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A Study on Classes of Magnetism

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Abstract
In this work we summarized the all the concepts of magnetism and its classes. The origin, construction, and the application.

Introduction
The origin of magnetism lies in the orbital and spin motions of electrons and how the electrons interact with one another. The best way to introduce the different types of magnetism is to describe how materials respond to magnetic fields. This may be surprising to some, but all matter is magnetic. It's just that some materials are much more magnetic than others. The main distinction is that in some materials there is no collective interaction of atomic magnetic moments, whereas in other materials there is a very strong interaction between atomic moments .The magnetic behavior of materials can be classified into the following five major groups [1,2]:

1. Diamagnetism
2. Paramagnetism
3. Ferromagnetism
4. Antiferromagnetism
5. Ferrimagnetisms

Materials in the first two groups are those that exhibit no collective magnetic interactions and are not magnetically ordered. Materials in the last three groups exhibit long-range magnetic order below a certain critical temperature. Ferromagnetic and ferromagnetic materials are usually what we consider as being magnetic (i.e., behaving like iron). The remaining three are so weakly magnetic that they are usually thought of as "nonmagnetic".

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 like a tiny magnet, producing a magnetic field. This dipole moment comes from the more fundamental property of the electron that it has quantum mechanical spin. Due to its quantum nature, the spin of the electron can be in one of only 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 of the electron about the nucleus. When these magnetic dipoles in a piece of matter are aligned, (point in the same direction) their individually tiny magnetic fields add together to create a much larger macroscopic field. However, materials made of atoms with filled electron shells have a total dipole moment of zero, because the electrons all exist in pairs with opposite spin, every electron's

magnetic moment is cancelled by the opposite moment of the second electron in the pair. 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 orbital angular momentum) tend to align in parallel to an external magnetic field, an effect called Paramagnetism. Ferromagnetism involves an additional phenomenon, however: in a few substances the dipoles tend to align spontaneously, giving rise to a spontaneous magnetization, even when there is no applied field [3].

Diamagnetism

Diamagnetism is a property of all materials, and always makes a weak contribution to the material's response to a magnetic field. However, other forms of magnetism (such as ferromagnetism or Paramagnetism) are so much stronger that when multiple different forms of magnetism are present in a material, the diamagnetic contribution is usually negligible. Substances where the diamagnetic behavior is the strongest effect are termed diamagnetic materials, or diamagnet. Diamagnetic materials are those that laypeople generally think of as non-magnetic, and include water, wood, most organic compounds such as petroleum and some plastics, and many metals including copper, particularly the heavy ones with many core electrons, such as mercury, gold and bismuth. The magnetic susceptibility values of various molecular fragments are called Pascal's constants. Diamagnetic materials, like water, or water-based materials, have a relative magnetic permeability that is less than or equal to 1, and therefore a magnetic susceptibility less than or equal to 0, since susceptibility is defined as $\chi_v = \mu_v - 1$. This means that diamagnetic materials are repelled by magnetic fields. However, since diamagnetism is such a weak property, its effects are not observable in everyday life. For example, the magnetic susceptibility of diamagnet such as water is $\chi_v = -9.05\times10^{-6}$. The most strongly diamagnetic material is bismuth, $\chi_v = -1.66\times10^{-4}$, although paralytics carbon may have a susceptibility of $\chi_v = -4.00\times10^{-4}$ in one plane. Nevertheless, these values are orders of magnitude smaller than the magnetism exhibited by paramagnets and Ferromagnets. Note that because χ_v is derived from the ratio of the internal magnetic field to the applied fie ld, it is a dimensionless value. All conductors exhibit an effective diamagnetism when they experience a changing magnetic field. The Lorentz force on electrons causes them to circulate around forming eddy currents. The eddy currents then produce an induced magnetic field opposite the applied field, resisting the conductor's motion .In rare cases; the diamagnetic contribution can be stronger than paramagnetic contribution. As is the case for gold, which has a magnetic susceptibility less than 0, so is by definition a diamagnetic material, but when measured carefully with X-ray magnetic circular dichroism, shows an extremely weak paramagnetic contribution that is overcome by a stronger diamagnetic contribution [4].

Demonstrations

Curving water surfaces

If a powerful magnet (such as a super magnet) is covered with a layer of water (that is thin compared to the diameter of the magnet) then the field of the magnet significantly repels the water. This causes a slight dimple in the water's surface that may be seen by its reflection [5].

Longevin Diamagnetism

's theory of diamagnetism (1905) [23] applies to materials containing Paul Langevin atoms with closed shells. A field with intensity *B*, applied to an electron with charge *e* and mass *m*, gives rise to Larmor precession with frequency
$\omega = eB / 2m$. The number of revolutions per unit time is $\omega / 2\pi$, so the current for an atom with *Z* electrons is (in SI units) [6].

$$I = \frac{-Ze^2B}{4\pi m} \quad (1)$$

The magnetic moment of a current loop is equal to the current times the area of the loop. Suppose the field is aligned with the *z* axis. The average loop area can be given as$\pi\langle\rho^2\rangle$, where $\langle\rho^2\rangle$is the mean square distance of the electrons perpendicular to the *z* axis. The magnetic moment is

Therefore

$$\mu = -\frac{Ze^2B}{4m}\langle\rho^2\rangle \quad (2)$$

If the distribution of charge is spherically symmetric, we can suppose that the distribution of *x*,*y*,*z* coordinates are independent and identically distributed. Then$\langle x^2\rangle = \langle y^2\rangle = \langle z^2\rangle = 1/3\langle r^2\rangle$, where $\langle r^2\rangle$is the mean square distance of the electrons from the nucleus. Therefore$\langle\rho^2\rangle = \langle x^2\rangle + \langle y^2\rangle = \frac{2}{3}\langle r^2\rangle$. If $\eta$is the number of atoms per unit volume, the volume diamagnetic susceptibility in SI units is

$$\chi = \frac{\mu_0\eta\mu}{B} = -\frac{\mu_o e^2 z_\eta}{6m}\langle r^2\rangle \quad (3)$$

Application

Because diamagnetism is essentially the expelling of magnetic fields within a material, strong diamagnetic materials can be levitated, or if they are sufficiently strong and enough area, can levitate magnets. The diamagnetic response leaves no internal magnetic field. These materials can be easily levitated in the presence of a strong permanent magnet. However, high temperature superconductors (~100 K are made from exotic materials with expensive processing routes and require cryogenic fluids to accomplish the superconducting state [7]

Paramagnetism

Relation to electron spins

Constituent atoms or molecules of paramagnetic materials have permanent magnetic moments (dipoles), even in the absence of an applied field. The permanent moment generally is due to the spin of unpaired electrons in atomic or molecular electron orbitals (see Magnetic moment). In pure Paramagnetism, the dipoles do not interact with one another and are randomly oriented in the absence of an external field due to thermal agitation, resulting in zero net magnetic moment. When a magnetic field is applied, the dipoles will tend to align with the applied field, resulting in a net magnetic moment in the direction of the applied field. In the classical description, this alignment can be understood to occur due to a torque being provided on the magnetic moments by an applied field, which tries to align the dipoles parallel to the applied field. However, the true origins of the alignment can only be understood via the quantum-mechanical properties of spin and angular momentum. If there is sufficient energy exchange between neighboring dipoles, they will interact, and may spontaneously align or anti-align and form magnetic domains, resulting in ferromagnetism (permanent magnets) or Antiferromagnetism, respectively. Paramagnetic behavior can also be observed in ferromagnetic materials that are above their Curie temperature, and in Antiferromagnetism above their Néel temperature. At these temperatures, the available thermal energy simply overcomes the interaction energy between the spins. In general, paramagnetic effects are quite small: the magnetic susceptibility is of the order of 10^{-3} to 10^{-5} for most paramagnets, but may be as high as 10^{-1} for synthetic paramagnets such as Ferro fluids [8].

Pauli Paramagnetism

For some alkali metals and noble metals, conductions electrons are weakly interacting and delocalized in space forming a Fermi gas. For these materials one contribution to the magnetic response comes from the interaction between the electron spins and the magnetic field known as Pauli Paramagnetism. For a small magnetic field H, the additional energy per electron from the interaction between an electron spin and the magnetic field is given by [9]:

$$\Delta E = -\mu_0 H\, , \mu_e \neq \mu_0 H.\left(-\, ge\frac{\mu_B}{h'}\, S\right) = \pm\mu_0\mu_B H \quad (4)$$

where $\mu_0$is the vacuum permeability, $\mu_e$is the electron magnetic moment, μ_B is the Bohr magneton, h is the reduced Planck constant, and the g-factor cancels with the spin S=± h′/2. The ± indicates that the sign is positive (negative) when the electron spin component in the direction ofHis parallel (antiparallel) to the magnetic field. For low temperatures with respect to the Fermi temperature(around 10^4kelvins for metals), the number density of electrons $\eta\uparrow(\eta\downarrow)$ pointing parallel (antiparallel) to the magnetic field can be written as:

$$\eta\uparrow \approx \frac{\eta e}{2} - \frac{\mu_0\mu_B}{2}\, g(E_f)H; \left(\eta\downarrow \approx \frac{\eta e}{2} + \frac{\mu_0\mu_B}{2}\, g(E_f)H\right) \quad (5)$$

with ηe the total free-electrons density and $g(E_f)$ the electronic density of states (number of states per energy per volume) at the Fermi energy. In this approximation the magnetization is given as the magnetic moment of one electron times the difference in densities:

$$M = \mu_B(\eta\downarrow - \eta\uparrow) = \mu_0\mu^2{}_B\, g(E_f)H \quad (6)$$

Which yields a positive paramagnetic susceptibility independent of temperature:

$$\chi_p = \mu_0\mu^2{}_B\, g(E_f) \qquad (7)$$

The Pauli paramagnetic susceptibility is a macroscopic effect and has to be contrasted with Landau diamagnetic susceptibility which is equal to minus one third of Pauli's and also comes from delocalized electrons. The Pauli susceptibility comes from the spin interaction with the magnetic field while the Landau susceptibility comes from the spatial motion of the electrons and it is independent of the spin. In doped semiconductors the ratio between Landau's and Pauli's susceptibilities changes as the effective mass of the charge carrier's m* can differ from the electron mass m_e. The magnetic response calculated for a gas of electrons is not the full picture as the magnetic susceptibility coming from the ions has to be included. Additionally, these formulas may break down for confined systems that differ from the bulk, like quantum dots, or for high fields, as demonstrated in the de Haas-van Alphen effect. Pauli Paramagnetism is named after the physicist Wolfgang Pauli. Before Pauli's theory, the lack of a strong Curie Paramagnetism in metals was an open problem as the leading model could not account for this contribution without the use of quantum statistics [10].

Application

Paramagnetism is a form of magnetism whereby the paramagnetic material is only attracted when in the presence of an externally applied magnetic field. Paramagnetic materials have a relative magnetic permeability greater or equal to unity (i.e., a positive magnetic susceptibility) and hence are attracted to magnetic fields. The magnetic moment induced by the applied field is linear in the field strength; it is also rather weak. Constituent atoms or molecules of paramagnetic materials have permanent magnetic moments (dipoles), even in the absence of an applied field. Generally, the permanent moment is caused by the spin of unpaired electrons in atomic or molecular electron orbitals. In pure Paramagnetism, the dipoles do not interact with each other and are randomly oriented in the absence of an external field due to thermal agitation; this results in a zero net magnetic moment. When a magnetic field is applied, the dipoles will tend to align with the applied field, resulting in a net magnetic moment in the direction of the applied field.

Paramagnetic materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed, as illustrated in. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field. Paramagnetic materials include magnesium, molybdenum, lithium and tantalum. Unlike Ferromagnets, paramagnets do not retain any magnetization in the absence of an externally applied magnetic field, because thermal motion randomizes the spin orientations responsible for magnetism. Some paramagnetic materials retain spin disorder at absolute zero (meaning they are paramagnetic in the ground state). Thus the total magnetization drops to zero when the applied field is removed. Even in the presence of the field there is only a small induced magnetization because only a small fraction of the spins will be oriented by the field [11].

Ferromagnetism

Ferromagnetism is a property not just of the chemical make-up of a material, but of its crystalline structure and microstructure. 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. Amorphous (non-crystalline) ferromagnetic metallic alloys can be made 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 is the rare-earth magnets. They contain lanthanide elements that are known for their ability to carry large magnetic moments in well-localized f-orbitals. Most ferromagnetic materials are metals, since the conducting electrons are often responsible for mediating the ferromagnetic interactions. It is therefore a challenge to develop ferromagnetic insulators, especially multi-ferric materials, which are both ferromagnetic and ferroelectric [12].

Application

The most common ferromagnetic materials are cobalt, iron, nickel, along with Lodestone a naturally magnetized mineral and other rare earth metal compounds. A common usage of ferromagnetic materials affecting our everyday lives is through magnetic storage in the form of data. Otherwise considered non-volatile storage since data cannot be lost when the device it is not powered. An advantage of this storage method is that it is one of the cheaper forms of storing data, as well as having the ability to be re-used. This is all possible because of Hysteresis. Once ferromagnetic materials are magnetized toward a specific direction it loses the ability to lose its magnetization (Hysteresis). Meaning it will not be able to go back to its original state without any magnetization. But another opposite magnetic field can be applied which would result in the creation of a hysteresis loop. This ultimately is the unique effect that allows these materials to retain data, after the magnetizing field is dropped to zero [13].

Antiferromagnetism

Antiferromagnetic materials occur commonly among transition metal compounds, especially oxides. Examples include hematite, metals such as chromium, alloys such as iron manganese (FeMn), and oxides such as nickel oxide (NiO). There are also numerous examples among high nuclearity metal clusters. Organic molecules can also exhibit Antiferromagnetic coupling under rare circumstances, as seen in radicals such as 5-dehydro-m-xylylene. Antiferromagnetism can couple to Ferromagnets, for instance, through a mechanism known as exchange bias, in which the ferromagnetic film is either grown upon the Antiferromagnetic or annealed in an aligning magnetic field, causing the surface atoms of the Ferromagnets to align with the surface atoms of the Antiferromagnetic. This provides the ability to "pin" the orientation of a ferromagnetic film, which provides one of the main uses in so-called spin valves, which are the basis of magnetic sensors including modern hard drive read heads. The temperature at or above which an Antiferromagnetic layer loses its ability to "pin" the magnetization direction of an adjacent ferromagnetic layer is called the blocking temperature of that layer and is usually lower than the Néel temperature[14].

Application

Antiferromagnetism are very interesting in nature but do not have a wide range of applications as other magnetic materials do. This is due to their lack of spontaneous magnetization. However because their structural magnetization is closely related to Ferrimagnets they can be used along with Ferromagnets to test theoretical models used to explain Ferrimagnetism. The lack an overall magnetic moment which makes them suitable for providing magnetic reference points in magnetic sensors since the structure of Antiferromagnetism is not sensitive to external fields. A growing theory and source of research on Antiferromagnetism is their contribution to superconductivity. There are materials that exhibit Antiferromagnetic and ferromagnetic transition states. Their corresponding structural and magnetic properties transition resemble that of a metal-insulator transition and as a result there is a large change in conductivity with an applied field. Since most nonmetallic superconductors have Antiferromagnetic phase, research continues to test Antiferromagnetism for sought after superconducting properties [15].

Ferrimagnetism

Unlike ferromagnetic materials, which are typically metals, ferrimagnetic materials are ceramics, in particular, ceramic oxides. The most widely used Ferrimagnets in technological devices are materials known as ferrites. Ferrites are electrically insulating transitional-metal oxides with the general chemical formula $MO{\cdot}Fe_2{\cdot}O_3$, where M is a divalent ion such as Mn^{2+}, Fe^{2+}, Co^{2+}, or Ni^{2+}. Ferrites are often prepared by standard ceramic processing techniques. In the case of $NiO.Fe_2{\cdot}O_3$ powders of NiO and Fe_2O_3 are mixed together and pressed into the desired shape before sintering (firing) at high temperature to form a dense ceramic of the desired composition. This method provides a reliable way of forming a wide variety of shapes and sizes of ferrimagnetic materials for embedding into technological devices [16].

Properties

Ferrimagnetic materials have high resistivity and have anisotropic properties. The anisotropy is actually induced by an external applied field. When this applied field aligns with the magnetic dipoles, it causes a net magnetic dipole moment and causes the magnetic dipoles to process at a frequency controlled by the applied field, called Larmor or precession frequency. As a particular example, a microwave signal circularly polarized in the same direction as this precession strongly interacts with the magnetic dipole moments; when it is polarized in the opposite direction, the interaction is very low. When the interaction is strong, the microwave signal can pass through the material. This directional property is used in the construction of microwave devices like isolators, circulators and gyrators. Ferrimagnetic materials are also used to produce optical isolators and circulators. Ferrimagnetic minerals in various rock types are used to study ancient geomagnetic properties of Earth and other planets. That field of study is known as pale magnetism [17].

Application

Ferrites have following application:

- Ferrites have importance in engineering and technology because they possess spontaneous magnetic moment below the Curie temperature just as iron, cobalt, nickel.
- Due to very low eddy current losses, ferrites are used as a core of coils in microwave frequency devices and computer memory core elements.
- Due to relatively low permeability and flux density compared to iron, ferrites are not suitable for the use in high field and high power applications, such as motors, generators and power transformers, but they can be used in low field and low power applications.
- Ferrites are used as ferromagnetic insulators in electrical circuits.

- Ferrites like ZnO find low frequency applications in timers. They are also used as switches in refrigerators, air conditioners, etc.
- Ferrites are used as magnetic head transducer in recording [18].

Conclusion

Magnetism and its classes is a class of physical phenomena that are mediated by magnetic fields. Electric currents and the magnetic moments of elementary particles give rise to a magnetic field, which acts on other currents and magnetic moments. The most familiar effects occur in ferromagnetic materials, which are strongly attracted by magnetic fields and can be magnetized to become permanent magnets, producing magnetic fields themselves. Only a few substances are ferromagnetic; the most common ones are iron, nickel and cobalt and their alloys such as steel. Although ferromagnetism is responsible for most of the effects of magnetism encountered in everyday life, all other materials are influenced to some extent by a magnetic field, by several other types of magnetism. Paramagnetic substances such as aluminum and oxygen are weakly attracted to an applied magnetic field; diamagnetic substances such as copper and carbon are weakly repelled; while Antiferromagnetic materials such as chromium and spin glasses have a more complex relationship with a magnetic field. The force of a magnet on paramagnetic, diamagnetic, and Antiferromagnetic materials is usually too weak to be felt, and can be detected only by laboratory instruments, so in everyday life these substances are often described as non-magnetic. The magnetic state (or magnetic phase) of a material depends on temperature and other variables such as pressure and the applied magnetic field. A material may exhibit more than one form of magnetism as these variables change. As with magnetizing a magnet, demagnetizing a magnet is also possible.

References

1. Chiba, A., Fukao, T., Ichikawa, O., Oshima, M., Takemoto, M., Dorrel, D. (2005). Magnetic Bearings and Bearingless Drives. Newnes.
2. Schweitzer, G., Maslen, H. (2009). Magnetic Bearings, Theory, Design,and Application to Rotating Machinery. Springer.
3. Jim Wilson (September 1999). "Beating Demon Friction". Popular Mechanics. Archived from the original on 2008-09-05.
4. Estelle Croot (1987–1995). Improved Magnetic Bearings. IPAustralia [Australian Patent Office database entries].
5. T. Lembke (2005). PhD Thesis "Design and Analysis of a Novel Low Loss Homopolar Electrodynamic Bearing" (PDF). Stockholm: Universitetsservice US AB. ISBN 91-7178-032-7
6. 1.Du Trémolet de Lacheisserie, Étienne; Damien Gignoux; Michel Schlenker (2005). Magnetism: Fundamentals. Springer. pp. 3–6. ISBN 978-0-387-22967-6.
7. Platonis Opera, Meyer and Zeller, 1839, p. 989.
8. The location of Magnesia is debated; it could be the region in mainland Greece or Magnesia ad Sipylum. See, for example, "Magnet". Language Hat blog. 28 May 2005. Retrieved 22 March 2013.
9. .Fowler, Michael (1997). "Historical Beginnings of Theories of Electricity and Magnetism". Retrieved 2008-04-02.
10. .Kumar Goyal, Rajendra (2017). Nanomaterials and Nanocomposites: Synthesis, Properties, Characterization Techniques, and Applications. CRC Press. p. 171. ISBN 9781498761673.
11. Li, Shu-hua (1954). "Origine de la Boussole II. Aimant et Boussole". Isis (in French). **45** (2): 175–196. doi:10.1086/348315. JSTOR 227361. un passage dans le Liu-che-tch'ouen-ts'ieou [...]: “La pierre d'aimant fait venir le fer ou elle l'attire.”

    7.In the section "A Last Word on Dragons" (亂龍篇 Luanlong) of the
12. .Schmidl, Petra G. (1996–1997). "Two Early Arabic Sources On The Magnetic Compass". Journal of Arabic and Islamic Studies. **1**: 81–132.
13. .A. Einstein: "On the Electrodynamics of Moving Bodies", June 30, 1905.
14. HP Meyers (1997). Introductory solid state physics (2 ed.). CRC Press. p. 362; Figure 11.1. ISBN 9781420075021
15. Catherine Westbrook; Carolyn Kaut; Carolyn Kaut-Roth (1998). MRI (Magnetic Resonance Imaging) in practice (2 ed.). Wiley-Blackwell. p. 217. ISBN 978-0-632-04205-0.
16. Du Trémolet de Lacheisserie, Étienne; Damien Gignoux; Michel Schlenker (2005). Magnetism: Fundamentals. Springer. pp. 3–6. ISBN 0-387-22967-1.
17. Kirschvink, Joseph L.; Kobayashi-Kirshvink, Atsuko; Diaz-Ricci, Juan C.; Kirschvink, Steven J. (1992). "Magnetite in Human Tissues: A Mechanism for the Biological Effects of Weak ELF Magnetic Fields". Bioelectromagnetics Supplement. 1: 101–113.
18. Catherine Westbrook; Carolyn Kaut; Carolyn Kaut-Roth (1998). MRI (Magnetic Resonance Imaging) in practice (2 ed.). Wiley-Blackwell. p. 217. ISBN 978-0-632-04205-0.