Magnetic Dipole and Magnetic materials

Applied physics

PH-122

Topics

- Magnetic Dipole
- Diamagnetism and properties
- Paramagnetism and properties
- Ferromagnetism and properties
- Comparison between diamagnetism, Para magnetism and ferromagnetism

Magnetic Dipole

- The coil behaves like a bar magnet placed in the magnetic field.
- Thus, like a bar magnet, a current-carrying coil is said to be a magnetic dipole.

Continued

We have two ways in which we can regard a current-carrying coil as a magnetic dipole:

(1) It experiences a torque when we place it in an external magnetic field;

(2) It generates its own intrinsic magnetic field, given, for distant points along its axis,

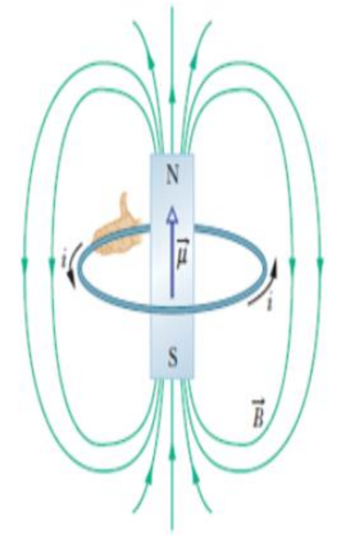


Figure A current loop produces a magnetic field like that of a bar magnet and thus has associated north and south poles. The magnetic dipole moment $\vec{\mu}$ of the loop, its direction given by a curled–straight right-hand rule, points from the south pole to the north pole, in the direction of the field $\vec{B}$ within the loop.

Proof

- In figure the back half of a circular loop of radius R carrying a current
- Consider a point P on the central axis of the loop, a distance z from its plane.
- The law of Biot-Savart to a differential element ds of the loop, located at the left side of the loop.
- Let us resolve dB into two components: dB, along the axis of the loop and perpendicular to this axis. From the symmetry, the vector sum of all the perpendicular components due to all the loop elements ds is zero. This leaves only the axial (parallel) components dB, and we have

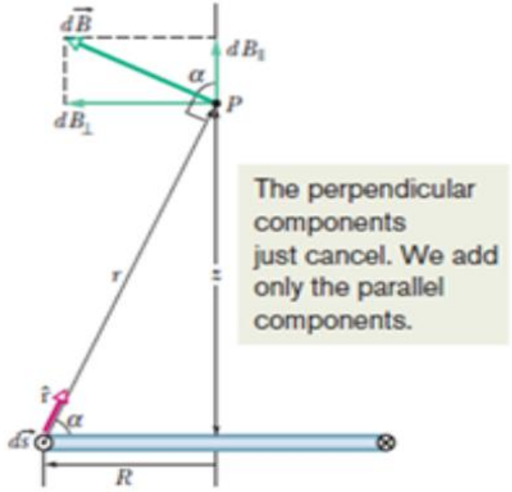


Figure 2. Cross section through a current loop of radius R. The plane of the loop is perpendicular to the page, and only the back half of the loop is shown. We use the law of Biot and Savart to find the magnetic field at point P on the central perpendicular axis of the loop.

Continued

- For the element in Fig, the law of Biot-Savart tells us that the magnetic field at distance r is

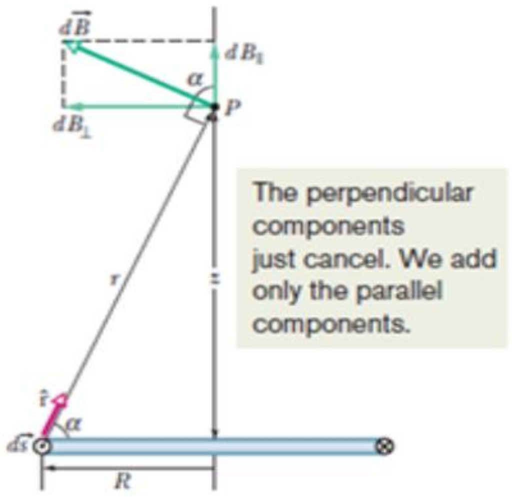
$$dB = \frac{\mu_0}{4\pi}\frac{i\,ds\sin 90^\circ}{r^2}.$$

$$dB_\parallel = dB\cos\alpha.$$

- Combining both equation

$$dB_\parallel = \frac{\mu_0 i\cos\alpha\,ds}{4\pi r^2}.$$

- Figure shows that r and a are related to each other. Let us express each term in the variable z, the distance between point P and the center of the loop. The relations are



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Continued

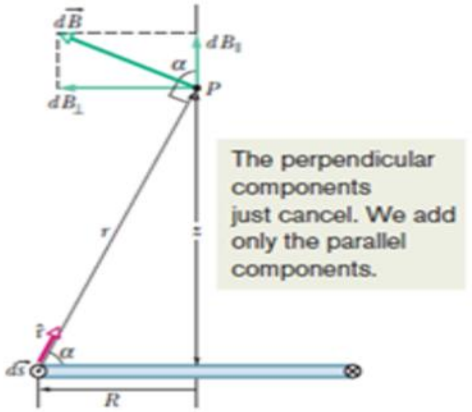
$$r = \sqrt{R^2 + z^2}$$

$$\cos \alpha = \frac{R}{r} = \frac{R}{\sqrt{R^2 + z^2}}.$$

$$dB_{\parallel} = \frac{\mu_0 i R}{4\pi (R^2 + z^2)^{3/2}}\, ds.$$

$$B = \int dB_{\parallel} = \frac{\mu_0 i R}{4\pi (R^2 + z^2)^{3/2}} \int ds$$

$$dB = \mu_o i R / 4\pi r (\sqrt{(R^2} + z^2)$$



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$\int ds$ simply the circumference 2πR of the loop, so Eq is

$$B(z) = \frac{\mu_0 i R^2}{2(R^2 + z^2)^{3/2}}.$$

Diamagnetism, Paramagnetism and ferromagnetism

- Substances can be classified as belonging to one of three categories, depending on their magnetic properties.
- Paramagnetic and ferromagnetic materials are those made of atoms that have permanent magnetic moments.
- Diamagnetic materials are those made of atoms that do not have permanent magnetic moments.
- For paramagnetic and diamagnetic substances, the magnetization vector M is proportional to the magnetic field strength H. For these substances placed in an external magnetic field, we can write

$$M = \times H$$

On application of external magnetic field

- When we apply external magnetic field two things occur

1. When we apply external manetic field first atomic dipole align with magnetic field
2. There occur induced dipole in any substance on applying external magnetic field here induce dipole opposes external magnetic field(lenz law).

Diamagnetism

- Atoms have electrons. when these electrons move around nucleus so due to motion of electron current produced in opposite direction. When we have current loop it behaves as magnetic dipole because current loop has magnetic moment. We find it direction by using right hand rule. These magnetic moment of electron responsible of magnetic moment of atom. there are also some other factors(like spin).Now when net magnetic moment of electron in atom adds upto zero means no atomic dipole this is called diamagnetism. Example water, Nacl, copper.
- They have paired electrons.

Properties

- Net magnetic moment of each atom is zero
- They are weekly repelled external magnetic field
- Magnetic susceptibility M=×h (how much magnetized(M))
- susceptibility is negative
- Permeability is slightly less than 1
- permeability=1-×
- In non uniform magnetic field Diamagnetic substance move strong to weak field.
- Magnetic fields lines become less dense inside diamagnetic substance.
- When suspended freely in a uniform magnetic field, they set themselves perpendicular to the direction of the magnetic field
- There are no atomic dipoles so there is no role of first point.
- Property 2 occurs when external magnetic field applied it forms very little dipole.so these dipole weakly repel in external magnetic field

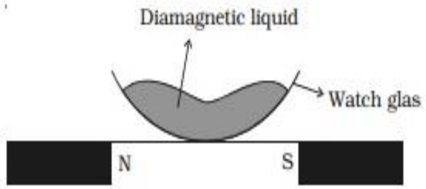

Fig. Diamagnetic liquid

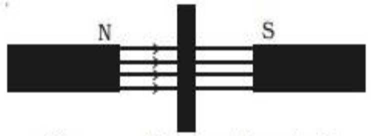

Fig. Diamagnetic material perpendicular to the field

Paramagnetism

- The net magnetic moment of all electrons in an atom donot add upto zero.hence atomic dipole exist

Na=11

$1s^2, 2s^2, 2p^6, 3s^1$

Net Magnetic moment is zero in any small volume.

- On applying external magnetic field, the atomic dipoles align in the direction of external magnetic field. If magnetic field increases torque increases so alignment can be increased.
- Temperature is low
- They are weakly attracted in external magnetic field.

Properties

- Susceptibility has a low positive value. (For example : χm for aluminum is +0.00002).
- Susceptibility is inversely proportional to absolute temperature (i.e) $\chi \propto 1/T$. As the temperature increases susceptibility decreases.
- The relative permeability is greater than one.
- When placed in a non uniform magnetic field, they have a tendency to move from weaker part to the stronger part of the field. They get magnetized in the direction of the field as shown in Fig.
- When suspended freely in a uniform magnetic field, they set themselves parallel to the direction of magnetic field (Fig.).

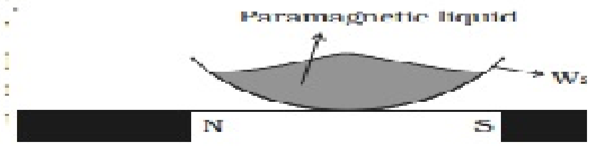

Fig. Paramagnetic liquic

Ferromagnetism

- Ferromagnetic substances are those in which each atom or molecule has a strong spontaneous net magnetic moment.
- These substances exhibit strong paramagnetic properties.
- The magnetic domains that cause ferromagnetism regions in which the spins of large numbers of unpaired electrons of neighboring atoms align with each other, creating a unidirectional magnetic field. This alignment of spins arises from an atomic-level quantum mechanical interaction

Properties

- The susceptibility and relative permeability are very large. (For example : permeability for iron = 200,000)
- Susceptibility is inversely proportional to the absolute temperature.
- When suspended freely in uniform magnetic field, they set themselves parallel to the direction of magnetic field.
- When placed in a non uniform magnetic field, they have a tendency to move from the weaker part to the stronger part of the field. They get strongly magnetised in the direction of the field.

Comparison between diamagnetism, Para magnetism and ferromagnetism

Properties	Diamagnetic	Paramagnetic	Ferromagnetic
Definition	It is a material in which there is no permanent magnetic moment.	It has permanent magnetic moment.	It has enormous permanent magnetic moment.
Examples	Copper, silver, and gold	Magnesium, molybdenum, lithium, and tantalum	Iron, nickel, and cobalt
State	Solid, liquid, or gas	Solid, liquid, or gas	Solid
Effect of magnet	slightly repelled	Slightly attracted	Strongly attracted
Behavior of non-uniform field	Movement from high to low field region	Movement from low to high field region	Movement from low to high field region
Does it retain the magnetic properties when the external field is removed?	No	No	Yes

Continued

Effects of temperature	No effect	With the rise of temperature, a parmagnetic substance becomes diamagnetic.	Above curie point, a ferromagnetic substance becomes ferromagnetic.
Permeability	Low $0 \leq \mu r < 1$	High $\mu r > 1$	Highest $\mu r >> 1$
Susceptibility	Negative ($\chi < 0$)	Low positive ($\chi > 0$)	High positive ($\chi >> 0$)
Spin/Magnetic moment/Dipole alignment	No spin alignment	Random alignment	Parallel and orderly alignment
Magnetized Direction	Opposite to the external magnetic field	Same direction as the external magnetic field	Same direction as the external magnetic field
Paired or unpaired electrons?	All are paired	Some unpaired	Some unpaired

If you have any questions regarding this lecture, please ask in the live session

Thank you