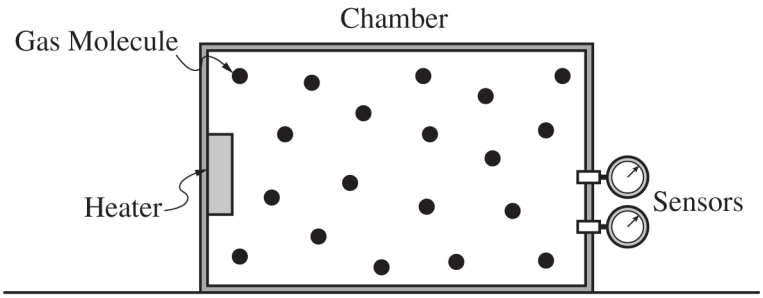
Begin your response to **QUESTION 2** on this page.



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.

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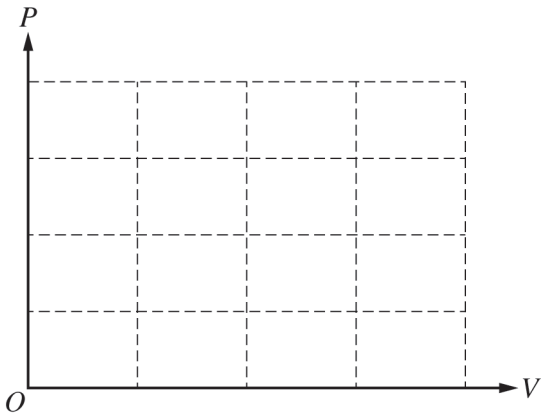
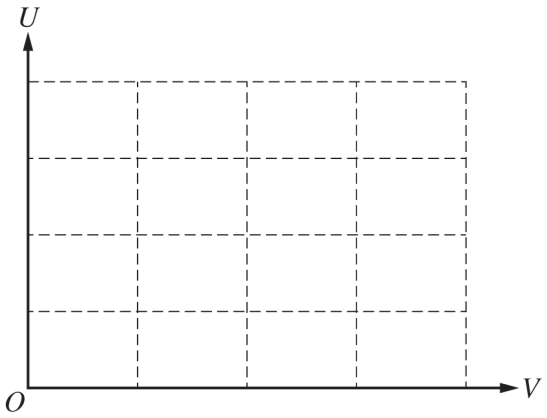
Continue your response to **QUESTION 2** on this page.

(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.

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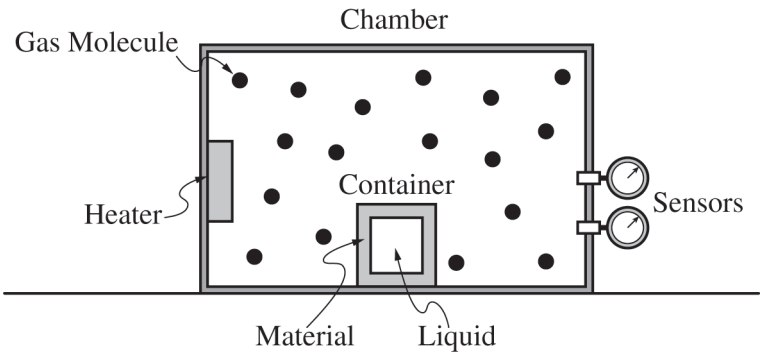
Continue your response to **QUESTION 2** on this page.



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 $0.06\ \text{m}^2$ 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)	$\frac{Q}{\Delta t}\left(\frac{\text{J}}{\text{s}}\right)$	
	295	295	0.0	
	371	303	26.3	
	425	308	43.1	
	475	313	60.0	
	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.

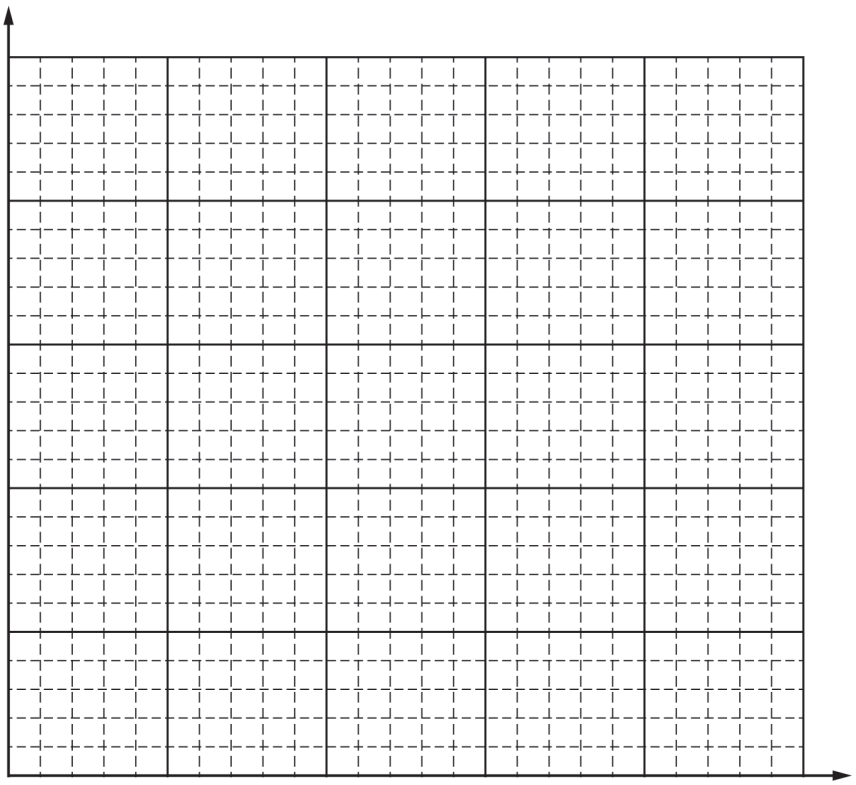
GO ON TO THE NEXT PAGE.

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: _____ Horizontal Axis: _____

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.

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Question 2: Experimental Design — 12 points

(a)

For indicating measurements that could be used to determine the volume of the gas — **1 point**

Scoring Note: Responses that include the volume of the heater may earn full credit.

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

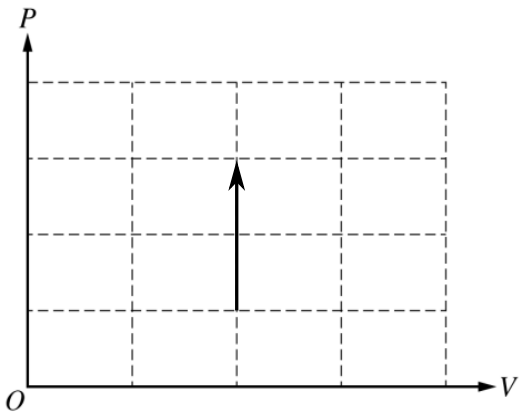
Measure the length, width, and height of the chamber. Activate the heater. Starting at time $t = 0$*, use the sensors to record the temperature and pressure of the gas every* $10\ \text{s}$ *until* $t = 60\ \text{s}$.

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



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