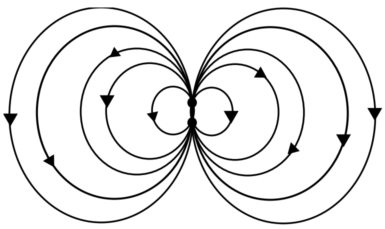
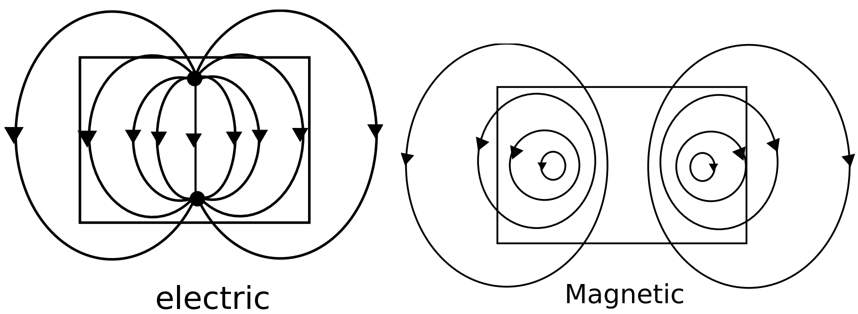
8.022 Lecture Notes Class 28 - 11/2/2006

Pure Dipole



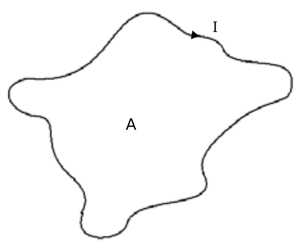
Physical Dipoles



Dipole in Spherical Polar Coords

$\vec{A} = \frac{\mu_0}{4\pi}\frac{m \cdot \sin\theta}{r^2}\hat{\phi}$ Dipole such that $\vec{m} = m\hat{z}$

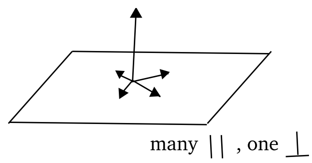
$$\vec{B} = \frac{\mu_0 m}{4\pi r^3}(2\cos\theta\hat{r} + \sin\theta\hat{\theta})$$



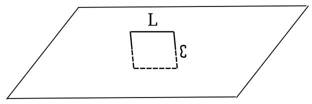
$$\vec{m} = I\int dA = IA\hat{a}$$

<u>Boundary Conditions</u>

$$\text{Perpendicular}: \ B_{\perp,\mathrm{a}} - B_{\perp,\mathrm{b}} \text{ b/c } \vec{\nabla}\cdot\vec{B} = 0$$
$$\text{Parallel}: \ \vec{B}_a^{rm\|} - \vec{B}_b^{\|} = \mu_0(\vec{K}\times\hat{n})$$
$$(\vec{B}_a - \vec{B}_b =)$$



$$\oint \vec{A}\cdot d\vec{l} = \int \vec{\nabla}\times\vec{A}d\vec{a}$$
$$= \int \vec{B}\cdot d\vec{a}$$
$$= \epsilon LB$$



$\epsilon \longrightarrow 0$, just have $B_{\text{above+below}}$, so

perp: $A_{\perp,a} - B_{\perp,b} = 0$ b/c $\vec{\nabla}\cdot\vec{A} = 0$

parallel: $\vec{A}_a^{\|} - \vec{A}_b^{\|} = 0$

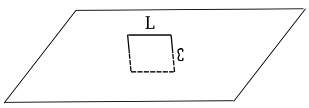
<u>Magnetization</u>

• substance with little
magnetic dipoles inside

Diamagnetic ($\vec{m}$ anti aligns with $\vec{B}$)

Paramagnetic ($\vec{m}$ aligns with $\vec{B}$)

Ferromagnetic $\longleftarrow$ really hard, non linear (depends on entire history of magnet)



<u>Force</u>

- Forces on sloping sides cancel out
- Forces on other side also cancel out No net force But there is a torque.

Torque

$$\begin{aligned}
\vec{N} = & \quad \hat{x} \cdot (a \sin\theta) \cdot IB \cdot b \\
= & \quad IabB \sin\theta \hat{x} \\
= & \quad (I \cdot A) B \sin\theta \hat{x} \\
= & \quad mB \sin\theta \hat{x} \\
= & \ \vec{m} \times \vec{B} \quad \text{; paramagnetism (unpaired)}
\end{aligned}$$

Diamagnetism

Examine using classical model- electron around proton; it moves fast enough that we can consider it constant current.

$$\begin{aligned}
I = & \ -\tfrac{e}{T} = -\tfrac{eV}{2\pi R} \\
|m| = & \quad I\pi R^2 \\
\vec{m} = & \ -\tfrac{1}{2} eVR\hat{\wp}
\end{aligned}$$

quantum stuff: $\vec{L}, \vec{S}$ $\qquad \vec{N} = \vec{m} \times \vec{B}$ weak effect

e $\longrightarrow$ $-$e

$$\frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{R^2} = m_e \frac{v^2}{R} \qquad (m_p >> m_e)$$

add magnetic force :

$$\frac{1}{4\pi\epsilon_0}\cdot\frac{e^2}{R^2}+ev'B=m_e\frac{v^2}{R} \qquad (m_p >> m_e)$$

$$\begin{aligned} ev'B =& \tfrac{m_e}{R}(v'^2-v^2)=\tfrac{m_e}{R}(v+v')(v'-v) \\ ev'B \approx& \qquad\qquad \tfrac{m_e}{R}(2v')(v'-v) \end{aligned}$$

$$\Longrightarrow \frac{eRB}{2m_e}=v'-v=\Delta v$$

What ? Magnetic field speeds up an electron? No, actually B generates a E that does the work

$$\Delta\vec{m}=-\frac{1}{2}e\Delta vR\hat{z}=\frac{-e^2R^2}{4m_e}\vec{B}$$

So, charge in magnetization is opposite of magnetic field. Change of velocity is independent of orbit direction! (works for both paired and unpaired , but its so weak that it's noticeable only when no paramagnetization) Diamagnetization!

$\vec{M}$ = magnetization = $\vec{m}$ per unit vol.