2021

AP CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free Response Question 1

- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

Question 1: Short Answer — 10 points

(a)

For indicating that $\Delta U = 0\ \text{J}$ — **1 point**

For correctly calculating the net work done during the two processes with correct units — **1 point**

$$W = -P\Delta V = -\left(100\times10^3\,\text{Pa}\right)\left[(4-1)\left(\times10^3\,\text{m}\right)\right] = -300\ \text{J}$$

Scoring note: The answer must either have the negative sign or indicate that the work is done by the gas.

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 — **1 point**

Scoring note: Acceptable responses include volume, surface area, time to traverse the container.

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**

Begin your response to **QUESTION 1** on this page.

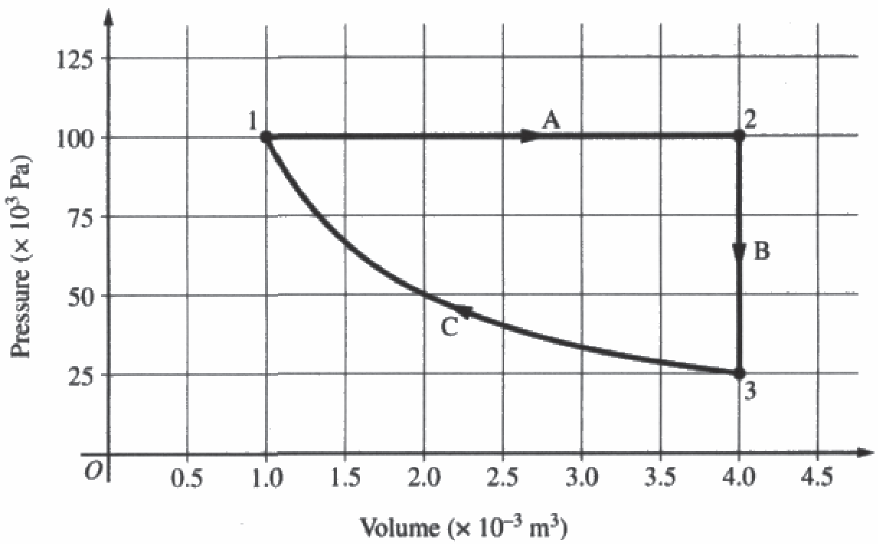
PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (10 points, suggested time 20 minutes)

A sample of ideal gas is taken through the thermodynamic cycle shown above. Process C is isothermal.

(a) Consider the portion of the cycle that takes the gas from state 1 to state 3 by processes A and B. Calculate the magnitude of the following and indicate the sign of any nonzero quantities.

- The net change in internal energy ΔU of the gas
- The net work W done on the gas
- The net energy Q transferred to the gas by heating

$W = -P\Delta V$

$W = -100\cdot10^3\,\text{Pa}\cdot(4\cdot10^{-3}\,\text{m}^3 - 1\cdot10^{-3}\,\text{m}^3)$

$W = -300\,\text{J}$

$\Delta U = Q + W$

$0 = Q - 300\,\text{J}$

$Q = 300\,\text{J}$

$\Delta U = 100\cdot10^3\,\text{Pa}\cdot 1\cdot10^{-3}\,\text{m}^3 - 25\cdot10^3\,\text{Pa}\cdot 4\cdot10^{-3}\,\text{m}^3$

$\Delta U = 0$

Continue your response to **QUESTION 1** on this page.

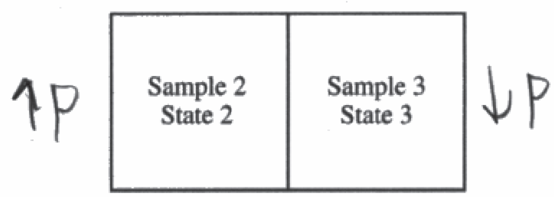
(b) Consider isothermal process C.

i. Compare the magnitude and sign of the work W done on the gas in process C to the magnitude and sign of the work in the portion of the cycle in part (a). Support your answer using features of the graph.

Work can be measured by the area under the process. Because process A has a greater average pressure than process C, the work done on the gas through process A is greater than that of process C. No work occurs during process B. Process A increases in volume, so negative work is done on the gas. Process C decreases the volume so positive work is done.

ii. Explain how the microscopic behavior of the gas particles and changes in the size of the container affect interactions on the microscopic level and produce the observed pressure difference between the beginning and end of process C.

As the volume decreases, gas particles move closer together, so they collide more frequently with each other and with the walls of the container.



(c) Consider two samples of the gas, each with the same number of gas particles. Sample 2 is in state 2 shown in the graph, and sample 3 is in state 3 shown in the graph. The samples are put into thermal contact, as shown above. Indicate the direction, if any, of energy transfer between the samples. Support your answer using macroscopic thermodynamic principles.

Because $PV=nRT$, $P_2 > P_3$, $V_2 = V_3$, and $n_3 = n_2$, $T_2 > T_3$, meaning sample 2 has a higher temperature than sample 3. Energy will flow from high temperature to low temperature so from sample 2 to sample 3.

Begin your response to **QUESTION 1** on this page.

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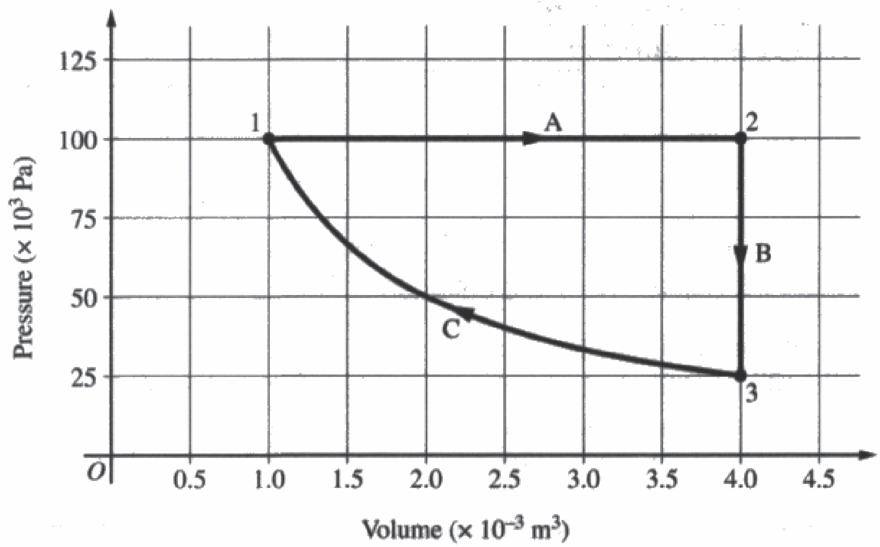


1. (10 points, suggested time 20 minutes)

A sample of ideal gas is taken through the thermodynamic cycle shown above. Process C is isothermal.

(a) Consider the portion of the cycle that takes the gas from state 1 to state 3 by processes A and B. Calculate the magnitude of the following and indicate the sign of any nonzero quantities.

$\Delta V = 4 - 1 = 3 \times 10^{-3}\ m^3$

- The net change in internal energy ΔU of the gas
- The net work W done on the gas
- The net energy Q transferred to the gas by heating

net change of internal: $(100 \times 10^3\ Pa) \cdot (1 \times 10^{-3}\ m^3) - (25 \times 10^3\ Pa)(4 \times 10^{-3}\ m^3) = 100 J - 100 J = 0 J = \Delta U$

net energy $Q = W - \Delta U = -75 J$

net work: $W = (3 \times 10^{-3}\ m^3) \cdot (25 \times 10^3\ Pa) = 75 J$

Continue your response to **QUESTION 1** on this page.

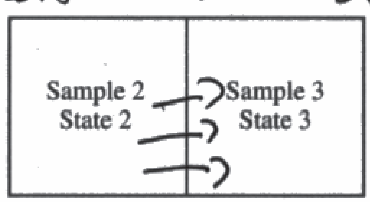
(b) Consider isothermal process C.

i. Compare the magnitude and sign of the work W done on the gas in process C to the magnitude and sign of the work in the portion of the cycle in part (a). Support your answer using features of the graph.

The sign of the work done on the gas in C is opposite to the portion of the cycle in part A because the area underneath the graph is negative, since Volume is decreasing whilst Pressure is increasing in C while moving backwards.

ii. Explain how the microscopic behavior of the gas particles and changes in the size of the container affect interactions on the microscopic level and produce the observed pressure difference between the beginning and end of process C.

The average speed of the particles is the same as the process is isothermal, however, since volume is being decreased and pressure is increased, there will be more collisions between particles within the space.



$$\frac{(100\,Pa)(4\times10^{-3}\,m^3)}{T_2} = \frac{(25\,Pa)(4\times10^{-3}\,m^3)}{T_3}$$

(c) Consider two samples of the gas, each with the same number of gas particles. Sample 2 is in state 2 shown in the graph, and sample 3 is in state 3 shown in the graph. The samples are put into thermal contact, as shown above. Indicate the direction, if any, of energy transfer between the samples. Support your answer using macroscopic thermodynamic principles.

Boyle's Law Ideal Gas Law $T_2 > T_3$ in order to make this true

↳ heat is transferred from areas with high heat to areas with low heat

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$$

$T_2 > T_3$

Begin your response to **QUESTION 1** on this page.

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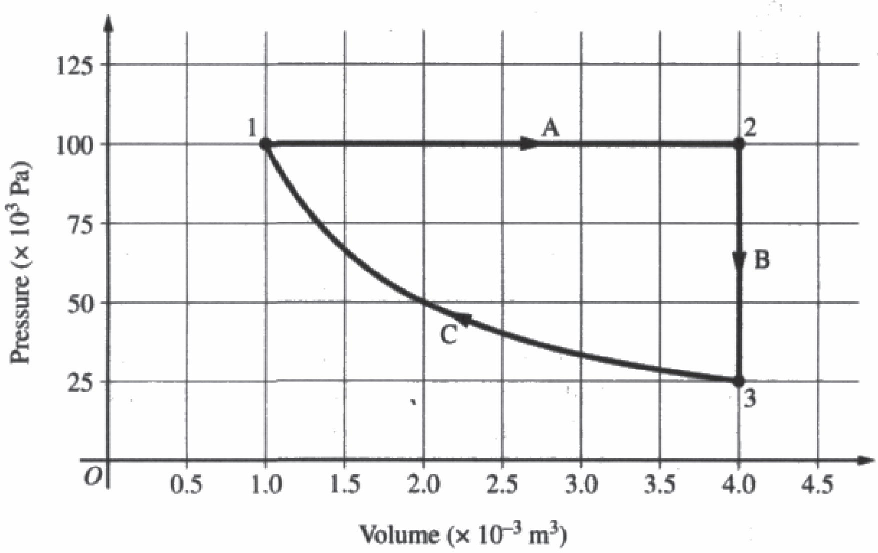


1. (10 points, suggested time 20 minutes)

A sample of ideal gas is taken through the thermodynamic cycle shown above. Process C is isothermal.

(a) Consider the portion of the cycle that takes the gas from state 1 to state 3 by processes A and B. Calculate the magnitude of the following and indicate the sign of any nonzero quantities.

$\Delta U = Q + W$

- The net change in internal energy ΔU of the gas The net change in ΔU is +300J
- The net work W done on the gas = Area under the curve = (100)(3) = -300J
- The net energy Q transferred to the gas by heating = The net energy Q transferred to the gas by heating is 0.

Continue your response to **QUESTION 1** on this page.

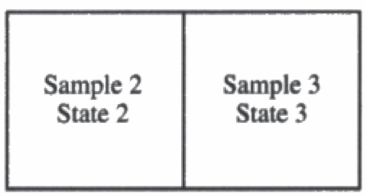
(b) Consider isothermal process C.

i. Compare the magnitude and sign of the work W done on the gas in process C to the magnitude and sign of the work in the portion of the cycle in part (a). Support your answer using features of the graph.

The magnitude and sign of the work done on the gas in process C is the same because the net work done on the gas is equal to the process of C where work is done on the gas.

ii. Explain how the microscopic behavior of the gas particles and changes in the size of the container affect interactions on the microscopic level and produce the observed pressure difference between the beginning and end of process C.

As volume decreases through process C, the pressure begins to increase due to the increase in the number of collisions between gas particles. The size of the container decreases resulting in a higher pressure and a higher rate of collisions.



(c) Consider two samples of the gas, each with the same number of gas particles. Sample 2 is in state 2 shown in the graph, and sample 3 is in state 3 shown in the graph. The samples are put into thermal contact, as shown above. Indicate the direction, if any, of energy transfer between the samples. Support your answer using macroscopic thermodynamic principles.

After being put into thermal contact, these two samples will slowly begin to transfer their energies to the other sample because eventually, these samples will mix due to contact

GO ON TO THE NEXT PAGE.

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses to this question were expected to demonstrate the following:

- Analyze a P vs. V graph to compare relative values of temperature based on states' pressures and volumes
- Analyze a P vs. V graph to calculate work through -P*ΔV (or -Area)
- Calculate thermal energy transferred using ΔU=Q+W given ΔU and W
- Make claims about sign and magnitude of work when analyzing processes in a P vs. V graph
- Explain a process on a P vs. V graph according to microscopic properties of gas (frequency of collisions between particles and container, average kinetic energy or average speed of particles, volume or distance or time for particles to move in)
- Make predictions about energy flow based on macroscopic properties of gas (T)

Sample: P2 Q1 A
Score: 9

Part (a) earned 3 points. One point was earned for a correct ΔU=0. One point was earned for a correct value for W with calculations, units, and sign. One point was earned for a response that shows W and ΔU used correctly in the first law to calculate Q. Part (b)(i) earned 2 points. One point was earned for a response that correctly identifies the magnitude of work greater in part A due to greater "average pressure" and also mentions area, and one point was earned for a response that identifies the sign of work in C as positive due to decrease in volume. Part (b)(ii) earned 2 points. There were no points earned for a response that does not discuss constant KE or v. The response earned 1 point for a response that notes a decrease in volume during process C, and 1 point was earned for an increase in collisions between gas molecules and the walls of the container. Part (c) earned 2 points. One point was earned for stating that T2>T3, and one point was earned for stating that energy flows from 2 to 3.

Sample: P2 Q1 B
Score: 5

Part (a) earned 1 point for having a response that correctly shows that ΔU=0. No points were earned for an incorrect value for W and for the first law not being used correctly (response has Q=W-ΔU instead of Q=ΔU-W). Part (b)(i) earned 1 point for a response that correctly identifies the sign of work in process C as opposite to part (a) because volume is decreasing, but there is no mention of magnitude. Part (b)(ii) earned 2 points. One point was earned for a response that correctly states that the average speed of the particles is the same, and 1 point was earned for a response that correctly states that volume is being decreased. No point was earned because while more collisions are referenced, there is no mention of the wall. Part (c) earned 1 point for using the ideal gas law correctly in the calculation to show that $T_2>T_3$. No point was earned for the response stating that "heat is transferred from areas with high heat," because "heat" is not a suitable substitution for hotter or temperature.

Question 1 (continued)

Sample: P2 Q1 C
Score: 2

Part (a) earned 1 point for a correct value for W with “area under the curve” shown for work. No points were earned for an incorrect ΔU and for not having evidence that the first law is used for Q. Part (b)(i) earned no points because the response incorrectly identifies magnitude of work in C equal to work in A and incorrectly identifies the sign of work in C equal to sign of work in A. Part (b)(ii) earned 1 point for a response that correctly identifies decrease in volume. No points were awarded for a response that does not discuss constant KE or v, and only discusses collisions between particles, not collisions between particles and the walls of the container. Part (c) earned no points because there is no mention of temperatures or the direction of energy flow from high T to low T.