Chapters for the Final Exam

Chapter 20: Electric forces and fields (Conceptual Questions)
Chapter 25: Electromagnetic Induction and EM Waves (Conceptual Questions)
Chapter 26: AC Circuits

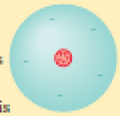
Chapter 17: Wave Optics
Chapter 18: Ray Optics
Chapter 19: Optical Instruments

Chapter 20: Electric Forces and Fields

GENERAL PRINCIPLES

Charge

There are two kinds of charges, called positive and negative.

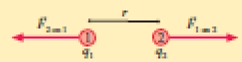


- Atoms have nuclei with positive charge and electrons with negative charge.
- The **fundamental charge** e is the magnitude of the charge on an electron or proton: $e = 1.60 \times 10^{-19}$ C
- Matter with equal amounts of positive and negative charge is neutral.
- Charge is conserved; it can't be created or destroyed.

Coulomb's Law

The forces between two charged particles q_1 and q_2 separated by distance r are

$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2}$$



These forces are an action/reaction pair directed along the line joining the particles.

- The forces are repulsive for two like charges, attractive for two opposite charges.
- The net force on a charge is the vector sum of the forces from all other charges.
- The unit of charge is the coulomb (C).

IMPORTANT CONCEPTS

The Electric Field

Charges interact with each other via the electric field $\vec{E}$.

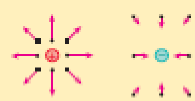
- Charge A alters the space around it by creating an electric field.

- The field is the agent that exerts a force on charge B. $\vec{F}_{\text{on B}} = q_B\vec{E}$
- An electric field is identified and measured in terms of the force on a probe charge q. $\vec{E} = \frac{\vec{F}_{\text{on } q}}{q}$ The unit of the electric field is N/C.
- The electric field is a vector. The electric field from multiple charges is the vector sum of the fields from the individual charges. $\vec{E}_{\text{total}} = \vec{E}_1 + \vec{E}_2 + \cdots$

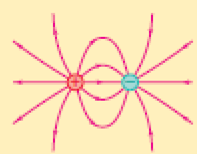
Visualizing the electric field

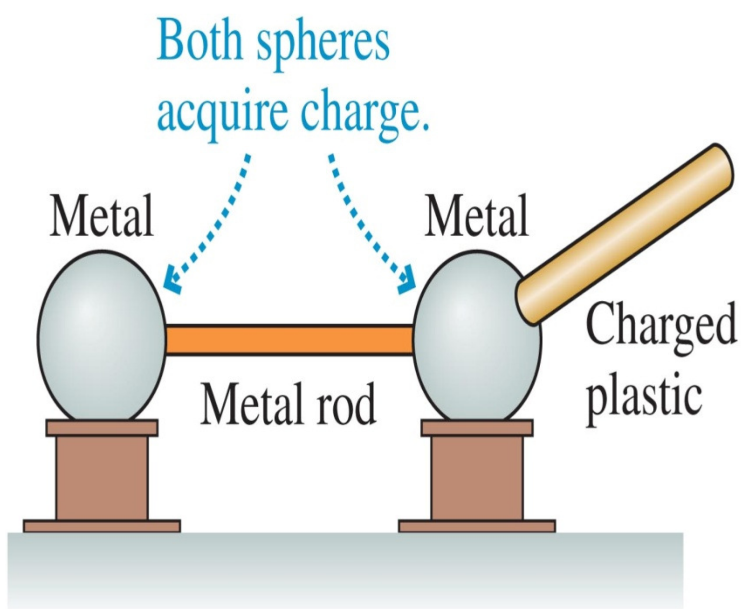
The electric field exists at all points in space.

- An electric field vector shows the field only at one point, the point at the tail of the vector.
- A **field diagram** shows field vectors at several points.



- Electric field lines:
  - are always parallel to the field vectors.
  - are close where the field is strong, far apart where the field is weak.
  - go from positive to negative charges.

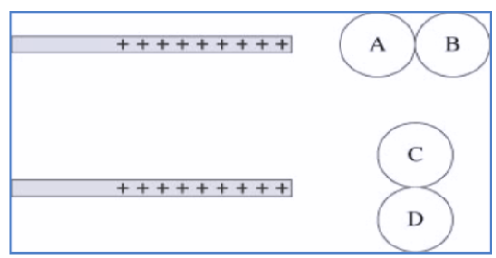




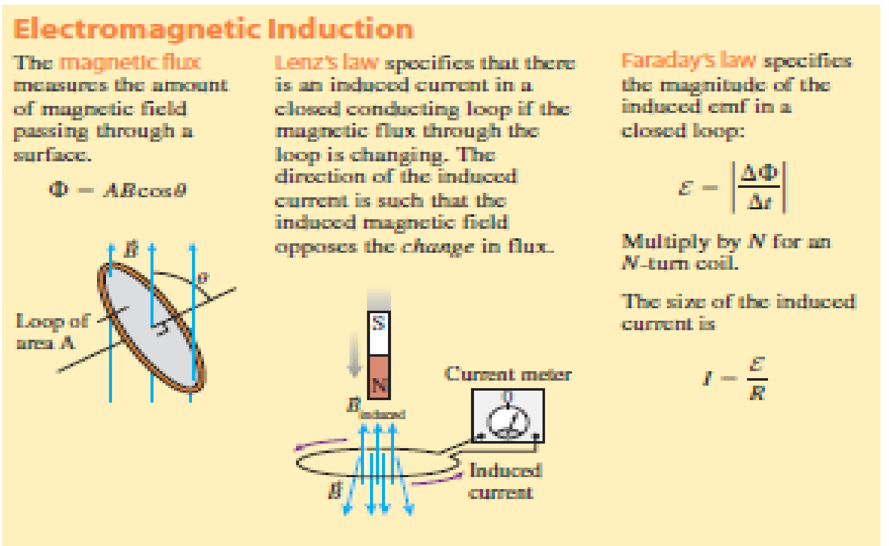
Sample Question: **Two spheres are touching each other. A charged rod is brought near. The spheres are then separated, and the rod is taken away. In the first case, the spheres are aligned with the rod, in the second case, they are perpendicular. After the charged rod is removed, which of the spheres is:**

i) Positive
ii) Negative
iii) Neutral

What are the magnitudes of the charge they acquire after separation?



Chapter 25: Electromagnetic Induction and EM Waves



Electromagnetic Induction

The magnetic flux measures the amount of magnetic field passing through a surface.

$$\Phi = AB\cos\theta$$

Lenz's law specifies that there is an induced current in a closed conducting loop if the magnetic flux through the loop is changing. The direction of the induced current is such that the induced magnetic field opposes the *change* in flux.

Faraday's law specifies the magnitude of the induced emf in a closed loop:

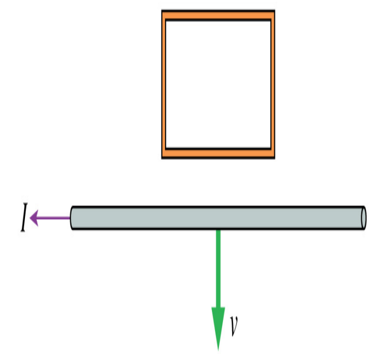
$$\mathcal{E} = \left|\frac{\Delta\Phi}{\Delta t}\right|$$

Multiply by N for an N-turn coil.

The size of the induced current is

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

Sample Question: **A current-carrying wire is pulled away from a conducting loop in the direction shown. As the wire is moving, is there a cw current around the loop, a ccw current or no current? What principles would you use to explain it?**



Chapter 17: Wave Optics

The wave model

The wave model considers light to be a wave propagating through space. Interference and diffraction are important. The wave model is appropriate when light interacts with objects whose size is comparable to the wavelength of light, or roughly less than about 0.1 mm.

Huygens' principle says that each point on a wave front is the source on a spherical wavelet. The wave front at a later time is tangent to all the wavelets.

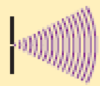
IMPORTANT CONCEPTS

The **index of refraction** of a material determines the speed of light in that material: $v = c/n$. The index of refraction of a material is always greater than 1, so that v is always less than c.

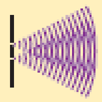
The wavelength λ in a material with index of refraction n is *less* than the wavelength λ_{vac} in vacuum: $\lambda = \lambda_{vac}/n$.

The *frequency* of light does not change as it moves from one material to another.

Diffraction is the spreading of a wave after it passes through an opening.



Constructive and destructive **interference** are due to the overlap of two or more waves as they spread behind openings.



APPLICATIONS

Diffraction from a single slit

A single slit of width a has a bright **central maximum** of width

$$w = \frac{2\lambda L}{a}$$

that is flanked by weaker **secondary maxima.**

Dark fringes are located at angles such that

$$a\sin\theta_p = p\lambda \qquad p = 1, 2, 3, \ldots$$

If $\lambda/a \ll 1$, then from the small-angle approximation

$$\theta_p = \frac{p\lambda}{a} \qquad y_p = \frac{p\lambda L}{a}$$

Interference from multiple slits

Waves overlap as they spread out behind slits. Constructive interference occurs along antinodal lines. Bright fringes are seen where the antinodal lines intersect the viewing screen.

Double slit with separation d.

Equally spaced bright fringes are located at

$$\theta_m = \frac{m\lambda}{d} \qquad y_m = \frac{m\lambda L}{d} \qquad m = 0, 1, 2, \ldots$$

The **fringe spacing** is $\Delta y = \dfrac{\lambda L}{d}$

Diffraction grating with slit spacing d.

Very bright and narrow fringes are located at angles and positions

$$d\sin\theta_m = m\lambda \qquad y_m = L\tan\theta_m$$

Circular aperture of diameter D.

A bright central maximum of diameter

$$w = \frac{2.44\lambda L}{D}$$

is surrounded by circular secondary maxima. The first dark fringe is located at

$$\theta_1 = \frac{1.22\lambda}{D} \qquad y_1 = \frac{1.22\lambda L}{D}$$

For an aperture of any shape, a smaller opening causes a greater spreading of the wave behind the opening.

Thin-film interference

Interference occurs between the waves reflected from the two surfaces of a thin film. A wave that reflects from a surface at which the index of refraction increases has a phase change.

Interference	0 or 2 phase changes	One phase change
Constructive	$2t = m\dfrac{\lambda}{n}$	$2t = \left(m + \dfrac{1}{2}\right)\dfrac{\lambda}{n}$
Destructive	$2t = \left(m + \dfrac{1}{2}\right)\dfrac{\lambda}{n}$	$2t = m\dfrac{\lambda}{n}$

Sample Questions: **Light from a sodium lamp (589nm) illuminates two narrow slits. The fringe spacing on a screen 150 behind the slits is 4.0 . What is the spacing (in) between the two slits?**

Two narrow slits 0.04 mm apart are illuminated by light from a HeNe laser (λ = 633 nm). What is the angle of the first (*m* = 1) bright fringe?

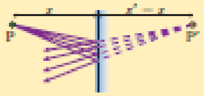
Chapter 18: Ray Optics

Reflection

Law of reflection: $\theta_r = \theta_i$

Reflection can be **specular** (mirror-like) or **diffuse** (from rough surfaces).

Plane mirrors: A virtual image is formed at P′ with $s = s'$, where s is the **object distance** and s' is the **image distance.**

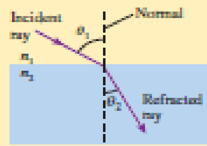


Refraction

Snell's law of refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Index of refraction is $n = c/v$. The ray is closer to the normal on the side with the larger index of refraction.



If $n_2 < n_1$, total internal reflection (TIR) occurs when the angle of incidence $\theta_1 > \theta_c = \sin^{-1}(n_2/n_1)$

IMPORTANT CONCEPTS

The ray model of light

Light travels along straight lines, called **light rays**, at speed $v = c/n$.

A light ray continues forever unless an interaction with matter causes it to reflect, refract, scatter, or be absorbed.

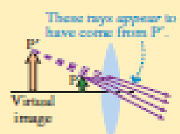
Light rays come from self-luminous or reflective **objects.** Each point on the object sends rays in all directions.

Ray diagrams represent all the rays emitted by an object by only a few select rays.

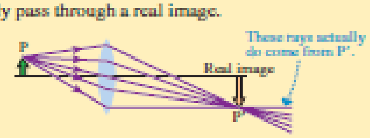
In order for the eye to see an object (or image), rays from the object or image must enter the eye.

Image formation

If rays diverge from P and, after interacting with a lens or mirror, *appear* to diverge from P′ without actually passing through P′, then P′ is a virtual image of P.



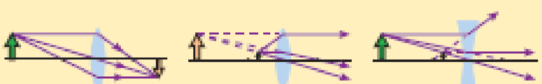
If rays diverge from P and interact with a lens so that the refracted rays *converge* at P′, then P′ is a real image of P. Rays actually pass through a real image.



APPLICATIONS

Ray tracing for lenses

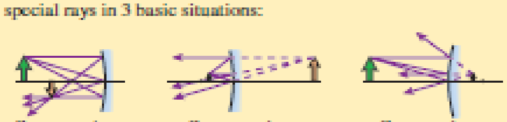
3 special rays in 3 basic situations:



Converging lens Real image | Converging lens Virtual image | Diverging lens Virtual image

Ray tracing for mirrors

3 special rays in 3 basic situations:



Concave mirror Real image | Concave mirror Virtual image | Convex mirror Virtual image

Magnification

The magnification is the ratio of the image height h' to the object height h. It can also be written in terms of the image and object distances:

$$m = \frac{h'}{h} = \frac{s'}{s}$$

Color and dispersion

The eye perceives light of different wavelengths as having different colors.

Dispersion is the dependence of the index of refraction n of a transparent medium on the wavelength of light: Long wavelengths have the lowest n, short wavelengths the highest n.

Sample Questions: **A laser beam is aimed at 1cm-thick sheet of glass at an angle 30 deg above the glass. What is the laser beam's direction of travel in the glass?**

A 3.0-cm-tall object is 45 in front of a concave mirror that has a 25 focal length. Calculate the image position.

Chapter 19: Optical Instruments

Finding the Image of a Lens or Mirror

For a lens or curved mirror, the object distance s, the image distance s', and the focal length f are related by the thin-lens equation:

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$$

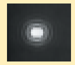
Sign conventions for the thin-lens equation are:

Quantity	Positive when	Negative when
s	Always	Not treated here
s'	*Real* image, on opposite side of a lens from object, or in front of a mirror.	*Virtual* image, on same side of a lens as the object, or behind a mirror.
f	Converging lens or concave mirror	Diverging lens or convex mirror.
h', M	Image is upright	Image is inverted

The magnification of a lens or mirror is

$$M=-\frac{h'}{h}=-\frac{s'}{s}$$

Resolution of Optical Instruments



The **resolution** of a telescope or microscope is limited by imperfections, or **aberrations**, in the optical elements, and by the more fundamental limits imposed by diffraction.

For a *microscope*, the minimum resolvable distance between two objects is

$$d_{min}=\frac{0.61\lambda_0}{\text{NA}}$$

For a *telescope*, the minimum resolvable angular separation between two objects is

$$\theta_1=\frac{1.22\lambda}{D}$$

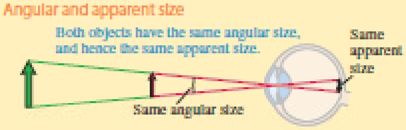
IMPORTANT CONCEPTS

Lenses in combination

When two lenses are used in combination, the image from the first lens serves as the object for the second.

The **refractive power** P of a lens is the inverse of its focal length: $P = 1/f$. When two lenses are in contact, their net refractive power is the sum of their individual refractive powers.

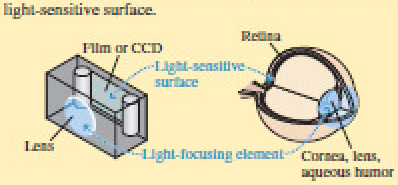
Angular and apparent size



APPLICATIONS

The camera and the eye

Both the camera and the eye work by focusing an image on a light-sensitive surface.

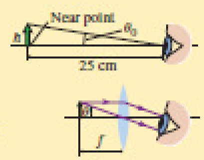


The camera focuses by changing the lens-film distance while the eye focuses by changing the focal length of its lens.

The magnifier

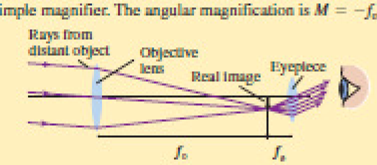
Without a lens, an object cannot be viewed closer than the eye's near point of ≈25 cm. Its angular size θ_0 is $h/25$ cm.

If the object is now placed at the focal point of a converging lens, its angular size is increased to $\theta = h/f$.



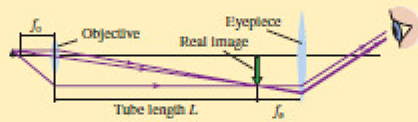
The angular magnification is $M = \theta/\theta_0 = 25\text{ cm}/f$.

The telescope magnifies distant objects. The objective lens creates a real image of the distant object. This real image is then further magnified by the eyepiece lens, which acts as a simple magnifier. The angular magnification is $M = -f_o/f_e$.



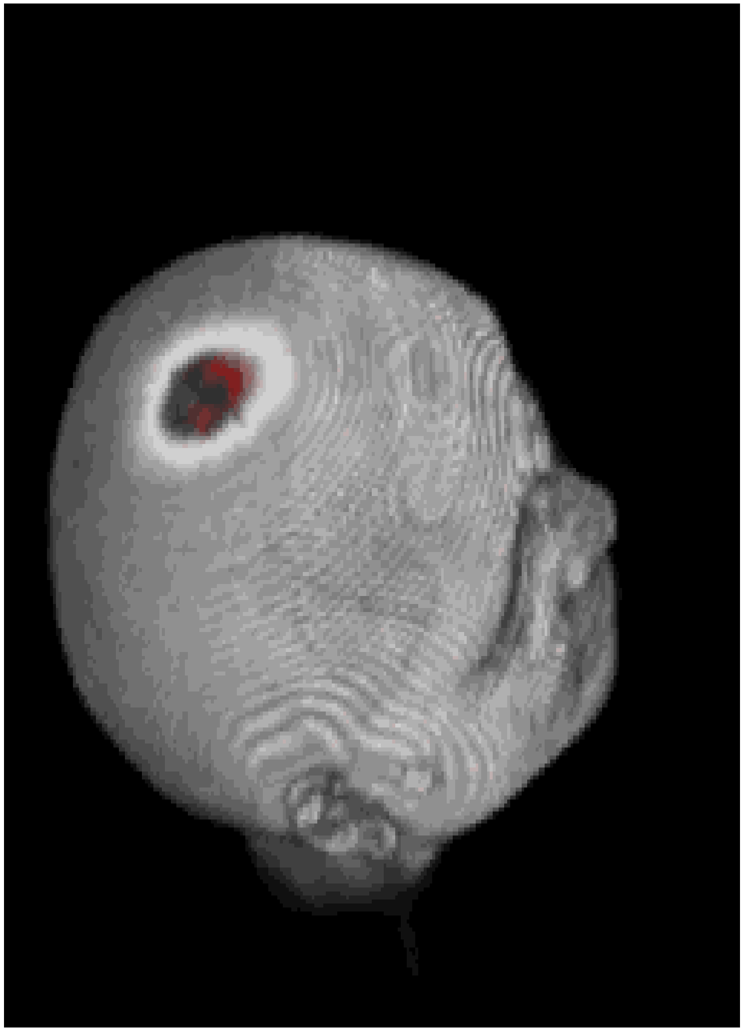
The microscope magnifies a small, nearby object. The objective lens creates a real image of the object. This real image is then further magnified by the eyepiece lens, which acts as a simple magnifier. The angular magnification is

$$-\frac{L\times 25\text{ cm}}{f_o f_e}$$



An object is 15 cm in front of a diverging lens with a focal length of 10 cm . What is the position of the image? Is it real or virtual?

Sanjaya has hyperopia. The near point of his left eye is 150cm. What prescription lens will restore normal vision?



Brain Activity for Finger Movement

New course: **Phys 4710/6710: Functional Neuroimaging** will be offered in the future.