Student Performance Q&A:

2009 AP® Physics C: Mechanics Free-Response Questions

The following comments on the 2009 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?

The purpose of this question was to check students' understanding of simple harmonic motion—without telling the students that is what it was. Students were expected to know how to find total mechanical energy and how to use that total mechanical energy to find the positions where the kinetic energy of the object was zero. They were also expected to be able to find the momentum at a given point, using conservation of energy. In addition, students were asked to find the acceleration of the object at a given point. The final part of the problem asked students to graph the object's position and kinetic energy as functions of time.

How well did students perform on this question?

Students performed well on this question: the mean score was 7.81 out of a possible 15 points. About 18 percent of students earned scores of 12 or higher, while about 20 percent earned scores of 3 or below.

What were common student errors or omissions?

- Many students were not able to solve algebraic equations correctly. They could set up an equation correctly, but solving it to get the right answer posed a challenge. For example, $4x^2 = 7$ would be converted to $x^2 = 3$. (The 4 would be subtracted from 7 rather than dividing it.)

- Students tried to use kinematic equations to solve for the acceleration at a given point, not recognizing that the acceleration was not constant.

- Student graphs of position versus time were incomplete. Most graphs showed only some of the motion of the object. To earn full credit, the graph had to show the full range of motion.

- Student graphs of kinetic energy versus time had the same problems, but students also had difficulty connecting the kinetic energy to the motion of the object. Many of the kinetic energy graphs included negative kinetic energy values; in many cases, the extrema and zeros of the kinetic energy did not appropriately match up with the graph of position versus time.

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?

- Impress upon your students (and their math teachers) the importance of good algebraic skills for achieving good performance in a calculus-based physics course.

- Ensure that all students taking the AP Exam know the definitions of various specific terms for the purposes of this test. Students need to know what is expected of them when they are asked to *calculate*, *derive*, or *sketch*. For example, in part (e) the vast majority of student graphs did not include the full motion of the object.

- Emphasize that the constant-acceleration kinematics equations cannot be used in circumstances where the acceleration is not constant. Furthermore, students need to know that an object in simple harmonic motion does not exhibit constant acceleration.

Question 2

What was the intent of this question?

Part (a) of this question assessed students' ability to analyze torques acting on a rigid swinging bar having a nonuniform mass density and pivoted at one end. Students were asked to apply the appropriate equation of motion to the bar, to write the differential equation for the angle the bar makes with the vertical, and, from their differential equation, to calculate the period of the bar's motion.

Parts (b) and (c) assessed students' ability to write an experimental procedure. Part (b) asked students to describe an experimental procedure they would use to take the additional measurements needed to determine the moment of inertia of the bar, including how the measurements would be used to obtain the moment of inertia and how to minimize experimental error. In part (c) students were not given the bar's center of mass, and they were asked to describe an experimental procedure, including the necessary equipment, that could be used to determine it.

How well did students perform on this question?

Students found this question very challenging: the mean score was 2.03 out of a possible 15 points. Only about 2 percent of students earned scores of 12 or higher, while about 83 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a)(i) many students who started the problem correctly using torques omitted the negative sign on the torque and/or calculated the torque using the length of the bar rather than the distance to the center of mass. The most common incorrect starting point was to use conservation of energy. A significant number of students appeared daunted by the need to write a differential equation and did not attempt a solution.

In part (a)(ii) a significant number of students remembered the form for the period of the physical pendulum and applied it correctly to the situation (these students did not receive the calculation points). Also, some of the students who were successful with part (a)(i) did not know how to use their differential equation to obtain the period.

In part (b) it was a challenge for students to present a clear, concise, and correct description of a valid experimental procedure to determine the moment of inertia of the bar. Many students did not indicate the physical principle they were attempting to apply to the situation. Many descriptions were flawed because they treated variable quantities as constants (i.e., treating as constant the changing torque acting on the rotating bar due to the changing lever arm of the gravitational force). Students were often vague in their descriptions of how the variables were to be measured or failed to specify how the equipment was to be used to measure the variable. They did not always distinguish between an electronic sensor and the computer program that received data from the sensor. A significant number of students were unclear on what constitutes experimental error. Invalid approaches often invoked the definition of moment of inertia or the use of the parallel axis theorem.

In part (c) many students looked for a complex solution when a simple solution would have sufficed. The most common omission was to specify a “thing” rather than stating a specific piece of equipment. The most common incorrect answers included attempting to determine the center of mass using the period of a simple pendulum or adding extra masses to the bar and assuming the center of mass was at the new balance point.

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?

- This level of physics involves quantities that may vary with time or position and thus require calculus concepts to address correctly. Calculus concepts and terminology should be integrated with physics early in the year. Provide regular opportunities for students to practice this merging of skills.

- Stress to students that it is just as important to be able to articulate physics concepts with words as it is to express them in the language of mathematics.

- Provide lab experiences that require clear, written expressions of the physics concepts involved. Use open-ended or inquiry-based labs to hone students’ ability to express ideas logically and coherently. Peer review of this written work can provide a positive learning experience for all parties involved.

- Give students practice with deciphering written descriptions of moderately complex physical situations. It is important that students understand what may, and what may not, realistically be modified in order to address these situations.

Question 3

What was the intent of this question?

The intent of this question was to test students' ability to utilize energy conservation (or alternatively, Newton's second law) to determine the speeds of two systems of masses, one discrete and one continuous, and to compare them. The first system was two discrete objects attached by a string, one on a horizontal table and the second hanging over a massless pulley. The second system was a rope with constant mass density hanging over the edge of a table. The level table was frictionless, and the mass over the edge of the table was accelerated by gravity.

How well did students perform on this question?

The mean score was 5.71 out of a possible 15 points. About 9 percent of students earned scores of 12 or higher, while about 34 percent earned scores of 3 or below.

What were common student errors or omissions?

Despite instructions to write answers in terms of given variables, many students did not. Some students did not differentiate either of these systems of masses from freefall (i.e., they assumed or even calculated that the acceleration of either or both was g). Many students used Newton's second law and constant-acceleration kinematics to solve problems that asked for speed in terms of distance. Using this approach made the first case (part [a], two discrete objects) more difficult, and it led to an incorrect answer in the second case (part [d], rope), since the rope's acceleration is not constant (many students did not seem to understand this). When applying energy conservation to a system, many students were unclear (or incorrect) about which energy was being attributed to which mass, or they often used the incorrect mass in either the potential or the kinetic energy expressions. Many students did not appear to understand the distinction between work done by a constant force and work done by a varying force; in a majority of student responses, the equation $W = Fd$ was applied to a variable force. Many students did not correctly integrate $(Mgy/L)dy$, with or without limits.

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?

- Carefully distinguish between constant-acceleration and varying-acceleration problems, and have students solve more problems in which the acceleration is not constant.

- Stress that the work–energy method is often a better way to solve a problem, especially a problem in which one is seeking the speed of an object in terms of displacement.

- Clearly differentiate freefall problems from problems where gravity accelerates the system, but not at an acceleration equal to g.