Chapter 29 Sources of the Magnetic Field

Introduction to Magnetic Field Sources

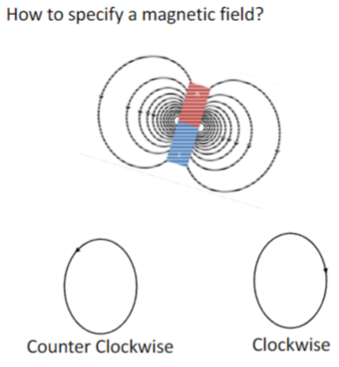
- **Focus**: Unlike the previous chapter that discussed magnetic fields as causes of force, this chapter explores what generates magnetic fields themselves.

Biot-Savart Law

- **Law Overview**:
  - Describes the magnetic field $d\vec{B}$ generated by a small segment of a current-carrying conductor.
  - The direction of $d\vec{B}$ is perpendicular to both the current segment $d\vec{s}$ and the position vector $\hat{r}$ from the segment to the observation point.
- **Mathematical Form**:

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{s} \times \hat{r}}{r^2}$$

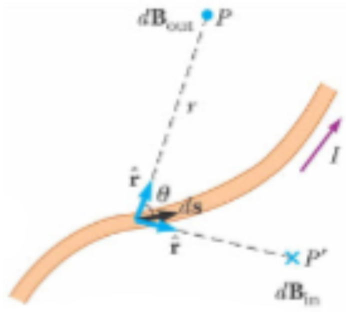
  - μ_0: Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$
  - I: Current in the wire
  - $d\vec{s}$: Small segment of the wire
  - $\hat{r}$: Unit vector from $d\vec{s}$ to point P
  - r: Distance between $d\vec{s}$ and point P



Total Magnetic Field

- **Integration**:
  - To find the total magnetic field $\vec{B}$ due to a current distribution, integrate $d\vec{B}$ over the entire current path:

$$\vec{B} = \frac{\mu_0}{4\pi} \int \frac{I d\vec{s} \times \hat{r}}{r^2}$$

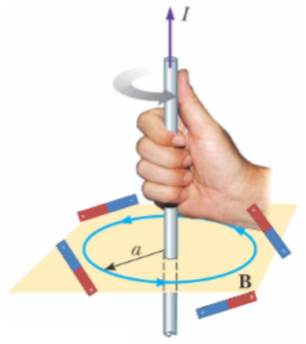


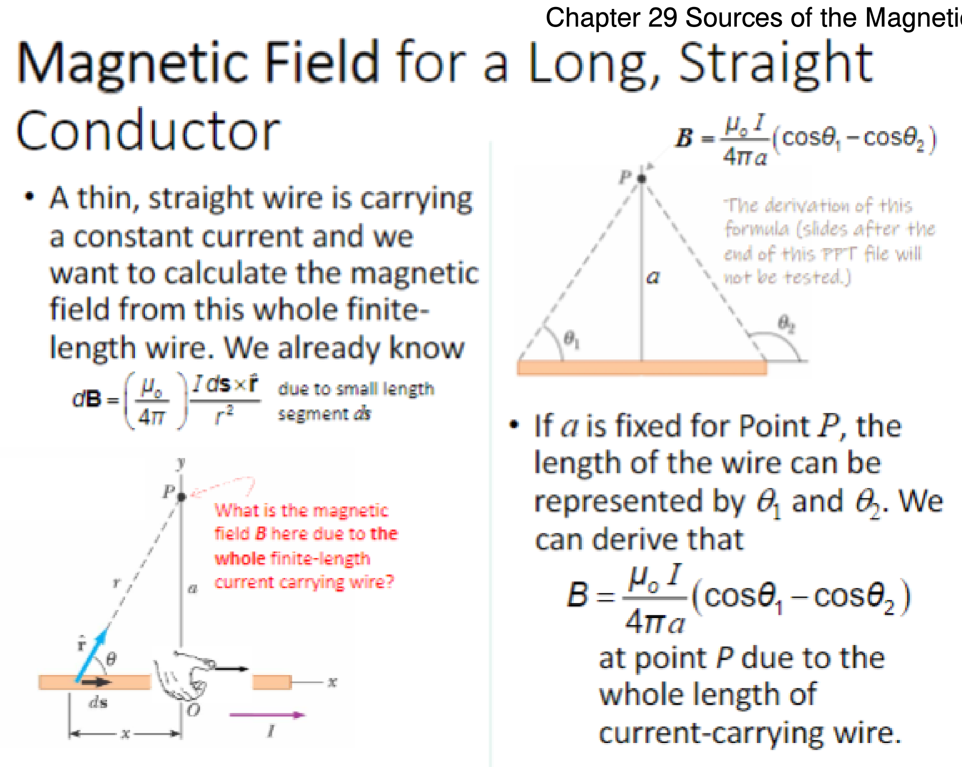
Magnetic Field Due to a Long, Straight Conductor

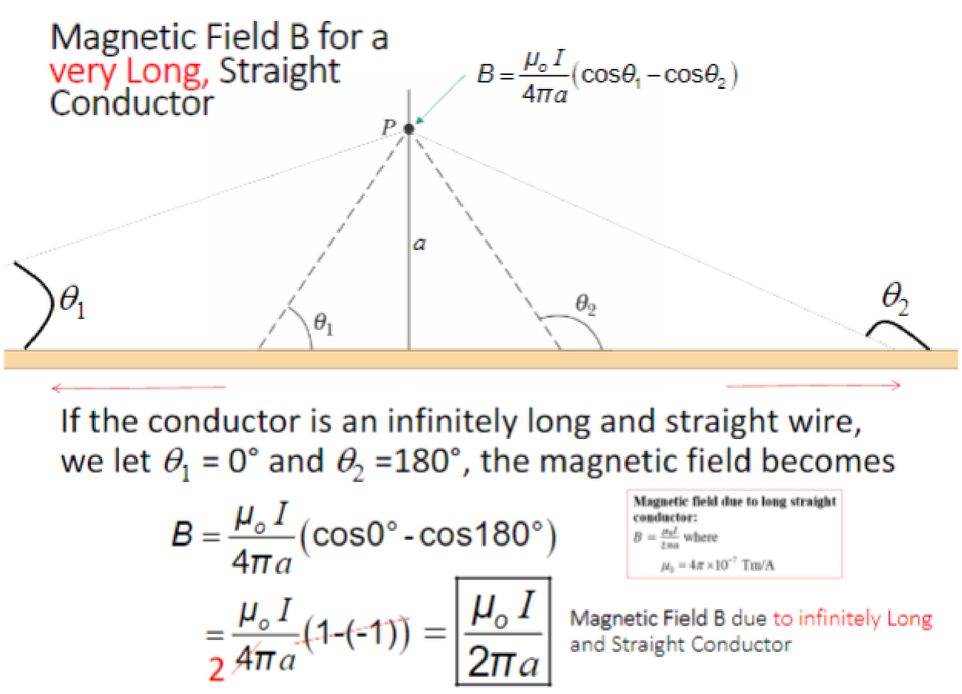
- **Result**:
  - For a straight conductor carrying current I, the magnetic field at a distance a from the wire is given by:

$$B = \frac{\mu_0 I}{2\pi a}$$

- **Direction**:
  - Determined by the right-hand rule: thumb in the direction of current, fingers curl in the direction of $\vec{B}$.





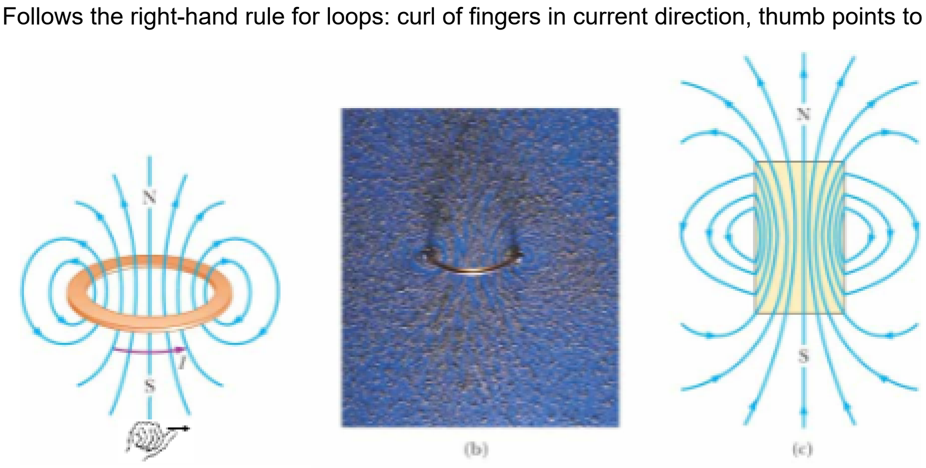


Magnetic Field of a Circular Loop

- **At the Center of a Loop**:

$$B = \frac{\mu_0 I}{2R}$$

  - R: Radius of the loop
- **Direction**:
  - Follows the right-hand rule for loops: curl of fingers in current direction, thumb points to $\vec{B}$ at the center.



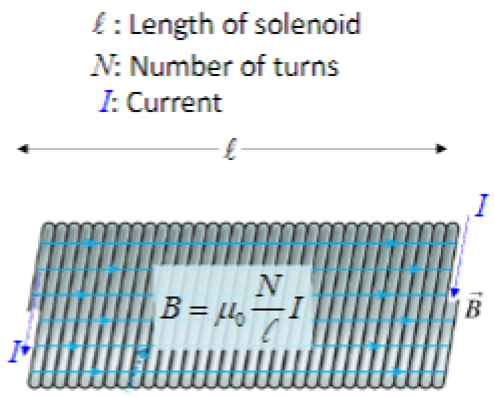
Ampère's Law

- **Law Statement**:
  - For any closed loop path, the sum of $B \cdot ds$ around the loop is proportional to the total current enclosed:

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{enc}}$$

- **Applications**:

- Used for calculating $\vec{B}$ in symmetrical situations such as solenoids and toroids.

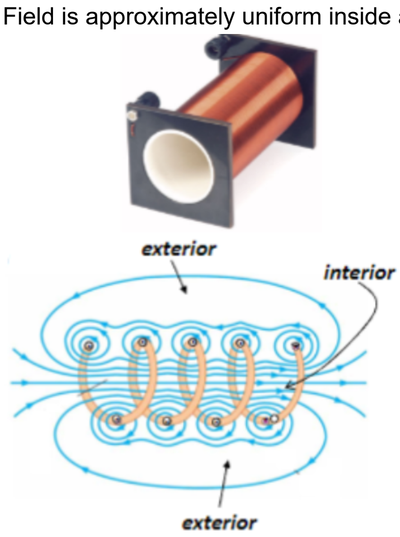


Magnetic Field of a Solenoid

- **Uniform Field**:
  - Inside a long solenoid:

$$B = \mu_0 n I$$

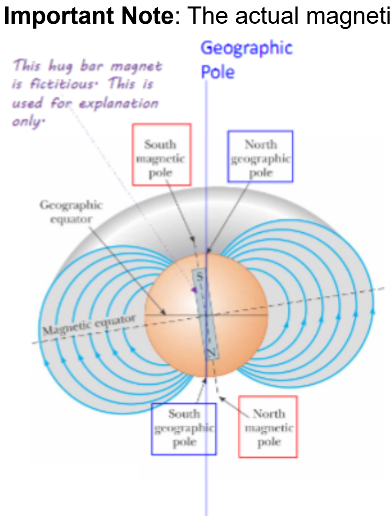
  - n: Number of turns per unit length
  - I: Current
- **Characteristics**:
  - Field is approximately uniform inside and zero outside.



- **Ideal Solenoid**
  - Infinitely long and the coils are closely packed
  - Many turns
  - Internal magnetic field is regarded as uniform and its magnitude is a constant
  - The external magnetic field is regarded as 0

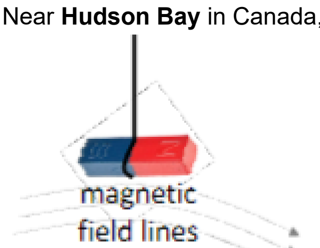
Earth’s Magnetic Field Overview

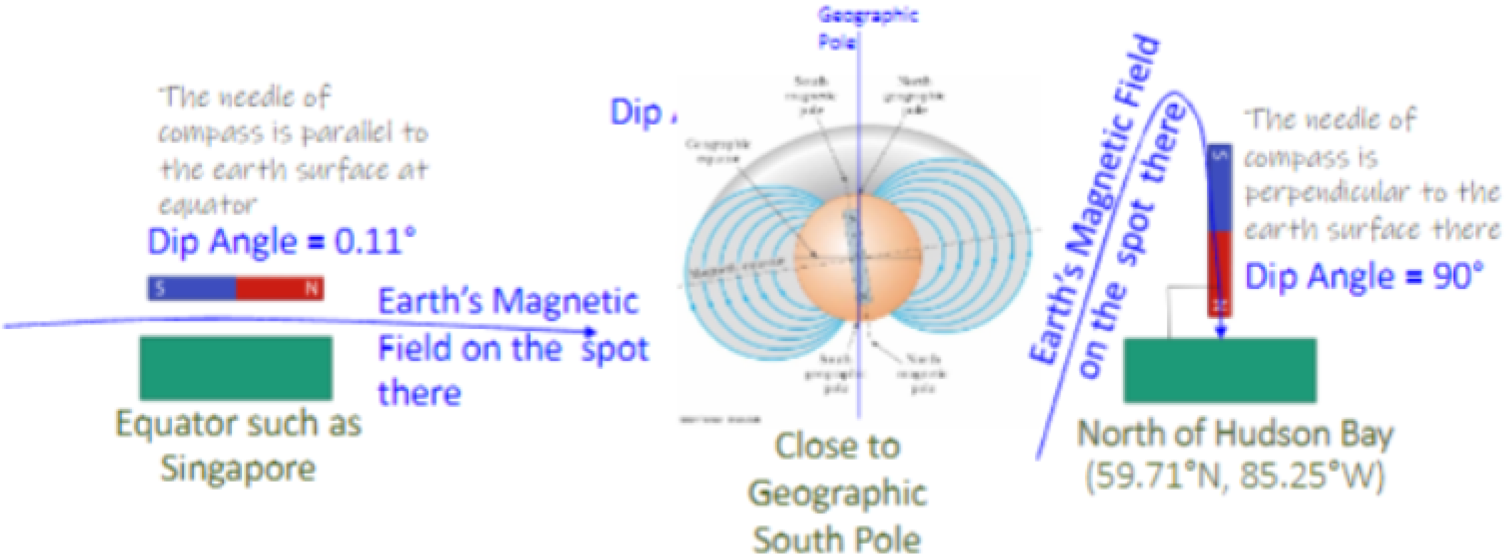
- **Model**: The Earth’s magnetic field resembles that produced by a large bar magnet buried within the Earth, although this is a simplified model for explanation.
- **Poles**:
  - The **south magnetic pole** is located near the **north geographic pole**.
  - The **north magnetic pole** is located near the **south geographic pole**.
- **Important Note**: The actual magnetic field is more complex than the bar magnet model due to variations and deviations.



Dip Angle of Earth’s Magnetic Field

- **Definition**:
  - The **dip angle** is the angle between the horizontal surface at a location and the direction of the magnetic field at that point.
- **Examples**:
  - At the **equator**, the dip angle is nearly **0°**, meaning the compass needle stays parallel to the Earth's surface.
  - Near **Hudson Bay** in Canada, the dip angle reaches **90°**, where the compass needle points directly down.





Magnetic Declination

- **Definition**:
  - The **magnetic declination** is the angle difference between **true north** (geographic north) and **magnetic north** as indicated by a compass.
- **Variation**:
  - Declination varies based on location on the Earth's surface and can be crucial for navigation.

A map of the continental United Sates showing several lines of constant magnetic declination

Source of the Earth's Magnetic Field

- **Explanation**:
  - The core of the Earth is too hot for permanent magnetization due to temperatures around **5200°C**.
  - The most likely source is **convection currents** in the molten metal part of the Earth's core.
  - The Earth's rotation may also contribute to generating the magnetic field.

Reversals of the Earth's Magnetic Field

- **Phenomenon**:
  - The direction of the Earth's magnetic field has reversed multiple times over millions of years.
  - Evidence is found in **basalt rocks** formed from volcanic activity, which contain records of the Earth's past magnetic orientations.
- **Uncertainty**:
  - The exact cause of these reversals is not fully understood.