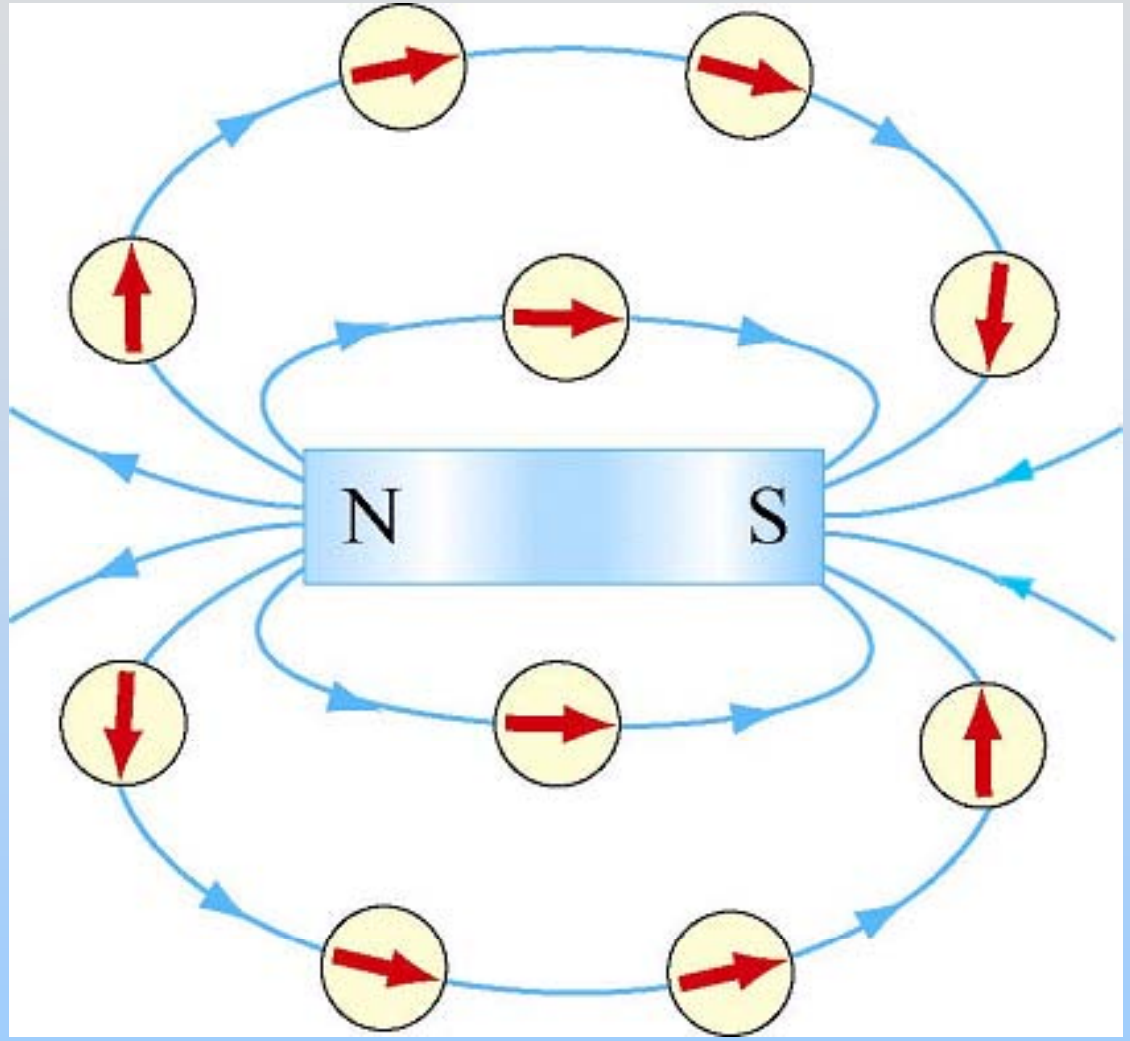
Module 16: Magnetic Fields

Module 16: Outline

Magnetic Field

Magnetic Fields

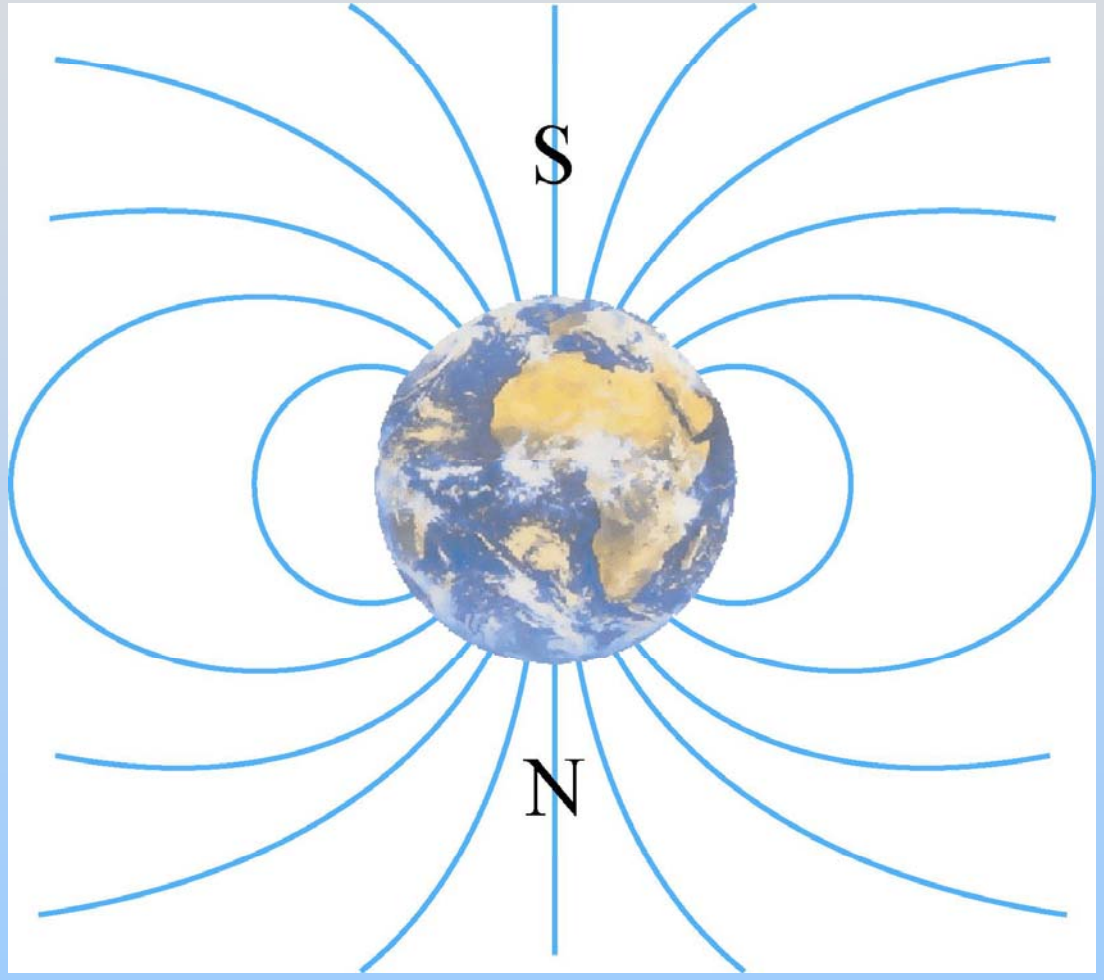
Magnetic Field of Bar Magnet



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

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

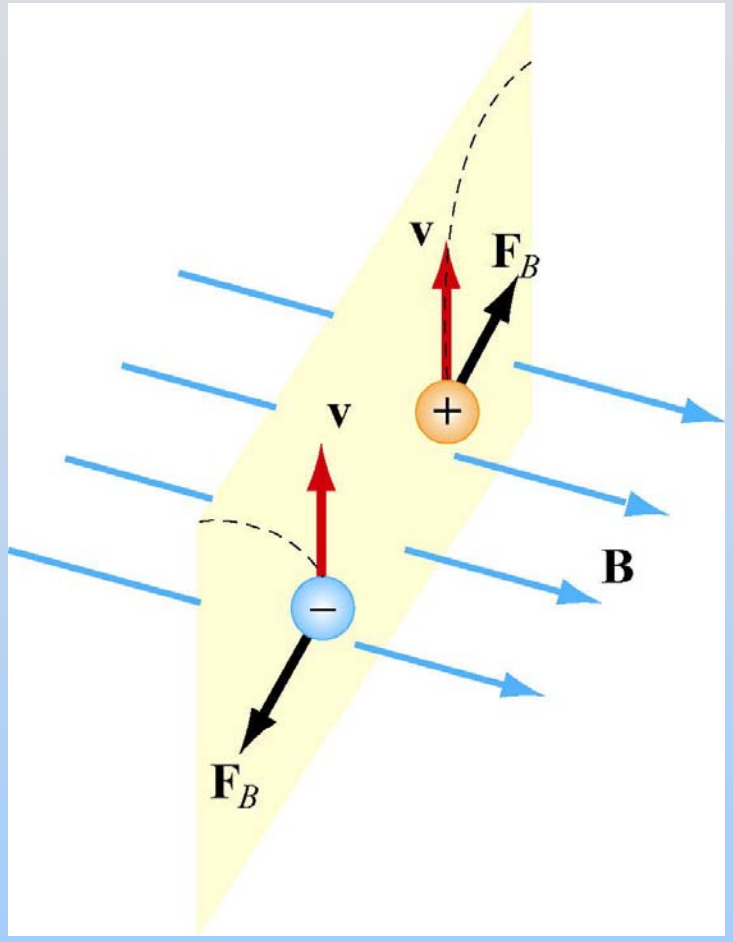
Magnetic Field of the Earth

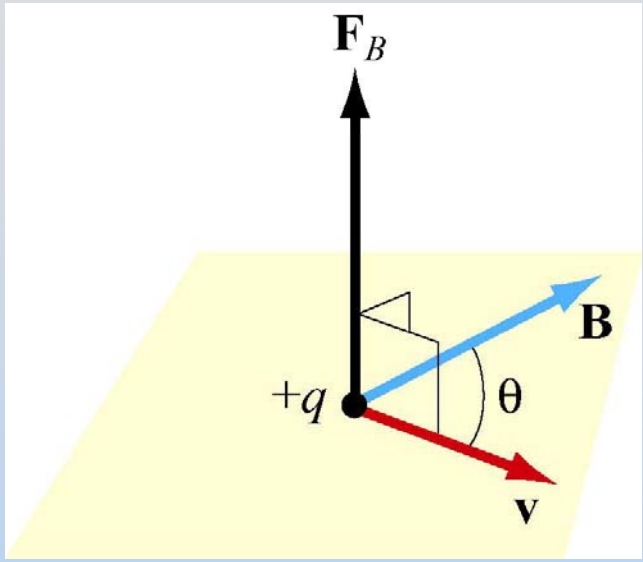


Also a magnetic dipole!

North magnetic pole located in southern hemisphere

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**

B Field Units

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

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

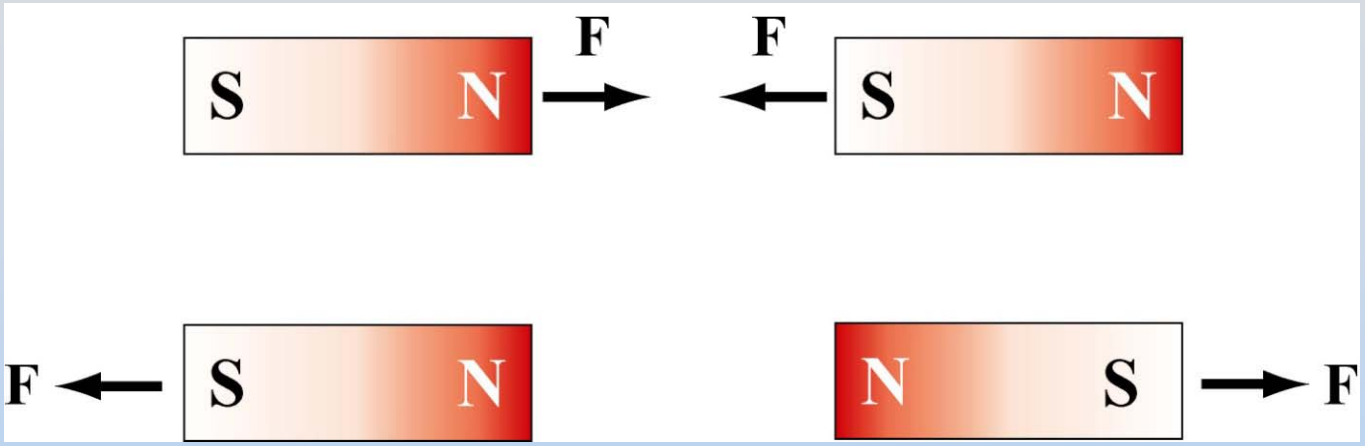
This is called 1 Tesla (T)

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

How Big is a Tesla?

- Earth's Field — 5×10^{-5} T = 0.5 Gauss
- Brain (at scalp) — ~1 fT
- Refrigerator Magnet
- Inside MRI — 3 T
- Good NMR Magnet — 18 T
- Biggest in Lab — 150 T (pulsed)
- Biggest in Pulsars

Magnetism – Bar Magnet

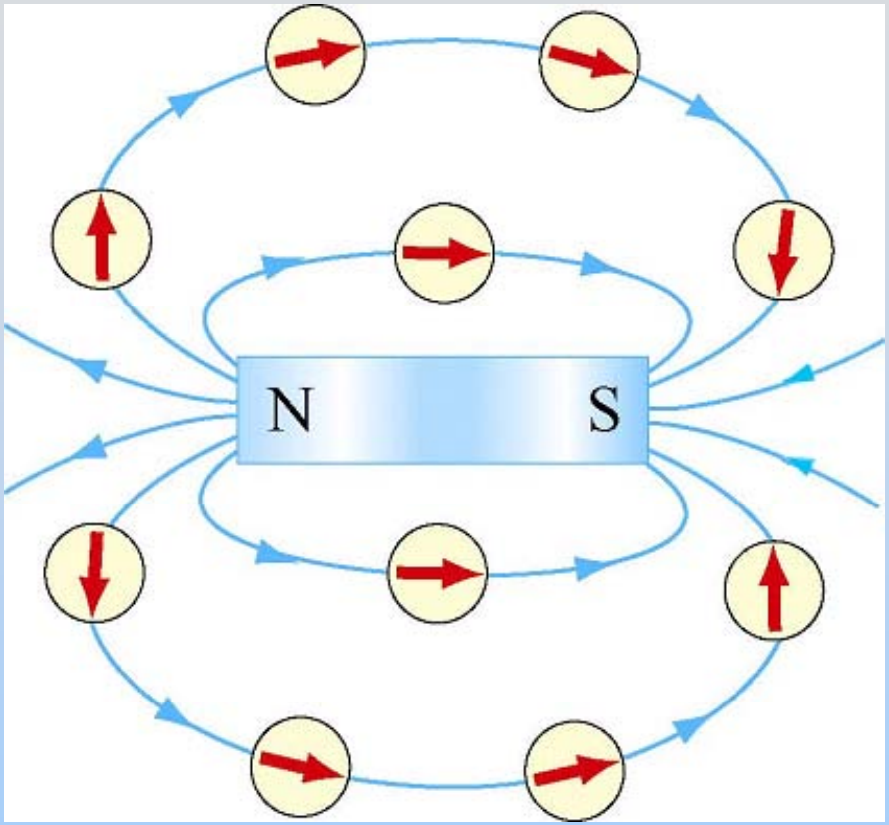


Like poles repel, opposite poles attract

Demonstration: Magnetic Field Lines from Bar Magnet

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

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

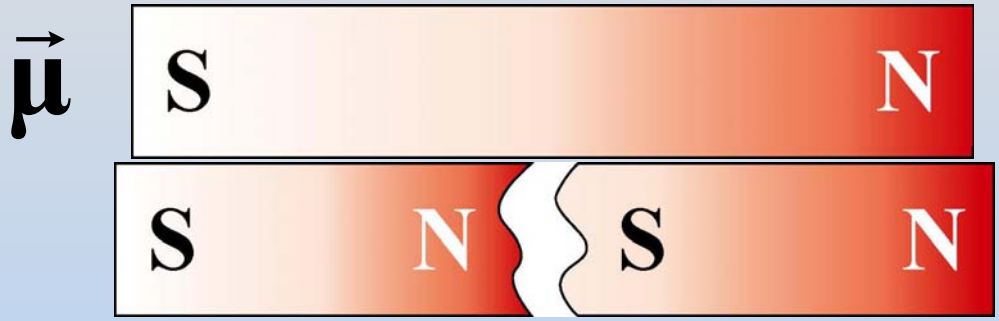
Magnetic Monopoles?

Electric Dipole

When cut:

2 monopoles (charges)

Magnetic Dipole



When cut: 2 dipoles

Magnetic monopoles do not exist in isolation
Another Maxwell's Equation! (2 of 4)

$$\oiint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0}$$

Gauss's Law

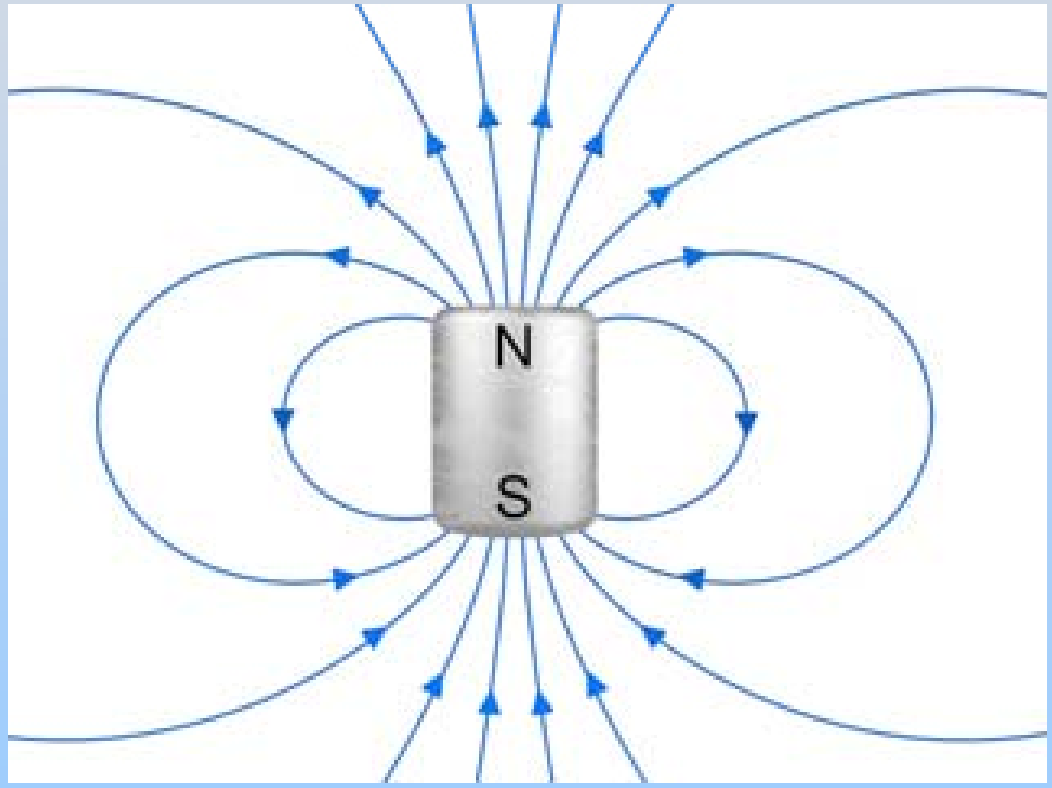
$$\oiint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$

Magnetic Gauss's Law

Concept Question:
B Field *inside* a Magnet

Concept Question: Magnetic Field Lines

The picture shows the field lines outside a permanent magnet The field lines inside the magnet point:



1. Up
2. Down
3. Left to right
4. Right to left
5. The field inside is zero
6. I don’t know

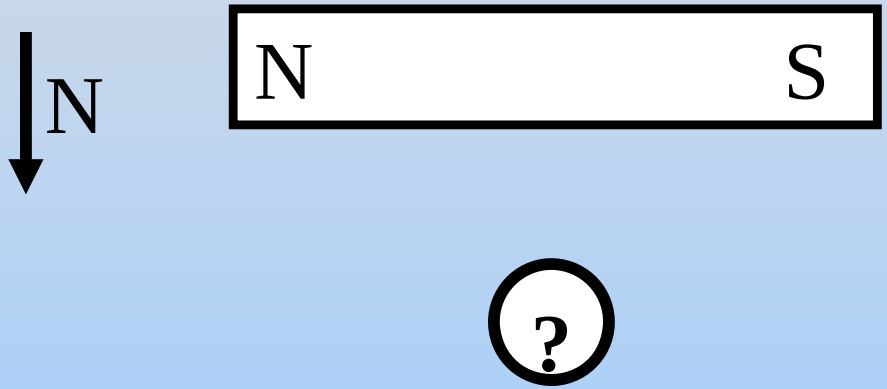
Experiment 5: Magnetic Fields: Bar Magnets & Wire Coils

Concept Question Question: Part I: B Field from Bar Magnet

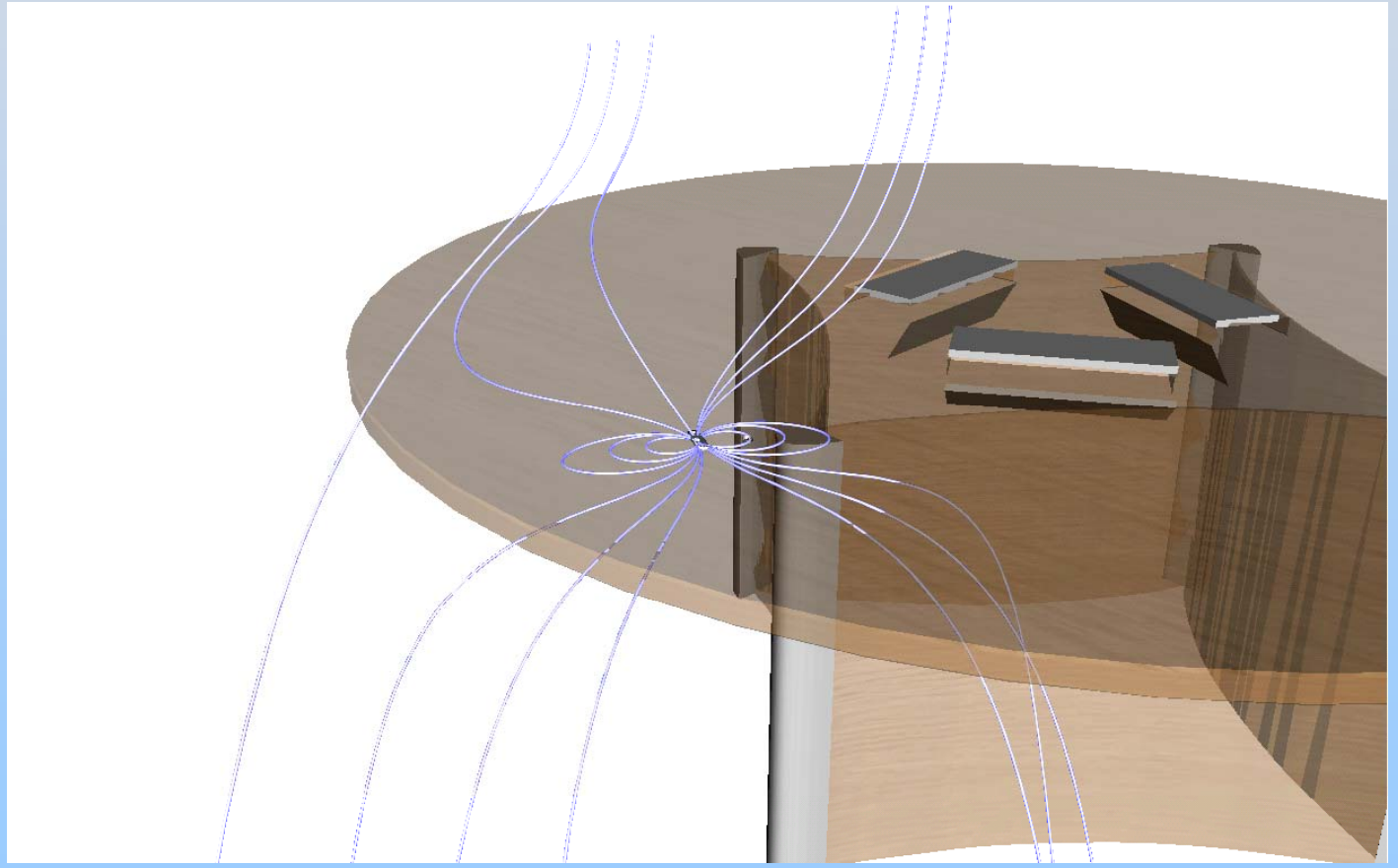
Concept Question: Bar Magnet B Field

Thinking of your map of the B field lines from part 1, assume that your magnet and compass were on the table in the orientation shown. The red end of the compass points:

1. Up
2. Down
3. Right
4. Left
5. Up & right
6. Up & left
7. Down & right
8. Down & left



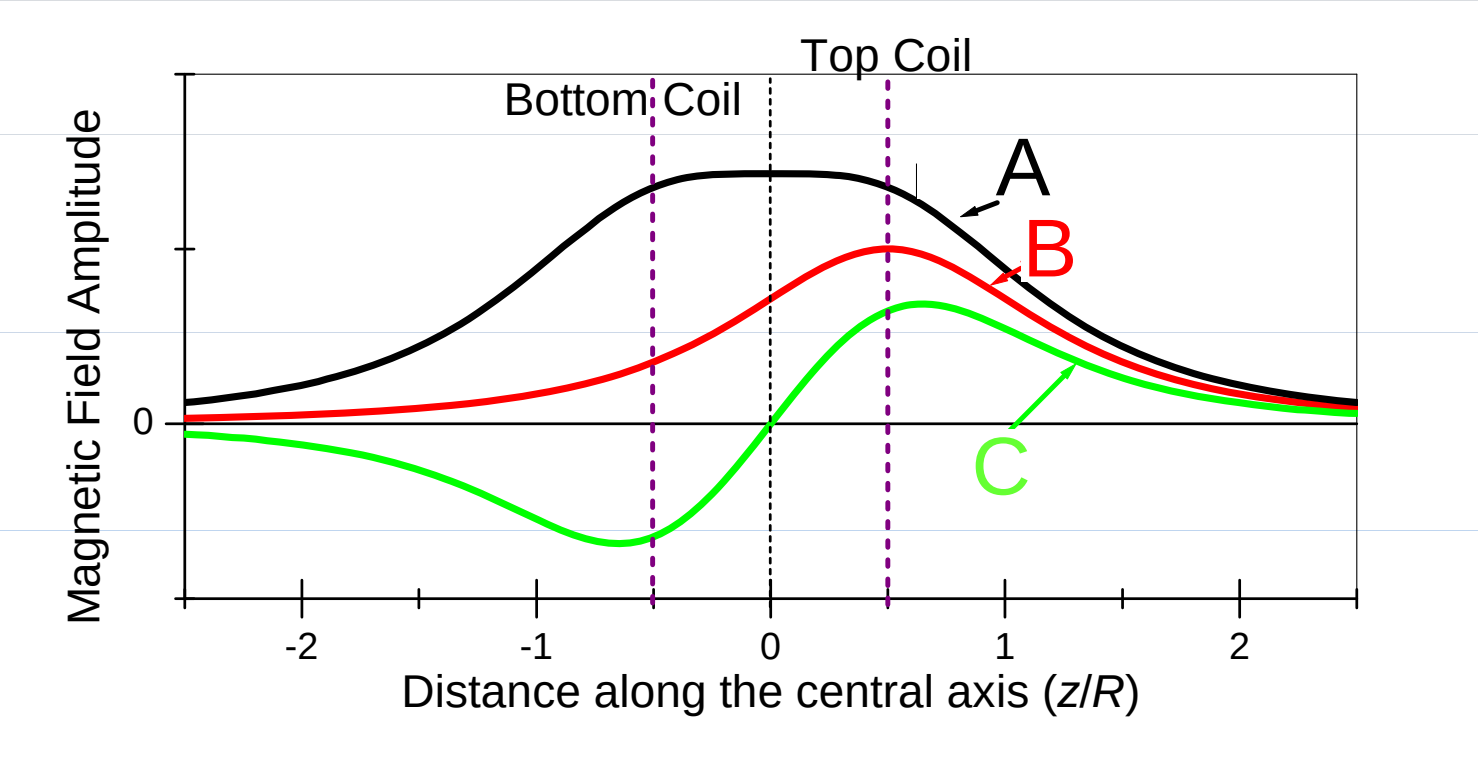
Visualization:
Bar Magnet &
Earth's Magnetic Field



Concept Question:
B Field from Helmholtz

Concept Question: Helmholtz

Identify the three field profiles that you measured as Single (Sgl), Helmholtz (Hh) or Anti-Helmholtz (A-H):



The curves, A, B & C are respectively:

1. Sgl, Hh, A-H
2. Hh, A-H, Sgl
3. A-h, Sgl, Hh
4. Sgl, A-H, Hh
5. A-H, Hh, Sgl
6. Hh, Sgl, A-H

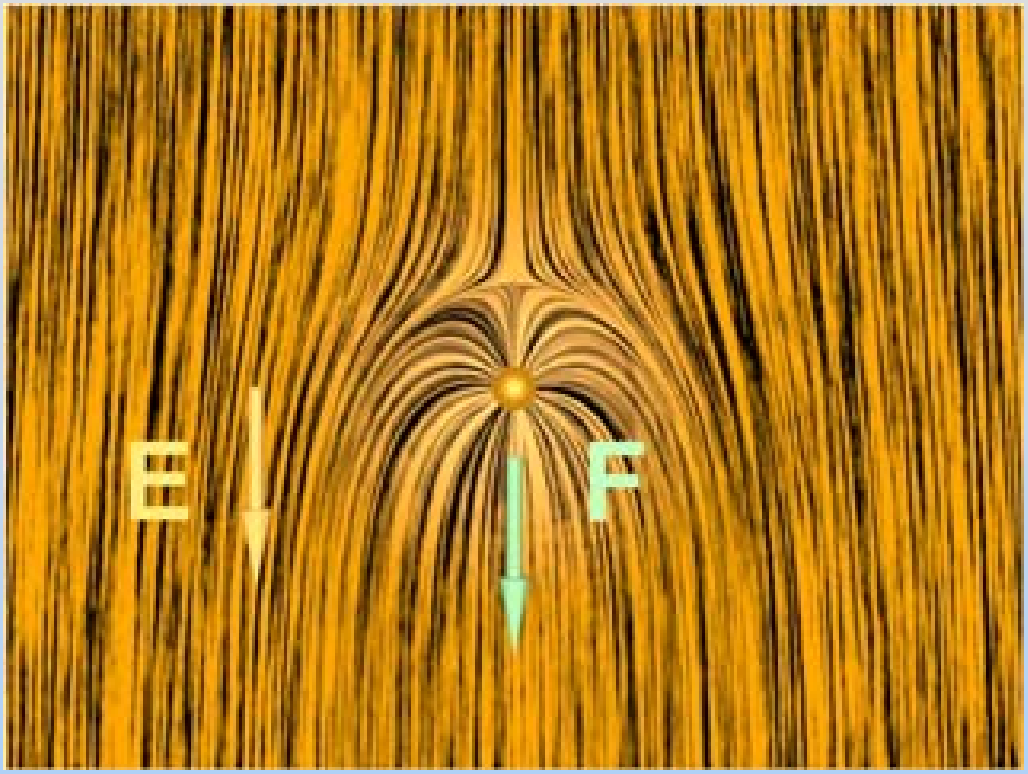
Field Pressures and Tensions: A Way To Understand the qVxB Magnetic Force

Tension and Pressures Transmitted by E and B

E & B Fields:

- Transmit tension along field direction (Field lines want to pull straight)
- Exert pressure perpendicular to field (Field lines repel)

Example of E Pressure/Tension



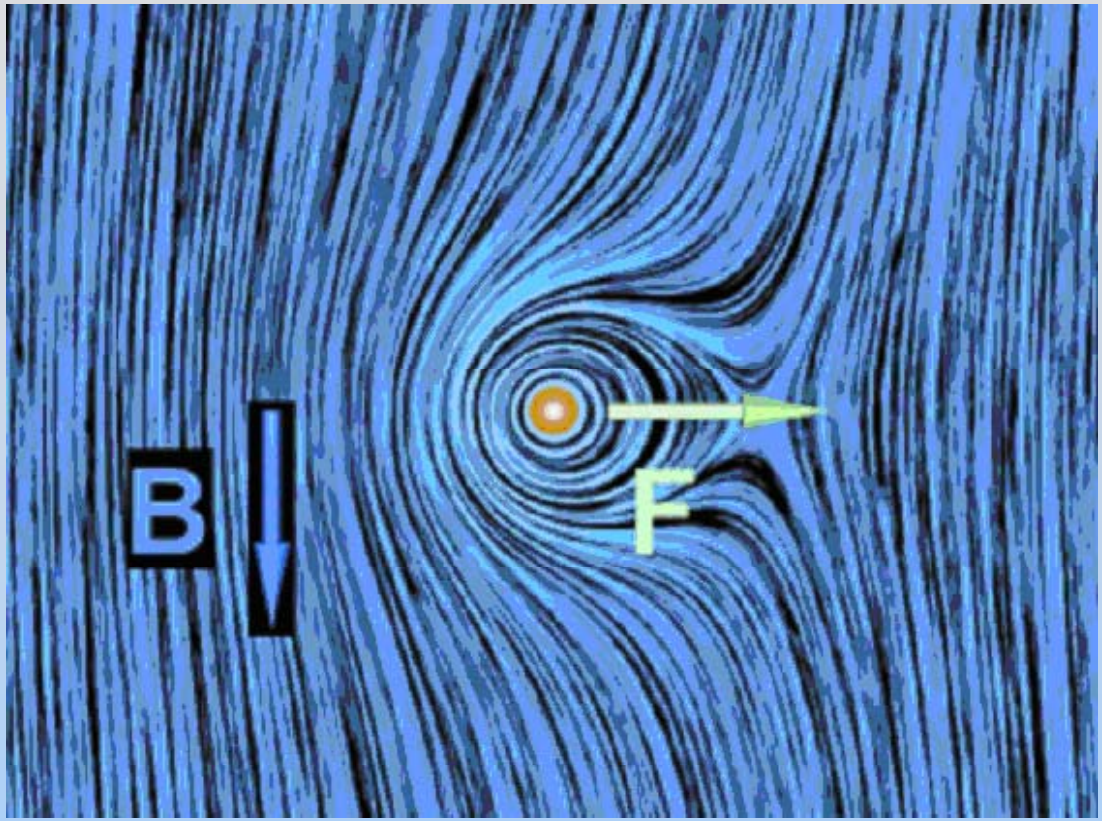
(Link to Animation)

Positive charge in uniform (downward) E field

Electric force on the charge is combination of

1. Pressure pushing down from top
2. Tension pulling down towards bottom

Example of B Pressure/Tension

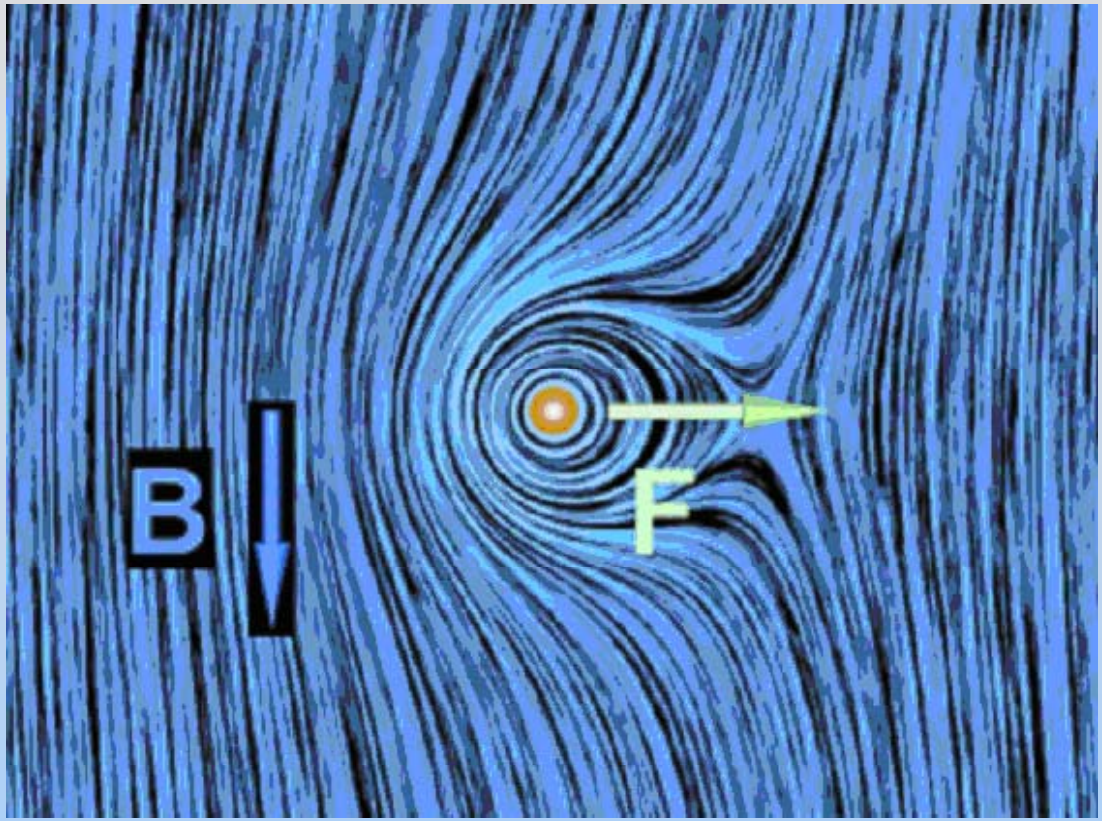


(Link to Animation)

Positive charge moving out of page in uniform (downwards) B field. Magnetic force combines:

1. Pressure pushing from left
2. Tension pulling to right

Example of B Pressure/Tension



Both cases: repelling “pressure” arises from HIGH field strength → HIGH energy density

8.02SC Physics II: Electricity and Magnetism

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