of transport mechanism: the potential flow of information. [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 ratio 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

Carbon displays quantum effects

Chemists at Ruhr-Universität Bochum have found evidence that carbon atoms cannot only behave like particles but also like waves. This quantum-mechanical property is well-known for light particles such as electrons or hydrogen atoms. However, researchers have only rarely observed the wave-particle duality for heavy atoms, such as carbon. The team led by Prof Dr Wolfram Sander and Tim Schleif from the Chair for Organic Chemistry II together with Prof Dr Weston Thatcher Borden, University of North Texas, reports in the journal *Angewandte Chemie*.

"Our result is one of few examples showing that carbon atoms can display quantum effects," says Sander. Specifically, the researchers observed that carbon atoms can tunnel. They thus overcome an energetic barrier, although they do not actually possess enough energy to do that.

Rarely observed for heavy particles

Wolfram Sander explains the paradox: "It's as though a tiger has left his cage without jumping over the fence, which is much too high for him. But he still gets out." This is only possible if he behaves like a wave, but not if he behaves like a particle. The probability of an object being able to tunnel depends on its mass. The phenomenon can, for instance, be observed much more easily for light electrons than for relatively heavy carbon atoms.

The researchers investigated the tunnel reaction using the Cope rearrangement, a chemical reaction that has been known for almost 80 years. The starting material for the reaction, a hydrocarbon compound, is identical to the product molecule. The same chemical compound thus exists before and after the reaction. However, the bonds between the carbon atoms change during the process.

In their experiment, the Bochum-based researchers marked one of the carbon atoms in the molecule: They replaced the hydrogen atom bonded to it with the hydrogen isotope deuterium, a heavier version of hydrogen. Molecules before and after the Cope rearrangement differed in terms of the distribution of the deuterium. Due to these different distributions, both molecular forms had slightly different energies.

Reaction shouldn't actually take place

At room temperature, this difference has little effect; due to the plentiful supply of thermal energy in the surrounding area, both forms occur equally frequently. However, at very low temperatures under ten Kelvin, one molecule form is significantly preferred due to the energy difference. When transitioning from room temperature to extremely low temperatures, the balance has to move from an equal distribution of both forms to an uneven distribution.

This transition cannot, however, occur in the classic way – since, when rearranging from one form to the other, an energy barrier has to be overcome, although the molecule itself does not have the energy for this and the cold environment is also unable to provide it. Although the new balance should not occur in the classic way, the researchers were nevertheless able to demonstrate it in the experiment. Their conclusion: the Cope rearrangement at extremely low temperatures can only be explained by a tunnel effect. They thus provided experimental evidence for a prediction made by Weston Borden over five years ago based on theoretical studies.

Solvents influence ability to tunnel

At Ruhr-Universität, Wolfram Sander undertakes research in the cluster of excellence Ruhr Explores Solvation, where he concerns himself with the interactions of solvents and dissolved molecules. "It is known that solvents influence the ability to tunnel," says the chemist. "However, so far it has not been understood how they do that." [32]

Microwaves reveal detailed structure of molecular motor

A team of scientists has used microwaves to unravel the exact structure of a tiny molecular motor. The nano-machine consists of just a single molecule, made up of 27 carbon and 20 hydrogen atoms (C₂₇H₂₀). Like a macroscopic motor it has a stator and a rotor, connected by an axle. The analysis reveals just how the individual parts of the motor are constructed and arranged with respect to each other. The team led by DESY Leading Scientist Melanie Schnell reports the results in the journal *Angewandte Chemie International Edition*.

The artificial molecular motor was synthesized by the team of Dutch Nobel laureate Ben Feringa from the University of Groningen who is a co-author of the paper. Feringa was awarded the 2016 Nobel Prize in Chemistry together with Jean-Pierre Sauvage from the University of Strasbourg and Sir Fraser Stoddart from the Northwestern University in the US for the design and synthesis of molecular machines.

"The functional performance of such nano-machines clearly emerges from their unique structural properties," the authors write in their study. "To better understand and optimise molecular machinery it is important to know their detailed structure and how this structure changes during key mechanical steps, preferably under conditions in which the system is not perturbed by external influences."

The rotary motor investigated here holds great promise for quite a few applications, as first author Sérgio Domingos from DESY and the Max Planck Institute for the Structure and Dynamics of Matter (MPSD) explains: "Chemists are all abuzz about this molecule and try to connect it with a range of other molecules." When activated by light, the nano-machine operates through consecutive photochemical and thermal steps, completing a half turn. A second trigger then forces the motor into completing a full turn, returning to its starting position.

"Such an activation by light is ideal as it provides a non-invasive and highly localized means to remotely activate the motor," says Domingos. "It could be used, for instance, as an efficient motor function that can be integrated with a drug, establishing control over its action and release it at a precisely targeted spot in the body: the light-activated drugs of the future. But also applications like light-activated catalysis and transmission of motion at the molecular level to the macroscopic world

come to mind. For such applications it is important to understand the motor molecule's exact structure and how it works in detail."

The atomic make-up of the motor molecule had been investigated before with X-rays. For the X-ray analysis the molecules had to be grown into crystals first. The crystals then diffract the X-rays in a characteristic way, and from the resulting diffraction pattern the arrangement of atoms can be calculated. "In contrast, we investigated free floating, isolated molecules in a gas," explains Schnell, who works at the Center for Free-Electron Laser Science (CFEL), a cooperation between DESY, the University of Hamburg and the Max Planck Society. "This way we can see the molecule as it is, free from any external influences like solvents or bindings."

In order to determine their structure, the free-floating molecules had to be exposed to a resonant microwave field. "We used an electromagnetic field to orient the molecules all in the same direction in a coherent way and then recorded their relaxation when the field is switched off," explains Schnell, who also leads a research group at MPSD and is a professor for physical chemistry at the University of Kiel. "This reveals the so-called rotational constants of the molecule, which in turn give us accurate information about its structural arrangement."

This analysis of this so-called microwave spectroscopy is not straightforward. In the case of the motor molecule, the scientists had to match more than 200 lines of the spectrum and compare their numbers with simulations from quantum chemistry calculations. "Regarding the number of atoms, the molecular motor currently is the largest molecule whose structure has been solved with microwave spectroscopy," explains Schnell.

In order to float the molecules in the microwave chamber, they had to be heated to 180 degrees Celsius before being cooled down rapidly to minus 271 degrees. "Heating made some of the motors fall apart, breaking at the axle," reports Domingos. "This way we could see the rotor and the stator independently of each other, confirming their structures. This also provides us with some hint about the mechanism via which it falls apart."

The final analysis indicates some small deviations from the structure determined with X-rays, where the molecules are interacting with each other in a crystal. "This shows that the structure of the motor is unmistakably affected by its environment," says Domingos. Even more importantly, the microwave technique opens the possibility to study the dynamics of the motor molecule. "Now that we can see the molecule like it really is, we want to catch it in action," underlines Domingos. The rotor goes through an intermediate state that lasts about three minutes - long enough to be investigated with microwave spectroscopy. The researchers are already planning such investigations from which they hope to learn in detail how the molecular motor works. [31]

Observation of skyrmion breathing motion with X-ray technique

Skyrmions are swirling spin structures with spiral shapes described in 2009. They have attracted attention in academia as representing a possible basic unit of ultra-high-density next-generation memory devices due to their unique topological stability, small size, and efficient movement. Recently, Korean researchers have developed a technology that can be applied to communication devices using skyrmions.

Researchers have predicted that it is possible to implement a unique kinetic dynamic of skyrmions called "skyrmion breathing" in next-generation high-frequency oscillator devices and memory devices. However, due to the ultra-small size and ultra-fast motion of skyrmions, direct observations of skyrmion breathing have been considered difficult to achieve.

The results of this research are the first to describe skyrmion breathing based on experimental observations. The DGIST-KIST collaborative research team successfully observed and measured the controlled motion and breathing of a skyrmion in response to external signals that occur within a few nanoseconds using a synchrotron X-ray technique with excellent time and space resolving powers.

In addition, this research has also developed an efficient skyrmion generation method using external current pulses. The results of this study are important, because they suggest that skyrmions can play a significant role in many other future electronic devices, beyond memory devices, which had been of primary focus till now.

Director Jung-Il Hong from the DGIST-LBNL Research Center for Emerging Materials said, "The new approach utilizing skyrmions presented in the results of this study suggest a new method of operation for an entire device, so its implications are great in light of the existing research trends."

Senior researcher Seong-hoon Woo from the KIST Center for Spintronics said, "The research results show that high-efficiency, next-generation communication devices based on skyrmions are actually feasible. This research will contribute to accelerating the development of next-generation communication devices for efficient communication among future high-performance electronic devices." [30]

Researchers image quasiparticles that could lead to faster circuits, higher bandwidths

Zhe Fei pointed to the bright and dark vertical lines running across his computer screen. This nano-image, he explained, shows the waves associated with a half-light, half-matter quasiparticle moving inside a semiconductor.

"These are waves just like water waves," said Fei, an Iowa State University assistant professor of physics and astronomy and an associate of the U.S. Department of Energy's Ames Laboratory. "It's like dropping a rock on the surface of water and seeing waves. But these waves are exciton-polaritons."

Exciton-polaritons are a combination of light and matter. Like all quasiparticles, they're created within a solid and have physical properties such as energy and momentum. In this study, they were launched by shining a laser on the sharp tip of a nano-imaging system aimed at a thin flake of molybdenum diselenide (MoSe₂), a layered semiconductor that supports excitons.

Excitons can form when light is absorbed by a semiconductor. When excitons couple strongly with photons, they create exciton-polaritons.

It's the first time researchers have made real-space images of exciton-polaritons. Fei said past research projects have used spectroscopic studies to record exciton-polaritons as resonance peaks

or dips in optical spectra. Until recent years, most studies have only observed the quasiparticles at extremely cold temperatures - down to about -450 degrees Fahrenheit.

But Fei and his research group worked at room temperature with the scanning near-field optical microscope in his campus lab to take nano-optical images of the quasiparticles.

"We are the first to show a picture of these quasiparticles and how they propagate, interfere and emit," Fei said.

The researchers, for example, measured a propagation length of more than 12 microns - 12 millionths of a meter - for the exciton-polaritons at room temperature.

Fei said the creation of exciton-polaritons at room temperature and their propagation characteristics are significant for developing future applications for the quasiparticles. One day they could even be used to build nanophotonic circuits to replace electronic circuits for nanoscale energy or information transfer.

Fei said nanophotonic circuits with their large bandwidth could be up to 1 million times faster than current electrical circuits.

A research team led by Fei recently reported its findings in the scientific journal Nature Photonics. The paper's first author is Fengrui Hu, an Iowa State postdoctoral research associate in physics and astronomy. Additional co-authors are Yilong Luan, an Iowa State doctoral student in physics and astronomy; Marie Scott, a recently graduated undergraduate at the University of Washington; Jiaqiang Yan and David Mandrus of Oak Ridge National Laboratory and the University of Tennessee; and Xiaodong Xu of the University of Washington.

The researchers' work was supported by funds from Iowa State and the Ames Laboratory to launch Fei's research program. The W.M. Keck Foundation of Los Angeles also partially supported the nano-optical imaging for the project.

The researchers also learned that by changing the thickness of the MoSe₂ semiconductor, they could manipulate the properties of the exciton-polaritons.

Fei, who has been studying quasiparticles in graphene and other 2-D materials since his graduate school days at University of California San Diego, said his earlier work opened the doors for studies of exciton-polaritons.

"We need to explore further the physics of exciton-polaritons and how these quasiparticles can be manipulated," he said.

That could lead to new devices such as polariton transistors, Fei said. And that could one day lead to breakthroughs in photonic and quantum technologies. [29]

Researchers shape the future of nano-electronics

The future of nano-electronics is here. A team of researchers from the Air Force Research Laboratory, Colorado School of Mines, and the Argonne National Laboratory in Illinois have

developed a novel method for the synthesis of a composite material that has the potential of vastly improving the electronics used by the Air Force.

The material, hexagonal boron nitride (hBN), is similar to graphene and can be formed and stabilized to a layered thickness of one atom. This synthesis of hBN in a controlled layer-by-layer fashion is critical to a number of applications, including tunneling barriers, used in transistors for low power devices, atomically thin capacitors, and two-dimensional (2D) transistors, which are smaller and use much less power than traditional silicon transistors.

"Fabricating devices from atomically thin 2D layers represents the future of nano-electronics," states Dr. Michael Snure, AFRL senior research physicist. "This development significantly increases device density, improving flexibility and significantly reducing power requirements."

As a 2D material, hBN has been of international interest for close to a decade. Researchers with AFRL's Sensors Directorate have been working on experimental methods for developing this technology since 2013, with Dr. Snure leading the effort. Dr. Stefan Badescu, AFRL research physicist, joined the team in 2015 to lead the computational modeling research that has assisted the team with understanding the system's properties and the mechanism for growth.

So how is a composite material intended for use in electronics scaled down to the thickness of a mere atom? Through a novel and complex method of synthesis, of course. Using a process that involves metal-organic chemical vapor disposition, the team discovered how to control the growth of hBN layers on a nanoscale.

The hBN from AFRL's work is currently being used in the development of prototype 2D electronics devices including transistors and photodetectors. However, the impact of this development reaches further.

"By developing a model of growth, our work more broadly benefits the field of materials science in the areas of thin film growth and chemical vapor disposition," reflects Badescu. "This modeling will help drive new discoveries in the synthesis of 2D materials."

Badescu adds that future applications of hBN include transistors for switching and logic devices that are flexible, transparent, low power, and high frequency. The next steps are to demonstrate the feasibility of integrating hBN with other 2D semiconductors, including graphene and phosphorene.

The team's work was published in a paper by Nano Letters, a scientific journal of the American Chemical Society, and the team is considering filing a patent for the technology and synthesis method pending successful future experiments with hBN and metal combinations. [28]

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

Physicists predict supercurrent driven by potential information transfer

Physicists have theoretically shown that a superconducting current of electrons can be induced to flow by a new kind of transport mechanism: the potential flow of information. This unusual phenomena is predicted to exist in chiral channels—channels in which electrons are usually restricted to flowing in one direction only—but has never been theoretically demonstrated before now.

The physicists, Xiao-Li Huang and Yuli V. Nazarov at the Delft University of Technology in The Netherlands, have published a paper on the supercurrent induced by potential information transfer in a recent issue of Physical Review Letters.

As the scientists explain, a transport mechanism for electrons that is based on information transfer is unprecedented and has so far never been observed. Further, chiral channels are thought to be incapable of carrying a superconducting current (one with little to no resistance) at all. So it's quite surprising that a supercurrent can be induced in a chiral channel in the first place, and especially by such an exotic mechanism.

The scientists explained that, by definition, the electrons in a chiral channel can only move in one direction. To induce supercurrent, an information transfer in the direction opposite to this direction is required. However, the supercurrent, as it's not the usual electric current, can flow in either direction, depending on the phases on the superconducting leads in the proposed set-up.

The physicists also predict that the supercurrent should persist in the ground state, where, by definition, no actual information transfer can take place. The reason why this is possible is because it's not an actual information flow, but rather the potential for such a flow to occur, that drives the supercurrent.

The physicists hope that this intriguing relation between superconductivity and potential information transfer can lead to some novel capabilities. For example, as they write in their paper, supercurrent might be used to "probe the potential for information transfer without actually transferring the information." The physicists expect that it should be possible to experimentally observe the effect in graphene-based chiral channels, and they hope to further investigate this possibility in the future. [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 Scherrer 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

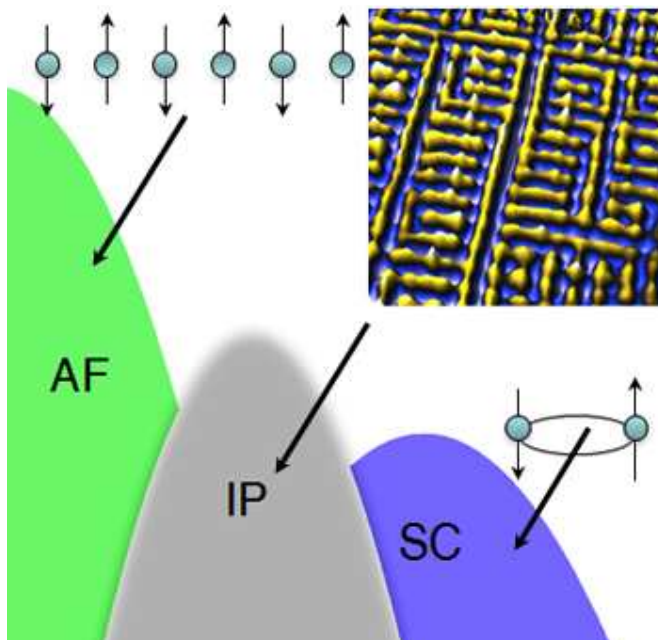
place. However, with doping, these electrons can act as mobile Cooper pairs and are able to superconduct. Anderson observed in his 1987 paper that the origins of superconductivity in doped cuprates was in the Mott insulator nature of crystalline copper oxide. RVB builds on the Hubbard and t-J models 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.* $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$. 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 $\text{Ba}^{0.6}\text{K}^{0.4}\text{Fe}^2\text{As}^2$ 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-T_c 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]

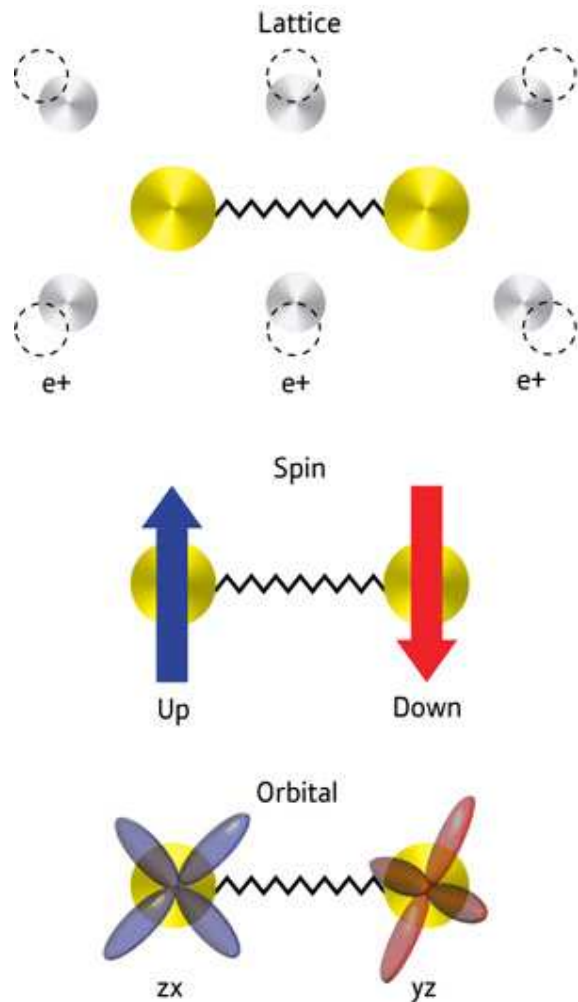
Concepts relating magnetic interactions, intertwined electronic orders, and strongly correlated superconductivity

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 ψ^\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:

$$\begin{aligned} \psi &\rightarrow e^{iq\phi(x)} \psi \\ A &\rightarrow A + \nabla\phi. \end{aligned}$$

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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