Student Performance Q&A:

2013 AP® Physics C-Electricity and Magnetism Free-Response Questions

The following comments on the 2013 free-response questions for AP® Physics C-Electricity & Magnetism were written by the Chief Reader, Jiang Yu of Fitchburg State University, Fitchburg, Massachusetts. 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 evaluated students' understanding of Gauss's law in a classic problem. In the first two parts of the problem, students were asked to derive an expression for the electric field E as a function of the distance r from the axis of a cylindrical non-conductor with a uniform charge distribution ρ and radius R. In part (a), students performed the derivation for the region inside the cylinder, and in part (b) students repeated the process for the region outside of the cylinder. In part (c), students sketched a qualitative graph of E as a function of r for $0 < r < 2R$. Part (d) required students to use their expression for E inside the cylinder to derive an expression for the potential difference ΔV between the cylinder axis and its surface, and to identify the point of highest potential as either $r = 0$ or $r = R$. In part (e), students sketched another qualitative graph of E as a function of r for $0 < r < 2R$, this time for a cylinder of identical radius and linear charge distribution but made of a conducting material.

How well did students perform on this question?

Almost all students attempted this question and they scored moderately well. The mean score was 6.8 out of a possible 15 points, with 11.6 percent of the scores ≥ 12 and 20 percent ≤ 3.

What were common student errors or omissions?

- Improper Gaussian surfaces included wrong shapes, such as spheres, or surfaces drawn outside of the cylinder for a derivation involving the interior.
- Some students did not write Gauss's law as a surface integral or use an acceptable alternative method to indicate that the integral must be performed over a closed surface.
- Some derivations omitted variables that canceled, such as cylinder length; in a problem involving a derivation, all steps should be clearly shown.

- It was not clear to all students that the electric field outside the charged cylinders did not depend on whether they were conducting or non-conducting.
- Some students failed to recognize that the E-field expression from inside the cylinder was needed to derive the potential difference between the axis and surface.
- Substitution of the E-field expression in the potential calculation was occasionally done after performing integration.
- Some students did not draw a horizontal line on the r axis to indicate regions where $E = 0$.
- Students often confused the variable r with the radius of the cylinder R in derivations.

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?

- Impress upon students that calculus notation is specific (e.g., an integral over a closed surface needs to be notated so).
- Avoid using mathematical shortcuts on the AP® Exam, particularly when asked to derive.
- Make lines drawn on a graph over the horizontal axis clearly visible.
- While a requested sketch does not have to be perfect, it should show some care. If the graph is not equal to 0 in the requested range, make sure that the graph does not touch the axis.

Question 2

What was the intent of this question?

This question examined students' understanding of RC circuits, such as those used in common physics classroom experiments, and evaluated if students could analyze data collected for the discharge cycle to obtain the time constant graphically from linearized data. In part (a), students determined the switch setting that would charge the capacitor from a sketch of an RC circuit. The question also asked students to show proper placement of a voltmeter to measure the potential across the capacitor. In part (b) students tabulated any additional calculated data for the pair of variables identified. In part (c), students graphed the tabulated data and draw a best-fit straight line through it. In part (d), students used the slope of the line to obtain the time constant of the circuit. In part (e)(i), students were given a known capacitance and asked to use the experimental time constant to calculate resistance. In part (e)(ii), students were asked to describe by drawing a dashed line on their graph how the line would change if the capacitance was changed but the resistance was not. Finally, students were asked to justify the placement of their dashed line.

How well did students perform on this question?

Again, almost all students attempted this question and they found it challenging. The mean score was 5.3 out of a possible 15 points, with 19.9 percent of the scores ≥ 12 and 44.2 percent ≤ 3.

What were common student errors or omissions?

- Students did not know that the function for the voltage of a discharging capacitor in an RC circuit followed the form $V = V_0 e^{-t/\tau}$.
- Students knew the exponential form, but did not realize the equation could be linearized using the natural log function.
- Students attempted to use the inverse of the voltage or time to linearize the data, plotting $1/V$ vs. t, for example.
- Students attempted to square the voltage or time to linearize the data.
- Students used data points not on the best fit line to solve for slope.

- Students used one data point with an equation to solve for slope.

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?

- Emphasize the difference between "line of best fit" and "smooth curve."
- Show examples of exponential functions that are linearized using natural logarithms.
- Show the difference between exponential and inverse relationships.
- Foster test taking skills (i.e., when you do not know how to calculate the answer to part (a) and you need it for part (b), explicitly assume a value in writing in part (a) and use it in part (b)).

Question 3

What was the intent of this question?

This question probed students' understanding of electromagnetic induction and assessed students ability to calculate energy dissipation in a circuit with changing current. In part (a), students were given an equation for magnetic field B as a function of time t, and asked to calculate the electric potential induced in a circular circuit of known area and resistance. Students used derived potential functions to calculate the current at a specific time. Because B was exponentially decaying in the time region for which the derivation was requested, calculus was required. In part (b), students sketched a graph of current as a function of time for the entire time period, which included regions where B was exponentially decreasing, constant, decreasing linearly, and zero. Students then justified their graphs by correctly describing the magnetic field behavior and explaining why this behavior resulted in the indicated current direction in terms of the production of the induced magnetic field. In part (c), students calculated the energy dissipated during the time period when the magnetic field was decreasing exponentially. Successful completion of this part of the problem required integration of an expression for power over time, with appropriate substitution of previously derived expressions for current or potential.

How well did students perform on this question?

Students found the problem somewhat challenging, and 98 percent of them attempted the question. The mean score was 6.5 out of a possible 15 points, with 19.5 percent of the scores ≥ 12 and 34.5 percent ≤ 3.

What were common student errors or omissions?

- Some students integrated instead of taking a derivative for Faraday's law. It is possible that these students did not know how to take the derivative of an exponential function.
- There was evidence students did not read the question carefully. Time values from different parts of the problem were incorrectly used. Some students calculated area using πR^2 even though area was given as 0.25 m^2.
- A common error was selecting the wrong direction for induced current.
- Graphing errors included graphing decay curves the wrong way (away from the horizontal axis) or leaving areas with zero current blank instead of drawing a line over the axis.
- Some students did not explain induced current direction carefully in physical terms. The word "oppose" was used in the wrong context (e.g., "the induced current will oppose the direction of the B field" instead of "the induced current will oppose the change in flux"). Sometimes the word "it" was used instead of specifying field, flux, or current. Some students wrote "Lenz's law" or "RHR" without elaboration.
- The calculation of power was sometimes performed instead of energy, and the correct relationship between energy and power was sometimes not recognized.

- Some students could not properly integrate the function for power over time to calculate energy; others did not recognize that an integral was required because the emf (and current) were changing with time.

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?

- Practice graphical analysis, both interpreting given graphs and creating graphs.
- Practice the appropriate application of calculus, particularly in indicating when calculus must be used, and when differentiation or integration is appropriate.
- Encourage students to always use complete sentences or thoughts, explicitly stating variable names.