

Question 1: Paragraph-Length Response

10 points

(a) For indicating that f_B is least and f_C is greatest 1 point

For correctly relating the frequency of a photon to the energy of the photon 1 point

For indicating that the kinetic energy or speed of an ejected electron is inversely related to the de Broglie wavelength of the electron 1 point

For indicating **one** of the following: 1 point

- That a greater photon energy or frequency results in a greater kinetic energy for an ejected electron
- That the lowest photon energy or frequency is below the work function or threshold frequency which results in no ejected electron

For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response 1 point

Example Response

An electron will be ejected if the incident photon has an energy greater than the work function of the metal. Because no electrons were ejected using f_B , the corresponding photon energy, and, therefore, frequency must be the least. A photon with greater frequency will result in an ejected electron with more kinetic energy; the kinetic energy of an electron is inversely related to the de Broglie wavelength of the electron. Because the de Broglie wavelength of electrons ejected by light of frequency f_A is greater than those ejected by light of frequency f_C , f_A must be less than f_C . Therefore, f_C is the greatest.

Total for part (a) 5 points

(b) For **one** of the following: 1 point

- Correctly relating electron de Broglie wavelength to a correct expression that includes h , m , and v
- Relating kinetic energy to a correct expression that includes momentum and mass

Example Responses

$$\lambda_e = \frac{h}{mv}$$

OR

$$K = \frac{p^2}{2m}$$

For correctly substituting an algebraic expression in terms of λ_e for the electron speed or momentum into a relevant equation for kinetic energy 1 point

Scoring Note: This point can be earned for substituting a numerical value for electron speed or momentum into a relevant equation for kinetic energy.

Example Responses

$$K = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2 \quad \text{OR} \quad K = \frac{\left(\frac{h}{\lambda_e}\right)^2}{2m}$$

For a correct answer with units 1 point

Example Response

$$K = 5 \times 10^{-19} \text{ J}$$

Example Solution

$$\lambda_e = \frac{h}{p} = \frac{h}{mv}$$

$$v = \frac{h}{m\lambda_e}$$

$$K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2$$

$$K = \frac{h^2}{2m\lambda_e^2}$$

$$K = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})^2}{2(9.11 \times 10^{-31} \text{ kg})(6.9 \times 10^{-10} \text{ m})^2} = 5 \times 10^{-19} \text{ J}$$

Scoring Note: An answer of 3 eV also earns the final point.

Total for part (b) 3 points

- (c) For indicating that the work function of Metal 1 is less than the work function of Metal 2 with an attempt at a relevant justification **1 point**

For indicating at least **two** of the following: **1 point**

- The correct relationship between the work function and the difference between hf and $K_{\max}$
- The frequency or energy of the incident photons is the same
- The de Broglie wavelength is inversely related to the energy of the ejected electrons

Example Response

The work function of Metal 1 is less than the work function of Metal 2. When light of the same frequency is incident on both metals, the electron ejected by Metal 1 has a smaller de Broglie wavelength than that of Metal 2, so an electron ejected from Metal 1 has more kinetic energy. The work function is the difference between the photon energy and the maximum kinetic energy. Since the photon energy is the same but the maximum kinetic energy is larger for Metal 1, the difference between the energies, and thus the work function, is smaller for Metal 1.

Total for part (c) 2 points

Total for question 1 10 points

2018

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AP Physics 2: Algebra-Based Scoring Guidelines

2018 SCORING GUIDELINES

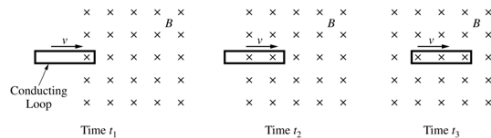
General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.
2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at <https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf>.
3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.
6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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Question 1

10 points total

Distribution
of points

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

- (a) LO 2.D.1.1, SP 2.2; LO 4.E.2.1, SP 6.4
5 points

In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1 , t_2 , and t_3 . Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

For indicating that the currents at t_1 and t_2 have equal nonzero magnitudes and are in the same direction	1 point
For indicating that there is no current at t_3	1 point
For correctly indicating that the currents depend on the change in flux through the loop or the forces on the charges moving in the field	1 point
For correctly identifying the direction of the current as counter-clockwise and either explaining that the direction of the current generates a magnetic field that opposes the change in flux <u>or</u> analyzing the force on the charge carriers in each segment of the loop	1 point
For an on-topic response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response	1 point

- (b)

The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



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Question 1 (continued)

Distribution
of points

- (b) (continued)

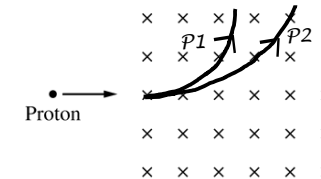
- i. LO 2.D.1.1, SP 2.2
1 point

Calculate the magnitude of the force on the proton as it enters the field.

For correct substitutions into a correct expression and correct units on the final answer	1 point
$F = qvB$	
$F = (1.6 \times 10^{-19} \text{ C})(3.0 \times 10^5 \text{ m/s})(0.03 \text{ T})$	
$F = 1.4 \times 10^{-15} \text{ N}$	

- ii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4; LO 3.C.3.1, SP 1.4
1 point

On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



For drawing a curved arc through the field, curved upward where the proton enters	1 point
Anything greater than a semi-circle or a path that does not reach the edge of the field does <u>not</u> earn credit. Any path after exiting the field is ignored.	

- iii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4
1 point

A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

For drawing a path with a larger radius that is consistent with answer to (b)(ii)	1 point
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Question 1 (continued)

Distribution
of points

(b) (continued)

- iv. LO 2.C.1.1, SP 6.4; LO 2.C.1.2, SP 2.2; LO 3.B.2.1, SP 1.4, 2.2
2 points

Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

For indicating a direction of the electric field that is consistent with the response to (b)(ii)		1 point
Given the correct response to (b)(ii) illustrated above, the electric field must be directed in the $-y$ direction (or toward the bottom of the page)		
For equating the electric and magnetic forces and substituting into the correct expression using values consistent with the response to (b)(i)		1 point
$qE = qvB$ (Implicitly equating the calculated magnetic force to the electric force is acceptable.)		
$E = vB$		
$E = (3.0 \times 10^5 \text{ m/s})(0.03 \text{ T})$		
$E = 9000 \text{ N/C}$		

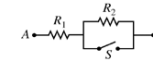
Learning Objectives (LO)

- LO 2.C.1.1:** The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation. [See Science Practices 6.4, 7.2]
- LO 2.C.1.2:** The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See Science Practice 2.2]
- LO 2.D.1.1:** The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practice 2.2]
- LO 3.B.1.4:** The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]
- LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
- LO 3.C.3.1:** The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practice 1.4]
- LO 4.E.2.1:** The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See Science Practice 6.4]

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Question 2

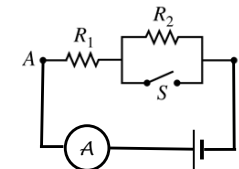
12 points total

Distribution
of points

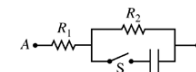
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2 , as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B . The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2 .

- (a) LO 4.E.5.3, SP 2.2, 4.2, 5.1; LO 5.B.9.5, SP 6.4; LO 5.C.3.4, SP 6.4
4 points

Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2 .



For a diagram with an ammeter and battery in series with the resistor combination		1 point
For indicating that the current should be measured with the switch closed and open		1 point
For correctly indicating that with the switch closed $R_1 = V/I_1$		1 point
For correctly indicating that with the switch open $R_2 = (V/I_2) - R_1$		1 point



A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between A and B is maintained at 9 V. The students close the switch and immediately begin to record the current through point B . The initial current is 0.9 A, and after a long time the current is 0.3 A.

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Question 2 (continued)

Distribution
of points

- (b)
- i. LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.5, SP 6.4; LO 5.C.3.7, SP 1.4
3 points

Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

For indicating that the current through resistor 1 immediately after the switch is closed is greater than the current a long time after the switch is closed	1 point
For indicating that the current through resistor 2 is zero immediately after the switch is closed and nonzero a long time after the switch is closed	1 point
For indicating that the current through the switch is nonzero immediately after the switch is closed and zero a long time after the switch is closed	1 point

- ii. LO 4.E.5.1, SP 2.2, 6.4
2 points

Calculate the values of R_1 and R_2 .

For using the correct value of current and correctly calculating R_1	1 point
$9\text{ V} = (0.9\text{ A})R_1$	
$R_1 = 10\ \Omega$	
For using the correct value of current and correctly calculating R_2 , consistent with the calculated value of R_1	1 point
$9\text{ V} = (0.3\text{ A})(R_1 + R_2) = (0.3\text{ A})(10\ \Omega + R_2)$	
$R_2 = 20\ \Omega$	

- iii. LO 4.E.5.1, SP 2.2; LO 5.B.9.6, SP 2.2, LO 5.C.3.7, SP 1.4, 2.2
1 point

Determine the potential difference across the capacitor a long time after the switch is closed.

For correctly calculating the potential difference across the capacitor, including correct units, consistent with part (b)(ii)	1 point
$V_C = V_{\text{battery}} - V_{\text{resistor 1}} = 9\text{ V} - (0.3\text{ A})(10\ \Omega)$	
$V_C = 6\text{ V}$	

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Question 2 (continued)

Distribution
of points

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

- (c) LO 5.B.9.7, SP 5.3
2 points

How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

For correctly explaining that the third group's measured current is smaller	1 point
For correctly indicating that the third group's value of R_1 is higher than the second group's or the resistance they will determine is actually $R_1 + r$	1 point

Learning Objectives (LO)

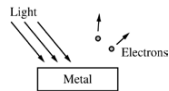
- LO 4.E.5.1:** The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2, 6.4]
- LO 4.E.5.2:** The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 6.1, 6.4]
- LO 4.E.5.3:** The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See Science Practices 2.2, 4.2, 5.1]
- LO 5.B.9.5:** The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice 6.4]
- LO 5.B.9.6:** The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]
- LO 5.B.9.7:** The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [See Science Practices 4.1, 4.2, 5.1, 5.3]
- LO 5.C.3.4:** The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]
- LO 5.C.3.7:** The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [See Science Practice 1.4, 2.2]

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Question 3

Distribution
of points

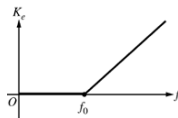
12 points total



Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

- (a) i. LO 5.B.4.2, SP 1.4, 2.1, 2.2; LO 6.F.3.1, SP 6.4
3 points

Based on conservation of energy, the relationship between K_e and f is predicted to be $Af = B + K_e$ when $f > f_0$ and $K_e = 0$ when $f \leq f_0$, where A and B are positive constants. A graph of this relationship is shown below. Indicate which aspects of the graph correspond to A and B . Also, explain the physical meaning of A , B , and f_0 .



For indicating that A represents the slope or the rate of change of K_e as a function of f and equals Planck's constant	1 point
For indicating that $-B$ is the intercept with the K_e axis and equals the minimum energy needed to release an electron from the metal (the work function)	1 point
For indicating that f_0 is the minimum frequency that will release an electron from the metal (the cutoff or threshold frequency)	1 point

- ii. LO 6.F.3.1, SP 6.4
1 point

Explain the physical meaning of the horizontal section of the graph between the origin and f_0 .

For indicating that the horizontal portion of the graph represents frequencies of light whose energy is insufficient to eject an electron	1 point
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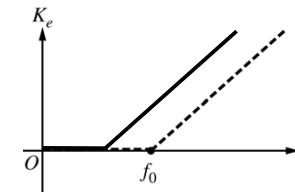
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Question 3 (continued)

Distribution
of points

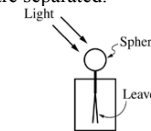
- (a) (continued)
iii. LO 6.F.3.1, SP 6.4
3 points

A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



For drawing a line that is parallel to the given line	1 point
For drawing the horizontal intercept on either side of f_0 with the line ending at the horizontal axis (The horizontal segment does not have to be drawn.)	1 point
For indicating that the K_e or f intercept changes because the work function or the frequency at which electrons can be emitted is different	1 point

- (b) The figure below shows an electroscope. A sphere is connected by a vertical bar to the leaves, which are thin, light strips of material. The sphere, leaves, and bar are all made of metal. The electroscope initially has a negative charge, so the leaves are separated.



- i. LO 1.B.1.2, SP 6.4, 7.2, LO 4.E.3.3, SP 6.4; LO 6.F.3.1, SP 6.4
2 points

Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

For indicating that the UV light causes electrons to be ejected from the electroscope	1 point
For indicating that the electroscope becomes less negatively charged, causing the leaves to move closer together	1 point

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Question 3 (continued)

Distribution
of points

(b) (continued)

- ii. LO 6.F.1.1, SP 6.4, 7.2, LO 6.F.3.1, SP 6.4
1 point

Green light then shines on an identical negatively charged electroscope. No movement of the leaves is observed. Explain why the green light does not make the leaves move, while the UV light does.

For indicating that the green light frequency or energy per photon is too low to eject electrons	1 point
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(c) LO 6.F.3.1, SP 6.4
2 points

The brightness of the green light is increased until the intensity (power per unit area) is the same as that of the UV light. What aspect of the green light changes when its brightness is increased? Would shining the brighter green light on the electroscope result in movement of the leaves? Explain why or why not.

For indicating that the increase in brightness causes an increase in the number of photons in the beam or increases the amplitude of the wave	1 point
For indicating that the leaves would not separate because the energy per photon or frequency of the light remains the same	1 point
The particle nature of light (photons) must be discussed to receive full credit.	

Learning Objectives (LO)

- LO 1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [See Science Practices 6.4, 7.2]
- LO 4.E.3.3:** The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [See Science Practices 1.1, 1.4, 6.4]
- LO 5.B.4.2:** The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]
- LO 6.F.1.1:** The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [See Science Practices 6.4, 7.2]
- LO 6.F.3.1:** The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [See Science Practice 6.4]

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Question 4

10 points total

Distribution
of points

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b . The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel} . The boat owners want to be able to carry as many beams as possible.

- (a) LO 1.E.1.2, SP 6.4; LO 3.B.2.1, SP 1.1, 1.4, 2.2; LO 5.B.10.1, SP 2.2
4 points

Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

For equating the correct forces acting on the boat-steel system: gravity (weight) and the buoyant force	1 point
For correctly calculating the weight of the boat-steel system $W_{\text{system}} = (M_b + N\rho_{\text{steel}}V_{\text{steel}})g$, where N is the number of steel beams (must clearly use mass of boat)	1 point
For correctly calculating the buoyant force $F_b = \rho_{\text{water}}gV_b$	1 point
For algebraic manipulation of the equations to get an expression for the number of beams consistent with the equations for weight and buoyant force $(M_b + N\rho_{\text{steel}}V_{\text{steel}})g = \rho_{\text{water}}gV_b$ $N = (\rho_{\text{water}}V_b - M_b)/\rho_{\text{steel}}V_{\text{steel}}$	1 point

- (b) LO 6.C.1.1, SP 6.4, 7.2; LO 6.E.1.1, SP 6.4, 7.2; LO 6.E.3.3, SP 6.4, 7.2
4 points

The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

The constructive interference is between light reflected from the air-oil interface and light reflected from the oil-water interface.	
For indicating that the green appearance is the result of interference of light from two waves	1 point
For indicating that there is a phase shift due to one of the reflections	1 point
For indicating that the wavelength of the light is different in air and oil	1 point
For indicating that there is a path-length difference of the light reflected from the two surfaces	1 point

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Question 4 (continued)

Distribution
of points

- (c) LO 5.F.1.1, SP 2.2, 7.2
2 points

Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

For an attempting to apply the principle of continuity		1 point
$A_{\text{wide}}v_{\text{wide}} = A_{\text{narrow}}v_{\text{narrow}}$		
$(60 \text{ m})(\text{depth})(5 \text{ km/hr}) = (30 \text{ m})(\text{depth})(v_{\text{narrow}})$		
For correctly calculating the speed		1 point
$v_{\text{narrow}} = 10 \text{ km/hr}$		

Learning Objectives (LO)

- LO 1.E.1.2:** The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [See Science Practices 4.1, 6.4]
- LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
- LO 5.B.10.1:** The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See Science Practice 2.2]
- LO 5.F.1.1:** The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [See Science Practices 2.1, 2.2, 7.2]
- LO 6.C.1.1:** The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See Science Practices 6.4, 7.2]
- LO 6.E.1.1:** The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See Science Practices 6.4, 7.2]
- LO 6.E.3.3:** The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [See Science Practices 6.4, 7.2]

AP[®] Physics 2
2016 Scoring Guidelines

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2016 SCORING GUIDELINES

Question 1

10 points total

Distribution
of points

(a)

i. 2 points

For showing the calculation of the force on the piston and a correct answer with units

1 point

$$F = PA = (1.0 \times 10^5 \text{ Pa})(5 \times 10^{-3} \text{ m}^2) = 500 \text{ N}$$

For explaining the force in terms of gas atom collisions — some change in the atoms' momentum or velocity must be identified to justify a force between atoms and piston

1 point

Example: The collisions of the gas atoms with the container walls cause a change in the momentum of the gas atoms, which means forces are exerted between the atoms and the piston. Each gas molecule colliding with a wall experiences a force from the wall that changes the molecule's velocity or momentum.

ii. 2 points

For showing the calculation of the temperature and a correct answer with units
 $PV = nRT$

1 point

$$T = PV/nR = (1.0 \times 10^5 \text{ Pa})(0.10 \text{ m}^3)/(2)(8.31 \text{ J/mol}\cdot\text{K}) = 602 \text{ K}$$

For indicating that temperature characterizes the average speed or average kinetic energy or RMS velocity of the molecules

1 point

(b)

i. 2 points

For identifying that the temperature increases due to increasing volume and constant pressure

1 point

For relating temperature change with internal energy change

1 point

Example: Because the volume increases at a constant pressure, the temperature goes up because $PV = nRT$. Increasing temperature means increasing average kinetic energy or total internal energy.

ii. 3 points

For calculating the work done in process ABC (i.e., the area under the line)

1 point

$$W_{AB} = -(1.0 \times 10^5 \text{ Pa})(0.10 \text{ m}^3 - 0.04 \text{ m}^3) = -6000 \text{ J and } W_{BC} = 0$$

For calculating T_A and T_C (or ΔT between the states) and using them to determine internal energy change

1 point

$$T_A = P_A V_A / nR = (1.0 \times 10^5 \text{ Pa})(0.04 \text{ m}^3)/(2 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K}) = 241 \text{ K}$$

$$T_C = P_C V_C / nR = (0.5 \times 10^5 \text{ Pa})(0.10 \text{ m}^3)/(2 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K}) = 301 \text{ K}$$

$$\Delta U = \Delta K_{\text{per molecule}} nN_0 = (3/2)k_B \Delta T nN_0$$

$$\Delta U = (3/2)(1.38 \times 10^{-23} \text{ J/K})(301 \text{ K} - 241 \text{ K})(2 \text{ mol})(6.02 \times 10^{23}) = 1500 \text{ J}$$

2016 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

(b)

ii. (continued)

Alternately, ΔU can be calculated directly from the given data

$$\Delta U = (3/2)nR\Delta T = (3/2)(P_C V_C - P_A V_A)$$

$$= (3/2)((0.5 \times 10^5 \text{ Pa})(0.10 \text{ m}^3) - (1.0 \times 10^5 \text{ Pa})(0.04 \text{ m}^3)) = 1500 \text{ J}$$

For substituting ΔU and W (whether correct or incorrect) into some form of the first law of thermodynamics to find Q and for including units in a numerical answer

1 point

$$Q = \Delta U - W = 1500 \text{ J} - (-6000 \text{ J})$$

$$Q = 7500 \text{ J}$$

(c)

1 point

For recognizing that the change in kinetic energy for process CA has the same numerical value as ΔU from (b)ii but with the opposite sign OR for calculating ΔK using the correct temperature change or $\Delta K_{\text{total}} = (3/2)nR \Delta T$ as shown below

1 point

$$\Delta K_{\text{total}} = (3/2)k_B \Delta T nN_0 \quad \text{or} \quad \Delta K_{\text{total}} = (3/2)nR \Delta T$$

$$\Delta K_{\text{total}} = (3/2)(1.38 \times 10^{-23} \text{ J/K})(241 \text{ K} - 301 \text{ K})(2 \text{ mol})(6.02 \times 10^{23} \text{ mol}^{-1})$$

$$\Delta K_{\text{total}} = -1500 \text{ J}$$

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Question 2

12 points total

Distribution
of points

(a) 3 points

- For graphing angles or functions of angles on the axes 1 point
- For plotting sines of angles on the axes and indicating or implying that the index of refraction of air is 1 1 point
- For indicating a method to determine the index of refraction of the glass that is consistent with the graph described 1 point
- Example: If 1 refers to air and 2 to the glass, use $n_1 \sin \theta_1 = n_2 \sin \theta_2$ and graph $\sin \theta_1$ as a function of $\sin \theta_2$. Because $n_1 = 1$, the slope of the line is n_2 .

(b) 4 points

- For indicating that the light from the lamp needs to be a beam when it enters the glass (either referring to a beam, explicitly describing how to create a beam, or showing a beam in a diagram) 1 point
- For describing some method of determining angles with a protractor (or equivalent tool) in both media at an appropriate boundary 1 point
- For using angles with respect to the normal (can measure any angles as long as reference is made to converting them to the correct ones) 1 point
- For repeating the measurement at three or more different incidence angles to obtain sufficient data 1 point

(c) 2 points

- For indicating that when light travels across the boundary from air to glass, the ray bends toward the normal 1 point
- For indicating that the speed of light is slower in glass than in air (or an answer consistent with response for bending of the ray) 1 point

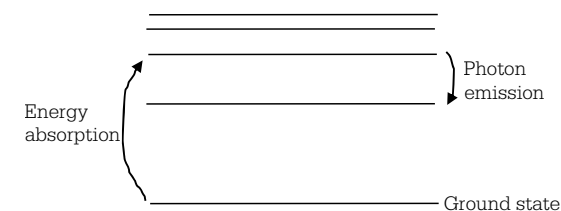
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Question 2 (continued)

Distribution
of points

(d) 3 points

- For an appropriate energy-level diagram showing absorption from the lowest level and emission 1 point
- For indicating that a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy 1 point
- For indicating that transitions to lower energy levels cause emission of photons 1 point
- Example:



Atoms in the ground state absorb energy from the electricity delivered to the lamp. The atoms enter an excited state. Then the atoms emit photons as they drop to a lower energy state.

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Question 3

12 points total

Distribution
of points

- (a) 1 point
- For correctly labeling the magnitude of lines ($A = 60 \text{ V}$ and $B = 80 \text{ V}$, units not required) and for having the correct signs on each line (either explicit positive signs or no negative signs) 1 point
- (b)
- i. 2 points
- For indicating that Y has more charge than X with a correct explanation, such as the nearest potential of the same value is farther from Y 1 point
- For indicating X and Y must be the same sign with a correct explanation 1 point
- Examples:
- Field vectors are perpendicular to equipotentials, and the pattern of field vectors indicates that both must have the same sign.
 - There is no zero potential line between the spheres, so the potentials from the two charges do not cancel anywhere.
- ii. 1 point
- For a correct explanation that addresses the charge to mass ratio and distance relationship 1 point
- Example: Both spheres would gravitationally attract a third sphere just like two charges of the same sign would attract a third charge of the opposite sign because both forces are dependent on the distance and also dependent on the product of the charges or masses.
- (c) 2 points
- For a similarity that does not generally apply to all forces 1 point
- Example: The forces have the same dependence on the distance and are both functions of $1/r^2$.
- For a difference that does not generally apply to all forces 1 point
- Examples:
- The proton is the same sign as the spheres, so it is electrostatically repelled, but gravity is always attractive. Therefore, the directions of the forces are different.
- The forces are different in magnitude.

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Question 3 (continued)

Distribution
of points

- (d)
- i. 2 points
- The proton is repelled by both spheres, so it will move toward point A . 1 point
- For some attempt to apply $\Delta U_E = q\Delta V$ using the given variables 1 point
- For using the correct variables and getting $\Delta U = q(V_A - V_B)$ (no credit for using numeric values of electric potential)
- ii. 2 points
- For using a correct expression for work 1 point
- $W = Fd$ or $-\Delta U_E = q\Delta V$
- For a correct expression for F or ΔV in terms of E_{avg} 1 point
- $F_{avg} = qE_{avg}$ or $\Delta V = E_{avg}d$
- $W = qE_{avg}d$ (full credit is awarded for just writing the correct expression)
- iii. 2 points
- For indicating that student 1 is correct and a correct discussion of why 1 point
- Example: Student 1 is correct. Because the system contains all the objects, the energy is transferred from one form to another within the system due to the law of conservation of energy.
- For indicating that student 2 is correct and a correct discussion of why 1 point
- Example: Student 2 is correct. Because the system is just the proton, there must be a force external to the system due to the electric field of the two spheres. That force does work on the proton which changes the kinetic energy of the proton.

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Question 4

10 points total

Distribution
of points

(a)

i. 1 point

For indicating that $I = \mathcal{E}/R$ and $V_C = 0$

Because there is no charge on the capacitor, there is no potential difference across it. Therefore, entire battery potential is across the resistor, so the current is that potential divided by the resistance.

1 point

ii. 1 point

For indicating that $I = 0$ and $V_C = \mathcal{E}$

Once the capacitor is fully charged, it allows no current to pass. Because all the components are in series, there is no current at all in the circuit. With no current, there is no potential difference across the resistor, so the entire battery potential is across the capacitor.

1 point

(b)

i. 2 points

For a calculation that indicates one of the following:

- The potential difference across each capacitor in the new circuit is half that across the single capacitor in the original circuit
- The equivalent capacitance of the new circuit is one-half the capacitance of the original circuit

$$U_1 = (1/2)C\mathcal{E}^2$$

$$U_2 = 2[(1/2)C(\mathcal{E}/2)^2] \text{ or } (1/2)(C/2)\mathcal{E}^2, \text{ which both equal } C\mathcal{E}^2/4$$

For correctly calculating the ratio

$$U_1/U_2 = (C\mathcal{E}^2/2)/(C\mathcal{E}^2/4) = 2$$

1 point

1 point

ii. 1 point

For any combination of area and spacing that is consistent with the student's answer for the ratio in part (b)(i), with a proper principle or model as support

Example: $U = (1/2)CV^2$. The potential difference across each of the single capacitors is the same. For the energy stored in the single new capacitor to be half that of the original single capacitor, the new capacitor must have half the capacitance. $C = \epsilon_0 A/d$, so half the plate area with the same distance between the plates will accomplish this.

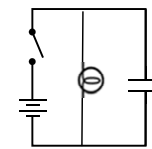
1 point

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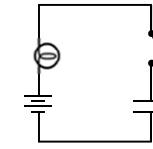
Question 4 (continued)

Distribution
of points

(c) 5 points



Arrangement 1



Arrangement 2

For two correct circuit diagrams, each matched with the correct situation — arrangement 1 has lightbulb and capacitor in parallel, and arrangement 2 has them in series

1 point

For indicating that the lightbulb is brightest when the current through it is maximum and that the capacitor eventually stops current from flowing in its branch when the potential difference across its plates is equal in magnitude to the emf of the battery (or something similar)

1 point

Response using current

For indicating that in the series circuit (where the same current flows through both components) the most current flows right after the switch is closed and decreases as the capacitor charges

Response using potential difference

For indicating that in the series circuit (where the potential is shared) the resistor has its maximum potential difference right after the switch is closed, because the capacitor starts out uncharged (no potential difference) and then charges until it has the same potential as the battery

1 point

For indicating that in the parallel circuit (where the current is shared between the components) the most current flows through the lightbulb a long time after the switch is closed, because the full current initially goes through the capacitor branch because it acts like a wire (very low potential difference), then ends up all through the lightbulb once the fully charged capacitor acts like an open circuit (same potential difference as battery)

For indicating that in a parallel circuit (where both components have the same potential difference) the bulb starts out with the same zero potential difference as the capacitor and ends up with the total battery potential

1 point

For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph-length response

1 point