Chief Reader Report on Student Responses:

2017 AP® Physics C-Mechanics Free-Response Questions

- Number of Students Scored 54,862
- Number of Readers 364
- Score Distribution

Exam Score	N	%At
5	19,996	36.4
4	14,880	27.1
3	8,683	15.8
2	6,843	12.5
1	4,460	8.1

- Global Mean 3.71

The following comments on the 2017 free-response questions for AP® Physics C-Mechanics were written by the Chief Reader, Peter Sheldon, Professor of Physics, Randolph College. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question #1 **Topic:** Experimental Newton's second law/Atwood machine

Max. Points: 15 **Mean Score:** 6.29

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- An understanding of forces acting on two objects.
- The ability to use free-body force diagrams.
- The ability to correctly write Newton's second law from a free-body force diagram.
- The ability to manipulate related equations in order to express the relationship between physical quantities associated with two objects.
- An understanding of how to use graphs to express a relationship between quantities.
- The ability to draw graphs, including labelling axes, including units and using an appropriate scale.
- An understanding of the information that can be derived from the slope of the best-fit line.
- An understanding of the effect on the acceleration of an object when the applied forces change.
- The ability to identify and explain possible physical factors that can affect an experimental result.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- The question required the student to draw the free-body force diagrams of two connected objects.
- The question required the student to use the forces on two free-body force diagrams and express them correctly using Newton's second law.
- The question required the algebraic manipulation of the two equations to derive a combined (given) expression of the relationship between physical quantities associated with two objects
- The question required the student to recognize the quantities of interest in the given equation and choose the appropriate quantities to graph.
- The question required the student to make an appropriate graph. This included an appropriate scale, correct labels with units, the ability to plot given data points, and the application of a best-fit line.
- The question required the student to determine an explicit relationship between the slope of the line and the acceleration due to gravity.
- The question required the student to explain the relationship between a change in acceleration and the tension force in the system.
- The question required the student to understand that an additional force will affect the measured acceleration and, therefore, the calculation of the acceleration due to gravity in this case.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Some students were unable to draw appropriate free-body force diagrams.	• Correct free-body force diagrams with appropriate forces and correct relative vector lengths.
• Some students were able to write a generic form of Newton's second law but not use it to describe a system of interest.	• Correctly write out Newton's second law expressions based on the forces from each free-body force diagram and combine them algebraically to derive an equation that was provided.
• Some students were able to write Netwon's second law for the system but not for the individual objects.	• Correctly write Newton's second law expressions for each object that is consistent with each free-body diagram.
• Many students did not demonstrate creating an effective graph. Specifically, many students were unable to choose appropriate quantities to graph and demonstrated an inability to use appropriate labels (with units), a useful scale, correctly plot given data points, and draw a best-fit line.	• Correctly draw an appropriate graph.
• Some students were unable to relate the slope of a line to the calculation of a particular quantity.	• Write out the equation for the slope and indicate its relationship to the acceleration due to gravity.
• Most students did not correlty describe the relationship between forces acting on the objects of a system and the resulting acceleration.	• State that acceleration of the system increases and explain why this results in the tension force decreasing.
• Some students did not correctly identify reasonable forces that would affect the acceleration, or did not correctly explain their effect on the acceleration due to gravity.	• Correctly identify at least one reasonable force and explain specifically how it would alter the experimentally found value for g.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Practice drawing free-body force diagrams.
- Practice writing Newton's second law for multi-body systems: students must recall that free Newton's second law is applied to each free-body diagram, and when applied to a system, that system must be clearly identified.
- Practice drawing graphs by hand, practicing the following skills: correct choice of variables, scale, labels and units, points, and best-fit line.
- Students should recognize information about physical quantities contained in the best-fit line. Practice using and understanding the slope when solving for physical quantities.
- Students should understand the relationships between individual forces on a system, net force, and acceleration. Articulate those relationships correctly and consistently.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics C can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The following curriculum modules will provide additional information on these concepts: 1. Multiple Representations of Knowledge: Mechanics and Energy, 2. Graphical Analysis. The downloadable AP 1 and AP 2 lab manual may be useful for the teachers of the AP Physics C course as well.

The AP Physics Online Teacher Community is very active, and there are many discussions concerning teaching tips, techniques, and activities that AP Physics teachers have found helpful. It is easy to sign up, and you can search topics of discussions from all previous years.

Newer teachers (and career changers) might want to consider signing up for an APSI. An APSI is a great way to gain in-depth teaching knowledge on the AP Physics curriculum and exam, as well as network with colleagues from around the country.

Question #2

Topic: Energy & SHM

Max. Points: 15 **Mean Score:** 5.16

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- An understanding of the relationship between different types of mechanical energy.
- The ability to use energy considerations to calculate relevant quantities.
- An understanding of an object transitioning from linear motion to simple harmonic motion.
- An understanding of an object undergoing simple harmonic motion.
- The ability to use the equations for simple harmonic motion.
- The ability to apply Newton's second law to a system experiencing a resistive force.
- The ability to express a resistive force equation as a differential equation.
- The ability to use separation of variables to solve a differential equation.
- The ability to carry out integration, including the appropriate choice of limits or constant of integration.
- An understanding of the behavior of objects experiencing a resistive force.
- The ability to describe that behavior using position vs. time, velocity vs. time, and acceleration vs. time graphs.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- The question required the application of conservation of energy to calculate three different quantities involving gravitational potential energy, kinetic energy, and elastic potential energy.
- The question required an explanation of the changes in velocity as an object moves under the influence of the gravitational force. This required the student to conceptually understand the relationship between gravitational potential energy and kinetic energy.
- The question required the student to recognize that the block was transitioning from linear motion to simple harmonic motion and to understand that a mass attached to a spring could be viewed as a simple harmonic oscillator.
- The question provided an expression for a resistive force and required that the student be able to express the force in terms of a differential equation and then successfully integrate that equation to determine the velocity as a function of time.
- The question required that the student exhibit an understanding of how to graph the position, velocity, and acceleration of an object experiencing a resistive force.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Many students failed to recognize that a moving block hitting and attaching to a spring will undergo simple harmonic motion.	• This required using the equation for the period of oscillation correctly.
• Many students did not recognize the fraction of the period described in the question.	• This required the student to know that the time for the spring to go from equilibrium to fully compressed was one quarter of the period of the block's oscillation.
• Many students did not demonstrate the understanding that a resistive force, such as friction, acts opposite the direction of motion.	• This required making the resistive force negative in the force equation.
• Many students failed to apply Newton's second law to the horizontally sliding block.	• This required students to recognize that the only horizontal force acting on the block was the resistive force provided in the question.
• Some students demonstrated an inability to express a force equation as a differential equation.	• This required replacing the acceleration in the force equation with the time derivative of the velocity.
• Many students demonstrated an inability to carry out separation of variables properly. Many did not attempt this part.	• This required applying the technique separation of variables.
• Some students were unable to carry out simple integration involving the power rule. Many students failed to set up an appropriate integral.	• This required the student to correctly set up and solve velocity and time integrals.
• Many students demonstrated a lack of understanding of the behavior of an object moving under the influence of a resistive force that is proportional to the square of the velocity.	• This required the student to correctly draw the position graph as a curve increasing to a horizontal asymptote, the velocity graph as a curve asymptotically decreasing to the horizontal axis, and the acceleration graph as a curve asymptotically approaching the horizontal axis from the negative side.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Practice problems involving different types of energy transformations.
- Students should understand how one variable changes when it depends nonlinearly on another variable (KE and V in this case).
- Practice setting up and solving simple differential equations with solutions that are not logarithms.
- Practice simple integration, and ask students to consider what integration means, not just the application of a method.
- Practice graphing nonlinear relationships and understanding why they are nonlinear.
- Practice producing matching sets of graphs that agree with each other (x vs. t, v vs. t, & a vs. t) for a variety of situations.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics C can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The following curriculum modules will provide additional information on these concepts: 1. Graphical Analysis, 2. Conservation Concepts.

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Question #3 **Topic:** Energy conservation and rotational dynamics

Max. Points: 15 **Mean Score:** 5.41

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- An understanding of conservation of energy, including the distinction between translational and rotational kinetic energy.
- An understanding of the difference and the relationship between linear and angular velocity of a rolling object.
- An understanding of projectile motion.
- An understanding of the effect of rotational inertia on the kinetic energy distribution for a rolling object.
- The ability to read, analyze, and correctly interpret the statement of a problem, including distinguishing between relevant and superfluous information for each part.
- The ability to apply the concept of energy conservation to a system where gravitational potential energy is converted into translational and rotational kinetic energy.
- The ability to analyze the kinematics of a rolling object.
- The ability to calculate the range of a horizontally launched projectile.
- The ability to determine how changes to the rotational inertia of an object affect an object's total kinetic energy, rotational kinetic energy, and projectile range.
- The ability to formulate concise and clear explanations of the behavior of a rolling object.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most students understood that when an object rolls without slipping down a ramp, all the gravitational potential energy is transformed into kinetic energy. However, many students were not clear about the differences between various types of kinetic energy.
- Most students did not realize that a rotating object launched as a projectile does not change its angular speed.
- Most students understood how to calculate the range of a horizontally launched projectile once they had the initial horizontal velocity, v_{ix}, but many had trouble finding this velocity from the information given.
- Many students had trouble making a cohesive argument; they were making mistakes in logic by analyzing the motion of a single object (e.g., comparing its initial energy to its final energy) instead of comparing the motion of two different objects.
- Many students incorrectly assumed that objects with different rotational inertia values have the same final angular speed when rolled down the same inclined plane.
- Most students seemed to have a clear idea that changing the shape of a rolling object changes the distribution of its kinetic energy between rotational and translational.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Students have the misconception that the kinetic energy of a rolling object is purely translational. Example: $Mgh = Mv^2/2$	$Mgh = Mv^2/2 + I\omega^2/2$
Students have the misconception that the kinetic energy of a rolling object is purely rotational. Example: $Mgh = I\omega^2/2$	$Mgh = Mv^2/2 + I\omega^2/2$
Students have the misconception that if an object has both tranlsational and rotational speed, the relationship $v = r\omega$ is <u>always</u> valid — even if it's not rolling.	The rotatational velocity of the object increases when it rolls down the incline, but it stops changing once it is airborne.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students should understand the difference between various types of mechanical energy.
- Students should practice problems in which there are various types of energy transfers but the total mechanical energy of the system is conserved.
- Students should understand how the moment of inertia of an object can affect the rotational kinetic energy and the translational kinetic energy of an object rolling without slipping.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics C can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The following curriculum modules will provide additional information on these concepts: 1. Conservation Concepts, 2. Graphical Analysis. The downloadable AP 1 and AP 2 lab manual may be useful for the teachers of the AP Physics C course as well.

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