Student Performance Q&A:

2013 AP® Physics B Free-Response Questions

The following comments on the 2013 free-response questions for AP® Physics B 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?

The intent of the question was to draw a free body diagram, use it to apply Newton's second law to the situation, and use the resulting equation it to solve for an unknown force. The question required students to calculate the weight of and buoyant force on an object, and to demonstrate a conceptual understanding of Archimedes' principle for a floating object and a submerged object.

How well did students perform on this question?

Students did well on this question. Nearly all students attempted the question. The mean score was 6.6 out of a possible 10 points, with 52.6 percent of the scores ≥ 8 and 10.5 percent ≤ 2.

What were common student errors or omissions?

- Not adding vector arrows on the dot on the free body diagram.
- Omitting one of the three forces on the free body diagram.
- Adding normal force to the free body diagram.
- Using unconventional labels for the forces.
- In the buoyancy calculation, students often calculated and used the density of the anchor rather than using the given density of water.
- Omitting units. In part (b), students often did not recognize that buoyant force is measured in newtons.
- There was often a disconnect between the free-body diagram in part (a) and the Newton's second law calculation in part (c). The forces that appeared on the diagram often did not match the ones that appeared in the math.
- Justification in part (d): students had trouble recognizing that the forces are balanced even after the boat moves to a greater depth. They often suggested that a force imbalance resulted in the greater depth.

- In the justification, students often used general language rather than using physics..
- Students often did not see the boat and anchor together as a system.
- In the parts that specifically asked the students to calculate, students often did not show their substitutions and work.
- Students often substituted incorrect values when calculating weight.

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?

- Teach standard notation for forces.
- Emphasize when there is and is not a normal force acting on an object.
- Encourage students to always show calculations.
- Stress the connection between free body diagrams and Newton's second law.
- **Always** require units.
- Make sure that students are familiar with the test forma (e.g., the proper use of checkboxes).
- Test strategy: often solving the parts of the question in the order they are presented will help lead students through the problem solving steps.
- Teachers should ask their students to justify answers in words. They should start with a physical law and work from there. Also, they should keep the answer brief.

Question 2

What was the intent of this question?

The intent of this question was to demonstrate understanding of the work-kinetic energy theorem and the mechanics of simple harmonic motion. In part (a), the goal was to show negative work was done by a spring in stopping a block and to calculate the work done by the spring. In part (b), the goal was to demonstrate the relationship between the work done by the spring and the potential stored energy. In part (c), the intent was to demonstrate an understanding of the relationship between Hooke's law and Newton's second law. In part (d), the intent was to demonstrate an understanding of simple harmonic motion. And in part (e), the intent was to allow students to show their ability to relate mathematical functions to appropriate graphs.

How well did students perform on this question?

Students did okay on this question. About 98.6 percent of students attempted the question. The mean score was 6.0 out of a possible 15 points, with 13.8 percent of the scores ≥ 12 and 34.8 percent ≤ 3.

What were common student errors or omissions?

- Misunderstanding of the spring force as a constant force, so kinematic equations are not appropriate because the acceleration is <u>not</u> constant.
- Using the formula for work that is only for a constant force: $W = Fd$.
- Using Hooke's law to find the spring constant rather than conservation of energy.
- Using kinematics to find time, and calling that the period of motion.
- Inability to sketch a graph from a known relationship.
- Confusing time on the horizontal axis with position on the horizontal axis.
- Confusing period and frequency.
- Trying to use rotational motion equations.
- Confusing kinetic energy and the spring 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?

- Emphasize that work equals the change in kinetic energy on a horizontal surface.
- Stress that kinematic equations for constantly accelerated motion are only appropriate when the acceleration is constant.
- Stress that $W = Fd$ can only be used when force is constant.
- Stress that the spring force is not constant, but is linear with position.
- Review graphing quantities by looking at the equation that describes the quantity. For example, the spring force ($F = -kx$) vs. position should be graphed as a straight line with a negative slope and elastic potential energy ($K = \frac{1}{2} kx^2$) vs. position should be graphed as a parabola with positive concavity.
- Use appropriate terminology for explanations. For example, the phrase "work fought against the motion", "it pushed the spring where it didn't want to go", and "the box turned kinetic energy into potential energy" are inappropriate statements. Also, avoid using the word " it" unless you define what "it" is.
- Students should make their answers concise and clear.

Question 3

What was the intent of this question?

This question assessed students' data analysis and graphing skills, understanding of refraction in general and total internal reflection specifically, and ability to design a lab using the critical angle.

How well did students perform on this question?

Student performance declined on this question. Although roughly 90 percent of students attempted the question, the mean score was 3.6 out of a possible 10 points, with 7.9 percent of the scores ≥ 8 and 40.2 percent ≤ 2.

What were common student errors or omissions?

- Part (a)
  - Graphing incorrect variables in order to find index of refraction.
  - Non-linear scaling of axes.
- Part (b)
  - Best-fit line often is drawn by just connecting end points.
  - Not demonstrating that Snell's law leads to connection between slope and index of refraction.
  - Not showing work for calculating slope of the best-fit line.
- Part (c)
  - Not understanding that the laser must point through the curved portion of the semicircular block in order to get total internal reflection.
  - Not understanding that the light must pass from a higher index of refraction to a lower index of refraction in order to have total internal reflection.

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?

- Teach students how to hand-draw graphs and best-fit lines.
- Teach how to linearize data in order to make a straight graph.
- Students need to learn and understand Snell's law and total internal reflection, which can only occur when light travels from a high index material to a low index material.

Question 4

What was the intent of this question?

This question assessed students' understanding of one- and two-dimensional kinematics as well as Newton's first and second laws.

How well did students perform on this question?

Students' performance on this question was polarized. About 96.4 percent of them attempted the question. The mean score was 3.6 out of a possible 10 points, with 29.5 percent of the scores ≥ 8 and 49.8 percent ≤ 2.

What were common student errors or omissions?

- Students did not read the question carefully; for example, in part (a) they were asked to find the velocity of the ball at launch and many students tried to find the velocity when it hit the ground.
- Throughout the problem, students would not show enough work, either not writing the equations they used or miscopying the equations from the given reference sheet. They did not show all steps needed to solve, which left their work incomplete or not understandable.
- In the kinematic section, students had difficulty separating the one dimensional section from the projectile motion section. They would use the correct kinematics equations, but would mix the distances, times and, accelerations from the two sections. In the projectile motion section, some students did not differentiate x and y quantities.
- Students did not understand that just because the friction on the table was negligible, that did not mean that the acceleration of the hanging mass was 9.8 m/s^2.
- For the modified Atwood's machine, students did not identify the system as all three objects. Or, if they tried to do multiple systems, could not correctly find the tension in the string.
- In the essay, many students thought that an increased mass would cause the ball to accelerate downward faster than 9.8 m/s^2.
- Students tried to use conservation of momentum in parts (c) and (d) despite the fact that the net force on the system was not zero.

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?

- Encourage students to consistently show all work, starting with fundamental equations.
- Encourage students to draw labeled force diagrams and write net force statements before applying F = ma.
- Emphasize the concept of inertia and Newton's first law. (Inertia is not a force).
- Have students practice writing about physics in clear terms. Students had difficultly clearly explaining their ideas in proper terminology. The terms "energy," "force," "momentum," and "velocity" tended to be used interchangeably.
- Students need to clearly understand the distinction between mass and weight and know when which concept applies. (Again, these terms were often used interchangeably.)

Question 5

What was the intent of this question?

This question evaluated students' understanding of a system containing an ideal gas. This question required students to understand thermodynamics beyond a simple familiarity with equations, as they were asked to explain the interrelationships among work on the gas and temperature, pressure and volume of the gas. In the second portion of the question, temperature was held constant for the gas while work was done on it. This part required students to understand the relationships among temperature, internal energy, work, and heat.

How well did students perform on this question?

Students' performance on this question was similar to that on question 3. Nearly all students attempted the question. The mean score was 3.6 out of a possible 10 points, with 7 percent of the scores ≥ 8 and 33.1 percent ≤ 2.

What were common student errors or omissions?

- Part (a)
  - Simple addition errors.
  - Students subtracted instead of added, indicating a misunderstanding of the sign conventions involved for heat, work, and energy.
- Part (b)
  - Students were not clear with their justifications, but often simply restated the question and answer, without providing any other support.
  - Incorrect selection of the check boxes was evenly distributed.
  - If the correct check box was selected, the common errors included:
    - (b)(i):
      - Students often did not understand the difference between positive and negative work, confusing the work done on the gas (positive) with the work done by the gas and stating the equation $W = -P\Delta V$.
      - Students assumed the phrase "work was done **on** the gas" was a full justification.
    - (b) (ii)
      - Students connected heat to temperature, but not to the internal energy.
      - Students connected kinetic energy or average kinetic energy to temperature, but did not discuss internal energy clearly.
      - The most common response was, "because the problem stated it was heated."
    - (b) (iii)
      - Students used $W = -P\Delta V$ and did not discuss the effect of temperature on the pressure.
      - Students discussed temperature and pressure using $PV = nRT$, but did not discuss the effect of volume.
      - Student discussed the increased force on the walls of the container because of the higher internal energy of the gas.
- In part (c), it was common for students to think the change in internal energy was equal to the work done on the gas (1800 J), even though the temperature was kept constant.
- In part (d), the most common errors when the correct check box was selected were:
  - The gas tried to reach equilibrium with the surroundings (only).
  - Heat always flows from hot to cold (only).

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?

- Provide strong support for student ideas, outside of the information given in the problem.
- Be consistent and clear in the treatment of positive and negative work and heat and change in internal energy.
- Guide students to fully understand the concepts behind the first law of thermodynamics ($\Delta U = W + Q$) as really representing a conservation of energy equation.
- Ask students to slow down a bit, taking care to add correctly, organize the important ideas, and write legibly.

Question 6

What was the intent of this question?

This question assessed students' knowledge of magnetostatics and electromagnetic induction, including the right-hand rules.

How well did students perform on this question?

Students' performance on this question was poor. About 93.2 percent of them attempted the question. The mean score was 3.5 out of a possible 15 points, with 3.2 percent of the scores ≥ 12 and 56.5 percent ≤ 3.

What were common student errors or omissions?

- Simple calculation errors were frequent.
- Incorrect use or value of the magnetic permeability, μ_0, in Ampere's law.
- Not understanding the intent of parts (a) and (b).
- Incorrectly calculating r as d/2.
- Did not clearly understand the nature of the question and the connection of the parts to each other.

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?

- Teach students to enter numbers correctly on their calculators.
- Teach students to show **all** work neatly and sequentially.
- Teach students to read questions carefully and do work for each part in each part.
- Teach students to pay careful attention to the symbols in the equations and their meanings/values.

Question 7

What was the intent of this question?

This question assessed students' understanding of the interaction between photons and electrons and the energy levels of an atom. It also assessed students' understanding of the ground state and the energy required to change the energy of the atom or to remove an electron from the atom.

How well did students perform on this question?

Students' performance on this last question was again poor. About 84.7 percent of them attempted the question. The mean score was 2.7 out of a possible 10 points, with 6.4 percent of the scores ≥ 8 and 52.7 percent ≤ 2.

What were common student errors or omissions?

- In part (a) students were asked to draw all possible energy transitions from state 3 to state 1. The intent was to draw only three lines, but students were drawing many other lines. Some students drew all of the possible combinations between all of the energy levels on the diagram. Other students had the directions of the transitions incorrect, which could be due to the student not paying attention to the instructions that say the photons were "emitted," thus reducing the electron's energy.
- In part (b) the biggest error was calculating a wavelength for one of the transitions, but not the *longest* wavelength.
- Part (c) had the issue of having the negative sign on an answer that should have been positive. This was most commonly due to students just copying the number off the diagram and not thinking about what the ionization energy means.
- Students who responded to part (d) struggled with the idea that nothing will happen if the incident photon's energy does not match the **change** between energy states of an atom. Many students responded that the electron would just be "excited" to another energy level.
- For part (e) the most common incorrect answer was that the electron was moved to a higher energy state or was not moved at all since the photon's energy did not match any of the given energy states.
- Also in part (e), instead of explaining the physical phenomenon, students used the photoelectric effect to explain the reason for a released electron.
- Many students mistook the zero energy level as the ground state of the atom, which confused them on the answer to some of the parts.

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?

- Ensure that students know what the ground state is.
- Distinguish between what happens to an electron in an atom when a photon is either emitted from or incident upon the electron.
- Emphasize that electrons can only exist in certain energy states, not in between. So, any energy that may be added/released by a photon will only move an electron to another state if the added/released energy matches the *change* in energy between those states.
- Review what exactly the ionization energy is and how it relates to "energy wells."
- Clarify when the photoelectric effect is applicable for the behavior of an electron.