AP PHYSICS 1

UNIT 2

Force and Translational Dynamics

18–23%
AP EXAM WEIGHTING

~22–27
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Progress Check 2

Multiple-choice: ~30 questions
Free-response: 4 questions

- Mathematical Routines
- Translation Between Representations
- Experimental Design and Analysis
- Qualitative/Quantitative Translation

UNIT 2

18–23% AP EXAM WEIGHTING | **~22–27** CLASS PERIODS

Force and Translational Dynamics

ESSENTIAL QUESTIONS

- Why do we feel pulled toward Earth but not toward a pencil?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?
- Why is it difficult to walk on ice?
- Why will a delivery truck filled with birds sitting on its floor be the same weight as a truck with the same birds flying around inside?

Developing Understanding

In Unit 2, students are introduced to the concept of force, which is an interaction between two objects or systems of objects. Part of 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 models and 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 they encounter Newton's second law in rotational form in Unit 5.

Building the Science Practices

2.A 2.D 3.B 3.C

Translation between models and representations is key in this unit. Students will continue to use models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside gaining proficiency in the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles (**2.A**) to help them make predictions using functional dependence between variables (**2.D**). The skills of making claims (**3.B**) and supporting those claims using evidence (**3.C**) can be developed throughout the unit by providing students with opportunities such as having them make predictions about the acceleration of a system based on the forces exerted on that system, and then justifying those predictions with appropriate physics principles.

Preparing for the AP Exam

The AP Physics 1 Exam requires students to re-express key elements of physical phenomena across multiple representations in the domain. This skill appears in the fourth question of the free-response section, the Qualitative/Quantitative Translation (QQT) question. In this question, students demonstrate translation between words and mathematics by describing and analyzing a scenario. Using content from any unit, the QQT first requires students to make a claim and provide evidence and reasoning to support their claim without reference to equations. Students are then asked to derive an equation or set of equations to mathematically represent the scenario. Lastly, students are required to make a connection between the claim made in the first part of the question and the equation(s) derived in the second part. Students exposed primarily to numerical problem solving often struggle with the QQT because it requires them to express a conceptual understanding of course content and representations. Opportunities to translate between different representations, including equations, diagrams, graphs, and verbal descriptions, can help students prepare for the QQT question.

UNIT AT A GLANCE

Topic	Suggested Skills
2.1 Systems and Center of Mass	**1.B** Create quantitative graphs with appropriate scales and units, including plotting data. **2.B** Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. **2.C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
2.2 Forces and Free-Body Diagrams	**1.A** Create diagrams, tables, charts, or schematics to represent physical situations. **2.B** Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. **2.C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
2.3 Newton's Third Law	**1.A** Create diagrams, tables, charts, or schematics to represent physical situations. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
2.4 Newton's First Law	**1.C** Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

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UNIT AT A GLANCE *(cont'd)*

Topic	Suggested Skills
2.5 Newton's Second Law	**1.A** Create diagrams, tables, charts, or schematics to represent physical situations. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
2.6 Gravitational Force	**1.A** Create diagrams, tables, charts, or schematics to represent physical situations. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
2.7 Kinetic and Static Friction	**1.C** Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system. **2.B** Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway. **2.C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

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UNIT AT A GLANCE *(cont'd)*

Topic	Suggested Skills
2.8 Spring Forces	**1.B** Create quantitative graphs with appropriate scales and units, including plotting data. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. **3.A** Create experimental procedures that are appropriate for a given scientific question. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
2.9 Circular Motion	**1.B** Create quantitative graphs with appropriate scales and units, including plotting data. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.A** Create experimental procedures that are appropriate for a given scientific question. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Go to **AP Classroom** to assign the **Progress Check** for Unit 2.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches in the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 153 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.2	**Changing Representations** Have students consider an accelerating two-object system from everyday life (e.g., person pushes a shopping cart, car pulls a trailer). Have them draw the forces on one object, then on the other, and then the external forces exerted on the two-object system.
2	2.5	**Working Backward** Put students in pairs. Have student A write a Newton's second law equation either with symbols or plugged-in numbers including units. Then, have student B describe a situation that the equation applies to, including the object's velocity direction and how velocity is changing, a diagram, and a free-body diagram.
3	2.5	**What, If Anything, Is Wrong?** Have students identify some force-related problem from their homework or textbook (that requires setting up Newton's second law and maybe more). Ask students to write out a detailed solution that has exactly one mistake in it (not a calculation error). Post everyone's problems/solutions, and then ask students to identify everyone else's errors. The last student to have their error found wins.
4	2.7	**Desktop Experiment Task** Have students measure the coefficient of static friction of their shoe on a wood plank or metal track. Level 1: Use a spring scale. Level 2: Use a pulley, a spring, a toy bucket, and an electronic balance. Level 3: Use a protractor.
5	2.6/2.9	**Desktop Experiment Task** Have students use the "My Solar System" PhET applet to create circular orbits of varying radii around the central star and record radius, period, and planet mass for various trials. Next, have them calculate the speed using $v = 2\pi r/T$ and force using $F = mv^2/r$. Using the data, have students show that gravitational force is directly proportional to the mass of each object and inversely proportional to the square of the radius.
6	2.9	**Construct an Argument** Ask students to consider two identical objects moving in circles (or parts of circles) of different radii. Then, ask them to think of a situation where the object with the smaller radius has a greater net force and another situation where the object with the larger radius has a greater net force.
7	2.9	**Changing Representations** Describe something a driver could be doing in a car (e.g., "turning the steering wheel to the right while pressing the brake"). Have students walk out the motion while holding out one arm representing the velocity vector and the other arm representing the acceleration vector.
8	2.9	**Predict and Explain** Attach an object of known weight (say, 2 N) to a force sensor and cause the object to swing in a 180-degree arc. Ask students, "At the bottom, the object is neither speeding up nor slowing down, so what force is registered at the bottom?" Expect students to (incorrectly) answer, "2 N" and discuss, as a class, why this answer is incorrect.

SUGGESTED SKILLS

1.B
Create quantitative graphs with appropriate scales and units, including plotting data.

2.B
Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

2.C
Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.

3.B
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

TOPIC 2.1
Systems and Center of Mass

Required Course Content

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.1.A Describe the properties and interactions of a system.	**2.1.A.1** System properties are determined by the interactions between objects within the system. **2.1.A.2** 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. **2.1.A.3** Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass. **2.1.A.4** Individual objects within a chosen system may behave differently from each other as well as from the system as a whole. **2.1.A.5** The internal structure of a system affects the analysis of that system. **2.1.A.6** As variables external to a system are changed, the system's substructure may change.

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LEARNING OBJECTIVE

2.1.B

Describe the location of a system's center of mass with respect to the system's constituent parts.

ESSENTIAL KNOWLEDGE

2.1.B.1

For systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.

2.1.B.2

The location of a system's center of mass along a given axis can be calculated using the equation

$$\vec{x}_{cm} = \frac{\sum m_i \vec{x}_i}{\sum m_i}$$

2.1.B.3

A system can be modeled as a singular object that is located at the system's center of mass.

BOUNDARY STATEMENT

AP Physics 1 only expects students to calculate the center of mass for systems of five or fewer particles arranged in a two-dimensional configuration or for systems that are highly symmetrical.

SUGGESTED SKILLS

1.A
Create diagrams, tables, charts, or schematics to represent physical situations.

2.B
Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

2.C
Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

TOPIC 2.2

Forces and Free-Body Diagrams

Required Course Content

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.2.A Describe a force as an interaction between two objects or systems.	**2.2.A.1** Forces are vector quantities that describe the interactions between objects or systems. **2.2.A.1.i** A force exerted on an object or system is always due to the interaction of that object with another object or system. **2.2.A.1.ii** An object or system cannot exert a net force on itself. **2.2.A.2** Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.
2.2.B Describe the forces exerted on an object or system using a free-body diagram.	**2.2.B.1** 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. **2.2.B.2** The free-body diagram of an object or system shows each of the forces exerted on the object by the environment. **2.2.B.3** 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.

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LEARNING OBJECTIVE

2.2.B

Describe the forces exerted on an object using a free-body diagram.

ESSENTIAL KNOWLEDGE

2.2.B.4

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.

BOUNDARY STATEMENT

AP Physics 1 only expects students to depict the forces exerted on objects, not the force components on free-body diagrams. On the AP Physics exams, individual forces represented on a free-body diagram must be drawn as individual straight arrows, originating on the dot and pointing in the direction of the force. Individual forces that are in the same direction must be drawn side by side, not overlapping.

SUGGESTED SKILLS

1.A
Create diagrams, tables, charts, or schematics to represent physical situations.

2.D
Predict new values or factors of change of physical quantities using functional dependence between variables.

3.B
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

TOPIC 2.3
Newton's Third Law

Required Course Content

LEARNING OBJECTIVE

2.3.A

Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object.

ESSENTIAL KNOWLEDGE

2.3.A.1

Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other.

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$

2.3.A.2

Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.

2.3.A.3

Tension is the macroscopic net result of forces that segments of a string, cable, chain, or similar system exert on each other in response to an external force.

2.3.A.3.i

An ideal string has negligible mass and does not stretch when under tension.

2.3.A.3.ii

The tension in an ideal string is the same at all points within the string.

2.3.A.3.iii

In a string with nonnegligible mass, tension may not be the same at all points within the string.

2.3.A.3.iv

An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.

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LEARNING OBJECTIVE

2.3.A

Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object.

ESSENTIAL KNOWLEDGE

BOUNDARY STATEMENT

AP Physics 1 only expects students to describe tension qualitatively in a string, cable, chain, or similar system with mass. For example, students might note that the tension in a hanging chain is greater toward the top of the chain.

BOUNDARY STATEMENT

The interaction between objects or systems at a distance is limited to gravitational forces in AP Physics 1. In AP Physics 2, gravitational, electric, and magnetic forces may be considered.

SUGGESTED SKILLS

1.C
Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.

2.A
Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

3.B
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

TOPIC 2.4
Newton's First Law

Required Course Content

LEARNING OBJECTIVE

2.4.A
Describe the conditions under which a system's velocity remains constant.

ESSENTIAL KNOWLEDGE

2.4.A.1
The net force on a system is the vector sum of all forces exerted on the system.

2.4.A.2
Translational equilibrium is a configuration of forces such that the net force exerted on a system is zero.

Derived equation:

$$\sum_i \vec{F}_i = 0$$

2.4.A.3
Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.

2.4.A.4
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.

2.4.A.5
An inertial reference frame is one from which an observer would verify Newton's first law of motion.

TOPIC 2.5

Newton's Second Law

Required Course Content

LEARNING OBJECTIVE

2.5.A

Describe the conditions under which a system's velocity changes.

ESSENTIAL KNOWLEDGE

2.5.A.1

Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.

2.5.A.2

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.

Relevant equation:

$$\vec{a}_{sys} = \frac{\sum \vec{F}}{m_{sys}} = \frac{\vec{F}_{net}}{m_{sys}}$$

2.5.A.3

The velocity of a system's center of mass will only change if a nonzero net external force is exerted on that system.

SUGGESTED SKILLS

1.A Create diagrams, tables, charts, or schematics to represent physical situations.

2.A Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

2.D Predict new values or factors of change of physical quantities using functional dependence between variables.

3.B Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

SUGGESTED SKILLS

1.A
Create diagrams, tables, charts, or schematics to represent physical situations.

2.A
Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

2.D
Predict new values or factors of change of physical quantities using functional dependence between variables.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

TOPIC 2.6
Gravitational Force

Required Course Content

LEARNING OBJECTIVE

2.6.A
Describe the gravitational interaction between two objects or systems with mass.

ESSENTIAL KNOWLEDGE

2.6.A.1
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.

Relevant equation:

$$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$$

2.6.A.1.i
The gravitational force is attractive.

2.6.A.1.ii
The gravitational force is always exerted along the line connecting the centers of mass of the two interacting systems.

2.6.A.1.iii
The gravitational force on a system can be considered to be exerted on the system's center of mass.

2.6.A.2
A field models the effects of a noncontact force exerted on an object at various positions in space.

2.6.A.2.i
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.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.6.A Describe the gravitational interaction between two objects with mass.	*Derived equation:* $\lvert\vec{g}\rvert = \frac{\lvert\vec{F}_g\rvert}{m} = G\frac{M}{r^2}$ **2.6.A.2.ii** If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s²) is numerically equal to the magnitude of the gravitational field strength (in N/kg) at that location. **2.6.A.3** The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight. *Derived Equation:* $\text{Weight} = F_g = mg$
2.6.B Describe situations in which the gravitational force can be considered constant.	**2.6.B.1** 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. **2.6.B.2** Near the surface of Earth, the strength of the gravitational field is $g \approx 10\ \text{N/kg}$
2.6.C 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.	**2.6.C.1** The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system. **2.6.C.2** 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. **2.6.C.3** 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. **2.6.C.4** 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.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.6.D Describe inertial and gravitational mass.	**2.6.D.1** Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object. **2.6.D.2** Gravitational mass is related to the force of attraction between two systems with mass. **2.6.D.3** Inertial mass and gravitational mass have been experimentally verified to be equivalent.

TOPIC 2.7

Kinetic and Static Friction

Required Course Content

LEARNING OBJECTIVE

2.7.A

Describe kinetic friction between two surfaces

ESSENTIAL KNOWLEDGE

2.7.A.1

Kinetic friction occurs when two surfaces in contact move relative to each other.

2.7.A.1.i

The kinetic friction force is exerted in a direction opposite to the motion of each surface relative to the other surface.

2.7.A.1.ii

The force of friction between two surfaces does not depend on the size of the surface area of contact.

2.7.A.2

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.

Relevant equation:

$$\left|\vec{F}_{f,k}\right| = \left|\mu_k \vec{F}_n\right|$$

2.7.A.2.i

The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact.

2.7.A.2.ii

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.

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SUGGESTED SKILLS

1.C Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.

2.B Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

2.C Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.

3.B Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.7.B Describe static friction between two surfaces.	**2.7.B.1** Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.
	2.7.B.2 Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface. *Relevant equation:* $\left\|\vec{F}_{f,s}\right\| \le \left\|\mu_s \vec{F}_n\right\|$
	2.7.B.2.i Slipping and sliding refer to situations in which two surfaces are moving relative to each other.
	2.7.B.2.ii There exists a maximum value for which static friction will prevent an object from slipping on a given surface. *Derived equation:* $F_{f,s,\max} = \mu_s F_n$
	2.7.B.3 The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.

TOPIC 2.8
Spring Forces

Required Course Content

LEARNING OBJECTIVE

2.8.A

Describe the force exerted on an object by an ideal spring

ESSENTIAL KNOWLEDGE

2.8.A.1

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.

2.8.A.2

The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law:

$$\vec{F}_s = -k\Delta\vec{x}$$

2.8.A.3

The force exerted on an object by a spring is always directed toward the equilibrium position of the object–spring system.

SUGGESTED SKILLS

1.B Create quantitative graphs with appropriate scales and units, including plotting data.

2.A Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

2.C Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.

3.A Create experimental procedures that are appropriate for a given scientific question.

3.B Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

SUGGESTED SKILLS

1.B
Create quantitative graphs with appropriate scales and units, including plotting data.

2.A
Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

2.D
Predict new values or factors of change of physical quantities using functional dependence between variables.

3.A
Create experimental procedures that are appropriate for a given scientific question.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

TOPIC 2.9

Circular Motion

Required Course Content

LEARNING OBJECTIVE

2.9.A
Describe the motion of an object traveling in a circular path.

ESSENTIAL KNOWLEDGE

2.9.A.1
Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.

2.9.A.1.i
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.

Relevant equation:

$$a_c = \frac{v^2}{r}$$

2.9.A.1.ii
Centripetal acceleration is directed toward the center of an object's circular path.

2.9.A.2
Centripetal acceleration can result from a single force, more than one force, or components of forces exerted on an object in circular motion.

2.9.A.2.i
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 speed, the gravitational force is the only force that causes the centripetal acceleration.

Derived equation:

$$v = \sqrt{gr}$$

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LEARNING OBJECTIVE

2.9.A

Describe the motion of an object traveling in a circular path.

ESSENTIAL KNOWLEDGE

2.9.A.2.ii

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.

2.9.A.2.iii

A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum.

2.9.A.3

Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.

2.9.A.4

The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.

2.9.A.5

The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.

2.9.A.5.i

The time to complete one full circular path, one full rotation, or a full cycle of oscillatory motion is defined as period, T.

2.9.A.5.ii

The rate at which an object is completing revolutions is defined as frequency, f.

Relevant equation:

$$T = \frac{1}{f}$$

2.9.A.5.iii

For an object traveling at a constant speed in a circular path, the period is given by the derived equation

$$T = \frac{2\pi r}{v}.$$

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LEARNING OBJECTIVE

2.9.B

Describe circular orbits using Kepler's third law.

ESSENTIAL KNOWLEDGE

2.9.B.1

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.

Derived equation:

$$T^2 = \frac{4\pi^2}{GM}R^3$$

BOUNDARY STATEMENT

AP Physics 1 only expects students to quantitatively analyze banked curves in which no friction is required to maintain uniform circular motion. Analysis of situations in which friction is required on a banked curve is limited to qualitative descriptions.

BOUNDARY STATEMENT

AP Physics 1 does not expect students to know Kepler's first or second laws of planetary motion.