Magnetic fields in matter - introduction

Saturday, April 6, 2019 4:42 PM

All magnetic phenomena are due to electric charges in motion

On a microscopic scale, materials show tiny currents moving around (ex. Electrons orbiting nuclei, magnetic moments of electron protons and neutrons).

From the macroscopic point of view, one can treat these tiny currents as dipoles. Normally, due to the random orientation of the dipoles, the total magnetic dipole of a chunk of material is zero.

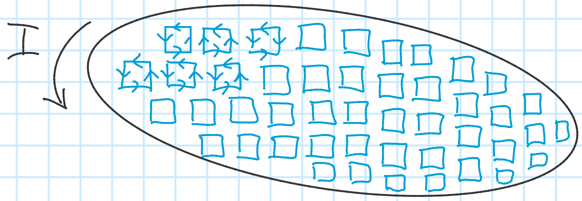
When an external magnetic field is applied to the material, the tiny dipoles can align. The material becomes magnetized.

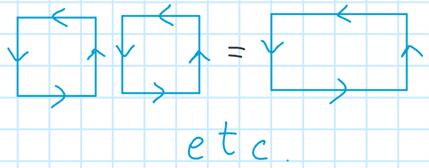
One can distinguish several behaviors of the magnetized material

1) Paramagnets: the dipoles in the material align to the external magnetic field
2) Diamagnetism: the dipoles align in the direction opposite to the external magnetic field
3) Ferromagnetism: materials that remain magnetized even when the external magnetic field is removed.

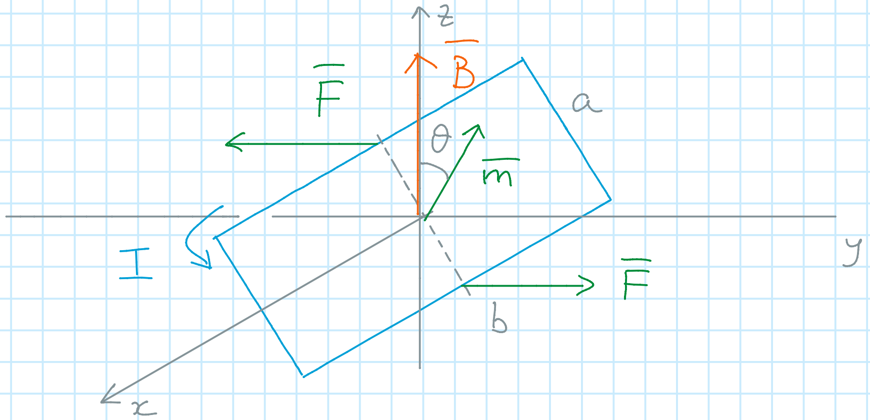
Torques and forces on magnetic dipoles.

A magnetic dipole experiences a torque in s magnetic field. Any loop of current can be seen as a combination of infinitesimal rectangular current loops





One can easily see that the torque applied by an external field on a rectangular loop tends to align the loop dipole moment to the field. To visualize this, one can assume a constant magnetic field directed along the z axis and a loop that is free to rotate along the x axis.



The magnitude of the force on the sides of length *b* is

$$F = IbB$$

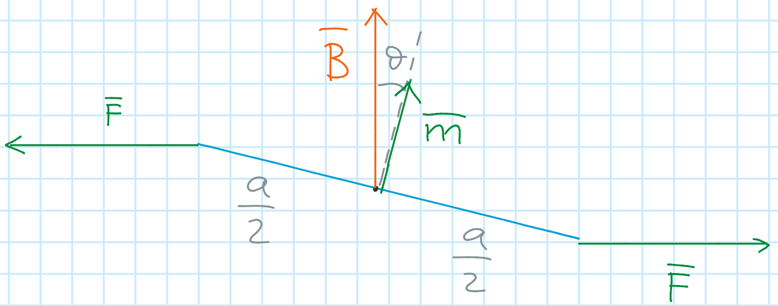
The forces on the two sides of length *b* create a torque of magnitude

$$\tau = 2\frac{a}{2}F\sin\vartheta = aF\sin\vartheta = abIB\sin\vartheta$$

$$= mB\sin\vartheta$$

$m \equiv abI$
magnetic dipole
moment of the
loop

$$\boxed{\bar{\tau} = \bar{m}\times\bar{B}}$$



The equation above gives the torque on any localized current distribution in a uniform magnetic field B. In a non uniform field it is the exact torque on a perfect dipole of infinitesimal size.

This torque tries to align the magnetic dipole moment to the magnetic field, and it is the cause of paramagnetic behavior. Indeed every electron orbit has a magnetic dipole that wants to be aligned to B. However, for quantum mechanical reasons (Pauli exclusion principle) electron tends to come in pairs of opposite magnetic dipole moment (and opposite spin). Because of these cancellations between magnetic dipoles moments of individual electrons, paramagnetism tends to occur in atoms with an odd number of electrons.

Notice the similarity between the equation above and the equation for the torque applied on an electric dipole by an electric field

$$\boxed{\bar{\tau} = \bar{p} \times \bar{E}} \qquad \boxed{\bar{\tau} = \bar{m} \times \bar{B}}$$