CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2005 AP® Physics C: Mechanics Free-Response Questions

The following comments on the 2005 free-response questions for AP® Physics C: Mechanics were written by the Chief Reader, Patrick Polley of Beloit College in Beloit, Wisconsin. 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 in one dimension. A ball that was thrown upward was subject to a drag force that depended on the velocity of the ball. In part (a) students were asked to state qualitatively if the acceleration changed as the ball traveled upward. In part (b) the students had to write the differential equation for the instantaneous velocity but were told not to solve it. Part (c) asked students to determine the terminal velocity of the ball. Parts (d) and (e) asked them to say whether the ball took longer to rise or fall and to graph the velocity of the ball as a function of time.

How well did students perform on this question?

Performance overall was worse than expected. The mean score was 5.02 out of 15 possible points. Fewer than 10 percent of students earned scores of 11 or better. More than 40 percent earned scores of 3 or less.

What were common student errors or omissions?

The most glaring error was students' inability to represent physical variables graphically. They could obtain points from their graph, so long as it was consistent with the analysis in part (d). Students would commonly say that the time for the ball to go up was less than the time for the ball to come down and then draw a graph that contradicted that assertion.

Other common errors were the inability to recognize the term *terminal speed* and unfamiliarity with what it means to write a differential equation. Students also demonstrated a lack of calculus skills by failing to realize that the area above the horizontal time axis bounded by the curve representing the velocity of the ball must equal the area bounded by that same curve below the time axis.

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?

The question tested students' understanding of Newtonian gravitation and Kepler's Third Law. Students also had to recall that the centripetal acceleration of an object in a circular orbit is u^2/R, where u is the speed of the object and R the radius of its orbit. Parts (a) and (b) asked students to derive Kepler's Third Law of planetary motion from the Newtonian expression of the gravitational force between two objects. Part (c) asked what quantities needed to be graphed in order to yield a linear equation. Parts (d), (e), and (f) probed students' abilities to perform graphical analysis on the given data on the period and orbital radii of four of Saturn's moons, with the object of determining the mass of Saturn.

How well did students perform on this question?

Performance was far below what was expected for a straightforward problem involving circular motion. The mean score was 3.47 out of a possible 15 points, with 1 being the most common score. Approximately 12 percent of students earned scores of 11 or better. Over half of students earned scores of 2 or less.

What were the common student errors or omissions?

The only point many students earned was for copying the expression for the Newtonian gravitational force and substituting in a variable M_S for the mass of Saturn. Students were unable to set this expression equal to the centripetal force acting on the moons of Saturn. Many did not realize that the orbital velocity is given by $2\pi R/T$, where T is the orbital period and R the orbital radius, and so could not derive Kepler's Third Law.

Yet even if students could not develop an algebraic expression for Kepler's Third Law, they could still have earned 9 points if they used their incorrect expression consistently in the graphical analysis parts of the problem. If students simply remembered Kepler's Third Law instead of deriving it, they could also have earned 9 points. The reason that students scored so poorly on this problem was their lack of graphing skills. Students were unable to put their data in a form that would result in a linear graph, and many of those who did draw a graph were unable to use its slope to determine the mass of Saturn.

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?

This question was an interesting combination of the principles of conservation of linear momentum, conservation of angular momentum, and conservation of energy. The problem revolved around a rod that was free to pivot in the horizontal plane about an axis located at one end of the rod. Part (a) was straightforward, asking students to write an expression for the angular momentum of the rod in terms of the mass, length, and angular velocity of the rod. In part (b) the rotating rod struck a ball of mass M_2. After the collision, the previously stationary ball sped off with a velocity u, and the rod remained stationary. Students needed to apply the conservation of angular momentum to find the velocity of the ball after the collision. In part (c) students were told that the collision was elastic, and they were asked to find the ratio of the mass of the rod to the mass of the ball. The final, most challenging, part of the question replaced the original ball with a ball of the same mass as that of the rod; students were directed to find the distance from the pivot at which the ball had to be placed if the rod were to come to rest after the elastic collision.

How well did students perform on this question?

The mean score was 3.61 out of a possible 15 points. Approximately 11 percent of students earned a score of 11 or higher. About half of students earned a score of 1 or 0.

What were common student errors or omissions?

Questions that revolve around the concepts of rotational kinematics and dynamics often pose difficulties for students, and this year was no exception. Many students received a point for substituting the value given for the rotational inertia of the rod into the expression $L = I\omega$ to obtain the initial angular momentum of the rod. Most students then fell by the wayside in part (b) by equating the initial angular momentum of the rod to the final linear momentum of the ball. Some students recouped their loss in part (b) by successfully applying the conservation of kinetic energy in order to find the ratio of the masses of the rod and ball in part (c).

It is clear from responses to this question that students' main problem is not with the algebra involved but with the physics concepts. Those students who did not complete part (d) were not stumped by the algebra but by a failure to see how to apply the conservation laws.

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?

The salient point that comes out of this year's Physics C: Mechanics Exam is that students need to work on their graphing skills. It is not clear if the lack of these skills results from not handling data in a laboratory setting or from an excessive reliance on software packages that do graphing for them. What is clear is that many students are unable to perform tasks involving the presentation of one-dimensional motion in a graphical form, or to analyze a set of data for orbital motion in order to extract physically significant information from it. It is also apparent that some students have forgotten material (such as centripetal acceleration) that they learned in earlier courses. Yet at the same time, the correct application of the conservation laws of energy and angular momentum eluded many students in question 3.