12.9: Sources of Magnetic Fields (Summary)

Key Terms

Ampère's law	physical law that states that the line integral of the magnetic field around an electric current is proportional to the current
Biot-Savart law	an equation giving the magnetic field at a point produced by a current-carrying wire
diamagnetic materials	their magnetic dipoles align oppositely to an applied magnetic field; when the field is removed, the material is unmagnetized
ferromagnetic materials	contain groups of dipoles, called domains, that align with the applied magnetic field; when this field is removed, the material is still magnetized
hysteresis	property of ferromagnets that is seen when a material's magnetic field is examined versus the applied magnetic field; a loop is created resulting from sweeping the applied field forward and reverse
magnetic domains	groups of magnetic dipoles that are all aligned in the same direction and are coupled together quantum mechanically
magnetic susceptibility	ratio of the magnetic field in the material over the applied field at that time; positive susceptibilities are either paramagnetic or ferromagnetic (aligned with the field) and negative susceptibilities are diamagnetic (aligned oppositely with the field)
paramagnetic materials	their magnetic dipoles align partially in the same direction as the applied magnetic field; when this field is removed, the material is unmagnetized
permeability of free space	μ_0, measure of the ability of a material, in this case free space, to support a magnetic field
solenoid	thin wire wound into a coil that produces a magnetic field when an electric current is passed through it
toroid	donut-shaped coil closely wound around that is one continuous wire

Key Equations

Permeability of free space	$\mu_0 = 4\pi \times 10^{-7} T \cdot m/A$
Contribution to magnetic field from a current element	$dB = \frac{\mu_0}{4\pi} \frac{I dl sin\theta}{r^2}$
Biot–Savart law	$\vec{B} = \frac{\mu_0}{4\pi} \int_{wire} \frac{I d\vec{l} \times \hat{r}}{r^2}$
Magnetic field due to a long straight wire	$B = \frac{\mu_0 I}{2\pi R}$
Force between two parallel currents	$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$
Magnetic field of a current loop	$B = \frac{\mu_0 I}{2R}$ (at center of loop)
Ampère's law	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

Magnetic field strength inside a solenoid	$B=\mu_0 nI$
Magnetic field strength inside a toroid	$B=\frac{\mu_o NI}{2\pi r}$
Magnetic permeability	$\mu=(1+\chi)\mu_0$
Magnetic field of a solenoid filled with paramagnetic material	$B=\mu nI$

Summary

12.2 The Biot-Savart Law

- The magnetic field created by a current-carrying wire is found by the Biot-Savart law.
- The current element $Id\vec{l}$ produces a magnetic field a distance r away.

12.3 Magnetic Field Due to a Thin Straight Wire

- The strength of the magnetic field created by current in a long straight wire is given by $B=\frac{\mu_0 I}{2\pi R}$ (long straight wire) where **I** is the current, **R** is the shortest distance to the wire, and the constant $\mu_0=4\pi\times 10^{-7}T\cdot m/s$ is the permeability of free space.
- The direction of the magnetic field created by a long straight wire is given by right-hand rule 2 (RHR-2): Point the thumb of the right hand in the direction of current, and the fingers curl in the direction of the magnetic field loops created by it.

12.4 Magnetic Force between Two Parallel Currents

- The force between two parallel currents I_1 and I_2, separated by a distance r, has a magnitude per unit length given by $\frac{F}{l}=\frac{\mu_0 I_1 I_2}{2\pi r}$.
- The force is attractive if the currents are in the same direction, repulsive if they are in opposite directions.

12.5 Magnetic Field of a Current Loop

- The magnetic field strength at the center of a circular loop is given by $B=\frac{\mu_0 I}{2R}$ **(at center of loop),**, where R is the radius of the loop. RHR-2 gives the direction of the field about the loop.

12.6 Ampère's Law

- The magnetic field created by current following any path is the sum (or integral) of the fields due to segments along the path (magnitude and direction as for a straight wire), resulting in a general relationship between current and field known as Ampère's law.
- Ampère's law can be used to determine the magnetic field from a thin wire or thick wire by a geometrically convenient path of integration. The results are consistent with the Biot-Savart law.

12.7 Solenoids and Toroids

- The magnetic field strength inside a solenoid is

  $$B=\mu_0 nI \text{ (inside a solenoid)}$$

  where **n** is the number of loops per unit length of the solenoid. The field inside is very uniform in magnitude and direction.

- The magnetic field strength inside a toroid is

  $$B=\frac{\mu_o NI}{2\pi r} \text{ (within the toroid)}$$

  where **N** is the number of windings. The field inside a toroid is not uniform and varies with the distance as **1/r.**

12.8 Magnetism in Matter

- Materials are classified as paramagnetic, diamagnetic, or ferromagnetic, depending on how they behave in an applied magnetic field.
- Paramagnetic materials have partial alignment of their magnetic dipoles with an applied magnetic field. This is a positive magnetic susceptibility. Only a surface current remains, creating a solenoid-like magnetic field.

- Diamagnetic materials exhibit induced dipoles opposite to an applied magnetic field. This is a negative magnetic susceptibility.
- Ferromagnetic materials have groups of dipoles, called domains, which align with the applied magnetic field. However, when the field is removed, the ferromagnetic material remains magnetized, unlike paramagnetic materials. This magnetization of the material versus the applied field effect is called hysteresis.
