CollegeBoard
Advanced Placement Program

# Student Performance Q&A:

## 2008 AP® Physics C: Mechanics Free-Response Questions

The following comments on the 2008 free-response questions for AP® Physics C: Mechanics were written by the Chief Reader, William H. Ingham of James Madison University in Harrisonburg, Virginia. 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 was intended to evaluate students' understanding of velocity-dependent drag forces and of the dynamics and mathematics required to set up and solve Newton's second law for a skier moving down a frictionless slope under the influence of a linear drag force. Part (a) asked students to draw a free-body diagram showing the forces acting on the skier. Part (b) required them to write a differential equation that could be used to find the velocity of the skier as a function of time. Part (c) asked students to write an expression for the terminal velocity of the skier. Part (d) required them to solve their differential equation from part (b) to determine the velocity of the skier as a function of time. Finally, in part (e) students had to draw a graph representing the acceleration of the skier as a function of time and to indicate the initial value of the acceleration.

***How well did students perform on this question?***

The mean score for this 15-point question was 6.76. About 13 percent of students earned scores of 12 or higher, while about 27 percent earned scores of 3 or below.

***What were common student errors or omissions?***

The two most general problems were (1) many students did not know or understand the mathematics of differential equations as applied to a problem like this and (2) students made mistakes involving dimensional analysis.

In part (a) common errors included placing the normal force vertically upward instead of perpendicular to the slope or omitting it altogether. Many students also placed extra vectors on the free-body diagram, such as the components of the weight, in addition to the weight vector or an additional force acting down the slope. There were also many labeling errors, such as labeling the weight vector as *g* or *gravity* instead of $F_g$ or *mg* or *weight*.

In part (b) many students did not write the equation using the differential form $dv/dt$. Additionally, many students attempted to use Newton's second law but instead set a velocity or acceleration term on one side of the equation equal to quantities of force on the other side of the equation. Many students interchanged the down-slope and normal components of the weight vector both in part (b) and on the free-body diagram.

Part (c) was done well for the most part. Students understood that terminal velocity is reached when the acceleration goes to zero.

In part (d) students were faced with solving a differential equation. Students who had a good foundation in calculus understood that they needed to separate variables and integrate (or use other, less common approaches, such as integration factors). The problems seen here were in the algebra of separating the variables and a failure to utilize limits for definite integrals (or omitting integration constants if using indefinite integrals). Many students did not attempt this part or did not have a sufficient understanding of calculus to know how to proceed.

In part (e) the most common error was labeling the initial value of the acceleration as $mg\sin\theta$ instead of $g\sin\theta$ (a very widespread error) or not indicating a value at all. The graphs were varied, but many had the acceleration first increase and then fall to zero, either abruptly or asymptotically.

### *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?*

Teachers should place strong emphasis on drawing proper free-body diagrams with appropriate vectors and labels. They should also stress the importance of dimensional analysis and understanding the units and equational forms of velocity, acceleration, and force. In addition, it is very important to provide definitions and examples of differential equations and the methods for solving them.

More generally, students should show steps to their solutions so that partial credit can be earned, even for questions that ask students to simply write or determine a quantity. Many students merely wrote an incorrect expression and thus did not earn any credit. Their work should be organized and flow logically from one step to another; on this problem, many students' attempts at solutions were difficult to follow.

## Question 2

### *What was the intent of this question?*

This question was intended to assess students' ability to analyze forces and torques acting on a rigid body with a continuous mass distribution, specifically a rod with a block attached to one end and supported at either end by a hinge and a cord. Part (a) asked students to draw and label a free-body diagram in which forces and their points of application were shown. In part (b) they had to calculate the reading on the spring scale that connected the cord to the upper support. In part (c) students were asked to find the rotational inertia of the rod-block system about one end of the rod. Finally, in part (d) students were told that the cord was cut, and they were asked to find the initial angular acceleration of the rod-block system about the hinge.

### *How well did students perform on this question?*

The mean score for this 15-point question was 6.51. About 15 percent of students earned scores of 12 or higher, while about 28 percent earned scores of 3 or below.

### *What were common student errors or omissions?*

In part (a) most students were able to construct at least three of the forces on the free-body diagram, but most students omitted the force exerted by the hinge on the body. Perhaps some students misinterpreted the reference to a "frictionless hinge" in the stem of the problem.

In part (b) many students summed forces rather than torques. Among those students who did utilize torque, many did not correctly treat the torque on the rod due to the string. Most of these students were able to correctly sum the torques on the rod due to the weight of the hanging object and the rod itself.

In part (c) many students understood that the parallel axis theorem was needed but were unable to apply it correctly. Some students used the parallel axis theorem for the bar but omitted the rotational inertia of the attached block. Many students failed to substitute correct distances for the bar and the block.

In part (d) many students used only the torque applied by the hanging mass in solving for the initial angular acceleration, omitting the torque applied by the weight of the bar itself.

### *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?*

Regarding free-body diagrams, students should represent each force in one of two ways, *either* the vector *or* its components, but *not* both. Students should include an arrowhead on any line intended to represent a vector. Students should label force vectors correctly (e.g., $W$ or $mg$ for weight, *not* $g$) and should make sure that one end of each vector is drawn touching the body. Students should avoid drawing any extraneous vectors, which could reduce a student's score on a problem. Each force vector drawn should represent a single force, not the net force or some other combination of forces. For example, in this problem students should have drawn a vector for the weight of the bar and a separate vector for the weight of the attached block. If a modified free-body diagram is needed to solve any successive part, students should be cautioned against putting in alterations on their original free-body diagram. They should instead draw another diagram.

Students need more experience with applying the parallel axis theorem and with summing the rotational inertias of several objects.

Teachers should continue to emphasize the importance of using correct units.

## Question 3

### *What was the intent of this question?*

This question had three basic sections. The intent of the first section [parts (a) and (b)] was to assess whether students could use the experimental data provided to (1) create an appropriate graph of length versus applied force for a stretchable cord and (2) obtain the force constant from the graph. Part (c) described the dropping of an object of unknown mass attached to the cord and asked students to determine the mass of the object based on a given maximum descent. The intent of this section was to assess their ability to utilize energy conservation. Finally, in part (d) students had to determine the position at which the object attached to the cord (after being dropped from rest) attained maximum speed and to calculate that maximum speed. Since the cord could be stretched but not compressed, this was not equivalent to the more usual mass-on-a-spring problem. Part (d) assessed the ability of students to do an analysis based on force (or energy) considerations when both gravitational and elastic forces are involved.

### *How well did students perform on this question?*

The mean score for this 15-point question was 5.16. About 6 percent of students earned scores of 12 or higher, while about 30 percent earned scores of 3 or below.

### *What were common student errors or omissions?*

In part (a) some students were unable to draw a best-fit straight line, although a majority did draw a reasonable one. There were very few students doing work but earning zeros or not attempting to answer this part.

In part (b) determination of the slope of the line proved challenging for many students. Common errors included using data points not on the line, calculating the reciprocal of the slope, and averaging weight-to-length ratios.

In part (c), which required an energy solution, the most common error was to try an approach based on Newton's second law. Some students started correctly but did not realize that the amount the cord stretched was different from the distance fallen. In fact, fewer than half of those students who earned some credit on part (c) obtained full credit for this part because of mistakes in relating the distance fallen to the stretch of the cord.

Part (d) was most easily solved using Newton's laws directly, and students who began this way were at least partially successful. Most students starting with an energy approach were not successful, although some found a potential energy minimum or kinetic energy maximum and managed to solve the problem.

Students who began part (d) correctly were usually able to earn at least one point for the justification in part (d)(ii). The final points were awarded for calculating the maximum velocity in part (d)(iii). This required an energy approach, but most students were unsuccessful even if they attempted this approach. Common errors included attempts to use kinematic equations, simple harmonic oscillators, or an incorrectly written energy equation.

### ***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?***

Students clearly need practice with manual graphing techniques, and they need to understand that the slope of the line has physical significance. Students also need to develop a better sense for when to use Newton's laws and when to use an energy approach. Quite a few students switched the two, using Newton's laws when energy conservation would have provided a better approach and vice versa. Teachers are encouraged to provide a variety of problems that can be solved by using either energy or dynamics and to give students more practice in deciding which approach is best. Students also need practice with justifying their problem solutions in words, in a clear and straightforward manner. Many students provided only vague general statements, which earned no credit.