AP® Physics 2
2016 Scoring Guidelines

CollegeBoard

AP® PHYSICS 2
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

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

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 — 1 point

$PV = nRT$

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

For indicating that temperature characterizes the <u>average</u> speed or <u>average</u> 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

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

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

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

$\Delta U = \Delta K_{\text{per molecule}}\, nN_0 = (3/2) k_B \Delta T n N_0$

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

Question 1 (continued)

Distribution of points

(b)

ii. (continued)

Alternately, ΔU can be calculated directly from the given data

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

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

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

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

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

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

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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

Question 2 (continued)

Distribution of points

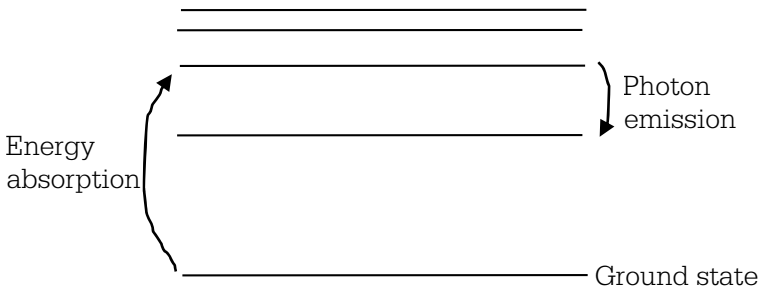
(d) 3 points

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 ($A = 60$ V and $B = 80$ 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.

Question 3 (continued)

Distribution of points

(d)

i. 2 points

The proton is repelled by both spheres, so it will move toward point A.
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) — 1 point

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 $V_C = 0$ 1 point

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.

ii. 1 point

For indicating that $I = 0$ and $V_C = \mathcal{E}$ 1 point

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.

(b)

i. 2 points

For a calculation that indicates one of the following: 1 point

- 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

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

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

For correctly calculating the ratio 1 point

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

ii. 1 point

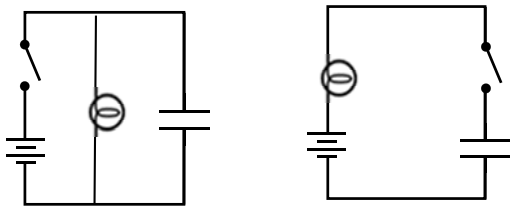
For any combination of area and spacing that is consistent with the student's answer for the ratio in part (b)(i), with a proper principle or model as support 1 point

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. $C = \varepsilon_0 A/d$, so half the plate area with the same distance between the plates will accomplish this.

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