Physics Learning Objectives

Program Learning Goals

- Utilize the mathematical models that describe and explain motion in the natural world.
- Understand that physics is based on a few key principles that can be applied to a wide range of natural phenomena.
- Use the main ideas of classical mechanics (kinematics to describe motion & changes in motion, dynamics & conservation principles to understand what causes changes in motion & what limits those changes) to solve fundamental & applied problems.
- Experience that physics is both a mathematical and an experimental science.

0. I: Be able to work in and switch between verbal, pictorial, graphical, and algebraic/symbolic representations. II: Connect and apply concepts and methods of physics to other disciplines, particularly math and chemistry.

1. Define, relate, and distinguish clearly the concepts of position and displacement, average and instantaneous velocity, and average and instantaneous acceleration.
2. Interpret and use motion diagrams and kinematics graphs (position vs. time, velocity vs. time, and acceleration vs. time) to analyze one-dimensional motion.
3. Learn and apply the basic ideas of calculus (derivatives and integrals) to kinematics problems.
4. State and apply the constant velocity and constant acceleration kinematics formulas appropriately to problems involving moving objects. Recognize that free-fall motion and motion on a frictionless inclined planes are constant acceleration situations.
5. Describe vector quantities using: magnitude and direction; rectangular components; and unit vector notation. Be able to convert from one representation to another using basic definitions from right triangle trigonometry and the Pythagorean Theorem. Use standard and tilted coordinate systems.
6. Add and subtract vectors using both the graphical method and the method of components.
7. Given an object's path in space (a motion diagram, position component vs. time graphs, or position vs. time equation in unit vector notation) in two or three dimensions, use vector methods or calculus to determine its velocity and acceleration at various locations and times.
8. Given an object's velocity and acceleration vectors, show how the acceleration vector is connected to the change in the velocity vector's magnitude (its speed) and its direction.
9. Use the independence of perpendicular components of motion to separate a motion problem in two or three dimensions into linked problems in one dimension.
10. Analyze uniform circular motion by relating period, velocity, radius, angular velocity, and centripetal acceleration, including the directional properties of velocity and acceleration.
11. Develop a robust problem-solving strategy in the context of solving quantitative kinematics problems using graphing and algebraic methods, and interpreting the results.

12. Characterize, catalog, identify, and use the properties of various types of forces. Apply the various properties of weight forces, normal forces, tension forces, spring forces, friction forces, and drag forces in analyzing problems. State and use the Hooke's law model for a restoring spring force, relating spring force to spring constant and displacement from equilibrium.
13. Explain the connection between force and motion as described in the law of inertia (Newton's First Law) and the connection between net force acting on a mass and its acceleration (Newton's Second Law).
14. Given a physical situation, apply Newton's Second and Third Laws by: a) drawing a sketch (including selecting an object or objects of interest and identifying forces); b) constructing a free-body (force) diagram for each object of interest (separately); c) determining the (vector) forces acting on each object in terms of knowns and unknowns; d) using concepts from kinematics to determine the acceleration for one-dimensional motion and in a plane, particularly circular motion, in terms of knowns and unknowns; and e) applying Newton's Second Law in component form to solve for unknowns.

15. Define momentum. Calculate momentum of various objects, recalling that momentum is a vector quantity.
16. Define impulse. State the impulse-momentum theorem and its connection to Newton's Second Law.
17. Apply Momentum Bar Charts and Before-and-After Pictorial Representations to problems involving momentum, momentum changes, and conservation of momentum.
18. State and recognize the conditions under which conservation of linear momentum applies. Relate conservation of momentum to Newton's Third Law.
19. Apply conservation of linear momentum to various isolated systems, including explosions and collisions in one or two dimensions.

20. Describe the Basic Energy Model and connect it to the First Law of Thermodynamics, including: kinetic energy, potential energy, and thermal energy as energy forms that can transform within a system; and work as a transfer of energy between environment and system.
21. a) Define kinetic energy in terms of mass and speed (magnitude of velocity); given any two of mass, speed, and kinetic energy, calculate the third. b) Define gravitational potential energy in terms of mass, gravitational field constant, and height with respect to a zero of potential energy. Given any two of gravitational potential energy, mass, and height, calculate the third. c) Define elastic potential energy in terms of spring constant and displacement from equilibrium; given any two, calculate the third. d) Define mechanical energy.
22. State the definition for potential energy and describe the types of forces with which a potential energy may be associated. For a given potential energy vs. position graph or function, calculate the corresponding force. Given a graph of an object's potential energy and total energy vs. position, determine the object's kinetic energy, turning points, points of stable and unstable equilibrium, and forbidden zones.
23. Use the dot product in both unit vector form and in magnitude and direction form.
24. State and use the definition of work. From a given force and the motion of an object, calculate the work done on the object by that force. Estimate or calculate the work done during one-dimensional motion by determining the area under a force-vs-displacement graph or by integration.
25. Apply the various forms of the Work-Kinetic Energy Theorem to a moving object subject to one or more forces.
26. State and recognize the conditions under which conservation of mechanical energy applies, and solve problems using this principle. For problems where mechanical energy is not conserved, relate the change in mechanical energy to the external work done by non-conservative forces.
27. For problems involving collisions, apply conservation of momentum during the collision, and conservation of mechanical energy before and after the collision (where appropriate) to solve for unknowns. For elastic collisions, use both conservation of momentum and conservation of mechanical energy (or alternately the equivalence between speed of approach and speed of recession) to solve for unknowns.

28. Relate angular/rotational quantities (angular position θ, angular velocity ω, angular acceleration α, moment of inertia I, torque τ, angular momentum L, rotational kinetic energy K_{rot}) to their analogous linear/translational quantities (position, velocity, acceleration, mass, force, linear momentum, translational kinetic energy). Use right hand rules and/or vector cross products to determine the vector direction of rotational quantities.
29. Solve problems involving rotational kinematics, particularly for situations involving constant angular acceleration or using calculus. Connect rotational kinematics to translational kinematics using $v = R\omega$ and $a = R\alpha$.
30. Describe the connections and distinctions between mass m and moment of inertia I. Calculate moment of inertia for a point particle m moving at a radius R using $I = mR^2$. or for extended objects of uniform density using a table of formulas.
31. Describe the connections and distinctions between force $\boldsymbol{F}$ and torque $\boldsymbol{\tau}$. Determine the magnitude and direction of torque given force, distance force is applied, and angle or using the vector cross product of position and force: $\tau = r\,F \sin(\varphi)$ or $\boldsymbol{\tau} = \boldsymbol{r} \times \boldsymbol{F}$.
32. Use Newton's 2nd Law for rotational motion to relate net torque to the rate of change of angular momentum or to the product of moment of inertia and angular acceleration: $\boldsymbol{\tau} = I\boldsymbol{\alpha} = d\boldsymbol{L}/dt$.
33. Relate rotational kinetic energy to moment of inertia and angular speed: $K_{rot} = 1/2\ I\omega^2$. Extend conservation of energy problems to include rotational kinetic energy.
34. Relate angular momentum to moment of inertia and angular velocity or using the vector cross product of position and linear momentum: $\boldsymbol{L} = I\boldsymbol{\omega} = \boldsymbol{r} \times \boldsymbol{p}$. Apply conservation of angular momentum to situations where the net torque equals zero or has a component equal to zero.