CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2006 AP® Physics C: Electricity and Magnetism Free-Response Questions

The following comments on the 2006 free-response questions for AP® Physics C: Electricity and Magnetism 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 explored student understanding of electric fields and electric potentials due to point charges, superposition of field vectors, and the scalar addition of potentials. Students were given four point charges (three negative and one positive) at the corners of a square. In part (a) students were asked to draw the direction of the net electric field at the center of the square. In part (b) they were asked to derive the magnitude of the electric field and the electric potential at the center of the square. In part (c) a positive charge was placed in the center of the four existing charges and then moved to the midpoint of the bottom side of the square. Students had to identify the work done on the moving charge by the field as positive, negative, or zero and explain their reasoning. In part (d-i) students were asked to replace one of the existing charges in order to make the electric field at the center equal to zero. They had to describe the replacement and justify their answer. In part (d-ii) students were asked to replace one of the existing charges in order to make the electric potential at the center equal to zero, yet have a nonzero electric field at that same point. They had to describe the replacement and justify their answer.

How well did students perform on this question?

This 15-point question was attempted by most students: less than 1 percent of the responses were blank. The mean score was 7.79. About 19 percent of students earned scores of 12 or higher, while approximately 16 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) students performed very well. In parts (b-i) and (b-ii) common errors included the following:

Part (b-i):

- Incorrectly calculating the distance from the center of the square to a point charge on the corner.
- Treating the electric field as a scalar and summing the charges rather than the vectors. (Many students may think this is appropriate when trying to find the magnitude of the field.)
- Failing to *derive* the result as instructed. See the *AP Physics Course Description* for a description of the meaning of “derive” and other terms in the context of the AP Physics Exams.

Part (b-ii):

- Attempting to treat the electric potential as a vector and summing only two kQ/r expressions.
- Attempting to obtain the potential by integrating the field—an arduous task if done correctly. The most common approach was to imply that the limits were from 0 to $a/\sqrt{2}$.
- Ignoring the instruction to derive their result.

Students had a difficult time justifying their choices in parts (c) and (d). The major problem was providing a succinct and complete statement. Partial explanations were common.

In part (c) most students correctly identified the work by the field as negative. Partial explanations were common (the potential increases or potential energy increases). There was a fair amount of written confusion about “who is doing what to whom”—i.e., keeping straight which agent does positive or negative work. Most often students avoided a direct discussion of work and talked about forces and fields, but there was a lot of confusion regardless of the approach.

In part (d-i) many students were unclear in their directions for charge replacement. The most common error in justification was to refer to charges canceling to yield a net zero electric field.

In part (d-ii) many students were once again unclear in their directions for charge replacement. It was very common for them to simply restate the question as their justification (i.e., “this would make the potential at the center equal to zero but a net field remains”).

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?

This question was designed to test students’ understanding of *RC* circuits, specifically with the capacitor in both series and parallel to the resistors. In part (a) students were asked to evaluate the circuit and write a differential equation that could be solved. Part (b) required students to solve the differential equation for the charge on the capacitor as a function of time. Part (c) required them to equate the expression for the charge determined in part (b) to the charge in the capacitor at a given voltage. Part (d) asked students to graph the currents in both the first and second resistor as a function of time (after the capacitor is charged and then switch S_2 was thrown).

How well did students perform on this question?

The mean score on this 15-point question was 5.37. About 7 percent of students earned scores of 12 or higher, while approximately 37 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) the final correct answer required an understanding of the loop rule, knowledge of the voltage across both a resistor and a capacitor, and understanding of the time dependence of current. A majority of students wrote an incomplete or wrong expression for the differential equation. The most common mistakes were providing incorrect loop equations and incorrect voltage for the capacitor, and omitting the expression of current as dQ/dt.

The solution to part (b) needed a differential equation from part (a) to solve. Many students had incorrect differential equations, which led to incorrect answers here. It was also evident that a number of students had memorized the equation for a charging capacitor or had it stored in their calculators. Some students showed no work and simply wrote down their proposed final result. For students who got the differential equation correct, the most common error came in the integration, which required them to use separation of variables and the substitution method. Some students, lost in the math, simply stated that they knew that the answer should be $Q = \mathcal{E}C\left(1 - e^{-t/RC}\right)$.

The solution for part (c) depended on the answer from part (b): students were to set the solution in part (b) equal to *CV*. Most students who got an answer for part (b) made the correct substitution here. However, many students substituted 4 volts and 12 volts incorrectly. Credit was awarded for answers that were less than the time constant and greater than 0, as these attempts displayed some knowledge of what would be a reasonable answer. Some students simply stated that their answer was wrong but did not explain why. It was obvious by the number of answers that were greater than the time constant that most students were not familiar with this situation.

Part (d) added the second resistor and required students to draw a graph of the current across each resistor as a function of time. The most common error was not having the currents converge after some time. Many students got the two currents backward, sketching I_1 starting at a nonzero value and decreasing to zero, and I_2 starting at zero increasing to some nonzero value.

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 probed student understanding of magnetic forces and induced emf. To correctly solve parts (a) and (b), students had to understand how to determine the magnitude and direction of the magnetic forces acting on current carrying wires. To correctly solve parts (c), (d), and (e), students had to work with the induced emf in a loop moving through a magnetic field, calculating the generated current and power dissipated, as well as justifying the magnetic-field dependence of the external force required to move the loop at constant speed.

How well did students perform on this question?

The mean score on this 15-point question was 6.79. About 22 percent of students earned scores of 12 or higher, while approximately 32 earned scores of 3 or below.

What were common student errors or omissions?

In part (a) some students failed to notice that the upper arm is outside of the region of magnetic field, and therefore the force on it is zero. A number of students gave incorrect directions for the forces on the other three sides of the loop.

If part (b) was set up correctly, the most common mistake consisted of using h or $2(w + h)$ instead of w for the length of wire in the expression for the magnetic force. Also, some students attempted to determine B by using the Biot-Savart Law or Ampere's Law.

The majority of students responded correctly in part (c-i). In part (c-ii) most students identified $\mathcal{E}$ as the voltage to use in $I = V/R$ but then had difficulty calculating $\Delta\phi/\Delta t$. In the equation $\mathcal{E} = B\ell\upsilon$, they again used an incorrect length.

In part (d) most students realized that they had to use I from part (c-ii). However, those who attempted to calculate $P = IV$ were often at a loss on what expression to use for V after substituting the expression for I from part (c-ii).

In part (e) most students correctly chose "Increases." They recognized that the external force must be equal to the magnetic force to keep υ_0 constant, and that a larger B results in a larger magnetic force. However they had difficulty articulating the justification. A number of students simply repeated "the force increases because the magnetic field increases." Most students attempted to use $F = I\ell B$ for the justification but failed to address the fact that I depends on B. Many simply made vague statements about "resisting change."

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?

Student performance on the AP Physics C: Electricity and Magnetism Exam was as expected. Many students failed to correctly apply Coulomb's Law and the law of superposition, incorrectly treating the electric field as a scalar or making mistakes in evaluating the components of a vector. Some of their difficulties with question 2 stemmed from an inability to apply the loop rule and/or from failing to recognize the relationship between current in the circuit and charge on the capacitor. Finally, students continued to have difficulty in providing prose justification for selecting one of several offered alternatives.