CollegeBoard
Advanced Placement
Program

Student Performance Q&A:

2006 AP® Physics B Free-Response Questions

The following comments on the 2006 free-response questions for AP® Physics B were written by the Chief Reader, William Ingham of James Madison University in Harrisonburg, Virginia. 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?

This question was designed to test student understanding of several topics in mechanics: basic kinematics, Newton's second law and statics, the properties of springs, and simple harmonic motion. Part (a) asked students to draw the free-body diagram for two blocks at rest connected by a string running over a pulley. One block (of mass 8 kg) was on a frictionless table connected to a wall by a spring, and the other block (of mass 4 kg) was freely hanging. Part (b) asked students to calculate the tension in the string. In part (c) students were asked to find the force constant of the spring. In part (d) the string was cut and the hanging block fell freely. Students were asked to find how long it took the block to fall a given distance to the floor. At the same time that the 4 kg block was falling, the 8 kg block on the table was undergoing simple harmonic motion since the spring was initially in a stretched position. Students were asked in part (e) to find the frequency of oscillation and in part (f) to find the maximum speed attained by the 8 kg block.

How well did students perform on this question?

The mean score on this 15-point question was 8.52. About 28 percent of students earned scores of 12 or higher, while approximately 15 percent earned scores of 3 or below.

What were common student errors or omissions?

In general, common student errors included:

- Great difficulty with decimal places: for example, writing 4.0 kg as 0.4 kg, evaluating 0.25-0.20 as 0.5, and so on.

- Calculating tension or time of free fall with the expression for the period of a pendulum or a mass on a spring given on the equation list.
- Setting energy equal to force in parts (b), (c), and (f) (e.g., force equals spring potential energy).
- Omitting units from some or all of their answers; however, providing reasonable numbers of digits was *not* a large problem.

Students often did well on certain parts of the problem but not others; for example, some students did well on parts (a), (b), and (d) but not on the other parts, while other students did well on everything *except* part (a).

More specific common errors for each part included the following.

Part (a) Free-body diagram

- Failure to draw good free-body diagrams recognizing forces that act on a body: many students mislabeled the cause of forces and attributed forces to an object that did not directly act on them (e.g., the 4 kg block pulls directly on the 8 kg block, and the spring pulls upward on the 4 kg block).
- Labeling weight wrongly as "*g*" or "*G*." Although the word "gravity" was accepted on this occasion, it was thought to be problematic.
- Drawing only two or three vectors on the 8 kg block; most commonly omitted were the weight and/or the normal force.
- Drawing the force vectors on the 4 kg block horizontally. (This appears to be a teaching technique for analyzing the dynamics but is an incorrect method to depict a free-body diagram.)
- Drawing a normal force on the 4 kg block, or showing both a normal force and a tension.
- Adding a friction force to the 8 kg block.
- NOTE: For many students, the only written work on the entire question was on part (a).

Part (b) Calculation of tension

- Not showing their work in using Newton's second law applied to a static situation.
- Setting $F = ma$ without showing that $T = mg$ by using the fact that the sum of forces is zero. Most of these students set $a = g$ when in fact $a = 0$.
- Incorrectly writing a single equation for the two blocks as if they were a system of mass 12 kg rather than either writing two equations (one for each block) or writing a correct equation for the 4 kg block.

Part (c) Calculation of spring constant

- Failing to continue their work from part (b) (implying that the two parts were not related).
- Leaving *k* as a negative answer that is unphysical. Many students started with $F = -kx$ and did not understand the negative sign.
- Misinterpreting the term "force constant" and concluding that they should calculate a force. Many students did this, assuming weird values of *k*, including 9×10^9 and 1.38×10^{-23}.
- Incorrectly stating that the spring stretch was either 0.25m or 0.20m, rather than $0.25\text{ m} - 0.20\text{ m}$. The most common mistake was to use 0.25 m for *x*.
- Confusing $F = -kx$ with $F = \mu F_N$ and solving for μ.
- Thinking that the spring constant had no units associated with it.

(d) Calculation of time for free fall of hanging block

- Starting with energy conservation and finding the impact speed but not knowing what kinematic relationship(s) could be used to find the fall time from the impact speed.
- Solving the kinematic equation $h = (1/2)at^2$ for t but not realizing that $a = g$. These students then solved an equation using the combined masses or used the equation for the acceleration of an Atwood's machine.

Part (e) Calculation of frequency of block-spring system

- Not using the computed k from part (c).
- Using the free-fall time from part (d) as the period and computing $f = 1/T$.
- Stopping immediately after finding T; there appeared to be some confusion between the terms "period" and "frequency."
- Finding f by using the thin lens formula; a significant number of students committed this error.
- Using the formula for the period of a pendulum or a "hybrid" by setting T equal to $2\pi\sqrt{m/g}$ or $2\pi\sqrt{\ell/k}$.
- Using $\upsilon = \lambda f$ in both part (e) and part (f), with υ found in part (f), and setting λ equal to twice the amplitude of the oscillator.

Part (f) Calculation of maximum velocity of the oscillating block

- Failing to use the computed k from part (c).
- Finding υ by misapplying constant-acceleration kinematics to the 8 kg block.
- Using an incorrect value for A, choosing instead 0.25 m or 0.20 m.
- Using mgh with the conservation of energy rather than $0.5kx^2$.
- NOTE: Many students used two totally different values for x in parts (c) and (f). Invariably they used 0.25, 0.2, 0.1, or 0.5 in (f) regardless of what they had used in (c), as if there were no connection between the two 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?

See general comments at the end of question 6.

Question 2

What was the intent of this question?

This question was intended to test a student's ability to design and analyze a simple kinematics experiment. Students were to determine the magnitude and duration of the acceleration of a runner in a 100-meter dash. In part (a) students were given an equipment list and told to choose equipment of relevance. In part (b) they were expected to describe a procedure and resulting data that would allow them to determine the desired quantities. In part (c) students were expected to outline the data analysis and extraction of the desired information.

How well did students perform on this question?

The mean score on this 15-point question was 7.24. About 18 percent of students earned scores of 12 or higher, while approximately 19 percent of students earned scores of 3 or below.

What were common student errors or omissions?

In part (a) most students could identify the need for distance-measuring and time-measuring equipment.

In part (b) students would sometimes attempt to measure the runner's distance at fixed time intervals (typically one second), a physically correct but experimentally imprecise technique. Another common error was not taking enough data points to adequately characterize the runner's motion over the entire run. Some students went so far as to only measure the time required to run the entire distance, not realizing that more data points were required to properly describe the periods of constant acceleration and constant velocity.

Most students handled parts (a) and (b) fairly well and had more serious conceptual errors in part (c); there, they routinely calculated velocity at each point as the ratio of the *total* distance from the beginning of the race to each position, divided by the corresponding *total* time, neglecting the need for a piece-wise differential quantity. Students also tried to apply the general kinematic equation $x = x_0 + \upsilon_0 t + (1/2)at^2$ over the entire dash. In general, students who had difficulty with this problem did not realize that there were two kinematically distinct stages and that the periods of constant acceleration and constant velocity needed to be handled separately.

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?

See general comments at the end of question 6.

Question 3

What was the intent of this question?

This question asked students to demonstrate their understanding of electric fields of point charges. Two charges, one known and the other unknown, existed on a line. Students were told that the total field strength at a place on the line was zero; they were asked to determine the magnitude and sign of the unknown charge from this information and to justify their answer. The question went on to ask for the force of the two charges upon one another, then for determination of the place between the charges where the potential was zero, and finally for the amount of work needed to bring a third charge from infinity to this place of zero potential.

How well did students perform on this question?

The mean score on this 15-point question was 3.93. About 8 percent of students earned scores of 12 or higher, but approximately 61 percent earned scores of 3 or below.

What were common student errors or omissions?

Those who earned the lowest scores relied upon recall of formulas for their answers; those who understood the meaning of electric field strength and electric potential did better; and those who also understood the vector nature of electric field strength and the scalar nature of potential performed best of all. Many students wrote confused or circular justifications or did not recognize what is meant by the word "justify."

Students were asked to find the position on an x-axis (i.e., the coordinate value) where the potential is zero; many gave this position relative to one of the two charges instead.

In the last part of the question, a number of students were unclear that the V in $W = qV$ is a potential *difference*, rather than a potential.

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?

See general comments at the end of question 6.

Question 4

What was the intent of this question?

This question was designed to test student understanding of two different topics in optics. The first portion of the question—parts (a) through (c)—referred to an experiment designed to obtain the index of refraction of a piece of glass. Students were given a set of data consisting of the angles of incidence and refraction, and they were asked to construct a graph from which the index of refraction could be obtained. The remainder of the question dealt with thin-film interference. Students were asked to identify at which (if any) of the interfaces there was a 180˚ phase change upon reflection and to calculate the minimum possible thickness of the film.

How well did students perform on this question?

The mean score on this 15-point question was 4.03. About 6 percent of students earned scores of 12 or higher, but approximately 59 percent of students earned scores of 3 or below.

What were common student errors or omissions?

In the first portion of the question, a great number of students did not know which quantities needed to be graphed in order to obtain the index of refraction. Some students recognized Snell's law but were not able to see the relationship among the variables.

Many students showed poor graphing skills; some of them had difficulty drawing a best-fit line and just connected the dots. Also, the majority of students found the slope by using data points instead of points on their line or by just using a single point (y/x) from the data or the graph. The relatively poor performance on this portion of the question suggests that students receive little or no exposure to optics, and/or that they do not "perform with understanding" experiments related to refraction.

Few students attempted the second portion of the question, which suggests that thin-film interference is a topic that is commonly omitted from the AP Physics class. Some students answered the phase shift part correctly, but others seemed to be guessing without understanding the boundary behavior. A number of students wrote the double slit equation trying to solve for thickness. The most common error while calculating the thickness of the film was to use the wavelength of the light in air instead of the wavelength in the film.

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?

See general comments at the end of question 6.

Question 5

What was the intent of this question?

This question was intended to test student understanding of thermodynamics. An unspecified amount of an ideal gas was taken through a cyclic thermodynamic process, which traced out a triangle as shown on the given PV diagram. Students were given the initial temperature of the gas. In part (a) they were to use the ideal gas equation of state along with pressure and volume data taken from the graph to calculate the temperatures in the two other states at the vertices of the cycle. In part (b) students were asked to calculate the net work done on the gas in one cycle. In part (c) they were directed to decide whether the net effect of the cycle was to add heat to the gas or remove heat from the gas, or whether no net heat transfer occurred. For full credit, students had to justify their answer.

How well students perform on this question?

The mean score on this 10-point question was 4.00. About 12 percent of students earned scores of 8 or higher, while approximately 30 percent earned scores of 2 or below.

What were common student errors or omissions?

Most students did well on part (a). The most common difficulty for those students not using ratios of temperature to pressure or volume was the failure to use the initial state of the gas to calculate the number of moles, which would then have allowed them to determine the unknown temperatures. Students using ratios usually succeeded, save for the occasional algebra error in constructing those ratios from the ideal gas equation of state.

Most students chose to compute the net work by treating the cycle as three separate processes. The most common errors were using an incorrect pressure for the process going from state 2 to state 3, during which the pressure varied, and not using opposite signs for the work done during the expansion and that done during the compression. Students who realized the net work was the triangular area generally succeeded in reaching the answer. These students, however, occasionally came up with the wrong sign for the work (many apparently interpreted the equation $W = -P\Delta V$ to mean $W = -\text{area}$).

Student responses in part (c) showed considerable confusion. A common answer was that after one cycle the gas returns to its original state, so nothing has changed—no work, no heat transfer. In particular, many students believed that since there was no temperature change from the beginning of the cycle to the end, there could be no heat transfer. Many also made reference to temperature and volume changes in various parts of the cycle but missed the point that the internal energy is left unchanged after a complete cycle. Others recognized this fact but failed to distinguish between heat and internal energy.

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?

See general comments at the end of question 6.

Question 6

What was the intent of this question?

This question was intended to test student knowledge of topics in modern physics: specifically, the energy of a photon and wave-particle duality. In part (a) students were given the wavelength of a photon and asked to calculate its energy. In part (b) they were asked to calculate the de Broglie wavelength of an electron with the same kinetic energy as the photon in part (a). In part (c) students were asked to describe an experiment that would demonstrate the wave nature of the electron.

How well did students perform on this question?

Overall, the performance on this 10-point question was better than on modern physics questions in previous years. The mean score was 3.04. About 8 percent of students earned scores of 8 or higher, while approximately 45 percent earned scores of 2 or below.

What were common student errors or omissions?

Many students were able to complete part (a) correctly. However, some of them incorrectly calculated the frequency of the photon, assuming $f = 1/\lambda$. Other students simply did not complete the algebra on this part correctly.

In part (b) the most common mistake was to treat the electron as if it were a photon and use $E = pc$ to calculate the momentum that was then used in the de Broglie wavelength equation. This circular logic then led students to a de Broglie wavelength equal to the wavelength of the photon in part (a). Some students attempted to use a formula containing the work function and expressing the conservation of energy in the photoelectric effect, but they did not get very far with this incorrect approach.

In part (c) about 10 percent of students correctly described an electron diffraction experiment. A fourth of those answering this part of the question described an experiment related to light waves interfering, neglecting the electron completely. Some students correctly described the photoelectric effect, not realizing it demonstrates the particle nature of the photon rather than the wave nature of electrons. A number of students named other modern physics experiments, such as the Rutherford gold foil experiment, the Millikan oil drop experiment, and so on. Many left part (c) completely blank.

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?

Performance on the Physics B Exam was as expected. Students need additional work in experimental technique in general and graphical analysis in particular. The relatively low scores on question 3 indicate that more attention to the electrostatics of point charges is needed. Students also had difficulty in bringing together concepts and results from different areas within physics, as was required for question 1.