Student Performance Q&A:

2002 AP® Physics Free-Response Questions

The following comments are provided by the Chief Reader regarding the 2002 free-response questions for AP Physics. *They are intended to assist AP workshop consultants as they develop training sessions to help teachers better prepare their students for the AP Exams*. They give an overview of each question and its performance, 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 included. Consultants are encouraged to use their expertise to create strategies for teachers to improve student performance in specific areas.

Physics B

Question 1

What was intended by the question?

This question asked students to solve a problem in one-dimensional kinematics. A model rocket is accelerated vertically upward, coasts upward after the rocket engine shuts off, then gently falls to earth after a parachute deploys. Students needed to deploy their knowledge of the kinematics equations, and to be able to accurately indicate the forces acting on the rocket during each of its three phases of flight.

How well did students perform?

The student performance on this problem was low for a one-dimensional kinematics problem. The average score was 7.7. The scoring distribution showed two peaks, the first at a score of 13 and the second at a score range of 6-8. These peaks correspond to students who worked the problem correctly through all five sections, and those who had difficulty in analyzing the different stages of the motion properly.

What were common errors or omissions?

Some students had difficulty in following the directions concerning the free-body diagram, and insisted on adding vectors for velocity as well. Some students also left gravity out of the calculation of the rocket's average acceleration, even though they had indicated the presence of gravity on their free-body diagram.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

When answering this type of question, students need to be aware of the applicability of the equations that they use, and the values of all of the terms in those equations for the motion they wish to analyze. They also need to label their diagrams carefully with no extraneous vectors. Extra vectors and non-existent forces usually result in a penalty being assessed.

Question 2

What was intended by the question?

This question asked students to interpret a potential-energy diagram, and apply it to an analysis of simple harmonic motion. The fifth of five parts of the question was a simple exercise in two-dimensional kinematics. In addition to the usual quantitative problem solving, students had to explain their reasoning in the second part of the problem, which asked students to determine the maximum amplitude of the oscillation.

How well did students perform?

The average score on the problem was 7.8. One out of four students scored a 14 or 15 on the problem, which is good news. The bad news is that slightly more than one out of six students received no credit for their response. Some students decided not to use the graph in their analysis, but to assume that the potential energy was of the form $kx^2/2$, and to solve for the constant k. This generated slightly different numerical answers than those generated by using the graph. Students received full credit for either approach.

What were common errors or omissions?

Student errors centered on two broad classes of error: inability to interpret the energy graph, and a lack of understanding of the relation between the kinetic energy, potential energy, and the total energy of a system. However, many teachers are obviously doing an excellent job on this topic, judging from the high number of 14s and 15s.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

More work on the kind of graphical analysis required by this problem would clearly benefit some students.

Question 3

What was intended by the question?

This question asked students to calculate the currents and resistances of two light bulbs of known power output. The students first performed these calculations for the bulbs in a parallel circuit, then in a series circuit. The students were then asked to rank the bulbs in order of brightness in the two cases, and finally to calculate the total power dissipated by the bulbs in the two cases.

How well did students perform?

The student performance was slightly worse than expected, with an average score of 6.7. Only 10 percent of the students received a 13, 14, or 15.

What were common errors or omissions?

This circuit, a simple one consisting of a power supply and two resistive components, seemed to baffle many students. Many students had difficulty with the series circuit, as they seemed to think that the bulbs *always* dissipated 30 W and 40 W, the rated values given for the standard household 120V. In fact, the power consumed by the two bulbs, and therefore their brightness, changes when they are moved from the parallel to the series circuit. The power output in both bulbs decreases, but in such a way that the 30 W bulb is now brighter than the 40 W bulb.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Students seem to need more work on straightforward circuit problems, especially in working backward from power ratings to resistances. Some might think that it is inherently incorrect to treat an inherently nonohmic device like a light bulb as an ohmic device in this problem. No other assumption allows the students to solve the problem successfully, and part of physics is learning what simplifying assumptions one must make in order to solve otherwise intractable problems.

Question 4

What was intended by the question?

This question dealt with geometrical optics, in particular ray diagrams and the thin-lens equation. The students were asked to find the position, orientation, and magnification of an object inside the focal point of a thin converging lens. They were then asked to do the same for an object placed at a distance equal to twice the focal length of the lens.

How well did students perform?

The student performance was good, with an average score of 8.3. Nearly 30 percent of those taking the exam received a 13, 14, or 15. Yet one out of four students received a score of 3 or less on this problem.

What were common errors or omissions?

It was clear that many students had had extensive experience with ray diagrams, and their use in determining the position, size, and orientation of an object. But many had only hazy notions of these techniques, and gathered their points solely through an application of the thin-lens equation. It was surprising how many students assumed that the ray diagram for an object placed inside of the focal point of a lens would look just like the ray diagram for an object placed outside of that focal point.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

The use of ray diagrams is important, and needs a significant amount of class time if students are to master this technique. Students need to be shown applications for various object positions, and to understand the difference between them, if they are to have success on this kind of problem.

Question 5

What was intended by the question?

This question is a combination of mechanics and electricity and magnetism. A charged particle moves through a region with crossed E and B fields at constant velocity, and then enters a region where there is only a B field. Students were asked to find the direction and magnitude of the E field, and to analyze the motion when it entered the region containing just the B field.

How well did students perform?

The most surprising thing about this problem was that nearly 35 percent of the students received no credit. These students either left it blank, or did no work that earned them any credit. Yet this is a standard problem. Fewer than 11 percent of the students scored a 9 or 10 on this 10-point problem. The average score of 3.2 is much lower than expected for this question.

What were common errors or omissions?

Why did students perform so badly? The length of the exam is not the answer, as there were fewer zeroes on questions 6 and 7 than on 5. An examination of the answers to the sections of this question on the direction of the electric field, and the trajectory of the particle in the B field, indicate that students, at least this year's students, had little mastery over these concepts.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Solving more integrative problems that combine mechanics and electricity and magnetism might help students deal more effectively with problems such as this one.

Question 6

What was intended by the question?

This year's 10-point laboratory-based question centered on an application of Archimedes' principle to determine the density of a fluid. The problem was more directed than in recent years, as students were asked to first determine the spring constant of a spring attached to an object of mass m. The object was then inserted in the fluid, and students asked what changes would result from this immersion. Finally, students were asked to use the apparatus described to develop a procedure for determining the density of the fluid.

How well did students perform?

The average score was 3.2, with 29 percent of the students receiving a zero for their efforts or lack of response. Fewer than 11 percent of the students received a 9 or a 10 on this problem. In fact, nearly 80 percent of the students received a 5 or lower, indicating that only 20 percent of the students received much credit for the experimental part of the problem.

What were common errors or omissions?

Many students did well on the first two parts, but faded markedly in the experimental part of the problem, indicating a widespread unfamiliarity with laboratory technique.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

As has been noted in previous years, students need more time in laboratory activities in the introductory course.

Question 7

What was intended by the question?

The last question dealt with Compton scattering, although it was never referred to as such. The phenomenon was described so that students could reason from fundamental concepts and need not have specifically studied the Compton effect. The collision was one in which the incoming photon is reflected from a stationary electron. The students were first asked to calculate the energy and momentum of the incoming photon. They were then asked if the photon's wavelength would increase or decrease as a result of the collision, and to explain their answer. The final section asked students to calculate the momentum acquired by the electron in the collision.

How well did students perform?

The average score was 2.7, with over 56 percent of the students receiving a score of 2 or less.

What were common errors or omissions?

Students could have simply run out of time during the exam. They may also have run out of time during the semester, as modern physics often gets short shrift in classes where the B course is the first physics course that students take. Students had difficulty even with the first two sections of the problem. The explanations asked for in the third section indicated a lack of understanding of some fundamental ideas, such as when students stated that the photon wavelength changes because the photon slows down as a result of the collision.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

It is clear that modern physics is not adequately covered in most courses. The number of topics to be covered in the B course clearly contributes to this state of affairs.

Physics C: Mechanics

Mechanics Question 1

What was intended by the question?

This question involved an analysis of an inelastic collision between two objects, one of which was stationary. Students were given the velocity of the system as a function of time after the collision took place, and the mass of the incoming object. The students were asked to find the mass of the stationary object. This task involved a simple application of the conservation of momentum. They were then asked to find the position of the object as a function of time, so that they had to integrate the velocity that they were given. The third part of the problem involved finding the resisting force acting on the system, so that they now had to differentiate the expression for velocity in order to find the acceleration of the system. Finally, the students were asked to determine the impulse delivered to the system over a two-second time interval ($t = 0$ to $t = 2$ s).

How well did students perform?

Students did very well on this question. The average score was 9.6, and more than one in four students received a 14 or 15.

What were common errors or omissions?

Most students made few errors using calculus in the problem. The more common errors involved a lack of understanding or a misunderstanding of the physics involved.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

One point that did arise is the divergence between the calculus notation used in most physics texts, and the notation used in some calculus courses. Physics and Calculus teachers should discuss these differences in notation, so that their students aren't penalized for misapplications of the notation. This applies principally to the integral calculus.

Mechanics Question 2

What was intended by the question?

This question involved a cart with wheels rolling down a ramp, and then making contact with a horizontal bumper. In the first half of the question, students were asked to find the velocity of the cart at the bottom of the ramp. This required them to apply the principle of conservation of energy to a case where the object in motion has both linear and rotational kinetic energy. The second two parts had the cart collide with the bumper, which was attached to a spring. Students were first told that the bumper had negligible mass, and asked to find the maximum compression of the spring. In the final part, students were told that the spring had non-negligible mass, and were told that spring only compressed to 90 percent of the value found previously for the maximum compression. They were then asked to give a reasonable explanation for this effect.

How well did students perform?

Student performance was high on this question, with an average score of 8.4. More than one of six students taking the exam scored a 13, 14, or 15, and fewer than 10 percent of the students had scores of 2 or lower.

What were common errors or omissions?

The primary errors that students made in the problem were the neglect of rotational motion in the first half of the problem, and incomplete or incorrect explanations in the final part of the problem.

The inability of many students to give good explanations for the effect described in the final part of the problem is more troubling. Students need to think through how the piece of information that they are given about the mass of the bumper can change the result. Statements such as "energy was lost as heat" explain nothing about the particular circumstances of the experiment.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Rotational motion is always difficult for students, and needs more work in the classroom and on homework. More good lab exercises may also help the students get a better handle on the concepts of rotational motion and rotational energy. More attention also needs to be paid to the development of the skills necessary to analyze and describe phenomena.

Mechanics Question 3

What was intended by the question?

This five-part question can be divided into two sections. In the first section, students are given a potential energy function. First, they are asked to graph the function. Second, they are asked to determine the force resulting from this potential. Finally, they are asked to determine the velocity of an object released from rest at the origin when the object reaches the position $x = 2$ m. The second section asked the students to develop an experiment, using items from a list of equipment, which would allow them to check the value of the velocity obtained in the first section of the question.

How well did students perform?

Student performance on this problem was good, with the average score being 8.2. There were few low scores, as fewer than one in six students received a score of 4 or less. There were also few high scores, as fewer that one in five students received a score of 12 or better.

What were common errors or omissions?

Most students scored most of their points on the first section of the problem, and did considerably less well on the second, lab-oriented, section. Students have the mathematical ability and training to solve the first section, but have little experience with experimental work that requires them to design an experiment.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

The lab work in the AP Physics courses must be more than a series of cookbook exercises that do not require the students to engage the problems of experimental design, data acquisition, and data analysis. Many students will continue to do poorly on the lab-based sections of the AP Physics exam unless more time is spent on lab work that engages the student in all aspects of experimental physics.

Physics C: Electricity and Magnetism

Electricity and Magnetism Question 1

What was intended by the question?

This question asks students to calculate the fields and potentials due to a circular arc of charge of linear charge density. After first finding the total charge, students find the electric field at the center of curvature of the circular arc, then the electric potential at that same point. The fourth and fifth parts ask students to find the force exerted on a proton at the center of curvature of the arc, and to describe its motion if it is released from rest. The students needed to be able to calculate the electric field and the electric potential that arise form continuous charge distributions to have much success with this problem.

How well did students perform?

As the average score of 6.5 might indicate, many students had difficulty with what might be thought of as a standard example for this sort of calculation. Only 10 percent of the students received a score of 12 or above.

What were common errors or omissions?

A full quarter of the students attempted to solve the problem using Gauss' law, an approach that was not crowned with success. The degree of symmetry in the problem is not sufficient to make this approach successful, and many students lost substantial numbers of points as a result. While Gauss' law often occurs in AP Physics C problems, it was of no use here, and students who tried to outfox the exam by guessing what concepts it should cover ran into trouble. It was also surprising how many students failed to adopt the correct approach for finding the total charge on the circular arc.

Most students were able to give good answers to the last part of the problem, even if their technique had failed them earlier. They understood that the proton would be subjected to a decreasing acceleration as it sped away, and that its velocity would approach a constant value at very large distances.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Performance on this question points to a weakness in determining fields and potentials of continuous charge distributions that are not susceptible to analysis using a Gaussian surface.

Electricity and Magnetism Question 2

What was intended by the question?

This question, involving the analysis of an *RC* circuit, began by asking students to find the charging voltage for an *RC* series circuit. Students were given the current as a function of time, and the value of the resistance. By setting the time equal to zero, the charging voltage can be found. From knowledge of the time constant, the value of the capacitor could then be found in the second part of the problem. The third part of the problem asked the students to consider the implications of finding out that the charging voltage is actually greater than the calculated value from the first part of the problem. The last section of the problem asked students to decrease the charging time by first adding only one resistor to the circuit, then in the second case by adding only one capacitor to the original circuit.

How well did students perform?

Student performance on this problem was good, with an average score of 9.0. Only 25 percent of the students received a score of 6 or less. Nearly a quarter of the students scored a 13, 14, or 15 on this question. Most students knew that some sort of additional resistance would explain the voltage difference in the third part, and that this implied that the capacitor must have a smaller capacitance than that calculated earlier. For the last part, most students realized that adding the resistor in parallel, and the capacitor in series, would produce the desired effect.

What were common errors or omissions?

There was a variety of errors made by the students, and no pattern of errors or ommissions to indicate any systematic problems.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

The results on this question indicate that most students had a good understanding of *RC* circuits.

Electricity and Magnetism Question 3

What was intended by the question?

The final question on the AP Physics Electricity and Magnetism exam was composed of five parts. The students were given a situation in which a circular loop was inserted in a time-varying magnetic field. The first part of the question involved finding the flux through the loop. The students then graphed the flux as a function of time, and determined the emf induced in the loop. The fourth part asked the students to find the magnitude and direction of the induced current. The fifth part involved finding the energy dissipated in the loop from $t = 0$ to $t = 4$ seconds. The concepts involved were magnetic flux and its relation to emf, Lenz' Law, and Joule heating.

How well did students perform?

Student performance was good, with an average score of 8.1. It is unusual for a question on electromagnetic induction to outscore one on electrostatics, but such was the case on this year's exam. Nearly 10 percent of the students received a 15, while fewer than one out of four students received a 4 or less. This was a pleasant turnaround from the student performance on electromagnetic induction problems in recent years, where student performance has been low.

What were common errors or omissions?

Student errors were often on the lines of forgetting the formula for the area of a circle (it is given on the equation sheet) or incorrectly differentiating a function linear in the variable of differentiation, rather than lapses in understanding the physics concepts. Perhaps the students were rushed at this point in the exam, but they seemed to have, in most cases, ample time to make a stab at all five parts of the problem.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

A little more care in the application of mathematics would have helped some students on this question, but they seemed to have a reasonable grasp of the physics.