Chief Reader Report on Student Responses:

2017 AP® Physics C-Electricity & Magnetism Free-Response Questions

- Number of Students Scored 24,249
- Number of Readers 364
- Score Distribution

Exam Score	N	%At
5	7,737	31.9
4	6,115	25.2
3	3,461	14.3
2	4,110	16.9
1	2,826	11.7

- Global Mean 3.49

The following comments on the 2017 free-response questions for AP® Physics C-Electricity & Magnetism were written by the Chief Reader, Peter Sheldon, Professor of Physics, Randolph College. 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 preparation 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

Topic: E&M, Elecrostatics and Gauss's Law

Max. Points: 15 **Mean Score:** 3.74

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- The ability to determine the direction of an electric field from a positively charged object.
- The ability to determine the flux through a Gaussian surface.
- The ability to apply Gauss's Law to determine the electric field at a particular location.
- An understanding of the electric field generated by a very large uniformly charged plate.
- An understanding that the total electric field can be found by finding the superposition of component fields.
- The ability to integrate the electric field over a given displacement to determine the electric potential difference between two locations.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most students were able to determine the direction of an electric field from a positively charged object and showed that they understood that the total electric field can be found from the superposition of component fields.
- Most of the students showed a relatively strong ability to determine the flux through a Gaussian surface.
- Many of the students demonstrated a knowledge of the electric field generated by a very large uniformly charged plate.
- Few students were able to demonstrate an understanding of flux and how to calculate it.
- Very few of the responses showed a capacity to apply Gauss's Law to determine the electric field at a particular location, or to integrate the electric field over a given displacement to determine the electric potential difference between two locations.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• When applying Gauss's Law to a cylinder, many students indicated that the total area of the Gaussian surface was "A." The question prompt, however, indicated that "A" was the cross-sectional area of the Gaussian surface. The actual area of the Gaussian surface with nonzero flux should have been 2A to include both the top and bottom surfaces of the cylinder.	• $\oint E \bullet dA = E(2A)$
• When applying Gauss's Law to a cylinder, many students didn't associate the length of the cylinder with the actual geometry of the Gaussian surface as indicated in the images associated with the question. This led them to indicate that the length of the Gaussian surface was "z" rather than "2z" as indicated in the drawing	• $z = h/2$
• When asked to determine where the electric field of a compound object went to zero, many students tried to balance regions of charge rather than summing the electric fields and setting that to zero.	• $\vec{E}_{\text{plates}} + \vec{E}_{\text{slab}} = 0$
• When calculating the total electric field, many students did not find the superposition of the two component fields.	• $\vec{E}_{\text{total}} = \vec{E}_{\text{plates}} + \vec{E}_{\text{slab}}$
• Many students didn't indicate that they understood that the electric field from a large uniformly charged plate is $\sigma/2\varepsilon_o$ on either side of the plate.	• The electric field from a large uniformly charged plate is $\sigma/2\varepsilon_0$.
• Many students struggled with performing the integral correctly, including selecting proper integration limits,	• Being able to integrate.
• Many students didn't demonstrate an understanding of electric potential and its relation to the electric field.	• $\Delta V = \int E \bullet dr$

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students should read each problem carefully because one misunderstood or omitted word may completely change the meaning of the question.
- Students should distinguish carefully and clearly between the terms that are closely related and sound similar, yet mean different things. Examples: surface charge density vs. volume charge density, electric charge vs. electric field vs electric potential.
- Students should not to resort to memorized equations — just because an equation is correct, does not mean it is applicable to a particular situation. Examples: Gauss's Law must be applied to a particular Gaussian surface, not to some predetermined formula.
- Students should give concise and clear verbal explanations when needed.
- Students should present their work clearly. They need to pause and think before touching the paper with a pencil

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

The AP Central website has a "module" on electrostatics (https://apcentral.collegeboard.org/pdf/physics-special-focus-electrostatics.pdf?course=ap-physics-c-mechanics) that would be useful for teachers. It includes ideas on teaching electrostatics and Gauss's Law appropriate for AP Physics C.

AP Physics C teachers can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The downloadable AP 1 and AP 2 lab manual may be useful for the teachers of the AP Physics C course as well.

The AP Physics Online Teacher Community is very active, and there are many discussions concerning teaching tips, techniques, and activities that AP Physics teachers have found helpful. It is easy to sign up, and you can search topics of discussions from all previous years.

Newer teachers (and career changers) might want to consider signing up for an APSI. An APSI is a great way to get in-depth teaching knowledge on the AP Physics curriculum and exam, as well as network with colleagues from around the country.

Veteran AP Physics teachers who have not been to an APSI in five to 10 years might want to consider attending an APSI to refresh some ideas concerning the AP Physics program and to exchange ideas with colleagues.

Question #2

Topic: RC Circuits

Max. Points: 15 **Mean Score:** 5.29

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- Graphing skills for exponential functions/behavior of RC circuits, especially regarding asymptotes.
- An understanding of charging and discharging behavior of RC circuits, including the importance of the time constant and how it relates to various graphs.
- An understanding of Ohm's Law and Kirchoff's Loop Rule as tools for analyzing RC circuits.
- An understanding of the relationships between charge, voltage, energy, and power for capacitors in an RC circuit.
- An understanding of equivalent resistance for resistors in series versus parallel.
- An understanding of how switches work in circuits.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most students understood that the charging of a capacitor is an exponentially decaying function that reaches a final value asymptotically.
- Most students understood the centrality of Ohm's Law, as well as how to apply it.
- Most students were very familiar with RC circuit behavior.
- Many students were confused by the use of the switch to shift from parallel to series behavior.
- Many students failed to grasp that a current can exist without a battery.
- Many students incorrectly assigned the properties of a simple wire or an open circuit to the capacitor.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Students have the misconception that a current cannot exist that without a battery.	• Once the switch is open, the charged capacitor acts as a diminishing voltage source, producing a current that varies exponentially in time.
• Students have the misconception that power and energy are the same physical quantities.	• Power is the rate of energy consumption, where power is i^2R.
• Students have the misconception that the time constant doesn't change if resistance changes.	• Since R_{eq} during discharge is greater than during charging, and the time constant is proportional to the resistance, it will take more time to discharge than charge.

• Students have the misconception that exponential functions reach the asymptote after a finite time.	• Although after several values of the time constant have passed the value of the function is very close to the asymptotic. value, the curve never intersects the asymptote.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students should read directions fully and provide each element of the answer requested in the question in the form that it was requested.
- Students should be clear and neat when drawing curves, especially when including dashed asymptotes.
- Students' responses should be brief, identifying the central and required issues only. Students should not include superfluous information.
- Students should understand that a "justification" requires a very clear sense of connection between a physical cause and the answer given. Circular reasoning is a frequent flaw in student responses.
- Students should understand that exponential functions never actually reach their asymptotes; students should understand how to show that on a graph.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics C can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The following curriculum modules will provide additional information on these concepts: 1. Multiple Representations of Knowledge: Mechanics and Energy, 2. The Capacitor as a Bridge from electrostatics to circuits. The downloadable AP 1 and AP 2 lab manual may be useful for the teachers of the AP Physics C course as well.

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Question #3

Topic: Circuits and Ideal Solenoid Magnetic Fields

Max. Points: 15 **Mean Score:** 6.43

What were responses expected to demonstrate in their response to this question?

The responses to this question were expected to demonstrate the following:

- How to use a multimeter to measure current in a circuit.
- An understanding of the magnetic properties of an ideal solenoid, as well as the properties of a real solenoid that best enable it to approximate the ideal.
- An understanding of how coil density and aspect ratio are invoked when using The Law of Biot & Savart to determine the value of magnetic field of an ideal solenoid.
- An understanding that real solenoids experience nonzero magnetic fields outside of the coils, as well as edge effects at the ends.
- An understanding that trendlines should be used rather than the data points from which they are formed in determining physical values from data.
- An understanding of how to compare measured and expected values using percent difference.
- An understanding that key physical values can be determined from graphs and how to extract those values.
- An understanding that the Earth's magnetic field can affect measurements of magnetic field strength; no experiment is in complete isolation from its surroundings. An understanding that real solenoids have a nonzero resistance that is very small.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most students wired the circuit correctly and placed the multimeter in series with the other elements.
- Most students understood ideal solenoid behavior and about the properties of its magnetic field.
- Nearly everyone understood that two points from the best-fit trendline needed to be selected for the computation of the desired constant.
- Most students understood that current becomes very large when the resistance is low, but not that solenoids themselves have low resistance, which may produce damaging currents through the multimeter.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Students have the misconception that current can be measured using a multimeter in parallel with the resistor.	• Placing the multimeter in series with the other elements guarantees you are measuring the current in that portion of the circuit.
• Students have the misconception that uncertainty in a measurement is due to "human error" or equipment failure in all cases.	• Extraneous sources of magnetic field may alter your measurements of the field of the solenoid, such as that of the Earth.

• Students have the misconception that resistance in a circuit is the single factor determining the current value in a circuit..	• Solenoids have very low resistance, so when connected to a voltage source, damagingly high currents can be generated.
• Students have the misconception that a "short circuit" means that a zero current exists in the circuit.	• The solenoid's low resistance acts like a wire with low resistance, and therefore may give the appearance of a short circuit.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students should avoid jargon and should instead answer the questions in terms of the most basic physical properties being assessed.
- Students should write larger, darker, and clearer.
- Students should not default necessarily to a mathematical approach if a well-reasoned physical/conceptual argument is equally compelling and more direct.
- Students should understand the importance of using and including correct units.
- Students should be doing significant lab work, which includes open-ended exploration.
- Students should understand the internal working of multimeters rather than treating them as black boxes.
- Circuits are frequently the context used to assess student understanding of basic physical laws and should make frequent appearances in the classroom.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics C can find useful resources in the Course Audit webpage and the AP Central Home Page for AP Physics C. The following curriculum modules will provide additional information on these concepts: 1. Multiple Representations of Knowledge: Mechanics and Energy, 2. Electrostatics. The downloadable AP 1 and AP 2 lab manual may be useful for the teachers of the AP Physics C course as well.

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