Answer on Question #69086, Physics / Electromagnetism

How do we differentiate between diamagnetic and paramagnetic materials? Show that for diamagnetic atoms placed in an external magnetic field B, the change in dipole moment is opposite to the direction of B.

Solution:

How do we differentiate between diamagnetic and paramagnetic materials?

1. Permeability slightly less than free space for diamagnetic material (e.g., for copper, μ_r= 0.9999980); permeability slightly greater than that of free space for paramagnetic materials (e.g., air μ_r =1.0000004).

2. Diamagnetic materials feebly repelled by external magnetic fields; paramagnetic materials feebly attracted by external magnetic fields.

3. The density of the lines of induction is a little less than the density of the lines of magnetic intensity for diamagnetic materials; the density of the lines of induction is a little greater than the density of the lines of magnetic intensity for paramagnetic materials.

4. The magnetic field created by paramagnetic materials is in the direction of the external magnetic field whereas the magnetic field created by diamagnetic materials are opposing in direction to the external magnetic field.

5. Paramagnetic materials have at least one unpaired electron in the system, but diamagnetic materials have all their electrons paired.

6. With the rise of temperature a paramagnetic materials becomes a diamagnetic materials; temperature no effects on a diamagnetic materials.

Show that for diamagnetic atoms placed in an external magnetic field B, the change in dipole moment is opposite to the direction of B.

Consider a very classical picture of a Hydrogen atom consisting of an electron revolving in a circular orbit of radius r around a nucleus.

The dipole moment of this current is equal to

$\overline{\mathrm{m}} = -\frac{1}{2}\mathrm{evr}\hat{\mathrm{k}}$ (1), where e is the charge of electron, v is the velocity of electron, r is the radius of orbit, $\hat{\mathrm{k}}$ is the unit vector

If the atom is placed in a magnetic field, it will be subject to a torque.

With no magnetic field present, the velocity of the electron v can be obtained by requiring that the centripetal force is sustained by just the electric force:

$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$ (2), where ε_0 is the electric constant, m is the mass of electron

In a magnetic field, the centripetal force will be sustained by both the electric and the magnetic field:

$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} + ev'B = \frac{mv'^2}{r}$ (3), where B is the induction of a magnetic field

Here we have assumed that the magnetic field is pointing along the positive z axis (in a direction opposite to the direction of the magnetic dipole moment). We have also assumed that the size of the orbit (r) does not change when the magnetic field is applied.

Combining the equations (2) and (3) we obtain:

$\frac{mv^2}{r} + ev'B = \frac{mv'^2}{r}$ (4)

Of (4) $\Rightarrow$ $ev'B = \frac{m}{r}(v - v')(v + v')$ (5)

Assuming that the change in the velocity is small we can use the following approximations:

$v' \cong v$ (6)

$v - v' \cong \Delta v$ (7)

(6) and (7) in (5):

$ev'B = 2\frac{m}{r}v\Delta v$ (8)

Equation (8) shows that the presence of the magnetic field will increase the speed of the electron. An increase in the velocity of the electron will increase the magnitude of the dipole moment of the revolving electron. The change in m is opposite to the direction of B. If the electron would have been orbiting the other way, it would have been slowed down by the magnetic field. Again the change in the dipole moment is opposite to the direction of B.