Unit 2 Dynamics

Content Area: **Science**
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Enduring Understandings

- 1.A: The internal structure of a system determines many properties of the system.
- 2.B: A gravitational field is caused by an object with mass.
- 3.C: At the macroscopic level, forces can be categorized as either long-range (action-ata-distance) forces or contact forces.
- 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.
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\mathbf{a} = \mathbf{\Sigma F}/m$.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\mathbf{a} = \mathbf{\Sigma F}/m$.

- Force describes an interaction between two objects.
- At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- Classically, the acceleration of an object interacting with other objects can be predicted by using a = SUM F/m.
- Unbalanced interactions cause an object's motion to change; the change in motion, not the motion itself, is in the direction of the unbalanced force.
- Certain types of forces are considered fundamental.

Essential Questions

Big Idea 1 (Systems)

- How can the properties of internal and gravitational mass be experimentally verified to be the same?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?

Big Idea 2 (Fields)

- How do objects with mass respond when placed in a gravitational field?
- Why is the acceleration due to gravity constant on Earth's surface?

Big Idea 3 (Force Interactions)

- Are different kinds of forces really different?

- How can Newton's laws of motion be used to predict the behavior of objects?

Big Idea 4 (Change)

- Why does the same push change the motion of a shopping cart more than the motion of a car?

- How can the forces acting on an object be represented?
- How can free-body diagrams be utilized in the analysis of physical interactions between objects?
- How can a free-body diagram be used to create a mathematical representation of the forces acting on an object?
- How do Newton's laws apply to interactions between objects at rest and in motion?
- How do Newton's laws apply to systems of two or more objects?
- How can you utilize Newton's laws of motion to predict the behavior of objects?
- Do action-reaction force pairs (Newton's third law) have a cause-and-effect relationship? Why or why not
- Why can't an object exert a force on itself?

Content

2.1 Systems

1.A.1: A system is an object or a collection of objects. Objects are treated as having no internal structure.

- a. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.
- b. Some elementary particles are fundamental particles, (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.
- c. The electric charges on neutrons and protons result from their quark compositions.

1.A.5: Systems have properties that are determined by the properties and interactions of their constituent atomic and molecular substructures. In AP 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.

2.2 The Gravitational Field

2.B.1: A gravitational field $\boldsymbol{g}$ 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.

- a. On Earth, this gravitational force is called weight.

- b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
- c. If the gravitational force is the only force exerted on the object, the observed freefall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.

Relevant Equation:

$\mathbf{g} = \mathbf{F}_g/m$

2.3 Contact Forces

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, spring (Physics 1), and buoyant (Physics 2).

Relevant Equations:

$F_f \leq \mu(F_n)$

$F_s = kx$

2.4 Newton's First Law

1.C.1: Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems.

- a. $\mathbf{a} = \Sigma\mathbf{F}/m$

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.

2.5 Newton's Third Law and Free-Body Diagrams

3.A.2: Forces are described by vectors.

- a. Forces are detected by their influence on the motion of an object.
- b. Forces have magnitude and direction.

3.A.3: A force exerted on an object is always due to the interaction of that object with another object.

- a. An object cannot exert a force on itself.
- b. Even though an object is at rest, there may be forces exerted on that object by other objects.
- c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

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.

2.6 Newton's Second Law

3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.

Relevant Equation:

$\mathbf{a} = \Sigma\mathbf{F}/m = \mathbf{F_{net}}/m$

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.

- a. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified.
- b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
- c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.
- d. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.

2.7 Applications of Newton's Second Law

4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables x, v, and a all refer to the center-of-mass quantities.

Relevant Equations:

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0}t + 1/2at^2$

$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$

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.

- a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.
- b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.
- c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.
- d. The variables x, v, and a all refer to the center-of-mass quantities.

Relevant Equations:

$\mathbf{a} = \Sigma\mathbf{F}/m_{system}$

$\mathbf{v_{avg}} = \mathbf{\Delta x}/\Delta t$

$\mathbf{a_{avg}} = \mathbf{\Delta v}/\Delta t$

4.A.3: Forces that the 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.

Relevant Equation:

$\mathbf{a} = \Sigma\mathbf{F}/m = \mathbf{F}_{net}/m$

Vocabulary

Vocabulary

- Dynamics
- Gravitational Field
- Gravitational Force
- Contact Force
- Long-range Force
- Newton’s First Law
- Net Force or sum of the forces
- Weight
- Spring Force
- Hookean
- Hooke's Law
- Spring constant
- Tension
- Atomic Model
- Macroscopic
- Microscopic
- Phenomenon
- Normal Force
- Friction (static/kinetic/rolling)
- Drag
- Drag Coefficient
- Coefficient of static friction
- Coefficient of kinetic friction
- Terminal Speed
- Thrust
- inertia
- inertial reference frame
- non-inertial reference frame
- Newton’s Second Law
- Newton
- Free-Body Diagram (FBD) or Force Diagram
- Newton’s Third Law
- Interaction
- Action/Reaction Pair
- Static Equilibrium
- Dynamic Equilibrium
- Mass

- Apparent weight
- Weightlessness
- Interacting objects: ropes and pulleys

Skills

Science Practices:

- 1.1: The student can create representations and models of natural or man-made phenomena and systems in the domain.
- 7.1: The student can connect phenomena and models across spatial and temporal scales.
- 2.2: The student can apply mathematical routines to quantities that describe natural phenomena.
- 7.2: The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
- 6.1: The student can justify claims with evidence.
- 6.2: The student can construct explanations of phenomena based on evidence produced through scientific practices.
- 4.2: The student can design a plan for collecting data to answer a particular scientific question.
- 1.4: The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- 6.4: The student can make claims and predictions about natural phenomena based on scientific theories and models.
- 1.5: The student can re-express key elements of natural phenomena across multiple representations in the domain.
- 5.1: The student can analyze data to identify patterns or relationships.
- 1.2: The student can describe representations and models of natural or man-made phenomena and systems in the domain.
- 2.3: The student can estimate quantities that describe natural phenomena.
- 5.3: The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

- Learning Objective (1.A.5.1): The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed.
- Learning Objective (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- Learning Objective (1.C.3.1): The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass, and to distinguish between the two experiments.
- Learning Objective (2.B.1.1): The student is able to apply $\mathbf{F} = m\mathbf{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.
- Learning Objective (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.

- Learning Objective (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.
- Learning Objective (3.A.3.2): The student is able to challenge a claim that an object can exert a force on itself.
- Learning Objective (3.A.3.3): The student is able to describe a force as an interaction between two objects and identify both objects for any force.
- Learning Objective (3.A.4.1): The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces.
- Learning Objective (3.A.4.2): The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact.
- Learning Objective (3.A.4.3): The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces.
- Learning Objective (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.
- Learning Objective (3.B.1.2): The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.
- Learning Objective (3.B.1.3): The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object.
- Learning Objective (3.B.2.1): The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
- Learning Objective (3.C.1.1): The student is able to use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion.
- Learning Objective (3.C.4.1): The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces.
- Learning Objective (3.C.4.2): The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.
- Learning Objective (3.G.1.1): The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.
- Learning Objective (4.A.2.2): The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified.
- Learning Objective (4.A.3.1): The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.
- Learning Objective (4.A.3.2): The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system.

Standards

AP Physics 1 (2021 - 2022)

AP: AP

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

- Enduring Understanding 1.A: The internal structure of a system determines many properties of the system.
    - Learning Objective (1.A.5.1): The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed. [See Science Practices 1.1 and 7.1]

- 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.
    - Learning Objective (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. [See Science Practice 4.2]
    - Learning Objective (1.C.3.1): The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass, and to distinguish between the two experiments. [See Science Practice 4.2]

Big Idea 2: Fields existing in space can be used to explain interactions.

- Enduring Understanding 2.B: A gravitational field is caused by an object with mass.
    - Learning Objective (2.B.1.1): The student is able to apply $\mathbf{F} = m\mathbf{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [See Science Practices 2.2 and 7.2]

Big Idea 3: The interactions of an object with other objects can be described by forces.

- Enduring Understanding 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
    - Learning Objective (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]
    - Learning Objective (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [See Science Practices 6.4 and 7.2]
    - Learning Objective (3.A.3.2): The student is able to challenge a claim that an object can exert a force on itself. [See Science Practice 6.1]
    - Learning Objective (3.A.3.3): The student is able to describe a force as an interaction between two objects and identify both objects for any force. [See Science Practice 1.4]
    - Learning Objective (3.A.4.1): The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [See Science Practices 1.4 and 6.2]
    - Learning Objective (3.A.4.2): The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [See Science Practices 6.4 and 7.2]
    - Learning Objective (3.A.4.3): The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's

third law to identify forces. [See Science Practice 1.4]

- Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using **a** =**ΣF**/m.
    - Learning Objective (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. [See Science Practices 6.4 and 7.2]
    - Learning Objective (3.B.1.2): The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [See Science Practices 4.2 and 5.1]
    - Learning Objective (3.B.1.3): The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5 and 2.2]
    - Learning Objective (3.B.2.1): The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, and 2.2]

- Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
    - Learning Objective (3.C.4.1): The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces . [See Science Practice 6.1]
    - Learning Objective (3.C.4.2): The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [See Science Practice 6.2]

Big Idea 4: Interactions between systems can result in changes in those systems.

- 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** = **ΣF**/m.
    - Learning Objective (4.A.1.1): The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [See Science Practices 1.2, 1.4, 2.3, and 6.4]
    - Learning Objective (4.A.2.2): The student is able to evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. [See Science Practice 5.3]
    - Learning Objective (4.A.3.1): The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [See Science Practice 2.2]
    - Learning Objective (4.A.3.2): The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [See Science Practice 1.4]

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.

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.

Learning Objective (3.C.1.1): The student is able to use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion. [See Science Practice 2.2]

Enduring Understanding 3.G: Certain types of forces are considered fundamental.
Learning Objective (3.G.1.1): The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [See Science Practice 7.1]

Resources