02 Force and Translational Dynamics

Content Area:	**Science**
Course(s):	**AP Physics C**
Time Period:	**Semester 1**
Length:	**3 weeks**
Status:	**Published**

Standards

SCI.HS.PS1.A	Structure and Properties of Matter
SCI.HS.PS2.A	Forces and Motion
SCI.HS.PS2.B	Types of Interactions
SCI.HS-ESS1-4	Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
SCI.HS-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
SCI.HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
SCI.HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
	Using Mathematics and Computational Thinking
	Obtaining, Evaluating, and Communicating Information
	Systems and System Models
	Structure and Function
	Scale, Proportion, and Quantity
	Analyzing and Interpreting Data
	Planning and Carrying Out Investigations
	Patterns
	Cause and Effect

AP Physics C Learning Objectives

Note: Learning Objectives are taken verbatim from the AP Physics C - Mechanics Course and Exam Description. The verb "describe" could refer to a variety of different methods of expression (e.g. words, diagrams, graphs, mathematical expressions), as appropriate.

Describe the properties and interactions of a system.
Describe the location of a system's center of mass with respect to the system's constituent parts.
Describe a force as an interaction between two objects or systems.
Describe the forces exerted on an object or system using a free-body diagram.
Describe the interaction of two objects or systems using Newton's third law and a representation of paired forces exerted on each object or system.
Describe the conditions under which a system's velocity remains constant.
Describe the conditions under which a system's velocity changes.

Describe the gravitational interaction between two objects or systems with mass.
Describe situations in which the gravitational force can be considered constant.
Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system.
Describe inertial and gravitational mass.
Describe the gravitational force exerted on an object by a uniform spherical distribution of mass.
Describe kinetic friction between two surfaces.
Describe static friction between two surfaces.
Describe the force exerted on an object by an ideal spring.
Describe the equivalent spring constant of a combination of springs exerting forces on an object.
Describe the motion of an object subject to a resistive force.
Describe the motion of an object traveling in a circular path.
Describe circular orbits using Kepler's third law.

Enduring Understandings

Interactions produce changes in motion.

Forces characterize interactions between objects and systems.

Fields predict and describe interactions.

The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

There are force pairs with equal magnitude and opposite directions between any two interacting objects.

A net force will change the translational motion of an object.

Objects of large mass will cause gravitational fields that create an interaction at a distance with other objects with mass.

The motion of some objects is constrained so that forces acting on the object cause it to move in a circular path.

Essential Questions

Why do we feel pulled toward Earth but not a pencil?

Why does the swirling motion continue after you've stopped stirring a cup of coffee?

If you apply the same amount of "push" to a car as you would a shopping cart, why doesn't the car move?

Why must you push backward to make a skateboard move forward?

How do you determine which team wins a tug-of-war: The team that pulls harder on the rope or the team that pushes harder on the ground?

Knowledge and Skills

Topic 2.1 Systems and Center of Mass
Knowledge:

- System properties are determined by the interactions between objects within the system.
- If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.
- Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.
- Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.
- The internal structure of a system affects the analysis of that system.
- As variables external to a system are changed, the system's substructure may change.
- For objects or systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.
- The location of a system's center of mass along a given axis can be calculated using the equation
- For a nonuniform solid that can be considered as a collection of differential masses, dm, the solid's center of mass can be calculated using the equation
- The linear mass density of a rod or other linear rigid body is the derivative of the rod's mass with respect to the position of the differential mass element on the rigid body.
- If a function of mass density is given for a solid, the total mass can be determined by integrating the mass density over the length (one dimension), area (two dimensions), or volume (three dimensions) of the solid.
- A system can be modeled as a singular object that is located at the system's center of mass.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 2.2 Forces and Free-Body Diagrams
Knowledge:

- Forces are vector quantities that describe the interactions between objects or systems.
- A force exerted on an object or system is always due to the interaction of that object or system with another object or system.
- An object or system cannot exert a net force on itself.
- Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.

- Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.
- The free-body diagram of an object or system shows each of the forces exerted on the object or system by the environment.
- Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as
  a dot. A system is treated as though all of its mass is located at the center of mass.
- A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free-body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.3 Newton's Third Law
Knowledge:

- Newton’s third law describes the interaction of two objects or systems in terms of the paired forces that each exerts on the other. Interactions between objects within a system (internal forces) do not influence the motion of a system’s center of mass.
- Tension is the macroscopic net result of forces that infinitesimal segments of a string, cable, chain, or similar system exert on each other in response to an external force.
- An ideal string has negligible mass and does not stretch when under tension.
- The tension in an ideal string is the same at all points within the string.
- In a string with nonnegligible mass, tension may not be the same at all points within the string.
- An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.4 Newton's First Law

Knowledge:

- The net force on a system is the vector sum of all forces exerted on the system.
- Translational equilibrium is the configuration of forces such that the net force exerted on a system is zero.
- Newton’s first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.
- Forces may be balanced in one dimension but unbalanced in another. The system’s velocity will change only in the direction of the unbalanced force.
- An inertial reference frame is one from which an observer would verify Newton’s first law of motion.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.5 Newton's Second Law

Knowledge:

- Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.
- Newton’s second law of motion states that the acceleration of a system’s center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force.
- The velocity of a system’s center of mass will only change if a nonzero net external force is exerted on that system.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.6 Gravitational Force

Knowledge:

- Newton's law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems' centers of mass.
- The gravitational force is attractive.
- The gravitational force is always exerted along the line connecting the center of mass of the two interacting systems.
- The gravitational force on a system can be considered to be exerted on the system's center of mass.
- A field models the effects of a noncontact force exerted on an object at various positions in space.
- The magnitude of the gravitational field created by a system of mass M at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass m to the mass of the test object.
- If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s^2) is numerically equal to the magnitude of the gravitational field strength (in N/kg) at that location.
- The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight.
- If the gravitational force between two systems' centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems.
- Near the surface of Earth, the strength of the gravitational field is $g \approx 10$ N/kg.
- The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.
- If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.
- A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.
- The equivalence principle states that an observer in a noninertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field.
- Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object.
- Gravitational mass is related to the force of attraction between two systems with mass.
- Inertial mass and gravitational mass have been experimentally verified to be equivalent.
- The net gravitational force exerted on an object by a uniform spherical distribution of mass is the sum of the individual forces from small differential masses that comprise the distribution.
- Newton's shell theorem describes the net gravitational force exerted on an object by a uniform spherical shell of mass.
- The net gravitational force exerted on an object inside a thin spherical shell is zero.
- The net gravitational force exerted on an object outside a thin spherical shell can be determined by treating the shell as a single massive object located at the center of the shell.
- An object inside a sphere of uniform density experiences a net gravitational force from only a partial mass of the sphere.
- The partial mass of a sphere that contributes to the net gravitational force exerted on an object within that sphere is the portion of the sphere's mass located a distance less than or equal to the object's distance from the center of the sphere and can be calculated using the density of the sphere.
- The gravitational force exerted on an object within a uniform sphere can be shown to be proportional to the object's distance from the sphere's center.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 2.7 Kinetic and Static Friction

Knowledge:

- Kinetic friction occurs when two surfaces in contact move relative to each other.
- The kinetic friction force is exerted in a direction opposite the motion of each surface relative to the other surface.
- The force of friction between two surfaces does not depend on the size of the surface area of contact.
- The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction.
- The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact.
- Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.
- Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.
- Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface.
- Slipping and sliding refer to situations in which two surfaces are moving relative to each other.
- There exists a maximum value for which static friction will prevent an object from slipping on a given surface.
- The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical
- mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting
- and following a logical computational pathway.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 2.8 Spring Forces

Knowledge:

- An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length. A nonideal spring either has nonnegligible mass or exerts a force that is not proportional to the change in its length as measured from its relaxed length.
- The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law.
- The force exerted on an object by a spring is always directed towards the equilibrium position of the object–spring system.
- A collection of springs that exert forces on an object may behave as though they were a single spring with an equivalent spring constant k_{eq}.
- The inverse of the equivalent spring constant of a set of springs in series is equal to the sum of the inverses of the individual spring constants.
- The equivalent spring constant of a set of springs arranged in series is smaller than the smallest constituent spring constant.
- The equivalent spring constant of a set of springs arranged in parallel is the sum of the individual spring constants.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.9 Resistive Forces

Knowledge:

- A resistive force is defined as a velocity-dependent force in the opposite direction of an object's velocity, for example: $F_r = -kv$.
- Applying Newton's second law to an object upon which a resistive force is exerted results in a differential equation for velocity.
- Using the method of separation of variables, the velocity can be determined by integrating over the proper limits of integration.
- The acceleration or position of a moving object that is subject to a velocity-dependent force may be determined using initial conditions of the object and methods of calculus, once a function for velocity is determined.
- The position, velocity, and acceleration as functions of time of an object under the influence of a resistive force of the form $F_r = -kv$ are exponential and have asymptotes that are determined by the initial conditions of the object and the forces exerted on the object.

- Terminal velocity is defined as the maximum speed achieved by an object moving under the influence of a constant force and a resistive force that are exerted on the object in opposite directions. The terminal condition is reached when the net force exerted on the object is zero.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 2.10 Circular Motion

Knowledge:

- Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.
- The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object's tangential speed squared to the radius of the circular path.
- Centripetal acceleration is directed toward the center of an object's circular path.
- Centripetal acceleration can result from a single force, more than one force, or components of forces that are exerted on an object in circular motion.
- At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum velocity, the gravitational force is the only force that causes the centripetal acceleration.
- Components of the static friction force and the normal force can contribute to the net force producing centripetal acceleration of an object traveling in a circle on a banked surface.
- A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum.
- Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.
- The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.
- The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.
- The time to complete one full circular path, one full rotation, or a full cycle of oscillatory motion is defined as period, T.
- The rate at which an object is completing revolutions is defined as frequency, f.
- For an object traveling at a constant speed in a circular path, the period is given by the derived equation: $T = 2\pi r / v$.
- For a satellite in circular orbit around a central body, the satellite's centripetal acceleration is caused

only by gravitational attraction.
- The period and radius of the circular orbit are related to the mass of the central body.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Transfer Goals

In Unit 2, students are introduced to the concept of force, which is an interaction between two objects or systems of objects. Within the larger study of dynamics, forces provide the context in which students analyze and come to understand a variety of physical phenomena. This understanding is accomplished by revisiting and building upon the representations presented in Unit 1—specifically, through the introduction of the free-body diagram. Students will further analyze the effect of forces on systems when then encounter Newton's second law in rotational form in Unit 5.

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing