# Chief Reader Report on Student Responses:

## 2018 AP® Physics 2 Free-Response Questions

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|---|---|---|---|
| • Number of Students Scored | 25,741 | | |
| • Number of Readers | 380 (for all Physics exams) | | |
| • Score Distribution | Exam Score | N | %At |
| | 5 | 3,368 | 13.1 |
| | 4 | 4,026 | 15.6 |
| | 3 | 8,846 | 34.4 |
| | 2 | 7,522 | 29.2 |
| | 1 | 1,979 | 7.7 |
| • Global Mean | 2.97 | | |

The following comments on the 2018 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.

## Question #1

**Task:** Paragraph

**Max. Points:** 10

**Topic:** EM Induction, Particles in Fields - LOs: 2.C.1.1, 2.C.1.2, 2.D.1.1, 3.B.1.4, 3.B.2.1, 3.C.3.1, 4.E.2.1

**Mean Score:** 4.60

***What were the responses to this question expected to demonstrate?***

- How to determine the direction of an induced current when the magnetic flux is changing through a wire loop.
- The understanding that there is no current when the magnetic flux is not changing and if the magnetic flux were changing, that the amount of current depends on the rate of change of magnetic flux.
- How to determine the magnitude and direction of the force on a moving charge due to a magnetic field.
- The understanding that a charge initially moving perpendicular to a magnetic field will undergo circular motion as it enters a uniform magnetic field, and the radius of the circle increases with the speed of the charged particle.
- The understanding that an electric field will exert a force on a positively charged particle in the same direction as the electric field, and the magnitude of this force is the charge times the magnitude of the electric field.

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

- In the paragraph response, the vast majority of the students were trying to make an argument for their claims, although some may be using the wrong principle. Very few students just wrote claims.
- Many students had trouble with direction of a current in a loop. They seemed to focus on one part of the loop without mentioning which part and stated directions such as “left” or “up.”
- The responses were better on calculating the magnitude of the magnetic force than on drawing the trajectory. This was similar for the magnitude of the electric force and the direction of the electric force.

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

| *Common Misconceptions* | *Responses that demonstrate understanding* |
|---|---|
| • Conflating magnetic field and magnetic flux. : Some students wrote that the magnetic field changed rather than the magnetic flux. | • The induced current depends on the change in magnetic flux given by the product of the magnetic field and the area that contains the magnetic field lines. |
| • Some students thought that the given magnetic field was created by the current in the wire loop. | • A current is induced in the wire as the magnetic flux changed. |
| • Language was not precise at times; some students wrote that the force was on the loop rather than the charges in the wire. | • The magnetic field exerted a force on the charges in the wire, according to the equation qv x B. |

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|---|---|
| • Right hand rule is a tool and not the principle itself. | • The direction of the magnetic force on a positive charge in the wire is from the cross product of the velocity and the magnetic field. This is found from the right hand rule. |
| • Direction of a current in a loop can be described by up, down, left, or right. | • The direction of the magnetic force on a positive charge in the right side of the loop is up, according to the cross product of the velocity and magnetic field. |
| • The amount of the induced current is related to the area rather than the change of area. | • The amount of the induced current depends on the magnetic flux, which is found from the change of area since the magnetic field is not changing. |
| • In getting the electric force to cancel the magnetic *force* in part b(iv), some students thought that directions of the two fields must be opposite. | • Since the magnetic force is up, then the electric force must be down to cancel it. |

***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?***

- Distinguish between magnetic field and magnetic flux and emphasize them as two different concepts. This could be done with an analogy to fluid flow. The speed of the fluid is different from the amount of fluid that passes through per second (flux), although the two concepts are related.
- Emphasize that the right hand rule is not a principle of physics. It is a tool to determine the direction of the cross product.
- Discuss that magnetic field and electric field are not added to get zero field, although magnetic force and electric force can be added.

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

- Teachers can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 2. The AP 1 and AP 2 lab manual may provide practical application of these concepts and the reference guide for students, Quantitative Skills in the AP Sciences

- The AP Physics Online Teacher Community is active and there are many discussions concerning teaching tips, techniques, and activities that many AP Physics 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 APSI. An APSI is a great way to get in-depth teaching knowledge on the AP Physics curriculum and exam, and is also a great way to network with colleagues from around the country.

**Question #2** **Task:** Experimental Design **Topic:** Circuits - LOs: 4.E.5.1, 4.E.5.2, 4.E.5.3, 5.B.9.5, 5.B.9.6, 5.B.9.7, 5.C.3.4, 5.C.3.7

**Max. Points:** 12 **Mean Score:** 4.97

***What were the responses to this question expected to demonstrate?***

- The ability to complete a working circuit diagram with the given materials as described.
- The ability to apply Ohm's law throughout a given circuit.
- The ability to explain the behavior of current in an RC Circuit.
- How to calculate and determine resistances and potential differences in a given circuit.
- The ability to describe the effects of internal resistance on the current and total resistance in a circuit.

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

- In part (a), students were able to follow the instructions and completed the diagram successfully. Many students did not understand that they had to draw a complete circuit loop. Others had difficulty explaining how to determine $R_1$ and $R_2$ using the given equipment.
- In b(i), students were able to recognize that current undergoes changes as the capacitor is charged. Many students simply failed to describe the changes in all three circuit elements, or failed to specify when the current was zero.
- Most students were able to solve for both $R_1$ and $R_2$, or at least understand that their sum equaled 30 Ω in b(ii).
- In b(iii), few students were able to determine the potential difference across the capacitor a long time after the switch is closed.
- Many students were able to determine the increase in $R_1$ in part c. Few students were able to explain the reasoning.

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

| *Common Misconceptions* | *Responses that demonstrate understanding* |
|---|---|
| • Connecting the ammeter and 9V battery at points A and B: Many students literally connected the ammeter and battery at points A and B without adding wire to complete the circuit loop. | • The ammeter and 9V battery are connected in series to the circuit elements at points A, and B and form a complete circuit. |
| • Taking measurements that can be used to determine $R_1$ and $R_2$ : Some students decided to add a voltmeter to "take measurements that can be used to determine $R_1$ and $R_2$". | • Taking current measurements with the ammeter while having the switch open and closed, and using ohm's law correctly to determine $R_1$ and $R_2$ . |
| • Comparing the currents through $R_1$, $R_2$, and the switch immediately after the switch is closed to the currents a long time after the switch is closed: Many students discussed the changes in the current to the capacitor without mentioning the switch. | • A simple list of the currents was acceptable:<br>• $I_{R1}$ before = 0.9A<br>• $I_{R2}$ before = 0<br>• $I_{switch}$ before = 0.9A<br>• $I_{R1}$ after = 0.3A<br>• $I_{R2}$ after = 0.3A<br>• $I_{switch}$ after = 0 |
| • Determining the potential difference across the capacitor: Many students assumed that the potential difference across the capacitor was equal to the battery's 9V. | • The capacitor is connected in parallel to R2, therefore Vc = V2 = (0.3A)R2. |
| • Determining and explaining the third group's value of $R_1$ when a 9V battery with internal resistance is used: Many students explained the greater $R_1$ value by using "$R_1$" = $R_1$ + r, rather than by using the lower current reading from the ammeter. | • The third group will observe a lower current due to the increase in the circuit's resistance which means that $R_1$ must have a larger value. |

***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?***

- Give students more practice in applying basic concepts, such as all complete circuit diagrams must form closed loops.
- Include lessons on series/parallel RC Circuits.
- Discuss the effect of internal resistance on the current.

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

- Teachers can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 2. The AP 1 and AP 2 lab manual may provide practical application of these concepts and the reference guide for students, Quantitative Skills in the AP Sciences

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

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## Question #3

**Task:** Qualitative/Quantitative Translation

**Max. Points:** 12

**Topic :** Photoelectric Effect – Los: 1.B.1.2, 4.E.3.3, 5.B.4.2, 6.F.1.1, 6.F.3.1

**Mean Score:** 6.45

***What were the responses to this question expected to demonstrate?***

An understanding of the photoelectric effect, both graphical and physical representations, including the following:

- The concepts of work function, Planck's constant, and threshold frequency.
- The relationship between the above ideas and the photoelectric equation.
- The relationship between the photoelectric equation and associated graphs.

An understanding of the operation of an electroscope.

An understanding of the properties of light, including the following:

- The variables that change with intensity.
- The relationship between visible light and UV on the electromagnetic spectrum.

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

The responses did an excellent job of:

- revealing gaps in student understanding of the photoelectric effect
- demonstrating student ability to connect an equation and its variable with the graphical representation
- showing student understanding of the operation of an electroscope
- showing the level of student understanding of the properties of light

***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 knew the terminology for the photoelectric effect but were not able to relate terms (work function, Planck's constant, threshold frequency) to the graph. | • Correctly used these terms and relate them to the graph and the equation in part (ai). |
| • Students were able to correctly relate the equation to the slope and intercepts, but did not understand the ideas of the photoelectric effect, such as electrons were emitted from the metal. | • Correctly state in part (bi) that the electrons were ejected and the charge decreased. |

| | |
|---|---|
| • Students identified the work function as the distance along the horizontal axis to $f_o$ rather than the y-intercept.<br><br>• Students stated the work function variable was the x-intercept. | • Correctly identify the y-intercept on the axis or state y-intercept in part (a) |
| • Students believed the light deposited positive charge on the electroscope rather than causing the ejection of electrons. | • Understanding of the process of the photoelectric effect, usually revealed in part (bi). |
| • Students believed leaves of the electroscope would come together if they had opposite charges. | • Students who understood the electroscope stated that with reduced electrostatic force the gravitational force pulls the leaves together (experience with electroscopes). |
| • Confusion on the relationship between intensity, frequency and wavelength of light | • Statements the intensity only changed the number of photons or amplitude of a wave in part (c). |
| • Misunderstaning of charged particles, such as protons and electrons in light waves. | • Correct responses in parts (bii) and (c) stating that the incident light contained photons and electrons were ejected. |

***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 be encouraged to organize and plan their thoughts before they start writing in order to produce more coherent responses.

Students should make sure they answer all parts of the questions. Many students failed to identify the meaning of $f_o$ in part (a) or what aspect of light changed when the brightness changed in part (c).

Students should use electroscopes in a lab setting or, if equipment is not available, with a computer simulation.

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

- Teachers can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 2. The following downloadable curriculum modules will also provide additional information on these concepts: the AP 1 and AP 2 lab manual may provide practical application of these concepts and the reference guide for students, Quantitative Skills in the AP Sciences

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

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**Question #4** | **Task:** Short Answer | **Topic:** Fluids, Thin Film Interference - LOs: 1.E.1.2, 3.B.2.1, 5.B.10.1, 5.F.1.1, 6.C.1.1, 6.E.1.1, 6.E.3.3

**Max. Points:** 10 | **Mean Score:** 4.36

***What were the responses to this question expected to demonstrate?***

- An understanding of buoyant force.
- An understanding of thin-film interference.
- An understanding of the equation of continuity.
- The ability to manipulate variables.
- The ability to solve an equation.

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

Part (a) of the question effectively assessed student understanding of buoyant force and density and the student's algebra skills:

- o equilibrium is reached when forces are equal, so the buoyant force had to equal the weight of the system
- o defining the two forces
- o combining and solving equations in variable form

Part b did not fully assess students understanding of thin film interference. Many students did not earn full credit for this portion because of incomplete, rather than incorrect answers.

Part c effectively assessed student understanding of the continuity equation and the skill of calculating a correct answer from given values.

***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 did not begin the derivation in part (a) from a fundamental physics equation or principle | • $F_G = F_B$ or $\Sigma F=0$ in part (a) |
| • Students did not understand the necessity of showing some work when the problem states "calculate," preferably starting with an equation. | • $A_1v_1 = A_2v_2$ in part (c)<br>• V=10 km/h |
| • Students creating and manipulating equations without applying the specifics of the situation or considering units. | $F_B = V_{boat}\rho_{water}g$<br>• $F_G = (M_{boat} + N\rho_{steel}V_{steel})g$<br>$\rho_{system} = \frac{m_{total}}{V_{boat}} = \frac{M_b + N\rho_{steel}V_{steel}}{V_{boat}}$ |

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|---|---|
| • The change in color due to interference has to do with two waves and not a frequency/wavelength shift inside the substance.<br><br>• Students believed the oil appeared green because the wavelength changed inside the material with a higher index of refraction. | • Correct identification in part (b) of the interference of two waves constructively<br><br>• Correct identification in part (b) of the interference of two waves constructively |
| • Students believed that waves experience a phase shift whenever they reflect, independent of relative indices of refraction. | • Students stated there was a phase shift at the air/oil interface and not at the oil/water interface because of the relative indices of refraction. |
| • Students attempted to apply Bernoulli's equation instead of equation of continuity in part (c), because it is a fluid equation that includes velocity. | • Correct application of equation of continuity in part (c). |

***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?***

- Use computer simulations to help students understand wave interference and thin film interference.
- Give students experience in manipulating equations that do not contain numbers.
- Work with students to organize their thoughts and identify all parts of an explanation. The students rarely earned full credit for part (b) because of incomplete explanations.

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

- Teachers can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 2. The AP 1 and AP 2 lab manual may provide practical application of these concepts and the reference guide for students, Quantitative Skills in the AP Sciences

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