Class 14: Outline

Hour 1:

Magnetic Fields

Expt. 5: Magnetic Fields

Hour 2:

Charges moving in B Fields

Exam Review

A New Topic:
Magnetic Fields

Gravitational – Electric Fields

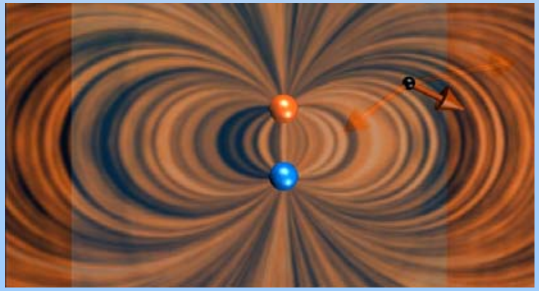
Mass *m* | Charge *q* (±)

Create: $\vec{\mathbf{g}} = -G\frac{m}{r^2}\hat{\mathbf{r}}$ $\qquad$ $\vec{\mathbf{E}} = k_e\frac{q}{r^2}\hat{\mathbf{r}}$

Feel: $\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$ $\qquad$ $\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$

Also saw…

Dipole **p**

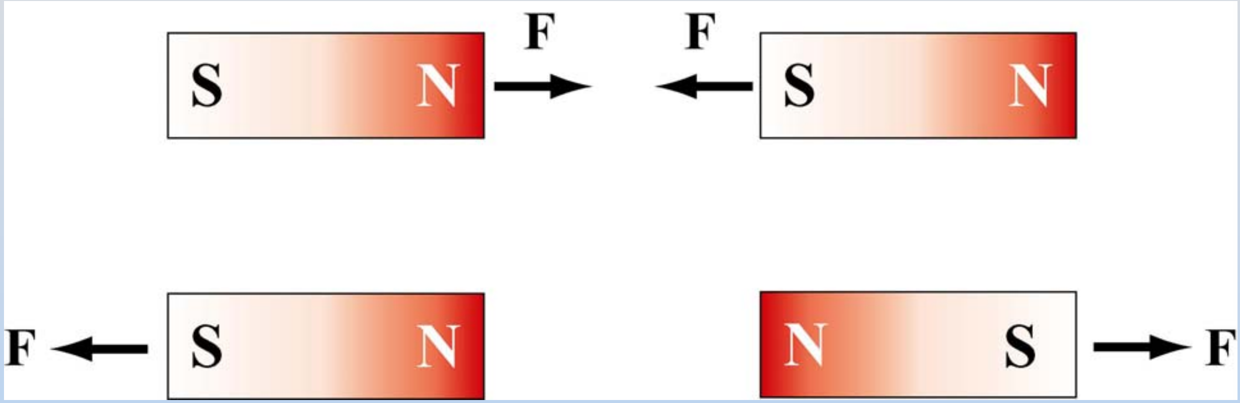


Create:

Feel:

$$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$$

Magnetism – Bar Magnet

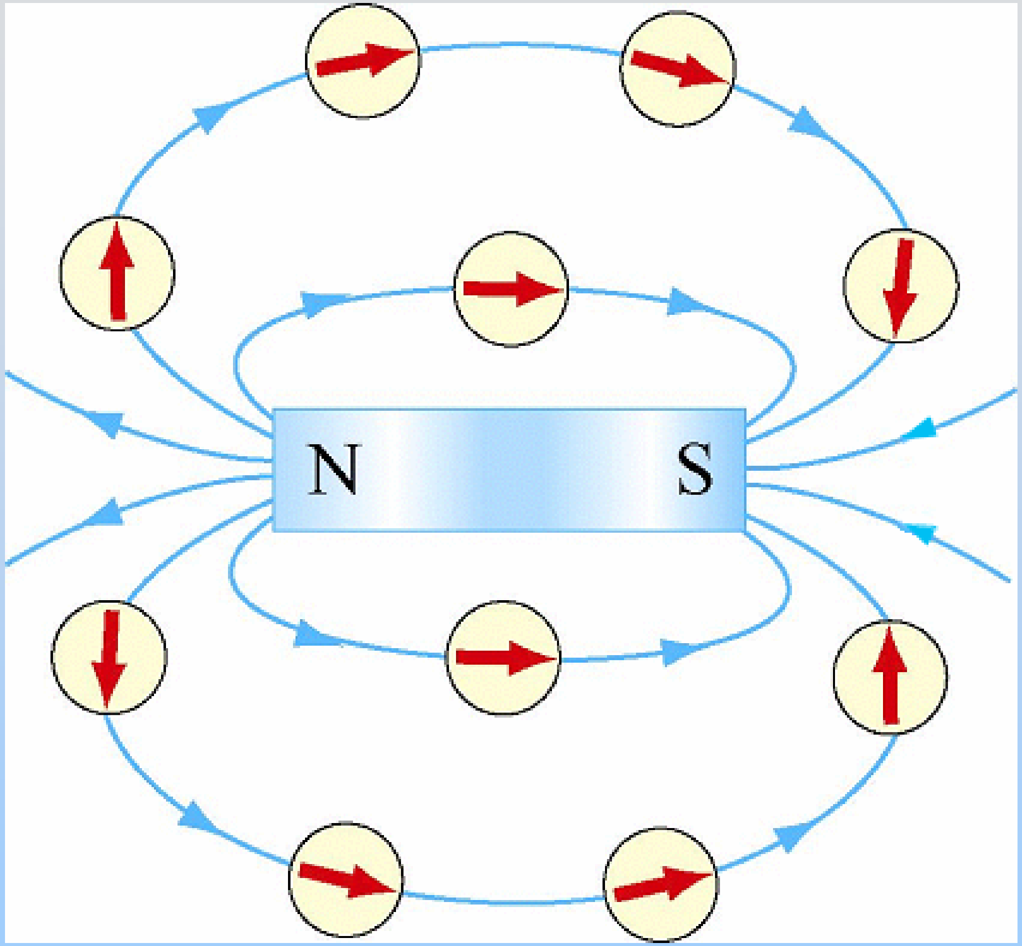


Like poles repel, opposite poles attract

Demonstration: Magnetic Field Lines from Bar Magnet

Demonstration:
Compass (bar magnet) in Magnetic Field Lines from Bar Magnet

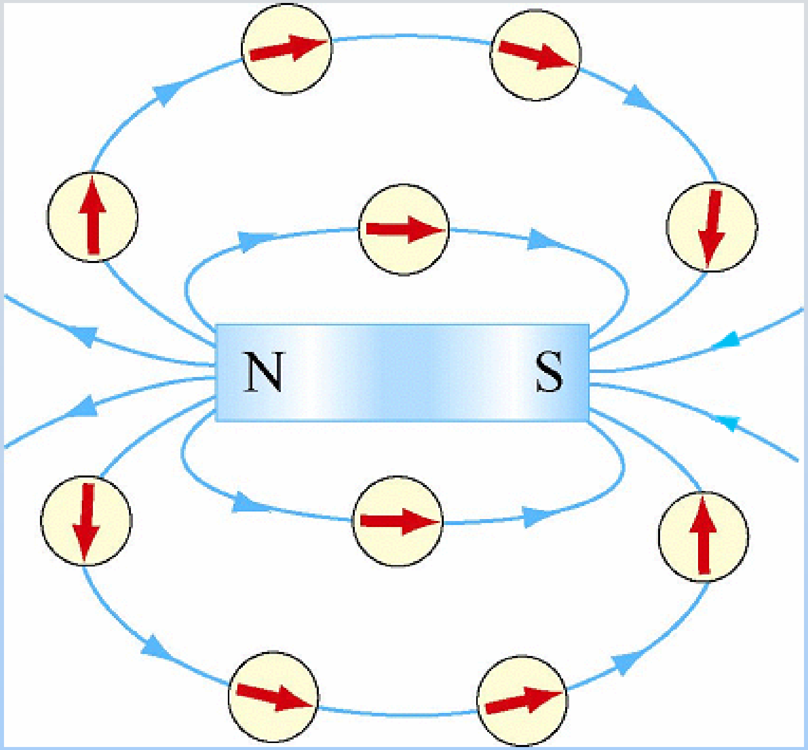
Magnetic Field of Bar Magnet



(1) A magnet has two poles, North (N) and South (S)

(2) Magnetic field lines leave from N, end at S

Bar Magnets Are Dipoles!

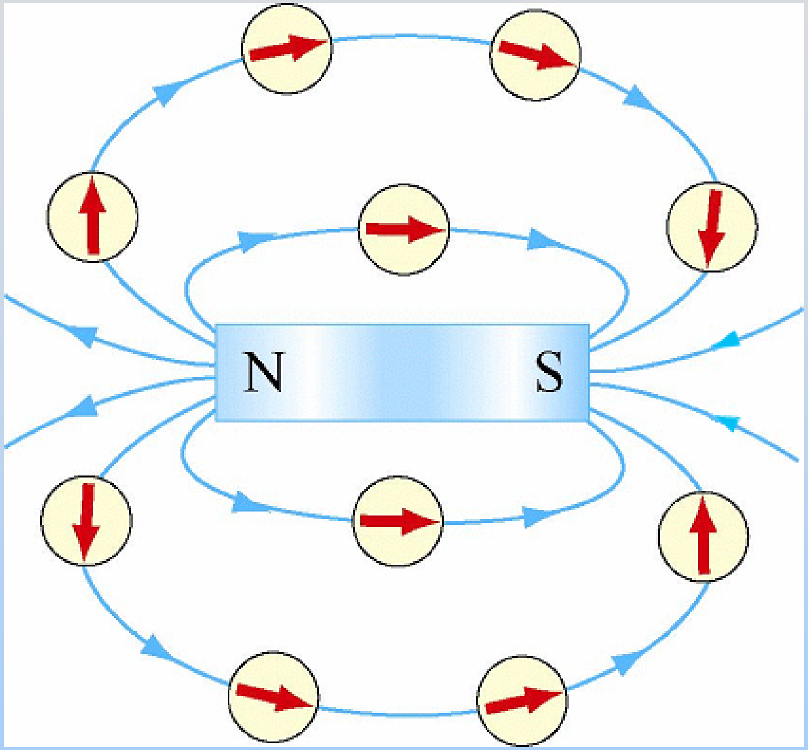


- Create Dipole Field
- Rotate to orient with Field

Is there magnetic "mass" or magnetic "charge?"

NO! Magnetic monopoles do not exist in isolation

Bar Magnets Are Dipoles!



- Create Dipole Field
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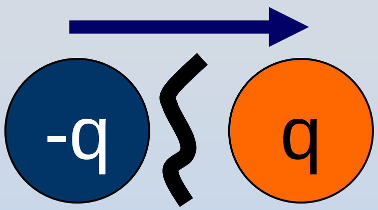
Magnetic Monopoles?

Electric Dipole

$\vec{\mathbf{p}}$

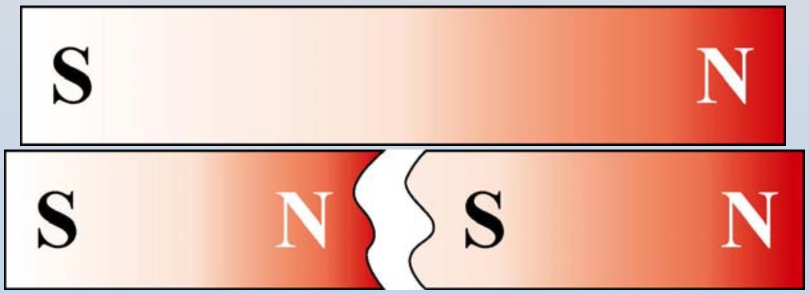


When cut:

2 monopoles (charges)

Magnetic Dipole

$\vec{\boldsymbol{\mu}}$



When cut: 2 dipoles

Magnetic monopoles do not exist in isolation

Another Maxwell's Equation! (2 of 4)

$$\oint\!\!\oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0}$$

Gauss's Law

$$\oint\!\!\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$

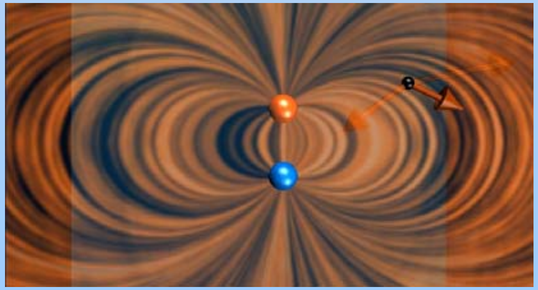
Magnetic Gauss's Law

Fields: Grav., Electric, Magnetic

	Mass m	Charge q (±)	No Magnetic Monopoles!
Create:	$\vec{\mathbf{g}} = -G\frac{m}{r^2}\hat{\mathbf{r}}$	$\vec{\mathbf{E}} = k_e\frac{q}{r^2}\hat{\mathbf{r}}$	
Feel:	$\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$	$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$	

Also saw…

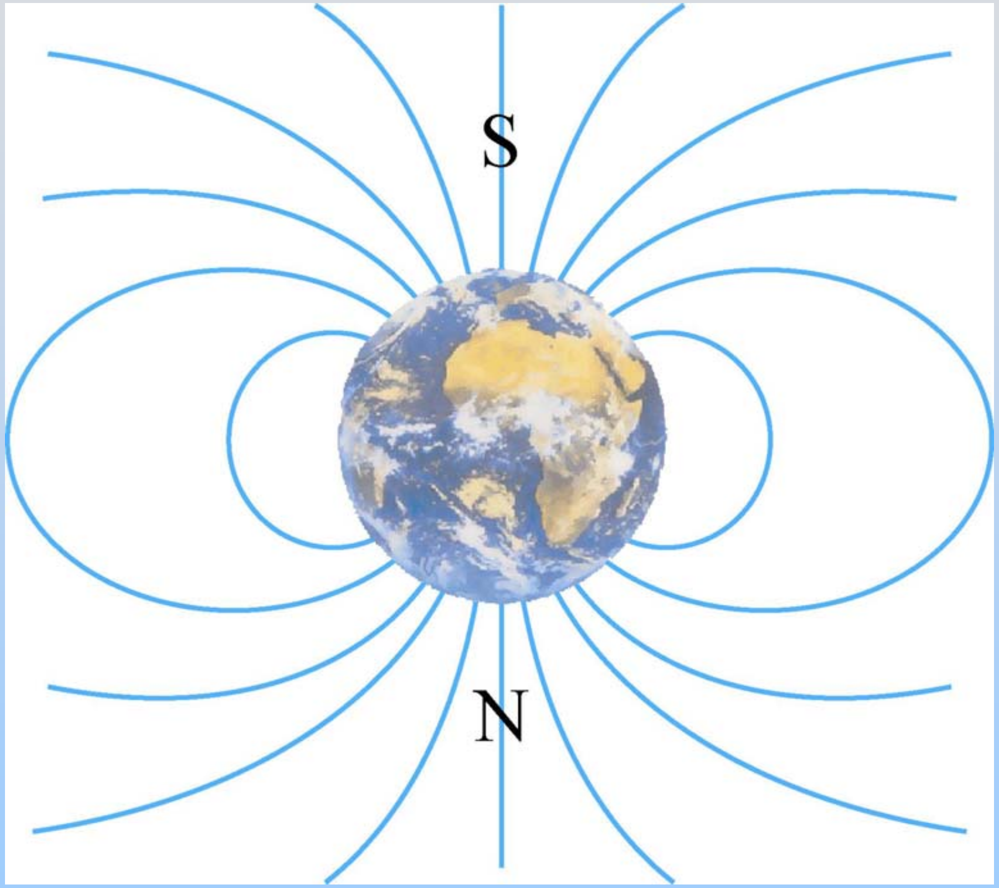
Dipole **p** Dipole μ

Create: $\vec{\mathbf{E}} \rightarrow$  $\leftarrow \vec{\mathbf{B}}$

Feel: $\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$ $\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\mathbf{B}}$

What else is magnetic?

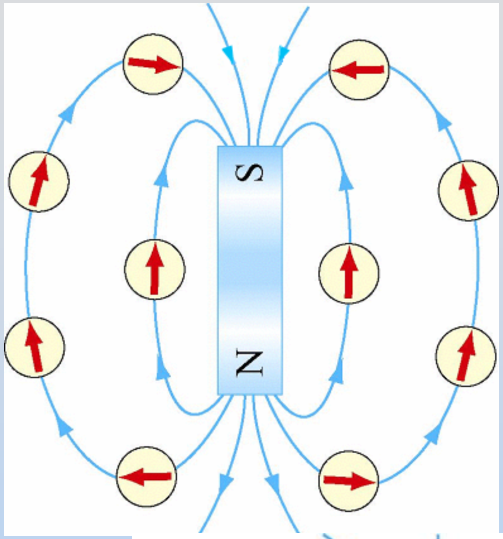
Magnetic Field of the Earth

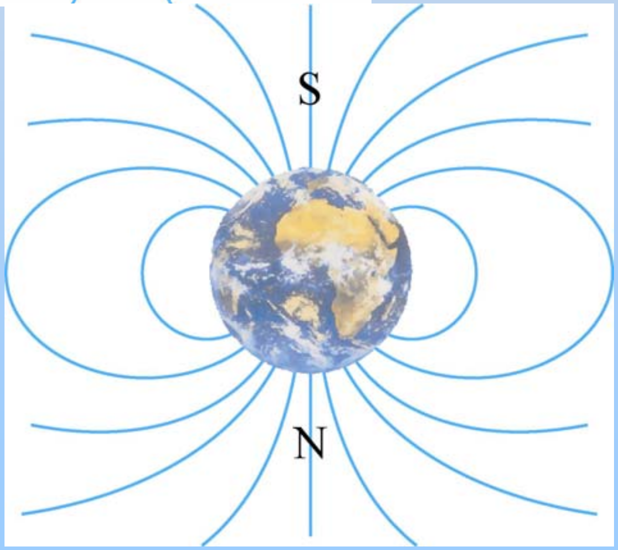


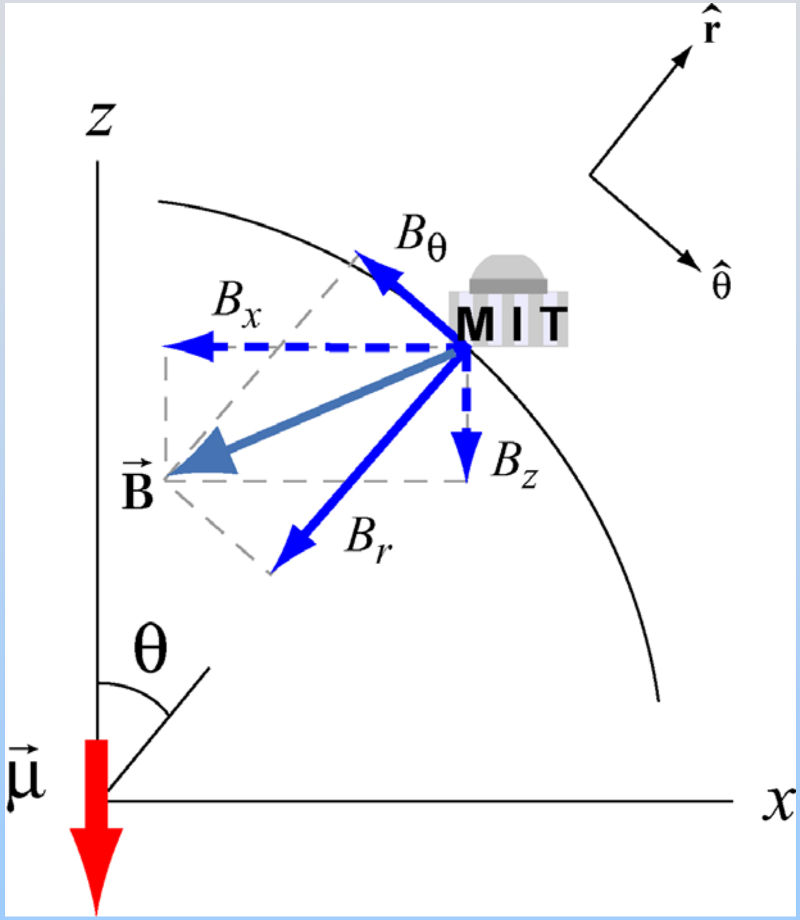
Also a magnetic dipole!

North magnetic pole located in southern hemisphere

Earth's Field at MIT





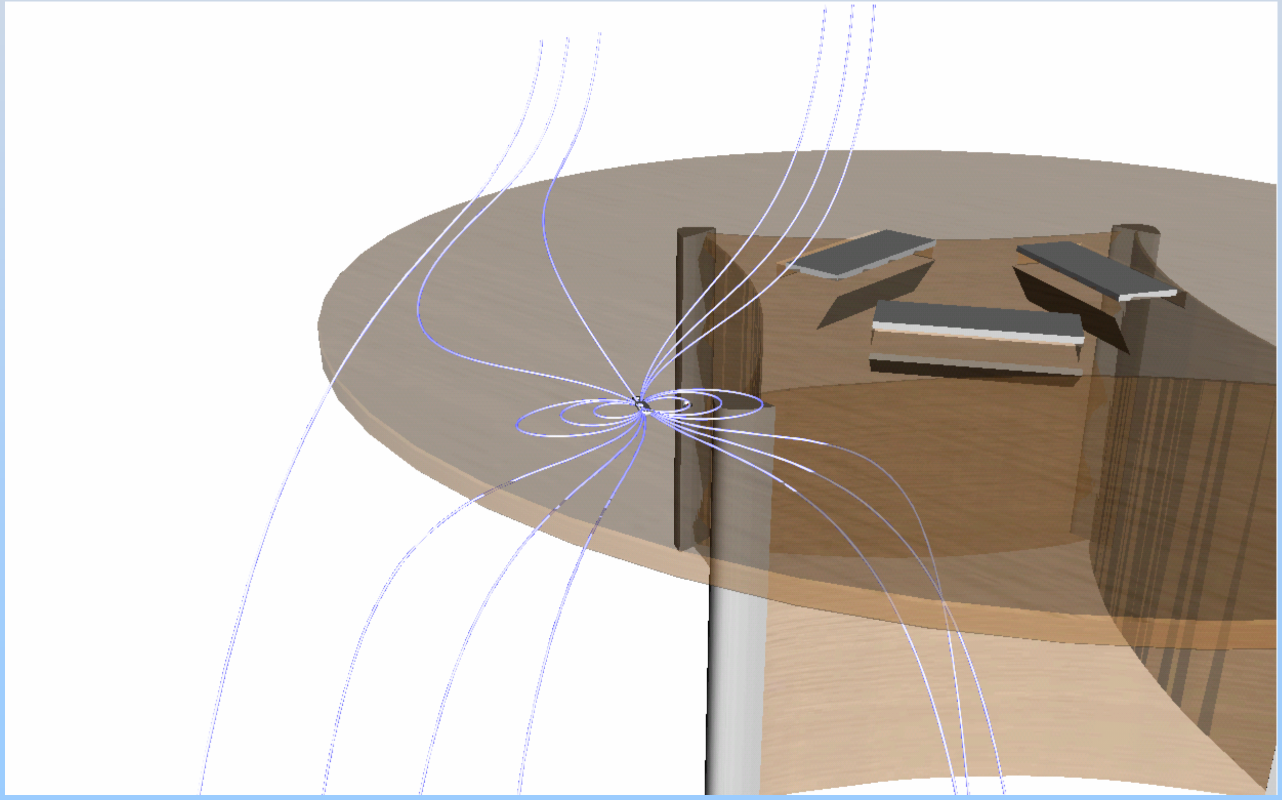


We will measure these components

Experiment 5: Bar Magnet & Earth's Magnetic Field

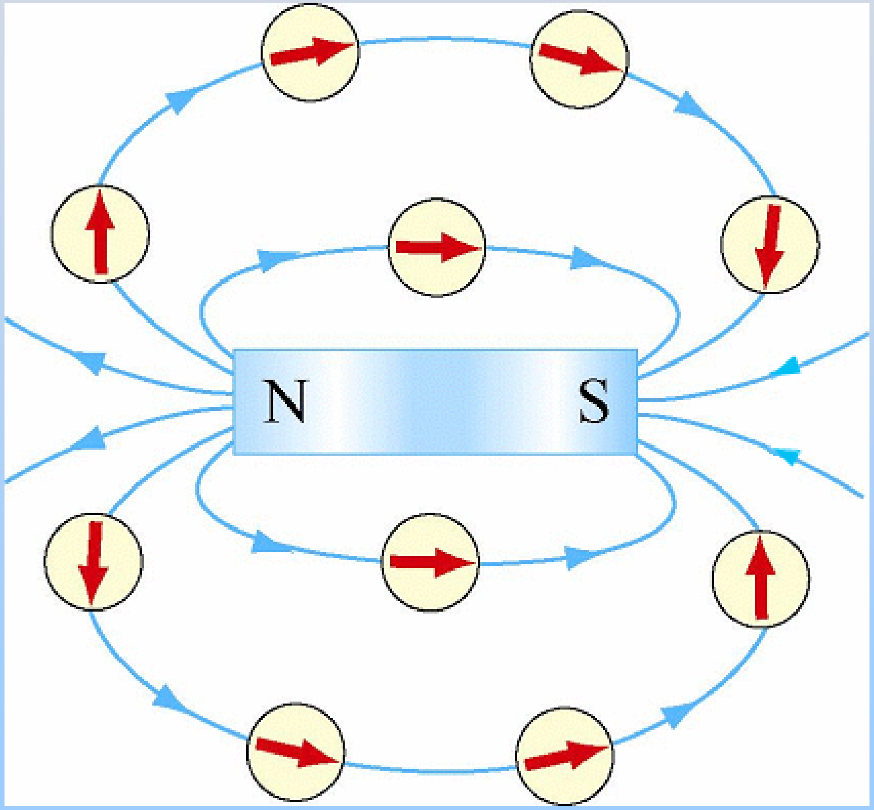
Visualization: Bar Magnet & Earth's Magnetic Field

(http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/magnetostatics/27-barmagontable/27-barmag320.html)



Magnetic Field B Thus Far…

Bar Magnets (Magnetic Dipoles)…

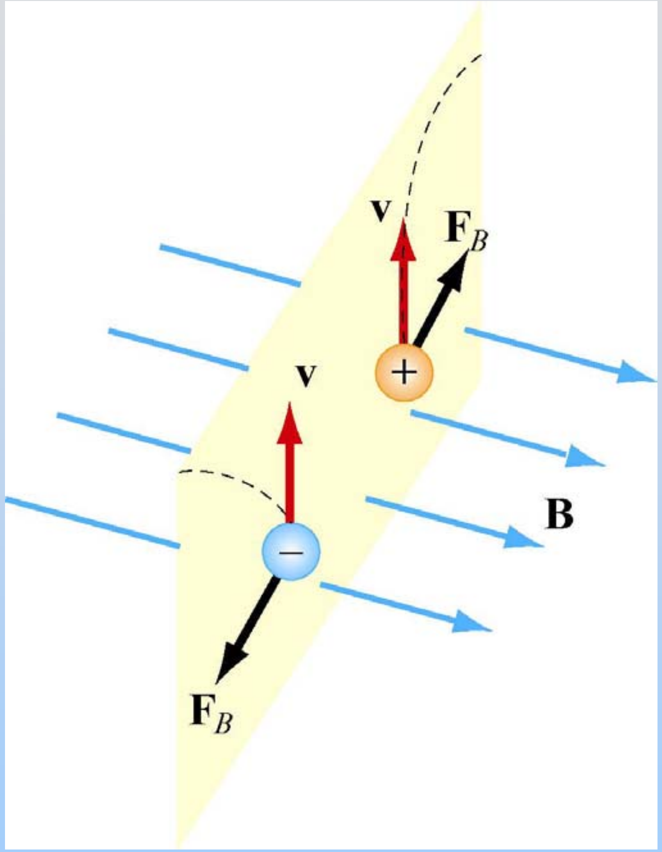


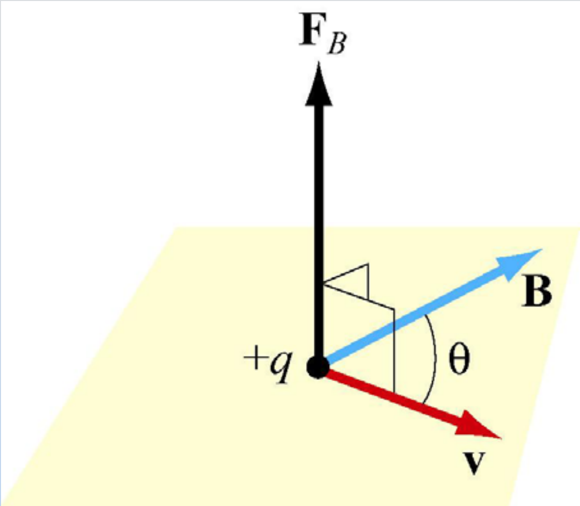
- **Create:** Dipole Field
  - **Feel**: Orient with Field

Does anything else create or feel a magnetic field?

Demonstration:
TV in Field

Moving Charges Feel Magnetic Force





$$\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Magnetic force perpendicular both to:
Velocity **v** of charge and magnetic field **B**

Magnetic Field B: Units

Since $\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}} \times \vec{\mathbf{B}}$

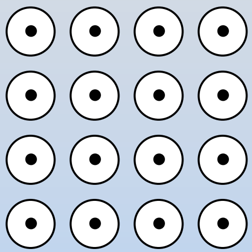
$$\text{B Units} = \frac{\text{newton}}{(\text{coulomb})(\text{meter/second})} = 1\frac{\text{N}}{\text{C}\cdot\text{m/s}} = 1\frac{\text{N}}{\text{A}\cdot\text{m}}$$

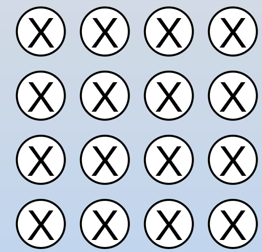
This is called 1 Tesla (T)

$$1\ \text{T} = 10^4\ \text{Gauss (G)}$$

Recall:
Cross Product

Notation Demonstration





OUT of page

“Arrow Head”

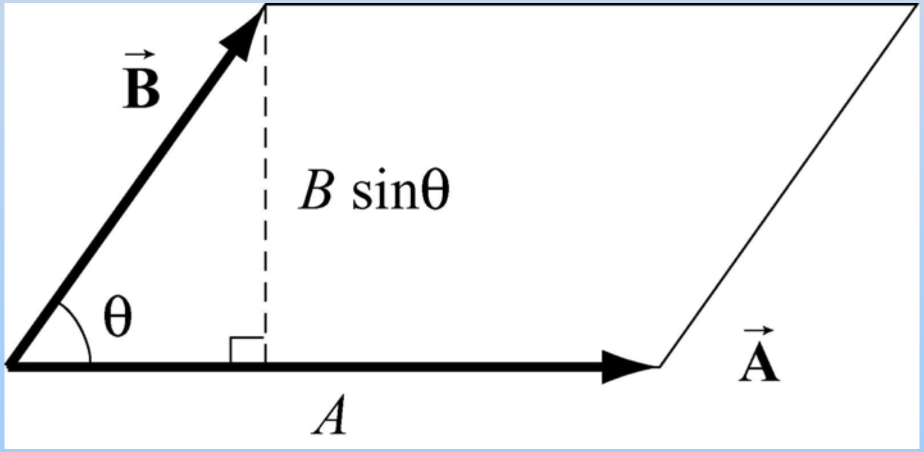
INTO page

“Arrow Tail”

Cross Product: Magnitude

Computing magnitude of cross product A x B:

$$\vec{\mathbf{C}} = \vec{\mathbf{A}} \mathrm{x} \vec{\mathbf{B}} \qquad \left|\vec{\mathbf{C}}\right| = \left|\vec{\mathbf{A}}\right|\left|\vec{\mathbf{B}}\right| \sin\theta$$



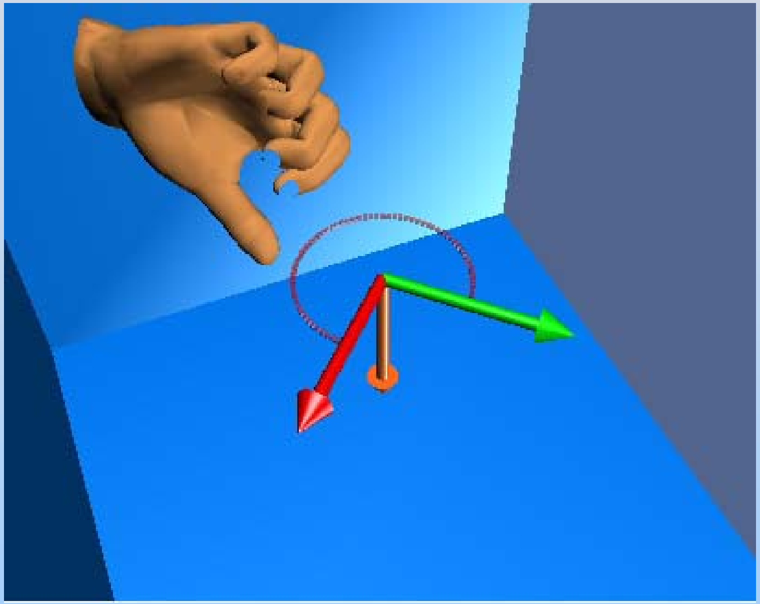
$|\vec{\mathbf{C}}|$: area of parallelogram

Cross Product: Direction

Right Hand Rule #1: $\vec{C} = \vec{A} \times \vec{B}$

1) Curl fingers of right hand in the direction that moves **A** (green vector) to **B** (red vector) through the smallest angle

2) Thumb of right hand will point in direction of the cross product **C** (orange vector)



http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/vectorfields/14-CrossProduct/14-crossprod320.html

Cross Product: Signs

$$\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}} \qquad \hat{\mathbf{j}} \times \hat{\mathbf{i}} = -\hat{\mathbf{k}}$$

$$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}} \qquad \hat{\mathbf{k}} \times \hat{\mathbf{j}} = -\hat{\mathbf{i}}$$

$$\hat{\mathbf{k}} \times \hat{\mathbf{i}} = \hat{\mathbf{j}} \qquad \hat{\mathbf{i}} \times \hat{\mathbf{k}} = -\hat{\mathbf{j}}$$

Cross Product is Cyclic (left column)

Reversing **A** & **B** changes sign (right column)

PRS Questions: Right Hand Rule

Putting it Together: Lorentz Force

Charges Feel...

$$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$$

Electric Fields

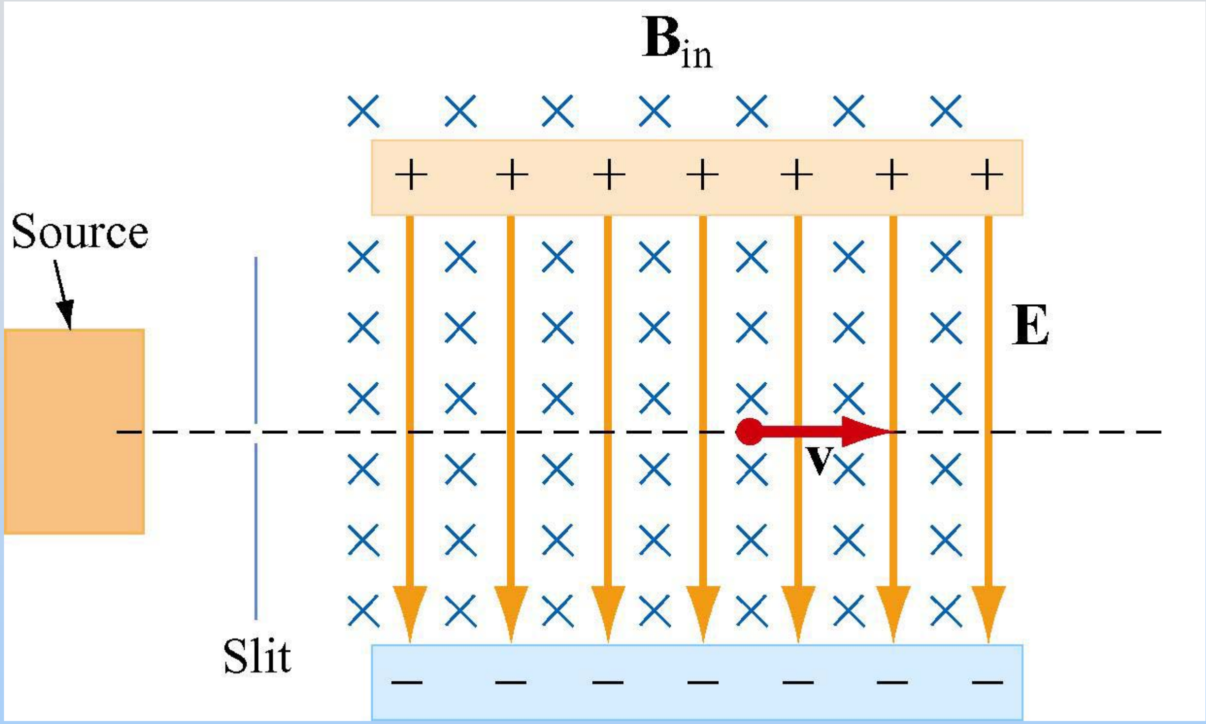
$$\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Magnetic Fields

$$\boxed{\vec{\mathbf{F}} = q\left(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}}\right)}$$

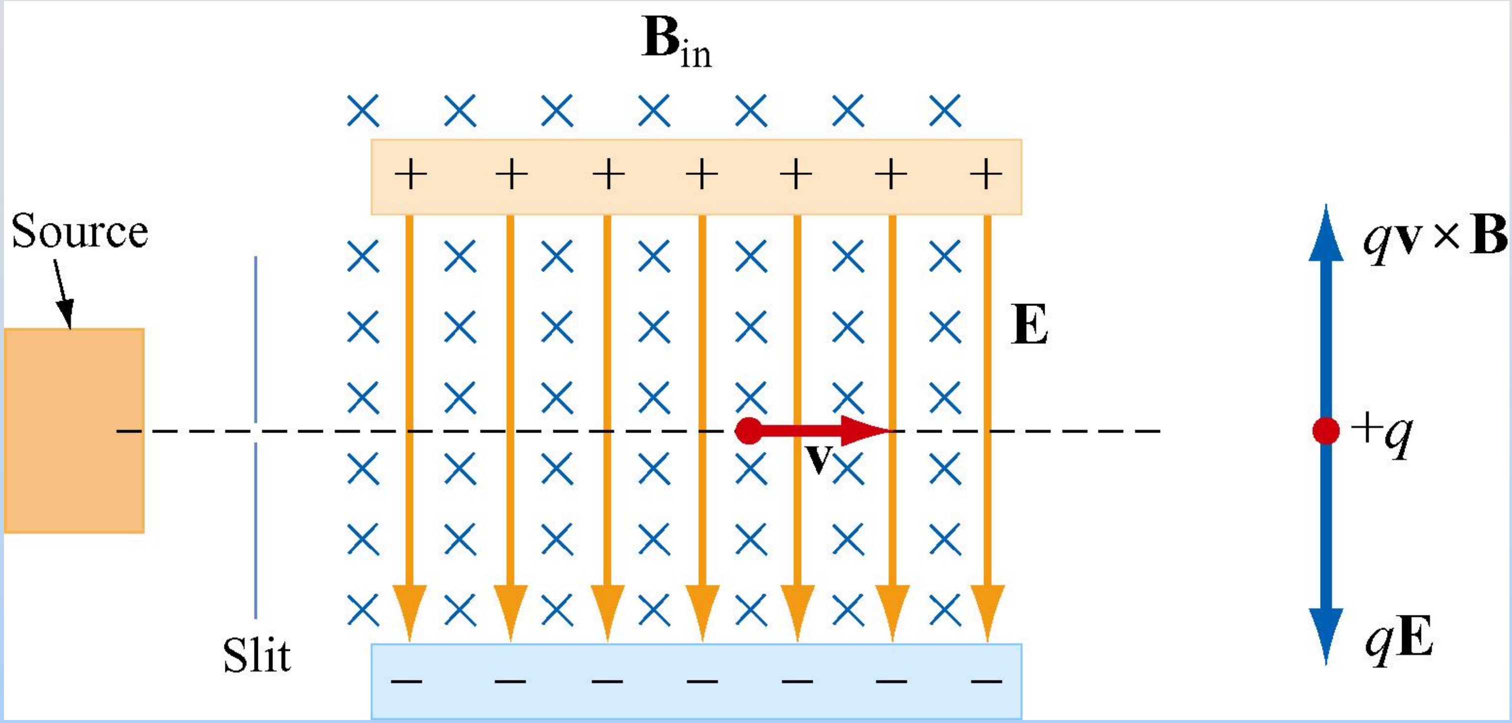
This is the final word on the force on a charge

Application: Velocity Selector



What happens here?

Velocity Selector



Particle moves in a straight line when

$$\vec{\mathbf{F}}_{net} = q(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}}) = 0 \Rightarrow v = \frac{E}{B}$$

PRS Question:
Hall Effect

Exam Review