Super – Conductivity in Vedic Physics

The Shanghai Mag Lev at Shanghai Pu Dong International Airport.

By John Frederick Sweeney

Abstract

Vedic Physics theory posits that Super Conductivity occurs amidst the 18 types of Quarks in the Thaamic type of matter, known as the Substratum, A.K.A. “Black Hole.” Specifically, Super Conductivity occurs at at an approximate phase - related velocity, between the 4th .and 6th power of light velocity, identified as Moha Thaama to Andha Thaama states. These states correspond to the Quark and Planck Mass phenomena in contemporary physics. Moreover, the phenomena described herein may help to explain the mysterious radio waves detected since the 1990’s from M82 and M87 in recent years.

Table of Contents

Introduction

This paper is based on a book about Vedic Physics that is poorly written and which had never been edited. This series of papers provides the editorial oversight needed in that original work with the hope that scientists may more readily accept a work that is correctly written, punctuated and edited according to the standards of American or International English.

The present author believes that this work is of vital importance to humanity. To allow bad writing and lack of editing stand in the way of comprehension of this monumental work would be a genuine shame and tremendous loss to the development of our species. We have the capacity to live in a much deeper way than most humans understand, and this science holds the key to that higher development and level of living.

Moreover, the book contains such startling concepts that would astound the average reader, who is inclined to believe otherwise, considering the power of today's prevailing ideological paradigm. Readers may find this work literally incredible since it may overpower their knowledge and grasp of science.

This paper proceeds quite simply: Wikipedia provides the standard explanation of Super Conductivity as understood today. The second part presents the view of Vedic Physics on Super Conductivity and how it originated.

In this way, the author hopes that the reader finds no contradiction between established paradigms and the Vedic concept. The reader may only discover the lack of imagination on the part of contemporary science, and come to understand the trail of ineptitude that has led science down the wrong path for more than a century.

Wikipedia on Super Conductivity

Superconductivity is a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a characteristic critical temperature. It was discovered by Dutch physicist Heike Kamerlingh Onnes on April 8, 1911 in Leiden. Like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon. It is characterized by the Meissner effect, the complete ejection of magnetic field lines from the interior of the superconductor as it transitions into the superconducting state. The occurrence of the Meissner effect indicates that superconductivity cannot be understood simply as the idealization of *perfect conductivity* in classical physics.

The electrical resistivity of a metallic conductor decreases gradually as temperature is lowered. In ordinary conductors, such as copper or silver, this decrease is limited by impurities and other defects. Even near absolute zero, a real sample of a normal conductor shows some resistance. In a superconductor, the resistance drops abruptly to zero when the material is cooled below its critical temperature. An electric current flowing through a loop of superconducting wire can persist indefinitely with no power source.[1]

In 1986, it was discovered that some cuprate-perovskite ceramic materials have a critical temperature above 90 K (−183 ° C).[2] Such a high transition temperature is theoretically impossible for a conventional superconductor, leading the materials to be termed high-temperature superconductors. Liquid nitrogen boils at 77 K, and superconduction at higher temperatures than this facilitates many experiments and applications that are less practical at lower temperatures.

In conventional superconductors, electrons are held together in Cooper pairs by an attraction mediated by lattice phonons. The best available model of high-temperature superconductivity is still somewhat crude. There are currently two main hypotheses - the resonating-valence-bond theory, and spin fluctuation which has the most support in the research community.[3] The second hypothesis proposed that electron pairing in high-temperature superconductors is mediated by short-range spin waves known as paramagnons.[4][5]

Superconductors can be classified in accordance with several criteria that depend on our interest in their physical properties, on the understanding we have about them, on how expensive is cooling them or on the material they are made of.

By their physical properties

- **Type I superconductors**: those having just one critical field, H_c, and changing abruptly from one state to the other when it is reached.
- **Type II superconductors**: having two critical fields, H_{c1} and H_{c2}, being a perfect superconductor under the lower critical field (H_{c1}) and leaving completely the superconducting state above the upper critical field (H_{c2}), being in a mixed state when between the critical fields.

By the understanding we have about them

- **Conventional superconductors**: those that can be fully explained with the BCS theory or related theories.
- **Unconventional superconductors**: those that failed to be explained using such theories.

This criterion is important, as the BCS theory is explaining the properties of conventional superconductors since 1957, but on the other hand there have been no satisfactory theory to explain fully unconventional superconductors. In most of cases type I superconductors are conventional, but there are several exceptions as niobium, which is both conventional and type II.

By their critical temperature

- **Low-temperature superconductors**, or LTS: those whose critical temperature is below 77K.
- **High-temperature superconductors**, or HTS: those whose critical temperature is above 77K.

This criterion is used when we want to emphasize whether or not we can cool the sample with liquid nitrogen (whose boiling point is 77K), which is much more feasible than liquid helium (the alternative to achieve the temperatures needed to get low-temperature superconductors).

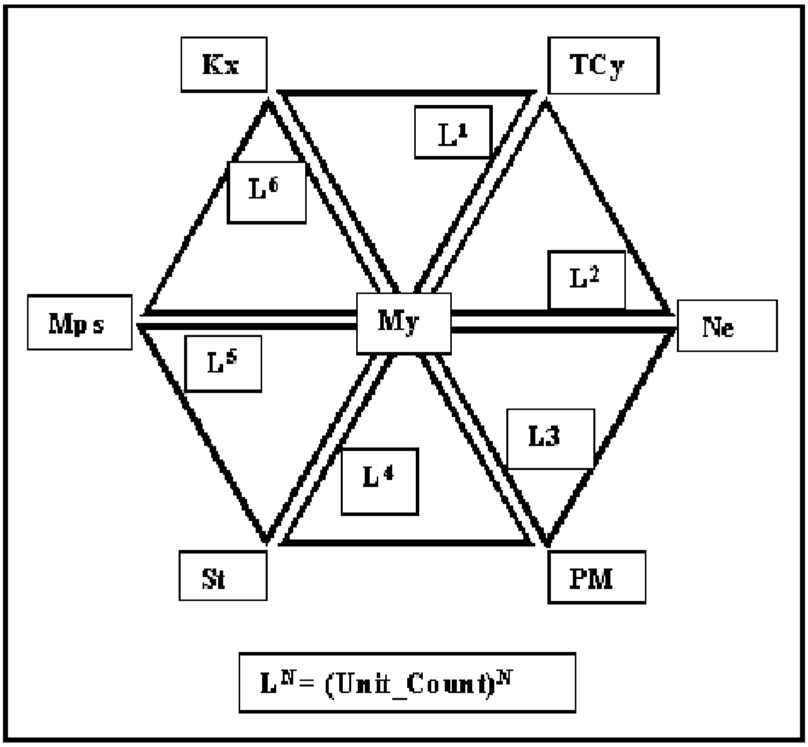
By material

- Some **Pure elements**, such as lead or mercury (but not all pure elements, as some never reach the superconducting phase).
    - Some **allotropes of carbon**, such as fullerenes, nanotubes, or diamond.[*citation needed*]

  Most superconductors made of pure elements are type I (except niobium, technetium, vanadium, silicon and the abovementioned carbons).

- **Alloys, such as**
    - **Niobium-titanium** (NbTi), whose superconducting properties were discovered in 1962.
- **Ceramics, which include**
    - **The YBCO family**, which are several yttrium-barium-copper oxides, especially $YBa_2Cu_3O_7$. They are the most famous high-temperature superconductors.
    - **Magnesium diboride** (MgB_2), whose critical temperature is 39K,[1] being the conventional superconductor with the highest known temperature.

Vedic Physics Explanation of Super Conductivity



Applying a modern flow chart concept, any unitary yardstick of logic placed in a minimal sequence of six equations of proof would close the loop in a circular mode and subsequent placements would only repeat the process already covered.

Further, the six logical yardsticks placed in a hexagonal form, automatically connected every vertex to the centre by the same unit of logic, thereby increasing the six sequential connections to 12, the additional 6 being simultaneous; forming a hexagonal ring with six spokes.

This is a concept of positive simultaneous affirmation or the principle of Siddhi (analysis of logical stream of information in a simultaneous mode) in Sanskrit, that an individual can apply to himself to know that his conclusions are correct within the framework of the chosen logic.

Perfection in real time control of a functioning system is ensured by the inclusion of redundant or parallel units operating simultaneously, but it is a negative use of the foregoing principle, for it moronically repeats the same process and is a trade - off obtained by sacrificing efficiency for higher reliability.

However, in simultaneous affirmation, which in effect is an incremental form of redundancy, the results of the previous analysis are the inputs to the next sequence, and that effectively changes the scale of the repetitive process.

In effect, it improves the confirmatory process by the power and is therefore highly efficient in exposing deviations as a value magnified by the power.

There are similar parallel processes in nature that improves performance many times over by creating a condition called negative resistance that produces an effective avalanche, which leads to resonant coherent states such as the phenomenon of superconductivity, identified as the Moha – Mahamoha – Andha Thaama Thaamasic regions.

Chart of Vedic Physics Parameters

Level	Vedic Physics	Western Science	
	Moolaprakriti	No concept	Kx = My
1	the constant rate of change		
2	Satwic Bhava	charge	Ne = My (L2) (2π/7) ^2.
3	Rajasic Linga/Bhava	EM / lepton / boson / hadron region	Me = My (L3)/P
4	Bhava Moha Thaama	Baryon region	St = My
5	Linga Mahamoha Thaama	Quark region	My / (7+1/7)
6	Andha Thaama	Planck Mass	Kx = My
7	Purusha / Abhiman core	Black Hole	10 ^25 GEV
7-1	Ahankar Tunnel	No concept	Tcy = My (L)/7

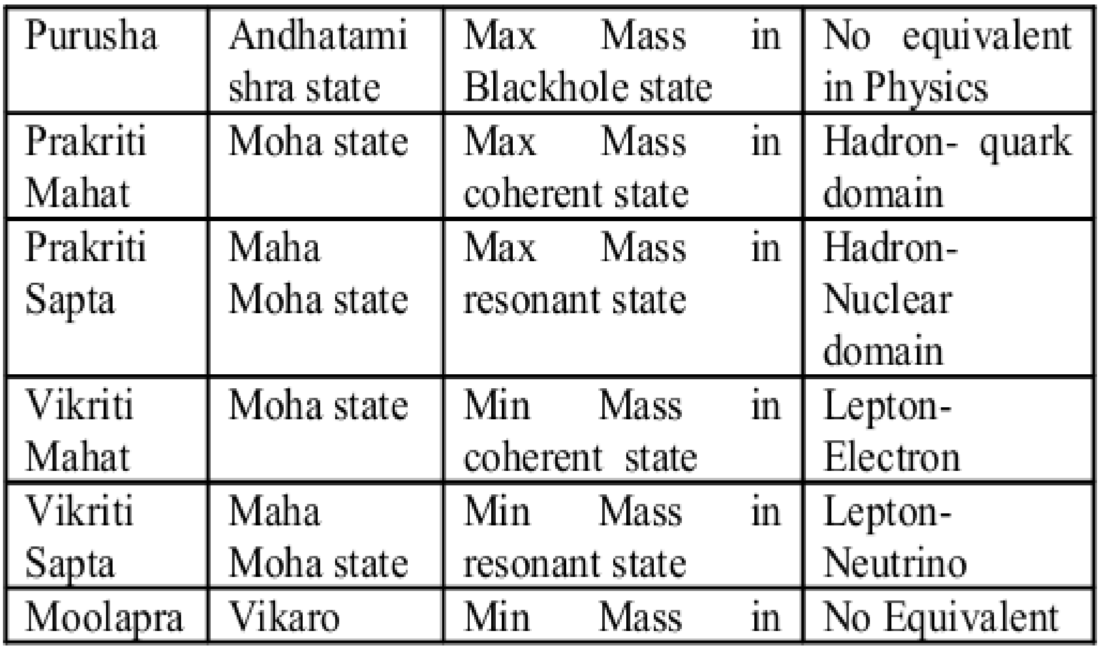
The coherent Purusha state or blackhole of maximum mass or inertia or delay or ‘ static’ state per cycle is Kx = My (L6) . The next state of increase in activity equals the Planck Mass equivalent of Mahad Prakriti state of Mps = My (L5)/(7+1/7). Third, the state of increase in activity equals the transition activity or the Stress transmigration ratio of 7 states St = My (L4).

Fourthly, the stable, neutral and fundamental nuclear state of Prakrithi or the Neutron as PM = My (L3)/Px. Here the interlocked Mahad Vikrithi or acclerative state of the Electron as Me equals the same My (L3)/Px. Fifth the fundamental particulate state of the Vikrithi or Neutrino as Ne = My (L2) (2π/7)

^2. Sixthly, the fundamental fraction of a time-cycle of simultaneity when the difference between the static and dynamic state is nil as Tcy = My (L)/7 and equals the Planck time in quantum theory.

The identification of Sathva as the electro - magnetic radiating force; Raja as the electro-weak bonding force and Thaama as the strong nuclear force, complements the concept of the triad of forces or GUNA, as the different phases of a standardised wave - form of an oscillating volume in the Substratum.

The Abhiman / Ahankar Factor indicates that distant gravitational potential changes can be detected, only as a local phase change, at an approximate phase - related velocity, between the 4th .and 6th power of light velocity, identified as Moha Thaama to Andha Thaama states, covering 10 ^18 modes of stress-phase- changes, not as a wave in the classical sense.



Purusha	Andhatamishra state	Max Mass in Blackhole state	No equivalent in Physics
Prakriti Mahat	Moha state	Max Mass in coherent state	Hadron- quark domain
Prakriti Sapta	Maha Moha state	Max Mass in resonant state	Hadron-Nuclear domain
Vikriti Mahat	Moha state	Min Mass in coherent state	Lepton-Electron
Vikriti Sapta	Maha Moha state	Min Mass in resonant state	Lepton-Neutrino
Moolapra	Vikaro	Min Mass in	No Equivalent

Only in a holographic Substratum could the cerebral vibrations resonate in synchrony with itself to faithfully reproduce an instant of its reality. Just as electromagnetic sequential resonance is the base for the entire spectrum of communication & entertainment devices, the same phenomenon in the form of simultaneous trans - migratory resonance, called coherent, super - posed, super - conductive activity, forms the base for a much wider spectrum of para - psychological, astrological, tidal and related spontaneous phenomenon.

In Vedic Physics this coherent state is encountered in the form of ferromagnetism, superconductivity, asymptotic freedom in quark behaviour etc. Based on Vedic Physics, one would say that all knowledge, intelligence, experience and existence itself is only a vibratory ensemble, with an extended field of reducing vibratory count-rate, and ending in equilibrium. While there is no doubt what so ever of the existence of the para - normal, it is not a magical quality.

Extending the principle of relativity, mathematically, to the forbidden zone of 'simultaneity', confirms the existence of the third order-damping interaction. It was the unification point of all forces hidden in the mathematics of self-similarity. Physics has discovered neither theoretically nor experimentally the existence of such a force.

However, the anomalies at the Planckian level of interactions, superconductivity, ferromagnetism and the EPR paradox, demands such a phenomenon to balance out the highly energetic behaviour of so - called empty space.

The reasons for this failure were elementary. The current scientific concept of an empty-space cannot logically justify the existence of any reactive property in it. Moreover, the third – order - damping phenomenon followed principles of self-similarity and scale invariance at the fundamental level.

Constant	**Particle**	**Vedic Region**	
C1	Photon		
C^2	Boson & Lepton		
C^3	Hadron		
C^4	Baryon		
C^5			
C^6			

Conclusion

The previous section on Vedic Physics consists of all the mentions in the original book about Super Conductivity and the places where it may be located in the atom and sub – atomic structures. For this reason, the section may read somewhat in a rough manner, despite best editing efforts to provide a smooth flow of logic.

Essentially, the reader may gather that Super Conductivity has to do with the concept of “negative resistance that produces an effective avalanche, which leads to resonant coherent states such as the phenomenon of superconductivity, identified as the Moha – Mahamoha – Andha Thaama Thaamasic regions.”

The reader may then see from the chart that

5	Linga Mahamoha Thaama	Quark region	
6	Andha Thaama	Planck Mass	

The Thaama region is that of what is presently considered as “Black Hole.”

Then the author explains:

The Abhiman / Ahankar Factor indicates that distant gravitational potential changes can be detected, only as a local phase change, at an approximate phase - related velocity, between the 4th .and 6th power of light velocity, identified as Moha Thaama to Andha Thaama states, covering 10 ^18 modes of stress-phase- changes, not as a wave in the classical sense.

This paragraph tells us that the speed of such interactions is 4 to 6 x C or the speed of light (the C in Vedic Physics is calculated in a different manner from physics, axiomatically, yet the two figures are close).

Next, the author explains that such states may only be coherent ones, which means to say states of matter which are in balance. Earlier papers by the author, published on Vixra, indicate that the 18 modes of stress and phase changes refers to the 18 varieties of Quarks, of which contemporary physics has only discovered six at the time of this writing.

Original research by the author of this paper indicates that Super Conductivity may be related to heretofore inexplicable astronomical phenomena. In the 1990’s, and then again in recent years, Galaxies M82 and M87 have given off unusual and inexplicable radio waves, at speeds between four and six times that of the speed of light.

Since by definition in Vedic Physics, those speeds correspond to Quarks and these regions of particles:

5	Linga Mahamoha Thaama	Quark region	
6	Andha Thaama	Planck Mass	

The author hypothesizes that the phenomena at M82 and M87 took place in these regions of Vedic Physics and they involve Quarks, the Planck Mass and Super – Conductivity. The author is writing a paper on this subject at present.

The last two paragraphs indicate the relationship between Super Conductivity and the para – normal. In other words, these cannot be separated, for the original author has stated that the para – normal is not magic, which brings to mind the quote from Sir Arthur C. Clark about his definition of magic.

Clarke's Three Laws are three "laws" of prediction formulated by the British writer Arthur C. Clarke. They are:

1. When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.
2. The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
3. Any sufficiently advanced technology is indistinguishable from magic.

Sir Roger Penrose provides the author's favorite example of No. 1, with his disregard of the “lost cause” Octonions, since they figure so intimately in the atomic model described in this paper, along with the Sedenions and Trigintaduonions.

Super Conductivity is a way of venturing past the limits of the possible, it has been done, and the results are visible in Shanghai, with the Mag Lev shuttle between Pu Dong and the distant Pu Dong International Airport at Shanghai.

By Clark’s definition, then, Vedic Physics is indeed a sufficiently advanced technology, which accounts for what many have described as “magic” for the past few millennia. Humanity has been in steady decline for the past twelve thousand years or so, and perhaps our only salvation is to embrace this “magical” advanced technology.

“Magic” is how some might explain Qi Men Dun Jia, the highly advanced method of divination preserved by the Chinese for millenia, which gave the impetus to this series of papers on Vixra. While Qi Men Dun Jia may appear magical to most, or as superstition to many more, it is in fact grounded in mathematics which contemporary humanity may prove capable of understanding.

Appendix I The EPR Paradox

Electron paramagnetic resonance (EPR) or **electron spin resonance** (ESR) spectroscopy is a technique for studying materials with unpaired electrons. The basic concepts of EPR are analogous to those of nuclear magnetic resonance (NMR), but it is electron spins that are excited instead of the spins of atomic nuclei.

Because most stable molecules have all their electrons paired, the EPR technique is less widely used than NMR. However, this limitation also means that EPR offers great specificity, since ordinary chemical solvents and matrices do not give rise to EPR spectra.

EPR was first observed in Kazan State University by Soviet physicist Yevgeny Zavoisky in 1944, and was developed independently at the same time by Brebis Bleaney at the University of Oxford.

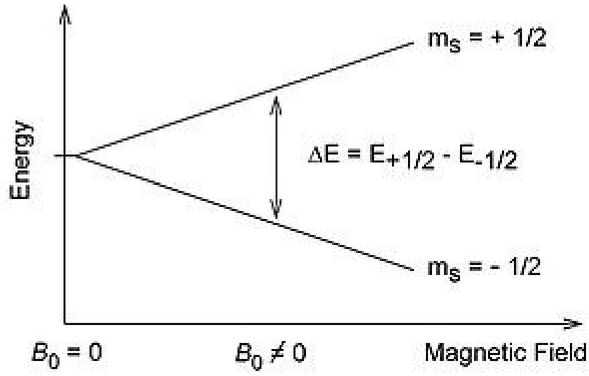
Origin of an EPR signal

Every electron has a magnetic moment and spin quantum number $s = \frac{1}{2}$, with magnetic components $m_\mathrm{s} = +\frac{1}{2}$and $m_\mathrm{s} = -\frac{1}{2}$. In the presence of an external magnetic field with strength B_0, the electron's magnetic moment aligns itself either parallel ($m_\mathrm{s} = -\frac{1}{2}$) or antiparallel ($m_\mathrm{s} = +\frac{1}{2}$) to the field, each alignment having a specific energy due to the Zeeman effect :

$E = m_\mathrm{s} g_\mathrm{e} \mu_\mathrm{B} B_0$where

- $g_\mathrm{e}$is the electron's so-called g-factor (see also the Landé g-factor). $g_\mathrm{e} = 2.0023$for the free electron[1]
- $\mu_\mathrm{B}$is the Bohr magneton.

Therefore, the separation between the lower and the upper state is $\Delta E = g_\mathrm{e}\mu_\mathrm{B}B_0$ for unpaired free electrons. This equation implies that the splitting of the energy levels is directly proportional to the magnetic field's strength, as shown in the diagram below.

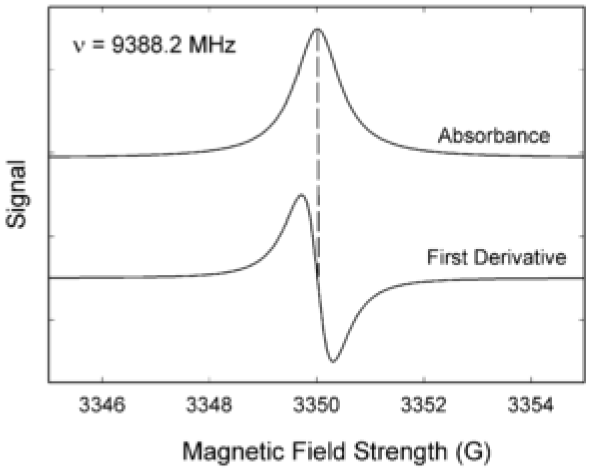


An unpaired electron can move between the two energy levels by either absorbing or emitting a photon of energy $h\nu$ such that the resonance condition, $h\nu = \Delta E$, is obeyed. This leads to the fundamental equation of EPR spectroscopy: $h\nu = g_\mathrm{e}\mu_\mathrm{B}B_0$.

Experimentally, this equation permits a large combination of frequency and magnetic field values, but the great majority of EPR measurements are made with microwaves in the 9000 – 10000 MHz (9 – 10 GHz) region, with fields corresponding to about 3500 G (0.35 T).

Furthermore, EPR spectra can be generated by either varying the photon frequency incident on a sample while holding the magnetic field constant or doing the reverse. In practice, it is usually the frequency that is kept fixed. A collection of paramagnetic centers, such as free radicals, is exposed to microwaves at a fixed frequency. By increasing an external magnetic field, the gap between the $m_\mathrm{s} = +\tfrac{1}{2}$ and $m_\mathrm{s} = -\tfrac{1}{2}$ energy states is widened until it matches the energy of the microwaves, as represented by the double-arrow in the diagram above.

At this point the unpaired electrons can move between their two spin states. Since there typically are more electrons in the lower state, due to the Maxwell-Boltzmann distribution (see below), there is a net absorption of energy, and it is this absorption that is monitored and converted into a spectrum. The upper spectrum below is the simulated absorption for a system of free electrons in a varying magnetic field. The lower spectrum is the first derivative of the absorption spectrum. The latter is the most common way to record and publish EPR spectra.



For the microwave frequency of 9388.2 MHz, the predicted resonance position is a magnetic field of about $B_0 = h\nu / g_e \mu_B$= 0.3350 tesla = 3350 gauss.

Because of electron-nuclear mass differences, the magnetic moment of an electron is substantially larger than the corresponding quantity for any nucleus, so that a much higher electromagnetic frequency is needed to bring about a spin resonance with an electron than with a nucleus, at identical magnetic field strengths. For example, for the field of 3350 G shown at the right, spin resonance occurs near 9388.2 MHz for an electron compared to only about 14.3 MHz for ^{1}H nuclei. (For NMR spectroscopy, the corresponding resonance equation is $h\nu = g_N \mu_N B_0$where $g_N$and $\mu_N$depend on the nucleus under study.)

Maxwell-Boltzmann distribution

In practice, EPR samples consist of collections of many paramagnetic species, and not single isolated paramagnetic centers. If the population of radicals is in thermodynamic equilibrium, its statistical distribution is described by the Maxwell-Boltzmann equation

$$\frac{n_{\text{upper}}}{n_{\text{lower}}} = \exp\left(-\frac{E_{\text{upper}} - E_{\text{lower}}}{kT}\right) = \exp\left(-\frac{\Delta E}{kT}\right) = \exp\left(-\frac{\epsilon}{kT}\right) = \exp\left(-\frac{h\nu}{kT}\right)(Eq.1)$$

where $n_{\mathbf{upper}}$is the number of paramagnetic centers occupying the upper energy state, $k$is the Boltzmann constant, and $T$is the temperature in kelvins. At 298 K, X-band microwave frequencies (ν ≈ 9.75 GHz) give $n_{\mathbf{upper}}/n_{\mathbf{lower}}\approx$ 0.998, meaning that the upper energy level has a smaller population than the lower one. Therefore, transitions from the lower to the higher level are more probable than the reverse, which is why there is a net absorption of energy.

The sensitivity of the EPR method (i.e., the minimum number of detectable spins $N_{\mathbf{min}}$) depends on the photon frequency νaccording to

$$N_{\text{min}} = \frac{k_1 V}{Q_0 k_f \nu^2 P^{1/2}}(Eq.2)$$

where $k_1$is a constant, $V$is the sample's volume, $Q_0$is the unloaded quality factor of the microwave cavity (sample chamber), $k_f$is the cavity filling coefficient, and $P$is the microwave power in the spectrometer cavity. With $k_f$and Pbeing constants, $N_{\mathbf{min}}$~ $(Q_0\nu^2)^{-1}$, i.e., $N_{\mathbf{min}}$~ $\nu^{-\alpha}$, where $\alpha\approx$ 1.5. In practice, αcan change varying from 0.5 to 4.5 depending on spectrometer characteristics, resonance conditions, and sample size.

A great sensitivity is therefore obtained with a low detection limit $N_{\mathbf{min}}$and a large number of spins. Therefore, the required parameters are:

- A high spectrometer frequency to maximize the eq.2. Common frequencies are discussed below
- A low temperature to decrease the number of spin at the high level of energy as shown in eq.1. This condition explain why spectra are often recorded on sample at the boiling point of liquid nitrogen or liquid helium.

Spectral parameters

In real systems, electrons are normally not solitary, but are associated with one or more atoms. There are several important consequences of this:

1. An unpaired electron can gain or lose angular momentum, which can change the value of its *g*-factor, causing it to differ from g_e. This is especially significant for chemical systems with transition-metal ions.
2. The magnetic moment of a nucleus with a non-zero nuclear spin will affect any unpaired electrons associated with that atom. This leads to the phenomenon of hyperfine coupling, analogous to J-coupling in NMR, splitting the EPR resonance signal into doublets, triplets and so forth.
3. Interactions of an unpaired electron with its environment influence the shape of an EPR spectral line. Line shapes can yield information about, for example, rates of chemical reactions.[ref needed]
4. The *g*-factor and hyperfine coupling in an atom or molecule may not be the same for all orientations of an unpaired electron in an external magnetic field. This anisotropy depends upon the electronic structure of the atom or molecule (e.g., free radical) in question, and so can provide information about the atomic or molecular orbital containing the unpaired electron.

The *g* factor

Knowledge of the *g*-factor can give information about a paramagnetic center's electronic structure. An unpaired electron responds not only to a spectrometer's applied magnetic field B_0but also to any local magnetic fields of atoms or molecules. The effective field B_{eff} experienced by an electron is thus written

$$B_{\text{eff}} = B_0(1 - \sigma)$$

where σincludes the effects of local fields (σ can be positive or negative). Therefore, the $h\nu = g_e\mu_B B_{\text{eff}}$resonance condition (above) is rewritten as follows:

$$h\nu = g_e\mu_B B_{\text{eff}} = g_e\mu_B B_0(1 - \sigma)$$

The quantity $g_e(1-\sigma)$is denoted $g$and called simply the g-factor, so that the final resonance equation becomes

$$h\nu = g\mu_B B_0$$

This last equation is used to determine $g$in an EPR experiment by measuring the field and the frequency at which resonance occurs. If $g$does not equal $g_e$the implication is that the ratio of the unpaired electron's spin magnetic moment to its angular momentum differs from the free electron value.

Since an electron's spin magnetic moment is constant (approximately the Bohr magneton), then the electron must have gained or lost angular momentum through spin-orbit coupling. Because the mechanisms of spin-orbit coupling are well understood, the magnitude of the change gives information about the nature of the atomic or molecular orbital containing the unpaired electron.

In general, the g factor is not a number but a second-rank tensor represented by nine numbers arranged in a 3×3 matrix. The principal axes of this tensor are determined by the local fields, for example, by the local atomic arrangement around the unpaired spin in a solid or in a molecule. Choosing an appropriate coordinate system (say, x,y,z) allows to "diagonalize" this tensor thereby reducing the maximum number of its components from nine to three, g_{xx}, g_{yy} and g_{zz}.

For a single spin experiencing only Zeeman interaction with an external magnetic field, the position of the EPR resonance is given by the expression $g_{xx}B_x + g_{yy}B_y + g_{zz}B_z$. Here B_x, B_y and B_z are the components of the magnetic field vector in the coordinate system (x,y,z); their magnitudes change as the field is rotated, so as the frequency of the resonance.

For a large ensemble of randomly oriented spins, the EPR spectrum consists three peaks of characteristic shape at frequencies $g_{xx}B_0$, $g_{yy}B_0$ and $g_{zz}B_0$: the low-frequency peak is positive in first-derivative spectra, the high-frequency peak is negative, and the central peak is bipolar.

Such situation is commonly observed in powders and the spectra are therefore called "powder-pattern spectra". In crystals, the number of EPR lines is determined by the number of crystallographically equivalent orientations of the EPR spin (called "EPR center").

Hyperfine coupling

Since the source of an EPR spectrum is a change in an electron's spin state, it might be thought that all EPR spectra for a single electron spin would consist of one line. However, the interaction of an unpaired electron, by way of its magnetic moment, with nearby nuclear spins, results in additional allowed energy states and, in turn, multi-lined spectra.

In such cases, the spacing between the EPR spectral lines indicates the degree of interaction between the unpaired electron and the perturbing nuclei. The hyperfine coupling constant of a nucleus is directly related to the spectral line spacing and, in the simplest cases, is essentially the spacing itself.

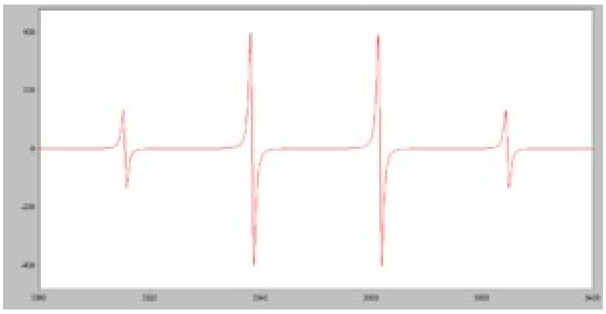
Two common mechanisms by which electrons and nuclei interact are the Fermi contact interaction and by dipolar interaction. The former applies largely to the case of isotropic interactions (independent of sample orientation in a magnetic field) and the latter to the case of anisotropic interactions (spectra dependent on sample orientation in a magnetic field).

Spin polarization is a third mechanism for interactions between an unpaired electron and a nuclear spin, being especially important for π-electron organic radicals, such as the benzene radical anion. The symbols "*a*" or "*A*" are used for isotropic hyperfine coupling constants while "*B*" is usually employed for anisotropic hyperfine coupling constants.[2]

In many cases, the isotropic hyperfine splitting pattern for a radical freely tumbling in a solution (isotropic system) can be predicted.

- For a radical having M equivalent nuclei, each with a spin of I, the number of EPR lines expected is $2MI + 1$. As an example, the methyl radical, CH_3, has three ^1H nuclei each with $I = 1/2$, and so the number of lines expected is $2MI + 1 = 2(3)(1/2) + 1 = 4$, which is as observed.

- For a radical having M_1 equivalent nuclei, each with a spin of I_1, and a group of M_2 equivalent nuclei, each with a spin of I_2, the number of lines expected is $(2M_1I_1 + 1)(2M_2I_2 + 1)$. As an example, the methoxymethyl radical, $H_2C(OCH_3)$, has two equivalent ^1H nuclei each with $I = 1/2$ and three equivalent ^1H nuclei each with $I = 1/2$, and so the number of lines expected is $(2M_1I_1 + 1)\ (2M_2I_2 + 1) = [2(2)(1/2) + 1][2(3)(1/2) + 1] = [3]$ $[4] = 12$, again as observed.



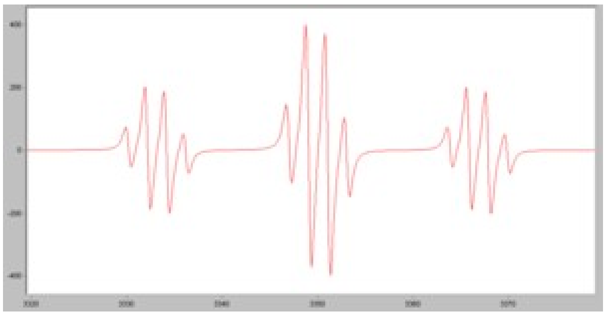
Simulated EPR spectrum of the CH_3 radical

- The above can be extended to predict the number of lines for any number of nuclei.

While it is easy to predict the number of lines a radical's EPR spectrum should show, the reverse problem, unraveling a complex multi-line EPR spectrum and assigning the various spacings to specific nuclei, is more difficult.

In the oft-encountered case of $I = 1/2$ nuclei (e.g., ^1H, ^{19}F, ^{31}P), the line intensities produced by a population of radicals, each possessing M equivalent nuclei, will follow Pascal's triangle.

For example, the spectrum at the right shows that the three ^1H nuclei of the CH_3 radical give rise to $2MI + 1 = 2(3)(1/2) + 1 = 4$ lines with a 1:3:3:1 ratio. The line spacing gives a hyperfine coupling constant of $a_H = 23\ G$ for each of the three ^1H nuclei. Note again that the lines in this spectrum are *first derivatives* of absorptions.



Simulated EPR spectrum of the $H_2C(OCH_3)$ radical

As a second example, consider the methoxymethyl radical, $H_2C(OCH_3)$. The two equivalent methyl hydrogens will give an overall 1:2:1 EPR pattern, each component of which is further split by the three methoxy hydrogens into a 1:3:3:1 pattern to give a total of 3×4 = 12 lines, a triplet of quartets.

A simulation of the observed EPR spectrum is shown at the right, and agrees with the 12-line prediction and the expected line intensities. Note that the smaller coupling constant (smaller line spacing) is due to the three methoxy hydrogens, while the larger coupling constant (line spacing) is from the two hydrogens bonded directly to the carbon atom bearing the unpaired electron.

It is often the case that coupling constants decrease in size with distance from a radical's unpaired electron, but there are some notable exceptions, such as the ethyl radical (CH_2CH_3).

Resonance linewidth definition

Resonance line - widths are defined in terms of the magnetic induction *B*, and its corresponding units, and are measured along the *x* axis of an EPR spectrum, from a line's center to a chosen reference point of the line. These defined widths are called halfwidths and possess some advantages: for asymmetric lines values of left and right halfwidth can be given.

The half - width $\Delta B_h$is the distance measured from the line's center to the point in which absorption value has half of maximal absorption value in the center of resonance line. First inclination width $\Delta B_{1/2}$is a distance from center of the line to the point of maximal absorption curve inclination. In practice, a full definition of linewidth is used. For symmetric lines, halfwidth $\Delta B_{1/2} = 2\Delta B_h$, and full inclination width $\Delta B_{max} = 2\Delta B_{1s}$

Pulsed EPR

For more details on this topic, see Pulsed EPR.

The dynamics of electron spins are best studied with pulsed measurements.[3] Microwave pulses typically 10 – 100 ns long are used to control the spins in the Bloch sphere. The spin-lattice relaxation time can be measured with an inversion recovery experiment.

As with pulsed NMR, the Hahn echo is central to many pulsed EPR experiments. A Hahn echo decay experiment can be used to measure the dephasing time, as shown in the animation below. The size of the echo is recorded for different spacings of the two pulses. This reveals the decoherence, which is not refocused by the πpulse. In simple cases, an exponential decay is measured, which is described by the T_2time.

High-field high-frequency measurements

High-field high-frequency EPR measurements are sometimes needed to detect subtle spectroscopic details. However, for many years the use of electromagnets to produce the needed fields above 1.5 T was impossible, due principally to limitations of traditional magnet materials.

The first multifunctional millimeter EPR spectrometer with a superconducting solenoid was described in the early 1970s by Prof. Y. S. Lebedev's group (Russian Institute of Chemical Physics, Moscow) in collaboration with L. G. Oranski's group (Ukrainian Physics and Technics Institute, Donetsk), which began working in the Institute of Problems of Chemical Physics, Chernogolovka around 1975.[8]

Two decades later, a W-band EPR spectrometer was produced as a small commercial line by the German Bruker Company, initiating the expansion of W-band EPR techniques into medium-sized academic laboratories.

Today there still are only a few scientific centers in the world capable of high-field high-frequency EPR; among them are the Grenoble High Magnetic Field Laboratory in Grenoble, France, the Physics

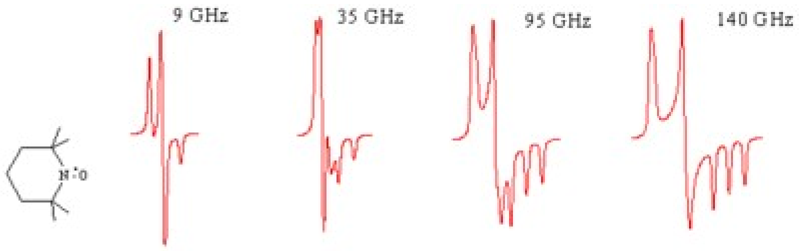
Department in Freie Universität Berlin, the National High Magnetic Field Laboratory in Tallahassee, US, the National Center for Advanced ESR Technology (ACERT) at Cornell University in Ithaca, US, the Department of Physiology, and Biophysics at Albert Einstein College of Medicine, Bronx, NY, the HLD and IFW in Dresden, Germany, the Institute of Physics of Complex Matter in Lausanne in Switzerland, and the Institute of Physics of the Leiden University, Netherlands.

Waveband	**L**	**S**	**C**	**X**	**P**	**K**	**Q**	**U**	**V**	**E**	**W**	**F**	**D**	**—**	**J**	**—**
λ/mm	300	100	75	30	20	12.5	8.5	6	4.6	4	3.2	2.7	2.1	1.6	1.1	0.83
ν/GHz	1	3	4	10	15	24	35	50	65	75	95	111	140	190	285	360
B_0/T	0.03	0.11	0.14	0.33	0.54	0.86	1.25	1.8	2.3	2.7	3.5	3.9	4.9	6.8	10.2	12.8

The EPR waveband is stipulated by the frequency or wavelength of a spectrometer's microwave source (see Table).

EPR experiments often are conducted at X and, less commonly, Q bands, mainly due to the ready availability of the necessary microwave components (which originally were developed for radar applications).

A second reason for widespread X and Q band measurements is that electromagnets can reliably generate fields up to about 1 tesla. However, the low spectral resolution over *g*-factor at these wavebands limits the study of paramagnetic centers with comparatively low anisotropic magnetic parameters. Measurements at $\nu >$ 40 GHz, in the millimeter wavelength region, offer the following advantages:



EPR spectra of TEMPO, a nitroxide radical, as a function of frequency. Note the improvement in resolution from left to right.[8]

1. EPR spectra are simplified due to the reduction of second-order effects at high fields.
2. Increase in orientation selectivity and sensitivity in the investigation of disordered systems.
3. The informativity and precision of pulse methods, e.g., ENDOR also increase at high magnetic fields.

4. Accessibility of spin systems with larger zero-field splitting due to the larger microwave quantum energy $h\nu$.
5. The higher spectral resolution over g-factor, which increases with irradiation frequency ν and external magnetic field B_0. This is used to investigate the structure, polarity, and dynamics of radical microenvironments in spin-modified organic and biological systems through the spin label and probe method. The figure shows how spectral resolution improves with increasing frequency.
6. Saturation of paramagnetic centers occurs at a comparatively low microwave polarizing field B_1, due to the exponential dependence of the number of excited spins on the radiation frequency ν. This effect can be successfully used to study the relaxation and dynamics of paramagnetic centers as well as of superslow motion in the systems under study.
7. The cross-relaxation of paramagnetic centers decreases dramatically at high magnetic fields, making it easier to obtain more-precise and more-complete information about the system under study.[8]

This was demonstrated experimentally in the study of various biological, polymeric and model systems at D-band EPR.[9]

Appendix II Planck Mass

In physics, the **Planck mass**, denoted by m_P, is the unit of mass in the system of natural units known as Planck units. It is defined so that

$$m_\mathrm{P} = \sqrt{\frac{\hbar c}{G}} \approx 1.2209 \times 10^{19}\ \mathrm{GeV}/c^2 = 2.17651(13) \times 10^{-8}\ \mathrm{kg},\ (\text{or } 21.7651\ \mu\mathrm{g}),$$ [1]

where c is the speed of light in a vacuum, G is the gravitational constant, and $\hbar$ is the reduced Planck constant.

Particle physicists and cosmologists often use the **reduced Planck mass**, which is

$$\sqrt{\frac{\hbar c}{8\pi G}} \approx 4.341 \times 10^{-9}\ \mathrm{kg} = 2.435 \times 10^{18}\ \mathrm{GeV}/c^2.$$

The added factor of $1/\sqrt{8\pi}$ simplifies a number of equations in general relativity.

The name honors Max Planck because the unit measures the approximate scale at which quantum effects, here in the case of gravity, become important. Quantum effects are typified by the magnitude of Planck's constant, $h = 2\pi\hbar$.

The Planck mass is approximately the mass of the Planck particle, a hypothetical minuscule black hole whose Schwarzschild radius equals the Planck length.

Unlike all other Planck base units and most Planck derived units, the Planck mass has a scale more or less conceivable to humans. It is traditionally said to be about the mass of a flea, but more accurately it is about the mass of a flea egg.

The Planck mass is an idealized mass thought to have special significance for quantum gravity when general relativity *and* the fundamentals of quantum physics become mutually important to describe mechanics.

Derivations

Dimensional analysis

The formula for the Planck mass can be derived by dimensional analysis. In this approach, one starts with the three physical constants ħ, c, and G, and attempt to combine them to get a quantity with units of mass. The expected formula is of the form

$$m_P = c^{n_1} G^{n_2} \hbar^{n_3},$$

where n_1, n_2, n_3 are constants to be determined by matching the dimensions of both sides. Using the symbol L for length, T for time, M for mass, and writing "[x]" for the dimensions of some physical quantity x, we have the following:

$$[c] = L T^{-1}$$

$$[G] = M^{-1} L^3 T^{-2}$$

$$[\hbar] = M^1 L^2 T^{-1}.$$

Therefore,

$$\left[c^{n_1} G^{n_2} \hbar^{n_3}\right] = M^{-n_2+n_3} L^{n_1+3n_2+2n_3} T^{-n_1-2n_2-n_3}$$

If one wants dimensions of mass, the following equations must hold:

$$-n_2 + n_3 = 1$$
$$n_1 + 3n_2 + 2n_3 = 0$$
$$-n_1 - 2n_2 - n_3 = 0.$$

The solution of this system is:

$$n_1 = 1/2, n_2 = -1/2, n_3 = 1/2.$$

Thus, the Planck mass is:

$$m_{\mathrm{P}} = c^{1/2} G^{-1/2} \hbar^{1/2} = \sqrt{\frac{c\hbar}{G}}.$$

Elimination of a coupling constant

Equivalently, the Planck mass is defined such that the gravitational potential energy between two masses m_{P} of separation r is equal to the energy of a photon (or graviton) of angular wavelength r (see the Planck relation), or that their ratio equals one.

$$E = \frac{G m_{\mathrm{P}}^2}{r} = \frac{\hbar c}{r}$$

Multiplying through,

$$G m_{\mathrm{P}}^2 = \hbar c$$

This equation has units of energy times length and equals the value $\hbar c$, a ubiquitous quantity when deriving the Planck units. Since the two quantities are equal their ratio equals one. From here, it is easy to isolate the mass that would satisfy this equation in our system of units:

$$m_{\mathrm{P}} = \sqrt{\frac{\hbar c}{G}}$$

Note in the second equation that if instead of planck masses the electron mass were used, the equation would no longer be unitary and instead equal a gravitational coupling constant, analogous to how the equation of the fine-structure constant operates with respect to the elementary charge and the Planck charge.

Thus, the planck mass is an attempt to absorb the gravitational coupling constant into the unit of mass (and those of distance/time as well), as the planck charge does for the fine-structure constant; naturally it is impossible to truly set either of these dimensionless numbers to zero.

Compton wavelength and Schwarzschild radius

The Planck mass can be derived approximately by setting it as the mass whose Compton wavelength and Schwarzschild radius are equal.[2] The Compton wavelength is, loosely speaking, the length-scale where quantum effects start to become important for a particle; the heavier the particle, the smaller the Compton wavelength.

The Schwarzschild radius is the radius in which a mass, if confined, would become a black hole; the heavier the particle, the larger the Schwarzschild radius. If a particle were massive enough that its Compton wavelength and Schwarzschild radius were approximately equal, its dynamics would be strongly affected by quantum gravity. This mass is (approximately) the Planck mass.

The Compton wavelength is

$$\lambda_c = \frac{h}{mc}$$

and the Schwarzschild radius is

$$r_s = \frac{2Gm}{c^2}$$

Setting them equal:

$$m = \sqrt{\frac{hc}{2G}} = \sqrt{\frac{\pi c\hbar}{G}}$$

This is not quite the Planck mass: It is a factor of larger.

However, this is a heuristic derivation, only intended to get the right order of magnitude. On the other hand, the previous "derivation" of the Planck mass should have had a proportional sign in the initial expression rather than an equal sign. Therefore, the extra factor might be the correct one.

Appendix III Ferro – Magnetism

Ferromagnetism is the basic mechanism by which certain materials (such as iron) form permanent magnets, or are attracted to magnets. In physics, several different types of magnetism are distinguished. Ferromagnetism (including ferrimagnetism)[1] is the strongest type; it is the only type that creates forces strong enough to be felt, and is responsible for the common phenomena of magnetism encountered in everyday life.

Other substances respond weakly to magnetic fields with two other types of magnetism, paramagnetism and diamagnetism, but the forces are so weak that they can only be detected by sensitive instruments in a laboratory. An everyday example of ferromagnetism is a refrigerator magnet used to hold notes on a refrigerator door. The attraction between a magnet and ferromagnetic material is "the quality of magnetism first apparent to the ancient world, and to us today".[2]

Permanent magnets (materials that can be magnetized by an external magnetic field and remain magnetized after the external field is removed) are either ferromagnetic or ferrimagnetic, as are other materials that are noticeably attracted to them. Only a few substances are ferromagnetic. The common ones are iron, nickel, cobalt and most of their alloys, some compounds of rare earth metals, and a few naturally-occurring minerals such as lodestone.

Ferromagnetism is very important in industry and modern technology, and is the basis for many electrical and electromechanical devices such as electromagnets, electric motors, generators, transformers, and magnetic storage such as tape recorders, and hard disks.

Historically, the term *ferromagnet* was used for any material that could exhibit spontaneous magnetization: a net magnetic moment in the absence of an external magnetic field. This general definition is still in common use.

More recently, however, different classes of spontaneous magnetization have been identified when there is more than one magnetic ion per primitive cell of the material, leading to a stricter definition of "ferromagnetism" that is often used to distinguish it from ferrimagnetism.

In particular, a material is "ferromagnetic" in this narrower sense only if *all* of its magnetic ions add a positive contribution to the net magnetization. If some of the magnetic ions *subtract* from the net magnetization (if they are partially *anti*-aligned), then the material is "ferrimagnetic".[3]

If the moments of the aligned and anti-aligned ions balance completely so as to have zero net magnetization, despite the magnetic ordering, then it is an antiferromagnet. These alignment effects only occur at temperatures below a certain critical temperature, called the Curie temperature (for ferromagnets and ferrimagnets) or the Néel temperature (for antiferromagnets).

Among the first investigations of ferromagnetism are the pioneering works of Aleksandr Stoletov on measurement of the magnetic permeability of ferromagnetics, known as the Stoletov curve.

Ferromagnetic materials

See also: Category:Ferromagnetic materials

Curie temperatures for some crystalline ferromagnetic (* = ferrimagnetic) materials[4]

Material	Curie temp. (K)
Co	1388
Fe	1043
$Fe_2O_3{}^*$	948
$FeOFe_2O_3{}^*$	858
$NiOFe_2O_3{}^*$	858
$CuOFe_2O_3{}^*$	728
$MgOFe_2O_3{}^*$	713
MnBi	630
Ni	627
MnSb	587
$MnOFe_2O_3{}^*$	573
$Y_3Fe_5O_{12}{}^*$	560
CrO_2	386
MnAs	318
Gd	292
Dy	88
EuO	69

The table on the right lists a selection of ferromagnetic and ferrimagnetic compounds, along with the temperature above which they cease to exhibit spontaneous magnetization (see Curie temperature).

Ferromagnetism is a property not just of the chemical make-up of a material, but of its crystalline structure and microscopic organization. There are ferromagnetic metal alloys whose constituents are not themselves ferromagnetic, called Heusler alloys, named after

Fritz Heusler. Conversely there are non-magnetic alloys, such as types of stainless steel, composed almost exclusively of ferromagnetic metals.

One can also make amorphous (non-crystalline) ferromagnetic metallic alloys by very rapid quenching (cooling) of a liquid alloy. These have the advantage that their properties are nearly isotropic (not aligned along a crystal axis); this results in low coercivity, low hysteresis loss, high permeability, and high electrical resistivity.

One such typical material is a transition metal-metalloid alloy, made from about 80% transition metal (usually Fe, Co, or Ni) and a metalloid component (B, C, Si, P, or Al) that lowers the melting point.

A relatively new class of exceptionally strong ferromagnetic materials are the rare-earth magnets. They contain lanthanide elements that are known for their ability to carry large magnetic moments in well-localized f-orbitals.

Actinide ferromagnets

A number of actinide compounds are ferromagnets at room temperature or become ferromagnets below the Curie temperature (T_C). PuP is one actinide pnictide that is a paramagnet and has cubic symmetry at room temperature, but upon cooling undergoes a lattice distortion to tetragonal when cooled to below its T_c = 125 K. PuP has an easy axis of <100>,[5] so that

$$\frac{c}{a} - 1 = -(31 \pm 1) \times 10^{-4}$$

at 5 K.[6] The lattice distortion is presumably a consequence of strain induced by the magnetoelastic interactions as the magnetic moments aligned parallel within magnetic domains.

In NpFe_2 the easy axis is <111>.[7] Above T_C ~500 K NpFe_2 is also paramagnetic and cubic. Cooling below the Curie temperature produces a rhombohedral distortion wherein the rhombohedral angle changes from 60° (cubic phase) to 60.53°. An alternate description of this distortion is to consider the length c along the unique trigonal axis (after the distortion has begun) and a as the distance in the plane perpendicular to c. In the cubic phase this reduces to $\frac{c}{a} = 1.00$. Below the Curie temperature

$$\frac{c}{a} - 1 = -(120 \pm 5) \times 10^{-4}$$

which is the largest strain in any actinide compound.[6] $NpNi_2$ undergoes a similar lattice distortion below $T_C = 32$ K, with a strain of $(43 \pm 5) \times 10^{-4}$.[6] $NpCo_2$ is a ferrimagnet below 15 K.

Lithium gas

In 2009, a team of MIT physicists demonstrated that a lithium gas cooled to less than one kelvin can exhibit ferromagnetism.[8] The team cooled fermionic lithium-6 to less than 150 billionths of one kelvin above absolute zero using infrared laser cooling. This demonstration is the first time that ferromagnetism has been demonstrated in a gas.

Explanation

The Bohr–van Leeuwen theorem shows that magnetism cannot occur in purely classical solids. Without quantum mechanics, there would be no diamagnetism, paramagnetism or ferromagnetism. The property of ferromagnetism is due to the direct influence of two effects from quantum mechanics: spin and the Pauli exclusion principle.[9]

Origin of magnetism

One of the fundamental properties of an electron (besides that it carries charge) is that it has a magnetic dipole moment, i.e., it behaves itself as a tiny magnet. This dipole moment comes from the more fundamental property of the electron that it has quantum mechanical spin.

The quantum mechanical nature of this spin causes the electron to only be able to be in two states, with the magnetic field either pointing "up" or "down" (for any choice of up and down).

The spin of the electrons in atoms is the main source of ferromagnetism, although there is also a contribution from the orbital angular momentum of the electron about the nucleus. When these tiny magnetic dipoles are aligned in the same direction, their individual magnetic fields add together to create a measurable macroscopic field.

However, in materials with a filled electron shell, the total dipole moment of the electrons is zero because the spins are in up/down pairs. Only atoms with partially filled shells (i.e., unpaired spins) can have a net magnetic moment, so ferromagnetism only occurs in materials with partially filled shells. Because of Hund's rules, the first few electrons in a shell tend to have the same spin, thereby increasing the total dipole moment.

These unpaired dipoles (often called simply "spins" even though they also generally include angular momentum) tend to align in parallel to an external magnetic field, an effect called paramagnetism. Ferromagnetism involves an additional phenomenon, however: The dipoles tend to align spontaneously, giving rise to a spontaneous magnetization, even when there is no applied field.

Exchange interaction

Main article: Exchange interaction

According to classical electromagnetism, two nearby magnetic dipoles will tend to align in *opposite* directions, so their magnetic fields will oppose one another and cancel out. However, this effect is very weak, because the magnetic fields generated by individual spins are small and the resulting alignment is easily destroyed by thermal fluctuations.

In a few materials, a much stronger interaction between spins arises because the change in the direction of the spin leads to a change in electrostatic repulsion between neighboring electrons, due to a particular quantum mechanical effect called the exchange interaction.

At short distances, the exchange interaction is much stronger than the dipole-dipole magnetic interaction. As a result, in a few materials, the ferromagnetic ones, nearby spins tend to align in the same direction.

The exchange interaction is related to the Pauli exclusion principle, which says that two electrons with the same spin cannot also have the same "position". Therefore, under certain conditions, when the orbitals of the unpaired outer valence electrons from adjacent atoms overlap, the distributions of their electric charge in space are further apart when the electrons have parallel spins than when they have opposite spins.

This reduces the electrostatic energy of the electrons when their spins are parallel compared to their energy when the spins are anti-parallel, so the parallel-spin state is more stable. In simple terms, the electrons, which repel one another, can move "further apart" by aligning their spins, so the spins of these electrons tend to line up. This difference in energy is called the exchange energy.

The materials in which the exchange interaction is much stronger than the competing dipole-dipole interaction are frequently called *magnetic materials*. For instance, in iron (Fe) the exchange force is about 1000 times stronger than the dipole interaction. Therefore below the Curie temperature virtually all of the dipoles in a ferromagnetic material will be aligned.

The exchange interaction is also responsible for the other types of spontaneous ordering of atomic magnetic moments occurring in magnetic solids, antiferromagnetism and ferrimagnetism. There are different exchange interaction mechanisms which create the magnetism in different ferromagnetic, ferrimagnetic, and antiferromagnetic substances. These mechanisms include direct exchange, RKKY exchange, double exchange, and superexchange.

Magnetic anisotropy

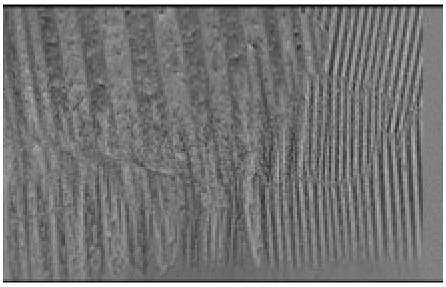
Main article: Magnetic anisotropy

Although the exchange interaction keeps spins aligned, it does not align them in a particular direction. Without magnetic anisotropy, the spins in a magnet randomly change direction in response to thermal fluctuations and the magnet is superparamagnetic. There are several kinds of magnetic anisotropy, the most common of which is magnetocrystalline anisotropy.

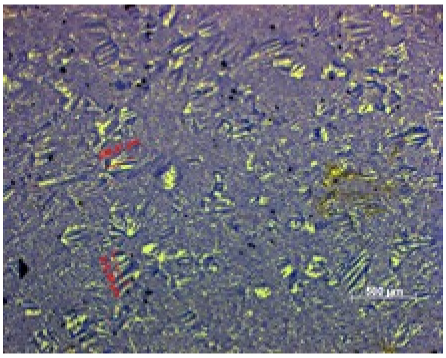
This is a dependence of the energy on the direction of magnetization relative to the crystallographic lattice. Another common source of anisotropy, inverse magnetostriction, is induced by internal strains.

Single-domain magnets also can have a *shape anisotropy* due to the magnetostatic effects of the particle shape. As the temperature of a magnet increases, the anisotropy tends to decrease, and there is often a blocking temperature at which a transition to superparamagnetism occurs.[10]

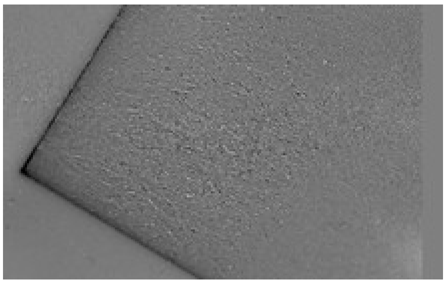
Magnetic domains



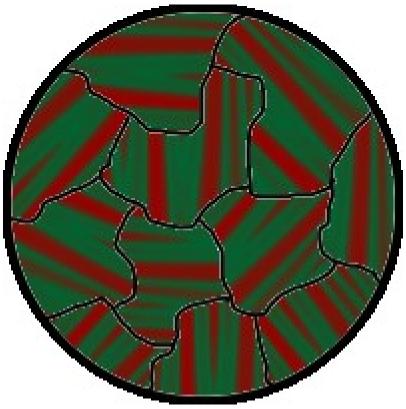
Electromagnetic dynamic magnetic domain motion of grain oriented electrical silicon steel



Domain orientations in non-grain-oriented steel imaged with magneto-optical sensor and polarizer microscope.



Magnetic domains of non-oriented silicon or electrical steel (recorded with CMOS-MagView).



Kerr micrograph of metal surface showing magnetic domains. The domains are the red and green stripes within each microcrystalline grain. The magnetic field in the red domains is in the opposite direction from the green domains.

Main article: Magnetic domain

The above would seem to suggest that every piece of ferromagnetic material should have a strong magnetic field, since all the spins are aligned, yet iron and other ferromagnets are often found in an "unmagnetized" state. The reason for this is that a bulk piece of ferromagnetic material is divided into tiny *magnetic domains*[11] (also known as *Weiss domains*).

Within each domain, the spins are aligned, but (if the bulk material is in its lowest energy configuration, i.e. *unmagnetized*), the spins of separate domains point in different directions and their magnetic fields cancel out, so the object has no net large scale magnetic field.

Ferromagnetic materials spontaneously divide into magnetic domains because the *exchange interaction* is a short-range force, so over long distances of many atoms the tendency of the magnetic dipoles to reduce their energy by orienting in opposite directions wins out. If all the dipoles in a piece of ferromagnetic material are aligned parallel, it creates a large magnetic field extending into the space around it. This contains a lot of magnetostatic energy.

The material can reduce this energy by splitting into many domains pointing in different directions, so the magnetic field is confined to small local fields in the material, reducing the volume of the field. The domains are separated by thin domain walls a number of molecules thick, in which the direction of magnetization of the dipoles rotates smoothly from one domain's direction to the other.

Magnetized materials

Thus, a piece of iron in its lowest energy state ("unmagnetized") generally has little or no net magnetic field. However, if it is placed in a strong enough external magnetic field, the domain walls will move, reorienting the domains so more of the dipoles are aligned with the external field.

The domains will remain aligned when the external field is removed, creating a magnetic field of their own extending into the space around the material, thus creating a "permanent" magnet. The domains do not go back to their original minimum energy configuration when the field is removed because the domain walls tend to become 'pinned' or 'snagged' on defects in the crystal lattice, preserving their parallel orientation.

This is shown by the Barkhausen effect: as the magnetizing field is changed, the magnetization changes in thousands of tiny discontinuous jumps as the domain walls suddenly "snap" past defects.

This magnetization as a function of the external field is described by a hysteresis curve. Although this state of aligned domains found in a piece of magnetized ferromagnetic material is not a minimal-energy configuration, it is metastable, and can persist for long periods, as shown by samples of magnetite from the sea floor which have maintained their magnetization for millions of years.

Alloys used for the strongest permanent magnets are "hard" alloys made with many defects in their crystal structure where the domain walls "catch" and stabilize. The net magnetization can be destroyed by heating and then cooling (annealing) the material without an external field, however. The thermal motion allows the domain boundaries to move, releasing them from any defects, to return to their low-energy unaligned state.

Curie temperature

Main article: Curie temperature

As the temperature increases, thermal motion, or entropy, competes with the ferromagnetic tendency for dipoles to align. When the temperature rises beyond a certain point, called the **Curie temperature**, there is a second-order phase transition and the system can no longer maintain a spontaneous magnetization, although it still responds para - magnetically to an external field.

Below that temperature, there is a spontaneous symmetry breaking and magnetic moments become aligned with their neighbors. The Curie temperature itself is a critical point, where the magnetic susceptibility is theoretically infinite and, although there is no net magnetization, domain-like spin correlations fluctuate at all length scales.

The study of ferromagnetic phase transitions, especially via the simplified Ising spin model, had an important impact on the development of statistical physics. There, it was first clearly shown that mean field theory approaches failed to predict the correct behavior at the critical point (which was found to fall under a *universality class* that includes many other systems, such as liquid-gas transitions), and had to be replaced by renormalization group theory.[

Contact

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Some men see things as they are and say *why?* I dream things that never were and say *why not?*

Let's dedicate ourselves to what the Greeks wrote so many years ago:

to tame the savageness of man and make gentle the life of this world.

Robert Francis Kennedy