AP®

Student Performance Q&A:

2016 AP® Physics C – Electricity & Magnetism Free-Response Questions

The following comments on the 2016 free-response questions for AP® Physics C: Electricity and Magnetism were written by the Chief Reader, Peter Sheldon of Randolph College in Lynchburg, Va. 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 intent was to assess understanding of electrical potential maps, the principal of superposition, the relation between potential and the electric field vector, the work done on charges, the direction of acceleration of a charge in an electric field, and Gauss's law.

How well did students perform on this question?

The mean score was 5.70 out of a possible 15 points.

What were common student errors or omissions?

a) Students often did not apply the principle of superposition to find the electric potential of a system of charges. The potential at a point in space is the sum of all the sources of electric potential, not just the electric potential due to the nearest charge.

b) Students would forget that the electric field vector is always perpendicular to electric equipotential lines and it points in the direction of maximum decrease of electric potential. They would neglect to use vector addition when applying the principle of superposition to a vector quantity.

c) Calculations would use single values when a <u>change</u> in a value is needed. The magnitude of the electric field is the (negative of) the <u>change</u> of electric potential with displacement, not just the potential over distance; work done on a charge is proportional to the <u>change</u> in voltage over the displacement, and not just some voltage value over distance; work done on a charge is equal to the <u>change</u> in kinetic energy, and not just the initial or final kinetic energy.

d) Students would directly integrate an expression for electric field through a closed surface instead of applying Gauss's law and using $q_{enclosed}/\varepsilon_0$.

e) When asked to find work done on a charge, students would directly integrate the force with respect to the displacement instead of realizing that an equipotential map has already done this integration, and to find the work done one need only determine the change in voltage and use $W = -q\left(V_f - V_1\right)$.

f) Often constant acceleration kinematics was applied in situations in which the forces and accelerations were not constant.

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?

a) When students are asked to "calculate" a numeric answer, they should first write down the relevant equation, then symbolically solve the equation for the variable to be computed, and lastly substitute numbers for the appropriate variables. This should be done explicitly on the exam booklet page and not just on the calculator.

b) Units matter! Students should always report a final answer with correct units.

c) For quantities such as work and electric potential difference, sign matters!

d) When asked to sketch a vector, the vector should be straight and should have a clear arrowhead.

e) A common misconception across many problems is that students are confused by quantities that are changes of other quantities. For example, work is change in kinetic energy, not just initial or final kinetic energy; work is the negative of change in potential energy, not just initial or final potential energy; the magnitude of the electric field is the negative of change in electric potential over a displacement, not just the initial potential or final potential. Relatedly, when approximating a derivative, it is the change of one quantity with respect to the change of another quantity.

f) Students often mistakenly think that when a particular quantity is zero, its derivative is also zero; e.g., thinking that the electric field must be zero where the electric potential is zero, or thinking that the acceleration is zero when the velocity is zero.

Question 2

What was the intent of this question?

This problem explored the relationship between resistance, voltage, and current in a simple circuit, and the means of experimentally verifying the relationships. The concepts stressed are the relationship between voltage, current, and resistance; the relationship between resistance and resistivity; the effects of a nonideal voltmeter and a nonideal ammeter on a circuit; and the experimental means to determine the resistance of an unknown resistor in a circuit.

How well did students perform on this question?

The mean score was 8.63 out of a possible 15 points.

What were common student errors or omissions?

a) Graphs were frequently missing units, missing axis labels, or not scaled linearly or reasonably. Students feel the need to connect data points. Students often use data points, rather than the best fit line, to calculate slope.

b) Students make frequent algebra errors such as incorrectly solving for a variable, mixing quantities inappropriately (e.g., adding voltage to resistance), and not being able to express a relationship in terms of a straight line.

c) Students have a number of misunderstandings related to circuits theory. They frequently do not understand Ohm's law. They do not understand the concept of an ideal versus a non-ideal voltmeter or ammeter, and do not understand that a non-ideal meter is not broken. Students mistakenly think that a current is "used up," and do not understand the concept of electric potential difference, often treating it like current.

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?

a) Students need to understand Kirchhoff's rules and Ohm's law and know when they are appropriate to use.

b) Students need to review the basics of making graphs: using appropriate scales and labels, drawing data points and a best fit line, etc.

c) Students should review the structure of equation for a line and discuss the meaning of the slope and the vertical intercept. Students need to be able to solve an equation for various quantities.

d) Do not skip steps in solving problems. Show clearly the process used to find the answer. Always start with the equation in the symbolic form, then manipulate the equation as necessary, plug in appropriate numbers, and solve. Don't just put a bunch of numbers down on a page.

e) Understand the meaning of and the difference between derive, determine, calculate, and justify as used on the AP Exam.

f) When writing a justification, do not repeat the question. Use appropriate terminology and write briefly and clearly. Do not use analogies: they are good for teaching, but not for showing that you understand the underlying physics of an AP question.

Question 3

What was the intent of this question?

The intent of this question was to elicit students' knowledge of how current is induced in response to a changing magnetic flux, of how this induced current can create a magnetic field, and how that induced field can affect the existing magnetic field. The question also assessed the students' knowledge of motional emf, terminal velocity, power dissipated in a resistor, and setting up and integrating Newton's second law in order to find velocity as a function of time.

How well did students perform on this question?

The mean score was 3.92 out of a possible 15 points.

What were common student errors or omissions?

a) In dealing with induced fields, students often referred to a changing area or a changing magnetic field alone without talking about the actual change in flux.

b) Students sometimes couldn't explain the direction of the magnetic field around the current-carrying bar.

c) Students sometimes confused "up" with "out of the page."

d) Many students left part (c) blank, indicating that they may not have known how to set up a differential equation.

e) Students often used qvB for the force on a current-carrying wire, rather than $I\ell B$, which made it impossible to substitute for I.

f) Students did not correctly use Newton's second law and were often missing gravity as one of the forces.

g) Students were often not able to find velocity as a function of time by separating variables and integrating.

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?

a) "Use the right hand rule" is not an appropriate justification by itself, there must be some additional information about how it is being applied.

b) Separation of variables should be reviewed.

c) Students should review the calculation of change in magnetic flux.