

## OVERVIEW

**GENERAL:** Physics deals with objects and waves. Objects can have mass and charge. Waves are mechanisms that transfer energy without the accompanying displacement of mass. Objects can be modeled as points for most motions. Rotational motion is an exception; the object is modeled as a 2-dimensional shape. A well defined collection of objects is a system.

**KINEMATICS:** An object has mass and can be abstractly represented by its center-of-mass. Kinematics is the study of object motion without its causes. Motion of objects requires a dynamic force interaction within a system that transfers energy between the object and the system. This interaction is ignored. It describes motion in terms of both scalar and vector quantities. The scalar quantities are position, distance, speed and acceleration. The vector quantities are displacement, velocity and acceleration. In dynamics, force on an object transfers kinetic energy to or from the object -- this is ignored. So the object's motion transfers both mass and energy from an initial position to a final position. The simplest motion is linear. Circular motion requires an acceleration that always points towards the center. Two dimensional projectile motion requires use of perpendicular vectors. The motion described by a two observers is relative to each observer.

**DYNAMICS:** The cause of motional changes is force. Force is a vector and alters motion, momentum and energy of individual objects. Unbalanced forces can alter 1-dimensional and 2-dimensional motion. Forces can balance to result in equilibrium.

**MOMENTUM:** Objects have the property of momentum. Impulse (force acting over time) changes the momentum of an object. The momentum of a system of objects is conserved.

**ENERGY:** There are many forms of energy. When objects interact, energy is conserved. However mechanical energy (kinetic and potential) is generally converted into other forms and is not conserved.

**ROTATION:** Force acting away from an objects center-of-mass causes rotational torque. The rotation of an object has motional quantities analogous to linear motion.

**ELECTRICITY:** Objects are composed of atoms with balanced positive and negative charges. Charges interact through a Coulomb force. An imbalance of one charge type results in an electrostatic charge. Energy of charges result in voltage. Charge can flow through metals in a current which carries energy.

## CURRICULUM

1. Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
  - A. **Enduring Understanding 1.A:** The internal structure of a system determines many properties of the system. **GENERAL**
    1. **Essential Knowledge 1.A.1:** A system is an object or a collection of objects. Objects are treated as having no internal structure. **GENERAL**
    2. **Essential Knowledge 1.A.5:** Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP

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- Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an *object*. **KINEMATICS**
- B. **Enduring Understanding 1.B:** Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. **ELECTRICITY**
1. **Essential Knowledge 1.B.1:** Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. **ELECTRICITY**
  2. **Essential Knowledge 1.B.2:** There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge. **ELECTRICITY**
  3. **Essential Knowledge 1.B.3:** The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge. **ELECTRICITY**
- C. **Enduring Understanding 1.C:** Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. **FORCE**
1. **Essential Knowledge 1.C.1:** Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems. **FORCE**
  2. **Essential Knowledge 1.C.2:** Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields. **FORCE**
  3. **Essential Knowledge 1.C.3:** Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. **FORCE**
- D. **Enduring Understanding 1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
1. **Essential Knowledge 1.E.2:** Matter has a property called resistivity. **ELECTRICITY**
2. **Big Idea 2:** Fields existing in space can be used to explain interactions.
- A. **Enduring Understanding 2.A:** A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena. **FORCE**
1. **Essential Knowledge 2.A.1:** A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector. **KINEMATICS FORCE**
- B. **Enduring Understanding 2.B:** A gravitational field is caused by an object with mass. **FORCE**
1. **Essential Knowledge 2.B.1:** A gravitational field  $g$  at the location of an object with mass  $m$  causes a gravitational force of magnitude  $mg$  to be exerted on the object in the direction of the field. **FORCE**
  2. **Essential Knowledge 2.B.2:** The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object. **FORCE**
3. **Big Idea 3:** The interactions of an object with other objects can be described by forces.

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- A. **Enduring Understanding 3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames. **FORCE**
1. **Essential Knowledge 3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. **KINEMATICS FORCE**
  2. **Essential Knowledge 3.A.2:** Forces are described by vectors. **FORCE**
  3. **Essential Knowledge 3.A.3:** A force exerted on an object is always due to the interaction of that object with another object. **FORCE**
  4. **Essential Knowledge 3.A.4:** If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction. **FORCE**
- B. **Enduring Understanding 3.B:** Classically, the acceleration of an object interacting with other objects can be predicted by using  $a = \frac{\Sigma F}{m}$  **FORCE**
1. **Essential Knowledge 3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **VECTORS FORCE**
  2. **Essential Knowledge 3.B.2:** Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. **FORCE**
  3. **Essential Knowledge 3.B.3:** Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator. **HARMONICS**
- C. **Enduring Understanding 3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **FORCE**
1. **Essential Knowledge 3.C.1:** Gravitational force describes the interaction of one object that has mass with another object that has mass. **FORCE**
  2. **Essential Knowledge 3.C.2:** Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge. **ELECTRICITY**
  3. **Essential Knowledge 3.C.4:** Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, and spring (Physics 1). **FORCE**
- D. **Enduring Understanding 3.D:** A force exerted on an object can change the momentum of the object. **MOMENTUM**
1. **Essential Knowledge 3.D.1:** The change in momentum of an object is a vector in the direction of the net force exerted on the object. **MOMENTUM**
  2. **Essential Knowledge 3.D.2:** The change in momentum of an object occurs over a time interval. **MOMENTUM**
- E. **Enduring Understanding 3.E:** A force exerted on an object can change the kinetic energy of the object. **ENERGY**
1. **Essential Knowledge 3.E.1:** The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. **ENERGY**
- F. **Enduring Understanding 3.F:** A force exerted on an object can cause a torque on that object. **ROTATION**

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1. **Essential Knowledge 3.F.1:** Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis. **ROTATION**
  2. **Essential Knowledge 3.F.2:** The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. **ROTATION**
  3. **Essential Knowledge 3.F.3:** A torque exerted on an object can change the angular momentum of an object. **ROTATION**
  - G. **Enduring Understanding 3.G:** Certain types of forces are considered fundamental. **FORCE**
    1. **Essential Knowledge 3.G.1:** Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales. **FORCE**
4. Big Idea 4: Interactions between systems can result in changes in those systems.
- A. **Enduring Understanding 4.A:** The acceleration of the center of mass of a system is related to the net force exerted on the system, where  $a = \frac{\Sigma F}{m}$ .
    1. **Essential Knowledge 4.A.1:** The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. : **KINEMATICS**
    2. **Essential Knowledge 4.A.2:** The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. : **KINEMATICS**
    3. **Essential Knowledge 4.A.3:** Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. **FORCE**
  - B. **Enduring Understanding 4.B:** Interactions with other objects or systems can change the total linear momentum of a system. **MOMENTUM**
    1. **Essential Knowledge 4.B.1:** The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. **MOMENTUM**
    2. **Essential Knowledge 4.B.2:** The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted. **MOMENTUM**
  - C. **Enduring Understanding 4.C:** Interactions with other objects or systems can change the total energy of a system. **ENERGY**
    1. **Essential Knowledge 4.C.1:** The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. **ENERGY**
    2. **Essential Knowledge 4.C.2:** Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. **WORK**
  - D. **Enduring Understanding 4.D:** A net torque exerted on a system by other objects or systems will change the angular momentum of the system. **ROTATION**
    1. **Essential Knowledge 4.D.1:** Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. **ROTATION**

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2. **Essential Knowledge 4.D.2:** The angular momentum of a system may change due to interactions with other objects or systems. **ROTATION**
  3. **Essential Knowledge 4.D.3:** The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. **ROTATION**
5. Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.
- A. **Enduring Understanding 5.A:** Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. **GENERAL**
1. **Essential Knowledge 5.A.1:** A system is an object or a collection of objects. The objects are treated as having no internal structure. **GENERAL**
  2. **Essential Knowledge 5.A.2:** For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. **GENERAL ENERGY ELECTRICITY MOMENTUM ROTATION**
  3. **Essential Knowledge 5.A.3:** An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. **FORCE ELECTRICITY MOMENTUM ROTATION**
  4. **Essential Knowledge 5.A.4:** The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis. **GENERAL**
- B. **Enduring Understanding 5.B:** The energy of a system is conserved. **ENERGY**
1. **Essential Knowledge 5.B.1:** Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. **ENERGY**
  2. **Essential Knowledge 5.B.2:** A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums.] **ENERGY**
  3. **Essential Knowledge 5.B.3:** A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. **ENERGY**
  4. **Essential Knowledge 5.B.4:** The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. **ENERGY**
  5. **Essential Knowledge 5.B.5:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. **[WORK POWER ENERGY]**
- C. **Essential Knowledge 5.B.9:** Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1. **ELECTRICITY**
- D. **Enduring Understanding 5.C:** The electric charge of a system is conserved. **ELECTRICITY**
1. **Essential Knowledge 5.C.3:** Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be

conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only.]

**ELECTRICITY**

E. **Enduring Understanding 5.D:** The linear momentum of a system is conserved. **MOMENTUM**

1. **Essential Knowledge 5.D.1:** In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

**MOMENTUM**

2. **Essential Knowledge 5.D.2:** In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision. **MOMENTUM ENERGY**

3. **Essential Knowledge 5.D.3:** The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.] **ROTATION**

F. **Enduring Understanding 5.E:** The angular momentum of a system is conserved. **ROTATION**

1. **Essential Knowledge 5.E.1:** If the net external torque exerted on the system is zero, the angular momentum of the system does not change. **ROTATION**

2. **Essential Knowledge 5.E.2:** The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples should include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. **ROTATION**

6. **Big Idea 6:** Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena. **WAVES**

A. **Enduring Understanding 6.A:** A wave is a traveling disturbance that transfers energy and momentum.

1. **Essential Knowledge 6.A.1:** Waves can propagate via different **oscillation modes** such as transverse and longitudinal.

2. **Essential Knowledge 6.A.2:** For **propagation**, mechanical waves require a medium, while

3. electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.

4. **Essential Knowledge 6.A.3:** The **amplitude** is the maximum displacement of a wave from its equilibrium value.

5. **Essential Knowledge 6.A.4:** Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves.

B. **Enduring Understanding 6.B:** A **periodic wave** is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.

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1. **Essential Knowledge 6.B.1:** For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time.
  2. **Essential Knowledge 6.B.2:** For a periodic wave, the wavelength is the repeat distance of the wave.
  3. **Essential Knowledge 6.B.4:** For a periodic wave, wavelength is the ratio of speed over frequency.
  4. **Essential Knowledge 6.B.5:** The observed frequency of a wave depends on the **relative motion** of source and observer. This is a qualitative treatment only.
- C. **Enduring Understanding 6.D:** Interference and superposition lead to standing waves and **beats**.
2. **Essential Knowledge 6.D.1:** Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called **superposition**.
  3. **Essential Knowledge 6.D.2:** Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave.
  4. **Essential Knowledge 6.D.3:** **Standing waves** are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes.
  5. **Essential Knowledge 6.D.4:** The possible wavelengths of a standing wave are determined by the size of the region to which it is confined (**resonance**).
  6. **Essential Knowledge 6.D.5:** **Beats** arise from the addition of waves of slightly different frequency.