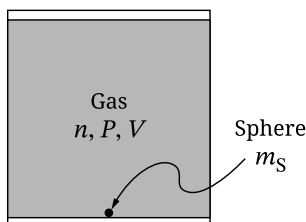


Question 1: Version J**1. Part A**

A sample of n moles of a monatomic, ideal gas is in a large, sealed, thermally conducting container with fixed volume. A small sphere of mass m_S is in the container. The volume of the sphere is much less than the volume of the container.

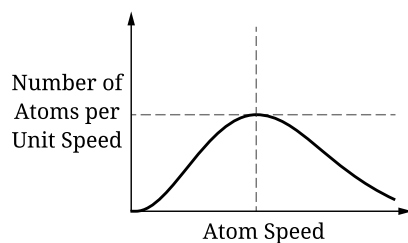
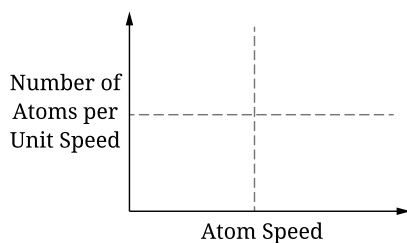
The gas is initially in State X with pressure P and volume V , as shown in Figure 1.

Figure 1**State X**

Note: Figure not drawn to scale.

The sphere is initially in thermal equilibrium with the gas. The gas undergoes a heating process until the gas is in State Y with pressure $3P$ and the sphere is again in thermal equilibrium with the gas. The total energy transferred to the sphere during the heating process is Q_S .

- i. The graph in Figure 2 represents the number of atoms per unit speed as a function of atom speed for the gas when the gas is in State X. On Figure 3, **sketch** a curve that could represent the number of atoms per unit speed as a function of atom speed for the gas when the gas is in State Y.

Figure 2**State X****Figure 3****State Y**

- ii. **Derive** an expression for the change ΔT in temperature of the gas for the heating process that the gas undergoes as the gas changes from State X to State Y. Express your answer in terms of n , P , V , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- iii. **Derive** an expression for the specific heat c_S of the sphere. Express your answer in terms of n , m_S , P , V , Q_S , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Part B

An insulated container is filled with a liquid of mass m_L and specific heat c_L . The original sphere is submerged in the liquid. The sphere has mass m_S , where $m_S < m_L$, and specific heat c_S , where $c_S < c_L$. The initial temperature of the sphere is greater than the initial temperature of the liquid. Later, the liquid and the sphere reach thermal equilibrium. The absolute values of the changes in the temperatures of the liquid and the sphere are $|\Delta T_L|$ and $|\Delta T_S|$, respectively.

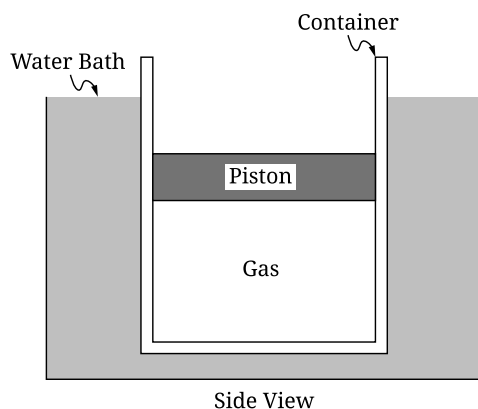
Indicate whether $|\Delta T_S|$ is greater than, less than, or equal to $|\Delta T_L|$. Include one of the following relationships in your response.

- $|\Delta T_S| > |\Delta T_L|$
- $|\Delta T_S| < |\Delta T_L|$
- $|\Delta T_S| = |\Delta T_L|$

Justify your answer. Your justification may include expressions/equations but must include conceptual reasoning beyond algebraic solutions.

Question 2: Version J

2. A sample of a monatomic ideal gas is sealed in a thermally conducting container by a movable piston of mass M and area A . The container is in a large water bath that is held at a constant temperature T_0 . The piston is free to move with negligible friction. At the instant shown, the gas is in thermal equilibrium with the water bath, the piston is at rest, and the gas occupies volume V_0 . The pressure of the air above the piston is P_{atm} .



Note: Figure not drawn to scale.

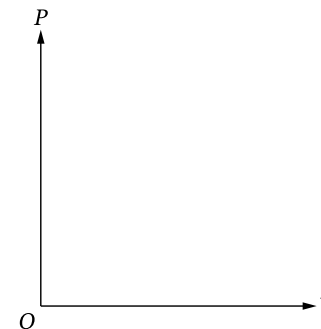
- A. On the dot shown, representing the piston, **draw** and **label** the forces that are exerted on the piston. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



- B. **Derive** an expression for the internal energy of the gas in terms of M , A , V_0 , P_{atm} , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

- C. A block, also of mass M , is placed on the piston at time $t = t_0$ and is slowly lowered. The piston comes to rest at $t = t_f$ when the block is completely released.

On the axes provided, **sketch** the expected relationship between the pressure P and volume V of the gas for the thermodynamic process that the gas undergoes during time interval $t_0 \leq t \leq t_f$. **Draw** an arrow on your sketch to represent the direction of the thermodynamic process.



- D. With the block still on the piston, the temperature of the water bath is changed to a new constant temperature T_{new} . The gas occupies the original volume V_0 when the sample of gas and the water bath come to thermal equilibrium.

Indicate whether T_{new} is greater than, less than, or equal to T_0 .

_____ $T_{\text{new}} > T_0$

_____ $T_{\text{new}} < T_0$

_____ $T_{\text{new}} = T_0$

Briefly **justify** your answer by referencing at least one feature of your answers to parts A, B, or C.

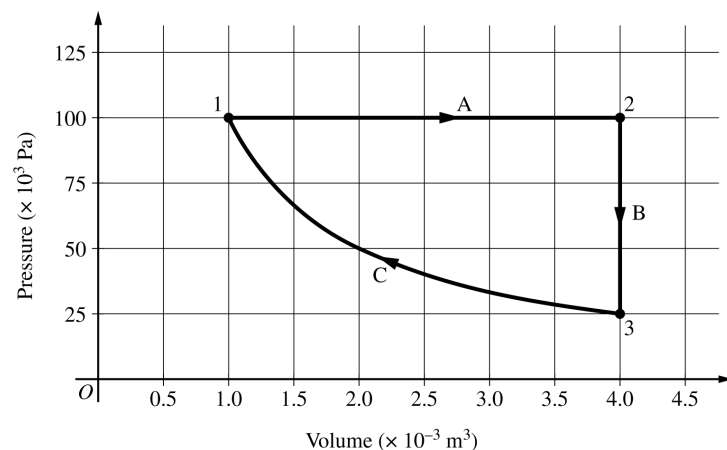
PHYSICS 2

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

GO ON TO THE NEXT PAGE.

Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

(b) Consider isothermal process C.

- 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.

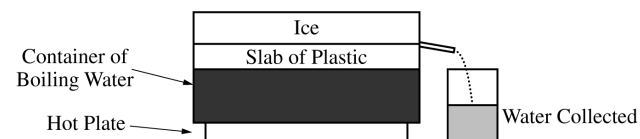
- Explain how the microscopic behavior of the gas particles and changes in the size of the container affect interactions on the microscopic level and produce the observed pressure difference between the beginning and end of process C.

Sample 2 State 2	Sample 3 State 3
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(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.

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Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.



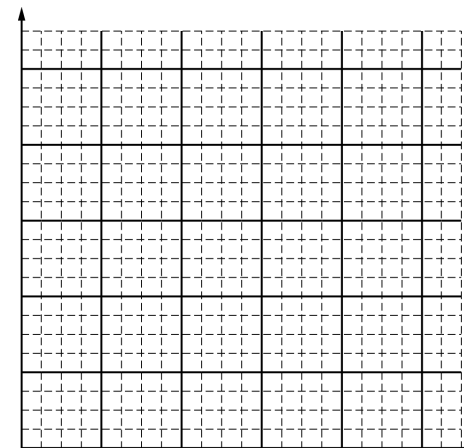
3. (12 points, suggested time 25 minutes)

A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of 100°C . They place a slab of the plastic with area 0.025 m^2 and thickness 0.010 m above the container so that the bottom surface of the slab is at a temperature of 100°C . They put a large block of ice with temperature 0°C on top of the plastic slab. Some of the ice melts, and the students measure the amount of water collected during a time Δt . The students correctly calculate the amount of energy Q delivered to the ice and thus determine $Q/\Delta t$. They repeat this experiment several times, each time adding an identical slab to increase the total thickness L of plastic. Their results are shown in the table below.

Energy flow rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total thickness of plastic L (m)	0.010	0.020	0.030	0.040	0.050

- (a) The students want to create a graph to yield a straight line whose slope could be used to calculate the thermal conductivity of the plastic.

- i. Label the axes below to indicate a pair of quantities that could be graphed to yield a straight line. Include units for the quantities.

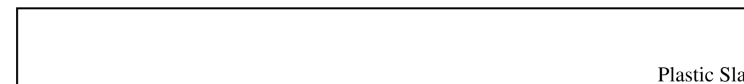


- ii. On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following.

- Add to the data table the values of any quantities to be plotted that are not already given.
- Scale the axes.
- Plot the data from the table.
- Draw a line that best represents the data.

- iii. Use the graph to calculate the thermal conductivity of the plastic.

- (b) Indicate one potential problem with the setup that could lead to an experimental value for the thermal conductivity that is different from the actual value. Use physics principles to explain the effect this problem could have on the experimental value.
- (c) The rectangle below represents a side view of the plastic slab. Draw a single arrow on the diagram representing the direction of the net flow of energy through the plastic.



Name:

AP Physics 2: 2019

- (d) Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).
- (e) An extra plastic slab sits on a wood surface, with both the plastic slab and the wood surface at room temperature. A student touches each and finds that the plastic slab feels cooler than the wood surface. Explain what causes this observation.