2024

AP

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

☑ Scoring Guidelines

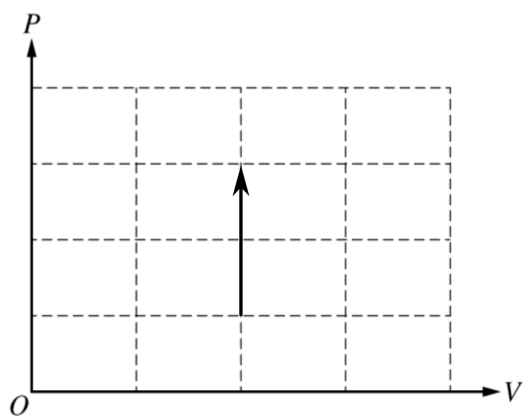
☑ Student Samples

☑ Scoring Commentary

Question 2: Experimental Design — 12 points

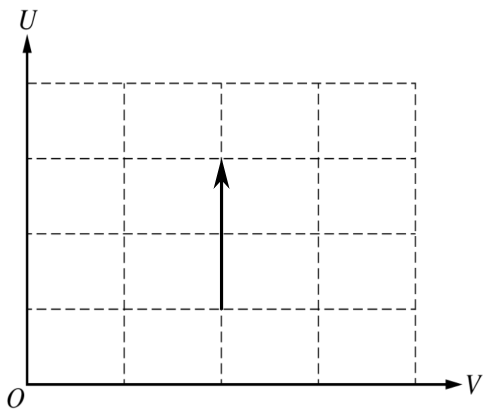
(a)	For indicating measurements that could be used to determine the volume of the gas **Scoring Note:** Responses that include the volume of the heater may earn full credit.	**1 point**
	For indicating that the sensors should be used to record the temperature and pressure of the gas	**1 point**
	For indicating that multiple different temperature and pressure measurements should be recorded	**1 point**
	Example Response *Measure the length, width, and height of the chamber. Activate the heater. Starting at time* $t = 0$*, use the sensors to record the temperature and pressure of the gas every* 10 s *until* $t = 60$ s.	
	Total for part (a)	**3 points**
(b)(i)	For sketching an upward vertical line that never touches the horizontal or vertical axes	**1 point**

Example Response



(b)(ii)	For sketching an upward vertical line that never touches the horizontal or vertical axes	**1 point**

Example Response



(b)(iii)	For a justification that correctly relates the volume of the chamber to the sketch or relates the energy transferred to the gas by the heater to the sketch that is consistent with the sketch in part (b)(ii)	**1 point**

Example Responses

The heater transfers energy to the gas by heating, so the internal energy of the gas increases.

OR

The gas has a constant volume.

Total for part (b) 3 points

(c)(i)	For indicating quantities that can be plotted on the graph to calculate an experimental value for k	**1 point**

Example Response

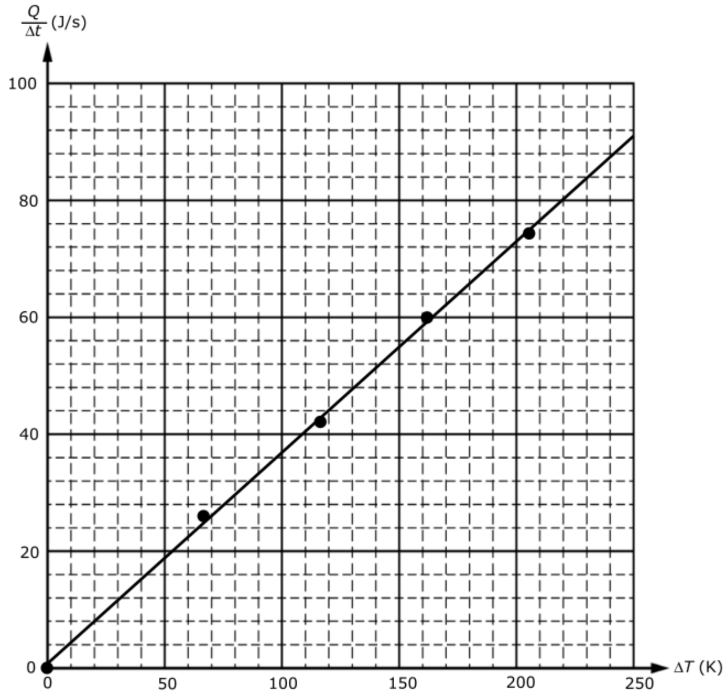
Vertical Axis: $\frac{Q}{\Delta t}$

Horizontal Axis: $\Delta T = T_G - T_L$

(c)(ii)	For labeling the axes correctly (including units) with a linear scale such that the data fill half the area of the graph	**1 point**
	For plotting the data points correctly	**1 point**

(c)(iii)	For drawing a straight line that approximates the trend of the data	**1 point**

Example Response



Total for part (c) **4 points**

(d)	For correctly relating the slope of the straight line of the graph to the equation $\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$	**1 point**

Example Response

$$\text{slope} = \frac{kA}{L}$$

For calculating an experimental value for k that is approximately equal to $0.06\ \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$ **1 point**

Example Response

$$k = 0.06\ \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$$

Example Solution

$$\text{slope} = \frac{\Delta y}{\Delta x}$$

$$\text{slope} = \frac{\Delta\left(\frac{Q}{\Delta t}\right)}{\Delta(\Delta T)}$$

$$\text{slope} = \frac{\left(\frac{Q}{\Delta t}\right)_2 - \left(\frac{Q}{\Delta t}\right)_1}{\Delta T_2 - \Delta T_1}$$

$$\text{slope} = \frac{(80-44)\,\frac{\text{J}}{\text{s}}}{(220-120)\,\text{K}}$$

$$\text{slope} = 0.36\,\frac{\text{J}}{\text{s}\cdot\text{K}}$$

$$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$$

$$\frac{Q}{\Delta t} = \left(\frac{kA}{L}\right)\Delta T$$

$$\text{slope} = \frac{kA}{L}$$

$$k = \frac{L}{A}(\text{slope})$$

$$k = \frac{0.01\,\text{m}}{0.06\,\text{m}^2}\left(0.36\,\frac{\text{J}}{\text{s}\cdot\text{K}}\right)$$

$$k = 0.06\,\frac{\text{J}}{\text{s}\cdot\text{K}\cdot\text{m}}$$

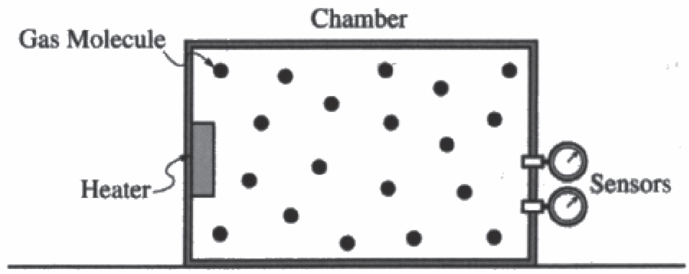
Total for part (d) 2 points

Total for question 2 12 points

Question 2

Begin your response to QUESTION 2 on this page.

$PV = Nk_BT$



Note: Figure not drawn to scale.

Figure 1

2. **(12 points, suggested time 25 minutes)**

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(a) Describe a procedure for collecting data that would allow the student to determine an experimental value for N. Provide enough detail so that a student could replicate the experiment, including any steps necessary to reduce experimental uncertainty.

Using a meterstick, measure the side lengths of the container to calculate its volume.
Switch the heater on. As the container heats up, collect several data points of P and T from the sensors (enough so that a line of best fit can be reasonably drawn through a graph of the data).
Switch the heater off, wait for the container to cool back down to its initial temperature, and repeat the process to ensure the sensors and data are reliable.
Graphing P versus T will yield a straight line with $\frac{Nk_B}{V}$ as the slope, so N can be calculated.

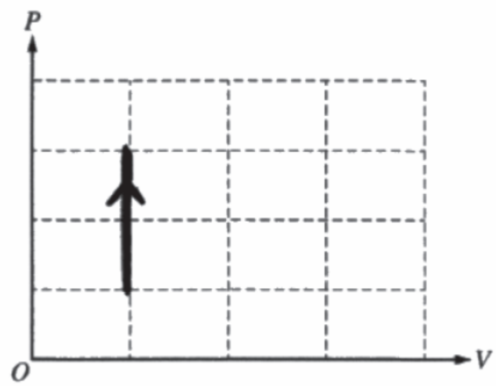
GO ON TO THE NEXT PAGE.

Question 2

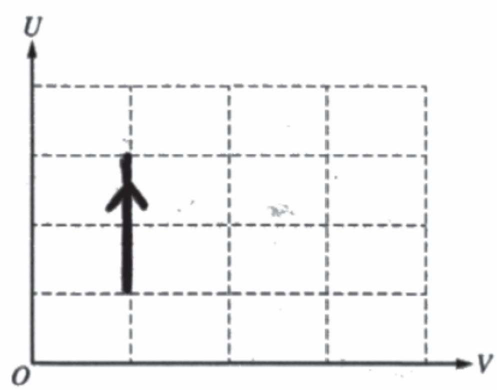
Continue your response to **QUESTION 2** on this page.

(b)

i. On the following axes, **sketch** a curve or line to represent the expected relationship between the pressure P and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.



ii. On the following axes, **sketch** a curve or line to represent the expected relationship between the internal energy U and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.



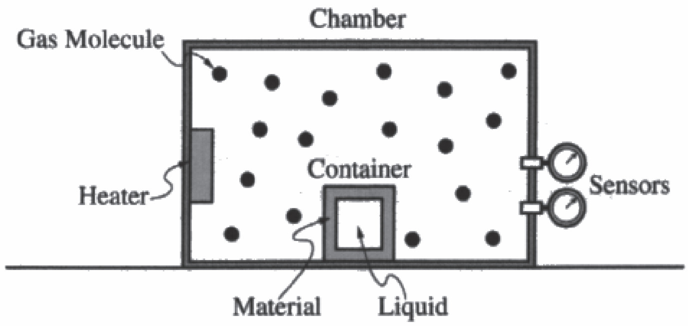
iii. Briefly **justify** why the curve or line drawn in part (b)(ii) has the shape that you sketched.

The Volume does not change as the container is rigid. As the container heats up, the average KE of the molecules increases, therefore increasing total internal energy.

Question 2

Continue your response to **QUESTION 2** on this page.

$\frac{Q}{t} = k\frac{A\Delta T}{L}$



Note: Figure not drawn to scale.

Figure 2

In Experiment 2, shown in Figure 2, a liquid-filled container that is completely wrapped with a material of uniform thickness 0.01 m is inside the sealed chamber that is filled with an ideal gas. The material has a total area of 0.06 m^2 in contact with the gas. The heater is turned on. As the temperature T_G of the gas increases, the following data for the temperature T_L of the liquid and the rate $\frac{Q}{\Delta t}$ of energy transfer are collected.

$T_g - T_L$	T_G (K)	T_L (K)	$\frac{Q}{\Delta t}\left(\frac{J}{s}\right)$	
0	295	295	0.0	
68	371	303	26.3	
117	425	308	43.1	
162	475	313	60.0	
205	528	323	75.0	

(c) The student is asked to determine an experimental value of the thermal conductivity k of the material used to wrap the container inside the sealed chamber.

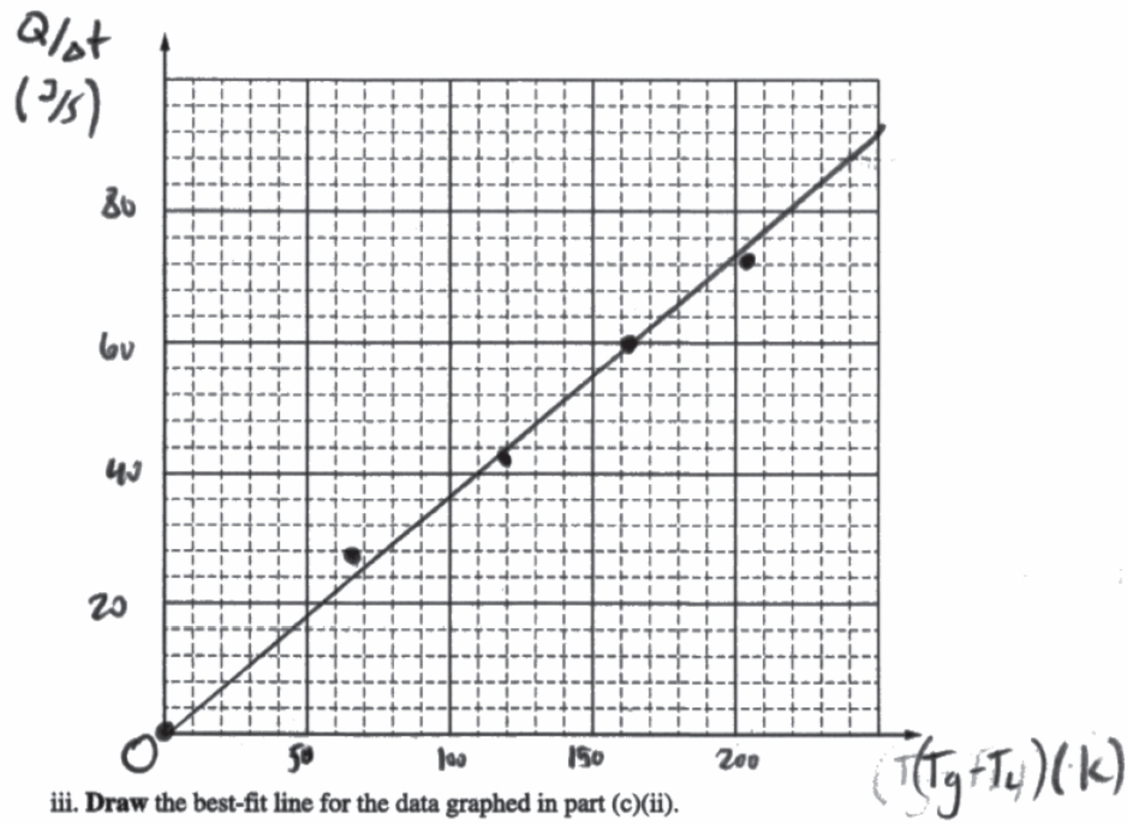
Question 2

Continue your response to **QUESTION 2** on this page.

i. **Indicate** what measured and/or calculated quantities could be graphed to yield a straight line that could be used to calculate an experimental value for the thermal conductivity k of the material. Use the blank columns in the table to list any calculated quantities you graph in addition to the data provided.

Vertical Axis: $Q/\Delta t$ Horizontal Axis: $T_g - T_L$

ii. **Plot** the data points for the quantities indicated in part (c)(i) on the graph provided. Clearly scale and **label** all axes, including units, as appropriate.



iii. **Draw** the best-fit line for the data graphed in part (c)(ii).

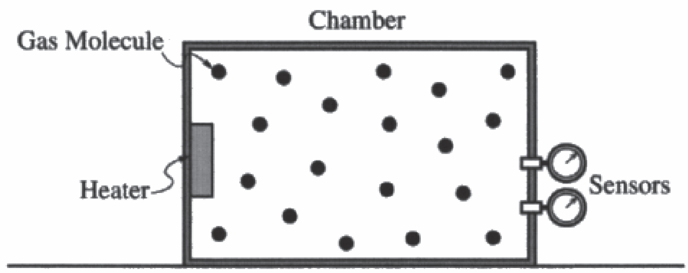
(d) Using the best-fit line, **calculate** an experimental value for k.

$\frac{Q}{\Delta t} = \frac{kA}{L}(T_g - T_L) \therefore \frac{kA}{L} = \text{slope} \Rightarrow k = \frac{L}{A}(\text{slope})$

$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(40-0)}{(110-0)} = 0.36\ \text{J/sK} \Rightarrow k = \frac{0.01}{0.06}(0.36) = \boxed{0.06\ \frac{\text{mJ}}{\text{sKm}}}$

Question 2

Begin your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

Figure 1

$PV=nRT$

2. (12 points, suggested time 25 minutes)

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(a) **Describe** a procedure for collecting data that would allow the student to determine an experimental value for N. Provide enough detail so that a student could replicate the experiment, including any steps necessary to reduce experimental uncertainty.

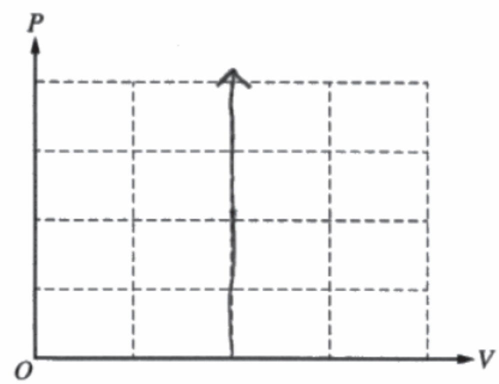
Heat up the chamber to a constant temperature T. Then note the current temperature and pressure of the gas. Measure the volume of the chamber. Use the equation $PV = Nk_BT$ to find N, the number of molecules. Perform multiple trials with different temperatures.

Question 2

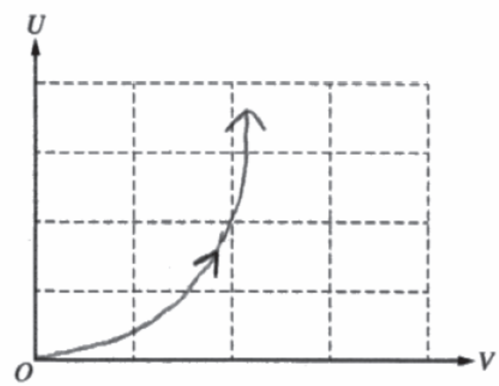
Continue your response to **QUESTION 2** on this page.

(b)

i. On the following axes, **sketch** a curve or line to represent the expected relationship between the pressure P and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.



ii. On the following axes, **sketch** a curve or line to represent the expected relationship between the internal energy U and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.



iii. Briefly **justify** why the curve or line drawn in part (b)(ii) has the shape that you sketched.

The internal energy should increase with volume

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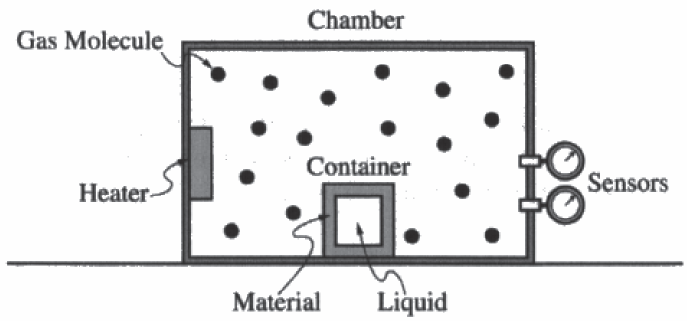
Question 2

Continue your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

Figure 2

In Experiment 2, shown in Figure 2, a liquid-filled container that is completely wrapped with a material of uniform thickness 0.01 m is inside the sealed chamber that is filled with an ideal gas. The material has a total area of 0.06 m^2 in contact with the gas. The heater is turned on. As the temperature T_G of the gas increases, the following data for the temperature T_L of the liquid and the rate $\frac{Q}{\Delta t}$ of energy transfer are collected.

ΔT	T_G (K)	T_L (K)	$\frac{Q}{\Delta t}\left(\frac{J}{s}\right)$	
0	295	295	0.0	
68	371	303	26.3	
117	425	308	43.1	
162	475	313	60.0	
205	528	323	75.0	

(c) The student is asked to determine an experimental value of the thermal conductivity k of the material used to wrap the container inside the sealed chamber.

$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$ $\quad k = \left(\frac{Q}{\Delta t}\right)\frac{AL}{\Delta T}$

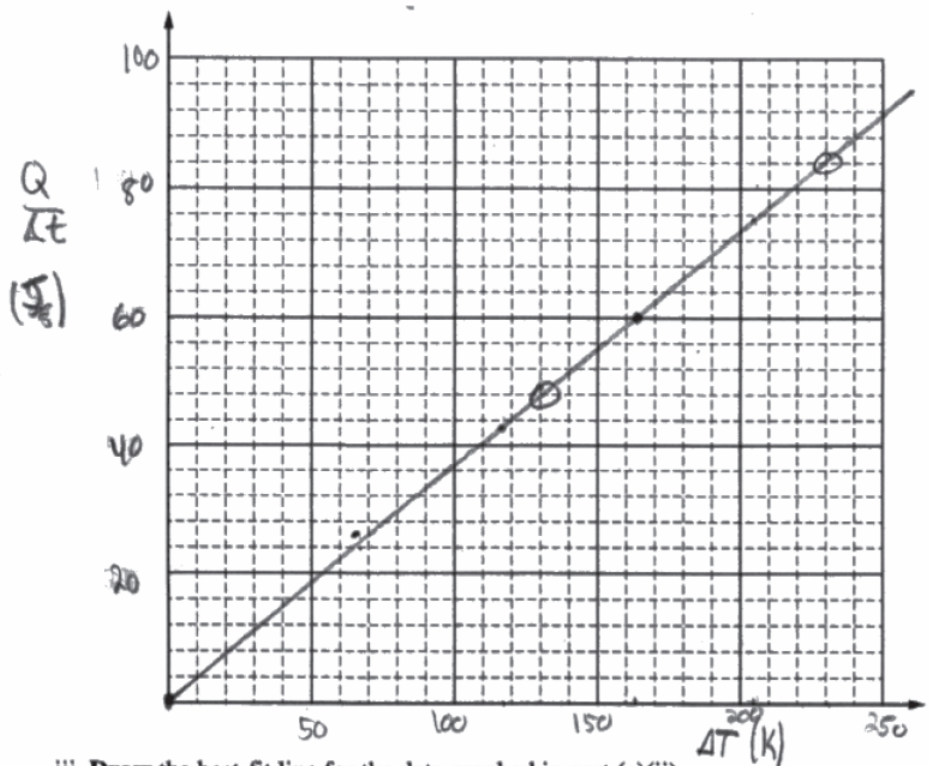
Question 2

Continue your response to **QUESTION 2** on this page.

i. **Indicate** what measured and/or calculated quantities could be graphed to yield a straight line that could be used to calculate an experimental value for the thermal conductivity k of the material. Use the blank columns in the table to list any calculated quantities you graph in addition to the data provided.

Vertical Axis: $\frac{Q}{\Delta t}$ Horizontal Axis: ΔT

ii. **Plot** the data points for the quantities indicated in part (c)(i) on the graph provided. Clearly scale and **label** all axes, including units, as appropriate.



iii. **Draw** the best-fit line for the data graphed in part (c)(ii).

(d) Using the best-fit line, **calculate** an experimental value for k.

$$\frac{(84 - 48)}{(230 - 130)} = .36$$

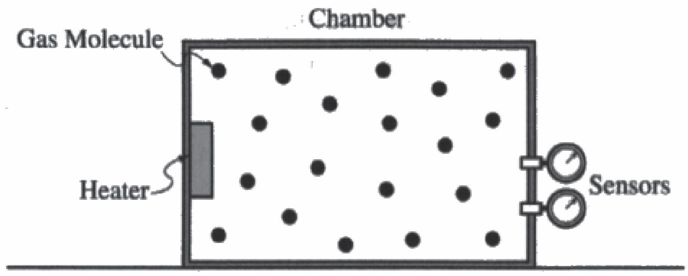
$(L)(A)$

$(.36)(.01)(.06)$

$= 2.16 \times 10^{-4}$

Question 2

Begin your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

Figure 1

$PV = nRT$

$PV = Nk_BT$

$\frac{PV}{k_BT} = \frac{Nk_BT}{k_BT}$

2. (12 points, suggested time 25 minutes)

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(a) **Describe** a procedure for collecting data that would allow the student to determine an experimental value for N. Provide enough detail so that a student could replicate the experiment, including any steps necessary to reduce experimental uncertainty.

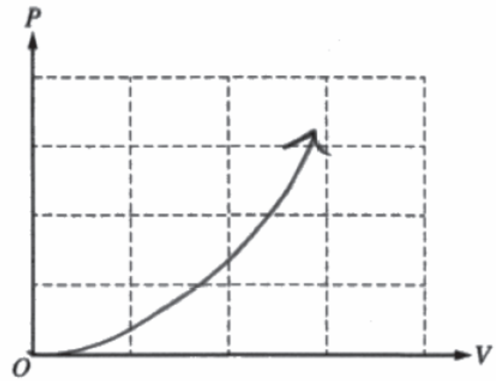
First, record the temperature using the heater and then record the volume of the chamber by measuring the width, height, and length of the chamber and multiplying it all. Then, use the sensors to record pressure of the gas. Using the equation $PV = Nk_BT$, ~~divide~~ each side by k_BT to get $N = \frac{PV}{k_BT}$. plug in all the values found as well as the Boltzmann's constant where $k_B = 1.38 \cdot 10^{-23}$ J/K to get the experimental value for N.

Question 2

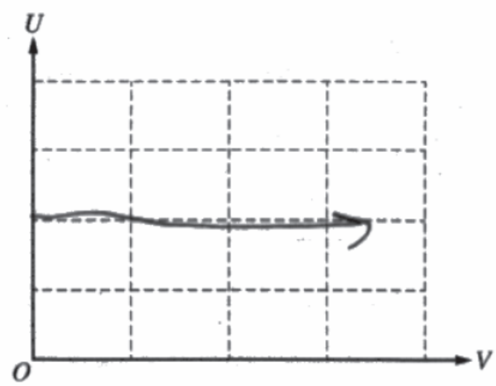
Continue your response to **QUESTION 2** on this page.

(b)

i. On the following axes, **sketch** a curve or line to represent the expected relationship between the pressure P and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.



ii. On the following axes, **sketch** a curve or line to represent the expected relationship between the internal energy U and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.

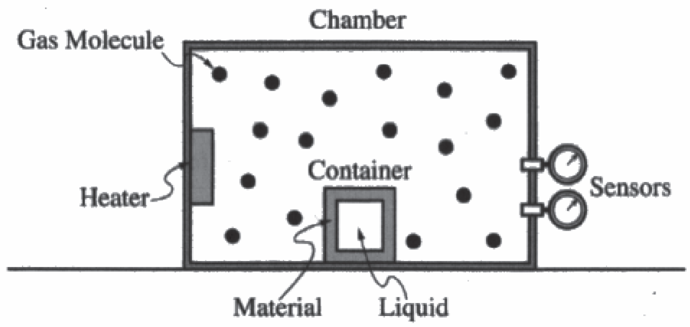


iii. Briefly **justify** why the curve or line drawn in part (b)(ii) has the shape that you sketched.

I drew this shape because internal energy will always be zero as Work goes up and $W = P\Delta V$

Question 2

Continue your response to QUESTION 2 on this page.



Note: Figure not drawn to scale.

Figure 2

In Experiment 2, shown in Figure 2, a liquid-filled container that is completely wrapped with a material of uniform thickness 0.01 m is inside the sealed chamber that is filled with an ideal gas. The material has a total area of $0.06\ m^2$ in contact with the gas. The heater is turned on. As the temperature T_G of the gas increases, the following data for the temperature T_L of the liquid and the rate $\frac{Q}{\Delta t}$ of energy transfer are collected.

	T_G (K)	T_L (K)	$\frac{Q}{\Delta t}\left(\frac{J}{s}\right)$	
	295	295	0.0	
	371	303	26.3	
	425	308	43.1	
	475	313	60.0	
	528	323	75.0	

$\frac{Q}{\Delta t} = \frac{kA\Delta t}{L}$ 26.3

(c) The student is asked to determine an experimental value of the thermal conductivity k of the material used to wrap the container inside the sealed chamber. $\Delta t = 371 - 303 = 68$ $k = 0.06446$

$\frac{Q}{\Delta t} = \frac{kA\Delta t}{L} \rightarrow 26.3 = \frac{k\,0.06 \cdot 68\,K}{0.01m} = \frac{26.3}{408} = \frac{k(408)}{408}$

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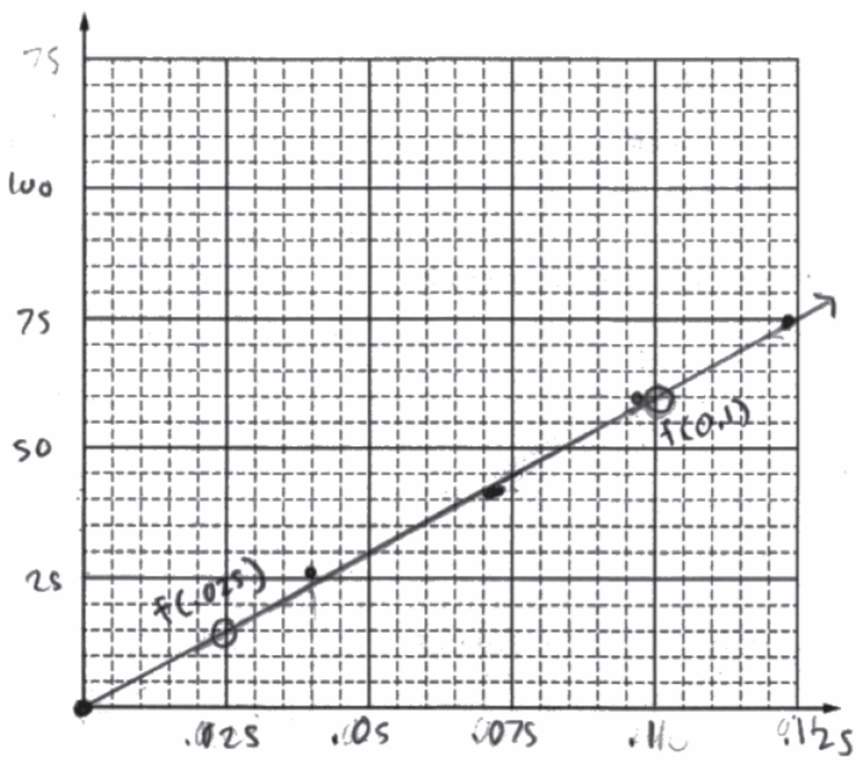
Question 2

Continue your response to **QUESTION 2** on this page.

i. **Indicate** what measured and/or calculated quantities could be graphed to yield a straight line that could be used to calculate an experimental value for the thermal conductivity k of the material. Use the blank columns in the table to list any calculated quantities you graph in addition to the data provided.

Vertical Axis: $\frac{Q}{\Delta t}$ Horizontal Axis: $\frac{kA}{\Delta t}$

ii. **Plot** the data points for the quantities indicated in part (c)(i) on the graph provided. Clearly scale and **label** all axes, including units, as appropriate.



iii. **Draw** the best-fit line for the data graphed in part (c)(ii).

(d) Using the best-fit line, **calculate** an experimental value for k.

$$k = \frac{f(0.1) - f(0.025)}{0.1 - 0.025} = \frac{60-15}{0.075} = \frac{45}{0.075} = 600$$

$k = 600$

Question 2

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

Overview

The responses were expected to demonstrate the ability to:

- Describe a procedure to properly collect data that can be used to determine the number of molecules of a gas in a chamber using the ideal gas law.
- Sketch a thermodynamic process on a PV diagram: draw a line and an arrow on the line to show the relationship between the pressure and volume of a gas in a chamber of fixed volume as the temperature of the gas increases.
- Sketch a thermodynamic process on an internal energy versus volume diagram: draw a line and an arrow on the line to show the relationship between the internal energy and volume of a gas in a chamber of fixed volume as the temperature of the gas increases.
- Justify the shape of the sketch of the relationship between the internal energy and volume of a gas in a container of fixed volume as the temperature of the gas increases.
- Recognize how the equation for the rate of energy transferred by conduction can be used to determine the thermal conductivity of a material by selecting appropriate variables to graph.
- Plot data with appropriate scaling and label axes of a graph with the appropriate quantities and units.
- Draw a best-fit line that follows the trend of the data.
- Use the slope of the best-fit line and appropriate equation to determine the thermal conductivity of a material.

Sample: 2A
Score: 12

Part (a) earned 3 points. The first point was earned for correctly indicating a method to determine the volume of the gas. The second point was earned for correctly indicating that the temperature and pressure should be measured. The third point was earned for correctly indicating that multiple different temperatures and pressures should be recorded. Part (b) earned 3 points. The first point was earned for correctly sketching an upward vertical line that never touches either axis. The second point was earned for correctly sketching an upward vertical line that never touches either axis. The third point was earned for correctly indicating that the volume of the gas is constant. The response correctly indicates that the internal energy of the gas increases. Part (c) earned 4 points. The first point was earned for correctly indicating quantities that can be plotted on the graph to calculate an experimental quantity for the thermal conductivity of the container. The second point was earned for correctly labeling the axes (including units) with a linear scale such that the data fill half the area of the graph. The third point was earned for correctly plotting the data points. The fourth point was earned for correctly drawing a straight line that approximates the trend of the data. Part (d) earned 2 points. The first point was earned for correctly relating the slope of the straight line to $\frac{kA}{L}$. The second point was earned for correctly calculating an experimental value for k that is approximately equal to $0.06\ \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$.

Question 2 (continued)

Sample: 2B
Score: 7

Part (a) earned 3 points. The first point was earned for correctly indicating to measure the volume of the gas. The second point was earned for correctly indicating that the temperature and pressure should be measured. The third point was earned for correctly indicating that multiple different temperatures and pressures should be recorded. Part (b) did not earn any points. The first point was not earned because although the sketch had an upward vertical line, it touched the horizontal axis. The second point was not earned because although the sketch had an upward vertical line, it incorrectly touches the axis. The third point was not earned because the response does not correctly justify why the internal energy increases with volume. Part (c) earned 4 points. The first point was earned for correctly indicating quantities that can be plotted on the graph to calculate an experimental quantity for the thermal conductivity of the container. The second point was earned for correctly labeling the axes (including units) with a linear scale such that the data fill half the area of the graph. The third point was earned for correctly plotting the data points. The fourth point was earned for correctly drawing a straight line that approximates the trend of the data. Part (d) did not earn any points. The first point was not earned for not correctly relating the slope of the straight line to $\frac{kA}{L}$ but instead to $\frac{k}{AL}$. The second point was not earned because although the slope of the line is calculated correctly, it is not used to determine the experimental value of k.

Sample: 2C
Score: 3

Part (a) earned 2 points. The first point was earned for correctly indicating a method to determine the volume of the gas. The second point was earned for correctly indicating that the temperature and pressure should be measured. The third point was not earned because the response does not correctly indicate that multiple different temperatures and pressures should be recorded. Part (b) did not earn any points. The first point was not earned because the response does not correctly sketch an upward vertical line on the pressure-volume graph that never touches either axis. The second point was not earned because the response does not correctly sketch an upward vertical line on the potential energy-volume graph that never touches either axis. The third point was not earned because the response states that the internal energy is zero while showing the internal energy as a constant nonzero value. Part (c) earned 1 point. The first point was not earned because the response does not correctly indicate quantities that can be plotted on the graph to calculate an experimental quantity for the thermal conductivity of the container because k is included in the quantities graphed. The second point was not earned because the response incorrectly labels the axes with the quantities graphed and neglects units. The third point was not earned because the response plots points, but it is unclear if they are data points. The fourth point was earned for correctly drawing a straight line that approximates the trend of the points. Part (d) did not earn any points. The first point was not earned because the response does not correctly relate the slope of the straight line to $\frac{kA}{L}$. The second point was not earned because the response does not correctly calculate an experimental value for k that is approximately equal to $0.06 \frac{\text{J}}{\text{s} \cdot \text{K} \cdot \text{m}}$.