Student Performance Q&A:

2011 AP® Physics B Free-Response Questions

The following comments on the 2011 free-response questions for AP® Physics B were written by the Chief Reader, Jiang Yu of Fitchburg State University in Fitchburg, Mass. 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 linear motion. Students were required to analyze the velocity versus time graph of an object's motion. They were also asked questions regarding the dynamics, work, and energy involved in the object's motion.

How well did students perform on this question?

The mean score was 10.41 out of a possible 15 points. Almost all (99 percent) students attempted to answer at least one part of the question, and all who attempted earned a nonzero score. Most students attempted all parts.

What were common student errors or omissions?

In part (a) many students had trouble drawing the acceleration versus time graph for the object based on the given velocity versus time graph. The most common error was not recognizing that the acceleration was constant for all three segments of the motion. Students also erroneously assigned a positive value to the last part of the motion where the velocity versus time graph had a negative slope.

In part (e) many students did not correctly calculate the work done on the object. The question asked for the work done over two segments where the forces were different. Many students added the two forces together or used the entire distance for one value of force. Also common was using the area under the velocity versus time graph as the work done.

Overall students simply lacked clarity and necessary details in both the calculated work and the justifications. Students often wrote calculations or answers with no indication of what idea or equation they were using or what values they were plugging into an equation. When asked to justify their answer, many gave unclear statements that did not indicate what they were referring to or what quantity or graph they were talking about.

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 students the expectations implied when asked to "calculate," "determine," or "derive." The definitions of these terms can be found in the AP Physics Course Description.
- In the course of the year's study, train students to be careful with the organization and clarity of their solutions. They need to know that writing equations, showing algebraic manipulations, substituting proper values, and explaining the results clearly are of utmost importance in demonstrating their knowledge.
- In teaching kinematics, help students to develop skills in drawing and interpreting motion graphs, including the meanings of slopes and areas for $x(t)$, $v(t)$, and $a(t)$ graphs. Students should recognize the differences between constant, variable, negative, and zero slopes in relation to physical situations.
- Help students better connect the conservation laws with the basic kinematics by incorporating motion graphs in questions involving conservation laws.

Question 2

What was the intent of this question?

This question assessed students' understanding of the electric field resulting from a continuous charge distribution on a conducting sphere.

How well did students perform on this question?

The mean score was 3.82 out of a possible 15 points. Some 93 percent of students attempted to answer at least one part of the question; 76 percent earned a nonzero score. The question was difficult for the average AP Physics B student. A substantial proportion of students demonstrated that they did not understand the physics involved in this question.

What were common student errors or omissions?

The serious problem is that students had not developed a basic concept of the electric field and the associated electric potential. Starting in part (a), many students did not recognize the difference between a point-charge field and a non-point-charge field. They did not understand that the potential is constant everywhere inside and on the surface of the conductor and used $V = kq/r$ indifferently to calculate potentials inside and outside the conductor. Many students confused electric field with electric potential and indicated that the potential must be zero inside the conductor. Still others stated that because the charge is zero inside the conductor, the potential must be zero there as well.

The lack of understanding of electric field was also demonstrated in various student mistakes in calculation. In part (a) many mistook the symbol e_0 for permittivity to be the electric field, or k in the given equation $V = kq/r$ as the Boltzmann constant. Many used the distance from the point of interest to the surface of the conductor, not the center, for r. There were also students who used a ratio to calculate the potential because the point of interest was exactly two radii from the center of the sphere.

This lack of basic understanding was further displayed in part (b), where very few students could correctly graph the potential inside or outside the conductor. They drew the potential as zero inside the conductor, and many left that section of the graph blank. Quite a few drew a $1/r$ curve everywhere, continuous from the center of the sphere, and indicated that the magnitude of the potential was *infinitely* large at the center. It is evident that a great many students treated the charged sphere simply as a point charge with all the charge located either at the center or at the surface of the conductor.

In part (c) i very few students recognized that the electric field is zero inside a conductor in electrostatic equilibrium. One common answer was to calculate $E = kq/r^2 = 5760\ \text{V/m}$ inside the conductor by using the given q and r. Another common answer was to incorrectly apply $E = V/d$ to this situation, taking V from part (a) i and letting $d = r = 0.10\ \text{m}$ as given.

In part (c) ii many students applied $E = V/d$ to the situation, taking the value of V from part (a) ii and letting $d = r = 0.24\ \text{m}$ as given. Though they coincidentally produced the correct answer of $1000\ \text{V/m}$, their approach was fundamentally incorrect. Another common incorrect approach was to attempt to calculate the electrostatic force $F = kq_1q_2/r^2$ and then use $E = F/q$; there was much confusion about what value to substitute for the second charge q_2.

In part (d) very few students showed a constant potential across the second conducting sphere. Most common was to draw a $1/r$ curve that was uninterrupted by the second sphere, as if the second sphere would have no effect at all on the potential. Some drew separate $1/r$ patterns originating at each sphere. Others drew a graph that resembled the electric field around the conductors, with the function equal to zero inside the conductors and a discontinuous jump at the conductor surfaces to a smoothly decreasing curve.

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 must develop a deeper understanding of electric field and its conceptualization. Their study must go beyond using equations blindly. Help students by having them visualize the field in 3-D situations. Do field- and potential-related sketches, diagrams and graphs.
- Whenever calculations are done, try to make students draw graphs to show what they just calculated. Students have to see the picture of a field before using formulas in calculations about the aspects of the field.

Question 3

What was the intent of this question?

This lab question required the design of a single-slit experiment using light. It assessed students' knowledge of the interference of light and methods of performing measurements involving the interference pattern.

How well did students perform on this question?

The mean score was 6.28 out of a possible 15 points. At least one part of the question was attempted by 96 percent of students; 95 percent earned a nonzero score.

What were common student errors or omissions?

Many students had problems organizing their work between sections where part (b) was a sketch, part (c) was an outline, and part (d) was showing how their measurements would be used to solve the initial problem. Furthermore, in part (c) many students were careless with the details (such as not indicating that a ruler would be used to measure distances) or simply omitted necessary steps of the process.

In part (d) many students did not recognize that they needed to use their measurements to solve for the angle or to note that for very small angles the tangent and sine of the angle could be taken as approximately equal. The most common misunderstanding was that the light distribution for a single slit was identical to that for a double slit or diffraction grating.

Perhaps the most troubling issue was that a substantial number of students did not realize that the situation involved diffraction, and that the slit width would be many orders too small to use a meterstick or a metric ruler to measure directly. They did not realize that the slit width would have to be obtained indirectly by designing and performing a diffraction of light experiment.

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 the importance of reading the entire question and providing all the details required in each section of the response. Students need to know that a 15-point problem that asks them to design an experiment is not meant to be accomplished by something as simple as using a ruler to measure a distance.
- Provide opportunities for students to design experiments. Require them to write up their design and procedure, including sketches of the equipment set-ups and step-by-step details of the procedure in their reports.

Question 4

What was the intent of this question?

This question assessed students' understanding of density, buoyancy and pressure under static conditions.

How well did students perform on this question?

The mean score was 6.35 out of a possible 10 points. Some 97 percent of students attempted to answer at least one part of the question; 95 percent earned a nonzero score. Most students attempted all parts.

What were common student errors or omissions?

In part (a) some students lacked a clear notion that quantities with different physical units, such as mass and density or mass and volume, cannot be added to or subtracted from each other. A number of students also had difficulty using the given volume of water and the density of water to calculate the mass and then the weight of the water.

In part (b) many students were deficient in drawing free-body diagrams. For example, they did not include arrows to indicate the directions of forces, or they drew force vectors in random directions, sometimes with elbows or curves. Many students did not label the vectors they drew or labeled them incorrectly. For example, "pressure," "m," "gravity," and "string" were all used frequently to label a force.

In part (c) many students used the density of water, the total volume of water in the beaker and gravity to calculate the buoyant force of the water on the ball. They did not realize that they were simply calculating the weight of the water in the beaker.

In part (d) students often included atmospheric pressure in their calculation for gauge pressure or incorrectly indicated $P_0 = 0$. Incorrect units for pressure were also common.

In part (e) some students suggested that because the ball was still in the beaker, the water level would not have changed, or they referred to surface area rather than volume of fluid displaced.

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?

- Help students to recognize the difference between mass and weight, and to differentiate the definitions of absolute pressure, atmospheric pressure and gauge pressure.
- Free-body diagrams need to include lines with arrows that start from the point representing the object of interest, point in the direction of the forces, and are clearly labeled with conventional abbreviations for the forces.

Question 5

What was the intent of this question?

This question assessed students' understanding of the behavior of an electrically charged object traveling at constant speed, in both electric and magnetic uniform fields.

How well did students perform on this question?

The mean score was 3.02 out of a possible 15 points. At least one part of the question was attempted by 86 percent of students; 58% earned a nonzero score. This was another rather difficult question for the average student and had the highest percentage of students that did not attempt it.

What were common student errors or omissions?

In part (a) many students equated forces other than F_E and F_g. Many confused the concepts and the quantities of electric force, electric field strength, electric potential and electric potential energy. Many students treated the charged plates as a point charge. Also, many students did not understand the meaning of "derive" and did not begin their derivations from general principles/definitions/equations.

In part (b) most students could not answer the question.

In part (c) most errors were simple algebra or calculation errors. Some students were not careful when reading a coordinate pair off the graph, leaving off the order of magnitude of the charge value. Many students did not connect the expression derived in part (a) and the calculation in part (c).

In part (d) many students did not realize that the motion of the charged sphere would be semicircular. Many thought the magnetic field was "charged," or that the charged sphere moved in or out of the page in the direction of the magnetic field, or that the magnetic field was irrelevant to the motion of the charged sphere.

In part (e) many students did not realize that the net force on the charged sphere is F_B. Some even used Ampere's law to equate B to F_c. Students also misinterpreted the radius of curvature of the charged sphere's path to be L rather than $L/2$.

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?

- Always push students to draw free-body diagrams whenever solving problems involving forces. Students would have done better with this question if they had started with a free-body diagram even though it was not required.
- Familiarize students with the use on the exams of terms such as "derive" and "calculate," which are defined in the AP Physics Course Description.
- Continually reinforce that centripetal force is not one of the physical forces that act on an object. Rather, it is the resultant of all identified forces and is always perpendicular to the moving object's velocity.

Question 6

What was the intent of this question?

This question assessed students' understanding of the atomic structure of a hypothetical atom by drawing an energy-level diagram and associating possible light emissions with electron transitions between the energy levels.

How well did students perform on this question?

The mean score was 2.46 out of a possible 10 points. Some 90 percent of students attempted to answer at least one part of the question; 67 percent earned a nonzero score.

What were common student errors or omissions?

In part (a) many students could not draw the correct energy-level diagram. They drew orbit diagrams instead, mismatched the energies and the principal quantum numbers, or did not understand the meaning of the negative energies associated with the atomic orbits.

In parts (b), (c), and (d) many students confused the energies of different levels with the change of energy between levels.

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?

- Spend time on atomic structure with students, even with those who have taken chemistry.
- Help students to identify and label energy levels and to develop a good understanding of electron transitions and their associated energy changes.