CollegeBoard AP

Student Performance Q&A:

2010 AP® Physics C: Mechanics Free-Response Questions

The following comments on the 2010 free-response questions for AP® Physics C: Mechanics were written by the Chief Reader, Jiang Yu of Fitchburg State College in Massachusetts. 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 performance 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

What was the intent of this question?

This question assessed students' understanding of forces in equilibrium. It also tested their ability to create a linear relationship from nonlinear data, to graph the linear relationship in order to determine a constant, to graphically represent the velocity of a falling body when air resistance is not neglected, to describe how distance could be calculated using that graph, and finally to determine an expression for the amount of mechanical energy dissipated during the fall owing to air resistance.

How well did students perform on this question?

The mean score for this question was 6.28 out of a possible 15 points. Most students tried to answer the question; very few left it blank.

What were common student errors or omissions?

Algebra mistakes were common.

In part (a) students tried using integration to derive the relationship between v_T and m, when it was not needed. They did not set the acceleration of the falling body to zero in the derivation, leading to many answers that contained an extra term.

In part (b) students generally did not square the velocity data to obtain a correct graph, even if the correct relationship between v_T and m was obtained in part (a). Often students chose inappropriate scales or did not draw correct best-fit lines through the data points, or both. If a correct relationship between v_T and m was derived and graphed, students often did not correctly use both the graph and the relationship to calculate the constant C from the best-fit line. Also, many students did not include units on their value for C.

Students displayed many incorrect representations of the speed versus time graph in part (c). Most often students had the initial speed as zero and then showed it as slowly increasing or drew a line representing a nearly constant acceleration with a slight (or no) curve at time T (the time the mass reached a speed very close to terminal velocity). When describing how to use their graph to approximate the distance Y, many students neglected including limits in their integration equation or their description of determining the area under the curve.

In part (d) students did not seem to understand how to write a correct expression for the energy dissipated during the fall.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Emphasize graphing skills. Students should be able to correctly scale x and y axes, make nonlinear data linear, and find useful information from the slope of the best-fit line for mathematical calculations or physical interpretations.

Question 2

What was the intent of this question?

Part (a) assessed students' ability to identify forces acting on a bowling ball that rolls down an incline without slipping and to produce a free-body diagram. Parts (b) and (c) assessed students' ability to determine the frictional force acting on the bowling ball as it is rolling and to determine the velocity of the ball at the end of an incline. The solution required various combinations of Newton's second law for linear motion, Newton's second law for rotational motion, conservation of energy, and kinematics, depending upon the methodology employed. Part (d) assessed students' understanding of the principles of projectile motion and the ability to solve for the final velocity of a system undergoing an inelastic collision that is constrained to move in one dimension after the collision.

How well did students perform on this question?

The mean score for this question was 5.79 out of a possible 15 points. Almost all students attempted the question.

What were common student errors or omissions?

In part (a) many students were able to identify the forces that acted on the ball: weight, normal force and friction. The most common errors included not identifying the correct point of application of the force, adding extra forces or components, or reversing the direction of the friction vector. Less common errors included mislabeling vectors or not including the direction arrow on the vector.

In part (b) the majority of students attempted to solve for the frictional force using Newton's laws. The most common errors included setting the frictional force equal to zero because the ball was not slipping; setting the acceleration down the plane equal to zero, thus giving the frictional force a value of $mg\sin\theta$; reversing the use of sine and cosine; attempting to use only the linear form or only the rotational form of Newton's second law; combining forces and torques in an incorrect manner; and assuming that a coefficient of friction was needed.

In part (c) the majority of students attempted to solve for the final speed using conservation of energy. The most common errors included ignoring either the linear or rotational form of kinetic energy and including an extra term for either work or energy. For those choosing to use kinematics, the most common error was to set the acceleration equal to g or $g\sin\theta$.

In part (d) most students correctly identified the need to use conservation of momentum to find the horizontal speed of the combined body after collision. The most common errors included using the total speed found in part (c) rather than its horizontal component or incorrectly determining the total mass after collision. In addition a significant number of students unnecessarily calculated the speed of the ball before collision using the principles of projectile motion. Another common error was to start the problem using the conservation of energy.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Place more emphasis on free body diagrams, in particular their application to the fundamentals of rotating systems, including using the diagrams to produce component forms of force and torque equations.
- Provide students with more exposure to the physical situations that are similar to the problems they are asked to solve, with the intent of linking the theoretical and concrete aspects.
- Give students experience in starting solutions from applicable fundamental principles.
- Conduct discussions that focus on the methodology of approach for classes of problems; for example, discuss when it is appropriate to start a problem from conservation of energy or dynamics.
- Expose students to problems in which they need to sort out what is appropriate in terms of method of attack and what can be neglected or set constant for the situation.

Question 3

What was the intent of this question?

The intent of this question was to have students look at a mechanics problem involving a segmented acceleration that varied with time, both conceptually and computationally. The problem involved extensive use of calculus and required conceptual knowledge in order to draw two graphs.

How well did students perform on this question?

The mean score for this question was 4.10 out of a possible 15 points, which was low for a 15-point question on the Physics C: Mechanics Exam. The score distribution was skewed with a mode of 2. Less than 1 percent of the students received a score of 15, but there were a lower number of blank responses than in previous years.
Two of the 15 points in the scoring guidelines were specifically allotted for doing the calculus properly. The other 13 points were for the physics involved in the problem. The scoring guidelines included entry points designed to allow students to gain some credit in each section. As a result,

the students who earned 2 points on this question did so in very different ways, as opposed to other questions where low scores were earned for much the same work.

What were common student errors or omissions?

In part (a) students often indicated they were going to take the antiderivative of the acceleration but then took the derivative. Students often incorrectly integrated the function or incorrectly evaluated the limits. Many students treated the variable acceleration as a constant acceleration and tried using kinematic equations or other methods appropriate to constant acceleration.

Part (b) was best solved by using the Work-Energy Theorem, but students often seemed to refer to the equation sheet to find and use an equation that included work. This led to a very messy equation that lost most of them. For those who did use the Work-Energy Theorem, many tried to base the work on the change in potential energy, or both potential and kinetic energy, instead of just the change in kinetic energy. Some students also indicated that $W = \int F \bullet dx$, then realized that the only variable was time (not distance). They arbitrarily used the limits of time or switched the equation to $W = \int F \bullet dt$, or both. This would lead to the value of work obtained being equal to the value of impulse in part (d).

For part (c) students appeared to confuse the net force with the tension on the rope. They often drew free body diagrams and then chose the wrong component. Many students understood that the acceleration of an object is zero at terminal velocity, but they did not seem to be sure which acceleration in this problem was zero. It appeared that they were familiar only with terminal velocity in problems involving air resistance, and some students tried to use a buoyant force in the equation.

In part (d) students often confused power and impulse, apparently not being able to tell the difference between P and ρ in the equation table. Many students seemed to have no idea what impulse was in the context of physics. Calculus problems again were evident if students chose to use the integral form of impulse, $J = \int F\,dt$. Some students seemed to have gone "equation hunting" from the tables, so it was not uncommon to see equations like $I = mr^2$ show up.

In part (e) a large number of students either did not include labels or reversed them. Some students did not use the labels they were told to use but instead used the equations for the acceleration as the labels (which did earn credit when correct). Many students skipped the graph completely. Other students would only put in one of the two graphs and not label it.

A general common error was not putting enough beginning and intermediate steps into the parts that asked for a derivation. Also, even though the parameters of the problem were all given as alphabetic and symbolic characters, many students insisted on putting in numeric values, most of which seemed to be just guesses derived from the figure that they were told was not to scale. And finally, it was apparent that many students had not taken calculus. Many Exam Readers reported reading comments like, "Don't laugh at me, I have not had calculus."

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Remind students that if the exam says “label,” they should do so!
- In problems that include only variables, encourage students not to substitute values for physical constants, guess at angles, or change trigonometry functions to numbers.
- Give students more practice dealing with problems with alphabetic and symbolic characters only. They need to feel comfortable with problems that have no numbers in them.
- Cover kinematics using calculus and varying accelerations at the beginning of the year, teaching enough calculus for students to understand the mathematics, or be sure to revisit kinematics after students have had enough calculus in their mathematics classes.