7.S: Magnetic Forces and Fields (Summary)

Key Terms

cosmic rays	comprised of particles that originate mainly from outside the solar system and reach Earth
cyclotron	device used to accelerate charged particles to large kinetic energies
dees	large metal containers used in cyclotrons that serve contain a stream of charged particles as their speed is increased
gauss	G, unit of the magnetic field strength; $1G = 10^{-4}T$
Hall effect	creation of voltage across a current-carrying conductor by a magnetic field
helical motion	superposition of circular motion with a straight-line motion that is followed by a charged particle moving in a region of magnetic field at an angle to the field
magnetic dipole	closed-current loop
magnetic dipole moment	term **IA** of the magnetic dipole, also called μ
magnetic field lines	continuous curves that show the direction of a magnetic field; these lines point in the same direction as a compass points, toward the magnetic south pole of a bar magnet
magnetic force	force applied to a charged particle moving through a magnetic field
mass spectrometer	device that separates ions according to their charge-to-mass ratios
motor (dc)	loop of wire in a magnetic field; when current is passed through the loops, the magnetic field exerts torque on the loops, which rotates a shaft; electrical energy is converted into mechanical work in the process
north magnetic pole	currently where a compass points to north, near the geographic North Pole; this is the effective south pole of a bar magnet but has flipped between the effective north and south poles of a bar magnet multiple times over the age of Earth
right-hand rule-1	using your right hand to determine the direction of either the magnetic force, velocity of a charged particle, or magnetic field
south magnetic pole	currently where a compass points to the south, near the geographic South Pole; this is the effective north pole of a bar magnet but has flipped just like the north magnetic pole
tesla	SI unit for magnetic field: $1T = 1N/A-m$
velocity selector	apparatus where the crossed electric and magnetic fields produce equal and opposite forces on a charged particle moving with a specific velocity; this particle moves through the velocity selector not affected by either field while particles moving with different velocities are deflected by the apparatus

Key Equations

Force on a charge in a magnetic field	$\vec{F} = q\vec{v} \times \vec{B}$

Magnitude of magnetic force	$F = qvBsin\theta$
Radius of a particle's path in a magnetic field	$r = \frac{mv}{qB}$
Period of a particle's motion in a magnetic field	$T = \frac{2\pi m}{qB}$
Force on a current-carrying wire in a uniform magnetic field	$\vec{F} = I\vec{l} \times \vec{B}$
Magnetic dipole moment	$\vec{\mu} = NIA\hat{n}$
Torque on a current loop	$\vec{\tau} = \vec{\mu} \times \vec{B}$
Energy of a magnetic dipole	$U = -\vec{\mu} \cdot \vec{B}$
Drift velocity in crossed electric and magnetic fields	$v_d = \frac{E}{B}$
Hall potential	$V = \frac{IBl}{neA}$
Hall potential in terms of drift velocity	$V = Blv_d$
Charge-to-mass ratio in a mass spectrometer	$\frac{q}{m} = \frac{E}{BB_0R}$
Maximum speed of a particle in a cyclotron	$v_{max} = \frac{qBR}{m}$

Summary

11.2 Magnetism and Its Historical Discoveries

- Magnets have two types of magnetic poles, called the north magnetic pole and the south magnetic pole. North magnetic poles are those that are attracted toward Earth's geographic North Pole.
- Like poles repel and unlike poles attract.
- Discoveries of how magnets respond to currents by Oersted and others created a framework that led to the invention of modern electronic devices, electric motors, and magnetic imaging technology.

11.3 Magnetic Fields and Lines

- Charges moving across a magnetic field experience a force determined by $\vec{F} = q\vec{v} \times \vec{B}$. The force is perpendicular to the plane formed by $\vec{v}$ and $\vec{B}$.
- The direction of the force on a moving charge is given by the right hand rule 1 (RHR-1): Sweep your fingers in a velocity, magnetic field plane. Start by pointing them in the direction of velocity and sweep towards the magnetic field. Your thumb points in the direction of the magnetic force for positive charges.
- Magnetic fields can be pictorially represented by magnetic field lines, which have the following properties:
    1. The field is tangent to the magnetic field line.
    2. Field strength is proportional to the line density.
    3. Field lines cannot cross.
    4. Field lines form continuous, closed loops.
- Magnetic poles always occur in pairs of north and south—it is not possible to isolate north and south poles.

11.4 Motion of a Charged Particle in a Magnetic Field

- A magnetic force can supply centripetal force and cause a charged particle to move in a circular path of radius $r = \frac{mv}{qB}$.
- The period of circular motion for a charged particle moving in a magnetic field perpendicular to the plane of motion is $T = \frac{2\pi m}{qB}$.

- Helical motion results if the velocity of the charged particle has a component parallel to the magnetic field as well as a component perpendicular to the magnetic field.

11.5 Magnetic Force on a Current-Carrying Conductor

- An electrical current produces a magnetic field around the wire.
- The directionality of the magnetic field produced is determined by the right hand rule-2, where your thumb points in the direction of the current and your fingers wrap around the wire in the direction of the magnetic field.
- The magnetic force on current-carrying conductors is given by $\vec{F} = I\vec{l} \times \vec{B}$ where I is the current and l is the length of a wire in a uniform magnetic field B.

11.6 Force and Torque on a Current Loop

- The net force on a current-carrying loop of any plane shape in a uniform magnetic field is zero.
- The net torque τ on a current-carrying loop of any shape in a uniform magnetic field is calculated using $\tau = \vec{\mu} \times \vec{B}$ where $\vec{\mu}$ is the magnetic dipole moment and $\vec{B}$ is the magnetic field strength.
- The magnetic dipole moment μ is the product of the number of turns of wire **N,** the current in the loop **I,** and the area of the loop **A** or $\vec{\mu} = NIA\hat{n}$.

11.7 The Hall Effect

- Perpendicular electric and magnetic fields exert equal and opposite forces for a specific velocity of entering particles, thereby acting as a velocity selector. The velocity that passes through undeflected is calculated by $v = \frac{E}{B}$.
- The Hall effect can be used to measure the sign of the majority of charge carriers for metals. It can also be used to measure a magnetic field.

11.8 Applications of Magnetic Forces and Fields

- A mass spectrometer is a device that separates ions according to their charge-to-mass ratios by first sending them through a velocity selector, then a uniform magnetic field.
- Cyclotrons are used to accelerate charged particles to large kinetic energies through applied electric and magnetic fields.
