CollegeBoard
Advanced Placement
Program

Student Performance Q&A:

2007 AP® Physics B Free-Response Questions

The following comments on the 2007 free-response questions for AP® Physics B were written by the Chief Reader, William 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 designed to measure students' understanding of several topics in mechanics: basic kinematics, Newton's second law, and kinetic friction. Part (a) asked a simple question involving constant-velocity motion of a sled on an incline. Part (b) asked students to draw the free-body diagram for the sled. In part (c) they had to calculate the frictional force on the sled and in part (d) find the coefficient of sliding friction. In part (e) students were told that the sled reached horizontal ground at the bottom of the incline, and they were asked to describe the subsequent motion and sketch a graph of speed versus time.

How well did students perform on this question?

The mean score on this 15-point question was 8.17. About 31 percent of students earned scores of 12 or higher, while about 19 percent earned scores of 3 or below.

What were common student errors or omissions?

The most common error had to do with the free-body diagram in part (b). Many students drew the vectors either without proper labels and/or arrowheads, or else they detached the vectors from the dot that represented the free body. Many students attempted to draw the weight vector as components but did so incorrectly. The errors in parts (c) and (d) frequently had to do with interchanging sine and cosine of the relevant angle. Although the two subparts of part (e) were really different versions of the same question, many students graphed a motion that was not consistent with their verbal description.

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 emphasize the proper rules for drawing free-body diagrams. Drawing correct free-body diagrams is a fundamental skill for students, yet it appears that many students are using teacher-directed patterns that are simply not correct. Teachers should also emphasize and re-emphasize the descriptions and meanings of graphs of motion, as well as the meanings of words such as "*describe*," "*calculate*," "*justify*," and so on.

Question 2

What was the intent of this question?

This question was intended to assess students' understanding of the motion of charged particles in electric and magnetic fields. Ions of charge +2*e* were accelerated by a potential difference $\mathcal{E}$ and then directed into a region containing a uniform magnetic field. The ions followed a semicircular path inside the magnetic field. Part (a) asked students to determine the direction of the magnetic field, and in part (b) they had to demonstrate a conceptual understanding of the circular motion of the ions. In part (c) students were expected to calculate the velocity of the ions. Part (d) asked students to determine the accelerating voltage of the ions.

How well did students perform on this question?

In general, students performed poorly on this 10-point question. The mean score was 1.91. About 7 percent of students earned scores of 8 or higher, while about 73 percent earned scores of 2 or below.

What were common student errors or omissions?

In part (a) common student errors included:

- Being confused about the use of the right-hand rule as it applies to the Lorentz force.
- Confusing the positively charged particles with electrons.
- Supposing that the ions are pushed in the direction of the magnetic field, so that the magnetic field must point either left or down or somewhere in between.

In part (b) many students did the following:

- Simply restated the stem of the question by writing, "The particle is moving at constant speed because it is in a uniform magnetic field."
- Used the words "*centripetal force*" without identifying the source of this force.
- Attempted to use a scalar force equation to argue that the velocity must be constant because all the other variables were constant; these students failed to recognize that the relative directions of the force and velocity are responsible for keeping the speed constant.

In part (c) common errors included:

- Inventing a value for F_B and then using $F_B = qvB\sin\theta$ to solve for v .

- Supposing the gravitational force *mg* is responsible for the downward force that directs the ions along the curved path.
- Using $\mathcal{E} = B\ell v$ or other inappropriate equations from the list provided.
- Using incorrect substitutions of numerical values for the variable quantities.

In part (d) many students did the following:

- Failed to recognize that the decrease in electric potential energy is equal to the kinetic energy increase.
- Used the equation for accelerating voltage for motional emf ($\mathcal{E} = B\ell v$) inappropriately (this was the most common error).

In part (d) some students attempted to use $U_C = \frac{1}{2}QV$, the energy stored in a capacitor, instead of $U_E = q\mathcal{E}$ for the electric potential energy decrease of the charged particle. There were also common errors of substitution of numerical values.

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 have performed well on questions with topics such as uniform circular motion and conservation of energy within the context of mechanics. However, they do not seem to recognize that the same principles apply when the context is electromagnetism. Teachers can help their students by emphasizing "the big picture." Teachers should also de-emphasize equation-hunting strategies and instead encourage their students to recognize the appropriate concepts first before seeking a specific equation.

Question 3

What was the intent of this question?

This question's purpose was to investigate students' knowledge of an electrical circuit containing a set of two parallel resistors in series with another resistor and a battery. The parts of this question required both conceptual and computational responses. Parts (a) and (b) assessed students' conceptual understanding of the circuit by asking for rankings of currents through, and voltages across, the resistors, along with justifications for those rankings. Parts (c) and (d) asked for calculations of the equivalent resistance for the whole circuit and of the current through a particular resistor. Part (e) required a calculation of steady-state capacitor charge when one of the parallel resistors is replaced by a capacitator.

How well did students perform on this question?

The mean score on this 15-point question was 6.04. About 19 percent of students earned scores of 12 or higher, while about 37 percent earned scores of 3 or below.

Most students could not do the conceptual parts, (a) and (b), of the problem. They did not understand the basic governing principles of voltages and currents in circuits. Some could do the rankings but either omitted the justifications or wrongly justified their rankings. Even when they seemed to understand the physics, they struggled to clearly articulate their reasoning. The voltage justifications proved to be more difficult than the current justifications for most students.

Many students could do the equivalent circuit resistance calculation in part (c) and the current calculation in part (d). However, many others struggled to calculate the current even after finding the equivalent resistance. They either did not see that these two parts of the problem were directly related or they were confused or mistaken about what current to find. Many other students did not understand the circuit at all in terms of which resistors were in series and which ones were in parallel.

Almost all students did poorly on part (e). Fewer than 5 percent of the students understood that replacing one resistor with a capacitor changes the properties of the circuit.

Many students could not do both the conceptual and the calculational parts of this problem together. If they got anything at all, they got only one part or the other; there seemed to be a large disconnect between the two parts. Many students only did or attempted the calculation in part (c), leaving the rest of the problem blank.

What were common student errors or omissions?

The most common errors in parts (a) and (b) were related to misunderstandings about current and voltage in a circuit. Students indicated that:

- Current could be trapped or used up in a resistor.
- R_A used up all or part of the current, with the rest left over for the parallel part.
- R_A received the most current because it was physically first in the circuit.
- Voltage flows or travels or passes through a circuit.
- Voltage gets to R_A first.
- Voltage gets spent in a resistor.
- Resistors draw voltage.
- A resistor has the most voltage because it is physically close to the battery.
- Voltage always splits equally between resistors in parallel.
- Voltage splits equally between resistors in series.
- Resistors in parallel have the same current, and resistors in series have the same voltage across them (a reversal of the roles of series and parallel resistors).
- All three resistors had the battery voltage across them.
- The physical height, the location, or the orientation of the resistors and battery in the drawing conveyed the value of the voltage across a resistor.

Students also tried to argue wrongly in terms of power in parts (a) and (b).

The most common errors in parts (c) and (d) were:

- Misunderstanding the circuit: many students had R_A and R_B in series, with R_C in parallel with them; others had R_A and R_C in series, with R_B in parallel with them; still others had all three in either series or parallel.
- Not uncoupling the series part from the parallel part in computation: putting all three in series or parallel in the equation; trying to write the whole solution in one equation and getting something mixed up; forgetting to reciprocate the inverse of the parallel resistance before adding it to the series resistance.
- Incorrectly performing reciprocal algebra operations.
- Thinking that equivalent resistance referred only to the parallel portion of the circuit.
- Uncoupling part (d) from part (c) in the sense of starting the calculation for part (d) over again with a totally different resistance in series with the battery (typically, 200 ohms or 400 ohms).
- Thinking that I_{total} was the same as I_C so that R_A and R_C were in series.
- Using the voltage across V_A (i.e., 9V) as the voltage across R_C.
- Mixing up the general formulas (from memory?) for the amount of current going through a parallel set of resistors so that, in this case, one-third went through R_C and two-thirds went through R_B.

Many students left part (e) blank. Among those who completed it, the two most common errors were:

- Using the battery voltage for the capacitor voltage.
- Using the voltage across R_C from part (d) as if replacing a resistor with a capacitor had not changed the circuit.

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 be certain to use precise and correct words when describing the properties of currents and voltages. Students should be learning both the conceptual description of circuits and the calculations needed, and teachers should be placing special emphasis on connecting conceptual understanding and calculations. Shortcuts that can be memorized for solutions to circuit problems ultimately do not help the student. Basic conceptual understanding and good calculational skills will stand students in good stead for any type of problem. Students need to learn to write clearly about physical phenomena, a skill that requires practice. Students need to know how to organize their calculations in a clear and straightforward way; illegible and/or poorly organized writing or calculations cannot be scored well.

Question 4

What was the intent of this question?

This question was intended to evaluate students' understanding of fluid motion. Part (a) judged their ability to calculate the volume flow rate of water through a hole, given the total volume collected during a specified time interval. In part (b) students were asked to calculate the flow speed based on the hole's diameter and volume rate, and in part (c) to calculate the height of the water surface, based on the speed obtained in part (b). In part (d) they had to decide how the height of the water surface affects the point along the tabletop at which the water stream lands.

How well did students perform on this question?

The mean score on this 10-point question was 4.49. About 15 percent of students earned scores of 8 or higher, while about 27 percent earned scores of 2 or below.

What were common student errors or omissions?

Most students did well on parts (a) and (d), while parts (b) and (c) appeared to be more challenging. The typographical error in part (d) decreased the difficulty somewhat, as the interpretation of the "container" as the "beaker" meant that a very simple explanation ("because the hole is on the right of the beaker") would suffice to justify the "right of the beaker" response, instead of the discussion of height, pressure, and speed that was intended. Nonetheless, this typographical error apparently affected fewer than three percent of exam-takers.

What were common student errors or omissions?

In part (b) students did not know the correct expression relating the volume flow rate to the cross-sectional area of the hole and the speed of the fluid through the hole. This formula is not given directly on the AP Physics B equation sheet. Many students realized the continuity equation from the equation sheet would apply ($A_1 v_1 = A_2 v_2$) but could not get beyond that statement. Many students attempted to use Bernoulli's equation for part (b), which left them with two unknowns. The answer from part (b) was required for part (c), which added to part (c)'s difficulty. Students also had difficulty in part (c) correctly simplifying Bernoulli's equation to obtain an expression they could evaluate with the given information, and many inserted incorrect values for the "constant" in Bernoulli's 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?

It appears that many courses do not include fluids. Students need to practice applying Bernoulli's equation between two points in a flowing system to succeed in this type of problem. Students should be instructed to begin with general equations and principles and to show the steps that are needed to apply these equations and principles to specific situations.

Question 5

What was the intent of this question?

This question was designed to measure students' understanding of thermodynamics. A specified amount of an ideal gas was confined at constant pressure. In part (a) students were asked to calculate the force exerted by the gas on a piston of specified diameter and in part (b) to calculate the volume occupied by the gas, given a specified temperature. A constant-pressure expansion was described in part (c), and students were required to calculate the work done *by the gas*. In part (d) they had to decide whether heat energy was transferred to or from the gas (or not at all) and to justify their choice.

How well did students perform on this question?

The average score on this 10-point question was 4.95. About 20 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?

In answering part (a), students generally knew the relationship $F = PA$ and were able to apply it to the problem. The most common errors here involved determining the area: some students confused diameter with radius, while others misinterpreted the problem, believing the gas to be contained *within* a cylindrical piston.

Part (b) had the highest rate of success for the entire problem. Nevertheless, a large number of students were unsure of the value for R, despite the fact that it was provided in the AP Physics B Table of Information. Many of these students used the value for the radius or Boltzmann's constant in place of R, while others chose to omit any substitution for R. Surprisingly, even though all of the needed values were provided in SI units, many students chose to convert some or all of the values into alternative units, often not consistently. It should also be noted that many students have the misconception that the SI unit of volume is the liter, as shown by their tendency to use liters and cubic meters interchangeably.

In part (c) there were two widely used methods to determine the work done. Students who elected to determine this by $W = Fd$ generally did quite well, as d was provided and F was determined in part (a). In addition, $W = Fd$ directly leads to a correct sign for the work done by the gas. Despite $W = Fd$ being the easier method, the majority of students decided to use $W = -P(\Delta V)$. Many of these students had difficulty in determining ΔV , the two most common errors being either using the initial volume determined in part (b) as the ΔV , or correctly calculating ΔV but mistakenly using it as final volume. In spite of the formula $W = -P(\Delta V)$ suggesting a negative answer, most students were able to correctly identify the work done *by the gas* as being positive, though a significant number failed to do so. Some students used an unnecessarily complex method to determine ΔV . These students first determined the length of the initial cylindrical volume, then added the additional length due to the movement of the piston, then found the final volume, and finally subtracted the initial volume. Few of these students were able to successfully execute the entire series of calculations.

In part (d) approximately half of the students correctly identified that the heat transfer was *to the gas*, with the majority of incorrect choices being heat transfer from the gas. Most of the students who claimed that heat is transferred from the gas gave a justification along the lines of “the gas did work and so it gave off heat,” which reveals confusion between *work* and *heat*.

Very few students who correctly identified the heat transfer as being “to the gas” were able to provide a complete justification. A typical justification was along the following lines: “The gas expanded at constant pressure, heat must have been added to the gas.” This was awarded no points because it is merely a restatement of the given information. Many students correctly gave a partial justification, mistakenly believing that it constituted a full justification. Most of these students correctly gave a justification for an increase in temperature, which they believed automatically implied that heat had been transferred to the gas.

Another common source of error was the mistaken belief that *heat* and *temperature* are synonymous terms. Student responses often included such claims as “since the volume increased at constant pressure, the heat increased.” Those students who attempted to use the First Law of Thermodynamics frequently failed to distinguish between U and ΔU. For example, students would incorrectly claim $\Delta U = (3/2)nRT$. These students arrived at the correct conclusion that ΔU is positive, but for the wrong reason. Other students stated that U did not change during the expansion, perhaps believing that the system was isolated or that the question was referring to an engine cycle.

Many students who fared poorly in part (d) seemed to have based their conclusions on their own private “laws” of thermodynamics, such as “heat makes things expand” or “expansion requires increased pressure.” These erroneous “laws” were sometimes so strongly held that they caused the students to refute given information; for example, students would insist that the pressure increased, despite being told the contrary.

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?

Some of the student errors on this problem were evidently due to careless reading or flawed understanding of the situation described and the information presented. More important, there appear to be some deeply held student misconceptions regarding pressure, temperature, heat, work, and internal energy. Finally, students need practice in keeping straight the distinction between internal energy and *change of* internal energy.

Question 6

What was the intent of this question?

This question was intended to assess students’ basic understanding of geometric optics and students’ facility with explaining an experimental procedure and utilizing data. Part (a) asked students to explain how to determine the focal length of a lens using a distant object, and part (b) directed them to select equipment to be used in making several “optical bench” measurements. In part (c) students were expected to sketch and label their planned experimental setup. Part (d) asked them to plot a set of data and draw a best-fit line on a grid for which both the scales and the variables to be plotted had already been provided. In part (e) they had to use the best-fit line to calculate the focal length of the lens.

How well did students perform on this question?

In general, students did not perform well on this 10-point question. The average score was 3.25. About 6 percent of students earned scores of 8 or higher, while about 47 percent of students earned scores of 2 or below.

What were common student errors or omissions?

Many students had clearly not performed optics experiments and were unprepared to answer parts (a) and (b). It was also evident that students do not have much experience plotting points and drawing best-fit lines. This may reflect an over-reliance on software that performs the fit for them.

A common error in part (a) was to respond that the estimate would be made by measuring the distance from the lens to the tree as well as the distance from the lens to an image on a screen, and then plugging those data into the thin lens equation. (Among students who seemed to have optics lab experience, it appeared that most were familiar only with relatively small object distances.)

Student responses in part (c) were usually missing labels on the equipment, and many students did not include a screen in their experimental diagram.

In part (d) many students either connected neighboring data points or did not draw a reasonable best-fit line. There was also considerable confusion between values for s and $1/s$.

In responding to part (e), most students were unable to properly interpret the graph to find the focal length.

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 spend more instructional time on laboratory work and on the construction and interpretation of graphs.

Question 7

What was the intent of this question?

The final question on the exam evaluated students' understanding of some basic ideas in modern physics: mass-energy equivalence and the conservation of energy; the relationships among photon energy, photon momentum, and the corresponding wavelength; and conservation of the total momentum of an isolated system.

How well did students perform on this question?

In general, students performed poorly on this 10-point question. The average score was 1.78. About 7 percent of students earned scores of 8 or higher, but about 73 percent earned scores of 2 or below, including 31 percent who responded but earned no points and 29 percent who did not respond at all.

What were common student errors or omissions?

In general, students needed to show more work. Many students lost points for only writing the answer and not showing their calculations. Perhaps they are not sufficiently familiar with the distinctions among the verbs "*determine*," "*calculate*," and "*derive*" on an AP Physics Exam.

Common errors made by some of the students included:

- Seeming not to understand the difference between a photon and a proton or other massive particle, and not knowing that particles of nonzero mass cannot travel at the speed of light (they used mv for the momentum of a photon).
- Not paying much attention to units in their calculations, often mixing electron volts and joules in the same calculation.
- Not knowing or neglecting to write the correct units for momentum ($\text{kg}\bullet\text{m/s}$, $\text{J}\bullet\text{s/m}$, or $\text{eV}\bullet\text{s/m}$).
- Not recognizing that the two photons have the same energy, despite the fact that it is clearly implied in the prompt for part (c); these students did *two* calculations in part (c).
- Using incorrect constants, such as confusing the speed of light with the elementary charge. Other students apparently thought that 1 eV is the rest energy of an electron.
- Neglecting the electron's rest energy and thinking that only the positron's rest energy is shared by the two emitted photons.
- Regarding the rest energy as zero because the electron-positron pair has negligible kinetic energy prior to the annihilation.
- Confusing frequency and wavelength.
- Exhibiting poor algebra skills.

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 consider:

- Giving more emphasis to units analysis.
- Discussing the nature of photons as mass-less particles, and contrasting them with massive particles (such as protons), which cannot travel at the speed of light.
- Encouraging students to read problems with a pen or pencil in hand in order to underline or circle important information.
- Emphasizing to students the importance of showing more of their work.
- Requiring students to learn the meaning of each variable in an equation and when an equation is and is not applicable.