CollegeBoard AP

Student Performance Q&A:

2009 AP® Physics C: Electricity and Magnetism Free-Response Questions

The following comments on the 2009 free-response questions for AP® Physics C: Electricity and Magnetism 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?

Many of the major electrostatic concepts were tested in this question, which begins with a description of an unknown spherical distribution of charge and a given relationship for the electric potential of the charge distribution inside and outside the sphere.

In part (a) students were asked to derive the functions for the electric field, which tested their understanding of the differential relationship $E = -dV/dr$ between a spherically symmetric electric potential and electric field. Since the given potential function was not a simple function, students' ability to correctly take a derivative was also tested. In part (b), which assessed students' understanding of Gauss's law, they were asked to use the electric field functions from part (a) to determine the charge distribution.

In part (c) students were asked about a possible surface charge on the sphere. (The overall charge distribution consisted of negative charge distributed within the sphere, plus positive charge placed on the surface of the sphere.) Students who correctly answered part (c) demonstrated a very good understanding of Gauss's law. In part (d) students were asked to graph the resulting electric force on a positive test charge. This assessed their understanding of the relationship between electrostatic force and field, as well as their visual understanding of the charge distribution. A correctly drawn graph would clearly show a discontinuity at the surface of the sphere, which allowed some students to uncover and resolve mathematical or conceptual mistakes that they may have made in earlier parts of the problem.

How well did students perform on this question?

The mean score was 6.27 out of a possible 15 points. About 10 percent of students earned scores of 12 or higher, while about 27 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) the most common mistake was incorrect differentiation of the given potential function. Since the second region ($r > R$) was a familiar function (the point charge), students made fewer mistakes for that region. Another common mistake in part (a) was getting the direction of the electric field wrong.

In part (b)(i) most students recognized the need to apply Gauss's law. However, many students made mistakes in constructing and evaluating the surface integral. Most common was a failure to recognize that in a spherically symmetric situation, the electric field is constant at all points on the Gaussian surface. These students pursued an actual integral involving the electric field function, resulting in a very complex (and incorrect) expression for the charge distribution.

Part (b)(ii) was answered correctly by a majority of the students who attempted it. The familiarity of the field expression external to the distribution evidently helped them to derive the expression for the enclosed charge.

Part (c) was the most challenging part of this problem for exam-takers. Many students stated that there was charge on the surface of the sphere, but they gave answers that indicated a lack of understanding. Examples of incorrect student statements included (1) "The sphere is a conductor and conductors have all of the charge on the surface"; (2) "The charge distribution function shows that charge exists everywhere on the sphere including the surface"; (3) "The negative charge inside the sphere induces a positive charge on the sphere"; and (4) "The net charge of $+Q_0$ rests entirely on the surface of the sphere." Such statements indicate lack of recognition that the potential function given at the beginning of the problem implied the existence of a spherically symmetric and negative charge distribution within the sphere plus a positive surface charge.

Many students who attempted part (d) earned 2 out of 3 points. Most students correctly displayed the force/field directional relationship on the graph, and most also drew graphs that were reasonably consistent with the field that they determined in part (a). A common error was the lack of a field discontinuity at $r = R$ on the graph.

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?

- Assign problems that give students substantial practice with differentiation beyond the very simplest examples, and emphasize the fundamental relationships among electrostatic potential, electrostatic field, and the distribution of electric charge.

- Encourage frequent construction and verbal interpretation of graphs that faithfully represent derived functional relationships.

Question 2

What was the intent of this question?

This question assessed students' understanding of (1) a simple circuit containing a bar-shaped resistor of given length, cross section, and resistivity; (2) the electric field inside the resistor; and (3) the consequences of imposing a uniform external magnetic field.

How well did students perform on this question?

The mean score was 8.06 out of a possible 15 points. About 25 percent of students earned scores of 12 or higher, while about 18 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) many students did not correctly calculate the bar's resistance, even though the equation for the resistance appeared on the equation sheet. However, many other students were able to correctly solve for power dissipated in the resistor, as well as the force on the resistor due to the added external magnetic field.

In part (b) students found it difficult to determine and explain the direction of the electric field inside the resistor. Many students either got the direction wrong or else simply stated the direction of the conventional current without addressing *how* the direction of the current was related to the direction of the electric field.

In part (e) many students incorrectly stated the direction of the additional electric field resulting from the imposition of the external magnetic field, which led to mistakes in solving for the electric field created by the separation of charges.

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?

- Describe and emphasize the connection between macroscopic circuit variables and the average motion of individual charge carriers.

- Be sure to give adequate attention to concepts other than the more abstract and mathematical aspects of calculus-based electricity and magnetism, including such mundane relationships as the formula for resistance of a resistor of uniform cross section.

Question 3

What was the intent of this question?

This question assessed students' understanding of induced emf and its effect in various circuits. Some parts of the problem also assessed students' mastery of simple circuits.

How well did students perform on this question?

The mean score was 6.39 out of a possible 15 points. About 18 percent of students earned scores of 12 or higher, while about 33 percent earned scores of 3 or below.

What were common student errors or omissions?

In part (a) many students had difficulties calculating the derivative of the magnetic flux with respect to time. They incorrectly manipulated the symbols associated with the derivative. Moreover, in expressing the flux as the integral of $B\,dA$, many students incorrectly obtained an expression that was the integral of $B(t)$ with respect to time.

A common mistake in part (c) was to substitute current or voltage inconsistently (for example, using the emf of the circuit as the voltage to calculate the power dissipated in only one resistor).

In parts (d) and (e) students had difficulties clearly distinguishing between the factors that determine the value of the emf (in this problem, the dependence of the magnetic field on time and the area through which the magnetic field was established) and the characteristics of the circuit in which the effect of the emf is manifested (for example, a particular combination of resistors).

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?

- Provide students with more practice in calculating derivatives and integrals using physical quantities.

- Give students more exposure to problems involving induced emfs in situations that go beyond the simplest standard examples offered in most textbooks.