AP PHYSICS 1

UNIT 2

Dynamics

12–18%
AP EXAM WEIGHTING

~19–22
CLASS PERIODS

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

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

Personal Progress Check 2

Multiple-choice: ~40 questions
Free-response: 2 questions

- Quantitative/Qualitative Translation
- Short Answer

UNIT 2

12–18% AP EXAM WEIGHTING | **~19–22** CLASS PERIODS

Dynamics

BIG IDEA 1
***Systems* SYS**
- 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* FLD**
- 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* INT**
- 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* CHA**
- Why does the same push change the motion of a shopping cart more than the motion of a car?

Unit Overview

In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change.

Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.

Preparing for the AP Exam

The AP Physics 1 Exam requires students to be able to re-express key elements of natural phenomena across multiple representations in the domain. This skill appears in the Qualitative/Quantitative Translation (QQT), a long free-response question that requires students to go between words and mathematics in describing and analyzing a situation. A QQT question might ask students to work with multiple representations or to evaluate another student's words or representations. Representations include mathematical equations, narrative descriptions, graphs, diagrams, and data tables.

Students who have primarily been exposed to numerical problem solving often struggle with a QQT question because it requires students to have a more conceptual understanding of both content and representations. Opportunities to translate between different representations, including equations, diagrams, graphs, and written descriptions, will help students prepare for the QQT question.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~19–22 CLASS PERIODS
1.A	2.1 Systems	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.B	2.2 The Gravitational Field	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.	
3.C	2.3 Contact Forces	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.*	
1.C	2.4 Newton's First Law	4.2 The student can design a plan for collecting data to answer a particular scientific question.	
3.A	2.5 Newton's Third Law and Free-Body Diagrams	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 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. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 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.	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~19–22 CLASS PERIODS
3.B	2.6 Newton's Second Law	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question.* 5.1 The student can analyze data to identify patterns or relationships. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 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.	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~19–22 CLASS PERIODS
4.A	2.7 Applications of Newton's Second Law	1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain.* 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 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. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.	

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

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

AVAILABLE RESOURCES FOR UNIT 2:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Multiple Representations of Knowledge: Mechanics and Energy**
- Classroom Resources > **Physics Instruction Using Video Analysis Technology**
- Classroom Resources > **Teaching Strategies for Limited Class Time**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches 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. 173 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.1	**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 acting on the two-object system.
2	2.4	**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.
3	2.5	**Desktop Experiment Task** Give students a yo-yo, a low mass, low friction pulley, 50 paper clips, and a scale. Have them find the acceleration of the falling, unrolling yo-yo and then determine the mass of the paper clips to attach to the free end of the string so that the paper clips stay at rest even as the yo-yo falls and the string passes over the pulley.
4	2.6	**Working Backward** Student A writes a Newton's second law equation either with symbols or plugged-in numbers including units. Student B must then 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.
5	2.7	**Troubleshooting** Students take some force-related problem from the homework or textbook (one that requires setting up Newton's second law and maybe more). Students 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 his or her error found wins.

Unit Planning Notes

Use the space below to plan your approach to the unit.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

Making Connections

7.1

The student can connect phenomena and models across spatial and temporal scales.

TOPIC 2.1
Systems

Required Course Content

ENDURING UNDERSTANDING

1.A

The internal structure of a system determines many properties of the system.

LEARNING OBJECTIVE

[While there is no specific learning objective for it, EK 1.A.1 serves as a foundation for other learning objectives in the course.]

ESSENTIAL KNOWLEDGE

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.5.1

Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed. **[SP 1.1, 7.1]**

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.

TOPIC 2.2

The Gravitational Field

Required Course Content

ENDURING UNDERSTANDING

2.B

A gravitational field is caused by an object with mass.

LEARNING OBJECTIVE

2.B.1.1

Apply $\vec{F} = m\vec{g}$ 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. **[SP 2.2, 7.2]**

ESSENTIAL KNOWLEDGE

2.B.1

A gravitational field $\vec{g}$ 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 free-fall 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:

$$\vec{g} = \frac{\vec{F}_g}{m}$$

SCIENCE PRACTICES

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Making Connections

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.

SCIENCE PRACTICES

Argumentation

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.

TOPIC 2.3

Contact Forces

Required Course Content

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

Make claims about various contact forces between objects based on the microscopic cause of these forces. **[SP 6.1]**

3.C.4.2

Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. **[SP 6.2]**

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

Relevant Equations:

$$\left|\vec{F}_f\right| \leq \mu\left|\vec{F}_n\right|$$

$$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$$

TOPIC 2.4

Newton's First Law

SCIENCE PRACTICE

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Required Course Content

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

Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

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. $\vec{a} = \frac{\sum \vec{F}}{m}$

LEARNING OBJECTIVE

1.C.3.1

Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. **[SP 4.2]**

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.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Argumentation

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.

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

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.

TOPIC 2.5

Newton's Third Law and Free-Body Diagrams

Required Course Content

ENDURING UNDERSTANDING

3.A

All forces share certain common characteristics when considered by observers in inertial reference frames.

LEARNING OBJECTIVE

3.A.2.1

Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1]**

ESSENTIAL KNOWLEDGE

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.

LEARNING OBJECTIVE

3.A.3.1

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. **[SP 6.4, 7.2]**

3.A.3.2

Challenge a claim that an object can exert a force on itself. **[SP 6.1]**

3.A.3.3

Describe a force as an interaction between two objects, and identify both objects for any force. **[SP 1.4]**

ESSENTIAL KNOWLEDGE

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.

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LEARNING OBJECTIVE

3.A.4.1

Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. **[SP 1.4, 6.2]**

3.A.4.2

Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6.4, 7.2]**

3.A.4.3

Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 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.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

1.5

The student can re-express key elements of natural phenomena across multiple representations in the domain.

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

TOPIC 2.6

Newton's Second Law

Required Course Content

ENDURING UNDERSTANDING

3.B

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

3.B.1.1

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. **[SP 6.4, 7.2]**

3.B.1.2

Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. **[SP 4.2, 5.1]**

3.B.1.3

Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. **[SP 1.5, 2.2]**

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. Projectile motion and circular motion are both included in AP Physics 1.

Relevant Equation:

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

BOUNDARY STATEMENT:

AP Physics 2 contains learning objectives for Enduring Understanding 3.B that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

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LEARNING OBJECTIVE

3.B.2.1

Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. **[SP 1.1, 1.4, 2.2]**

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.

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.

SCIENCE PRACTICES *(CONT'D)*

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

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.

SCIENCE PRACTICES

Modeling

1.2
The student can describe representations and models of natural or man-made phenomena and systems in the domain.

1.4
The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.2
The student can apply mathematical routines to quantities that describe natural phenomena.

2.3
The student can estimate quantities that describe natural phenomena.

Data Analysis

5.3
The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Argumentation

6.4
The student can make claims and predictions about natural phenomena based on scientific theories and models.

TOPIC 2.7
Applications of Newton's Second Law

Required Course Content

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 $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

4.A.1.1
Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.
[SP 1.2, 1.4, 2.3, 6.4]

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. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$$

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

LEARNING OBJECTIVE

4.A.2.2
Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified.
[SP 5.3]

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.

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.

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LEARNING OBJECTIVE

4.A.2.2

Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. **[SP 5.3]**

ESSENTIAL KNOWLEDGE

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:

$$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$$

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

4.A.3.1

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. **[SP 2.2]**

4.A.3.2

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. **[SP 1.4]**

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:

$$\vec{a} = \frac{\Sigma \vec{F}}{m_{system}} = \frac{\vec{F}_{net}}{m}$$