This is a review of the topics will be covered in Exam 2.

Chapter 20

Magnetic Force on an Electric Current

Like electric fields, we can use **magnetic fields** to describe the force between magnets, and **magnetic field lines** to visualize them.

Magnetic fields exert a force on current-carrying wires. The force will be perpendicular to both the magnetic field and the current in the wire. Use the right-hand rule to find the direction of the force. Fingers in the direction of the current, curl in the direction of the magnetic field, thumb is the direction of the force. The magnitude of the force is

$$F = IlB\sin\theta$$

where θ is the angle between the magnetic field and the current, and B is the magnitude of the magnetic field. The units for the magnetic field are **tesla** where $1T = 1N/Am$.

Magnetic Force on a Moving Electric Charge

Moving electric charges, outside a wire, also experience a force from a magnetic field. The force on each charged particle is

$$F = qvB\sin\theta$$

where θ is the angle between the magnetic field and the direction of the velocity. If the charge is moving perpendicular to the magnetic field, the force is simply qvB. If moving parallel, the force is zero. Use the right-hand rule to know the direction. Fingers in the direction of velocity, curl in the direction of B, thumb in direction of force. *This is the direction for positively charged particles. Negatively charged particles feel a force in the opposite direction.*

Magnetic Field Due to a Long Straight Wire

A current in a wire produces a magnetic field around it in a loop. In order to know the direction the magnetic field is going, use the **right-hand rule** of pointing your thumb in the direction of the current and loop your fingers around. The direction your fingers curl is the direction of the magnetic field.

The magnitude of the magnetic field created by a current in a wire is found by

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

where $\mu_0 = 4\pi \times 10^{-7} T \cdot m/A$ is the **permeability of free space**.

Chapter 20.6: Force Between Two Parallel Wires

Two parallel wires separated by a distance d carrying currents I_1 and I_2 will exert a force on each other. The first wire will create a magnetic field at the location of the second wire of

$$B_1 = \frac{\mu_0}{2\pi}\frac{I_1}{d}$$

This exerts a force of

$$F_2 = I_2 B_1 l_2$$

or

$$F_2 = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d} l_2$$

The force the second wire exerts on the first wire is

$$F_1 = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d} l_1$$

Using the right-hand rule, currents in the same direction attract, while currents in opposite directions repel.

Chapter 21

Induced EMF

A changing magnetic field through a solenoid will produce an **induced current**. A constant magnetic field has no effect. In general, a changing magnetic field induces an emf $\mathcal{E}$. The induced emf depends on the change of **magnetic flux**, Φ_B, through the current loop, where the magnetic flux is found by

$$\Phi_B = B_\perp A = BA\cos\theta$$

where θ is the angle between the magnetic field and a vector perpendicular to the surface of the loop. The magnetic flux is analogous to the number of magnetic field lines passing through the surface. It has units of **weber** where $1Wb = 1T \cdot m^2$. If there are N loops in the coil, then the emf is found by

$$\mathcal{E} = -\mathrm{N}\frac{\Delta\Phi_B}{\Delta t}$$

The negative indicates that the current that is produced is in a direction so that its magnetic field opposes the original change in flux. This is known as **Lenz's Law**, which can be used to find the direction of the current induced in any situation.

While a changing magnetic field produces an emf, this indicates an electric field is being created. That electric field exists without the wire. *A changing magnetic field induces an electric field.*

Induced EMF in a Moving Circuit

One way to induce an emf by moving a rod of length l along rails at a velocity v. The magnitude of the induced emf will be

$$\mathcal{E} = Blv$$

If the rails are connected to a circuit with total resistance R, the current in the circuit will be

$$I = \frac{\mathcal{E}}{R}$$

Transformers

A **transformer** increases (**step-up)** or decreases (**step-down**) an ac voltage. It consists of two coils, a **primary** and **secondary**, woven around an iron core. By changing the number of coils in the primary and secondary, the magnitude of the voltage can be changed in the secondary while keeping the same ac frequency. The magnitude of the induced voltage in the secondary coil is

$$V_s = N_s\frac{\Delta\Phi_B}{\Delta t}$$

while the primary voltage is

$$V_p = N_p \frac{\Delta\Phi_B}{\Delta t}$$

The *transformer equation* is found by dividing these two equations to find

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

These voltages can be the rms or peak voltages. While the voltage can increases, the power does not, which means the current will decrease as

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Chapter 22

Maxwell's Equations

Maxwell's equations explain all electromagnetic phenomena. Among these equations, Faraday's Law describes how (A) a changing magnetic field produces an electric field. Ampere's Law describes how a magnetic field is produced by a (B) current or (C) a changing electric field.

Electromagnetic Waves

If there is a change in electric field, for example by changing the current in an antenna, it will produce a magnetic field (C above) that goes around the antenna (B). During the creation of the magnetic field, it is changing, and a changing magnetic field will then produce an electric field (A). That in turn will create a new magnetic field (C). This results in a wave of electric and magnetic fields that will *propagate* through space in all direction around the antenna. These are called **electromagnetic waves.**

The magnetic and electric fields in an EM wave are perpendicular to each other and to the direction of travel. They oscillate from maximum to minimum **in phase**.

An antenna can create constant EM waves by having the charges oscillate up and down its length. The magnitude of the EM waves will be greatest in the direction perpendicular to the oscillating charges (perpendicular to the antenna), and will go to zero in the direction of the charge oscillation. The electric field in the EM wave will oscillate in the direction of the antenna (if the antenna was vertical, the electric field will be as well). In order to detect the electric field with a receiving antenna, it will have the best reception if it is aligned with the electric field in the EM wave.

Speed of Light

The speed of the waves moving through space will be

$$v = c = \frac{E}{B}$$

where c is the speed of the EM waves in empty space, and it was shown that

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8 m/s$$

which is the measured speed of light in a vacuum. This measurement of the speed of light is a constant and does not depend on the movement of the objects that produce or measure it.

Electromagnetic Spectrum

The relationship between the wavelength and frequency of light is found by

$$c = \lambda f$$

where f is the frequency and λ is the wavelength.

Visible light ranges from

$$\lambda = 400nm - 750nm$$
$$f = 4 \times 10^{14}Hz - 7.5 \times 10^{14}Hz$$

where $1Hz = 1s^{-1}$. Visible light is only part of the **EM spectrum**.

Chapter 23

Ray Model of Light: Mirrors

Light travels in straight lines, so we use the **ray model** to visualize where **rays** of light will travel.

The **angle of incidence**, θ_i, is the angle a ray makes with perpendicular (normal) to the surface. The **angle of reflection**, θ_r, is the angle the reflected ray makes with the normal. The **law of reflection** state that for a smooth, flat surface, the angle of reflection equals the angle of incidence:

$$\theta_r = \theta_i$$

When looking at objects in a mirror, you are looking at the **image**, which looks like it's behind the mirror.

The **image distance**, d_i, the distance between the mirror and the image, is the same as the **object distance**, d_o, the distance the actual object is from the mirror. The height of the image, h_i, is also the same as the object, h_o.

Because the rays do not actually travel behind the mirror through the image we see, it is a **virtual image.** A **real image** is when the light actually travels through the location of the image, and could be projected onto a screen.

Formation of Images by Spherical Mirrors

Mirrors can be *curved*, often *spherical*. **Convex** mirrors are when the center mirror surface bulges outward, while **concave** mirrors have the mirror sink away from the viewer like a cave.
Rays traveling to a curved mirror will cross each other (or appear to cross, in the case of the convex mirror) at the **focal point** f. The focal point is half the distance to the center of curvature of the mirror. This means

$$f = \frac{r}{2}$$

where r is the radius of curvature of the mirror.

Mirror / Thin Lens Equation

In order to calculate the distance from a mirror or lens to an object, the following relationships can be used.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

and

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

We will consider h_o and d_o as being positive quantities. If the image is upright, h_i is positive; negative if inverted. The sign convention for d_i depends on whether we are using a mirror or lens, and will be detailed below.

Ray Diagrams

In order to find the location of an image created by a curved mirror, create a ray diagram. The **principal axis** is a line that travels through the center of curvature, focal point, and the mirror. Rays that travel parallel with these lines are **paraxial rays**.

Ray Diagram – Concave Mirror

For a concave mirror, the focal point and center of curvature are on the same side of the mirror as the object. The following rays can be used to find the image location for an object.

1. Draw paraxial ray from the object to the mirror, reflect it off the mirror back through the focal point.
2. Draw ray through the object and focal point to the mirror, reflect it back off the mirror as a paraxial ray.
3. Draw a line through the object and the center of curvature for the mirror, to the mirror, and back directly along the same path.
4. Draw a line from the object to the center of the mirror, at the principal axis, and reflect it back with the same angle it hit the mirror.

If $d_o > f$, these rays converge at a point on the same side of the mirror as the object. That is the location of the image. The image distance, d_i, is positive. The image is real and inverted, so h_i is negative.

If $d_o < f$, these rays do not converge on the same side as the object. Trace the reflected rays back to the opposite side of the mirror, making d_i negative. This is where they all appear to be coming from, and will be the location of the image. The rays never actually passed through this point, so the image is virtual, and it will be upright, making h_i positive.

If $d_o = f$, the rays are parallel and do not converge. The image will appear to be infinitely large and located infinitely far away ($h_i = d_i = \infty$).

Ray Diagram – Convex Mirror

For a convex mirror, the focal point and center of curvature are on the opposite side of the mirror as the object. The following rays can be used to find the image location for an object.

1. Draw paraxial ray from the object to the mirror, reflect it off the mirror exactly away from the focal point. A line can be drawn through the focal point to where the ray hits the mirror, and extend it away from the mirror to draw this ray.
2. Draw a ray that is directed toward the focal point, but when the ray reaches the mirror, reflect it away from mirror as a paraxial line. This paraxial line can be extended beyond the mirror.
3. Draw a line through the object toward the center of curvature of the mirror. When it reaches the mirror, the ray reflects back, but you can extend this line through the mirror to the center of curvature.
4. Draw a line to the center of the mirror, at the principal axis, and reflect it back with the same angle it hit the mirror. The reflected ray can be extended through the mirror.

The convex mirror will create a virtual image on the opposite side of the mirror as the object, so d_i is negative. It will be upright, so h_i is positive.

Ray Diagram – Convex Lens

A convex lens is a converging lens, passing all paraxial rays through the focal point on the opposite side. Lenses have focal points on both sides, and the following rays can be used to find the image location for an object.

1. Draw paraxial ray from the object to the lens, bend the ray toward the focal point on the opposite side.
2. Draw ray through the object and the focal point on the same side as the object. When it reaches the lens, bend the ray as a paraxial ray on the opposite side of the lens.
3. Draw a line through the object and the center of the lens, at the principal axis, and make it stay straight as it passes through the lens.

If $d_o > f$, these rays converge at a point on the opposite side of the lens as the object. That is the location of the image. The image distance, d_i, is positive. The image is real and inverted, so h_i is negative.

If $d_o < f$, these rays do not converge on the opposite side of the lens as the object. Trace the rays back to the object's side of the lens, making d_i negative. This is where they all appear to be coming from, and will be the location of the image. The rays never actually passed through this point, so the image is virtual, and it will be upright, making h_i positive.

If $d_o = f$, the rays are parallel and do not converge. The image will appear to be infinitely large and located infinitely far away ($h_i = d_i = \infty$).

Ray Diagram – Concave Lens

For a concave lens, it will cause the rays to diverge, and the *focal lengths will be negative*. The following rays can be used to find the image location for an object.

1. Draw paraxial ray from the object to the lens, then bend it exactly away from the focal point on the same side as the object. A line can be drawn through the focal point to where the ray hits the lens, which would then extended through the lens as the ray.
2. Draw a ray that is directed toward the focal point on the opposite side as the object. When the ray reaches the lens, bend it through the lens as a paraxial line. This paraxial line can be extended back to the object's side of the lens.
3. Draw a line through the object and straight through the center of the lens, at the principal axis. This line can also be extended beyond the object away from the lens.

A converging lens will create a virtual image on the same side of the lens as the object, so d_i is always negative. It will also be upright, so h_i is positive.