# Fields and Waves

Lesson 3.6

MAGNETIC MATERIALS

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# Magnetic Materials

Today's Lesson:

- linkage between <u>H</u> and <u>B</u> fields
- <u>M</u> - magnetization
- re-visit Ampere's Law
- boundary conditions
- permanent magnets

# Magnetic Materials

Magnetic properties tend to either very strong or very weak

Vast majority of materials

- ferromagnets (Fe) and permanent magnets
- exhibit strong non-linear effects
- demonstrate "memory" or hysterisis effects

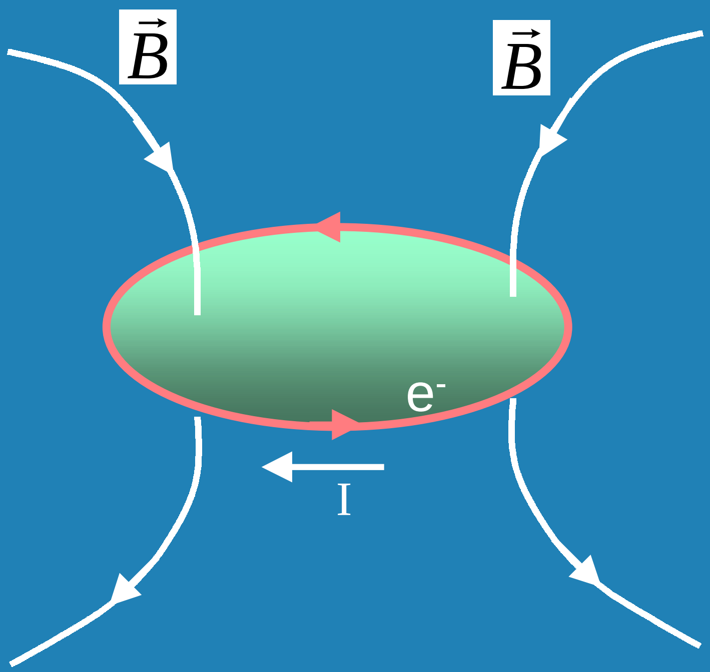
*Use simple, linear model*

Recall in electrostatics that most materials have <u>moderate</u> effect:

$$1 < \varepsilon < 10$$

# Magnetic Materials

In Quantum mechanics, atoms have "spin"




In the classical picture:

- electron orbits the nucleus
- acts like a current loop

Usually in most materials, the loops has random orientation - so the net effect is small

In ferromagnets, neighboring atoms have spins that are aligned - strong effects

# Magnetic Dipole Moment

The individual current loops can be thought of as having a dipole moment, $\vec{m}$

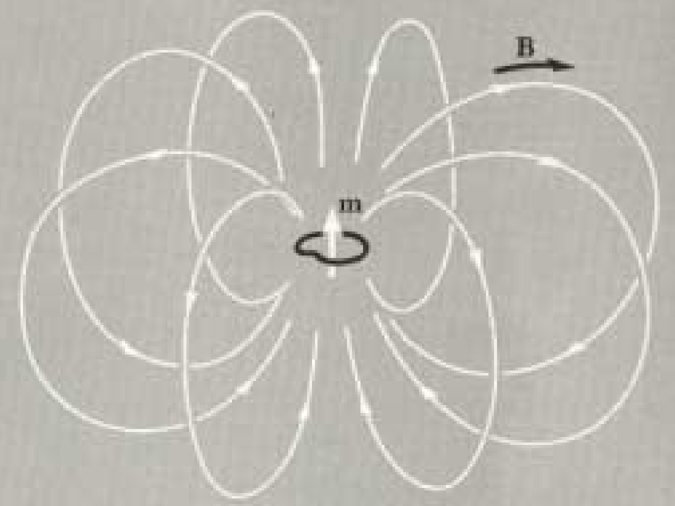



*Fig. 10.7* Some magnetic field lines in the field of a magnetic dipole, that is, a small loop of current.

# Magnetic and Electric Dipole Moment

The current loop approximates the dipole moment, $\vec{m}$

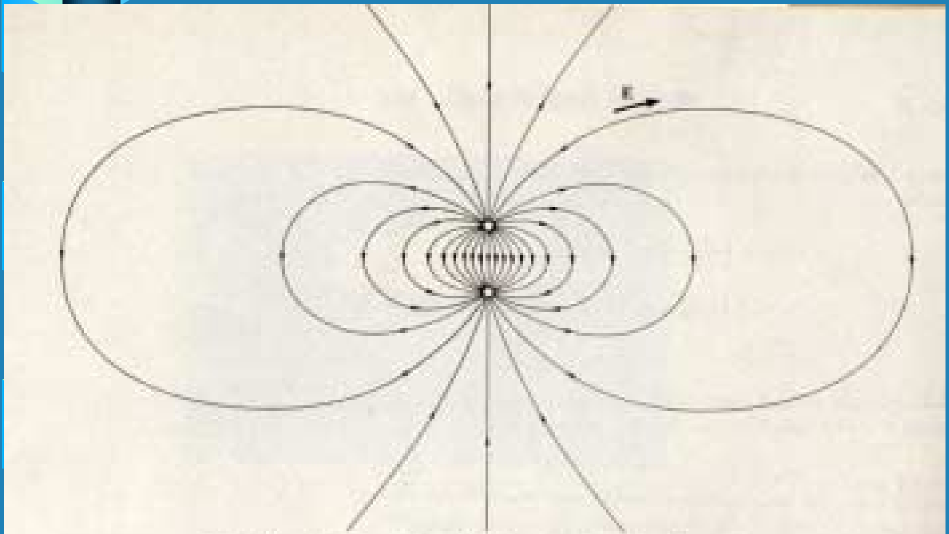
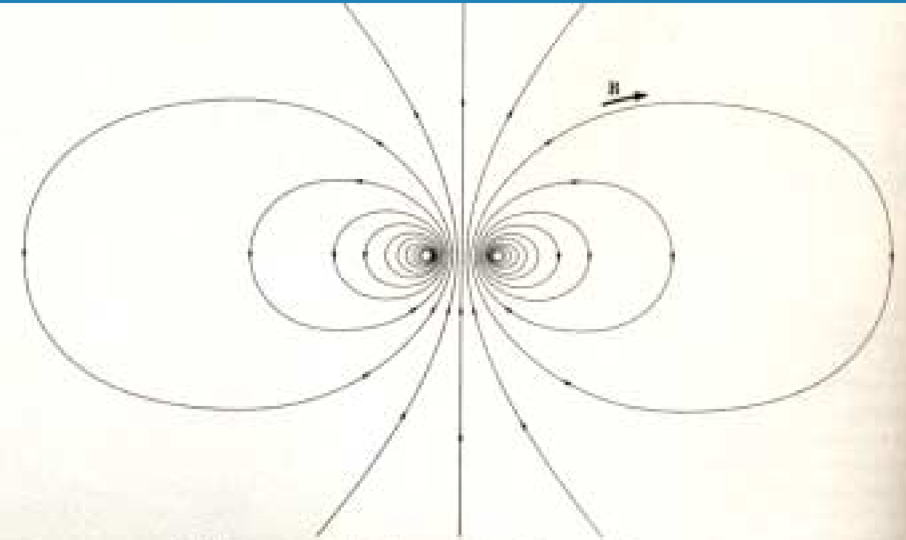



Fig. 10.8 (a) The electric field of a pair of equal and opposite charges. Far away it becomes the field of an electric dipole.




(b) The magnetic field of a current ring. Far away it becomes the field of a magnetic dipole.

E-field of electric dipole

B-field of magnetic dipole

Far-fields look the same for both types of dipoles

# Relationship between $\vec{B}$ & $\vec{H}$

In general, one can write:

$$\vec{M} = \sum_i \vec{m}_i$$

magnetization

Sum over all atoms

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$$

where,

$\vec{B}$ -flux due to all sources

$\vec{M}$ -flux due to atomic sources

$\vec{H}$ -flux due to free current

(e.g. conduction current, e-beam)

# Relationship between $\vec{B}$ & $\vec{H}$

Maxwell's equation: $\oint \vec{H} \bullet d\vec{l} = I_{net} = \int \vec{j} \bullet d\vec{s}$

these are free-currents

• we can determine H without determining M

In most general form: $\vec{B} = \mu_0 \cdot (\vec{H} + \vec{M})$

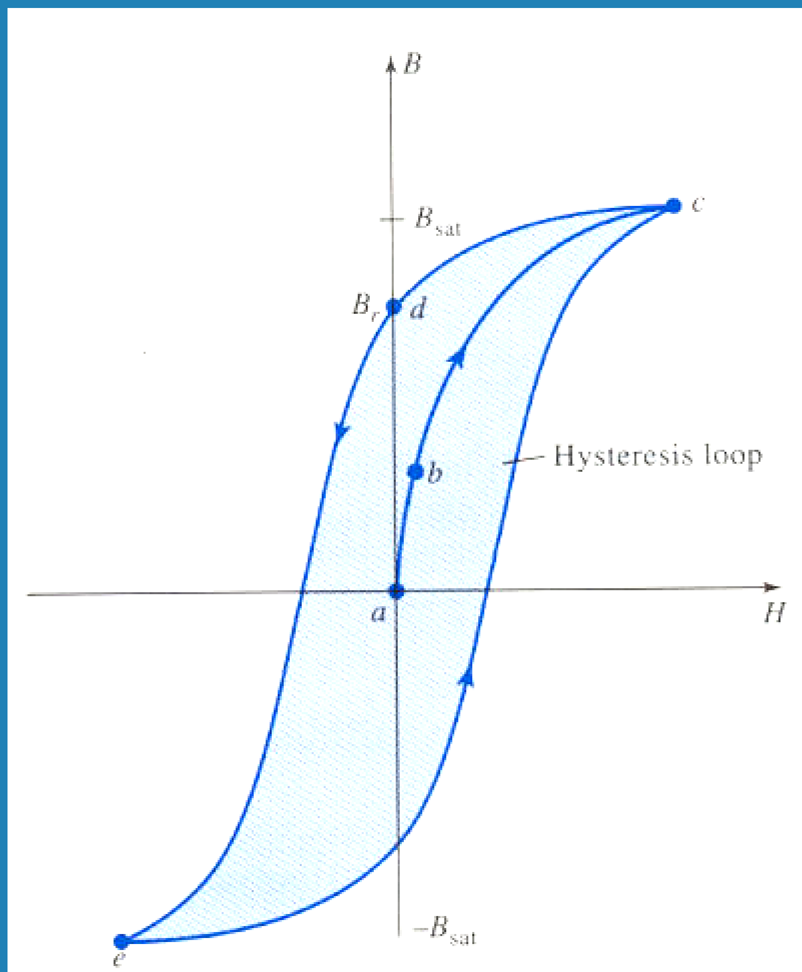
If, $\vec{M} \propto \vec{H}$ $\Rightarrow \vec{B} = \mu \cdot \vec{H} = \mu_r \cdot \mu_0 \cdot \vec{H}$

Values, $\mu_0 = 4\pi \times 10^{-7}\ H/m$

$\mu_r = 1 \times 10^{-4}$ most materials

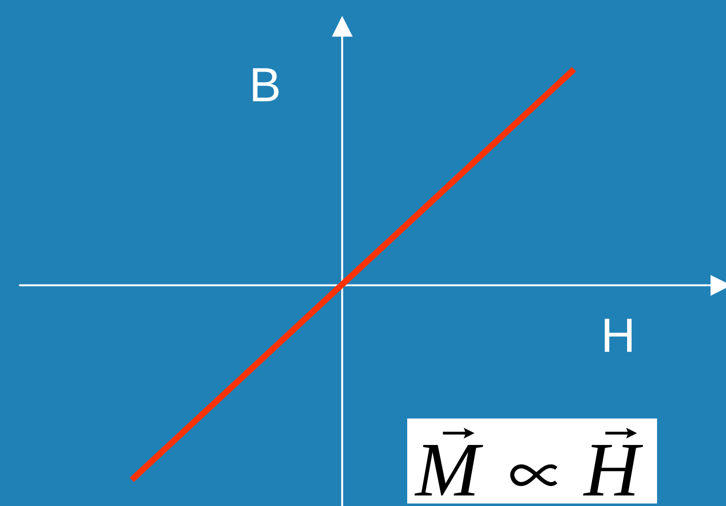
$\rightarrow \approx 5000$ for iron

# Curves for $\vec{B}$ & $\vec{H}$




Typical B-H Curve for materials

For course, use ideal curve:



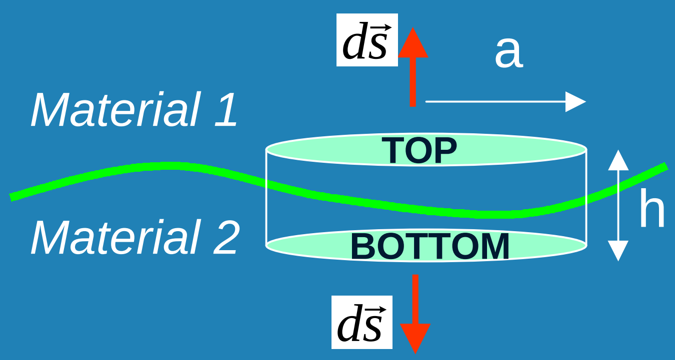

$$\vec{M} \propto \vec{H}$$

# Boundary Conditions

*Do problem 1a:* use $\oint \vec{H} \bullet d\vec{l} = I_{net}$ then apply $\vec{B} = \mu \cdot \vec{H}$

## Boundary Conditions:

<u>Normal component:</u>




$$\oint \vec{B} \bullet d\vec{s} = 0 = \int_{TOP} \vec{B} \bullet d\vec{s} + \int_{BOTTOM} \vec{B} \bullet d\vec{s}$$

$$B_{n1} \cdot AREA - B_{n2} \cdot AREA = 0$$

$$\therefore B_{n1} = B_{n2}$$

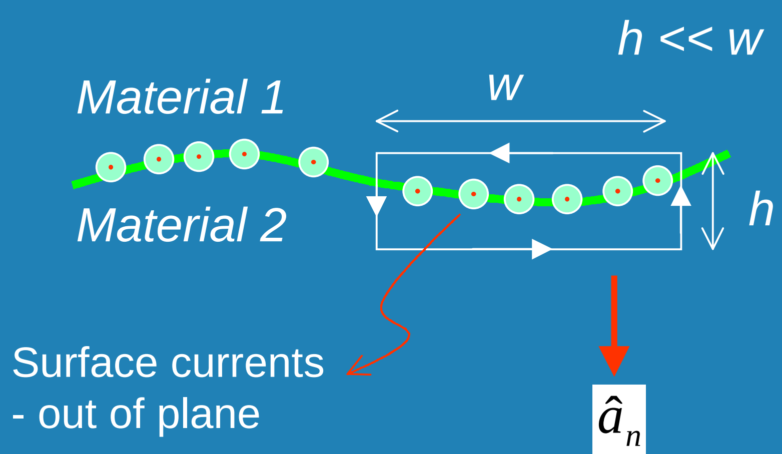
Take h << a **(a thin disc)**

- ignore contribution from the sides

# Boundary Conditions

## Boundary Conditions:

### <u>Tangential component:</u>




$$\oint \vec{H} \bullet d\vec{l} = H_{t2} \cdot w - H_{t1} \cdot w = I_{net}$$

*$I_{net}$ can only be due to surface currents = $J_s.w$*

$$\therefore H_{t2} - H_{t1} = J_s$$

or

$$\hat{a}_n \times (\vec{H}_2 - \vec{H}_1) = \vec{J}_s$$

- If non-conductor, $J_s = 0$ ,then, $H_{t1} = H_{t2}$
- If conductor in 1 and $H_{t1} \rightarrow 0, then, H_{t2} = J_s$

# Magnetic Materials

*Do Problems 1b and 2*

*Problem 2 : Field lines exit normally in high μ materials*

*Also, field lines like to travel through high μ materials*

Transformers : • use IRON to direct flux

• primary and secondary windings intercept almost all the flux - no need for “smoothly-wound” coils

• Noise reduction

• increase Inductance with increasing μ

*Do Problem 3*