Student Performance Q&A:

2010 AP® Physics B Free-Response Questions

The following comments on the 2010 free-response questions for AP® Physics B were written by the Chief Reader, Jiang Yu of Fitchburg State College in Massachusetts. 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 designed to assess students' knowledge of projectile motion, conservation of energy, conservation of momentum, and inelastic collisions.

How well did students perform on this question?

The mean score for this question was 7.03 out of a possible 15 points. Students either did very well or not well at all. Most scores were under 5 or above 10, with very few in between.

What were common student errors or omissions?

The most common error on part (a) was using the standard equation for the period of a spring to determine the time for the mass to fall. Another common error was mixing up the horizontal and vertical information given. Some students also used the horizontal and vertical distances given along with the Pythagorean Theorem to calculate the displacement and then used that calculation in the kinematics equation to figure out the time for the mass to fall.

The most common error for part (b) was to apply the acceleration due to gravity to the horizontal motion. Students mixed the vertical information with the horizontal information to solve for the speed of the mass when it left the table.

Many students used the appropriate concept of conservation of energy in part (c). However, the most common error was to use incorrect forms of energy. For example, gravitational potential energy was used instead of kinetic energy.

Instead of using conservation of momentum in part (d), many students used conservation of energy. They used several different forms of energy to solve for the speed of the combined mass and then used kinematics to find the distance.

Finally, in part (e) the most common error was checking the $E_1 = E_2$ space and then justifying it by saying that energy is always conserved. Few students recognized that the kinetic energy in an inelastic collision is not conserved.

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 were required to apply the law of conservation of momentum in part (d). However, many students used ideas of energy conservation. This could imply that students need to be assigned more problems that are combinations of concepts (as was the case with this problem, in which ideas of projectile motion, conservation of energy, and conservation of momentum were all combined) in order to give them more practice in determining an appropriate approach to solving problems. Teachers are encouraged to include the laws of conservation of energy and momentum in topics other than mechanics as well. Teachers should also make sure that students know the difference between elastic and inelastic collisions and how energy behaves in each type of collision.

Question 2

What was the intent of this question?

This question was based on a hydrostatics experiment. Parts (a) and (b) evaluated students' ability to deal with equilibrium situations in a fluid mechanics setting. Parts (c) through (e) asked them to analyze and interpret experimental data. This question in particular gave students with strong laboratory skills a chance to show their knowledge.

How well did students perform on this question?

The mean score for this question was 8.34 out of a possible 15 points, which represents very strong performance, especially for a lab-based question. For many years the AP Physics courses have emphasized laboratory experience and experimental skills. It seems that many students and teachers are taking that message to heart. Many students — even those who struggled with the first parts of the question — earned substantial credit for graphing and interpreting their data.

What were common student errors or omissions?

Part (b) asked for a derivation; yet many students simply wrote down the correct answer without starting from a statement of hydrostatic equilibrium.

In parts (c) through (e) it was clear that some students had never before graphed experimental data. A significant number did not know how to scale axes or draw a best-fit line. By far the most common mistake was to misinterpret the physical meaning of the slope of the best-fit line — for example, as the density. In fact, since the volume of displaced oil is equal to m_s/ρ_o, the slope of the V_o versus m_s graph is the *inverse* of the oil's density.

Finally, numerous students stated the oil's density without giving proper units or with far too many significant figures, or both.

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 development of laboratory skills takes practice. AP Physics Exams require students to make and interpret graphs. Thus teachers should require students to learn proper data-graphing techniques, especially scaling axes, plotting data, and drawing best-fit lines or curves (rather than connecting point-to-point). Furthermore, laboratory exercises should emphasize interpreting the *physical* meaning of the slope and intercept of linear graphs.

Question 3

What was the intent of this question?

The intent of this question was to determine students' understanding of various electrical concepts pertaining to point charges, as well as fundamental mechanics concepts involving the vector nature of force. Part (a) asked students to determine the signs of two point charges that together would produce a given direction of net electric force on a third point charge in a triangle formation, as seen in the given diagram. Part (b) asked students to draw the force vectors acting on this third point charge from the first and second point charges. Part (c) then asked students to calculate the magnitude of the net electric force acting on the third point charge, while part (d) had the students calculate the net electric field experienced by the third point charge. Finally, part (e) asked the students to determine a suitable location for a fourth point charge that could result in there being zero net electric force on the third point charge, and to justify their choice.

How well did students perform on this question?

The mean score for this question was 4.53 out of a possible 10 points. The distribution of scores was far from Gaussian, with the full spectrum of scores nearly equally represented. The question did a very good job of discriminating between all levels of student understanding of this topic.

What were common student errors or omissions?

In part (b) many students failed to label their vectors, while others did not draw vectors that were unambiguously acting on the point charge in question.

In part (c) many students did not add the two forces as vectors, instead performing a scalar sum. Of those students who did perform the vector addition, students who used the Pythagorean Theorem generally did well. Students who chose a components-based approach frequently made errors in their use of trigonometry or algebra in determining and adding the components. Finally, many students had difficulty with the fact that one of the charges was negative. These students often incorporated the negative in their calculation of force, which frequently led to confusion with the directions of the components.

In part (d) many students failed to recognize that the force from part (c) could be used to determine the electric field in one step. These students attempted to determine and then add the individual contributions to the electric field from each of the other two charges, which led to many of the same challenges discussed above. Responses for this part also showed a frequent lack of knowledge of the unit for electric field. Among the many erroneous units that appeared, tesla was surprisingly common.

In part (e) students were generally able to determine the correct location but were often unable to provide a cogent justification for it. Many students were under the impression that the point charges were in motion, despite being told that the charges were "fixed in place."

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 relationship between field and force, and the directional nature of such vector quantities.
- Give more emphasis to the importance of drawing free body diagrams.
- Give students plenty of practice adding vectors, including vectors that are not aligned in a "preferred" orientation such as horizontal or vertical.
- Provide students more opportunities to recognize when a result from one part of a problem should be used in a subsequent part, and more practice in responding in words rather than equations.
- Remind students to include units for all numerical answers.

Question 4

What was the intent of this question?

The intent of this thermodynamics problem was to assess students' understanding of concepts such as efficiency, power output, power input, and determination of force on an object moving at constant speed. The second section of this question involved interpretation and analysis of a *PV* diagram: understanding what the area bounded by the path represented, determination of power output, and recognition of paths involving heat energy added or removed during the process.

How well did students perform on this question?

The mean score for this question was 3.61 out of a possible 10 points. Students confused work and power in both equations and units. A large number of students inappropriately used concepts for power and pressure. Some students attempted to use the equation for heat conduction or electrical power to solve portions of this problem. Students were not familiar with the pressure versus volume diagram; many were unable to correctly calculate the area enclosed and could not distinguish between processes that involved heat energy added to or removed from the system. Many students could not explain what was represented by the area of the cycle plotted on the *PV* diagram.

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 would have scored higher on this problem if they had shown their work and attached proper units to their answers. There were answers that had units for "rate of heat delivered" in K/sec, °C/sec, W/sec, W/time or J/time.

The Exam Readers encountered a large number of stand-alone numbers with absolutely no work shown and no units attached, basic mathematical errors, incorrect algebraic manipulations, and incorrect use of power of 10 notation. Quite a few students simply dropped the power of 10 in the second step of the solution. Many were not correctly using 0.12 for 12 percent and divided by 4 rather than multiplying by 4 (or dividing by 0.25) when determining the power output in part (c)(ii).

Along with more work on thermodynamic process concepts, students need practice manipulating equations and correctly using basic mathematics.

Question 5

What was the intent of this question?

This question probed students' knowledge of refraction, total internal reflection, changes in light waves as they travel between different media, and thin film interference.

How well did students perform on this question?

The mean score for this question was 2.68 out of a possible 10 points. Most students could successfully apply Snell's Law to solve for θ_2 in the first part. Students did not do well justifying the necessary modification to the setup to achieve total internal reflection. Although most students could identify the formula for the critical angle, many interpreted the meaning of the critical angle incorrectly. The majority of students did not attempt the last part concerning the minimum film thickness.

What were common student errors or omissions?

Many students lacked a good understanding of total internal reflection. They used the formula for the critical angle in part (b) to calculate an angle that should be θ_3 but incorrectly identified it as θ_1. Many students were unable to use geometry and Snell's law to determine the changes in θ_1 and θ_2 that would result in the total internal reflection at the right side of the prism. In part (c) many students did not know the relationship between index of refraction and wavelength and failed to use the basic wave equation to obtain the wavelength in the film. Most students were unable to determine the appropriate relationship (one-fourth wavelength) between the wavelength of the light in the film and the thickness of the film that would create destructive interference for the red light.

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 give students more practice in the following areas:

- Solving problems related to Snell's law — students need to know that the index of refraction of air is 1.
- Performing laboratory experiments to become familiar with the behavior of light as it travels from one medium to another, as well as situations that will result in total internal reflection.
- Determining the wavelength, speed and frequency of waves as they travel across boundaries between media.
- Finding relationships between film thickness and wavelength for constructive or destructive interference with various combinations of indices of refraction for the film and surrounding media.

Question 6

What was the intent of this question?

This question was designed to assess students' understanding of magnetic induction and magnetic force on current-carrying wires.

How well did students perform on this question?

Not well! The mean score for this question was 1.90 out of a possible 10 points. There were many blank responses and zero scores.

What were common student errors or omissions?

Students frequently misapplied the right-hand rule to determine the direction of the induced current in part (a). Many times they believed there was a force to the right (pushing the car into the magnetic field) and misinterpreted this as the magnetic force. Some students seemed to have difficulty interpreting the diagram. A surprising number of students showed currents going perpendicular to the wire or flying through midair as if they were charged particles going through a uniform field, like a mass spectrometer.

In part (b) students frequently attempted to solve Ampere's law for the current instead of finding the emf from Faraday's law (or from the motional emf equation, $\mathcal{E} = B\ell v$) and then applying Ohm's law to find the current. Students attempting this method substituted x for r and then used x for ℓ in the equation for magnetic force in part (ii), $F_B = BI\ell \sin\theta$.

In part (c) many students recognized the net force is zero, but they failed to explain it by asserting that the current is zero. Instead, they often tried to argue that the magnetic forces on each side of the rectangle balance out to zero. In fact, because the current is zero, there are no magnetic forces to balance out. Also, attempting to justify that the net force is zero because the sum of the forces is zero (without further details) is redundant. A surprisingly large number of students interpreted part (c) as if the cart were now at rest and claimed that the flux is not changing because the cart was not moving. There were even a few students who thought the velocity was zero in part (a) because velocity was mentioned only in part (b).

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?

- Make sure to cover magnetism. A large number of students claimed their classes never covered this material.
- Use standard language when teaching the right-hand rules. Students attempted to employ an astounding variety of right-hand rules, and even quite a few left-hand rules. Use of the conventional right-hand rules as they are presented in textbooks would make students' responses more comprehensible.
- Ensure that students understand motional emf before introducing magnetic flux and Faraday's and Lenz's laws. Students could have answered the entire question perfectly in terms of motional emf, without the wordy and confusing language associated with "changing magnetic flux."
- Help students understand magnetic induction in the simplest possible terms. Many students were confused about "flux," claiming the magnetic flux was zero in part (c) when

in fact it was at maximum. Apparently they thought that “flux” somehow implies a “change.”

- Train students not to restate the question, and not to use redundant or repetitive language (for example, “the net force is zero because the sum of all the forces is zero”).
- Train students how to answer “justify” questions appropriately and logically. Many students either understood the concepts or understood the math but could not do both. Help students hone their skills in both areas.

Question 7

What was the intent of this question?

The intent of this question was to assess students’ knowledge of the photoelectric effect. In part (a) students were asked to calculate the frequency of light given its wavelength. In part (b) they had to find the work function of the metal surface. In part (c) students were asked for the stopping potential for the electrons. Part (d) asked students to calculate the momentum of the electrons given the kinetic energy maximum.

How well did students perform on this question?

The mean score for this question was 3.15 out of a possible 10 points, which is a little higher than in some years for a modern physics question, possibly because the question was primarily calculations.

What were common student errors or omissions?

In part (a) some students demonstrated a lack of understanding of the speed at which light travels. The students used the kinetic energy maximum to calculate the value of the speed. Another mistake was to use Planck's equation for energy ($E = hf$) to calculate the frequency. Another fairly common mistake was incorrectly converting nanometers to meters.

In part (b) a large majority of students correctly substituted the appropriate values in the photoelectric effect equation, but quite a few of them made algebraic mistakes when solving for the work function.

For part (c) the most common mistake was the claim that the kinetic energy maximum was equal to the stopping potential, which resulted in a failure to address the conservation of energy.

Finally, in part (d) the most common misunderstanding was calculating the momentum of the electron using the de Broglie 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?

Teachers can help their students by deemphasizing equation-hunting strategies and instead encouraging students to identify the relevant concepts prior to seeking a specific equation. Students should also know the importance of showing all their work, keeping track of units in numerical substitutions, and writing the units in their final answers.