X-ray from Nucleus

A team around Kilian Heeg from the Max Planck Institute for Nuclear Physics in Heidelberg has now found a way to make the spectrum of the x-ray pulses emitted by these sources even narrower. [28]

Physicists from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and Deutsches Elektronen-Synchrotron (DESY, Hamburg) have developed a method to improve the quality of X-ray images over conventional methods. [27]

A team of researchers with members from several countries in Europe has used a type of X-ray diffraction to reveal defects in the way a superconductor develops. In their paper published in the journal Nature, the team describes the technique they used to study one type of superconductor and what they saw. Erica Carlson with Perdue University offers a News & Views piece on the work done by the team in the same journal issue. [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

Sharp X-ray pulses from the atomic nucleus

X-rays make the invisible visible: they permit the way materials are structured to be determined all the way down to the level of individual atoms. In the 1950s it was x-rays which revealed the double-helix structure of DNA. With new x-ray sources, such as the XFEL free-electron laser in Hamburg, it is even possible to "film" chemical reactions. The results obtained from studies using these new x-ray sources may be about to become even more precise. A team around Kilian Heeg from the Max Planck Institute for Nuclear Physics in Heidelberg has now found a way to make the spectrum of the x-ray pulses emitted by these sources even narrower. In contrast to standard lasers, which generate light of a single colour and wavelength, x-ray sources generally produce pulses with a broad spectrum of different wavelengths. Sharper pulses could soon drive applications that were previously not feasible. This includes testing physical constants and measuring lengths and times even more precisely than can be achieved at present.

Researchers use light and other electromagnetic radiation for developing new materials at work in electronics, automobiles, aircraft or power plants, as well as for studies on biomolecules such as protein function. Electromagnetic radiation is also the tool of choice for observing chemical reactions and physical processes in the micro and nano ranges. Different types of spectroscopy use different individual wavelengths to stimulate characteristic oscillations in specific components of a structure. Which wavelengths interact with the structure – physicists use the term resonance – tells us something about their composition and how they are constructed; for example, how atoms within a molecule are arranged in space.

In contrast to visible light, which has a much lower energy, x-rays can trigger resonance not just in the electron shell of an atom, but also deep in the atomic core, its nucleus. X-ray spectroscopy therefore provides unique knowledge about materials. In addition, the resonances of some atomic nuclei are very sharp, in principle allowing extremely precise measurements.

X-ray sources generate ultra-short flashes with a broad spectrum

Modern x-ray sources such as the XFEL free electron laser in Hamburg and the PETRA III (Hamburg), and ESRF (Grenoble) synchrotron sources are prime candidates for carrying out such studies. Free-electron lasers in particular are optimized for generating very short x-ray flashes, which are primarily used to study very fast processes in the microscopic world of atoms and molecules. Ultra short light pulses, however, in turn have a broad spectrum of wavelengths. Consequently, only a small fraction of the light is at the right wavelength to cause resonance in the sample. The rest passes straight through the sample, making spectroscopy of sharp resonances rather inefficient.

It is possible to generate a very sharp x-ray spectrum – i.e. x-rays of a single wavelength – using filters; however, since this involves removing unused wavelengths, the resulting resonance signal is still weak.

The new method developed by the researchers in Heidelberg delivers a three to four-fold increase in the intensity of the resonance signal. Together with scientists from DESY in Hamburg and ESRF in Grenoble, Kilian Heeg and Jörg Evers from Christoph Keitel's Division and a team around Thomas Pfeifer at the Max Planck Institute for Nuclear Physics in Heidelberg have succeeded in making some of the x-ray radiation that would not normally interact with the sample contribute to the resonance signal. They have successfully tested their method on iron nuclei both at the ESRF in Grenoble and at the PETRA III synchrotron of DESY in Hamburg.

A tiny jolt amplifies the radiation

The researchers' approach to amplifying the x-rays is based on the fact that, when x-rays interact with iron nuclei (or any other nuclei) to produce resonance, they are re-emitted after a short delay. These re-emitted x-rays then lag exactly half a wavelength behind that part of the radiation which has passed straight through. This means that the peaks of one wave coincide exactly with the troughs of the other wave, with the result that they cancel each other out. This destructive interference attenuates the X-ray pulses at the resonant wavelength, which is also the fundamental origin of absorption of light.

"We utilize the time window of about 100 nanoseconds before the iron nuclei re-emit the x-rays," explains project leader Jörg Evers. During this time window, the researchers move the iron foil by about 40 billionths of a millimetre (0.4 angstroms). This tiny jolt has the effect of producing constructive interference between the emitted and transmitted light waves. "It's as if two rivers, the waves on one of which are offset by half a wavelength from the waves on the other, meet," says Evers, "and you shift one of the rivers by exactly this distance." This has the effect that, after the rivers meet, the waves on the two rivers move in time with each other. Wave peaks coincide with wave peaks and the waves amplify, rather than attenuating, each other. This trick, however, does not just work on light at the resonance wavelengths, but also has the reverse effect (i.e. attenuation) on a broader range of wavelengths around the resonance wavelength. Kilian Heeg puts it like this. "We squeeze otherwise unused x-ray radiation into the resonance."

To enable the physicists to move the iron foil fast enough and precisely enough, it is mounted on a piezoelectric crystal. This crystal expands or contracts in response to an applied electrical voltage. Using a specially developed computer program, the Heidelberg-based researchers were able to adjust the electrical signal that controls the piezoelectric crystal to maximize the amplification of the resonance signal.

Applications in length measurement and atomic clocks

The researchers see a wide range of potential applications for their new technique. According to Thomas Pfeifer, the procedure will expand the utility of new high-power x-ray sources for high-resolution x-ray spectroscopy. This will enable more accurate modelling of what happens in atoms and molecules. Pfeifer also stresses the utility of the technique in metrology, in particular for high-precision measurements of lengths and the quantum-mechanical definition of time. "With x-rays, it is possible to measure lengths 10,000 times more accurately than with visible light," explains Pfeifer. This can be used to study and optimize nanostructures such as computer chips and newly developed batteries. Pfeifer also envisages x-ray atomic clocks which are far more precise than even the most advanced optical atomic clocks nowadays based on visible light.

Not least, better X-ray spectroscopy could enable us to answer one of physics' great unanswered questions – whether physical constants really are constant or whether they change slowly with time. If the latter were true, resonance lines would drift slowly over time. Extremely sharp x-ray spectra would make it possible to determine whether this is the case over a relatively short period.

Evers reckons that, once mature, the technique would be relatively easy to integrate into experiments at DESY and ESRF. "It should be possible to make a shoe-box sized device that could be rapidly installed and, according to our calculations, could enable an approximately 10-fold amplification," he adds. [28]

X-ray imaging with a significantly enhanced resolution

Physicists from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and Deutsches Elektronen-Synchrotron (DESY, Hamburg) have developed a method to improve the quality of X-ray images over conventional methods. The technique, incoherent diffractive imaging (IDI), could image individual atoms in nanocrystals or molecules faster and with a much higher resolution.

For more than 100 years, X-rays have been used in crystallography to determine the structure of molecules. At the heart of the method are the principles of diffraction and superposition, to which all waves are subject: Light waves consisting of photons are deflected by the atoms in the crystal and overlap like water waves generated by obstacles in a slowly flowing stream. If a sufficient number of these photons can be measured with a detector, a characteristic diffraction pattern or wave pattern is obtained, from which the atomic structure of the crystal can be derived. This requires that photons are scattered coherently, meaning that there is a clear phase relationship between incident and reflected photons. To stay with the water analogy, this corresponds to water waves that are deflected from the obstacles without vortexes or turbulences. If photon scattering is incoherent, the fixed phase relationship between the scattered photons disperses, which makes it impossible to determine the arrangement of the atoms, just as in turbulent waters.

But coherent diffractive imaging also has a problem: "With X-ray light, in most cases incoherent scattering dominates, for example, in the form of fluorescence resulting from photon absorption and subsequent emission," says Anton Classen, member of the FAU working group Quantum Optics and Quantum Information. "This creates a diffuse background that cannot be used for coherent imaging and reduces the reproduction fidelity of coherent methods."

Making use of incoherent radiation

It is exactly this seemingly undesirable incoherent radiation that is key to the FAU researchers' novel imaging technique. "In our method, the incoherently scattered X-ray photons are not recorded over a longer period of time, but in time-resolved short snapshots," says Professor Joachim von Zanthier. "When analysing the snapshots individually, the information about the arrangement of the atoms can be obtained."

The trick is that the light diffraction is still coherent within short sequences. However, this is only possible with extremely short X-ray flashes with durations of no more than a few femtoseconds—that is, a few quadrillionths of a second—which has only been achieved recently using free-electron lasers like the European XFEL in Hamburg or the Linac Coherent Light Source (LCLS) in California.

Visualising single molecules is possible

Since the new method uses fluorescence light, a much stronger signal can be obtained, which is also scattered to significantly larger angles, gaining more detailed spatial information. In addition, filters can be used to measure the light of specific atomic species only. This makes it possible to determine the position of individual atoms in molecules and proteins with a significantly higher resolution compared to coherent imaging using X-ray light of the same wavelength. This method could improve the study of proteins in structural biology and medicine. [27]

X-ray images of cuprate superconductors reveals fractures, clumps and defects

As scientists continue with efforts to discover a superconductor that can work at room temperature, they are also studying the properties of superconductors that have already been found, a necessary prerequisite to actually using superconductors in real-world applications. In this latest effort, the researchers used scanning micro X-ray diffraction to study the structure of a copper oxide superconductor as electrons were flowing through it. As Carlson notes, the technology allowed for viewing electron-density distribution, which prior research had shown, at the quantum level, the material looked like stripped wallpaper. Instead of uniform striping however, which the team expected, they observed a mish-mash of clumps of various shapes. Further research showed that the density of the clumps was related to the how much doping was used to create the material.

Carlson further explains that the findings by the team are important for two reasons: connectivity and dimensionality. The first could have implications for the transfer of charge between different domains, possibly serving as a hindrance to flow, making such materials impractical for use. Also the odd shapes appear to reduce dimensionality options which could wind up causing superconductors to behave differently than has been theorized. Complicating things is that the clumps appear to follow a power law, which suggests they may form in a way similar to fractals—electron behavior in such structures is not very well understood.

The findings by the team suggest the path to understanding superconductors may be more complex than has been thought, though it also appears they may offer opportunities that have not yet been discovered. More work needs to be done—Carlson suggests a better observation of the morphology of the path that electrons take as they move through the material, should help. [26]

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

Conventional superconductivity

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

High-temperature superconductivity

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

Superconductivity and magnetic fields

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

Room-temperature superconductivity

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

Exciton-mediated electron pairing

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

Resonating valence bond theory

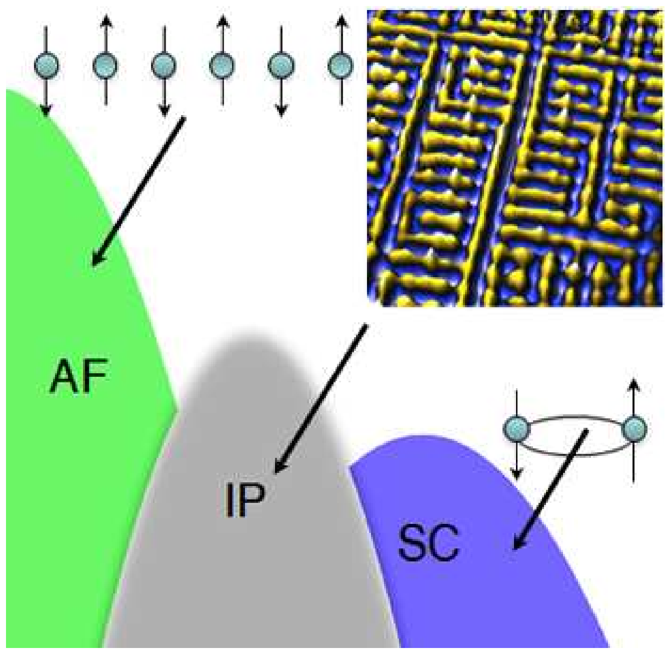
In condensed matter physics, the resonating valence bond theory (RVB) is a theoretical model that attempts to describe high temperature superconductivity, and in particular the superconductivity in cuprate compounds. It was first proposed by American physicist P. W. Anderson and the Indian theoretical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

Strongly correlated materials

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

New superconductor theory may revolutionize electrical engineering

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



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

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

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

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

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

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

A grand unified theory of exotic superconductivity?

The role of magnetism

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

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

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

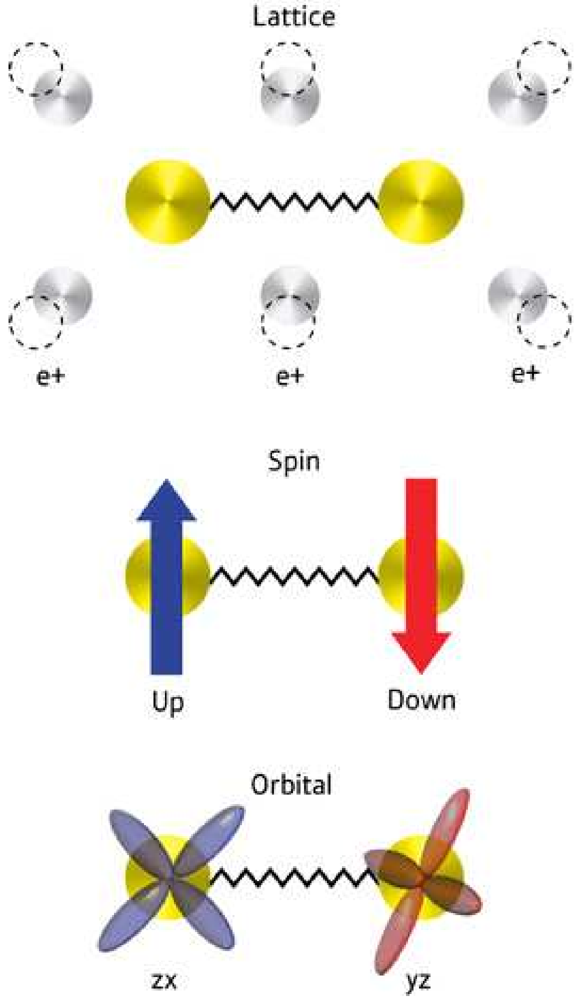
Concepts relating magnetic interactions, intertwined electronic orders, and strongly correlated superconductivity

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

Significance

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

Superconductivity's third side unmasked



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

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

Strongly correlated materials

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

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

Fermions and Bosons

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

The General Weak Interaction

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

Higgs Field and Superconductivity

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

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

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

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

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

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

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

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

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

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

The condensate wave function can be written as

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

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

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

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

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

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

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

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

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

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

This is a harmonic oscillator with frequency

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

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

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

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

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]

References:

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

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

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

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

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

[6] Superconductivity switched on by magnetic field

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

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

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

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

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

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

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

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

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

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

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

[17] Superconductivity's third side unmasked

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

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

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

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

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

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

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

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

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

[26] http://phys.org/news/2015-09-x-ray-images-cuprate-superconductors-reveals.html

[27] X-ray imaging with a significantly enhanced resolution

https://phys.org/news/2017-08-x-ray-imaging-significantly-resolution.html

[28] Sharp X-ray pulses from the atomic nucleus

https://phys.org/news/2017-08-sharp-x-ray-pulses-atomic-nucleus.html