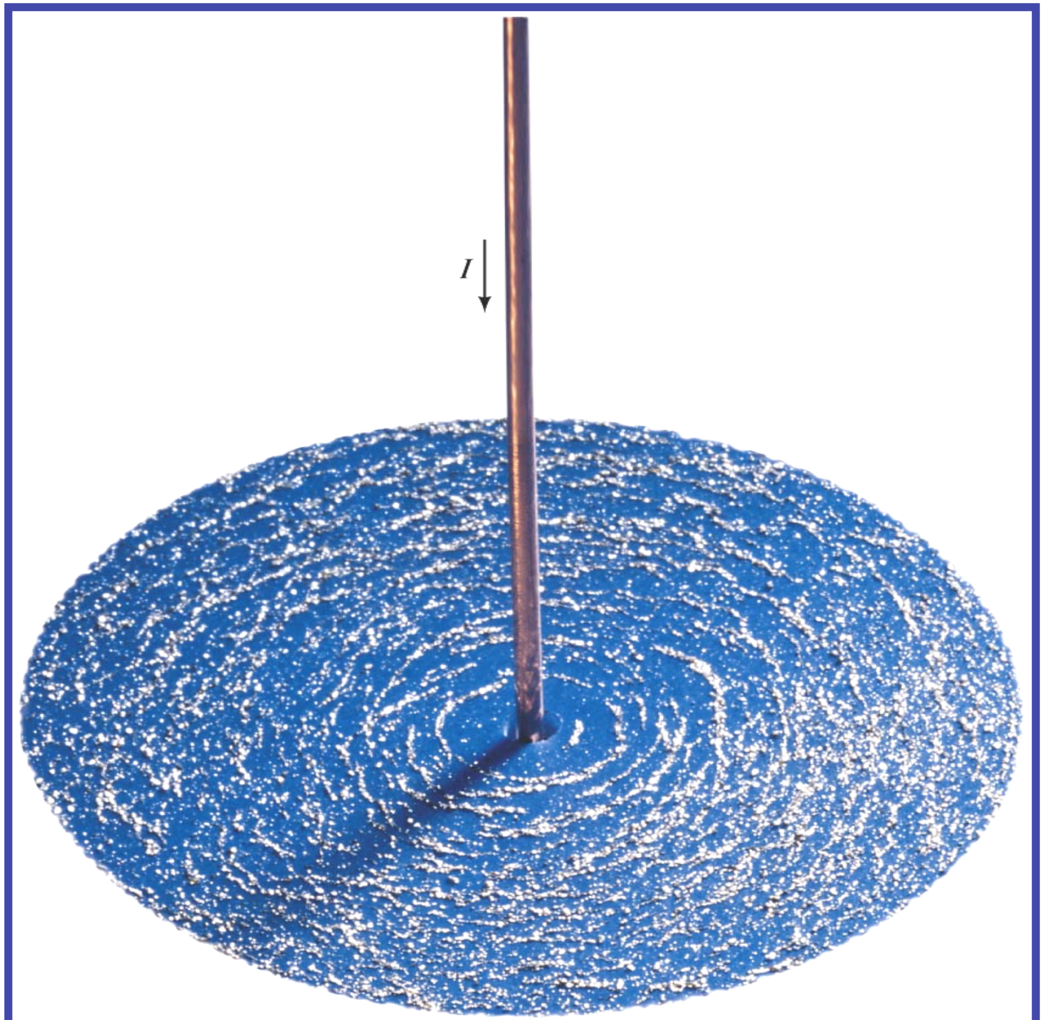
Chapter 29: Magnetic Fields



Chapter 29 Outline

- **Magnets** & **Magnetic Fields** ? **B Fields**
  Electric Currents ***Produce*** **B Fields!!**
- Force on an **Electric Current** in a **B** Field;
  Definition of **B**
- Force on an **Electric Charge** moving in a **B** Field
- Torque on a **Current Loop**
- Magnetic **Dipole Moment : μ**
- **Applications:** Motors, Loudspeakers, Galvanometers
- Discovery & Properties of the **Electron**
- The **Hall Effect**
- **Mass Spectrometer**

Brief History of Magnetism

- **13th Century BC**: The Chinese used **a compass.**
  - Uses a magnetic needle
  - Probably an invention of Arabic or Indian origin
- **800 BC**: The Greeks
  - Discovered that **magnetite (Fe_3O_4)** attracts pieces of iron
- **1269**: Pierre de Maricourt
  - Found that the direction of a needle near a spherical natural magnet formed lines that encircled the sphere.
  - The lines also passed through two points
  - Diametrically opposed to each other.

He called the points *poles*

- **1600:** William Gilbert
  - Expanded experiments with magnetism to a variety of Materials
  - Suggested the Earth itself was a large permanent magnet
- **1750:**
  - Experimenters showed that magnetic poles exert attractive or repulsive forces on each other.
- **1819:**
  - Found that an electric current deflected a compass needle
- **1820's:** Faraday and Henry
  - Further connections between electricity and magnetism
  - A changing magnetic field creates an electric field.

James Clerk Maxwell

- A changing electric field produces a magnetic field.

Hans Christian Oersted

1777 – 1851:

Discovered a relationship between electricity & magnetism.

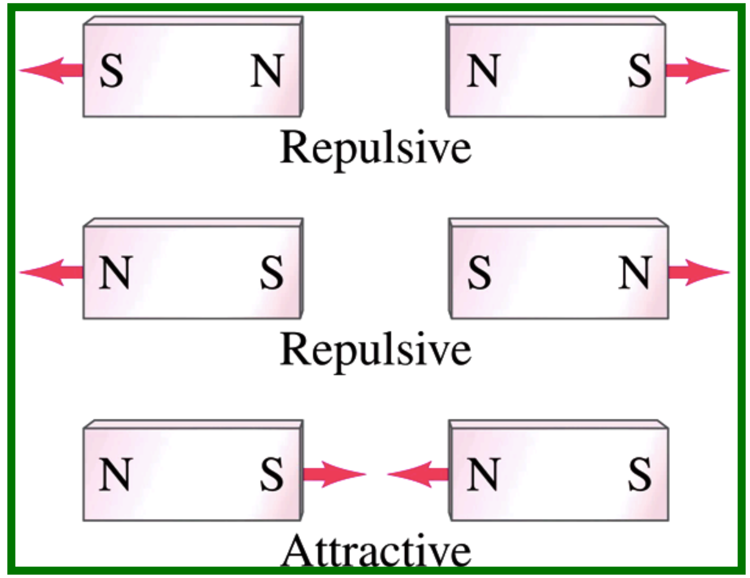
- He found that an electric current in a wire will deflect a compass needle.

He was the first to find evidence of a connection between electric & magnetic phenomena.

- Also was the first to prepare pure Aluminum.

Magnets & Magnetic Fields

- Every magnet, regardless of its shape, has two ends called **"Poles"**. They are the
  "North (N) Pole"
  & the
  "South (S) Pole"



- The poles exert forces on one another:

Like poles repel &

opposite poles attract

The poles received their names due to <u>the way a magnet behaves in the Earth's magnetic field:</u>

- If a bar magnet is suspended so that it can move freely, it will rotate. The North pole of a magnet points toward the Earth's North magnetic pole.
- This means that

<u>Earth's North magnetic pole is actually a magnetic South pole</u>!

- Similarly, ***<u>the Earth's South magnetic pole is actually a magnetic North pole!</u>***

- The force between two poles varies as the inverse square of the distance between them.

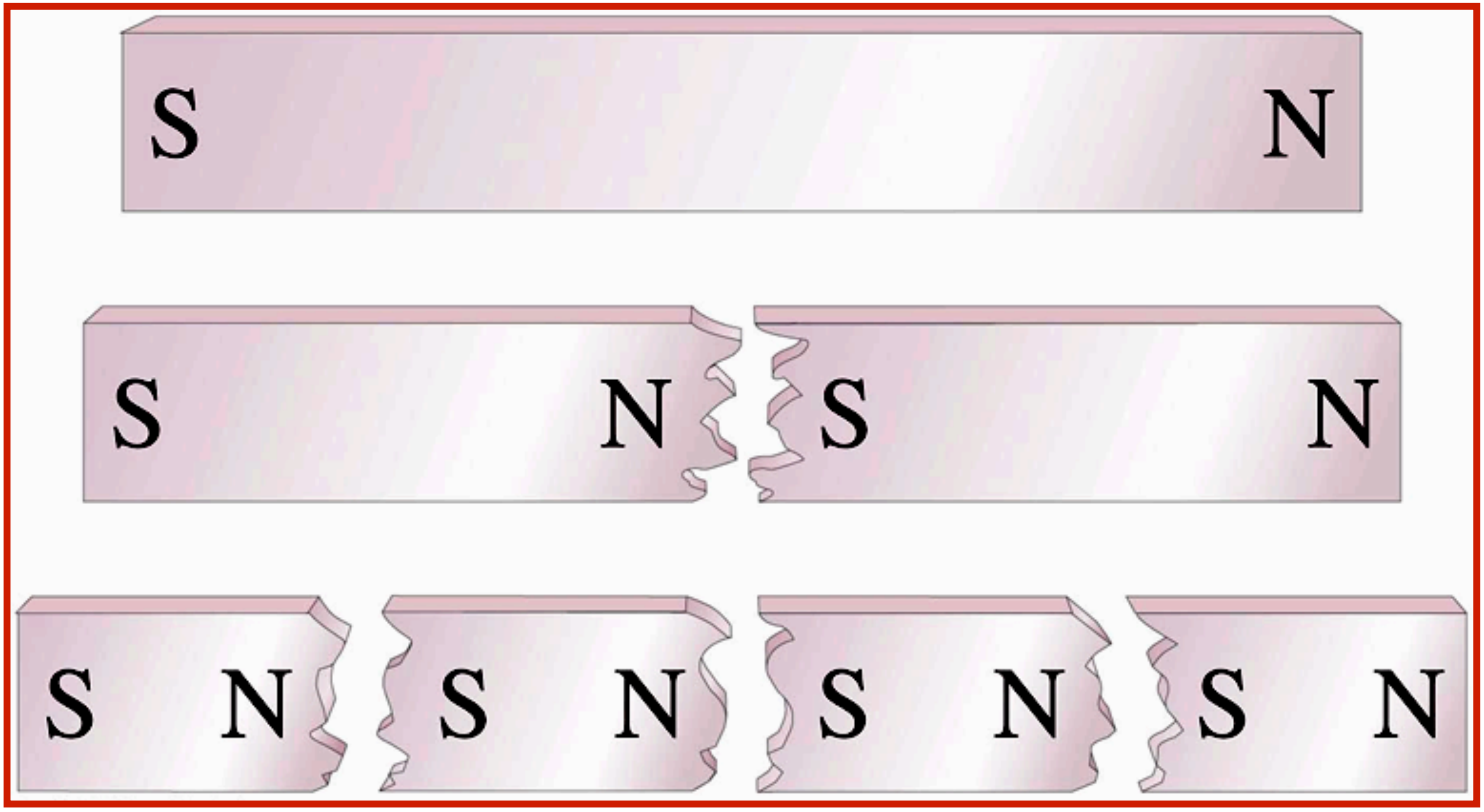
(Similar to the force between 2 point charges)

A single magnetic pole has never been isolated.

In other words, magnetic poles are always found in pairs.

- All attempts so far to detect an isolated magnetic pole (a magnetic monopole) have been unsuccessful.
- No matter how many times a permanent magnet is cut in 2, each piece always has north & south poles.

If a magnet is cut in half, the result isn't a north pole & a south pole!! ***The result is two smaller magnets!!***



Magnetic Fields

- **Reminder: An electric field surrounds any electric charge.** Similarly,

The region of space surrounding any MOVING electric charge

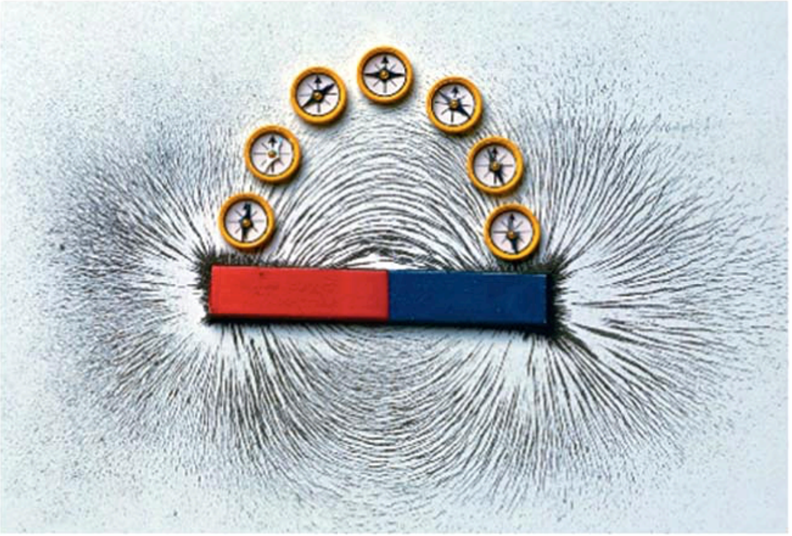
also contains a magnetic field.

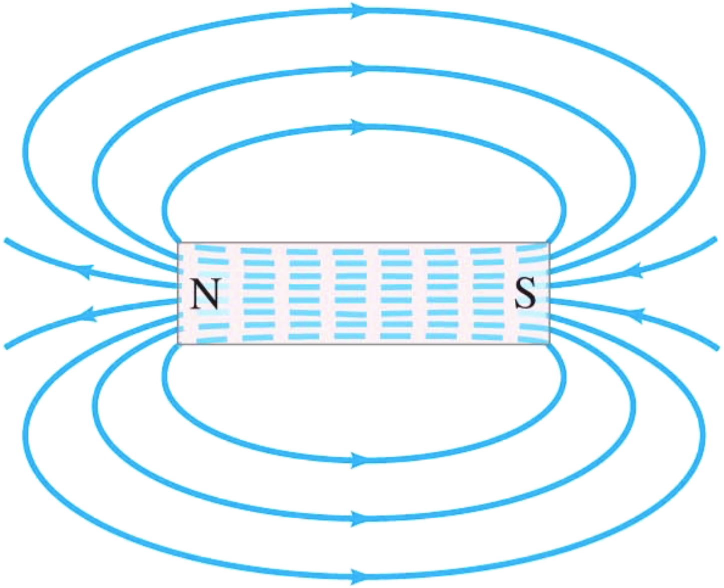
- A magnetic field also surrounds a magnetic substance making up a permanent magnet. A magnetic field is a vector quantity. It is symbolized by **B.**
- The direction of field **B** is given by the direction the North pole of a compass needle points in that location. Magnetic field lines can be used to show how the field lines, as traced out by a compass, would look.

Magnetic fields can be visualized using

Magnetic Field Lines,

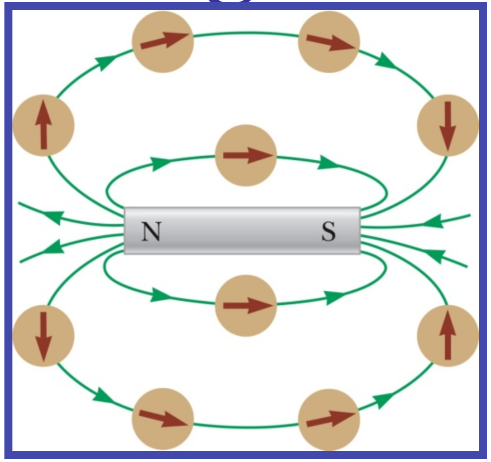
which are ***always closed loops.***

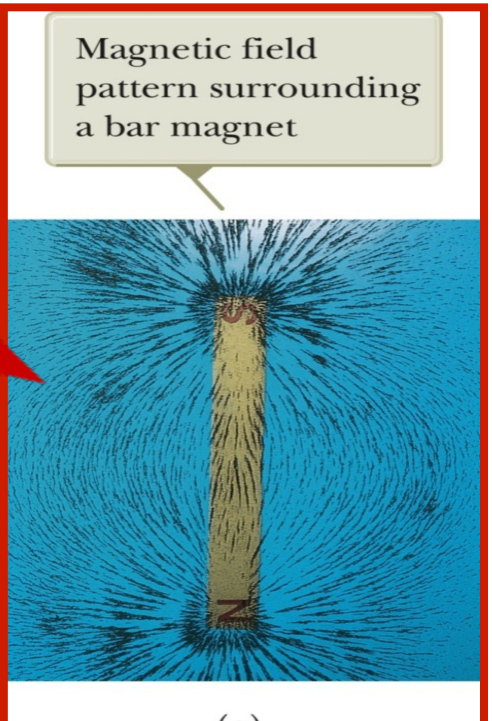




Magnetic Field Lines, Bar Magnet

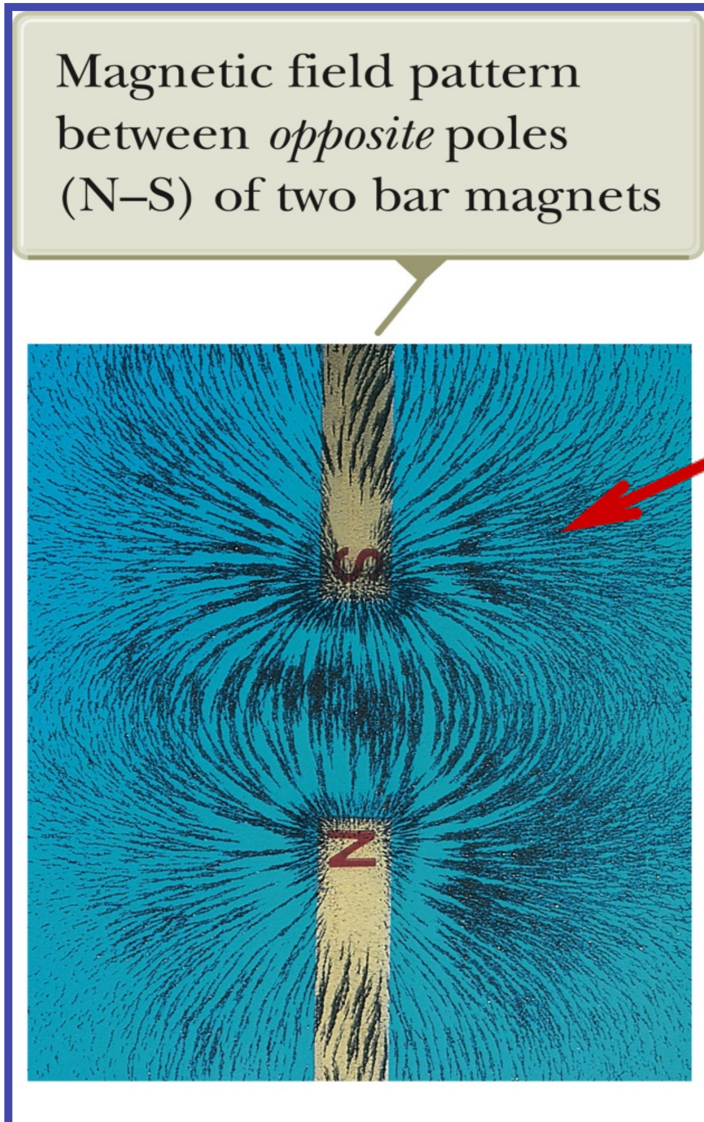
- A compass can be used to trace the field lines.
- The lines outside the magnet point from the North pole to the South pole.
- Iron filings can also be used to show the pattern of the magnetic field lines.
- The direction of the magnetic field is the direction a north pole would point.





(a)

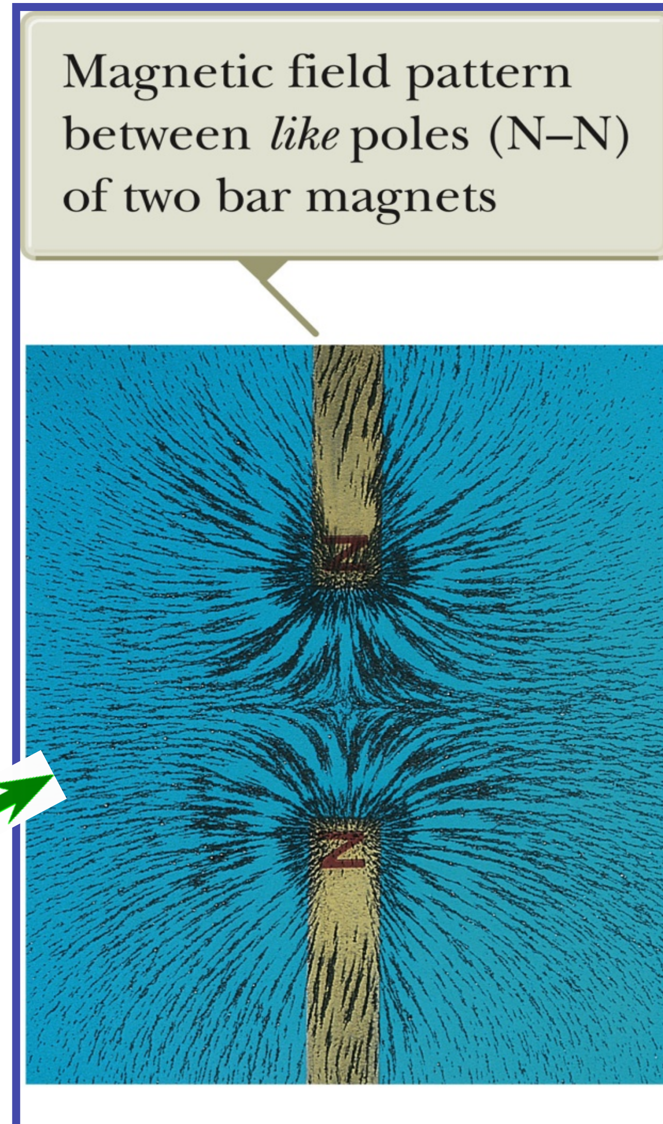
Magnetic Field Lines



(b)

Opposite Poles

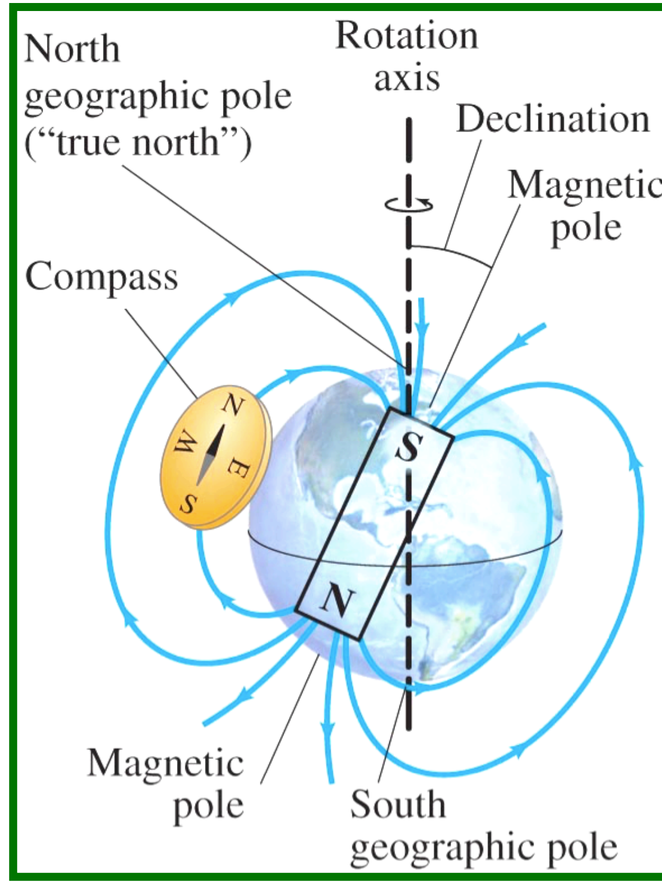
Like Poles



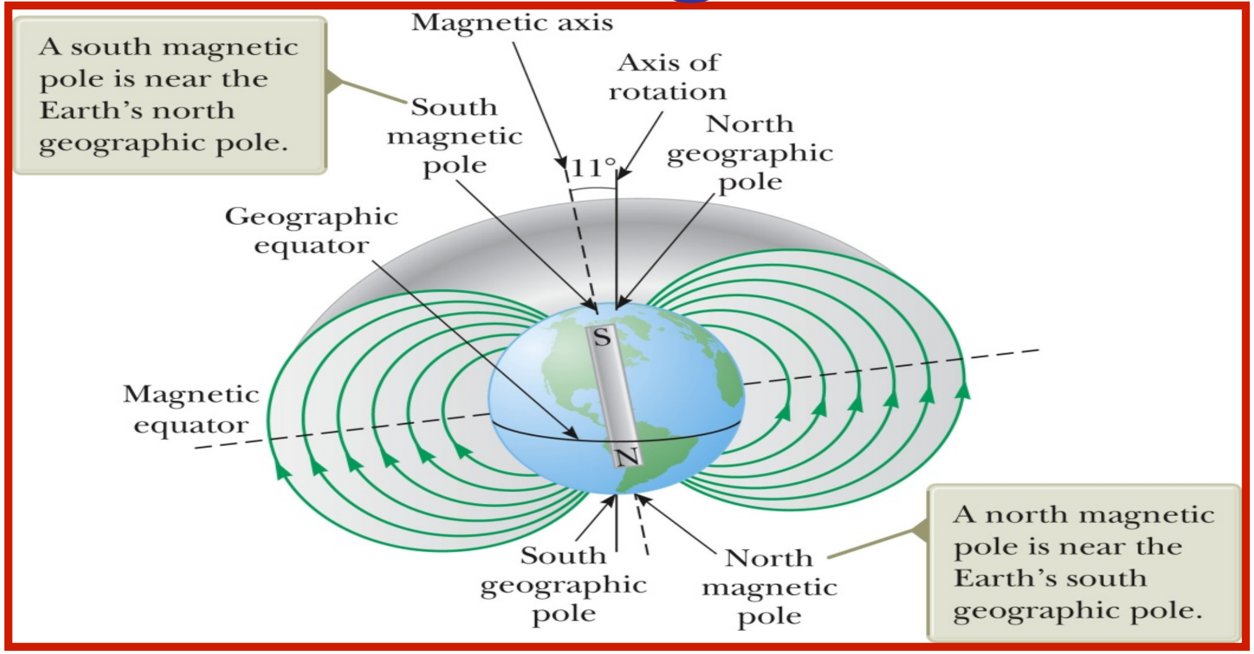
(c)

Earth's Magnetic Field

- Earth's magnetic field is ***very small***: $\mathbf{B_{earth} \sim 50\ \mu T}$
- It **depends on location & altitude**. It is also slowly ***changing with time!***
- ***Note!!!*** The Earth's magnetic **"North Pole"** ***is really*** a **South Magnetic Pole**, because the North poles of magnets are attracted to it.



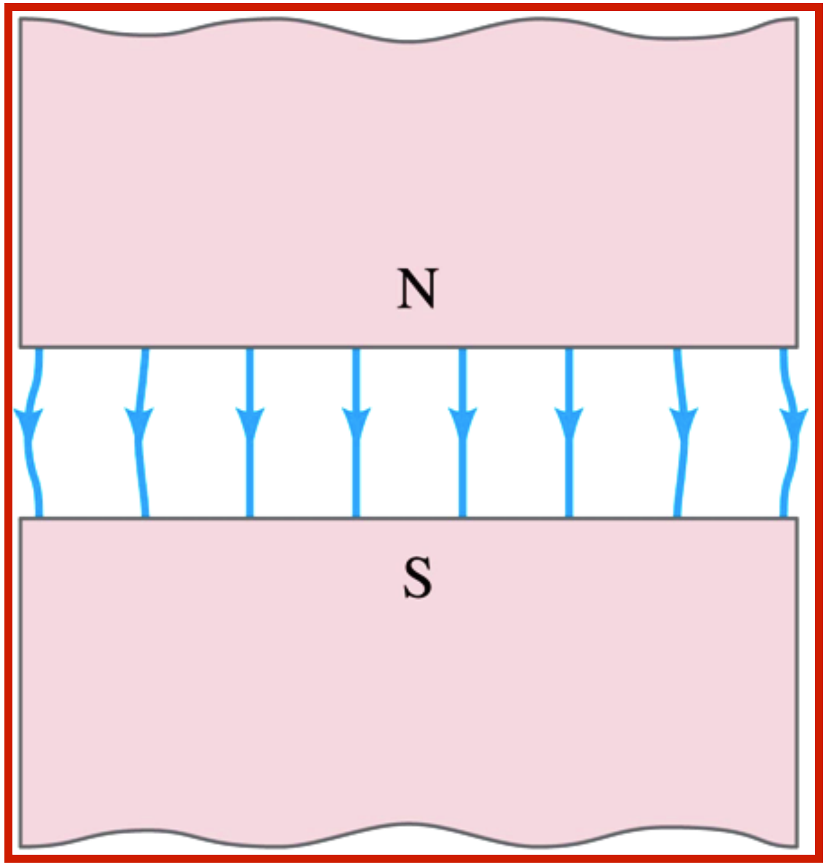
Earth's Magnetic Field



- The source of the Earth's magnetic field is likely convection currents in the Earth's core.
- There is strong evidence that the magnitude of a planet's magnetic field is related to its rate of rotation.
- The direction of the Earth's magnetic field reverses Periodically (over thousands of years!).

A ***Uniform Magnetic Field*** is constant in magnitude & direction.

The magnetic field **B** between these two wide poles is nearly uniform.



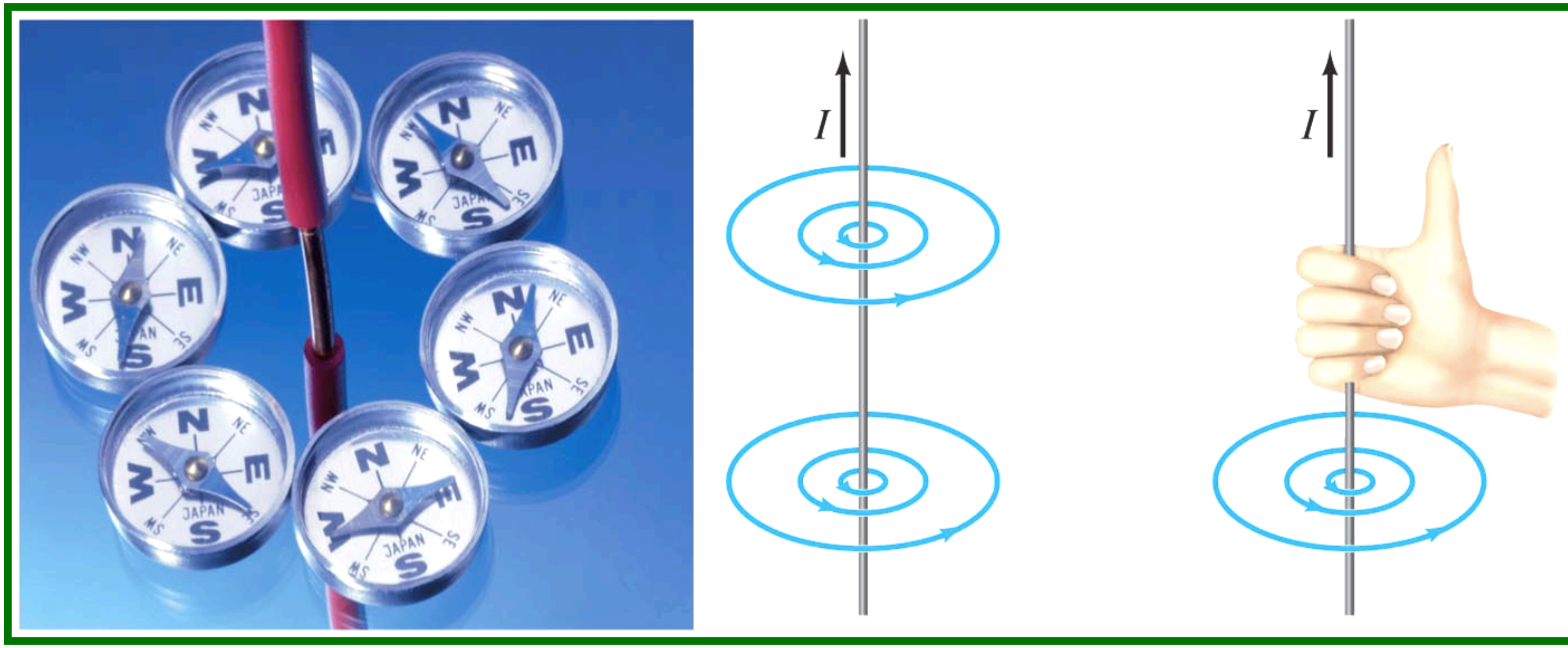
Electric Currents Produce Magnetic Fields

Experiments show that

Electric Currents Produce Magnetic Fields.

- The direction of the field is given by a

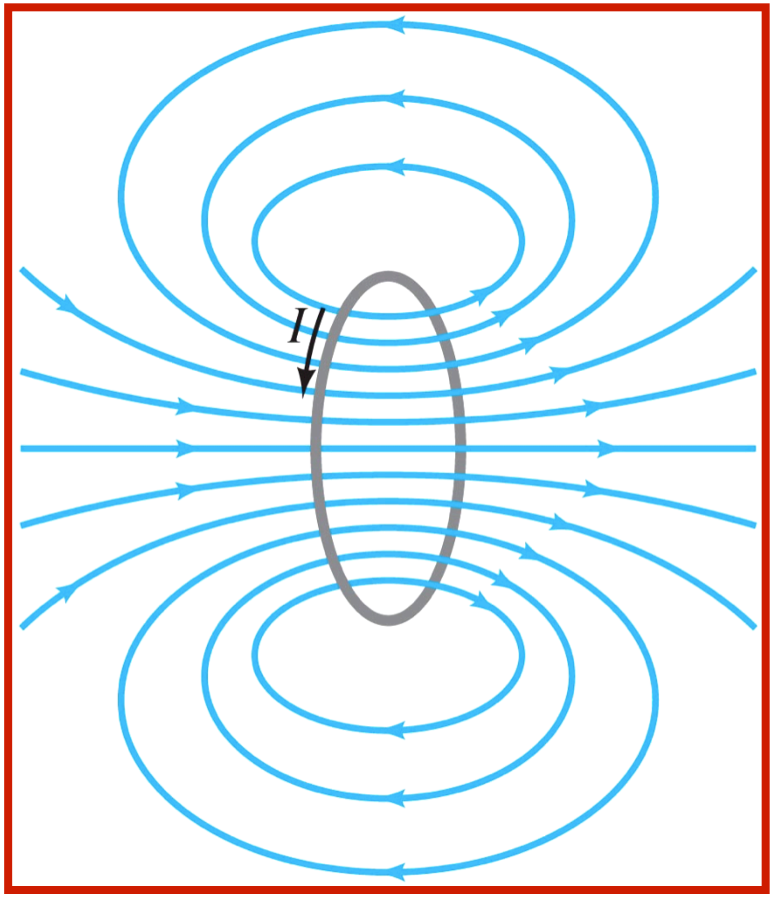
Right-Hand Rule.

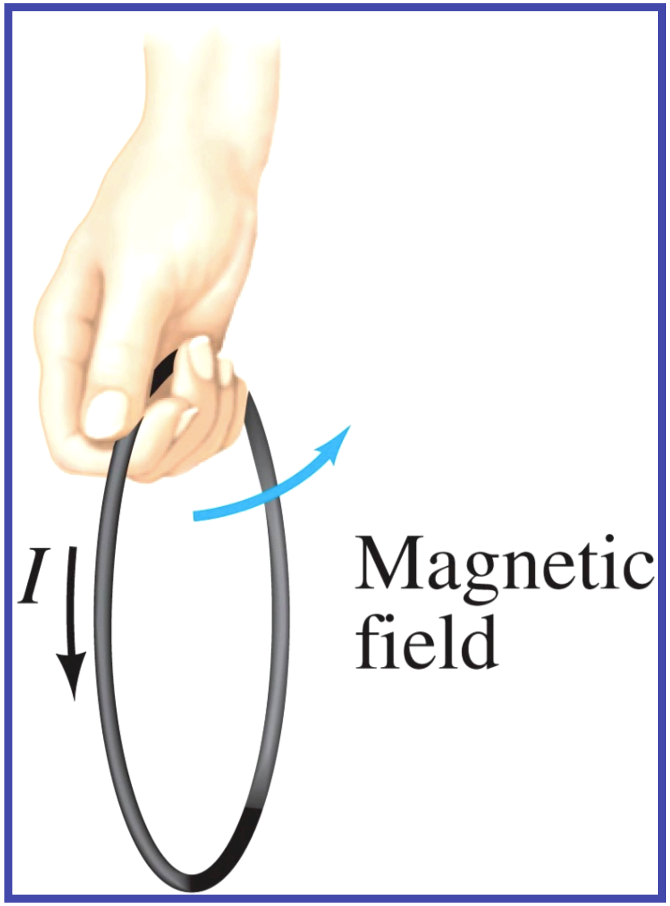


Magnetic Field Due to a Current Loop

The direction is given by a

Right-Hand Rule.

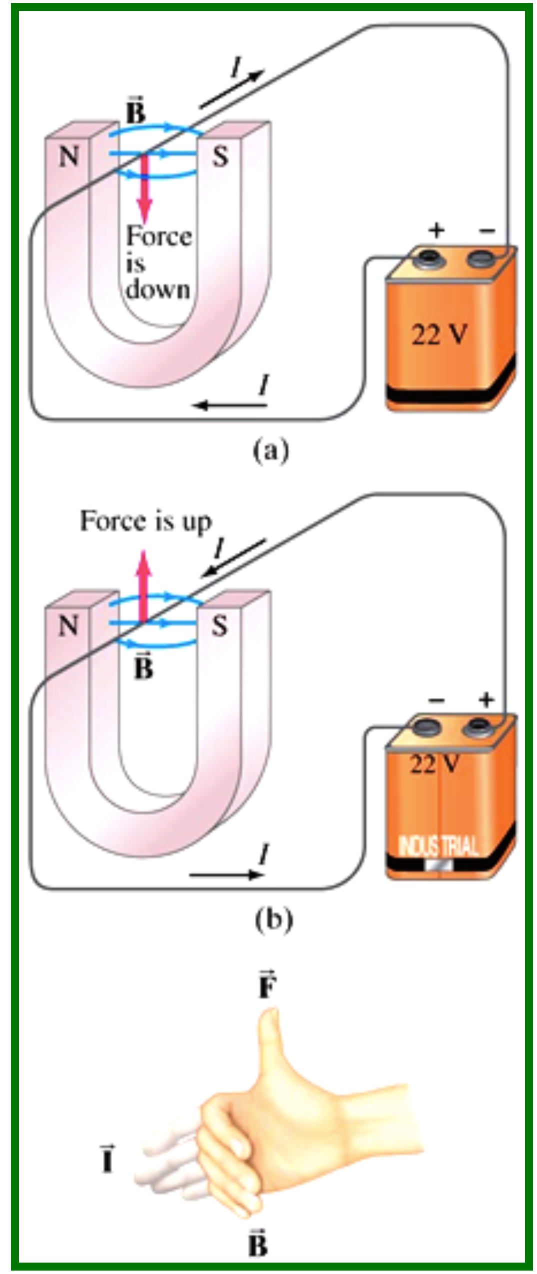




Force on a Current in a Magnetic Field &
the ***DEFINITION*** of B

- A magnet exerts a force **F** on a current-carrying wire. The ***DIRECTION*** of **F** is given by a

Right-Hand Rule



- The force **F** on the wire depends on the current, the length ***l*** of the wire, the magnetic field **B** & its orientation:

$$F = I\ell B \sin\theta.$$

This equation *defines* the Magnetic Field B.

In vector notation the force is given by

$$\vec{\mathbf{F}} = I\vec{\ell} \times \vec{\mathbf{B}}.$$

The SI Unit of the **Magnetic Field B is**

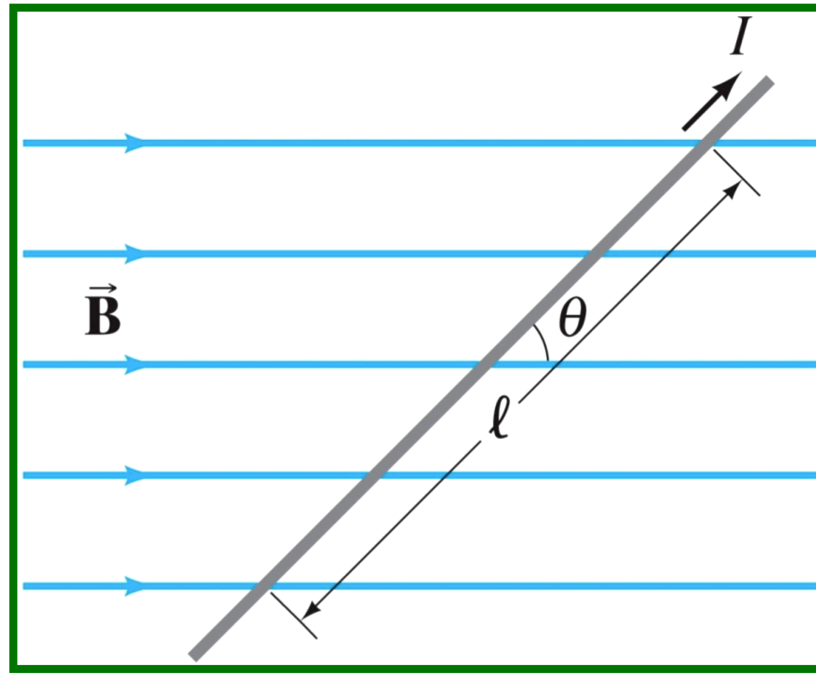
The **Tesla (T): 1 T = 1 N/A·m**

Another unit that is sometimes used (from the cgs system) is

The **Gauss (G): 1 G = 10^{-4} T**

Example: Magnetic Force on a Current Carrying Wire

- A wire carrying a current **I = 30 A** has length ***l* = 12 cm** between the pole faces of a magnet at angle **θ = 60°** as shown.
- The magnetic field is approximately uniform & is **B = 0.90 T**.
- Calculate the magnitude of the force **F** on the wire.



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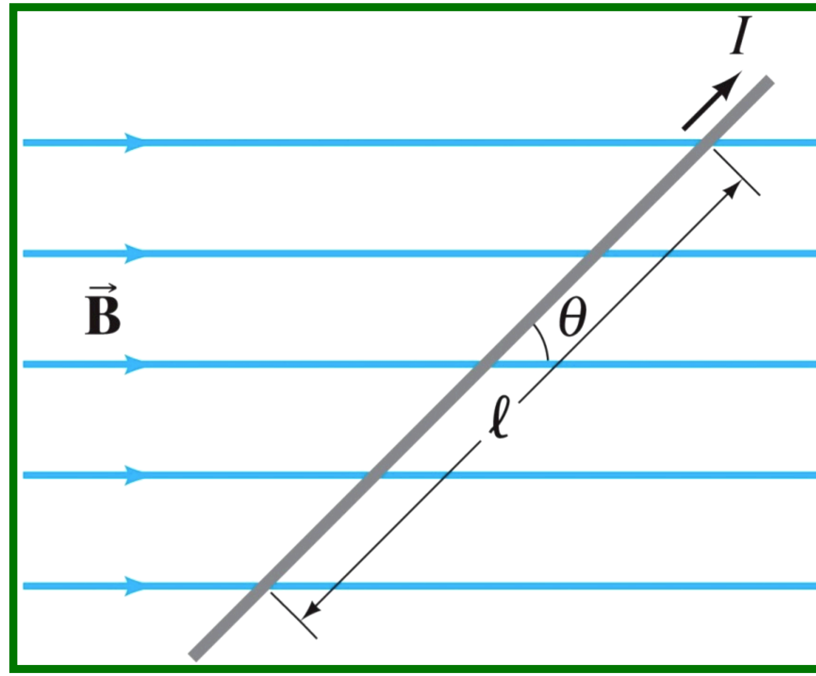


Solution: Use

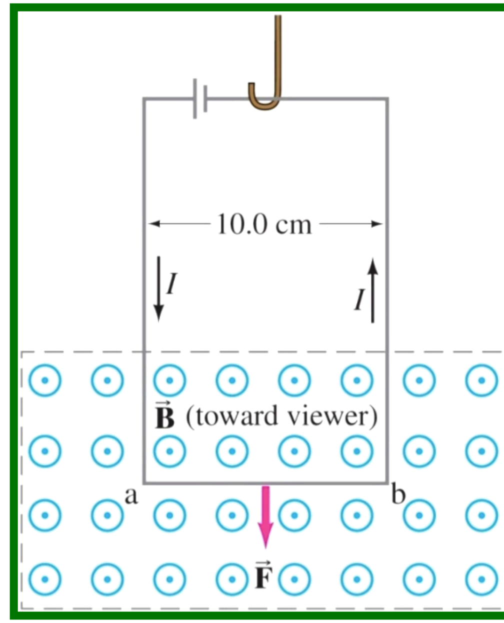
$$F = I\ell B \sin\theta.$$

Solve & get:

F = 2.8 N

Example: Measuring a Magnetic Field

- A rectangular wire loop hangs vertically.
- A magnetic field **B** is directed horizontally, perpendicular to the wire, & points out of the page. **B** is uniform along the horizontal portion of wire **(l = 10.0 cm)** which is near the center of the gap of the magnet producing **B**.



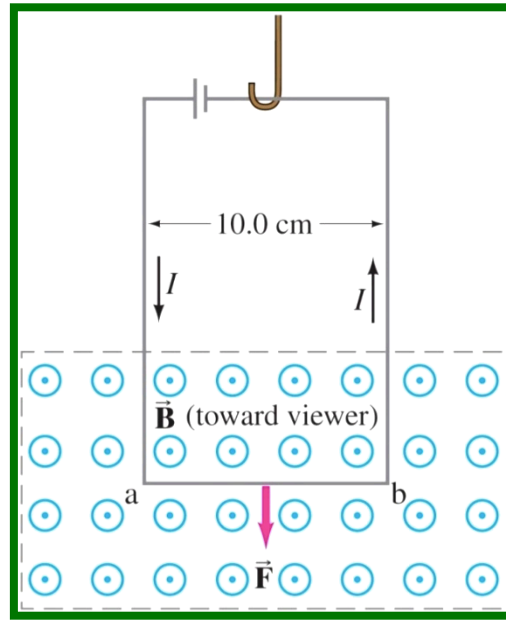
- The top portion of the loop is free of the field. The loop hangs from a balance which measures a downward magnetic force (in addition to gravity)

$F = 3.48 \times 10^{-2}$ N

when the wire carries a current **$I = 0.245$ A.**

Calculate B.

Example: Measuring a Magnetic Field



- The loop hangs from a balance which measures a downward magnetic force (in addition to gravity)

  $F = 3.48 \times 10^{-2}$ N

  when the wire carries a current

  $I = 0.245$ A.

  Calculate **B.**

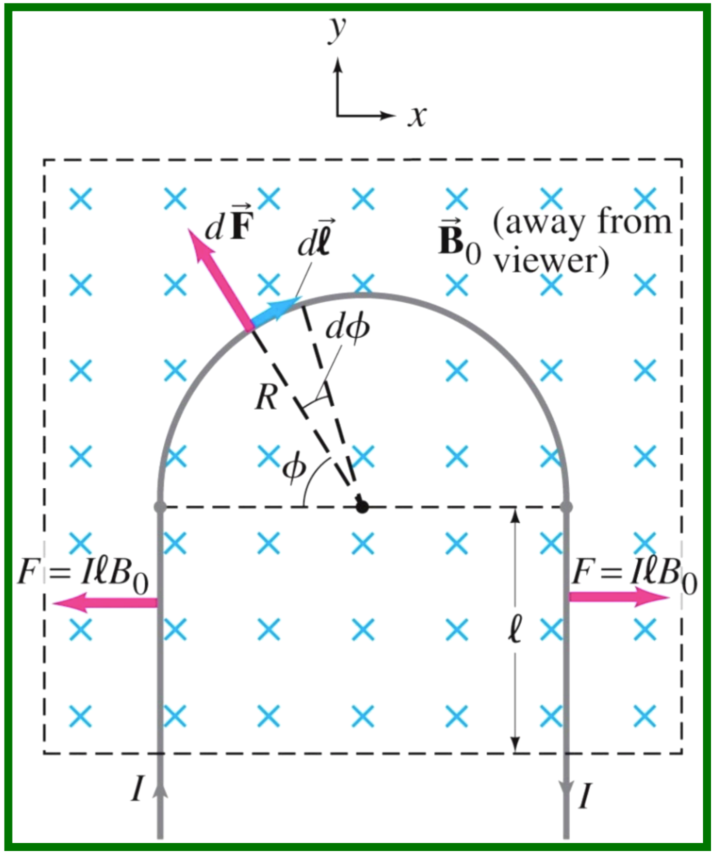
Solution:

Use $F = I\ell B \sin\theta$.

Solve & get: B = 1.42 T

Example: Magnetic Force on a Semicircular Wire.

A rigid wire carrying a current **I** consists of a semicircle of radius **R** & two straight portions. It lies in a plane perpendicular to a uniform magnetic field $\mathbf{B_0}$. (Note the choice of **x** & **y** axes). Straight portions each have length ***l*** within the field.



Calculate the net force **F** on the wire due to $\mathbf{B_0}$.

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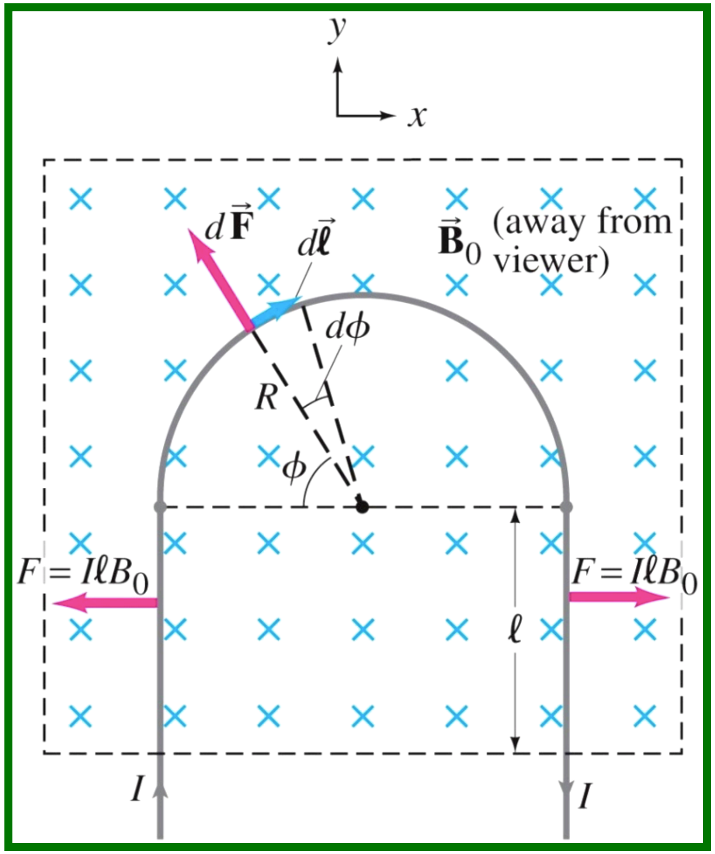

Calculate the net force **F** on the wire due to $\mathbf{B_0}$.

Solution gives:

$$\mathbf{F = 2IB_0R}$$