Chief Reader Report on Student Responses:

2019 AP® Physics 2 Free-Response Questions

- Number of Students Scored: 23,802
- Number of Readers: 377 (for all Physics exams)
- Score Distribution:

Exam Score	N	%At
5	3,380	14.2
4	4,993	21.0
3	7,188	30.2
2	6,237	26.2
1	2,004	8.4

- Global Mean: 3.06

The following comments on the 2019 free-response questions for AP® Physics 2 were written by the Chief Reader, Shannon Willoughby, Montana State University. 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.

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Question #1 **Task:** Paragraph **Topic:** E&M

Max. Points: 10 **Mean Score:** 5.31

What were the responses to this question expected to demonstrate?

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

- An understanding of the path a proton takes in a uniform electric field such that students can represent it by drawing a path that is curved and in the direction of the field.
- An understanding of the path a proton takes in a uniform magnetic field by drawing a path that requires the use of the right-hand rule to determine what direction the proton curves.
- How the path of a charge particle in an electric field is parabolic like that of an object in a gravitational field near the Earth's surface because both fields apply a constant downward force.
- The various paths that protons of varying velocity can take in a region of crossed fields such as that used in a velocity selector. This requires an understanding of net force and the dependence of the magnetic force on velocity while the electric force is independent of velocity.
- The ability to put together a clear and coherent paragraph-length response that answers the question with clear reasoning.

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?

- A large number of students properly drew the two curved paths downward. However, there was a wide variety of incorrect responses ranging from straight diagonal lines to horizontal lines to ones that attempted to curve the protons into or out of the page though an incorrect application of the Right Hand Rule.
- Part (a)(iii), where students had to demonstrate understanding of the similarity of the gravitational field and the electric field, also had a wide variety of answers. Many students correctly picked the electric field but did not thoroughly describe how the paths were similar. Many said they were similar because the paths were both down or that the fields were both down. Students often did not state that the fields created forces that were constant, as taking both fields into account is required for a complete solution.
- Another common issue with part (a)(iii) was not answering the question that was asked. Many students discussed how the gravitational field was not like the magnetic field instead of discussing how it was like the electric field.
- The paragraph pointed out a large gap in students' understanding of the differences between fields and forces. Many students used these words interchangeably as if they were the same thing. Discussion of one field being stronger than the other and relating that to the resulting direction of deflection was very common.
- Lack of the application of Newton's 2^{nd} Law was also common.
- Another common issue with the paragraph was extensive restatement of the question. Students often restated the prompt instead of answering the question or giving their reasoning.

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 drew proton paths that were diagonal or upward through an electric field	• Correct responses had paths that curved downward, did not have a component toward the left, and that reached the edge of the region

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• Paths that were more than a semicircle or even a complete circle	• A path that curved downward and was, at most, a semicircle
• An incomplete description of how a uniform electric field is like a uniform gravitional field by stating Coulomb's Law and Newton's Law of Universal Gravitation are similar, as you approach the ground or bottom of the field the force increases	• Responses that recognized uniform electric and gravitational fields both create constant forces in the same direction
• Confusing the terms "fields" and "forces" as if they were the same thing	• Stating that fields result in forces: since it is a proton, the electric force is in the same direction as the electric field: due to the Right Hand Rule the magnetic force is downward
• Discussing how one field being stronger than the other resulted in the difference in exit points	• Realizing that the velocity of the particle greatly affects which force is larger than the other

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

- Practice drawing the paths of charged particles as they pass through various fields (electric, magnetic, and crossed fields).
- Review AP Physics 1 instruction on the path of projectiles in uniform gravitational fields, as well as particles going in circular paths prior to teaching about electric fields and magnetic fields so students can make the connection.
- Spend time in class going over past rubrics for paragraph-length response questions. Many students had correct answers that were incomplete. Some responses failed to state things, perhaps because students thought these points were obvious. For example, many stated that protons with high speeds had large magnetic forces acting on them but they failed to state that what mattered was whether the magnetic force was larger than the electric force.

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

- The new AP Physics 1 Student Workbook contains many helpful scenarios that specifically address the skills surrounding projectiles and particles in circular motion. These scenarios can be modified or scaffolded to meet student needs in AP Physics 2.

- Teachers can find useful resources in the Course Audit webpage and on the AP Central Home Page for AP Physics 2. In addition, topic questions that are tied to specific learning objectives and science practices can be found on the new AP Classroom.

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

- New teachers (and career changers) might want to consider signing up for an Advanced Placement Summer Institute (APSI). An APSI is a great way to get in-depth teaching knowledge about the AP Physics curriculum and exam, and is also a great way to network with colleagues from around the country.

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Question #2 | **Task:** Qualitative/Quantitative Translation | **Topic:** Circuits

Max. Points: 12 | **Mean Score:** 7.61

What were the responses to this question expected to demonstrate?

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

- An understanding of Ohm's law such that the correct linear relationship between current and potential difference, as well as a *y*-intercept of zero, was graphed.
- Recognition that for the given axes, the graph of Circuit 2 should have a slope less than Circuit 1.
- A statement of Kirchhoff's loop rule that satisfies the Law of Conservation of Energy in terms of the given variables.
- The ability to translate between the qualitative graph and the quantitative equations and show how they are related.
- Proper use of Ohm's law to determine the current through the circuit, as well as recognizing that the potential difference across the ammeter would be the difference between the given potential difference values for use with Ohm's law a second time to determine the internal resistance of the ammeter.
- Recognizing which resistors are in parallel and which resistor is in series and being able to calculate the equivalent resistance of the full circuit.
- Understanding that the addition of the resistor in parallel changed the circuit and the potential difference across the various elements in Circuit 3 is different from what they were in Circuit 2.
- Proper application of Ohm's law to the new circuit.

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?

- A large number of students produced correct graphs for part (a) that represented both their understanding of Ohm's Law and how the circuits were different.
- Some students did not understand what the question was asking for (write an equation that satisfies conservation of energy) because the responses were sometimes equations for power or the potential energy of a capacitor.
- The ability to translate between multiple representations is something students continue to struggle with. Strong answers to this part were uncommon.
- Application of Ohm's Law appears to be something students are comfortable with. Students demonstrated a strong ability to manipulate the equation for the variables depending on what was being solved for. The struggle came when Ohm's Law needed to be used multiple times in the same question.
- Students were able to calculate the equivalent resistance of the resistors in parallel but responses often failed to add the calculated value for the resistance of the ammeter.
- Part (e)(ii) showed clearly that students struggle with changes in circuits, such as the addition of a new element. A common response to this part of the question was believing the potential difference across the resistors in parallel was 3.0 V or 2.5 V, as in part D. This showed students did not understand how adding the 120 Ω resistor changed the current in the circuit and the potential difference across the resistors.

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

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Graphs that were curved	• Graphs that showed the correct linear relationship between current and potential difference
• Power equations or potential energy equations	• Kirchhoff's Loop Rule equations that include the proper resistance(s)
• Incomplete translations that showed students did not know how to handle multiple representations	• Recognizing that if the equations are rearranged properly one can see that the slope of the graphs is the inverse of the slope
• Calculations of just the equivalent resistance of the resistors in parallel or mixing up how the resistors were connected	• Proper calculation of the equivalent resistance of the parallel branches and then adding that to the calculated value from part (d)
• Calculating the current through the parallel resistors using 3 V or 2.5 V	• Calculating the new current and using that to determine the new potential difference across the resistors in parallel in order to determine the current through those resistors

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

- Teachers should emphasize the concept of conservation laws when teaching circuits. It was clear some students did not make the connection between Kirchhoff's Rules and conservation laws. This was especially apparent when calculating power or potential energy.
- Practice with multiple representations and being able to recognize the relationships between the representations is vital. Students had correct graphs and equations but struggled with articulating how they were related.
- More work needs to be done on calculations associated with more complex circuits that are not just simple series or parallel circuits.

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

- The new AP Physics 1 Student Workbook contains many helpful scenarios that specifically address circuits. These scenarios can be modified or scaffolded to meet student needs.

- Teachers can find useful resources in the Course Audit webpage and on the AP Central Home Page for AP Physics 2. In addition, topic questions that are tied to specific learning objectives and science practices can be found on the new AP Classroom.

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

- New teachers (and career changers) might want to consider signing up for an Advanced Placement Summer Institute (APSI). An APSI is a great way to get in-depth teaching knowledge about the AP Physics curriculum and exam, and is also a great way to network with colleagues from around the country.

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Question #3 **Task:** Lab question **Topic:** Thermal conductivity

Max. Points: 12 **Mean Score:** 5.89

What were the responses to this question expected to demonstrate?

Parts (a) and (b) of this question assessed students' laboratory and graphing skills. In part (a) students were expected to determine which quantities to graph to linearize the data, graph the data, and extract experimental results from the slope. Part (b) assessed student understanding of experimental error. Parts (c), (d), and (e) assessed student understanding of energy transfer via thermal processes, specifically that energy flows from hot to cold objects (through increased kinetic energy and collisions) and that thermal conductivity is a property of a material that determines energy flow.

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?

- The student responses revealed an understanding of the skills and knowledge required by this course. There were enough skills and concepts incorporated into this lab question to assess a wide range of student abilities.

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

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• How to linearize data. In this problem the inverse of one of the variables had to be plotted.	• Labeling the axes in part ai with $Q/\Delta t$ vs $1/L$ or $\Delta t/Q$ vs L or some similar combination.
• How to find a quantity from a graph.	• Finding thermal conductivity in part aiii using two points from the best fit line and recognizing it might be necessary to manipulate the value further, depending on what was graphed (to include the constant area and change in temperature).
• Experimental error occurs due to the set up of the experiment, not the manipulation of the data.	• Students needed to recognize that the system was not isolated from the environment in part b; this could cause excessive energy gain or loss. Less likely causes were thermal expansion or melting of the plastic, uneven surfaces, and inaccurate collection of the melted water. Students often stated that the boiling water was not 100° C or the ice was not 0° C without including reasoning.

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

- A strong lesson on linearizing data and graphing should be taught at the beginning of the year and assessed regularly throughout the year.
- Students need more experience with realistic experimental error.

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

- The new AP Physics 1 Student Workbook contains many helpful scenarios that specifically address the skills of linearization of data and graphing. These scenarios can be modified or scaffolded to meet student needs.

- Teachers can find useful resources in the Course Audit webpage and on the AP Central Home Page for AP Physics 2. In addition, topic questions that are tied to specific learning objectives and science practices can be found on the new AP Classroom.

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Question #4 **Task:** Other **Topic:** Optics and gas laws

Max. Points: 10 **Mean Score:** 3.72

What were the responses to this question expected to demonstrate?

Part (a) of this question assessed student understanding of refraction. Part (b) required students to understand work, buoyant force, fluids, and potential and kinetic energies. Part (c) required students to understand the ideal gas law and pressure.

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?

- For part a students were required to consider rays moving from high to low and back to high indices of refraction. The surfaces were curved, which added to the complexity of the problem.
- The derivation in part b was challenging in part because the algebra was somewhat complex.
- Students frequently earned full credit on parts ci and cii because the calculations were straightforward.

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

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• The net force is based on the weight of the displaced fluid	• Using the density of water for the upward force and the density of air for the downward force with the volume of the air bubble

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

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