CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2008 AP® Physics B Free-Response Questions

The following comments on the 2008 free-response questions for AP® Physics B 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?

This question was intended to test students' ability to analyze a one-dimensional mechanics problem that involved motion with constant-velocity and constant-acceleration stages and that utilized momentum conservation in collisions.

How well did students perform on this question?

Almost all students attempted this question, and the mean score was 4.68 out of a possible 10 points. About 18 percent of students earned scores of 8 or higher, while about 29 percent earned scores of 2 or below.

What were common student errors or omissions?

In part (a) many students failed to recognize that the precollision motion of car *A* had two distinct stages: constant acceleration and then constant velocity. It appeared that many students may have failed to read the entire prompt for part (a).

In part (b) students often assumed that the velocity of car *A* at impact was $2\ \text{m/s}$ (the speed before accelerating given in the initial prompt) rather than the $5\ \text{m/s}$ given in part (a). They often equated the final momentum of each car, rather than equating the total momentum of the cars before the collision with the total momentum after it. About 20 percent of students assumed that kinetic energy was conserved in the collision; about 10 percent assumed that velocity was conserved.

In part (c) the majority of students did not fully understand the meaning of the word “elastic.” Many thought that it meant partially elastic; others thought that if a collision was not elastic, then it must be perfectly inelastic. Still others thought all collisions were elastic. Many thought that the collision was elastic because the cars did not stick together. However, most students knew that the word “elastic” is related to kinetic energy.

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 should read each question carefully and be aware that definitions of words in physics are precise. If they had followed these good practices, many students would have doubled their score on this question.

Question 2

What was the intent of this question?

Students were given a system of two blocks connected by a spring, moving on a frictionless surface under the influence of a constant force applied to one block. The two blocks had the same acceleration. This question tested students’ ability to appropriately define a system when applying Newton’s second law, as they were asked to calculate the force exerted by the spring and the stretch in the spring. Students were then asked to analyze the same system when the same force is applied to the other block. They were to decide how (if at all) the acceleration and extension of the spring differed from before, and they had to justify their answers. Again, the key was to apply Newton’s second law to the appropriate system.

Finally, in a section that was independent of previous parts of the problem, students had to apply conservation of energy to find the compression in the spring after one of the blocks underwent a completely inelastic collision with a wall, given the initial velocity of the blocks.

How well did students perform on this question?

The mean score was 6.60 out of a possible 15 points. Approximately 19 percent of students earned scores of 12 or higher, while about 30 percent earned scores of 3 or below.

What were common student errors or omissions?

Throughout the first four parts of this five-part problem, a common error was treating the 4.0 N applied force as the net force acting on the leading block. Students failed to recognize that the force exerted by the spring could only be neglected if the two blocks were treated as a system, thereby making the force exerted by the spring an *internal* force. Many students believed the answer to be given—that if you pull on the first block with 4.0 N of force, thereby stretching the spring with 4.0 N, the spring pulls back with the same force, an apparent misunderstanding of both the second and the third laws.

Part (b) was a simple application of Hooke’s law, using the force exerted by the spring to calculate the extension of the spring. A surprising number of students used potential energy interchangeably with force when answering this part. More than a few students seemed unfamiliar with the term “extension.” Many did not see the connection between part (b) and the force exerted by the spring calculated in part (a).

Some of these students even ignored a correct answer in part (a) and reverted to the "obvious" value of 4.0 N for the force exerted by the spring when applying Hooke's law.

Part (c) asked about the acceleration of the system when the force is applied to the other block. Many students answered this part correctly and provided justifications that were (at least partially) correct. Many students gave a logically circular justification, merely restating their conclusion or the given information. The wording in the stem of the question seemed to have confused some students. They believed that the phrase "equal constant acceleration" meant that the acceleration is equal to what it was in the first part and that it remains constant throughout the problem (as opposed to constant with respect to time). Therefore, they used the wording in the question as the justification for their answer.

Part (d) asked students to compare the stretch in the spring when the external force is applied to the less massive block to the stretch when the force is applied to the more massive block. Students who provided verbal justification had great difficulty articulating a coherent response. Although they were told that the surfaces were frictionless, many invoked static friction. Students made frequent references to "overcoming inertia" and to the more massive block providing "more resistance to being dragged" or being "harder to get moving." Variations on this last answer were very frequent, arising from an alternative view of the situation described in the problem. A significant fraction of students imagined the system starting at rest; the external force is then applied to one block, putting it into motion, and the second block is pulled by the extended spring. In this view of the problem, if the second block is more massive, its displacement is less than that of the first block. (Remember that for these students, the statement that the blocks have equal acceleration was not taken to mean that they are equal to *each other*.) In hindsight, it is not surprising that this was a frequent misinterpretation. The state of motion described in the problem is somewhat contrived; to actually produce that motion would require artful preparation of the system.

Part (e) was conceptually separate from the previous parts, and many students were unable to even approach a solution, though they had no trouble with applying Newton's laws in the prior parts. Conversely, numerous students left parts (a) through (d) mostly blank but then provided correct solutions to this part. Of those who attempted a solution using energy conservation but did not succeed, the most common error was the use of an incorrect mass (usually the total mass) or an incorrect initial velocity (which students attempted to find by applying momentum conservation to the inelastic collision). In addition to errors with algebra or calculator use, or the neglect of exponents, there was also confusion of energy and force. For example, some students calculated the initial kinetic energy and then set it equal to kx. Many students attempted to use kinematic equations appropriate to motion with constant acceleration.

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 should be encouraged to read each question *carefully*. Taking time to digest the situation that has actually been presented can reduce the tendency to substitute an alternative scenario of the student's own devising.

The more students are required to justify their thinking, whether on homework, in the lab, or on exams, the better they should perform on tasks such as those given in this problem. Students need explicit instruction on what constitutes a valid (noncircular) argument based on fundamental principles. Students should also be reminded that legible writing is critically important.

The difficulty that many students seemed to have in picturing the behavior of the system described in this problem may be reduced by giving them opportunities to actually observe the motion of such systems, either in the lab or in classroom demonstrations.

Question 3

What was the intent of this question?

Part (a) assessed students' understanding of the relationships among resistance, resistivity, length, and area for a wire, in the context of a wire connected across a power supply. Concepts of series resistance and Ohm's law were also needed to answer the question. Part (b) assessed understanding of the force on a current-carrying wire in a magnetic field and the corresponding reaction force on the magnet. Understanding of magnetic field directions, application of an appropriate hand rule, and Newton's third law were needed to answer this part of the question. Part (c) assessed application of the equation $F = BI\ell\sin\theta$. Part (d) assessed students' ability to explain how a change in the orientation of the wire loop would affect the experiment results. For part (e) students had to interpret experimental results and provide a rationale for experimental error.

How well did students perform on this question?

The mean score was 5.25 out of a possible 15 points. Approximately 6 percent of students earned scores of 12 or higher, while about 38 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) the most common method used was to substitute the internal resistance of the power supply for the total resistance.

In part (b) most students found the direction of the magnetic force on the wire, not the force on the magnet. Students had difficulty providing complete justification for the direction of the force on the magnet.

Students performed well on part (c) since it simply involved substituting given information into the equation $F = BI\ell\sin\theta$. However, many students substituted their answer from part (a), the total length of the wire, instead of the length of the lower wire segment.

Students generally did well on part (d).

Only a small percentage of students were able to answer part (e) correctly.

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?

Part (a), which involved three separate equations, showed that students need practice solving multiple-step problems. Students need to read questions carefully to make note of all the given information. They need to be able to explain what they are doing when finding magnetic force direction with a hand rule. When justifying a direction of magnetic force, merely stating "right hand rule" and giving a direction is insufficient. Students should know that sketching a theoretical relationship between two variables means sketching a line or curve of best-fit. Students should be able to translate between different representations of theoretical relationships, graphical or formulaic. Students should practice analyzing experimental procedures and data to determine reasonable causes of systematic error. In this case specifically, students needed to understand that the lower magnetic field strength at the edges of the poles would reduce the magnetic force on a wire whose length approaches or exceeds the width of the poles.

Question 4

What was the intent of this question?

This question tested students' knowledge of projectile motion, fluids, and the application of the Bernoulli equation.

How well did students perform on this question?

The mean score on this question was 2.23 out of a possible 10 points. About 4 percent of students earned scores of 8 or higher, about 60 percent earned scores of 2 or below, and 37 percent earned a score of 0 or wrote no response for this question.

What were common student errors or omissions?

In part (a) many students made errors in treating projectile motion. Most students who attempted part (a) solved for the vertical velocity alone, not realizing that this is only one component of the answer.

In part (b) the most common mistake was not knowing the correct area of a circle.

In part (c) very few students recognized the need for the full Bernoulli equation, incorrectly using the gauge pressure equation instead.

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?

More work on projectile motion is needed. Given two variables, students should be able to find any component of a projectile problem. They should also have more practice with fluid mechanics problems, including use of the full Bernoulli equation.

Question 5

What was the intent of this question?

The intent of this question was primarily to determine students' ability to interpret a pressure versus volume graph and secondarily to determine their ability to correctly use the ideal gas laws for specific thermodynamic processes. Parts (a) and (b) investigated understanding of different forms of energy and their roles in thermodynamic processes, including understanding of the specific relationships among work, internal energy, and heat. Part (c) focused on the ideal gas law.

How well did students perform on this question?

The mean score on this question was 3.02 out of a possible 10 points. About 10 percent of students earned scores of 8 or higher, about 52 percent earned scores of 2 or below, and 31 percent earned a score of 0 or wrote no response for this question.

What were common student errors or omissions?

By far the most common mistake was confusing the concepts of "heat" and "temperature." An increase in the temperature of a gas does not necessarily mean that heat must have been added to that gas. It is only in the cases of constant or increasing volume that increasing temperature implies added heat. However, many students stated that Q was positive because "heat goes up when temperature goes up." These students apparently did not have a clear understanding of heat as a *transfer* of thermal energy.

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?

It is not sufficient for students to be able to do simple calculations with the first law of thermodynamics. Students must understand precisely what is meant by heat added to a gas, work done on a gas, and internal energy of a gas. Students must also be able to articulate in words these concepts, their relationship, and their role in a thermodynamic process. Attention should be paid to students' use of language: when Q is positive, that does not mean that "the heat is increasing"; rather, it means that heat was added to the gas. In this way, students might be more likely to understand the first law of thermodynamics as an expression of the conservation of energy.

Many more students indicated the correct signs of W, Q, and ΔU for process $A \rightarrow B$ than for the other processes, perhaps because the question required students to explain their answers. By verbalizing their understanding, they managed to get the mathematical symbols correct. If students are consistently required to express themselves in words in the classroom, they may be able to better demonstrate their knowledge during exams.

Lastly, students should use the sign convention for W as printed on the equation tables in the exam booklet and in the *AP Physics Course Description*. Work done *on* a gas is considered positive. Although some textbooks use the opposite sign convention, for success on the AP Exam students need to be acquainted with the stated AP convention.

Question 6

What was the intent of this question?

The intent of this question was to test students' understanding of the properties of reflection by asking them to draw a diagram. The question examined whether students know the difference between a real and a virtual image, and whether they know how images are formed. It also tested whether students are able to calculate the position of an image.

How well did students perform on this question?

Overall, students did well on this question. The mean score was 5.50 out of a possible 10 points. There were many perfect scores (15 percent of the exam-takers). About 32 percent of students earned scores of 8 or higher, while about 24 percent earned scores of 2 or below.

What were common student errors or omissions?

Many students completed this problem as if the mirror were a lens. Some students may have misinterpreted the shading behind the mirror as representing lens material.

In part (a) many students did not show reflection from the mirror when they drew a ray through the center of curvature. Some students circled the intersection of the reflected rays instead of drawing the image. Some students simply drew a line, omitting the arrowhead, which gave an incomplete image. Many students did not utilize a straightedge, causing the image location to be quite far from the actual location.

In part (b) many students worded their answer in an incomplete or unclear manner (e.g., “the image is on the same side” or “the image is outside the mirror”). Many students cited rules for converging mirrors but did not demonstrate understanding of why the image is real.

In part (c) many students plugged in a negative focal length or object distance. Other students made algebraic mistakes or substituted 8 cm for the image distance and solved for the object distance.

In part (d) students did not distinguish very well between reflected rays and extrapolated rays. Some students drew all solid lines, some drew all dotted lines, and others drew some of each, but not consistently (e.g., a student might show one reflected ray was solid and another dotted). Many students showed only the incident and extrapolated rays and not the reflected rays. Some students did not draw the image, or they did not draw the image where the projected rays intersected. Many students worded their answer in an incomplete or unclear manner (e.g., “image is virtual, so it’s smaller” or “because it’s a diverging mirror”). Many students incorrectly identified the mirror of part (d) as concave or converging. Many students simply stated the rules for diverging mirrors rather than justifying them through mathematics or a diagram. Some students used the image distance from the converging mirror in part (c) to get the incorrect magnification. Some students divided the image distance by the focal length instead of dividing by the object distance and thus obtained an incorrect value for the magnification.

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?

More teachers need to cover optics as a part of their course. When teaching optics, teachers are encouraged to spend less time on mnemonics and the memorization of rules and more time on the “why.” Students were able to “plug and chug” in part (c) and recite rules for images in the justification sections, but many students had difficulty justifying their answers, apparently because of an incomplete understanding of the physics behind image formation.

Question 7

What was the intent of this question?

The intent of this question was to test students' knowledge of topics in modern physics, specifically wave-particle duality and the photoelectric effect. In part (a) students were asked to calculate the momentum of an electron given its de Broglie wavelength. In part (b) they had to find the kinetic energy of the electron. In part (c) students were asked for the accelerating voltage required to create the beam of electrons. Part (d) asked students to calculate the threshold frequency given the work function of a tungsten cathode.

How well did students perform on this question?

Overall, students did not perform very well on this question. The mean score was 1.90 out of a possible 10 points. About 6 percent of students earned scores of 8 or higher, about 75 percent earned scores of 2 or below, and 45 percent earned a score of 0 or wrote no response for this question.

What were common student errors or omissions?

In part (a) the most common mistake was in the unit conversion of the electron wavelength from nanometers to meters.

A large majority of students thought that part (b) was related to a photoelectric effect process, and they erroneously calculated the kinetic energy maximum instead of using the momentum value from part (a) to find the kinetic energy.

In part (c) many students failed to recognize that the decrease in electric potential energy is equal to the increase in kinetic energy.

In part (d), among those students who were aware of the fact that the kinetic energy maximum is zero, a majority successfully found the minimum frequency. The most common error was to use the value of the kinetic energy found in part (b) as the kinetic energy maximum in the photoelectric effect.

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. More emphasis should be given to unit analysis. Students should also know the importance of showing all of their work and keeping track of units in numerical substitutions.