College Board
Advanced Placement
Program

Student Performance Q&A:

2006 AP® Physics C: Mechanics Free-Response Questions

The following comments on the 2006 free-response questions for AP® Physics C: Mechanics were written by the Chief Reader, William 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 probed students' understanding of Newtonian dynamics and kinematics, along with conservation laws. A block with a given initial velocity slid on a slab that was initially at rest, with friction between the two objects. There was no friction between the slab and the supporting surface. In part (a) students were asked to analyze the forces acting on the block and slab. In part (b) students could use conservation of momentum or a kinematic approach to determine a common final speed for the block and slab. In part (c) students were asked to determine the distance the slab traveled to reach that speed. In part (d) students were asked to find the work done by friction on the slab.

How well did students perform on this question?

The mean score on this 15-point question was 8.42. About 28 percent of students earned scores of 12 or higher, while approximately 14 percent earned scores of 3 or below. Very few students omitted the question.

What were common student errors or omissions?

The most common error was failing to correctly apply Newton's Third Law in considering the friction between the block and slab. Many students assumed the acceleration of the block was equal to the acceleration of the slab. The other common error was misreading the question: many students calculated the distance and work for the *block*, rather than the slab.

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?

See general comments at the end of question 3.

Question 2

What was the intent of this question?

This question was intended to test two sets of skills. Parts (a) through (d) examined student graphing and graphical analysis skills: how to linearize data and how to calculate values from a graph. Parts (e) and (f) examined student skills at applying physics and calculus to a nonlinear spring: how to calculate work done in compressing the spring, and how to apply the conservation of energy to a spring-cart system.

How well did students perform on this question?

The mean score on this 15-point question was 6.48. About 18 percent of students earned scores of 12 or higher, while approximately 36 percent earned scores of 3 or below.

What were common student errors or omissions?

Common student errors and omissions included:

- Failing to clearly identify two quantities to graph in part (a).
- Trying to calculate A using each pair of values in the data table.
- Failing to clearly plot in part (c) the values identified in part (a).
- Utilizing an incorrect relationship between the slope of the graph and the constant A in part (d), or not clearly relating A to the slope.
- Using the constant-force expression $W = Fd$ to calculate work in part (e).
- Recognizing the appropriateness of using conversation of energy but then incorrectly applying the linear-spring expression $kx^2/2$ for the potential energy of the compressed spring in part (f).

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?

See general comments at the end of question 3.

Question 3

What was the intent of this question?

Parts (a) and (b) involved a hoop rolling down an incline and asked student to derive expressions for the acceleration and velocity of the center of mass of the hoop. These parts of the question were intended to test students' understanding of the physical behavior of an object that is rolling down an incline without slipping. Student papers were straightforward to analyze. There were two basic approaches, one based on rotational and translational dynamics using Newton's Second Law, and a simpler one based on conservation of mechanical energy. After the hoop rolled to the bottom of the incline in parts (a) and (b), it proceeded to roll off a table of a given height in part (c). Students were required to perform a straightforward analysis using only the horizontal velocity of the hoop to find how far from the table it would land. Part (d) asked students to make a prediction regarding a similar situation in which a disk rather than a hoop was rolled down the incline. To analyze part (d) correctly, students needed to understand how the rotational inertia would change if the mass distribution were altered and how this would impact the translational velocity of the object after it rolled down the incline, and hence the horizontal distance it would travel as it fell. This derivation problem required students to show how they arrived at the answer from a recognizable and fundamental starting point.

How well did students perform on this question?

The mean score on this 15-point question was 6.17. About 19 percent of students earned scores of 12 or higher, while approximately 37 percent earned scores of 3 or below.

What were common student errors or omissions?

Very few students left this question completely blank, and most who wrote something down got some credit, although many solutions were disorganized. The part of the problem that students answered most successfully was part (c). Credit was given for correct expression of the time, use of a nonaccelerated equation of motion, and appropriate substitution of the time and the velocity values previously calculated into the equation of motion. Many, if not most, students showed a correct derivation of the time it takes the projectile to hit the floor and understood that horizontal motion is not accelerated. It was fairly common for them to begin calculation of the time correctly but make a mistake in the algebra. It was also apparent that some students felt that they needed to multiply the horizontal velocity from part (b) by $\cos\theta$ before using it in the equation $x = vt$. Mistakes such as these still enabled students to receive 2 or 3 of the 4 possible points awarded on this part of the question. A small percentage of students still believe that horizontal motion is accelerated for an object in free fall. These students could, at most, receive 1 point if they showed a correct expression for the time of fall.

Students were quite successful answering part (d) of the problem, understanding that the disk would travel farther than the hoop horizontally. If they correctly stated that the disk would travel farther than the hoop, they were usually able to reason that this was because the rotational inertia of the disk was less than that of the hoop, resulting in more translational kinetic energy and a higher velocity for the disk. The only credit some students received was for part (d).

Parts (a) and (b) were scored as a unit, and only a very small percentage of students received full credit for them. Not surprisingly, most students used the conservation of mechanical energy approach to derive an expression for the velocity as the first step. Fewer than half of the students arrived at the correct velocity, usually because they did not recognize that there were two forms of kinetic energy for the hoop and instead elected to use one or the other. They had somewhat more success in correctly deriving an expression for the potential energy change.

Other students started with the dynamic approach to first calculate the acceleration, but they tended to meet with less success. Usually, students elected to use either rotational dynamics or translational dynamics but not both together. A fairly common problem was writing the expression for torque ($I\alpha$) as part of the linear equation (i.e. $\sum F = ma + I\alpha$). Another common problem in the dynamic approach was to try to calculate the friction using a static friction formula, which was incorrect since this gives the maximum possible value and not the actual value. The most common answer was $a = g\sin\theta$, rather than $a = (1/2)g\sin\theta$. Some students reasoned their way to the correct answer without showing sufficient detail or used a memorized formula. These students received partial credit only.

The most surprising finding was that so few students saw the easy way of linking velocity and acceleration using kinematics. Even students who got perfect scores on parts (a) and (b) usually did so by doing independent calculations for those parts—for example, they would use energy for part (b) and dynamics for part (a). This may have been due in part to the design of the exam. Part (a) asked for acceleration, which suggests a dynamic approach. Some students appeared to have gotten stuck on (a), left it incomplete, and went on to work the rest of the problem successfully.

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?

Student performance on the AP Physics C: Mechanics Exam was as expected. Students found it difficult to correctly utilize Newton’s Third Law (“action and reaction”). As in prior years, they also had considerable difficulty with experimental technique and data analysis. Many of them were unable to recognize the relationship between angular acceleration and center-of-mass acceleration of a rolling object.