2021

AP® | CollegeBoard

AP® Physics 2: Algebra-Based

Scoring Guidelines

Question 1: Short Answer — 10 points

(a)		For indicating that $\Delta U = 0$ J	**1 point**
		For correctly calculating the net work done during the two processes with correct units $W = -P\Delta V = -\left(100 \times 10^3 \text{ Pa}\right)\left[(4-1)\left(\times 10^3 \text{ m}\right)\right] = -300 \text{ J}$ **Scoring note:** The answer must either have the negative sign or indicate that the work is done by the gas.	**1 point**
		For substituting ΔU and W into the first law of thermodynamics to obtain a value for Q OR for applying the first law to show that Q is equal in magnitude to W but opposite in sign	**1 point**
		Example response for part (a) *The change in internal energy is zero because the initial and final temperatures are the same at points 1 and 3. The work done on the gas is -PΔV = -300 J. Because the work is negative, 300 J of energy must be transferred to the gas by heating in order for the internal energy of the gas to remain constant.*	
		Total for part (a)	**3 points**
(b)	**i.**	For indicating that the work is less than in part (a), with a reference to less area under the curve	**1 point**
		For indicating that the work is positive or opposite the sign indicated in part (a), with a reference to the sign of the change in volume or the direction of the process as indicated in the graph	**1 point**
		Example response for part (b)(i) *The magnitude of the work done is less than the work in part (a) because there is less area under the curve. The work is also the opposite sign from part (a) because the volume decreases, as shown by the direction of the arrow.*	
	ii.	For stating that there is no change in average kinetic energy/speed of gas molecules	**1 point**
		For indicating a change that is relevant to the collision rate **Scoring note:** Acceptable responses include volume, surface area, time to traverse the container.	**1 point**
		For indicating that there are more collisions with the walls of the container; thus, more force per area (must refer to the walls)	**1 point**
		Example response for part (b)(ii) *Temperature does not change, so the speed of the molecules and the force of collisions with the walls of the container stays the same. Volume decreases, so the density of the gas molecules increases, and they collide more frequently. This means more net force due to collisions with the container walls. The smaller volume also means less surface area.*	
		Total for part (b)	**5 points**
(c)		For indicating that the temperature in state 2 is higher than in state 3	**1 point**
		For indicating that energy flows from the state indicated as hotter to the state indicated as cooler	**1 point**
		Example response for part (c) *The temperature of the gas in sample 2 is higher than the temperature of sample 3. Energy goes from hot to cold, so energy will transfer from sample 2 to sample 3.*	

Total for part (c)	**2 points**
Total for question 1	**10 points**

Question 2: Experimental Design — 12 points

(a)	**i.**	For describing a valid method for keeping the temperature constant	**1 point**
		For describing a valid use of the objects of known mass to affect the pressure	**1 point**
		For explicitly measuring the height h and the radius r (or diameter) of the piston	**1 point**
		For explicitly obtaining more than two data points	**1 point**
		Example response for part (a)(i) *Place the container in an ice bath, so the part below the piston is submerged. Measure the radius and height of the piston. For eight different objects of known mass, add each object on the piston and measure the height of the piston for each object.*	
	ii.	For an equation that correctly relates pressure to measured quantities consistent with the procedure in (a)(i)	**1 point**
		Example response for part (a)(ii) $P_{tot} = P_{atm} + \left(m_p + Nm_o\right)g/A = P_{atm} + \left(m_p + Nm_o\right)g/\left(\pi r^2\right)$, *where N is the number of objects on the piston and r is the radius of the piston.*	
	iii.	For an equation that correctly relates the density of the gas to measured quantities	**1 point**
		Example response for part (a)(iii) $\rho = M_g/V = M_g/\left(\pi r^2 h\right)$	
	iv.	For referring to the ideal gas law or Boyle's Law and using the equation to show pressure and volume are inversely proportional	**1 point**
		For a conclusion based on an analysis of the slope of the graph and a correct relationship between pressure and density	**1 point**
		Example response for part (a)(iv) *According to the ideal gas law, pressure is proportional to 1/V. Because the mass of this gas is constant, pressure is, therefore, directly proportional to density. The graph does not show a linear relationship between density and pressure, so the gas is not ideal.*	
		Total for part (a)	**8 points**
(b)		For indicating that the water pressure, and thus the pressure on the balloon and of the gas, increases as the depth is increased	**1 point**
		Example response for part (b) *When the balloon goes deeper in the fluid, the pressure increases. This will cause the volume of the balloon to decrease.*	

(c)	For correctly applying Newton's second law with some specific elements of the problem, including one of the two weights	**1 point**
	For a correct expression for the weight of the balloon and gas	**1 point**
	For a correct expression for the buoyant force	**1 point**
	Example response for part (c) $\sum F = 0 = F_B - W_{\text{balloon}} - W_{\text{gas}} - F_{\text{student}}$ $F_B = \rho_w V_b g$ $W = \rho_g V_b g + m_b g$ $F_{\text{student}} = \rho_w V_b g - \left(\rho_g V_b g + m_b g\right)$	
	Total for part (c)	**3 points**
	Total for question 2	**12 points**

Question 3: Quantitative/Qualitative Translation — 12 points

(a)	For indicating that the magnetic field needs to double in order to double the force (since the force equals qvB)	**1 point**
	For correctly explaining why the magnitude of the current must double, without any incorrect statements	**1 point**
	For indicating that the current must go in the opposite direction, i.e. be negative	**1 point**
	Example response for part (a) *The current must change direction and double in magnitude. The graph shows that when the current doubles the magnetic field doubles. When the magnetic field doubles, the magnetic force doubles. Reversing the direction of the current will reverse the direction of the magnetic field, and therefore the direction of the force.*	
	Total for part (a)	**3 points**
(b)	For indicating that the emf is the same	**1 point**
	For indicating that larger resistance and/or less current means less power, without making any incorrect statements	**1 point**
	For indicating that the slope between t_1 and t_3 is less, or the horizontal line segment at right would be below the one shown	**1 point**
	Example response for part (b) *The slope of the energy vs. time graph represents power. Because the induced emf is the same, but resistance is higher, power is lower. Therefore, the slope would be smaller.*	
	Total for part (b)	**3 points**
(c)	For indicating that the greater change in magnetic field means a greater change in magnetic flux or a larger emf	**1 point**
	For indicating that power increases with increasing emf so the power and thus the energy dissipated is greater, or for an answer that is consistent with the response to the previous point in (c).	**1 point**
	For indicating that the slope between t_1 and t_3 is greater, or the horizontal line segment at right would be above the one shown, or for an answer that is consistent with the response to the first point in (c)	**1 point**
	Example response for part (c) *The induced emf is larger than it was before because the magnetic field changed by a larger amount in the same time period. Power is proportional to the square of the emf, so the power is larger. Power is the slope of energy vs time, so the slope is greater for the new graph.*	
	Total for part (c)	**3 points**
(d)	For any indication the cumulative energy dissipated depends on the time elapsed	**1 point**
	For indicating that the emf depends on the rate of change of the magnetic flux, i.e., it is inversely proportional to the time elapsed	**1 point**
	For indicating that the power is proportional to the square of the emf and the energy dissipated is power times time, so energy is inversely proportional to the time	**1 point**
	Total for part (d)	**3 points**
	Total for question 3	**12 points**

Question 4: Short Answer Paragraph Argument — 10 points

(a)	For obtaining the correct relationship between electron wavelength and speed	**1 point**
	For correctly substituting values	**1 point**

Example response for part (a)

$\lambda = h/p = h/mv$

$$v = \frac{(6.63 \times 10^{-34}\ \text{J}\bullet\text{s})}{(9.11 \times 10^{-31}\ \text{kg})(5.0 \times 10^{-9}\ \text{m})}$$

$v = 1.5 \times 10^{5}\ \text{m/s}$

Total for part (a) — 2 points

(b)	For using $E = mc^2$ to convert mass to energy	**1 point**
	For including the kinetic energy of the electron	**1 point**
	For including the equivalent energy of both particles and correct substitutions, with a speed consistent with the answer to part (a)	**1 point**

Example response for part (b)

$E_{tot} = 2(9.11 \times 10^{-31}\ \text{kg})(3 \times 10^{8}\ \text{m/s})^2 + (1/2)(9.11 \times 10^{-31}\ \text{kg})(1.5 \times 10^{5}\ \text{m/s})^2$

$E_{tot} = 1.6 \times 10^{-13}\ \text{J}$

Total for part (b) — 3 points

(c)	For indicating that the photon has a component of momentum (or velocity) toward the bottom of the page	**1 point**
	For indicating that momentum must be conserved in both the horizontal and vertical directions	**1 point**
	For indicating that energy is conserved	**1 point**
	For indicating that the new photon has less energy, so it has a lower frequency	**1 point**
	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 for part (c)

In order to conserve momentum in the vertical direction, the photon must have a component of its momentum toward the bottom of the page. If the horizontal component of the momentum of the electron after the collision is less than the initial momentum of the photon, then the photon must move toward the right after the interaction. In order to conserve energy, the frequency of the photon after the collision is less than what it was before the collision because it gave some of its energy to the electron.

Total for part (c) — 5 points

Total for question 4 — 10 points