Magnetic Molecular Chessboard

Achieving magnetic order in low-dimensional systems consisting of only one or two dimensions has been a research goal for some time. [34]

The electron microscope, a powerful tool for science, just became even more powerful, with an improvement developed by Cornell physicists. Their electron microscope pixel array detector (EMPAD) yields not just an image, but a wealth of information about the electrons that create the image and, from that, more about the structure of the sample. [33]

An innovative new technique to produce the quickest, smallest, highest-capacity memories for flexible and transparent applications could pave the way for a future golden age of electronics. [32]

The shrinking of electronic components and the excessive heat generated by their increasing power has heightened the need for chip-cooling solutions, according to a Rutgers-led study published recently in Proceedings of the National Academy of Sciences. Using graphene combined with a boron nitride crystal substrate, the researchers demonstrated a more powerful and efficient cooling mechanism. [31]

Materials like graphene can exhibit a particular type of large-amplitude, stable vibrational modes that are localised, referred to as Discrete Breathers (DBs). [30]

A two-dimensional material developed by Bayreuth physicist Prof. Dr. Axel Enders together with international partners could revolutionize electronics. [29]

Researchers have found a way to trigger the innate, but previously hidden, ability of graphene to act as a superconductor - meaning that it can be made to carry an electrical current with zero resistance. [28]

Researchers in Japan have found a way to make the 'wonder material' graphene superconductive - which means electricity can flow through it with zero resistance. The new property adds to graphene's already impressive list of attributes, like the fact that it's stronger than steel, harder than diamond, and incredibly flexible. [27]

Superconductivity is a rare physical state in which matter is able to conduct electricity—maintain a flow of electrons—without any resistance. It can only be found in certain materials, and even then it can only be achieved under controlled conditions of low temperatures and high pressures. New research from a team including Carnegie's Elissaios Stavrou, Xiao-Jia Chen, and

Alexander Goncharov hones in on the structural changes underlying superconductivity in iron arsenide compounds—those containing iron and arsenic. [26]

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.

Contents

Author: George Rajna

Magnetic order in a two-dimensional molecular chessboard

Achieving magnetic order in low-dimensional systems consisting of only one or two dimensions has been a research goal for some time. In a new study published in the journal Nature Communications, Uppsala researchers show that magnetic order can be created in a two-dimensional chessboard lattice consisting of organometallic molecules that are only one atomic layer thick.

Magnetic order is a common phenomenon in three-dimensional materials, such as ferromagnetic order in iron bar magnets, where the magnetic moments on all iron atoms point in the same direction. In one or two dimensions, long-range magnetic order at temperatures higher than zero is not possible, however, according to the Mermin-Wagner theorem. A possibility to achieve a magnetic phase without such long-range order was suggested by Kosterlitz and Thouless (Nobel Prize 2016), who predicted that a topological magnetic vortex in which the magnetic moments point in different directions and compensate each other could be realizable in a two-dimensional film.

Researchers Ehesan Ali and Peter Oppeneer from Uppsala University have now shown in an international collaboration with researchers from Switzerland and India that long-range magnetic order can be created in specially designed molecular systems consisting of iron and manganese phthalocyanine molecules. These molecules, which have great similarities to the iron porphyrins that are found in natural blood, were adsorbed on a gold metal surface. The molecules do not react with gold atoms, but instead order themselves in a two-dimensional chessboard pattern consisting of alternating iron and manganese-based molecules. In this two-dimensional molecule lattice, the researchers could demonstrate magnetic order at low temperatures of just a few degrees Kelvin.

Through large-scale computer simulations, the Uppsala researchers were able to demonstrate a weak interaction between magnetic moments on the neighbouring molecule, which were

transmitted through the gold electrons, the so-called Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction. Although the metal phthalocyanine molecules do not react chemically with the noble metal gold, the gold's electrons sense the spin magnetic moments on the molecule and transmit this information to the neighbouring molecule.

The researchers also detected that another fundamental physical interaction, the Kondo screening, counteracted the magnetic order. This occurred because the gold electrons changed their spin magnetic moments to neutralize the molecule's moment, something they didn't quite succeed in, and therefore long-range magnetic order was formed.

"It was amazing that our careful calculations could establish how magnetic order is formed in the molecular layer," says Peter Oppeneer, Professor at the Department of Physics and Astronomy at Uppsala University. "Our discovery can pave the way for studying thus far unknown quantum magnetic states, and contributes to the realization of molecular quantum spintronics." [34]

New electron microscope sees more than an image

The electron microscope, a powerful tool for science, just became even more powerful, with an improvement developed by Cornell physicists. Their electron microscope pixel array detector (EMPAD) yields not just an image, but a wealth of information about the electrons that create the image and, from that, more about the structure of the sample.

"We can extract local strains, tilts, rotations, polarity and even electric and magnetic fields," explained David Muller, professor of applied and engineering physics, who developed the new device with Sol Gruner, professor of physics, and members of their research groups.

Cornell's Center for Technology Licensing (CTL) has licensed the invention to FEI, a leading manufacturer of electron microscopes (a division of Thermo Fisher Scientific, which supplies products and services for the life sciences through several brands). FEI expects to complete the commercialization of the design and offer the detector for new and retrofitted electron microscopes this year.

"It's mind-boggling to contemplate what researchers around the world will discover through this match of Cornell's deep expertise in detector science with market leader Thermo Fisher Scientific," said Patrick Govang, technology licensing officer at CTL.

The scientists described their work in the February 2016 issue of the journal Microscopy and Microanalysis.

In the usual scanning transmission electron microscope (STEM), a narrow beam of electrons is fired down through a sample, scanning back and forth to produce an image. A detector underneath reads the varying intensity of electrons coming through and sends a signal that draws an image on a computer screen.

The EMPAD that replaces the usual detector is made up of a 128x128 array of electron-sensitive pixels, each 150 microns (millionths of a meter) square, bonded to an integrated circuit that reads out the signals – somewhat like the array of light-sensitive pixels in the sensor in a digital camera, but not to form an image. Its purpose is to detect the angles at which electrons emerge, as each

electron hits a different pixel. The EMPAD is a spinoff of X-ray detectors the physicists have built for X-ray crystallography work at the Cornell High Energy Synchrotron Source (CHESS), and it can work in a similar way to reveal the atomic structure of a sample.

Combined with the focused beam of the electron microscope, the detector allows researchers to build up a "four-dimensional" map of both position and momentum of the electrons as they pass through a sample to reveal the atomic structure and forces inside. The EMPAD is unusual in its speed, sensitivity and wide range of intensities it can record – from detecting a single electron to intense beams containing hundreds of thousands or even a million electrons.

"It would be like taking a photograph of a sunset that showed both details on the surface of the sun and the details of darkest shadows," Muller explained.

The improvement is also exciting to life scientists because collecting all the scattered electrons makes the instrument much more sensitive, using a less intense exposure to get an image and limiting damage to a living specimen.

"The EMPAD records an image frame in less than a millisecond and can detect from one to a million primary electrons per pixel, per image frame," Muller explained. "This is 1,000 times the dynamic range, and 100 times the speed of conventional electron image sensors."

"Now we can get a better look at processes inside intact cells," said Lena Kourkoutis, assistant professor of applied and engineering physics. The low dose of radiation allows multiple exposures, to take time-lapse "movies" of cellular processes or to view the same specimen from different angles to get a clearer 3-D image. Kourkoutis plans to use these techniques in work with the new Cornell Center for the Physics of Cancer Metabolism, looking at how cancer progresses from cell to cell.

The researchers tested their first EMPAD by installing it in spare port in a state-of-the-art FEI microscope. The prototype is used intensively for experiments in the Cornell Center for Materials Research. [33]

New ultrafast flexible and transparent memory devices could herald new era of electronics

An innovative new technique to produce the quickest, smallest, highest-capacity memories for flexible and transparent applications could pave the way for a future golden age of electronics.

Engineering experts from the University of Exeter have developed innovative new memory using a hybrid of graphene oxide and titanium oxide. Their devices are low cost and eco-friendly to produce, are also perfectly suited for use in flexible electronic devices such as 'bendable' mobile phone, computer and television screens, and even 'intelligent' clothing.

Crucially, these devices may also have the potential to offer a cheaper and more adaptable alternative to 'flash memory', which is currently used in many common devices such as memory cards, graphics cards and USB computer drives.

The research team insist that these innovative new devices have the potential to revolutionise not only how data is stored, but also take flexible electronics to a new age in terms of speed, efficiency and power.

The research is published in the leading scientific journal ACS Nano.

Professor David Wright, an Electronic Engineering expert from the University of Exeter and lead author of the paper said: "Using graphene oxide to produce memory devices has been reported before, but they were typically very large, slow, and aimed at the 'cheap and cheerful' end of the electronics goods market.

"Our hybrid graphene oxide-titanium oxide memory is, in contrast, just 50 nanometres long and 8 nanometres thick and can be written to and read from in less than five nanoseconds—with one nanometre being one billionth of a metre and one nanosecond a billionth of a second."

Professor Craciun, a co-author of the work, added: "Being able to improve data storage is the backbone of tomorrow's knowledge economy, as well as industry on a global scale. Our work offers the opportunity to completely transform graphene-oxide memory technology, and the potential and possibilities it offers." [32]

How graphene could cool smartphone, computer and other electronics chips

With graphene, Rutgers researchers have discovered a powerful way to cool tiny chips – key components of electronic devices with billions of transistors apiece.

"You can fit graphene, a very thin, two-dimensional material that can be miniaturized, to cool a hot spot that creates heating problems in your chip, said Eva Y. Andrei, Board of Governors professor of physics in the Department of Physics and Astronomy. "This solution doesn't have moving parts and it's quite efficient for cooling."

The shrinking of electronic components and the excessive heat generated by their increasing power has heightened the need for chip-cooling solutions, according to a Rutgers-led study published recently in Proceedings of the National Academy of Sciences. Using graphene combined with a boron nitride crystal substrate, the researchers demonstrated a more powerful and efficient cooling mechanism.

"We've achieved a power factor that is about two times higher than in previous thermoelectric coolers," said Andrei, who works in the School of Arts and Sciences.

The power factor refers to the effectiveness of active cooling. That's when an electrical current carries heat away, as shown in this study, while passive cooling is when heat diffuses naturally.

Graphene has major upsides. It's a one-atom-thick layer of graphite, which is the flaky stuff inside a pencil. The thinnest flakes, graphene, consist of carbon atoms arranged in a honeycomb lattice that looks like chicken wire, Andrei said. It conducts electricity better than copper, is 100 times stronger than steel and quickly diffuses heat.

The graphene is placed on devices made of boron nitride, which is extremely flat and smooth as a skating rink, she said. Silicon dioxide – the traditional base for chips – hinders performance because it scatters electrons that can carry heat away.

In a tiny computer or smartphone chip, billions of transistors generate lots of heat, and that's a big problem, Andrei said. High temperatures hamper the performance of transistors – electronic devices that control the flow of power and can amplify signals – so they need cooling.

Current methods include little fans in computers, but the fans are becoming less efficient and break down, she said. Water is also used for cooling, but that bulky method is complicated and prone to leaks that can fry computers.

"In a refrigerator, you have compression that does the cooling and you circulate a liquid," Andrei said. "But this involves moving parts and one method of cooling without moving parts is called thermoelectric cooling."

Think of thermoelectric cooling in terms of the water in a bathtub. If the tub has hot water and you turn on the cold water, it takes a long time for the cold water below the faucet to diffuse in the tub. This is passive cooling because molecules slowly diffuse in bathwater and become diluted, Andrei said. But if you use your hands to push the water from the cold end to the hot, the cooling process – also known as convection or active cooling – will be much faster.

The same process takes place in computer and smartphone chips, she said. You can connect a piece of wire, such as copper, to a hot chip and heat is carried away passively, just like in a bathtub.

Now imagine a piece of metal with hot and cold ends. The metal's atoms and electrons zip around the hot end and are sluggish at the cold end, Andrei said. Her research team, in effect, applied voltage to the metal, sending a current from the hot end to the cold end. Similar to the case of active cooling in the bathtub example, the current spurred the electrons to carry away the heat much more efficiently than via passive cooling. Graphene is actually superior in both its passive and active cooling capability. The combination of the two makes graphene an excellent cooler.

"The electronics industry is moving towards this kind of cooling," Andrei said. "There's a very big research push to incorporate these kinds of coolers. There is a good chance that the graphene cooler is going to win out. Other materials out there are much more expensive, they're not as thin and they don't have such a high power factor."

The study's lead author is Junxi Duan, a Rutgers physics post-doctoral fellow. Other authors include Xiaoming Wang, a Rutgers mechanical engineering post-doctoral fellow; Xinyuan Lai, a Rutgers physics undergraduate student; Guohong Li, a Rutgers physics research associate; Kenji Watanabe and Takashi Taniguchi of the National Institute for Materials Science in Tsukuba, Japan; Mona Zebarjadi, a former Rutgers mechanical engineering professor who is now at the University of Virginia; and Andrei. Zebarjadi conducted a previous study on electronic cooling using thermoelectric devices. [31]

The secrets of vibration-enhanced conductivity in graphene

Graphene, the one-atom-thick material made of carbon atoms, still holds some unexplained qualities, which are important in connection with electronic applications where high-conductivity matters, ranging from smart materials that collectively respond to external stimuli in a coherent, tunable fashion, to light-induced, all-optical networks. Materials like graphene can exhibit a particular type of large-amplitude, stable vibrational modes that are localised, referred to as Discrete Breathers (DBs). The secret to enhancing conductivity by creating DBs lies in creating the external constraints to make atoms within the material oscillate perpendicular to the direction of the graphene sheet. Simulations-based models describing what happens at the atomic level are not straightforward, making it necessary to determine the initial conditions leading to the emergence of DBs. In a new paper published in EPJ B, Elham Barani from the Ferdowsi University of Mashhad, Iran, and colleagues from Russia, Iran and Singapore use a systematic approach to identify the initial conditions that lend themselves to exciting DBs in graphene, ultimately opening the door to understanding the keys to greater conductivity.

The authors first used simulations to understand the dependency of the amplitude of the DB vibrations on the frequency of oscillations. Barani and colleagues then established the dynamic equations describing the vibrating motion of the atoms in graphene and the influence of external energy potentials. They discovered that there is exactly one solution to the equation corresponding to the emergence of DB excitations, which is dictated by the regular symmetry of graphene.

The most surprising finding of this study is that the solution describing the conditions for triggering DBs is not affected by the amplitude of the vibrational mode. Nor does the type of interatomic energy potentials used in the simulations to model the external constraints on the atomic lattice alter how to best induce DBs. These findings offer a valuable theoretical basis for future experimental work. [30]

A revolutionary atom-thin semiconductor for electronics

A two-dimensional material developed by Bayreuth physicist Prof. Dr. Axel Enders together with international partners could revolutionize electronics.

Semiconductors that are as thin as an atom are no longer the stuff of science fiction. Bayreuth physicist Prof. Dr. Axel Enders, together with partners in Poland and the US, has developed a two-dimensional material that could revolutionize electronics. Thanks to its semiconductor properties, this material could be much better suited for high tech applications than graphene, the discovery of which in 2004 was celebrated worldwide as a scientific breakthrough. This new material contains carbon, boron, and nitrogen, and its chemical name is "Hexagonal Boron-Carbon-Nitrogen (h-BCN)". The new development was published in the journal ACS Nano.

"Our findings could be the starting point for a new generation of electronic transistors, circuits, and sensors that are much smaller and more bendable than the electronic elements used to date. They are likely to enable a considerable decrease in power consumption," Prof. Enders predicts, citing the CMOS technology that currently dominates the electronics industry. This technology has clear limits with regard to further miniaturization. "h-BCN is much better suited than graphene when it comes to pushing these limits," according to Enders.

Graphene is a two-dimensional lattice made up entirely of carbon atoms. It is thus just as thin as a single atom. Once scientists began investigating these structures more closely, their remarkable properties were greeted with enthusiasm across the world. Graphene is 100 to 300 times stronger than steel and is, at the same time, an excellent conductor of heat and electricity. However, electrons are able to flow through unhindered at any applied voltage such that there is no defined on-position or off-position. "For this reason, graphene is not well suited for most electronic devices. Semiconductors are required, since only they can ensure switchable on and off states," Prof. Enders explained. He had the idea of replacing individual carbon atoms in graphene with boron and nitrogen, resulting in a two-dimensional grid with the properties of a semiconductor. He has now been able to turn this idea into reality with his team of scientists at the University of Nebraska-Lincoln. [29]

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

Graphene's sleeping superconductivity awakens

Researchers have found a way to trigger the innate, but previously hidden, ability of graphene to act as a superconductor - meaning that it can be made to carry an electrical current with zero resistance.

The finding, reported in Nature Communications, further enhances the potential of graphene, which is already widely seen as a material that could revolutionise industries such as healthcare and electronics. Graphene is a two-dimensional sheet of carbon atoms and combines several remarkable properties; for example, it is very strong, but also light and flexible, and highly conductive.

Since its discovery in 2004, scientists have speculated that graphene may also have the capacity to be a superconductor. Until now, superconductivity in graphene has only been achieved by doping it with, or by placing it on, a superconducting material - a process which can compromise some of its other properties.

But in the new study, researchers at the University of Cambridge managed to activate the dormant potential for graphene to superconduct in its own right. This was achieved by coupling it with a material called praseodymium cerium copper oxide (PCCO).

Superconductors are already used in numerous applications. Because they generate large magnetic fields they are an essential component in MRI scanners and levitating trains. They could also be used to make energy-efficient power lines and devices capable of storing energy for millions of years.

Superconducting graphene opens up yet more possibilities. The researchers suggest, for example, that graphene could now be used to create new types of superconducting quantum devices for high-speed computing. Intriguingly, it might also be used to prove the existence of a mysterious form of superconductivity known as "p-wave" superconductivity, which academics have been struggling to verify for more than 20 years.

The research was led by Dr Angelo Di Bernardo and Dr Jason Robinson, Fellows at St John's College, University of Cambridge, alongside collaborators Professor Andrea Ferrari, from the Cambridge Graphene Centre; Professor Oded Millo, from the Hebrew University of Jerusalem, and Professor Jacob Linder, at the Norwegian University of Science and Technology in Trondheim.

"It has long been postulated that, under the right conditions, graphene should undergo a superconducting transition, but can't," Robinson said. "The idea of this experiment was, if we couple graphene to a superconductor, can we switch that intrinsic superconductivity on? The question then becomes how do you know that the superconductivity you are seeing is coming from within the graphene itself, and not the underlying superconductor?"

Similar approaches have been taken in previous studies using metallic-based superconductors, but with limited success. "Placing graphene on a metal can dramatically alter the properties so it is technically no longer behaving as we would expect," Di Bernardo said. "What you see is not graphene's intrinsic superconductivity, but simply that of the underlying superconductor being passed on."

PCCO is an oxide from a wider class of superconducting materials called "cuprates". It also has well-understood electronic properties, and using a technique called scanning and tunnelling microscopy, the researchers were able to distinguish the superconductivity in PCCO from the superconductivity observed in graphene.

Superconductivity is characterised by the way the electrons interact: within a superconductor electrons form pairs, and the spin alignment between the electrons of a pair may be different depending on the type - or "symmetry" - of superconductivity involved. In PCCO, for example, the pairs' spin state is misaligned (antiparallel), in what is known as a "d-wave state".

By contrast, when graphene was coupled to superconducting PCCO in the Cambridge-led experiment, the results suggested that the electron pairs within graphene were in a p-wave state. "What we saw in the graphene was, in other words, a very different type of superconductivity than in PCCO," Robinson said. "This was a really important step because it meant that we knew the superconductivity was not coming from outside it and that the PCCO was therefore only required to unleash the intrinsic superconductivity of graphene."

It remains unclear what type of superconductivity the team activated, but their results strongly indicate that it is the elusive "p-wave" form. If so, the study could transform the ongoing debate about whether this mysterious type of superconductivity exists, and - if so - what exactly it is.

In 1994, researchers in Japan fabricated a triplet superconductor that may have a p-wave symmetry using a material called strontium ruthenate (SRO). The p-wave symmetry of SRO has never been fully verified, partly hindered by the fact that SRO is a bulky crystal, which makes it challenging to fabricate into the type of devices necessary to test theoretical predictions.

"If p-wave superconductivity is indeed being created in graphene, graphene could be used as a scaffold for the creation and exploration of a whole new spectrum of superconducting devices for fundamental and applied research areas," Robinson said. "Such experiments would necessarily lead to new science through a better understanding of p-wave superconductivity, and how it behaves in different devices and settings."

The study also has further implications. For example, it suggests that graphene could be used to make a transistor-like device in a superconducting circuit, and that its superconductivity could be incorporated into molecular electronics. "In principle, given the variety of chemical molecules that can bind to graphene's surface, this research can result in the development of molecular electronics devices with novel functionalities based on superconducting graphene," Di Bernardo added. [28]

Wonder material graphene has been turned into a superconductor

Researchers in Japan have found a way to make the 'wonder material' graphene superconductive - which means electricity can flow through it with zero resistance.

The new property adds to graphene's already impressive list of attributes, like the fact that it's stronger than steel, harder than diamond, and incredibly flexible.

But superconductivity is a big deal, even for graphene, because when electricity can flow without resistance, it can lead to significantly more efficient electronic devices, not to mention power lines. Right now, energy companies are losing about 7 percent of their energy as heat as a result of resistance in the grid.

Before you get too excited, this demonstration of superconductivity in graphene occurred at a super cold -269 degrees Celsius, so we're not going to be making power lines out of graphene any time soon.

But what is exciting, is that this research suggests that graphene could be used to build nano-sized, high-speed electronic devices. Just imagine all the electricity we could save with computers that rely on tiny graphene circuity, capable of zooming electrons around without wasting energy as heat.

For those who aren't already familiar with graphene, the material is a one-atom-thick layer of graphite (the stuff that makes up your pencils), which is made up of carbon atoms arranged in a hexagonal honeycomb patterns.

The electrons inside graphene are already pretty special, because they're able to take on a special state called Dirac-cone, where they behave as if they have no mass. That makes them very speedy, but even though graphene is a very efficient conductor, it's not a superconductor, which is a state that requires zero resistance.

Now a team from Tohoku University and the University of Tokyo have managed to achieve superconductivity by creating two graphene sheets and inserting calcium atoms between them - sort of like a calcium sandwich, with graphene acting as the bread.

These graphene sheets were grown on a silicon carbide crystal (the SiC substrate in the image above), and the team was able to show that when the temperature gets to around 4 Kelvin, or -269 degrees Celsius, the electrical conductivity of the material rapidly drops - a clear indication of superconductivity.

Superconductivity generally relies on electrons not repelling each other, as they usually do, and pairing up instead, so they can flow through materials effortlessly. As you can imagine, when that happens in a material with electrons that are already acting like they have no mass, scientists get pretty excited.

"This is significant because electrons with no mass flowing with no resistance in graphene could lead to the realisation of an ultimately high-speed nano electronic device," Tohoku University explains.

Just last year, researchers were able to make graphene superconductive by coating it in lithium, but the Japanese team has now managed to achieve the same thing while keeping the material in its original state.

They were also able to show that superconductivity didn't occur when the graphene bilayers were on their own, or when they were coated in lithium, suggesting that the calcium atoms are what's important to the process - although the researchers admit they still don't know what phenomenon is taking place in graphene to achieve superconductivity, so there's more work to be done.

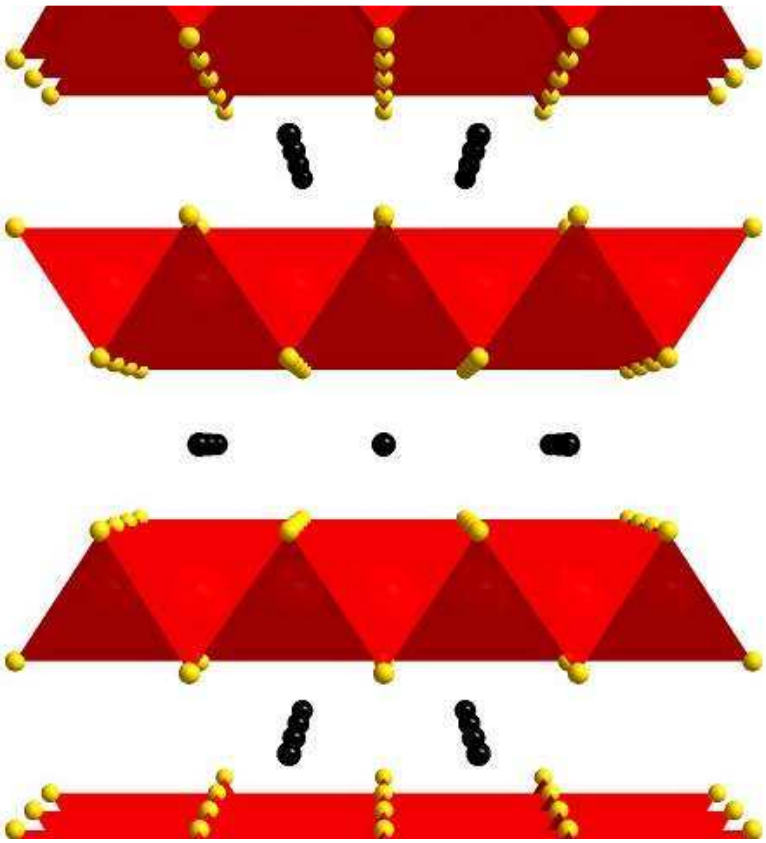
But if they can figure out what's going on, they might be able to tweak the process and find a way to achieve superconductivity in graphene at higher temperatures, and that would be huge.

As we mentioned before, graphene is unlikely to be used to build power lines - there are more promising high-temperature superconductors that would be better suited to that job - but it could revolutionise our computers.

"The latest results pave the way for the further development of ultrahigh-speed superconducting nano devices," says Tohoku University, "such as a quantum computing device, which utilises superconducting graphene in its integrated circuit."

We're looking forward to seeing what amazing thing graphene does next. [27]

Linking superconductivity and structure



Although superconductivity has many practical applications for electronics (including scientific research instruments), medical engineering (MRI and NMR machines), and potential future applications including high-performance power transmission and storage, and very fast train travel, the difficulty of creating superconducting materials prevents it from being used to its full potential. As such, any newly discovered superconducting ability is of great interest to scientists and engineers.

Iron arsenides are relatively recently discovered superconductors. The nature of superconductivity in these particular materials remains a challenge for modern solid state physics. If the complex links between superconductivity, structure, and magnetism in these materials are unlocked, then iron arsenides could potentially be used to reveal superconductivity at much higher temperatures than previously seen, which would vastly increase the ease of practical applications for superconductivity.

When iron arsenide is combined with a metal—such as in the sodium-containing NaFe2As2 compound studied here—it was known that the ensuing compound is crystallized in a tetrahedral structure. But until now, a detailed structure of the atomic positions involved and how they change under pressure had not been determined.

The layering of arsenic and iron (As-Fe-As) in this structure is believed to be key to the compound's superconductivity. However, under pressure, this structure is thought to be partially misshapen into a so-called collapsed tetragonal lattice, which is no longer capable of superconducting, or has diminished superconducting ability.

The team used experimental evidence and modeling under pressure to actually demonstrate these previously theorized structural changes—tetragonal to collapsed tetragonal—on the atomic level. This is just the first step toward definitively determining the link between structure and superconductivity, which could potentially make higher-temperature superconductivity a real possibility.

They showed that at about 40,000 times normal atmospheric pressure (4 gigapascals), NaFe2As2 takes on the collapsed tetragonal structure. This changes the angles in the arsenic-iron-arsenic layers and is coincident with the loss in superconductivity. Moreover, they found that this transition is accompanied by a major change in bonding coordination in the formation of the interlayer arsenic-arsenic bonds. A direct consequence of this new coordination is that the system loses its two-dimensionality, and with it, superconductivity.

"Our findings are an important step in identifying the hypothesized connection between structure and superconductivity in iron-containing compounds," Goncharov said. "Understanding the loss of superconductivity on an atomic level could enhance our ease of manufacturing such compounds for practical applications, as well as improving our understanding of condensed matter physics." [26]

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

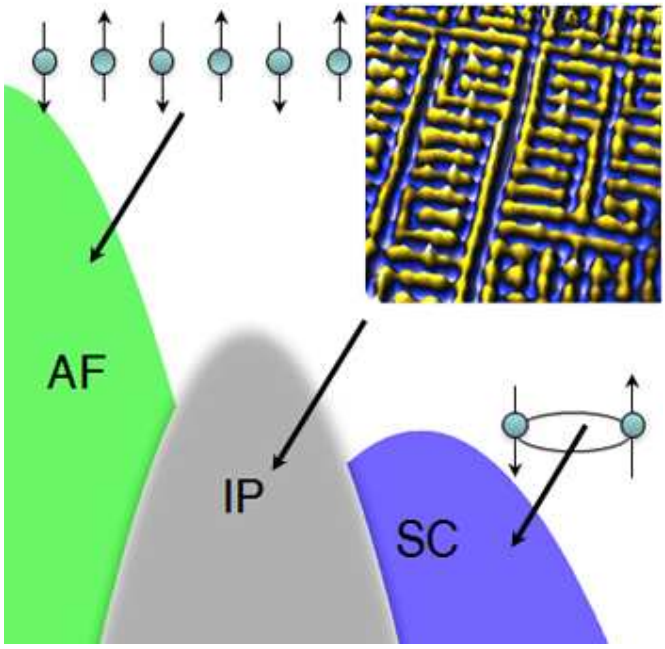
In condensed matter physics, the resonating valence bond theory (RVB) is a theoretical model that attempts to describe high temperature superconductivity, and in particular the superconductivity in cuprate compounds. It was first proposed by American physicist P. W. Anderson and the Indian theoretical 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

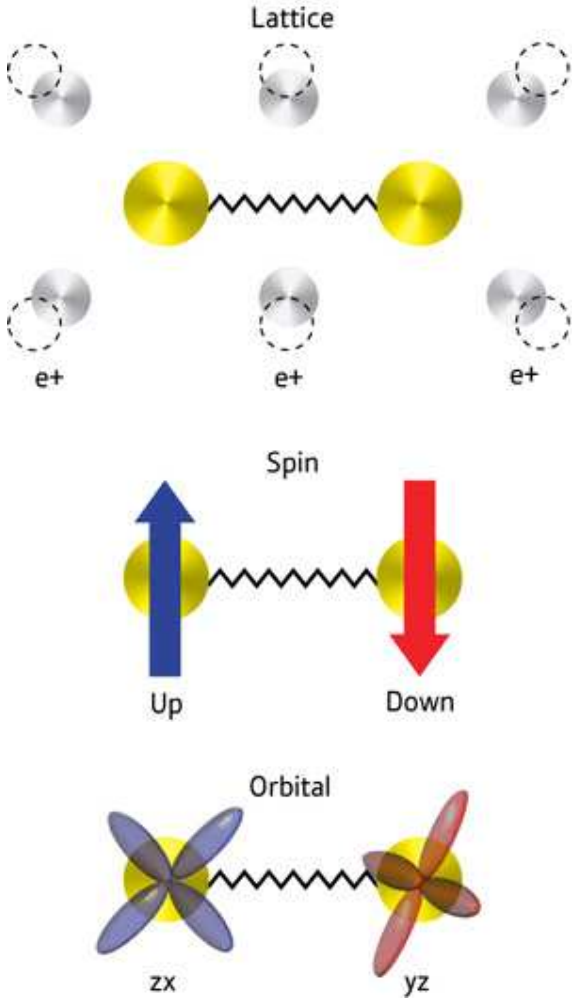
Unconventional superconductivity (SC) is said to occur when Cooper pair formation is dominated by repulsive electron–electron interactions, so that the symmetry of the pair wave function is other than an isotropic s-wave. The strong, on-site, repulsive electron–electron interactions that are the proximate 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, *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]

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]

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