Objectives for AP Physics B

1. NEWTONIAN MECHANICS

A. Kinematics

1. Motion in One Dimension

a) Students should understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line, so that:

1. Given graph of one of the kinematic quantities, position, velocity, r acceleration, as function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.

b) Students should understand the special case of motion with constant acceleration so that they can:

1. Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities.

2. Use the equations $v = v_0 + at$, $s_0 = s_0 + v_0t + at^2/2$, and $v^2 - v_0^2 = 2a(s- s_0)$

2. Motion in Two Dimensions

a) Students should know how to deal with displacement and velocity vectors so they can:

1. Relate velocity, displacement, and time for motion with constant velocity.

2. Calculate the component of a vector along a specified axis, or resolve a vector into components alone two specified mutually perpendicular axes.

3. Add vectors in order to find the net displacement of particle that undergoes successive straight-line displacements.

4. Subtract displacement vectors in order to find the location of one particle relative to another, or calculate the average velocity of a particle.

5. Add or subtract velocity vectors in order to calculate the velocity change or average acceleration of a particle, or the velocity of one particle relative to another.

b) Students should understand the motion of projectiles in a uniform gravitational field so they can:

i. Write down expressions for the horizontal and vertical components of velocity positions as functions of time, and sketch or identify graphs of these components.

ii. Use these expressions in analyzing the motion of a projectile that is projected above level ground with a specified initial velocity.

B. Newton's Law of Motion

1. Static Equilibrium (First Law)

a) Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.

2. Dynamics of a Single Particle (Second Law)

a) Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.

i. Calculate, for a body moving in one direction, the velocity change that results when a constant force *F* acts over a specified time interval.

ii. Determine, for a body moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the body.

b) Students should understand how Newton's Second Law, **F** = *m***a**, applies to a body subject to forces such as gravity, the pul of strings, or contact forces, so they can:

i. Draw a well-labeled diagram showing all real forces that act on the body.

ii. Write down the vector equation that results from applying Newton's Second Law to the body, and take components of this equation along appropriate axes.

c) Students should be able to analyze situations in which a body moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, in situations such as the following:

i. Motion up or down with constant acceleration (in an elevator, for example).

ii. Motion in a horizontal circle (e.g., mass on a rotating merry-go-round, or car rounding a banked curve).

iii. Motion in a vertical circle (e.g., mass swinging on the end of a string cart rolling down a curved track, rider on a Ferris wheel).

d) Students should understand the significance of the coefficient of friction so they can:

i. Write down the relationship between the normal and frictional forces on a surface.

ii. Analyze situations in which a body slides down a rough incline plane or is pulled or pushed across a rough surface.

iii. Analyze static situations involving friction to determine under what circumstances a body will start to slip, or to calculate the magnitude of the force of static friction.

3. Systems of Two or More Bodies (Third Law)

a) Students should understand Newton's Third Law so that, for a given force, they can identify the body on which reaction force acts and state the magnitude and direction of this reaction.

b) Students should be able to apply Newton's Third Law in analyzing the force of contact between two bodies that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.

c) Students should know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyzing the motion of a system of two bodies joined by a string.

C. Work, Energy, and Power

1. Work and the Work-Energy Theorem

a) Students should understand the definition of work so they can:

i. Calculate the work done by a specified constant force on a body that undergoes a specified displacement.

ii. Relate the work done by a force to the area under a graph of forces as a function of position, and calculate this work in the case where the force is a linear function of position.

iii. Use the scalar product operation to calculate the work performed by a specified constant force F on a body that undergoes a displacement in a plane.

b) Students should understand the work-energy theorem so they can:

i. Calculate the change in kinetic energy or speed that results from performing a specified amount of work on the body.

ii. Calculate the work performed by the net force, or by each of the forces that makes up the net force, on a body that undergoes a specified change in speed or kinetic energy.

iii. Apply the theorem to determine the change in a body's kinetic energy and speed that results from the application of specified force, or to determine the force that is required in order to bring a body to rest in a specified distance.

2. Conservative Forces and Potential Energy

a) Students should understand the concept of potential energy so they can:

i. Write an expression for the force exerted by an ideal spring and for the potential energy stored in a stretched or compressed spring.

ii. Calculate the potential energy of a single body in a uniform gravitational field.

3. Conservation of Energy

a) Students should understand conservation of energy so they can:

i. Identify situations in which mechanical energy is or is not conserved.

ii. Apply conservation of energy in analyzing the motion of bodies that are moving in a gravitational field and are subject to constraints imposed by strings or surfaces.

iii. Apply conversation of energy in analyzing the motion of bodies that move under the influence of springs.

4. Power

a) Students should understand the definition of power so they can:

i. Calculate the power required to maintain the motion of a body with constant acceleration (e.g., to move a body along a level surface, to raise a body at a constant rate, or to overcome friction for a body that is moving at a constant speed).

ii. Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.

D. Systems of Particles, Linear Momentum

1. Impulse and Momentum: Students should understand impulse and linear momentum so they can:

a) Relate mass, velocity, and linear momentum for a moving body, and calculate the total linear momentum of a system of bodies.

b) Relate impulse to the change in linear momentum and the average force acting on a body.

2. Conservation of Linear Momentum, Collisions

a) Students should understand linear momentum conservation so they can:

i. Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.

ii. Apply linear momentum conservation to determine the final velocity when two bodies that are moving along the same line, or at right angles, collide and stick together, and calculate how much kinetic energy is lost in such a situation.

iii. Analyze collisions of particles in one or two dimensions to determine unknown masses or velocities, and calculate how much kinetic energy is lost in a collision.

E. Circular Motion and Rotation

1. Uniform Circular Motion

a) Students should understand the uniform circular motion of a particle so they can:

i. Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.

ii. Describe the direction of the particle's velocity and acceleration at any instant during the motion.

iii. Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.

2. Angular Momentum and Its Conservation

a) Students should understand angular momentum conservation so they can:

i. Recognize the conditions under which the law of conservation is applicable and relate this law to one- and two-particle systems such as satellite orbits.

2. Torque and Rotational Statics

a) Students should understand the concept of torque so they can:

i. Calculate the magnitude and sense of the torque associated with a given force.

ii. Calculate the torque on a rigid body due to gravity.

b) Students should be able to analyze problems in statics so they can:

i. State conditions for translational and rotational equilibrium of a rigid body.

ii. Apply these conditions in analyzing the equilibrium of a rigid body under the combined influence of a number of coplanar forces applied at different locations.

F. Oscillations

1. Students should understand the kinematics of simple harmonic motion so they can:

a). sketch or identify a graph of displacement as a function of time, and determine from such a graph the amplitude, time, and frequency of the motion.

b). Write down an appropriate expression for displacement of the form $A \sin\omega t$ or $A \cos\omega t$ to describe the motion.

c). Identify points in the motion where the velocity is zero or achieves its maximum positive or negative value.

d) State qualitatively the relation between acceleration and displacement.

e) Identify points in the motion where the acceleration is zero or achieves its greatest positive or negative value.

f) State and apply the relation between frequency and period.

g) State how the total energy of an oscillating system depends on the amplitude of the motion, sketch or identify a graph of kinetic or potential energy as a function of time, and identify points in the motion where this energy is all potential or all kinetic.

h) Calculate the kinetic and potential energies of an oscillating system as functions of time, sketch or identify graphs of these functions, and prove that the sum of kinetic and potential energy is constant.

2. Students should be able to apply their knowledge of simple harmonic motion to the case of a mass on a spring, so they can:

a) Apply the expression for the period of oscillation of a mass on a spring.

3. Students should be able to apply their knowledge of simple harmonic motion to the case of a pendulum, so they can:

a) Apply the expression for the period of a simple pendulum.

b) State what approximation must be made in deriving the period.

G. Gravitation

1. Students should know Newton's Law of Universal Gravitation so they can

a) Determine the force that one spherically symmetrical mass exerts on another.

b) Determine the strength of the gravitational field a ta specified point outside a spherically symmetrical mass.

2. Students should understand the motion of a body in orbit under the influence of gravitational forces so they can:

a) For a circular orbit recognize that the motion does not depend on the body's mass; describe qualitatively how the velocity, period of revolution, and centripetal acceleration depend upon the radius of the orbit; and derive expressions for the velocity and period of revolution in such an orbit.

b) For a general orbit:

i. Apply conservation of angular momentum to determine the velocity and radial distance at any point in the orbit.

ii. Apply angular momentum conservation and energy conservation to relate the speeds of a body at the two extremes of an elliptic orbit.

II. HEAT, KINETIC THEORY, AND THERMODYNAMICS

A. Fluid Mechanics

1. Hydrostatic Pressure

a) Students should understand that a fluid exerts pressure in all directions

b) Students should understand that a fluid at rest exerts pressure perpendicular to any surface that it contacts

c) Students should understand and be able to use the relationship between pressure and depth in a liquid, $\Delta p = \rho g \Delta h$.

2. Buoyancy

a) Students should understand that the difference in the pressure on the upper and lower surfaces of an object immersed in liquid results in an upward force on the object.

b) Students should understand and be able to apply Archimedes' principle: the buoyant force on a submersed object is equal to the weight of the liquid it displaces.

3. Fluid flow continuity

a) Students should understand that for laminar flow, the flow rate of a liquid through its cross section is the same at any point along its path.

b) Students should understand and be able to apply the equation of continuity, $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

4. Bernoulli's Equation

a) Students should understand that the pressure of a flowing liquid is low where the velocity is high, and vice versa.

b) Students should understand and be able to apply Bernoulli's equation, $\rho + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$

B. Temperature and Heat

1. Students should understand the "mechanical equivalent of heat" so they can calculate how much a substance will be heated by the performance of a specified quantity of mechanical work.

2. Students should understand the concepts of specific heat, heat of fusion, and heat of vaporization so they can:

a) Identify, given a graph relating the quantity of heat added to a substance and its temperature, the melting point, and boiling point and determine the heats of fusion and vaporization and the specific heat of each phase.
b) Determine how much heat must be added to a sample of a substance to raise its temperature from one specified value to another, or to cause it to melt or vaporize.

3. Students should understand heat transfer and thermal expansion so they can:

a) Determine the final temperature achieved when substances, all at different temperatures, are mixed and allowed to come to thermal equilibrium.
b) Calculate how the flow of heat through a slab of material is affected by changes in the thickness or area of the slab, or the temperature difference between the two faces of the slab.
c) Analyze qualitatively what happens to the size and shape of a body when it is heated.

C. Kinetic Theory and Thermodynamics

1. Ideal Gases

a) Students should understand the kinetic theory model of an ideal gas so they can:

i. State the assumptions of the model.
ii. State the connection between temperature and mean translational kinetic energy, and apply it to determine the mean speed of gas molecules as a function of their mass and the temperature of the gas.
iii. State the relationship among Avogadro's number, Boltzmann's constant, and the gas constant R, and express the energy of a mole of a monatomic ideal gas as a function of its temperature.
iv. Explain qualitatively how the model explains the pressure of a gas in terms of collisions with the container walls, and explain how the model predicts that, for fixed volume, pressure must be proportional to temperature.

b) Students should know how to apply the ideal gas law and thermodynamic principles so they can:

i. Relate the pressure and volume of a gas during an isothermal expansion or compression.
ii. Relate the pressure and temperature of a gas during constant-volume heating or cooling, or the volume and temperature during constant pressure heating or cooling.
iii. Calculate the work performed on or by a gas during an expansion or compression at constant pressure.
iv. Understand the process of adiabatic expansion or compression of a gas.

v. Identify or sketch on *pV* diagram the curves that represent each of the above processes.

2. Laws of Thermodynamics

a) Students should know how to apply the first law of thermodynamics so they can:

i. Relate the heat absorbed by a gas, the work performed by the gas, and the internal energy change of the as for any of the processes above.

ii. Relate the work performed by a gas in a cyclic process to the area enclosed by a curve on a *pV* diagram.

b) Students should understand the second law of thermodynamics, the concept of entropy, and heat engines and the Carnot cycle so they can:

i. Determine whether entropy will increase, decrease, or remain the same during a particular situation.

ii. Compute the maximum possible efficiency of a heat engine operating between two given temperatures.

iii. Compute the actual efficiency of a heat engine.

iv. Relate the heats exchanged at each thermal reservoir in a Carnot cycle to the temperatures of the reservoirs.

III. ELECTRICITY AND MAGNETISM

A. Electrostatics

1. Charge, Field, and Potential

a) Students should understand the concept of electric field so they can:

i. Define it in terms of the force on a test charge.

ii. Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.

iii. Given a diagram on which an electric field is represented by flux lines, determine the direction of the field at a given point, identify locations where the field is strong and where it is weak, and identify where positive or negative charges must be present.

iv. Analyze the motion of specified charge and mass in a uniform electric field.

b) Students should understand the concept of electric potential so they can:

i. Calculate the electrical work done on a positive or negative charge that moves through a specified potential difference.

ii. Given a sketch of equipotentials for a charge configuration, determine the direction and approximate magnitude of the electric field at various positions.

iii. Apply conservation of energy to determine the speed of a charged particle that has been accelerated through a specified potential difference.

            iv. Calculate the potential difference between two points in a uniform electric field, and state which is at the higher potential.

    2. Coulombs Law and Field and Potential of Point Charges

        a) Students should understand Coulomb's Law and the principle of superposition so they can:

            i. Determine the force that acts between specified point charges, and describe the electric field of a single point charge.

            ii. Use vector addition to determine the electric field produced by two or more point charges.

        b) Students should know the potential function for a point charge so they can:

            i. Determine the electric potential in the vicinity of one or more point charges.

    3. Fields and Potentials of Other Charge Distributions

        a) Students should know the fields of highly symmetric charge distributions so they can:

            i. Describe the electric field of parallel charged plates.

B. Conductors, Capacitors, Dielectrics

    1. Electrostatics with Conductors

        a) Students should understand the nature of electric fields in and around conductors so they can:

            i. Explain the mechanics responsible for the absence of electric field inside a conductor, and why all excess charge must reside on the surface of the conductor.

            ii. Explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires.

            iii. Determine the direction of the force on a charged particle brought near an uncharged or grounded conductor.

        b) Students should be able to describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere.

        c) Students should understand induced charge and electrostatic shielding so they can:

            i. Describe qualitatively the process of charging by induction.

            ii. Determine the direction of the force on a charged particle brought near an uncharged or grounded conductor.

    2. Capacitors

        a) Students should know the definition of capacitance so they can relate stored charge and voltage for a capacitor.

        b) Students should understand energy storage in capacitors so they can:

            i. Relate voltage, charge, and stored energy for a capacitor.

ii. Recognize situations in which energy stored in a capacitor is converted to other forms.

c) Students should understand the physics of the parallel-plate capacitor so they can:

i. Describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation.

ii. Determine how changes in dimension will affect the value of the capacitance.

C. Electric Circuits

1. Current, Resistance, Power

a) Students should understand the definition of electric current so they can relate the magnitude and direction of the current in a wire or ionized medium to the rate of flow of positive and negative charge.

b) Students should understand conductivity, resistivity, and resistance so they can:

i. Relate current and voltage for a resistor.

ii. Describe how the resistance of a resistor depends upon its length and cross-sectional area.

iii. Apply the relationships for the rate of heat production in a resistor.

2. Steady-State Direct Current Circuits with Batteries and Resistors Only

a) Students should understand the behavior of series and parallel combinations of resistors so they can:

i. Identify on a circuit diagram whether resistors are in series or parallel.

ii. Determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel.

iii. Calculate the equivalent resistance of two or more resistors connected in series or in parallel, or of a network of resistors that can be broken down into series and parallel combinations.

iv. Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single battery.

v. Design a simple series-parallel circuit that produces a given current and terminal voltage for one specified component, and draw a diagram for the circuit using conventional symbols.

b) Students should understand the properties of ideal and real batteries so they can calculate the terminal voltage of a battery of a specified emf and internal resistance from which a known current is flowing.

c) Students should be able to apply Ohm's Law and Kirchhoff's rules to direct-current circuits in order to determine a single unknown current, voltage, or resistance.

d) Students should understand the properties of voltmeters and ammeters so they can:

i. State whether the resistance of each is high or low.

ii. Identify or show correct methods of connecting meters into circuits in order to measure voltage or current.

3. Capacitors in Circuits

a) Students should understand the behavior of capacitors connected in series or in parallel so they can:

i. Calculate the equivalent capacitance of a series or parallel combination.

ii. Describe how stored charge is divided between two capacitors connected in parallel.

iii. Determine the ratio of voltages for two capacitors connected in series.

b) Students should be able to calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors.

c) Students should develop skill in analyzing the behavior of circuits containing several capacitors and resistors so they can determine voltages and currents immediately after a switch has been closed and also after steady-state conditions have been established.

D. Magnetostatics

1. Forces on Moving Charges in Magnetic Fields

a) Students should understand the force experienced by a charged particle in a magnetic field so they can:

i. Calculate the magnitude and direction of the force in terms of q, v, and B, and explain why the magnetic force can perform no work.

ii. Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field.

iii. State and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field, and derive this formula from Newton's Second Law and the magnetic force law.

iv. Describe the most general path possible for a charged particle moving in a uniform magnetic field, and describe the motion of a particle that enters a uniform magnetic field moving with specified initial velocity.

v. Describe quantitatively under what conditions particles will move with constant velocity through crossed electric and magnetic fields.

2. Forces on Current-carrying Wires in Magnetic Fields

a) Students should understand the force experienced by a current in a magnetic field so they can:

i. Calculate the magnitude and direction of the force on a straight segment of current-carrying wire in a uniform magnetic field.

ii. Indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces.

3. Fields of Long Current-carrying Wires

a) Students should understand the magnetic field produced by a long straight current-carrying wire so they can:

i. Calculate the magnitude and direction of the field ata appoint in the vicinity of such a wire.

ii. Use superposition to determine the magnetic field produced by two long wires.

iii. Calculate the force of attraction or repulsion between two long current-carrying wires.

E. Electromagnetism

1. Electromagnetic Induction

a) Students should understand the concept of magnetic flux so they can calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.

b) Students should understand Faraday's Law and Lenz's Law so they can:

i. Recognize situations in which changing flux through a loop will cause an induced emf or current in the loop.

ii. Calculate the magnitude and direction of the induced emf and current in:

a) A square loop of wire pulled at a constant velocity into or out of a uniform magnetic field.

b) A loop of wire placed in a spatially uniform magnetic field whose magnitude is changing at a constant rate.

c) A loop of wire that rotates at a constant rate about an axis perpendicular to a uniform magnetic field.

d) A conducting bar moving perpendicular to a uniform magnetic field.

IV. WAVES AND OPTICS

A. Wave Motion (including Sound)

1. Students should understand the description of traveling waves so they can:

a) Sketch or identify graphs that represent traveling waves and determine the amplitude, wavelength, and frequency of a wave from such a graph.
b) State and apply the relation among wavelength, frequency, and velocity for a wave.
c) Sketch or identify graphs that describe reflection of a wave from the fixed or free end of a string.
d) Know qualitatively what factors determine the speed of waves on a string and the speed of sound.

2. Students should understand the physics of standing waves so they can:
a) Sketch possible standing wave modes for a stretched string that is fixed at both ends, and determine the amplitude, wavelength, and frequency of such standing waves.
b) Describe possible standing sound waves in a pipe that has either open or closed ends, and determine the wavelength and frequency of such standing waves.

3. Students should understand the Doppler effect for sound so they can:
a) Explain the mechanism that gives rise to a frequency shift in both the moving-source and moving-observer case, and derive an expression for the frequency heard by the observer.
b) Write and apply the equations that describe the moving-source and moving-observer Doppler effect, and sketch or identify graphs that describe the effect.

4. Students should understand the principle of superposition so they can apply it to traveling waves moving in opposite directions, and describe how a standing wave may be formed by superposition.

B. Physical Optics

1. Students should understand the interference and diffraction of waves so they can:
a) Apply the principles of interference to coherent sources oscillating in phase in order to:
i. Describe the conditions under which the waves reaching an observation pint from two or more sources will all interfere constructively, or under which the waves from two sources will interfere destructively.
ii. Determine locations of interference maxima or minima for two sources or determine the frequencies or wavelengths that can lead to constructive or destructive interference at a certain point.
iii. Relate the amplitude and intensity produced by two or more sources that interfere constructively to the amplitude and intensity produced by a single source.
b) Apply the principles of interference and diffraction to waves that pass through a single or double slit or through a diffraction grating so they can:

i. Sketch or identify the intensity patter that results when monochromatic waves pass through a single slit and fall on a distant screen, and describe how this pattern will change if the slit width or the wavelength of the waves is changed.
ii. Calculate, for a single-slit pattern, the angles or the positions on a distant screen where the intensity is zero.
iii. Sketch or identify the intensity pattern that results when monochromatic waves pass through a double slit, and identify which features of the pattern result from single-slit diffraction and which from two-slit interference.
iv. Calculate, for a two-slit interference pattern, the angles or the positions on a distant screen at which intensity maxima or minima occur.
v. Describe or identify the interference pattern formed by a grating of many equally spaced narrow slits, calculate the location of intensity maxima, and explain qualitatively why a multiple-slit grating is better than a two-slit grating for making accurate determinations of wavelength.

c) Apply the principles of interference to light reflected by thin films so they can:
i. State under what conditions a phase reversal occurs when light is reflected form the interface between two media of different indices of refraction.
ii. Determine whether rays of monochromatic light reflected from two such interfaces will interfere constructively or destructively, and thereby account for Newton's rings and similar phenomena, and explain how glass may be coated to minimize reflection of visible light.

2. Students should understand dispersion and the electromagnetic spectrum so they can:
a) Relate a variation of index of refraction with frequency to a variation in refraction.
b) Know the names associated with electromagnetic radiation and be able to arrange in order of increasing wavelength the following: visible light of various colors, ultraviolet light, infrared light, radio waves, x-rays, and gamma rays.

3. Students should understand the transverse nature of light waves so they can explain qualitatively why light can exhibit polarization.

4. Students should understand the inverse-square law so they can calculate the intensity of light at a given distance from a source of specified power and compare the intensity of light at different distances from the source.

C. Geometrical Optics
1. Students should understand the principles of reflection and refraction so they can:
a) Determine how the speed and wavelength of light change when light passes from one medium into another.

b) Show on a diagram the directions of reflected and refracted rays.
c) Use Snell's Law to relate the directions of the incident ray and the refracted ray, and the indices of refraction of the media.
d) Identify conditions under which total internal reflection will occur.

2. Students should understand image formation by plane or spherical mirrors so they can:

a) Relate the focal point of a spherical mirror to its center of curvature.
b) Given a diagram of a mirror with the focal point shown, locate by ray tracing the image of a real object and determine whether the image is real or virtual, upright or inverted, enlarged or reduced in size.

3. Students should understand image formation by converging or diverging lenses so they can:

a) Determine whether the focal length of a lens is increased or decreased as a result of a change in the curvature of its surfaces or in the index of refraction of the material of which the lens is made or the medium in which it is immersed.
b) Determine by ray tracing the location of the image of a real object located inside or outside the focal point of the lens, and state whether the resulting image is upright or inverted, real or virtual.
c) Use the thin lens equation to relate the object distance, image distance, and focal length for a lens, and determine the image size in terms of the object size.
d) Analyze simple situations in which the image formed by one lens serves as the object for another lens.

V. MODERN PHYSICS

A. Atomic Physics and Quantum Effects

1. STUDENTS SHOULD BE ABLE TO DESCRIBE THE RUTHERFORD SCATTERING EXPERIMENT AND TO EXPLAIN HOW IT PROVIDES EVIDENCE FOR THE EXISTENCE OF THE ATOMIC NUCLEUS.

2. Students should know the properties of photons and understand the photoelectric effect so they can:

a) Relate the energy of a photon in joules or electron-volts to its wavelength or frequency.
b) Relate the linear momentum of a photon to its energy or wavelength, and apply linear momentum conservation to simple processes involving the emission, absorption, or reflection of photons.
c) Calculate the number of photons per second emitted by a monochromatic source of specific wavelength and power.
d) Describe a typical photoelectric effect experiment, and explain what experimental observations provide evidence for the photon nature of light.
e) Describe qualitatively how the number of photoelectrons ejected by photons of one energy or wavelength, determine the maximum

kinetic energy of photoelectrons for a different photon energy or wavelength.

f) When given the maximum kinetic energy of photoelectrons ejected by photons of one energy or wavelength, determine the maximum kinetic energy of photoelectrons for a different photon energy or wavelength.

g) Sketch or identify a graph of stopping potential versus frequency for a photoelectric effect experiment, determine from such a graph the threshold frequency and work function, and calculate an approximate value of *h/e*.

3. Students should understand the concept of energy levels for atoms so they can:

a) Calculate the energy or wavelength of the photon emitted or absorbed in a transition between specified levels, or the energy or wavelength required to ionize an atom.

b) Explain qualitatively the origin of emission or absorption spectra of gases.

c) Given the wavelengths or energies of photons emitted or absorbed in a two-step transition between levels, calculate the wavelength or energy for a single-step transition between the same levels.

d) Write an expression for the energy levels of hydrogen in terms of the groundstate energy, draw a diagram to depict these levels, and explain how this diagram accounts for the various "series" in the hydrogen spectrum.

e) STATE THE ASSUMPTIONS AND CONCLUSIONS FOR THE BOHR MODEL FOR THE HYDROGEN ATOM.

4. Students should understand the concept of DeBroglie wavelength so they can:

a) Calculate the wavelength of a particle as a function of its momentum.

b) Describe the Davisson-Germer experiment, and explain how it provides evidence for the wave nature of electrons.

5. Students should understand the nature and production of x-rays so they can calculate the shortest wavelength of x-rays that may be produced by electrons accelerated through a specified voltage.

6. Students should understand Compton scattering so they can:

a) Describe Compton's experiment, and state what results were observed and by what sort of analysis these results may be explained.

b) Account qualitatively for the increase of photon wavelength that is observed, and explain the significance of the Compton wavelength.

B. Nuclear Physics

1. STUDENTS SHOULD UNDERSTAND THE SIGNIFICANCE OF HALF-LIFE IN RADIOACTIVE DECAY SO THEY CAN:

a) RECOGNIZE THAT HALF-LIFE IS INDEPENDENT OF THE NUMBER OF NUCLEI PRESENT OR OF EXTERNAL CONDITIONS.

b) SKETCH OR IDENTIFY A GRAPH TO INDICATE WHAT FRACTION OF A RADIOACTIVE SAMPLE REMAINS AS A FUNCTION OF TIME, AND INDICATE THE HALF-LIFE ON SUCH A GRAPH.

c) DETERMINE, FOR AN ISOTOPE OF SPECIFIED HALF-LIFE, WHAT FRACTION OF THE NUCLEI HAVE DECAYED AFTER A GIVEN TIME HAS ELAPSED.

2. Students should understand the significance of the mass number and charge of nuclei so they can:

a) Interpret symbols for nuclei that indicate these quantities.

b) Use conservation of mass number and charge to complete nuclear reactions.

c) Determine the mass number and charge of a nucleus after it has undergone specified decay processes.

d) Describe the process of α, β, and λ decay and write a reaction to describe each.

e) Explain why the existence of the neutrino had to be postulated in order to reconcile experimental data from β decay with fundamental conservation laws.

3. Students should know the nature of the nuclear force so they can compare its strength and range with those of the electromagnetic force.

4. Students should understand nuclear fission so they can describe a typical neutron-induced fission and explain why a chain reaction is possible.

5. Students should understand the relationship between mass and energy (mass-energy equivalence) so they can:

a) Qualitatively relate the energy released in nuclear processes to the change in mass.

b) Apply the relationship $E = mc^2$ in analyzing nuclear processes.