AP PHYSICS 1

UNIT 3

Work, Energy, and Power

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 3

Multiple-choice: ~18 questions

Free-response: 4 questions

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

UNIT 3 | **18–23%** AP EXAM WEIGHTING | **~22–27** CLASS PERIODS

Work, Energy, and Power

Developing Understanding

In Unit 3, students are introduced to the idea of conservation as a foundational principle of physics, along with the concept of work as the primary agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of content and skills in Units 1 and 2 to determine the most appropriate technique for approaching a problem and will be challenged to understand the limiting factors of each technique.

ESSENTIAL QUESTIONS

- How much money can you save by charging your cell phone at school instead of at home?
- If energy is conserved, why are we running out of it?
- Does pushing an object always change its energy?
- Why does it seem easier to carry a large box up a ramp rather than up a set of stairs?

Building the Science Practices

1.A 1.C 2.A 3.C

Describing, creating, and using representations (**1.A**, and **1.C**) will help students grapple with common misconceptions that they may have about energy, such as whether a force does work on an object, even though the object doesn't move, or whether a single object can "have" potential energy. A thorough understanding of energy will support students' ability to justify claims with evidence (**3.C**) about physical situations. This understanding is crucial, as the mathematical models and representations (**2.A**) used in Unit 3 will spiral throughout the course and appear in subsequent units. As students' comprehension of energy evolves, students will begin to connect and relate knowledge across scales, concepts, and representations, as well as across disciplines—particularly, physics, chemistry, and biology.

Preparing for the AP Exam

The first free-response question on the AP Physics 1 Exam—the Mathematical Routines (MR) question—focuses on assessing students' ability to create and use mathematical models. Students will be required to calculate or derive an expression for a physical quantity. They will also be required to create and/or use a representation and make and justify claims. The final part of the MR question requires students to demonstrate their ability to communicate their understanding of a physical situation in a reasoned, expository analysis. A student's analysis of the situation should be coherent, organized, and sequential. It should draw from evidence, cite physical principles, and clearly present the student's thinking. While Unit 3 offers content perfect for practicing the MR question, the MR question on the AP Physics 1 Exam can pull content from any of the eight units of the course.

UNIT AT A GLANCE

Topic	Suggested Skills
3.1 Translational Kinetic Energy	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. 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.
3.2 Work	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.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.B Apply an appropriate law, definition, theoretical relationship, or model to make a claim
3.3 Potential Energy	1.C Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system. 2.C Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. 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.
3.4 Conservation of Energy	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.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.

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UNIT AT A GLANCE *(cont'd)*

Topic	Suggested Skills
3.5 Power	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.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 3.
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	3.1	**Concept-Oriented Demonstration** Release a low friction cart (mass m) from the top of a ramp, and have students time how long it takes to reach the bottom, as well as measure the release height h and track length L. Have students calculate the cart's velocity using $v = L/t$, and then calculate mgh and $\frac{1}{2}mv^2$. The two speeds are different; discuss with students what incorrect assumptions lead to the difference in speeds.
2	3.4	**Desktop Experiment Task** Divide students into groups and give each group a spring-loaded ball launcher, scale, and meterstick. Ask students to determine the spring constant of the spring in the launcher.
3	3.2/3.4	**Four-Square Problem Solving** Have students create representations of scenarios related to work and conservation of energy. First square: Provide a description, in words, of an everyday situation (e.g., "a car goes downhill, speeding up even as the brakes are pressed") along with a diagram. Second square: Draw a free-body diagram with an arrow off to the side representing the object's displacement. Third square: Create energy bar charts (initial and final). Fourth square: For each force on the free-body diagram, state whether that force performs positive or negative work and what energy transformation that force is responsible for.
4	3.4	**Construct an Argument** Ask students to consider a cart that rolls from rest down a ramp and then around a vertical loop. Have students explain why it is the case, using energy and circular motion principles, that for the cart to complete the loop without falling out, the cart must be released at a height higher than the top of the loop.
5	3.4	**Working Backward** Put students in pairs. Have student A write a conservation of energy equation (either symbolically or with numbers and units plugged in). Then, have student B describe a situation that the equation could apply to, draw a diagram, and draw energy bar charts.

TOPIC 3.1
Translational Kinetic Energy

Required Course Content

LEARNING OBJECTIVE

3.1.A

Describe the translational kinetic energy of an object in terms of the object's mass and velocity.

ESSENTIAL KNOWLEDGE

3.1.A.1

An object's translational kinetic energy is given by the equation

$$K = \frac{1}{2}mv^2$$

3.1.A.2

Translational kinetic energy is a scalar quantity.

3.1.A.3

Different observers may measure different values of the translational kinetic energy of an object, depending on the observer's frame of reference.

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.

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.

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

TOPIC 3.2
Work

Required Course Content

LEARNING OBJECTIVE

3.2.A
Describe the work done on an object or system by a given force or collection of forces.

ESSENTIAL KNOWLEDGE

3.2.A.1
Work is the amount of energy transferred into or out of a system by a force exerted on that system over a distance.

3.2.A.1.i
The work done by a conservative force exerted on a system is path-independent and only depends on the initial and final configurations of that system.

3.2.A.1.ii
The work done by a conservative force on a system—or the change in the potential energy of the system—will be zero if the system returns to its initial configuration.

3.2.A.1.iii
Potential energies are associated only with conservative forces.

3.2.A.1.iv
The work done by a nonconservative force is path-dependent.

3.2.A.1.v
Examples of nonconservative forces are friction and air resistance.

3.2.A.2
Work is a scalar quantity that may be positive, negative, or zero.

3.2.A.3
The amount of work done on a system by a constant force is related to the components of that force and the displacement of the point at which that force is exerted.

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LEARNING OBJECTIVE

3.2.A

Describe the work done on an object or system by a given force or collection of forces.

ESSENTIAL KNOWLEDGE

3.2.A.3.i

Only the component of the force exerted on a system that is parallel to the displacement of the point of application of the force will change the system's total energy.

Relevant equation:

$$W = F_{\parallel}d = Fd\cos\theta$$

3.2.A.3.ii

The component of the force exerted on a system perpendicular to the direction of the displacement of the system's center of mass can change the direction of the system's motion without changing the system's kinetic energy.

3.2.A.4

The work-energy theorem states that the change in an object's kinetic energy is equal to the sum of the work (net work) being done by all forces exerted on the object.

Relevant equation:

$$\Delta K = \sum_i W_i = \sum_i F_{\parallel,i}d$$

3.2.A.4.i

An external force may change the configuration of a system. The component of the external force parallel to the displacement times the displacement of the point of application of the force gives the change in kinetic energy of the system.

3.2.A.4.ii

If the system's center of mass and the point of application of the force move the same distance when a force is exerted on a system, then the system may be modeled as an object, and only the system's kinetic energy can change.

3.2.A.4.iii

The energy dissipated by friction is typically equated to the force of friction times the length of the path over which the force is exerted

$$\Delta E_{\text{mech}} = F_f d\cos\theta$$

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LEARNING OBJECTIVE

3.2.A

Describe the work done on an object or system by a given force or collection of forces.

ESSENTIAL KNOWLEDGE

3.2.A.5

Work is equal to the area under the curve of a graph of $F_{\parallel}$ as a function of displacement.

BOUNDARY STATEMENT

AP Physics 1 only expects students to analyze the transfer of mechanical energy (as defined in Unit 3, Topic 4: Conservation of Energy), although students should be aware that mechanical energy may be dissipated in the form of thermal energy or sound. In AP Physics 2, students will also study how thermal energy can be transferred between systems through heating or cooling.

TOPIC 3.3

Potential Energy

Required Course Content

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.3.A Describe the potential energy of a system.	**3.3.A.1** A system composed of two or more objects has potential energy if the objects within that system only interact with each other through conservative forces. **3.3.A.2** Potential energy is a scalar quantity associated with the position of objects within a system. **3.3.A.3** The definition of zero potential energy for a given system is a decision made by the observer considering the situation to simplify or otherwise assist in analysis. **3.3.A.4** The potential energy of common physical systems can be described using the physical properties of that system. **3.3.A.4.i** The elastic potential energy of an ideal spring is given by the following equation, where Δx is the distance the spring has been stretched or compressed from its equilibrium length. *Relevant equation:* $U_s = \frac{1}{2}k(\Delta x)^2$

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

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.

LEARNING OBJECTIVE

3.3.A

Describe the potential energy of a system.

ESSENTIAL KNOWLEDGE

3.3.A.4.ii

The general form for the gravitational potential energy of a system consisting of two approximately spherical distributions of mass (e.g., moons, planets or stars) is given by the equation

$$U_g = -G\frac{m_1 m_2}{r}$$

3.3.A.4.iii

Because the gravitational field near the surface of a planet is nearly constant, the change in gravitational potential energy in a system consisting of an object with mass m and a planet with gravitational field of magnitude g when the object is near the surface of the planet may be approximated by the equation

$$\Delta U_g = mg\Delta y.$$

3.3.A.5

The total potential energy of a system containing more than two objects is the sum of the potential energy of each pair of objects within the system.

TOPIC 3.4

Conservation of Energy

Required Course Content

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.4.A Describe the energies present in a system.	**3.4.A.1** A system composed of only a single object can only have kinetic energy. **3.4.A.2** A system that contains objects that interact via conservative forces or that can change its shape reversibly may have both kinetic and potential energies.
3.4.B Describe the behavior of a system using conservation of mechanical energy principles.	**3.4.B.1** Mechanical energy is the sum of a system's kinetic and potential energies. **3.4.B.2** Any change to a type of energy within a system must be balanced by an equivalent change of other types of energies within the system or by a transfer of energy between the system and its surroundings. **3.4.B.3** A system may be selected so that the total energy of that system is constant. **3.4.B.4** If the total energy of a system changes, that change will be equivalent to the energy transferred into or out of the system.

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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.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.

LEARNING OBJECTIVE

3.4.C

Describe how the selection of a system determines whether the energy of that system changes.

ESSENTIAL KNOWLEDGE

3.4.C.1

Energy is conserved in all interactions.

3.4.C.2

If the work done on a selected system is zero and there are no nonconservative interactions within the system, the total mechanical energy of the system is constant.

3.4.C.3

If the work done on a selected system is nonzero, energy is transferred between the system and the environment.

BOUNDARY STATEMENT

AP Physics 1 expects students to know that mechanical energy can be dissipated as thermal energy or sound by nonconservative forces.

TOPIC 3.5

Power

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

Required Course Content

LEARNING OBJECTIVE

3.5.A

Describe the transfer of energy into, out of, or within a system in terms of power.

ESSENTIAL KNOWLEDGE

3.5.A.1

Power is the rate at which energy changes with respect to time, either by transfer into or out of a system or by conversion from one type to another within a system.

3.5.A.2

Average power is the amount of energy being transferred or converted, divided by the time it took for that transfer or conversion to occur.

Relevant equation:

$$P_{\text{avg}} = \frac{\Delta E}{\Delta t}$$

3.5.A.3

Because work is the change in energy of an object or system due to a force, average power is the total work done, divided by the time during which that work was done.

Relevant equation:

$$P_{\text{avg}} = \frac{W}{\Delta t}$$

3.5.A.4

The instantaneous power delivered to an object by the component of a constant force parallel to the object's velocity can be described with the derived equation.

$$P_{\text{inst}} = F_{||} v = Fv \cos \theta.$$