CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2008 AP® Physics C: Electricity and Magnetism Free-Response Questions

The following comments on the 2008 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?

The first three parts of this question assessed students' understanding of electrostatics, specifically Gauss's law, as applied to conductors. Students were first asked to determine and give explanations for the values of the charges on various conductor surfaces. They were then asked to determine and sketch the electric field in various regions. The final part of this question assessed students' ability to apply conservation of energy to find the speed of a charged particle that had been released from rest at a very large distance from the conductors.

How well did students perform on this question?

The mean score for this 15-point question was 7.01. About 20 percent of students earned scores of 12 or higher, while about 27 percent earned scores of 3 or below. It was disappointing to see this rather low mean score for a question that combined relatively simple applications of Gauss's law with a final section requiring straightforward use of the principle of the conservation of energy.

What were common student errors or omissions?

In part (a) students made a number of common errors: giving only the sign of the charges rather than both magnitude and sign; writing inadequate explanations that made poor use of such terms as "polarization," "induction," and "equilibrium"; providing incomplete explanations invoking Gauss's law without specifically identifying the regions where the law was being applied; stating that positive charges in the shell moved or were repelled toward the outer surface of the shell; and regarding the inner surface of the shell incorrectly as the surface of the sphere.

In part (b) the straightforward use of Gauss's law appeared to puzzle many students. The most common error was treating the inner sphere as a nonconducting sphere with a uniform charge distribution. Other common difficulties included using a, b, or c or some combination of them and their squares instead of the variable r in otherwise appropriate expressions; making an inappropriate substitution for a surface area (e.g., the circumference, the area of a circle, or the volume of a sphere); determining electric potential rather than electric field; using surface charge density instead of charge; using a generic charge q rather than the specific value Q that was given; and interchanging the sections with and without field (e.g., having a nonzero field inside the sphere and a zero field between the sphere and the shell).

In part (c) students' graphs exhibited several deficiencies, such as unclear curvature, unclear separation of the various regions, unclear or absent delineation of zero-field regions, and indefinite starting and ending points for inverse-square portions of the graph. Several types of errors revealed an incomplete understanding of the physical significance of the inverse square law. These included graphs that indicated an infinite field at one or more surfaces or that failed to incorporate the extra distance (the width of the shell) when showing the magnitude of the electric field just outside the shell. Some graphs even showed the magnitude of the field just outside the shell exceeding that at the outer edge of the gap between the sphere and the shell.

In part (d) many students did not identify an appropriate way to proceed. Common difficulties included trying to use Newton's second law with a constant force and acceleration or equating electric force, electric field, and/or electric potential to kinetic energy. Common errors in manipulation included making incorrect substitutions and algebraic errors in solving for the speed (e.g., leaving off the square root or dropping a variable).

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 the directions carefully!
- Practice writing brief, accurate explanations.
- Start with basic relationships and equations. Students should not be encouraged to take shortcuts when responding to a prompt that uses the words "calculate" or "derive."
- Consider giving a mathematical explanation if and only if they can be very clear as to what the equation refers.
- Write clearly and legibly. If words and symbols cannot be read, the response cannot earn points.
- Practice using Gauss's law to find electric fields both for cases in which there are discontinuities in the field and for cases in which the field is everywhere continuous.
- Keep the physics firmly in mind while sketching graphs. On this question, many responses showed little or no connection between the correct physics in part (b) and what students sketched in part (c). Conversely, some students could not do the mathematics in part (b) but correctly sketched the fields in part (c).
- Think carefully about when a question can and cannot be correctly answered using Newton's laws or constant-acceleration kinematics.

Question 2

What was the intent of this question?

This question was intended to assess students' knowledge of circuits, including *RC* and *RL* circuits. In part (a)(i) students had to know how to determine voltages in a resistive network involving both series and parallel connections. In parts (a)(ii) and (a)(iii) students needed to understand how capacitors and inductors behave just after the power supply is connected. Part (b) required students to graph the current through the branch of the circuit containing the various replaceable elements. Students had to demonstrate understanding of how the capacitor, inductor, and resistor affected the time dependence of the current in that branch.

How well did students perform on this question?

The mean score for this 15-point question was 8.59. About 34 percent of students earned scores of 12 or higher, while about 19 percent earned scores of 3 or below.

Students could generally be divided into three groups: those who could not do much with the problem, those who understood series and parallel circuits of resistors only, and those who could do the whole problem with few or no errors. Many students earned a score of 14 or 15, which indicates a very good understanding of circuits.

What were common student errors or omissions?

In part (a)(i) many students could find the equivalent resistance and the total current in the circuit, but they evidently did not know how to find the voltage across R_2. They simply multiplied the *total* current by R_2, which is incorrect. Some students did not read the question carefully and solved for the wrong voltage or for the current. Many students made algebraic mistakes; 5 to 10 percent of responses included the "equation" $1500\text{ V}/300\ \Omega = 500\text{A}$. Incorrect substitutions for the supply voltage were also quite common.

In parts (a)(ii) and (a)(iii) many students did not know how to handle inductors and capacitors at all. Of those who did have an idea of how to proceed, many confused the two circuit elements, assuming that the inductor allowed current to flow immediately and that the capacitor did not. A very common mistake was to correctly indicate that the inductor does not allow current to flow initially and then to incorrectly conclude that no current is flowing anywhere in the circuit and thus the voltage across R_2 is zero. When students tried to solve parts (a)(ii) and (a)(iii) using Kirchhoff's rules, they did not know how to handle the inductor and capacitor. They frequently substituted $L(dI/dt)$ or q/C for the voltages across those elements but then did not know how to proceed. Some students did not distinguish between different currents in different branches; in writing the loop rule, they simply added up $V = IR$ for all the resistors in the circuit, using the same current for every resistor.

In part (b) many students seemed to have memorized some general shapes of graphs and applied those to the resistor, inductor, and capacitor somewhat haphazardly. Other students appeared to know what they were doing, but their sketches were not careful enough to earn full credit. For example, if the graph of the current in R_3 with the capacitor in place did not touch the *y*-axis, it was not clear whether the student knew there was a finite initial current or if the student mistakenly believed that the curve was asymptotic to the y-axis.

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 need to spend some time on complex *RC* and *RL* circuits. It seems many students have handled circuits with one resistor and one capacitor or inductor and are familiar with the shapes of graphs, but they do not know how to handle multiple resistors in an *RC* or *RL* circuit. These should be covered in greater detail, perhaps by having students do labs where there is more than one resistor in an *RC* circuit, so that they can examine the behavior of the currents and voltages for the various elements. Also, students should be taught to carefully sketch graphs. Even if the problem requires only a sketch, they should pay attention to details (e.g., initial and steady-state values) and carefully draw their functions. In this question, many students who may have known the physics did not communicate their knowledge because they did not use sufficient care when constructing their sketches. In addition to learning the physics, students need to learn to effectively communicate their knowledge.

Question 3

What was the intent of this question?

The intent of this question was to assess students' understanding of a magnetic field, including its vector nature. Parts (a) and (b) required a calculation using the Biot-Savart law and an application of the principle of superposition. Parts (c) and (d) addressed the concept of magnetic flux, both with the loop fixed perpendicular to a magnetic field and with the orientation of the loop varying with respect to the direction of the magnetic field.

How well did students perform on this question?

The mean score for this 15-point question was 5.82. About 7 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) some students tried to use Ampere's law, which is not useful in this case because there is no field line with simple geometry on which the magnitude of the magnetic field would be constant. Few students showed the direction of $d\mathbf{B}$ in the diagram, and very few attempted to calculate the vertical component of $d\mathbf{B}$. When using the Biot-Savart law, students had difficulty correctly identifying r (often using R or $R/2$ instead). Many students expressed $d\ell$ incorrectly; using $r\,d\theta$ instead of $R\,d\theta$ was a common mistake, as was using $\sin\theta\,dr$ or $\cos\theta\,dr$ and integrating (e.g., from 0 to $R/2$).

In part (b) many students stated that the direction of the magnetic field at P generated by the second loop was *opposite* to that of the field generated by the first loop.

In part (d) some students had difficulty identifying that the time dependence of the flux comes from the angle formed by the field and the normal to the loop. They introduced ω as merely multiplying some other factors in the expression for ϕ or $\mathcal{E}$.

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 understand the conditions under which it is useful to use Ampere's law to calculate a magnetic field. They should be able to clearly identify each vector in the expression for $d\mathbf{B}$ in the Biot-Savart law. Students should also understand how the relative directions of the field and the perpendicular to a surface affect the flux of the magnetic field through that surface.