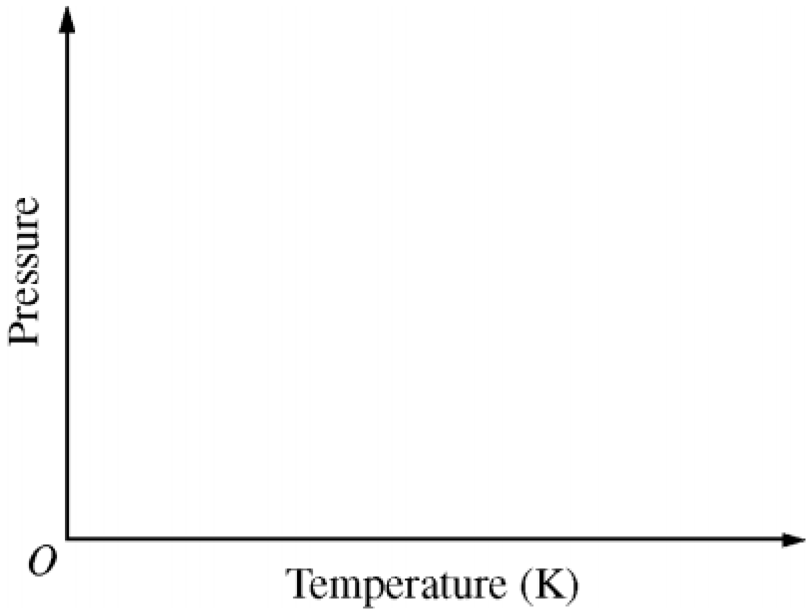
Thermodynamics Practice

1. A cylindrical container is fitted with a frictionless piston that is initially locked in place. The cylinder contains a fixed amount of an ideal gas that is initially at room temperature and atmospheric pressure.

(a) The cylinder is placed in a hot-water bath. On the axes below, sketch a graph of pressure versus temperature for the process the gas undergoes as a result, and indicate the direction of the process on the graph.



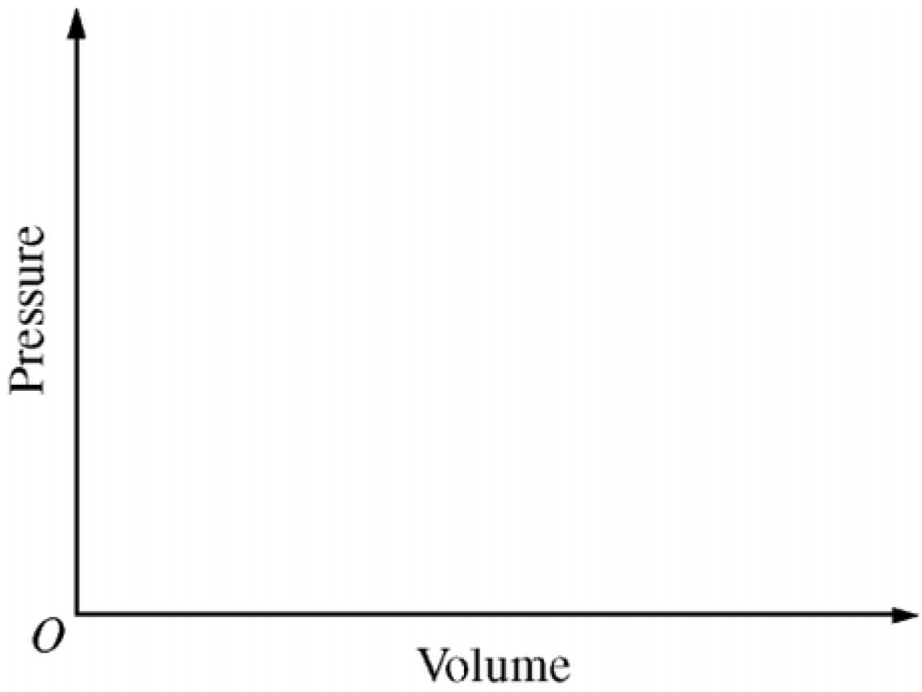
(b) The cylinder is removed from the hot-water bath. After equilibrium is reached, the lock is removed so the piston is free to move. Indicate whether the piston moves up, moves down, or remains stationary.

____ Moves up ____ Moves down ____ Remains stationary

Justify your answer.

(c) When the system is again at equilibrium, the piston is pushed down very slowly. On the axes below, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "C."

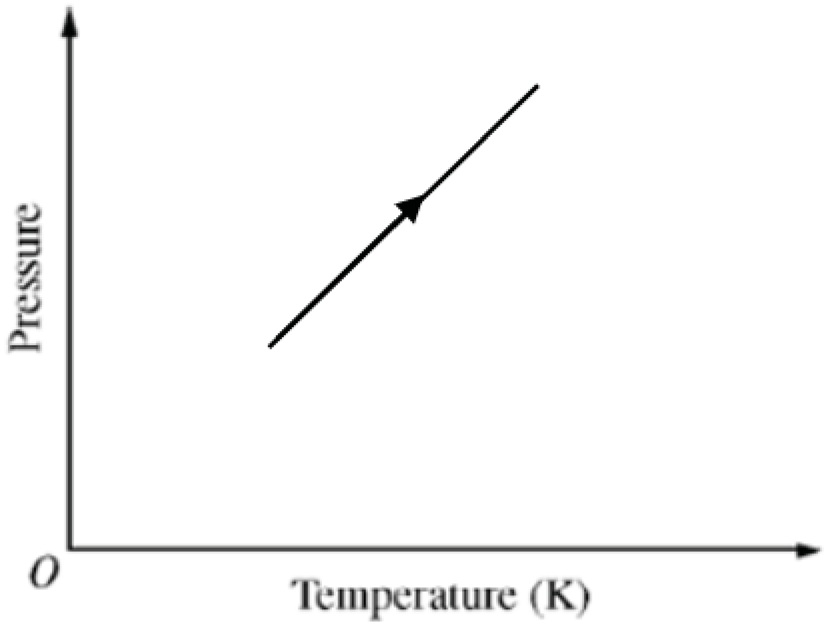
Thermodynamics Practice



(d) Now the piston is pulled up quickly, so no heat is added to or removed from the gas during the process. On the axes above, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process “D.”

Please respond on separate paper, following directions from your teacher.

Part A



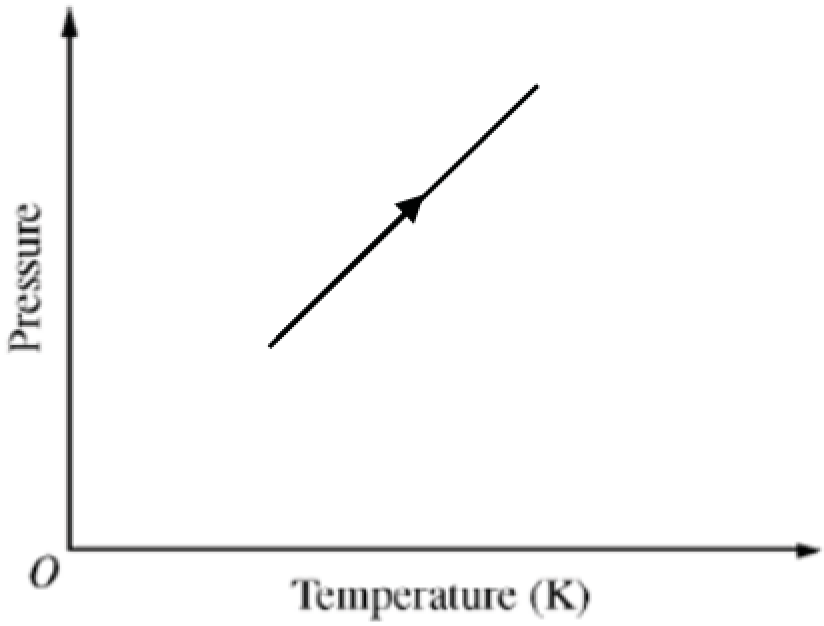
1 point(s) earned for: a graph showing pressure proportional to temperature (i.e., a straight line segment that, if extended, would pass through the origin)

1 point(s) earned for: showing that the initial pressure and initial temperature are not zero

1 point(s) earned for: a final state that is at a higher pressure and temperature than the initial state (regardless of the shape of the path)

0	1	2	3 ✔

The student earns three of the following points:



1 point(s) earned for: a graph showing pressure proportional to temperature (i.e., a straight line segment that, if extended, would pass through the origin)

1 point(s) earned for: showing that the initial pressure and initial temperature are not zero

1 point(s) earned for: a final state that is at a higher pressure and temperature than the initial state (regardless of the shape of the path)

Part B

1 point(s) earned for: selecting "Moves down"

1 point(s) earned for: recognition of the piston's mass, which is pulled down by the force of gravity

Note: One point could be earned for selecting "Remains stationary" with a clear explanation that the internal and external pressures are equal or that the system returned to the original pressure P_0

0	1	2 ✓

The student earns two of the following points:

1 point(s) earned for: selecting "Moves down"

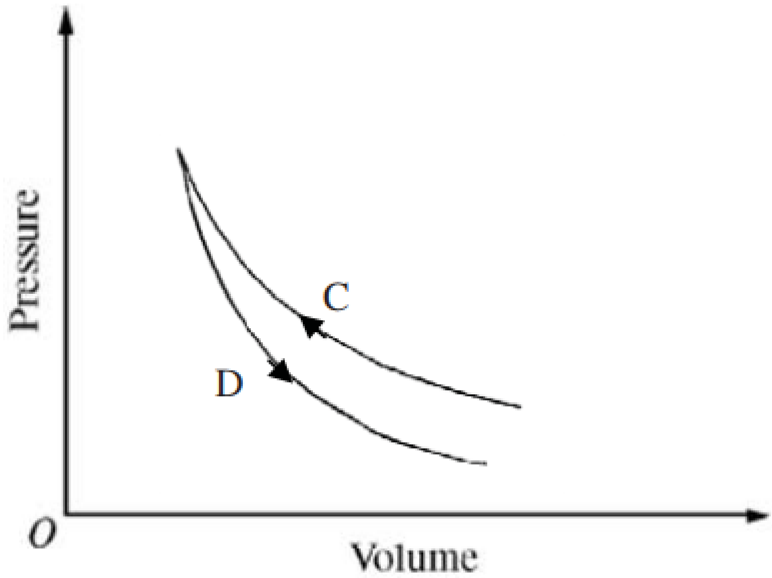
Thermodynamics Practice

1 point(s) earned for: recognition of the piston's mass, which is pulled down by the force of gravity

Note: One point could be earned for selecting "Remains stationary" with a clear explanation that the internal and external pressures are equal or that the system returned to the original pressure P_0

Part C & D

These two parts are closely linked; therefore they are scored as a unit.



1 point(s) earned for: drawing curve C as concave up, with a negative slope

1 point(s) earned for: drawing curve D as concave up, with a negative slope

1 point(s) earned for: drawing the final state of curve C and the initial state of curve D as the only point where the two curves intersect

1 point(s) earned for: drawing curve C above curve D

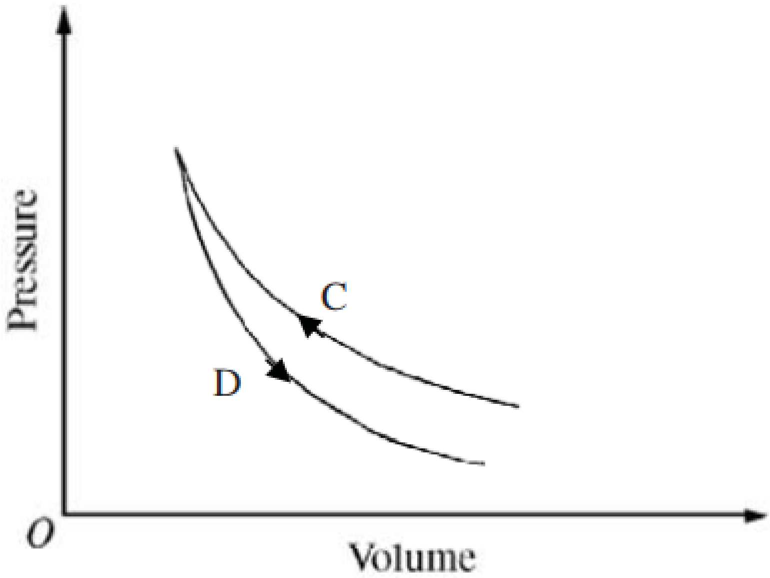
1 point(s) earned for: correct labels and directions of arrows on both processes

0	1	2	3	4	5

Thermodynamics Practice

The student earns five of the following points:

These two parts are closely linked; therefore they are scored as a unit.



1 point(s) earned for: drawing curve C as concave up, with a negative slope

1 point(s) earned for: drawing curve D as concave up, with a negative slope

1 point(s) earned for: drawing the final state of curve C and the initial state of curve D as the only point where the two curves intersect

1 point(s) earned for: drawing curve C above curve D

1 point(s) earned for: correct labels and directions of arrows on both processes

---

2. A gas undergoes an expansion in which 400 J of energy is added to the gas by heating. The internal energy of the gas changes from 700 J to 800 J. The work done by the gas is

Thermodynamics Practice

(A) 1,900 J

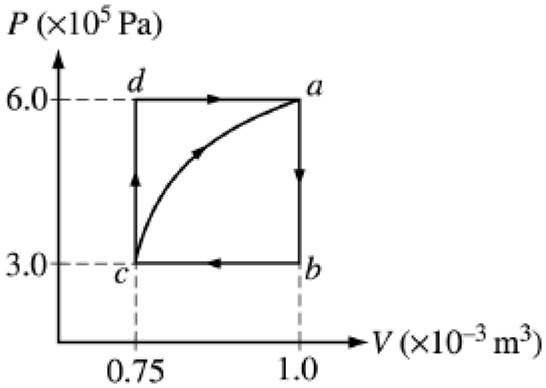
(B) 1,100 J

(C) 500 J

(D) 300 J ✔

(E) 100 J

3.



A cylinder with a movable piston contains 0.1 mole of a monatomic ideal gas. The gas, initially at state a, can be taken through either of two cycles, abca or abcda, as shown on the PV diagram above. The following information is known about this system.

$Q_{c \to a} = 685 J$ along the curved path

$W_{c \to a} = -120 J$ along the curved path

$U_a - U_b = 450 J$

$W_{a \to b \to c} = 75 J$

(a) Determine the change in intemal energy, U_a-U_c, between states a and c.

Thermodynamics Practice

(b) i. Is heat added to or removed from the gas when the gas is taken along the path abc?

____added to the gas ____removed from the gas

ii.Calculate the amount added or removed.

(c) How much work is done on the gas in the process cda?

(d) Is heat added to or removed from the gas when the gas is taken along the path cda?

____added to the gas ____removed from the gas

Explain your reasoning.

Please respond on separate paper, following directions from your teacher.

Part A

1 point(s) earned: For a correct calculation of the change in internal energy

$U_a - U_c = \Delta U_{c\to a} = Q_{c\to a} + W_{c\to a}$ $\Delta U_{c\to a} = 685\text{J} - 120\text{J}$ $\Delta U_{c\to a} = 565\text{J}$

0	1

The student earns one of the following points:

1 point(s) earned: For a correct calculation of the change in internal energy

$U_a - U_c = \Delta U_{c\to a} = Q_{c\to a} + W_{c\to a}$ $\Delta U_{c\to a} = 685\text{J} - 120\text{J}$ $\Delta U_{c\to a} = 565\text{J}$

Part B(i,ii)

(i)

1 point(s) earned: For correct choice of heat removed from the gas

(ii)

Thermodynamics Practice

1 point(s) earned: For recognition that the change in internal energy is opposite in sign from part (a) answer

$\Delta U_{a\rightarrow b\rightarrow c} = -\Delta U_{c\rightarrow a} = -565J$ Calculating the heat: $Q_{c\rightarrow d\rightarrow a} = \Delta U_{c\rightarrow d\rightarrow a} - W_{c\rightarrow d\rightarrow a}$ $Q_{c\rightarrow d\rightarrow a} = -565J - 75J$

1 point(s) earned: For the correct answer

$Q_{c\rightarrow d\rightarrow a} = -640J$

0	1	2	3 ✓

The student earns three of the following points:

(i)

1 point(s) earned: For correct choice of heat removed from the gas

(ii)

1 point(s) earned: For recognition that the change in internal energy is opposite in sign from part (a) answer

$\Delta U_{a\rightarrow b\rightarrow c} = -\Delta U_{c\rightarrow a} = -565J$ Calculating the heat: $Q_{c\rightarrow d\rightarrow a} = \Delta U_{c\rightarrow d\rightarrow a} - W_{c\rightarrow d\rightarrow a}$ $Q_{c\rightarrow d\rightarrow a} = -565J - 75J$

1 point(s) earned: For the correct answer

$Q_{c\rightarrow d\rightarrow a} = -640J$

Part C

The total work done is the sum of the work for the two sections of the path

$W_{c\rightarrow d\rightarrow a} = W_{c\rightarrow d} + W_{d\rightarrow a}$

1 point(s) earned: For some indication that the work done along path c → d is zero

The work done along path d → a is the area under the curve

Thermodynamics Practice

$W_{c\rightarrow d\rightarrow a}$=0-PΔV

1 point(s) earned: For correct substitution

$W_{c\rightarrow d\rightarrow a} = -(6.0\times 10^5 \text{ Pa})(1.0\times 10^{-3} \text{ m}^3 - 0.75\times 10^{-3} \text{ m}^3)$

1 point(s) earned: For the correct answer

$W_{c\rightarrow d\rightarrow a}$ = -150J

0	1	2	3 ✔

The student earns three of the following points:

The total work done is the sum of the work for the two sections of the path

$W_{c\rightarrow d\rightarrow a} = W_{c\rightarrow d} + W_{d\rightarrow a}$

1 point(s) earned: For some indication that the work done along path c → d is zero

The work done along path d → a is the area under the curve

$W_{c\rightarrow d\rightarrow a}$=0-PΔV

1 point(s) earned: For correct substitution

$W_{c\rightarrow d\rightarrow a} = -(6.0\times 10^5 \text{ Pa})(1.0\times 10^{-3} \text{ m}^3 - 0.75\times 10^{-3} \text{ m}^3)$

1 point(s) earned: For the correct answer

$W_{c\rightarrow d\rightarrow a}$ = -150J

Part D

1 point(s) earned: For correct choice of heat added to the gas

2 point(s) earned: For a complete explanation that references the first law

Example: Since $\Delta U_{c\rightarrow d\rightarrow a}$ is positive (i.e. 565 J) and work is done, *Q* must be positive.

Thermodynamics Practice

1 point(s) earned: An incomplete argument with correct relevant assertions and no mistakes earned 1 point.

An incomplete argument with irrelevant or incorrect assertions earned no points

0	1	2	3 ✓

The student earns three of the following points:

1 point(s) earned: For correct choice of heat added to the gas

2 point(s) earned: For a complete explanation that references the first law

Example: Since $\Delta U_{c \to d \to a}$ is positive (i.e. 565 J) and work is done, *Q* must be positive.

1 point(s) earned(extra): An incomplete argument with correct relevant assertions and no mistakes earned 1 point.

An incomplete argument with irrelevant or incorrect assertions earned no points

---

4. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v, is their average speed after the absorption of heat, what is the ratio v_2/ v_1 ?

(A) 1/2

(B) 1

(C) $\sqrt{2}$ ✔

(D) 2

(E) 4

---

5. A sample of gas has a temperature of 200 K. If the speed of every gas molecule in the sample is doubled, what is the new temperature of the gas?

(A) 800 K ✔

(B) 400 K

(C) 200 K

(D) 100 K

---

6. A series of measurements are made of the pressure *P* and the volume *V* of a sample of nitrogen gas kept at a constant temperature. It is desired to represent the data graphically so that the graph will be a straight line if the behavior of the gas is ideal. Accordingly, which of the following should be plotted?

(A) P as a function of V

(B) V/P as a function of V

(C) P/V as a function of V

(D) P as a function of $1/V$ ✓

(E) $1/P$ as a function of $1/V$

---

7. A slab of metal and a slab of wood are placed in a classroom and allowed to sit undisturbed for a long time. A student then places one hand on the metal and the other hand on the wood. Which of the following describes the student's perception of the temperatures of the slabs and their actual temperatures?

(A) The metal slab feels colder to the student because it is at a lower temperature.

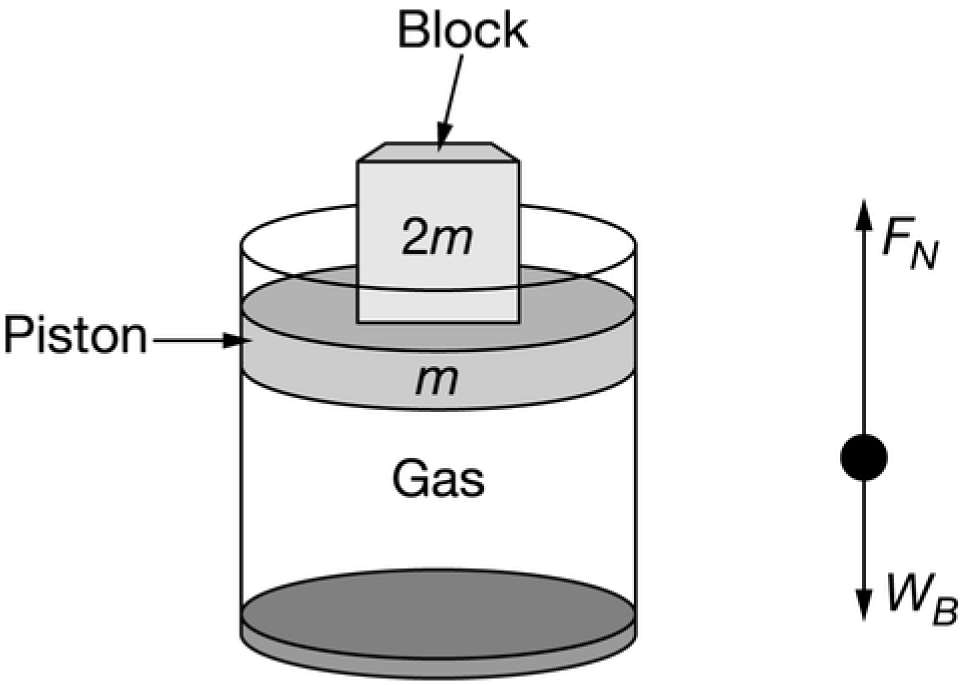
(B) The metal slab feels colder to the student because it conducts thermal energy away from the student's hand faster, but the slabs have the same temperature. ✓

(C) The metal slab feels warmer to the student because it conducts thermal energy to the student's hand faster, but the slabs have the same temperature.

(D) Both slabs feel the same to the student because they are at the same temperature.

Thermodynamics Practice

8.



A sample of gas is confined in a cylinder with a moveable piston of mass m that is initially held fixed. There is a block of mass $2m$ on top of the piston, as shown in the figure. A free-body diagram for the block is also shown, which includes the normal force F_N exerted on the block by the piston and the weight W_B of the block. The upward force that the gas exerts on the piston has magnitude F_{gas}. What is the acceleration of the block immediately after the piston is released?

(A) $(F_N - W_B)/2m$ ✔

(B) $(F_N - W_B)/3m$

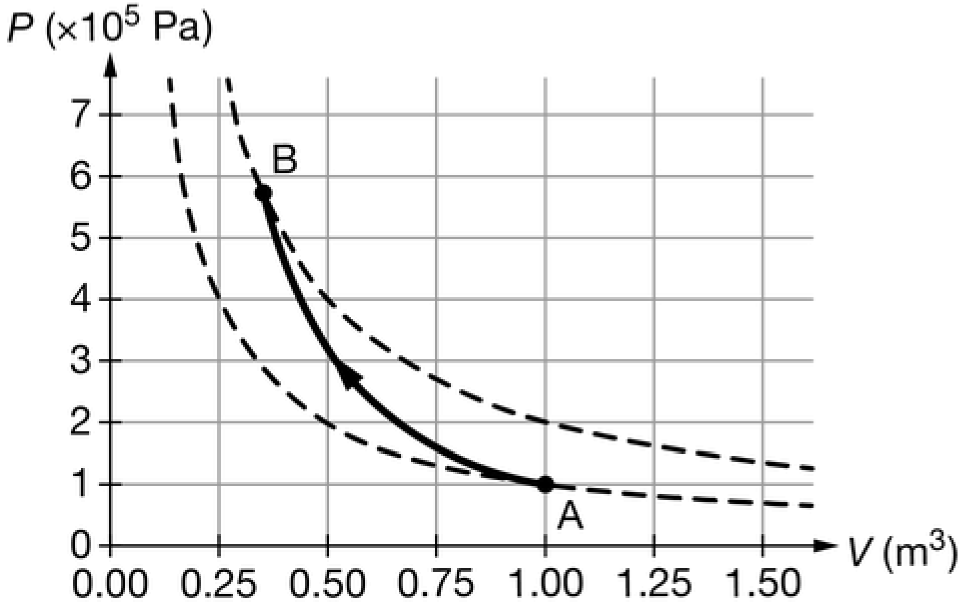
(C) $(F_N + F_{gas} - W_B)/2m$

(D) $(F_N + F_{gas} - W_B)/3m$

---

9. This question is a long free-response question. Show your work for each part of the question.

Thermodynamics Practice



(12 points, suggested time 25 minutes)

A sample of ideal gas in a thermally insulated container with a moveable piston is initially in state A. As shown in the graph of pressure P as a function of volume V, the gas is taken from state A to state B by an adiabatic process. The dashed lines represent isotherms.

(a) Let W be the work done on the gas, Q be the energy transferred to the gas by heating, and ΔU be the change in the internal energy of the gas during the process shown.

i. Is W greater than, less than, or equal to zero? Briefly explain your answer.

Please respond on separate paper, following directions from your teacher.

ii. Is Q greater than, less than, or equal to zero? Briefly explain your answer.

Please respond on separate paper, following directions from your teacher.

iii. Is ΔU greater than, less than, or equal to zero? Briefly explain your answer.

Thermodynamics Practice

Please respond on separate paper, following directions from your teacher.

(b) If the temperature of the gas in state A is $200 \mathrm{~K}$, what is the approximate temperature of the gas in state B ?

Please respond on separate paper, following directions from your teacher.

(c) Is your numerical result for part (b) consistent with your explanation for part (a)(iii)? Briefly justify your answer.

Please respond on separate paper, following directions from your teacher.

Part (a)(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3

Student response accurately includes all of the following criteria.
This is a translation part.

- ☐ 1 point is earned for indicating that W is greater than zero with some attempt at a relevant explanation
- ☐ 1 point is earned for indicating that the work done is related to the area under the curve
- ☐ 1 point is earned for indicating that the direction of the process determines whether the work on the gas is positive or negative

Claim: W is greater than zero.

Evidence: The process on the graph has area under it and has an arrowheaad indicating the direction of the process.

Reasoning: Nonzero area under the curve means a nonzero amount of work is done. The arrow toward the left means the work is done on the gas.

Example response:

The area under the curve is nonzero and the volume decreases, so positive work is done on the gas.

Part (a)(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✔

Student response accurately includes both of the following criteria.

This is a translation part.

- ☐ 1 point is earned for indicating that Q is zero with some attempt at a relevant explanation
- ☐ 1 point is earned for indicating that adiabatic means no energy transfer by heating

Claim: Q is zero.

Evidence: The given process is adiabatic.

Reasoning: Adiabatic means no energy transferred by heating.

Example response:

By definition, in an adiabatic process no energy is transferred by heating, so Q is zero.

Part (a)(iii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Thermodynamics Practice

0	1	2

Student response accurately includes both of the following criteria.

This is a translation part.

- ☐ 1 point is earned for indicating that ΔU is greater than zero with some attempt at a relevant explanation
- ☐ 1 point is earned for explicitly or implicitly applying the first law of thermodynamics

Claim: ΔU is greater than zero.

Evidence: Conservation of energy, Q is zero, and W is greater than zero

Reasoning: Energy is conserved, Q is zero, and W is greater than zero, so the internal energy increased.

Example explanation: Work was done, adding energy, but no energy was transferred out of the gas by heating, so the internal energy increased.

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3

Student response accurately includes both of the following criteria.

This is a quantitative part.

- ☐ 1 point is earned for attempting to apply the ideal gas law
- ☐ 1 point is earned for relating the temperatures, pressures, and volumes for the two states

  Example:

$$T_B = \frac{P_B V_B}{P_A V_A} T_A$$

☐ 1 point is earned for substituting reasonable values from the graph

Example:

$$T_B \approx \frac{(5.8\times10^5 \text{ Pa})(0.37 \text{ m}^3)}{(1\times10^5 \text{ Pa})(1 \text{ m}^3)}(200 \text{ K})$$

Part (c)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2

Both of the following are done.

This is a translation part.

☐ 1 point is earned for indicating that internal energy depends on the temperature

☐ 1 point is earned for writing a response consistent with the answer for part (a)(iii)

Example response:

Yes. The internal energy depends on the temperature. A higher temperature means a higher internal energy, and that is consistent with the increase noted in part (a).

10. An ideal gas with molecules of mass *m* is contained in a cube with sides of area *A*. The pressure exerted by the gas on the top of the cube is *P*, and *N* molecules hit the top of the cube in a time Δt. What is the average vertical component of the velocity of the gas molecules?

(A) $PA\Delta t/m$

(B) $PA\Delta t/2m$

(C) $PA\Delta t/Nm$

(D) $PA\Delta t/2Nm$ ✔

---

11. An ideal gas with molecules of mass m is contained in a cube with sides of area A. The average vertical component of the velocity of the gas molecules is v, and N molecules hit the side of the cube in a time Δt . What is the pressure exerted by the gas on the bottom of the cube?

(A) $mv / A\Delta t$

(B) $2mv / A\Delta t$

(C) $Nmv / A\Delta t$

(D) $2Nmv / A\Delta t$ ✔

---

12. An insulated container with a divider in the middle contains two separated gases. Gas 1 is initially at a higher temperature than gas 2. The divider is then removed. Which of the following observations might be made over a period of time as the two gases mix together, and why?

Thermodynamics Practice

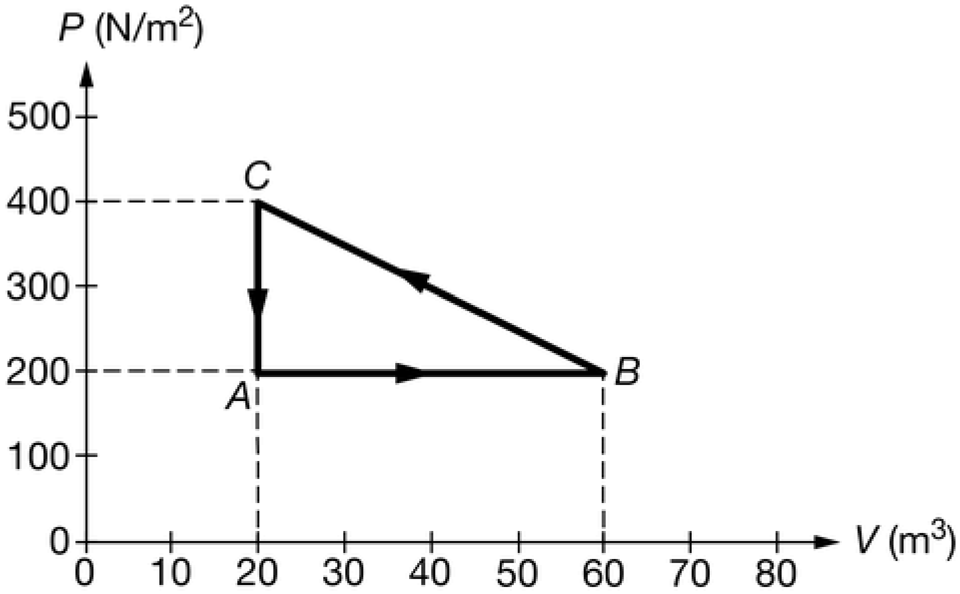
(A) Gas 1 remains at a higher temperature than gas 2 because gas 1 started at a higher temperature.

(B) Gas 1 remains at a higher temperature than gas 2 because gas 1 started with a higher kinetic energy.

(C) On average, the molecules of gas 1 lose all of their kinetic energy to the molecules of gas 2 through collisions, resulting in gas 2 eventually having a higher temperature than gas 1.

(D) On average, the molecules of gas 1 lose some of their kinetic energy to the molecules of gas 2 through collisions, resulting in the two gases eventually having the same temperature. ✔

13.



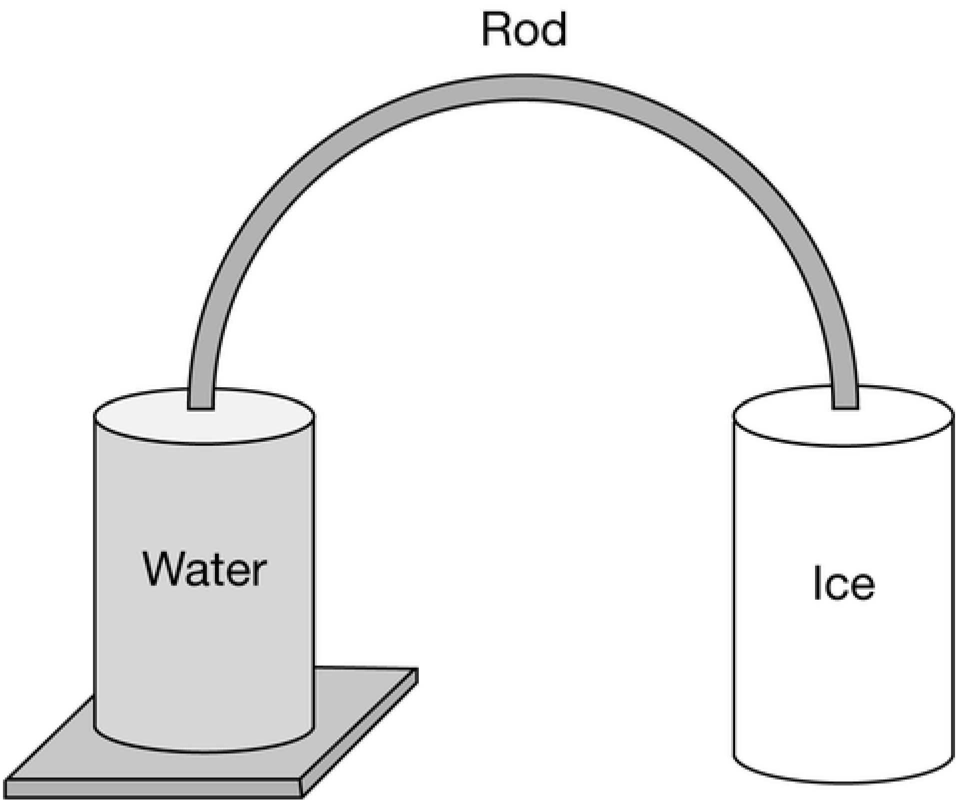
One mole of an ideal gas is sealed in a cylindrical container with a movable piston. The volume and pressure of the gas are recorded as the gas is taken through process $ABCA$, as shown in the graph. Which of the following features of the graph, if any, is equivalent to the amount of work done on the gas during the complete cycle?

(A) The slope of the line BC

(B) The area under the line AB

(C) The area bound by the triangle $ABCA$ ✔

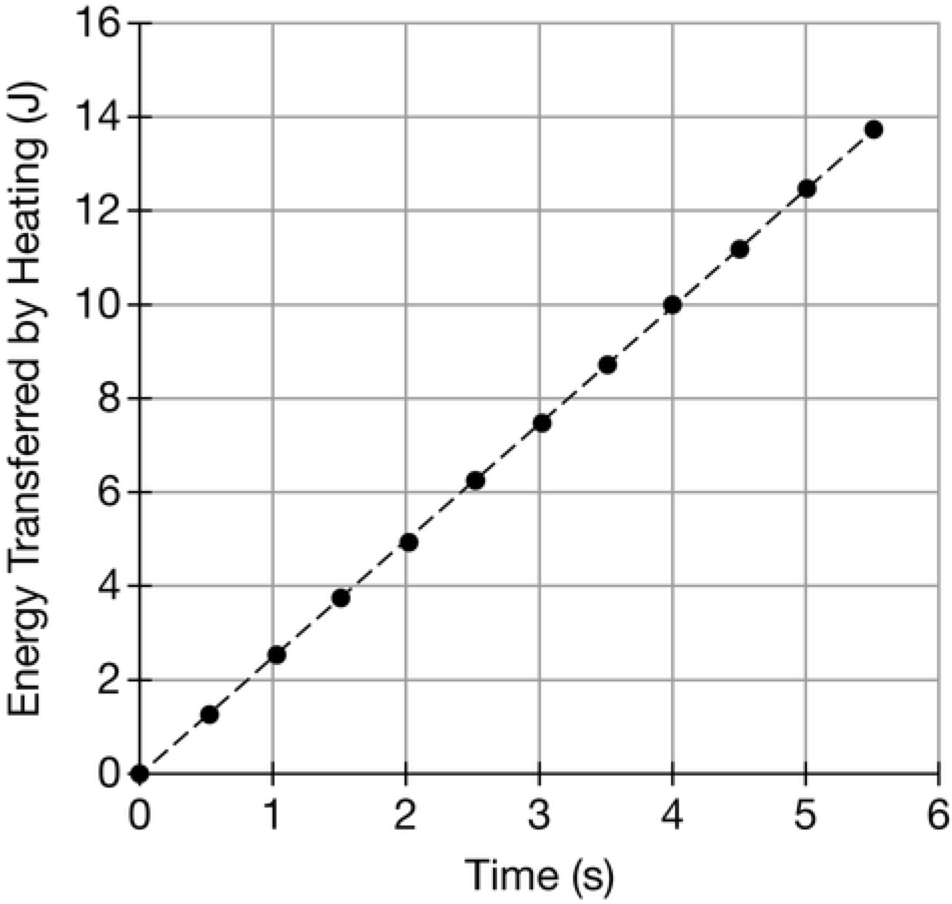
(D) The average slope of the lines AB, BC, and CA



Students design an experiment with a curved, insulated rod of an unknown thermally conducting material, as shown in the figure. The rod is 1 m long and 2 cm in diameter. One end of the rod is touching the surface of water kept at 350K by a hot plate, and the other end is just touching the surface of a well-insulated block of ice.

Thermodynamics Practice

14.



The figure shows a graph of the energy transferred by heating from the water through the rod and to the ice over time. If the temperature of the ice is held constant at $250\ \mathrm{K}$, what is the thermal conductivity of the rod?

(A) 0.03 $\mathrm{W/(m \cdot K)}$

(B) 2.5 $\mathrm{W/(m \cdot K)}$

(C) 80 $\mathrm{W/(m \cdot K)}$ ✔

(D) 314 $\mathrm{W/(m \cdot K)}$

Thermodynamics Practice

15. In a mixture of gases, a carbon atom of mass $12\ m$ is moving to the right with speed v when it collides with and sticks to an oxygen atom of mass $16\ m$ moving to the right with speed $v/2$. What is the final speed of the resulting molecule?

(A) $\frac{1}{7}v$ to the left

(B) $\frac{1}{7}v$ to the right

(C) $\frac{5}{7}v$ to the left

(D) $\frac{5}{7}v$ to the right ✔

16. A student conducts an experiment in which two solid rods, X and Y , are each held vertically with the bottom end just submerged in a bath of boiling water. The temperature of the room is $21^{\circ}\mathrm{C}$, and the rods are each $80\ \mathrm{cm}$ long. After each rod has been in the water for the same amount of time, the student measures the temperature at $20\ \mathrm{cm}$ intervals along each rod. The student's data are shown below. Which of the following correctly describes an analysis of the data that can be used to compare the thermal conductivity of the rods?

Height Above Water (cm)	Temperature of Rod X (°C)	Temperature of Rod Y (°C)
0	100	100
20	86.7	97.8
40	73.3	95.6
60	60.0	93.3
80	46.7	91.1

(A) Compare the temperatures of the rods at $0\ \mathrm{cm}$.

(B) Compare the temperatures of the rods at each height. ✔

(C) Determine which rod has differences in temperatures between adjacent positions that are most similar for all pairs of positions.

(D) The data cannot be used to compare the thermal conductivities because the top ends of the rods are not at room temperature.

Thermodynamics Practice

17. A student collects two data points for a sample of a gas that can be treated as ideal and is in a rigid container: $T_1 = 300\ \mathrm{K}$, $P_1 = 3.0\ \mathrm{kPa}$ and $T_2 = 310\ \mathrm{K}$, $P_2 = 3.1\ \mathrm{kPa}$. Which of the following is the best conclusion about the pressure of an ideal gas at absolute zero (that is, $T = 0\ \mathrm{K}$) that can be made from this data?

(A) The pressure is $0\ \mathrm{kPa}$.

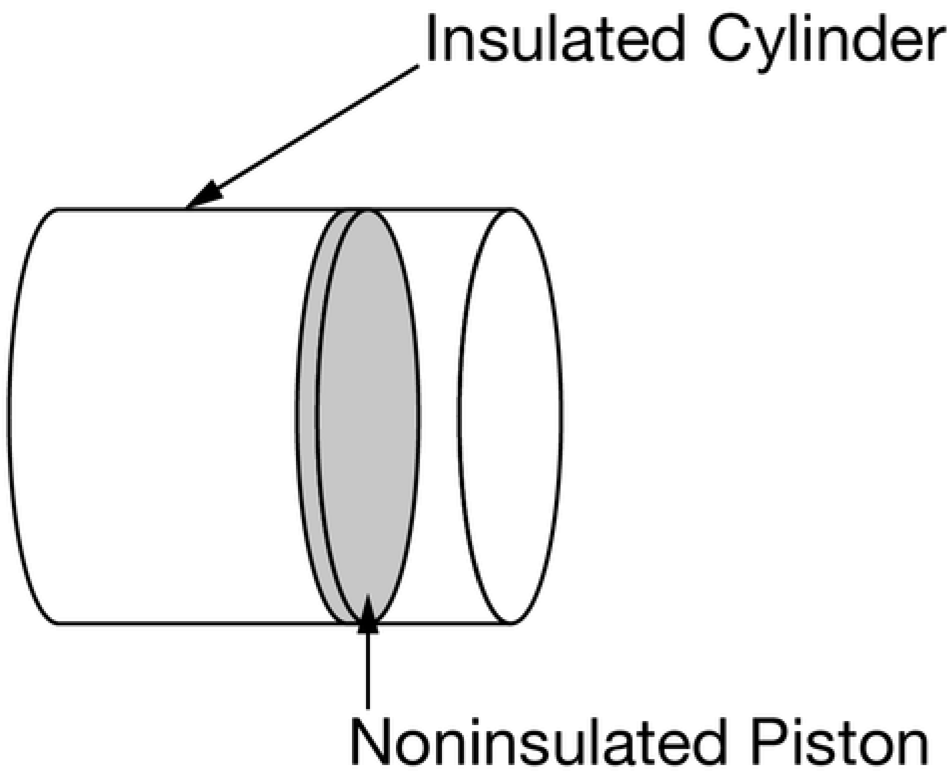
(B) No conclusion can be made, because a pattern cannot be validated based on only two data points. ✔

(C) No conclusion can be made, because the substance is no longer a gas near absolute zero.

(D) No conclusion can be made, because the volume of the gas is zero at absolute zero, and $PV = 0$ does not necessarily imply that pressure is zero.

---

18. This question is a short free-response question. Show your work for each part of the question.

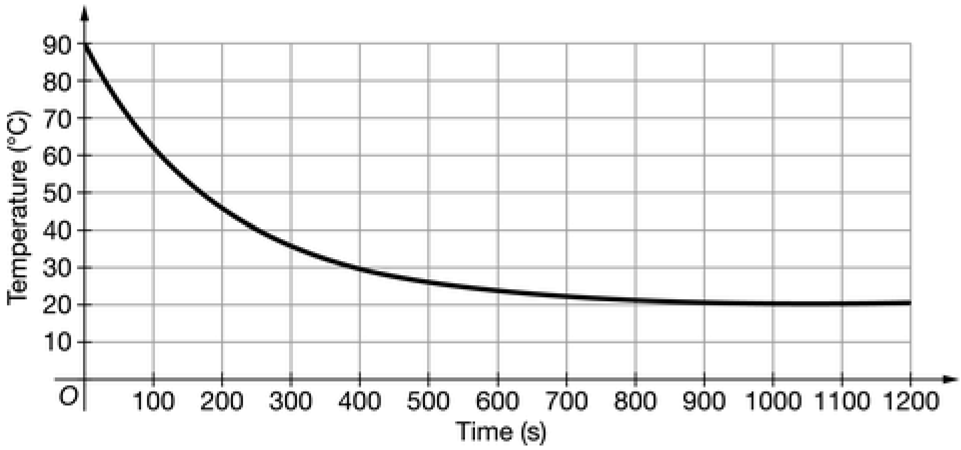


(10 points, suggested time 20 minutes)

Thermodynamics Practice

An insulated cylinder with a noninsulated piston contains a gas that is initially at $90^{\circ}\mathrm{C}$. The piston has an area of $0.056\ \mathrm{m}^2$, a thickness of $4.2 \times 10^{-3}\ \mathrm{m}$, and a thermal conductivity of $1.05\ \mathrm{W/mK}$. The temperature of the surrounding room is $20^{\circ}\mathrm{C}$.

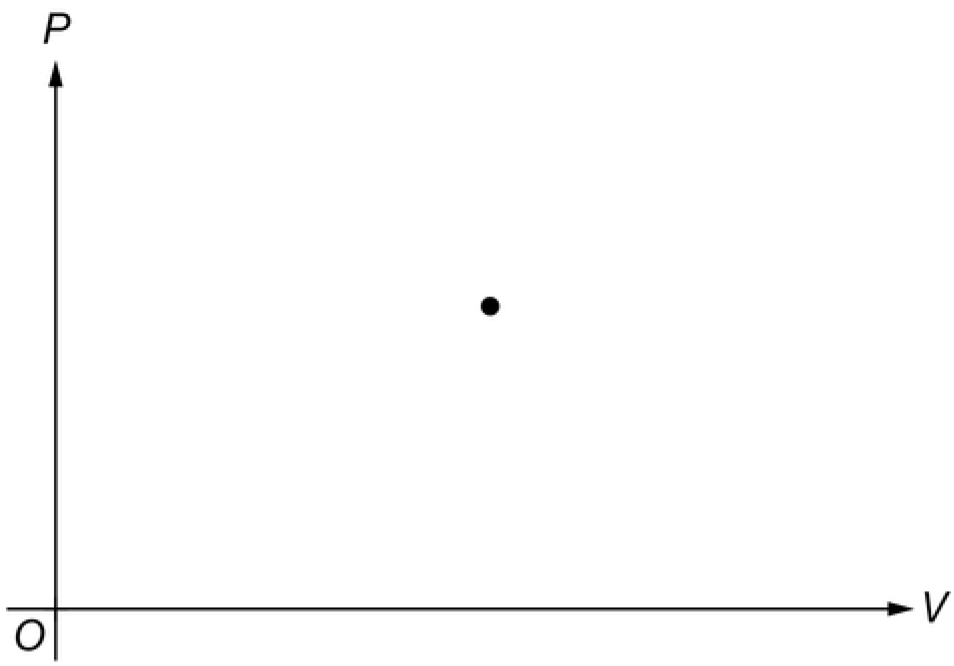
(a) The graph below shows the temperature of the gas as a function of time as the gas cools to room temperature. Describe a method for using the graph to estimate the amount of energy that is conducted through the piston.



Please respond on separate paper, following directions from your teacher.

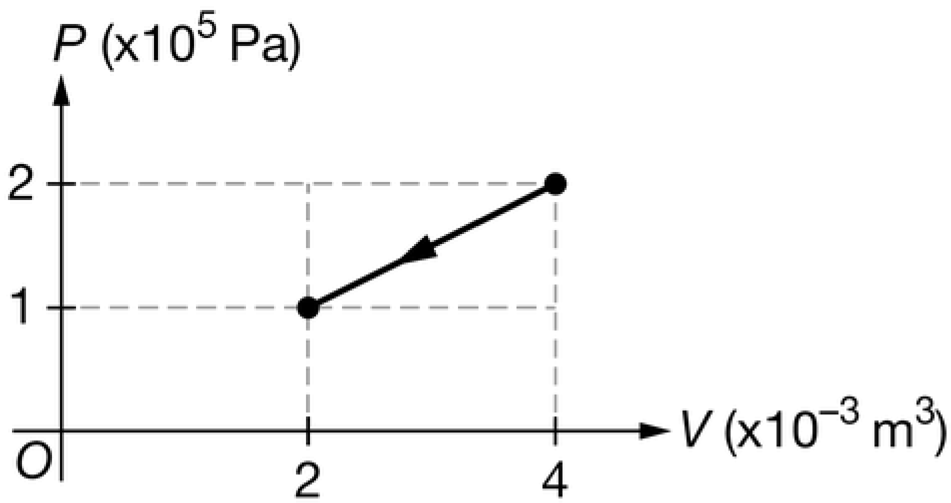
(b) The pressure inside the cylinder is initially equal to the atmospheric pressure P_{atm}, and the cooling process happens slowly enough for the pressures to remain at equilibrium. The dot on the graph below of pressure P as a function of volume V represents the initial state of the gas at $90^{\circ}\mathrm{C}$. On the graph, draw a line or curve that could represent the process that the gas goes through as it cools.

Thermodynamics Practice



Please respond on separate paper, following directions from your teacher.

(c) In a different process, the gas loses $500\ \text{J}$ of energy by cooling. Pressure as a function of volume for the process is shown on the graph below. What is the change in the internal energy of the gas during the process?



Please respond on separate paper, following directions from your teacher.

Thermodynamics Practice

(d) After the gas has reached equilibrium with the surroundings, the piston is pushed in very quickly. Qualitatively describe the change in the internal energy of the gas, if any, due to this rapid compression.

Please respond on separate paper, following directions from your teacher.

Part (a)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for attempting to use the equation for energy transfer by conduction in conjunction with the graph
- ☐ 1 point is earned for indicating that the area under the curve can be used to estimate the total energy conducted

Example response:

Thermal conduction is governed by the equation $\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$. Rewriting this as $Q = \frac{kA\,\Delta T \Delta t}{L}$, the values of k ,A , and L are given. Estimating the area under the curve between $90^{\circ}\mathrm{C}$ and $20^{\circ}\mathrm{C}$ will allow an estimate of Q to be calculated.

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

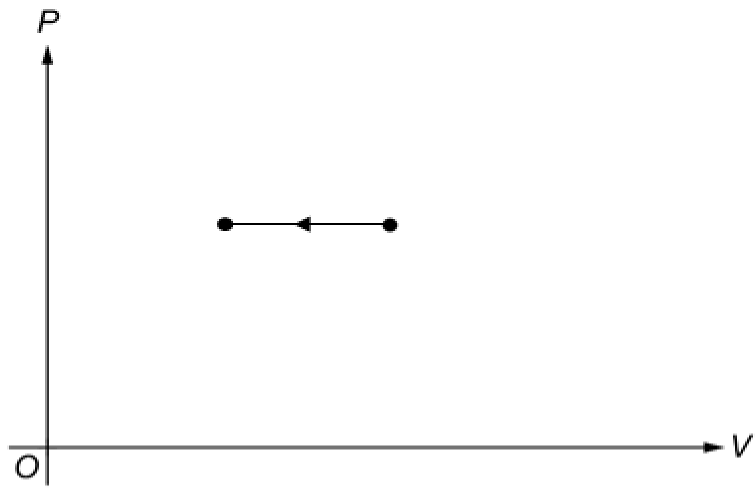
0	1	2

Thermodynamics Practice

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for drawing a line with constant pressure
- ☐ 1 point is earned for showing decreasing volume

Example response:



Part (c)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for calculating the magnitude of the work done on the gas by taking an area under the curve
- ☐ 1 point is earned for taking the correct area under the curve

  Example:

  $$W = \frac{1}{2}\left(1 \times 10^5 \text{ Pa}\right)\left(2 \times 10^{-3} \text{ m}^3\right) + \left(1 \times 10^5 \text{ Pa}\right)\left(2 \times 10^{-3} \text{ m}^3\right) = 300 \text{ J}$$

Thermodynamics Practice

- ☐ 1 point is earned for using the first law of thermodynamics to determine the change in internal energy

  Example:

  $\Delta U = Q + W = -500\ \mathrm{J} + 300\ \mathrm{J} = -200\ \mathrm{J}$

Part (d)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✔

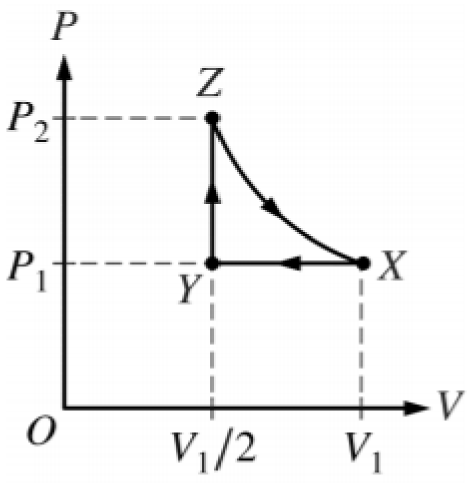
Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for indicating that work is done on the gas, which adds energy
- ☐ 1 point is earned for indicating that the process being quick means no energy is transferred through heating and/or cooling
- ☐ 1 point is earned for indicating that $\Delta U = W$, or that the internal energy increases

Example response:

Work is done on the gas, so energy is added to the gas. Since the piston is pushed in quickly, no energy is transferred through heating or cooling. So the change in internal energy equals the work done, and thus the internal energy increases.

Thermodynamics Practice



A closed chamber filled with a gas that is modeled as ideal has a movable piston of area *A*. The graph above of pressure *P* as a function of volume *V* shows three processes that make up cycle *XYZX* through which the gas is taken. Process *ZX* is isothermal.

---

19. During which process is no work done on or by the gas?

(A) *XY*

(B) *YZ* ✔

(C) *ZX*

(D) Work was done on or by the gas during every process

---

20. In the kinetic theory of gases, it is assumed that collisions between particles in an ideal gas are perfectly elastic. Which of the following claims is true based on this assumption?

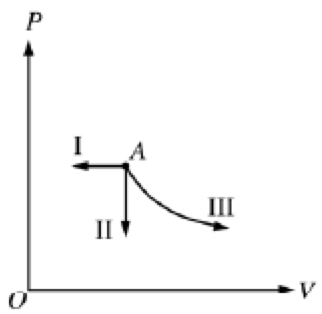
Thermodynamics Practice

(A) The average kinetic energy of the gas particles does not change due to interactions between particles. ✔

(B) The temperature of the gas does not depend on the motion of the gas particles.

(C) No energy is transferred between gas particles when they collide.

(D) All the gas particles have the same speed.



A monatomic ideal gas is initially in state *A*, as shown in the *PV* diagram above. The gas undergoes a transition from state *A* by the three different processes shown, where process III is isothermal.

21. Energy is added to the gas by heating in which of the following processes?

(A) I only

(B) III only ✔

(C) I and II only

(D) II and III only

(E) I, II, and III

---

22. Positive work is performed on the gas in which of the following processes?

(A) I only ✔

(B) III only

(C) I and II only

(D) II and III only

(E) I, II, and III

---

23. An ideal gas is contained in a thermally insulated cylinder with a movable piston. The piston moves toward the bottom of the cylinder, decreasing the volume occupied by the gas. Which of the following correctly explains why the gas pressure increases? Select two answers.

(A) The average force exerted by the gas molecules on the cylinder walls during collisions has increased because the average speed of the gas molecules has increased. ✓

(B) The average force exerted by each individual gas molecule on the cylinder walls during collisions has increased because the surface area inside the cylinder has decreased.

(C) The number of collisions per time interval of the gas molecules against the cylinder walls has increased because the gas molecules do positive work on the piston as it moves.

(D) The number of collisions per time interval of the gas molecules against the cylinder walls has increased because the gas molecules have a shorter distance to travel between collisions. ✓

---

24. A vertical cylinder has a piston on top with mass m and area A that is open to the atmosphere and moves without friction. The piston is at rest when n moles of an ideal gas are contained in a volume V. When the gas is heated to temperature T the piston begins to move upward with acceleration a. Which of the following correctly describes the magnitude of the force exerted by the piston on the gas as the piston first begins to move upward?

(A) $mg + P_{\text{atmosphere}} A$

(B) $\frac{nRTA}{V} - mg - P_{\text{atmosphere}} A$

(C) $\frac{nRTA}{V}$ ✓

(D) ma

---

25. A student fills balloons using an insulated helium tank with a known fixed volume V. The student fills each balloon with helium, then measures the pressure P, temperature T, and number of moles n of the remaining helium in the tank. Which of the following is the best relationship to graph to determine the value of the universal gas constant R?

(A) P as a function of $\frac{T}{V}$

(B) P as a function of $\frac{nT}{V}$ ✔

(C) P as a function of $\frac{1}{VT}$

(D) P as a function of $\frac{1}{nVT}$

---

26. A mixture of two ideal gases, A and B, is in a container. Molecules of gas A have half the mass of molecules of gas B. One molecule of gas A is moving with velocity $+v$ when it collides head-on with a molecule of gas B moving with velocity $-v$. After the collision the molecule of gas B moves with velocity $+v/3$. What is the velocity of the molecule of gas A after the collision?

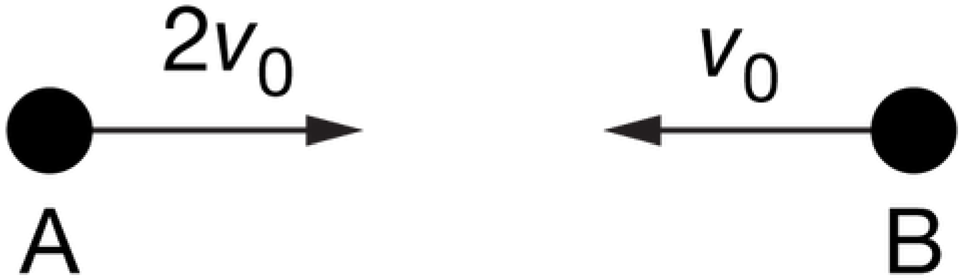
(A) $-5v/3$ ✔

(B) $-2v/3$

(C) $-v/3$

(D) $+v/3$

27.



Two ideal gas molecules with identical masses travel toward each other as shown in the figure. Molecule A has an initial velocity of $2v_0$ to the right and molecule B has an initial velocity of v_0 to the left. The molecules collide head-on. Which of the following claims correctly describes their motion after the collision?

(A) The molecules must have velocities in opposite directions to conserve momentum.

(B) The molecules must have velocities in opposite directions to conserve kinetic energy.

(C) Momentum is conserved because the collision is assumed to be elastic.

(D) Determining the magnitudes of their velocities includes applying conservation of kinetic energy because the collision is assumed to be elastic. ✔

28. A positive gas ion with mass $1.5 \times 10^{-27}\ \mathrm{kg}$ is traveling with speed $200\ \mathrm{m/s}$ in the $+y$-direction when it collides head-on with a negative gas molecule with mass $2.8 \times 10^{-27}\ \mathrm{kg}$ traveling with speed $200\ \mathrm{m/s}$ in the $-y$-direction. The molecules stick together. What is the total kinetic energy of the two-ion system immediately after the collision?

(A) $0\ \mathrm{J}$

(B) $7.9 \times 10^{-24}\ \mathrm{J}$ ✔

(C) $2.6 \times 10^{-23}\ \mathrm{J}$

(D) $8.6 \times 10^{-23}\ \mathrm{J}$

Thermodynamics Practice

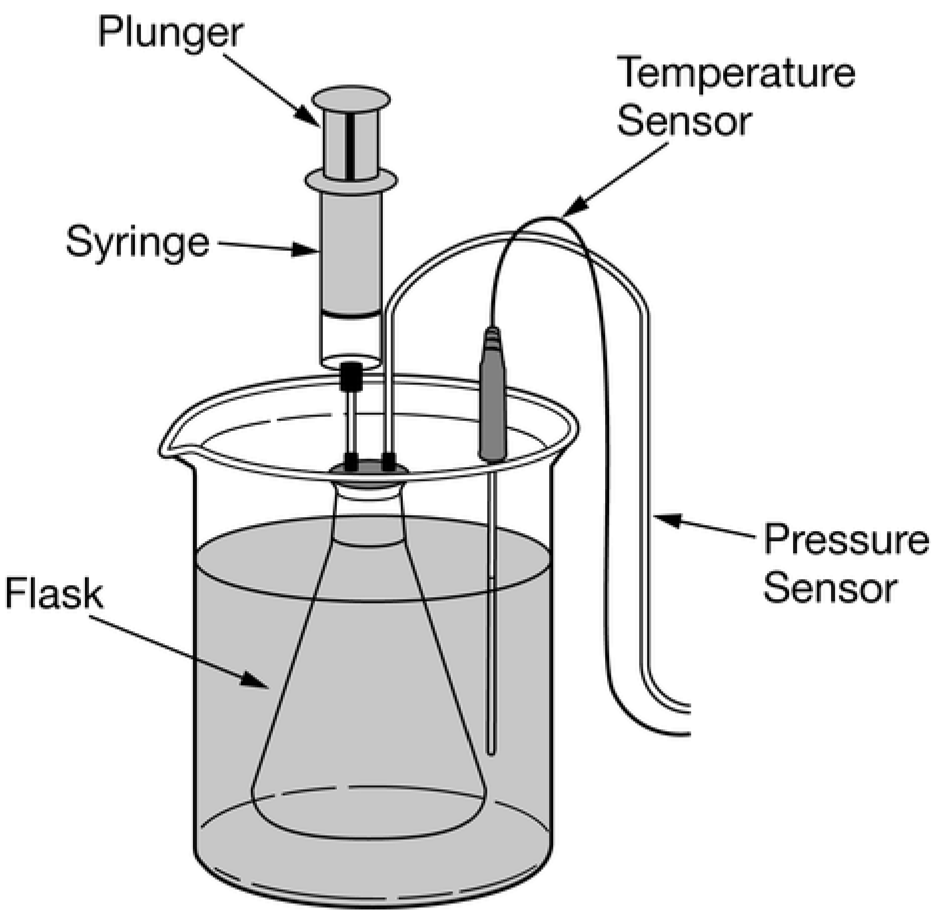
29. Which of the following is a correct claim about the effect of an elastic collision between two molecules of an ideal gas on the kinetic energy of the molecules? Select two answers.

(A) The kinetic energy of the system of the two the molecules remains constant. ✔

(B) The kinetic energy of each of the molecules increases.

(C) The kinetic energy of each of the molecules decreases.

(D) If the kinetic energy of one of the molecules increases, then the kinetic energy of the other molecule decreases. ✔



Students perform an experiment to determine the relationship between the pressure and temperature of an ideal gas. They have a flask with a stopper through which a syringe and a pressure sensor are inserted, as shown in the figure. The flask is in a water bath whose temperature can be adjusted. There is a temperature sensor to measure the temperature of the water.

30. The students now press the plunger inward rapidly, decreasing the volume of the gas. Which of the following describes the effect this has on the pressure and the temperature of the gas?

(A) The volume of the gas decreases, so the gas molecules hit the walls of the flask more often. This increases the pressure and thus the average force exerted on the gas molecules. The speed of the gas molecules increases, which means greater kinetic energy, and thus an increase in the temperature. ✔

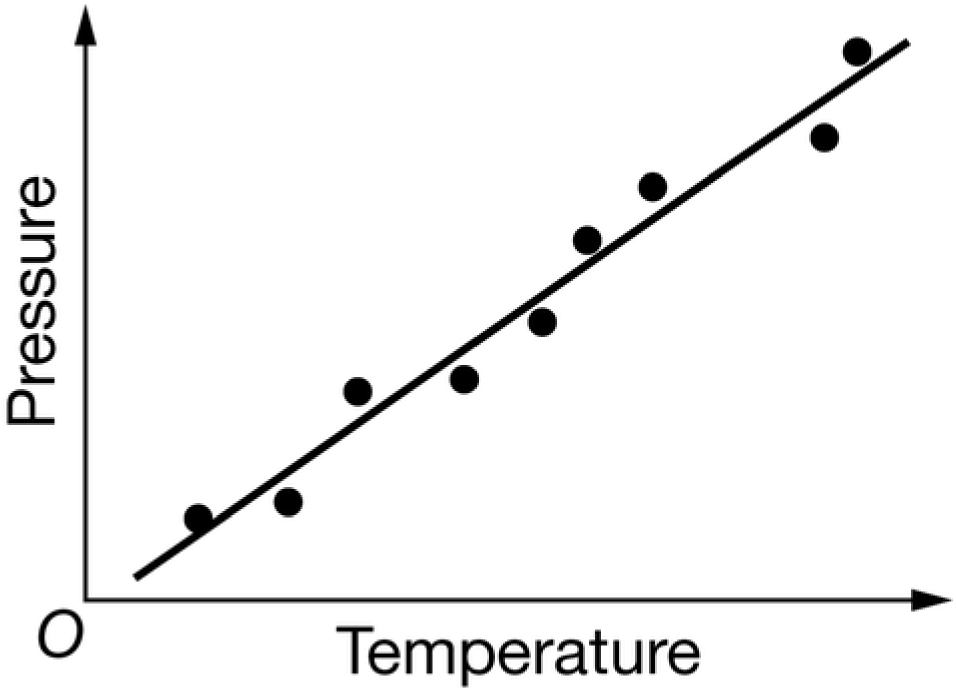
(B) The volume of the gas decreases, so the pressure inside the flask increases. The gas molecules slow down due to the increased pressure, which means their kinetic energy increases. Collisions of molecules with the walls involve less force. As a result, temperature decreases.

(C) The volume of the gas decreases. The pressure inside the flask increases and so does the temperature. As a result the molecules hit the walls with a greater force and thus exert a larger pressure. The gas reaches instant equilibrium with the surroundings.

(D) The volume of the gas decreases. The pressure inside the flask increases; however, there is no change in the temperature of the gas.

Thermodynamics Practice

31.



The students fix the plunger in place and take measurements of temperature and pressure. They graph the data and draw a best-fit line, as shown. Which of the following is equal to the slope of the line?

(A) nRV

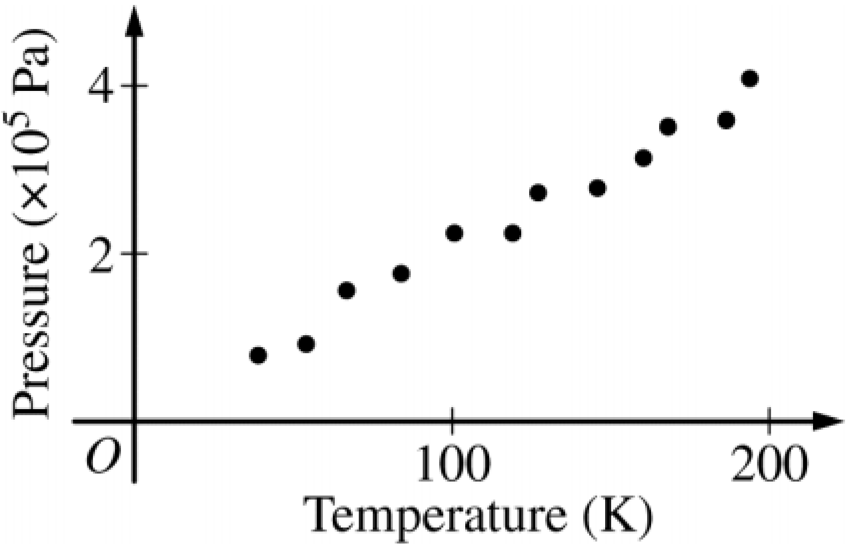
(B) $\frac{V}{nR}$

(C) $\frac{nR}{V}$ ✔

(D) $\frac{1}{nRV}$

Thermodynamics Practice

32.

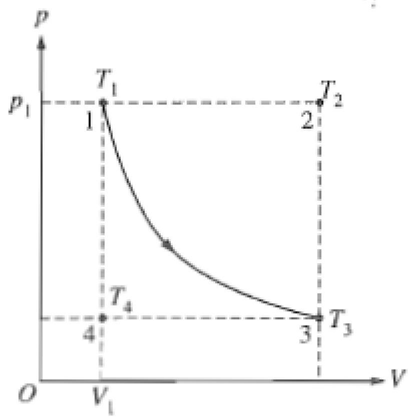


A sample of gas is in a sealed container whose volume is held fixed. The pressure of the gas is measured as its absolute temperature is increased. A graph of pressure measurements as a function of temperature is shown above. According to the ideal gas law, which of the following is expected if the sealed container's volume is increased to three times the original value and the experiment is repeated?

- (A) The graph will show a linear relationship that still extrapolates to the origin, but with a smaller slope. ✓
- (B) The graph will show a linear relationship that still extrapolates to the origin, but with a larger slope.
- (C) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the horizontal axis to the right of the origin.
- (D) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the vertical axis above the origin.

Thermodynamics Practice

33.



An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1 volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true?

(A) $T_1 < T_3$

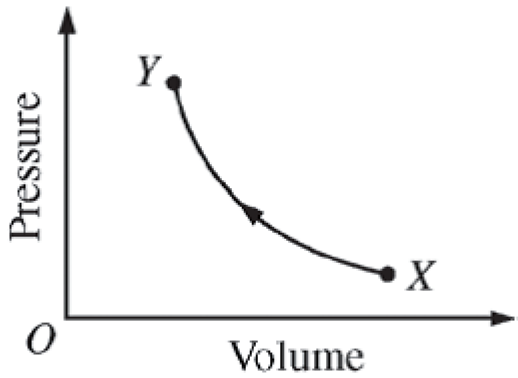
(B) $T_1 < T_2$ ✔

(C) $T_1 < T_4$

(D) $T_1 = T_2$

(E) $T_1 = T_4$

34.



The graph above shows the pressure as a function of volume for a sample of gas that is taken from state X to state Y at constant temperature. Which of the following indicates the sign of the work done on the gas, and whether thermal energy is absorbed or released by the gas during this process?

(A)

Work done	Thermal energy
Positive	Absorbed

(B) ✓

Work done	Thermal energy
Positive	Released

(C)

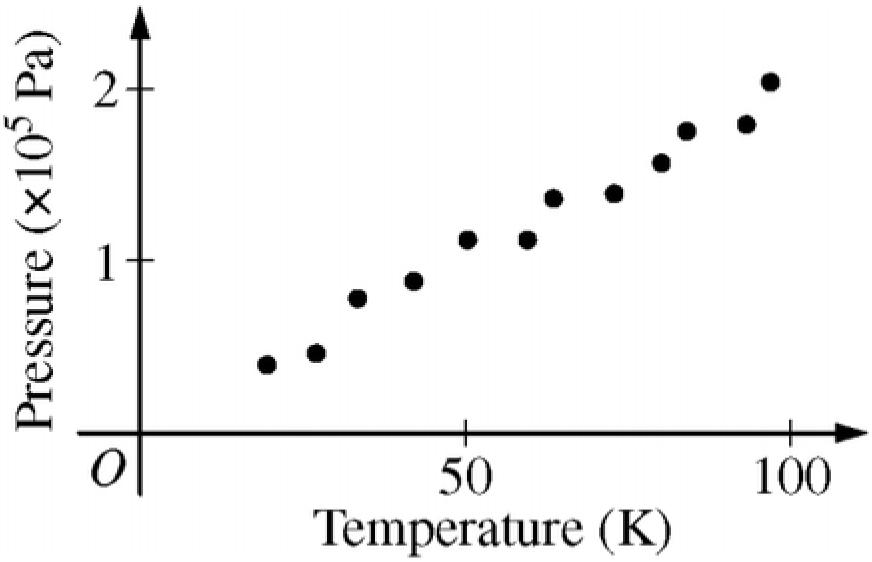
Work done	Thermal energy
Negative	Absorbed

(D)

Work done	Thermal energy
Negative	Released

Thermodynamics Practice

35.



A sample of gas is in a container of fixed volume. The pressure of the gas is measured as its absolute temperature is increased. A graph of pressure measurements as a function of temperature is shown above. According to the ideal gas law, which of the following will be true if the container volume is reduced to half the original value and the experiment is repeated?

(A) The graph will still show a linear relationship that extrapolates to the origin, but with a smaller slope.

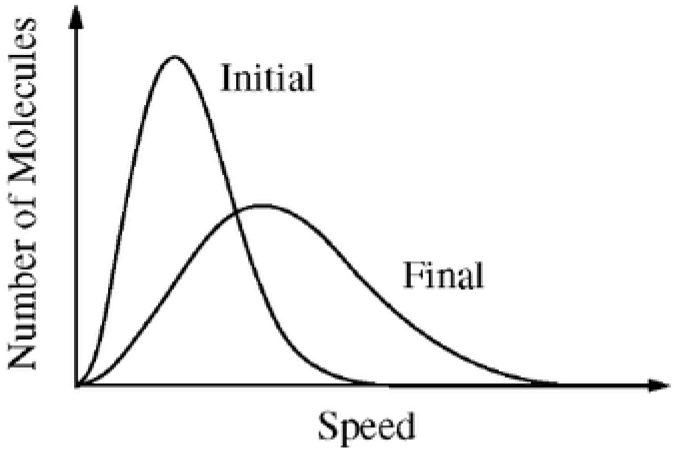
(B) The graph will still show a linear relationship that extrapolates to the origin, but with a larger slope. ✓

(C) The graph will still show a linear relationship, but it will not extrapolate to the origin.

(D) The graph will not show a linear relationship, but it will still extrapolate to the origin.

Thermodynamics Practice

36.



The graph above shows the initial and final molecular speed distributions of a gas as a result of a thermodynamic process. Which of the following processes could produce this change?

(A) Expansion of the gas at constant temperature

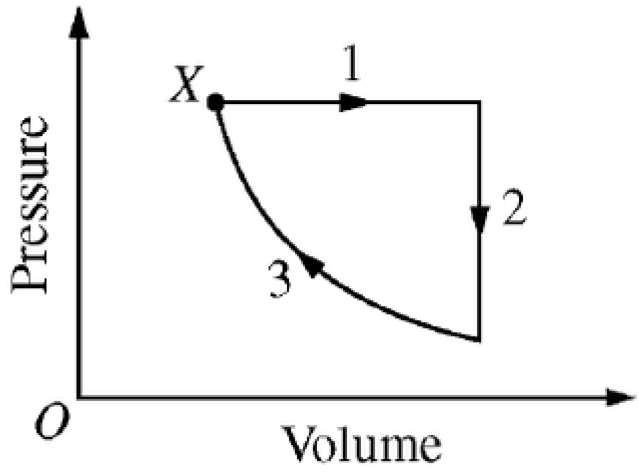
(B) Compression of the gas with no transfer of energy by heating ✔

(C) Cooling of the gas at constant volume

(D) Cooling of the gas at constant pressure

Thermodynamics Practice

37.



The graph above shows pressure as a function of volume for a sample of an ideal gas. The gas has an internal energy of 1000 J at state X and is taken through the cycle shown. Process 3 is isothermal. The work that the gas does on the environment is 400 J during process 1 and 250 J during one complete cycle. What is the net thermal energy transferred into the gas during one complete cycle?

(A) 0 J

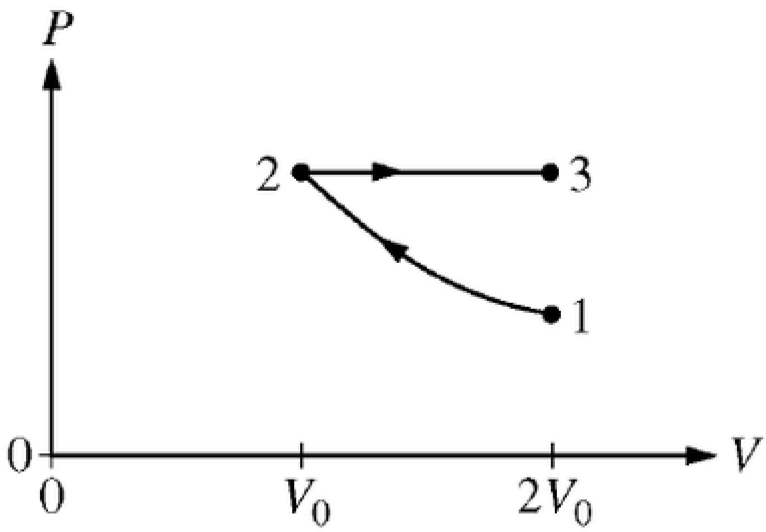
(B) 250 J ✔

(C) 400 J

(D) 650 J

Thermodynamics Practice

38.



An ideal gas is initially in state 1 at a temperature of 200 K. The gas is taken through the two reversible thermodynamic processes shown in the PV diagram above. The process from state 1 to state 2 is isothermal. The process from state 2 to state 3 is isobaric. What is the temperature of the gas when it is in state 3?

(A) 800 K

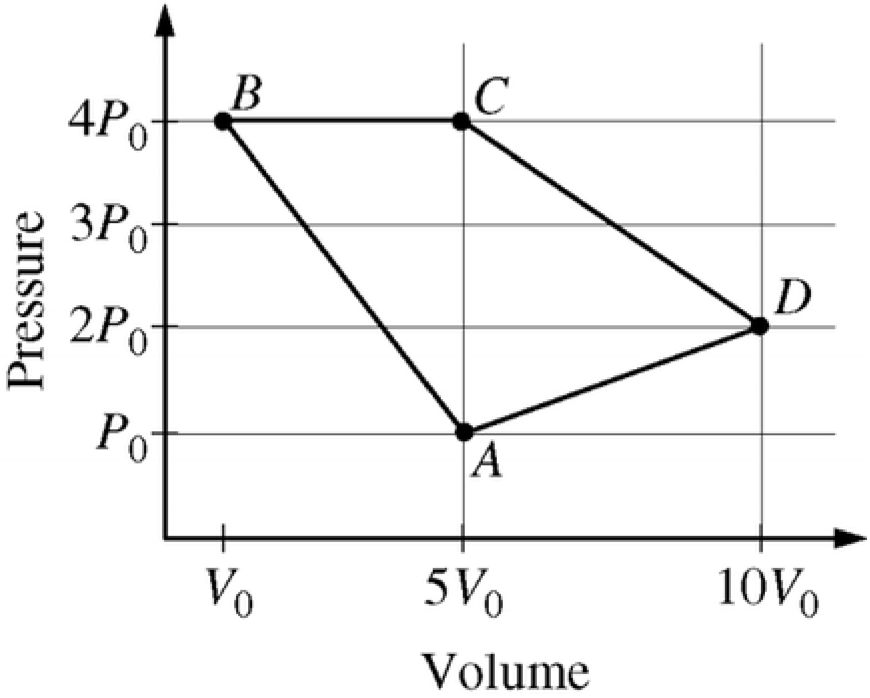
(B) 400 K ✔

(C) 200 K

(D) 100 K

Thermodynamics Practice

39.



In a laboratory experiment, students recorded the pressure and volume of a sample of ideal gas as its temperature was varied. Their results are represented in the figure above. Which of the following ranks the internal energy U of the gas at the labeled points from greatest to least?

(A) $(U_B = U_C) > U_D > U_A$

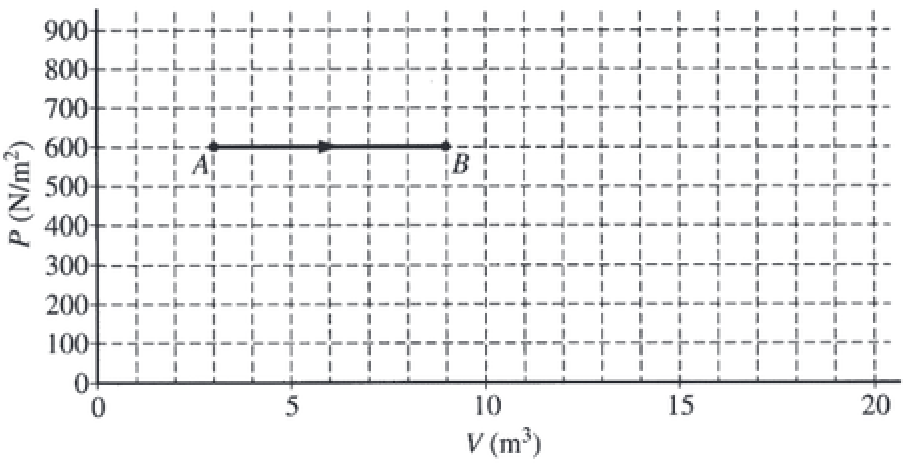
(B) $(U_C = U_D) > U_B > U_A$

(C) $(U_C = U_D) > U_A > U_B$ ✔

(D) $U_D > (U_C = U_A) > U_B$

40.

Thermodynamics Practice



The diagram above of pressure *P* versus volume *V* shows the expansion of 2.0 moles of a monatomic ideal gas from state *A* to state *B*. As shown in the diagram, $P_A = P_B = 600\ \text{N/m}^2$, $V_A = 3.0\ \text{m}^3$, and $V_B = 9.0\ \text{m}^3$.

(a)

i. Calculate the work done *by the gas* as it expands.

ii. Calculate the change in the internal energy of the gas as it expands.

iii. Calculate the head added to or removed from the gas during this expansion.

(b) The pressure is then reduced to 200 N/m^2 without changing the volume as the gas is taken from state *B* to state *C*. Label state on the diagram and draw a line or curve to represent the process from state *B* to state *C*.

(c) The gas is then compressed isothermally back to state *A*.

i. Draw a line or curve on the diagram to represent this process.

ii. Is head added to or removed from the gas during this isothermal compression?

____added to ____removed from

Justify your answer.

Thermodynamics Practice

Please respond on separate paper, following directions from your teacher.

Part A

One point is earned for a correct calculation of the work done on the gas

$W_{on} = -P\Delta V$

$W_{on} = -(600\text{N/m}^2)(9.0\text{m}^3 - 3.0\text{m}^3)$

$W_{on} = -3600\text{J}$

$W_{on} = 3600\text{J}$

One point is earned for recognition that the work done *by* the gas is the negative of the work done *on* the gas

$W_{by} = 3600\text{J}$

One point is earned for a correct expression or derivation of the expression for ΔU

$$\Delta U = \frac{3}{2}nR\Delta T$$

One point is earned for a correct calculation of *T*'s or Δ*T* using the ideal gas law, *PV* = *nRT*

$$\Delta U = \frac{3}{2}(2\,moles)(8.31\frac{\text{J}}{\text{mo1K}})(325\text{K} - 108\text{K})$$

or

$$P\Delta V = nR\Delta T, \Delta U = \frac{3}{2}P\Delta V = \frac{3}{2}(600\text{N/m}^2)(9\text{m}^3 - 3\text{m}^3)$$

One point is earned for correct answer Δ*U*=5400J

One point is earned for correct substitution of answers from parts (i) and (ii) into the first law of thermodynamics

$\Delta U = Q + W_{on}$

$Q = \Delta U - W_{on}$

Q=5400 J-(-3600 J)

Q=9000 J

Thermodynamics Practice

0	1	2	3	4	5	6 ✓

The student earns all of the following points:

One point is earned for a correct calculation of the work done on the gas

$W_{on} = -P\Delta V$

$W_{on} = -(600 N/m^2)(9.0 m^3 - 3.0 m^3)$

$W_{on} = -3600 J$

$W_{on} = 3600 J$

One point is earned for recognition that the work done *by* the gas is the negative of the work done *on* the gas

$W_{by} = 3600 J$

One point is earned for a correct expression or derivation of the expression for ΔU

$$\Delta U = \frac{3}{2} nR\Delta T$$

One point is earned for a correct calculation of *T*'s or Δ*T* using the ideal gas law, *PV* = *nRT*

$$\Delta U = \frac{3}{2}(2\, moles)(8.31 \frac{\mathrm{J}}{\mathrm{mo1K}})(325\mathrm{K} - 108\mathrm{K})$$

or

$$P\Delta V = nR\Delta T, \Delta U = \frac{3}{2} P\Delta V = \frac{3}{2}(600\mathrm{N/m^2})(9\mathrm{m^3} - 3\mathrm{m^3})$$

One point is earned for correct answer Δ*U*=5400J

One point is earned for correct substitution of answers from parts (i) and (ii) into the first law of thermodynamics

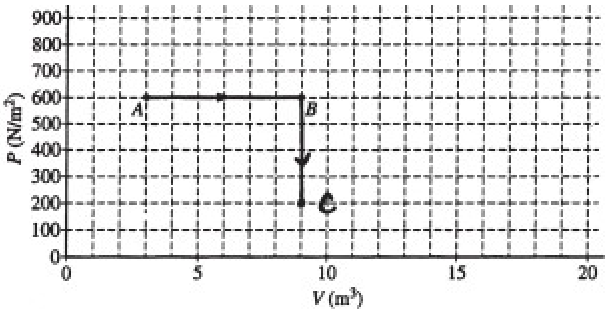
$\Delta U = Q + W_{on}$

$Q = \Delta U - W_{on}$

$Q = 5400 J - (-3600 J)$

$Q = 9000 J$

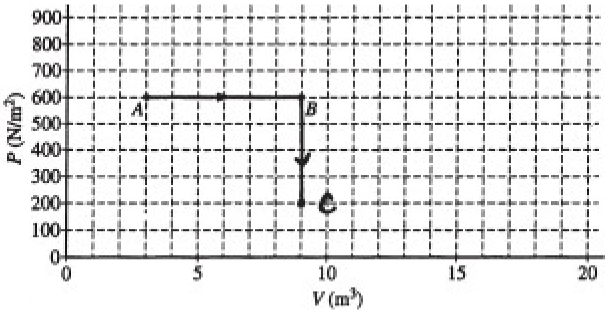
Part B



One point is earned for point *C* plotted and labeled correctly as above, and for a correct straight line from point *B* to point *C*

0	1

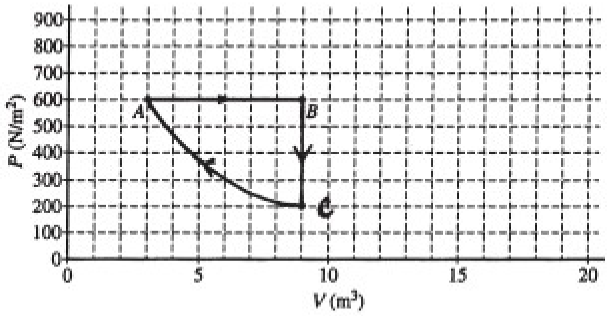
The student earns all of the following points:



One point is earned for point *C* plotted and labeled correctly as above, and for a correct straight line from point *B* to point *C*

Part C

Thermodynamics Practice



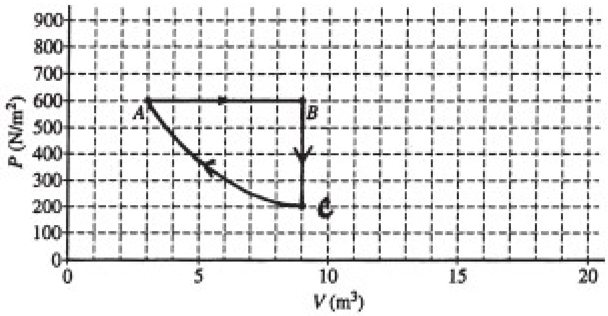
One point is earned for a correct curve from point *C* to point *A* (curve must be concave upward)

One point is earned for correctly indicating that heat is removed from the gas

One point is earned for correct justification such as explaining in words or symbols that the change in internal energy is zero, so from first law of thermodynamics $Q = -W$. Since the work done on the gas is greater than zero, Q is negative, Therefore heat is removed from the gas.

0	1	2	3

The student earns three of the following points:

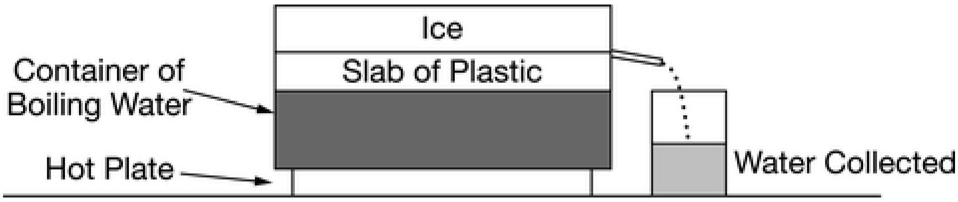


One point is earned for a correct curve from point *C* to point *A* (curve must be concave upward)

One point is earned for correctly indicating that heat is removed from the gas

One point is earned for correct justification such as explaining in words or symbols that the change in internal energy is zero, so from first law of thermodynamics $Q = -W$. Since the work done on the gas is greater than zero, Q is negative, Therefore heat is removed from the gas.

41. This question is a long free-response question. Show your work for each part of the question.



(12 points, suggested time 25 minutes)

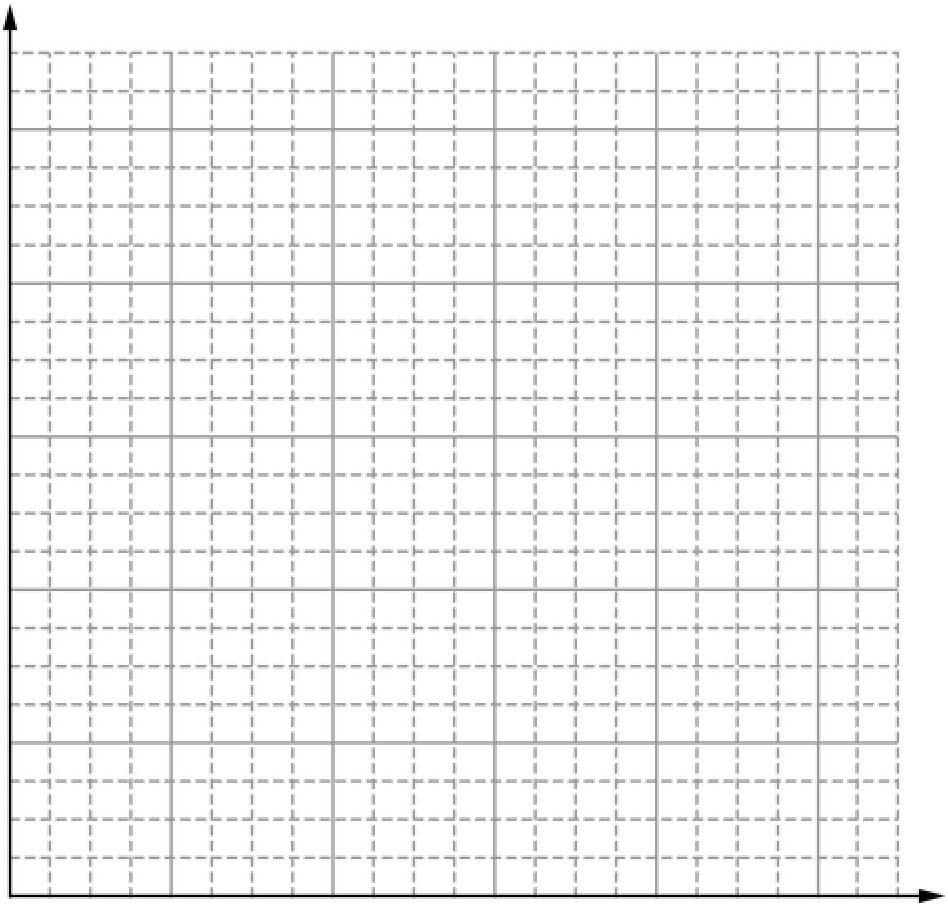
A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of $100^\circ\mathrm{C}$. They place a slab of the plastic with area $0.025\ \mathrm{m}^2$ and thickness $0.010\ \mathrm{m}$ above the container so that the bottom surface of the slab is at a temperature of $100^\circ\mathrm{C}$. They put a large block of ice with temperature $0^\circ\mathrm{C}$ 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 $Q/\Delta t$ $(\mathrm{J/s})$	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.

Thermodynamics Practice



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.

Please respond on separate paper, following directions from your teacher.

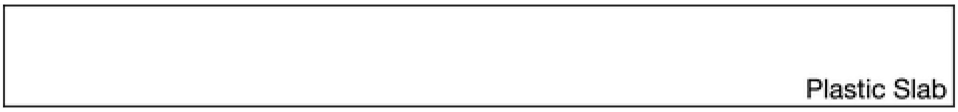
iii. Use the graph to calculate the thermal conductivity of the plastic.

Please respond on separate paper, following directions from your teacher.

(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.

Please respond on separate paper, following directions from your teacher.

(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.



Please respond on separate paper, following directions from your teacher.

(d) Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).

Please respond on separate paper, following directions from your teacher.

(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.

Please respond on separate paper, following directions from your teacher.

Part A(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✔

Thermodynamics Practice

Student response does accurately

- ☐ label the axes with two quantities that would produce a linear graph, including units.

Example Response:

$Q/\Delta t$ and $1/\text{thickness}$

Part A(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3

The response accurately includes all **three** of the following criteria:

- ☐ Scaling the axes linearly so the data extends over at least half of each axis
- ☐ Accurately plotting the data
- ☐ A best-fit curve or line that fits the trend in the data

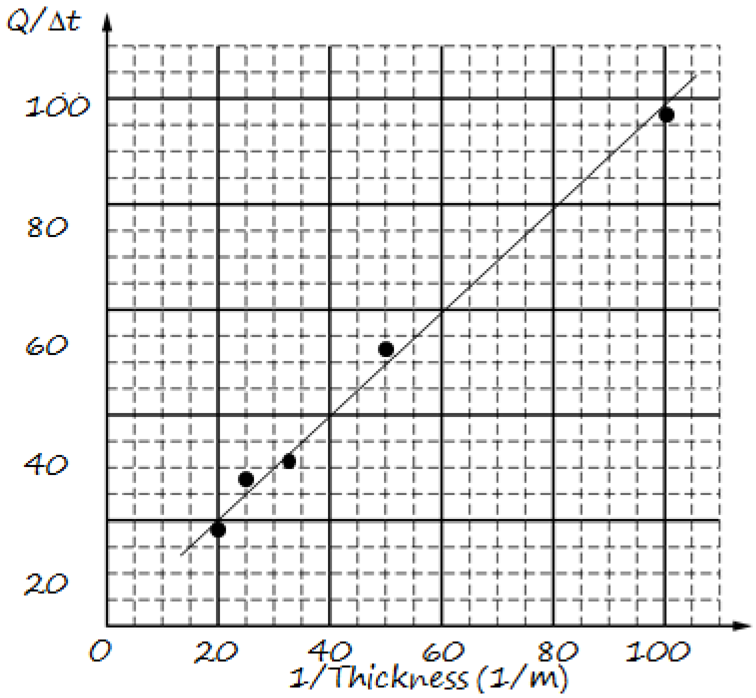
Example Response:

Sample entries corresponding to example response for part (a)(i)

Energy Flow Rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total Thickness of Plastic (m)	0.01	0.02	0.03	0.04	0.05
1/thickness (1/m)	100	50	33.3	25	20

Sample graph using above data

Thermodynamics Practice



Part A(iii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2

The response accurately includes both of the following criteria:

- ☐ A correct method for calculating the slope using points on the best-fit line
- ☐ Determining the thermal conductivity k, with or without units using the slope found above

Example Response:

For the graph above, $\text{slope} = \frac{(80-20)(\text{J/s})}{(80-20)(1/\text{m})} = 1.0\ \text{J} \cdot \text{m/s}$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$ so $\text{slope} = kA\,\Delta T$

Using slope above:

$k = \text{slope}/A\,\Delta T = 1\,(\text{J}\cdot\text{m/s})\,/\,(0.025\ \text{m}^2)\,(100^\circ\ \text{C}) = 0.40\ \text{J/s}\cdot\text{m}^\circ\text{C}$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✔

The response accurately includes both of the following criteria:

- ☐ Any valid indication of an additional thermal interaction with the environment
- ☐ A reasonable explanation of how additional energy added or lost could change the experimental value of conductivity

Example Response 1:

The given setup allows energy to be transferred to the ice from the air around it. This means the values of $Q/\Delta t$ contain energy that did not go through the plastic slab, resulting in a value of k that is too large.

Example Response 2:

The given setup allows energy to be lost out the sides of the plastic slab. This means the values of $Q/\Delta t$ do not contain all the energy that went through the plastic slab, resulting in a value of k that is too small.

Claim: The problem leads to a value of k that is too small/large.

Evidence: The problem allows energy transfer into/out of the system that is not accounted for.

Reasoning: The values of $Q/\Delta t$ contain less/more energy than went through the plastic slab, resulting in a value of k that is too small/large.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

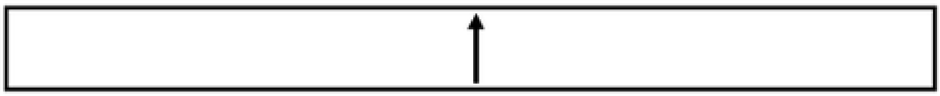
Thermodynamics Practice

0	1 ✓

Student response does accurately include:

- ☐ A drawing of an arrow toward the top of the page

Example Response:



Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

The response accurately includes both of the following criteria:

- ☐ Indicating that particles at the bottom (or a location consistent with part (c)) have a higher temperature or kinetic energy, so they vibrate faster
- ☐ indicating that particles collide with neighboring particles, transferring energy from faster to slower particles in the process

Example Response:

Energy absorbed at the lower surface makes particles jiggle faster, they jiggle particles above them, and so forth until energy reaches the other side.

Part E

Thermodynamics Practice

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1

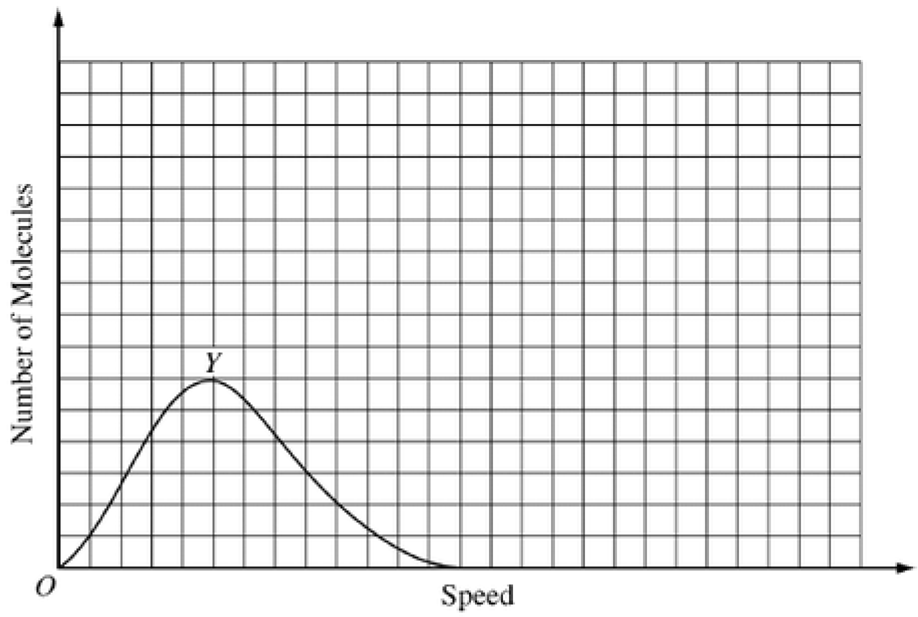
Student response accurately includes:

- ☐ An indication that the slab and wood have different thermal conductivities or that energy is transferred into the plastic and wood at different rates, with no incorrect statements

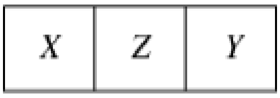
---

42. Three samples of a gas, *X, Y, and Z,* are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample *X* is T_X, the temperature of sample *Y* is lower than that of sample *X,* and the temperature of sample *Z* is lower than that of sample *Y* ($T_X > T_Y > T_Z$).

(a) The graph below shows the distribution of the speeds of the molecules in sample *Y*. On the graph, sketch and label possible distributions for sample *X* and sample *Z*.



The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample Z in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.



(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample X

Sample Y

Sample Z

(c) Indicate whether the net entropy of sample X increases, decreases, or remains the same as a result of the process of reaching equilibrium.

____ Increases ____ Decreases ____ Remains the same

Justify your answer at the microscopic level.

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

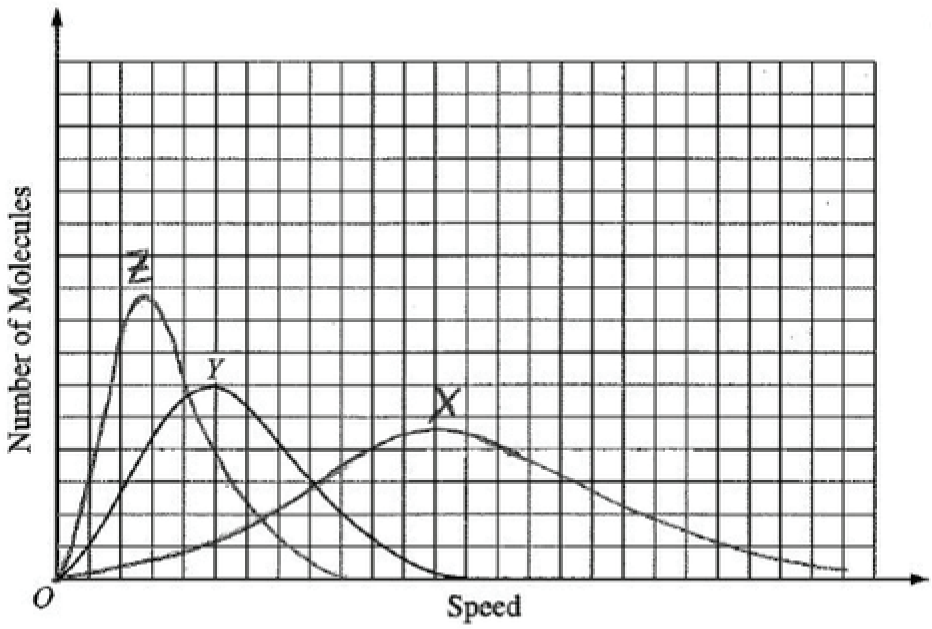
____ Increases ____ Decreases ____ Remains the same

Justify your answer.

Please respond on separate paper, following directions from your teacher.

Thermodynamics Practice

Part A



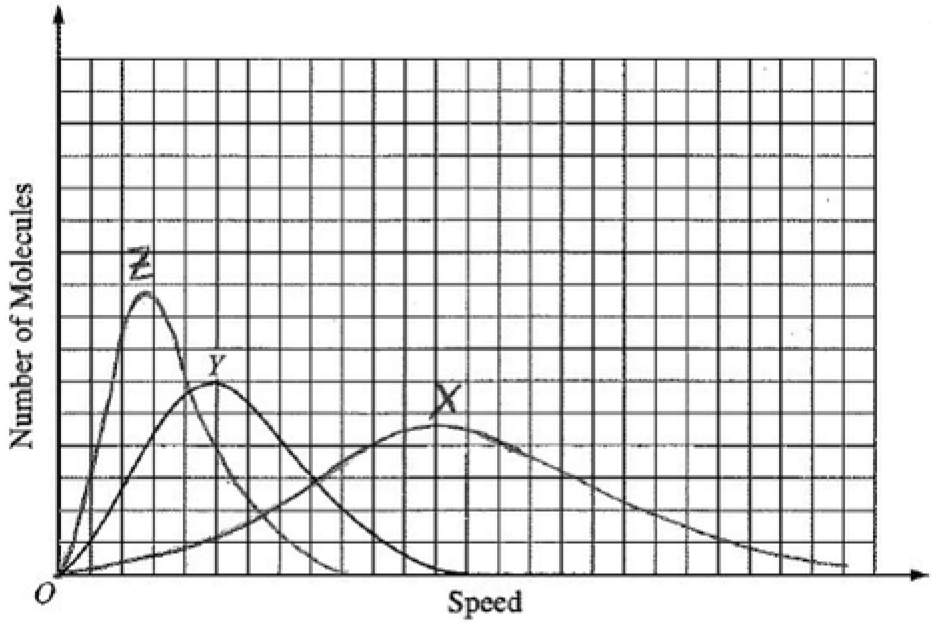
1 point is earned: For the peak of the curve for *Z* at a smaller speed than *Y,* and *X* at a greater speed than *Y*

1 point is earned: For the curve for Z having a higher peak and less spread than Y, and X with a lower peak and greater spread

One earned point was deducted for correct curves that are not labeled

0	1	2 ✔

The student response earns two of the following points:



1 point is earned: For the peak of the curve for *Z* at a smaller speed than *Y,* and *X* at a greater speed than *Y*

1 point is earned: For the curve for Z having a higher peak and less spread than Y, and X with a lower peak and greater spread

One earned point was deducted for correct curves that are not labeled

Part B

The kinetic energy of X decreases. It has the highest temperature and so to reach the same equilibrium temperature as the other samples it must lose energy, which flows into Z.

The kinetic energy of Y decreases and then increases. It has a higher temperature than Z, and so initially loses energy which flows into Z. But it eventually must end up at a higher temperature than it initially had, so the net energy flow must be into Y. That can only happen if the direction of energy flow reverses.

The kinetic energy of Z could always increase, or it can increase and then decrease. Initially energy flows into it, since it has the lowest temperature. At some point energy begins to flow from Z to Y. Whether the temperature and thus the kinetic energy of Z continually increases or not depends on how much energy keeps flowing to it from X.

1 point is earned: For exhibiting understanding that energy flows from systems at higher temperature to systems at lower temperature

1 point is earned: For exhibiting understanding that higher temperature corresponds to higher kinetic energy

1 point is earned: For exhibiting understanding that the energy flow stops

1 point is earned: For exhibiting understanding that the energy flow for a sample can change direction

1 point is earned: For using the above understanding to indicate that the average kinetic energy of all three samples are the same when equilibrium is reached

0	1	2	3	4	5

The student response earns five of the following points:

The kinetic energy of X decreases. It has the highest temperature and so to reach the same equilibrium temperature as the other samples it must lose energy, which flows into Z.

The kinetic energy of Y decreases and then increases. It has a higher temperature than Z, and so initially loses energy which flows into Z. But it eventually must end up at a higher temperature than it initially had, so the net energy flow must be into Y. That can only happen if the direction of energy flow reverses.

The kinetic energy of Z could always increase, or it can increase and then decrease. Initially energy flows into it, since it has the lowest temperature. At some point energy begins to flow from Z to Y. Whether the temperature and thus the kinetic energy of Z continually increases or not depends on how much energy keeps flowing to it from X.

1 point is earned: For exhibiting understanding that energy flows from systems at higher temperature to systems at lower temperature

1 point is earned: For exhibiting understanding that higher temperature corresponds to higher kinetic energy

1 point is earned: For exhibiting understanding that the energy flow stops

1 point is earned: For exhibiting understanding that the energy flow for a sample can change direction

1 point is earned: For using the above understanding to indicate that the average kinetic energy of all three samples are the same when equilibrium is reached

Part C

1 point is earned: For checking either the correct response or one consistent with the answer to part (b), with a reasonable attempt at justification

1 point is earned: For a correct or consistent justification that relates the spread of the molecular distribution to entropy

For example: The entropy decreases. When the temperature goes down, the spread of the speeds and thus the kinetic energies of the individual molecules is less. This means less disorder and thus less entropy.

0	1	2 ✓

The student response earns two of the following points:

1 point is earned: For checking either the correct response or one consistent with the answer to part (b), with a reasonable attempt at justification

1 point is earned: For a correct or consistent justification that relates the spread of the molecular distribution to entropy

For example: The entropy decreases. When the temperature goes down, the spread of the speeds and thus the kinetic energies of the individual molecules is less. This means less disorder and thus less entropy.

Part D

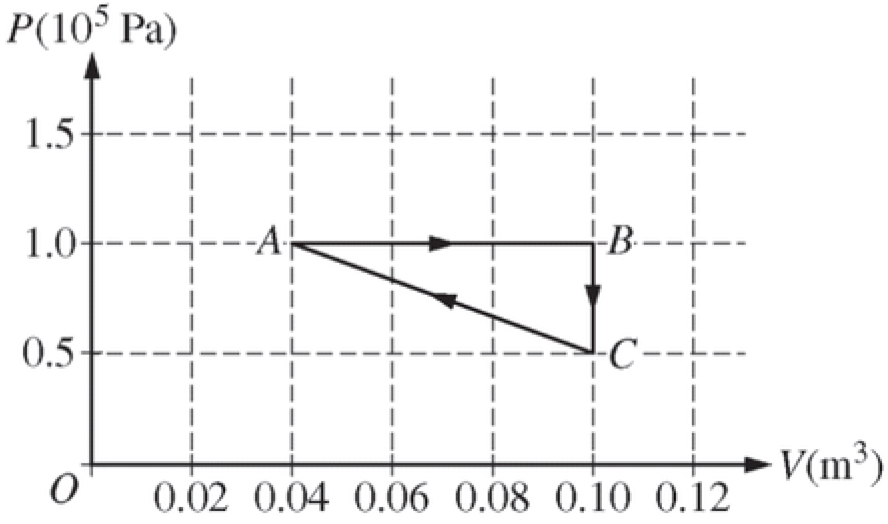
1 point is earned: For correctly indicating that the entropy of the system increases, and explaining that the entropy of a closed system increases for an irreversible process.

0	1 ✓

The student response earns one of the following points:

1 point is earned: For correctly indicating that the entropy of the system increases, and explaining that the entropy of a closed system increases for an irreversible process.

43.



Two moles of a monatomic ideal gas are enclosed in a cylinder by a movable piston. The gas is taken through the thermodynamic cycle shown in the figure above. The piston has a cross sectional area of
$5 \times 10^{-3}\ m^2$

i. Calculate the force that the gas exerts on the piston in state *A*, and explain how the collisions of the gas atoms with the piston allow the gas to exert a force on the piston.

ii. Calculate the temperature of the gas in state *B*, and indicate the microscopic property of the gas that is characterized by the temperature.

i. Predict qualitatively how the internal energy of the gas changes as it is taken from state *A* to state *B*. Justify your prediction.

ii. Calculate the energy added to the gas by heating as it is taken from state *A* to state *C* along the path *ABC*.

Thermodynamics Practice

c. Determine the change in the total kinetic energy of the gas atoms as the gas is taken directly from state *C* to state *A*.

Please respond on separate paper, following directions from your teacher.

Part A

Part (i)

1 point(s) earned: For showing the calculation of the force on the piston and a correct answer with units

F = PA = (1.0 × 105 Pa)(5 × 10-3m2) = 500 N

1 point(s) earned: 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

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

Part(ii)

1 point(s) earned: For showing the calculation of the temperature and a correct answer with units

PV = nRT

T = PV/nR = (1.0 × 105 Pa) (0.10 m3) / (2)(8.31 J/mol · K) = 602 K

1 point(s) earned: For indicating that temperature characterizes the average speed or average kinetic energy or RMS velocity of the molecules

0	1	2	3	4

Thermodynamics Practice

The student response earns 4 of 4 point(s)

Part (i)

1 point(s) earned: For showing the calculation of the force on the piston and a correct answer with units

F = PA = (1.0 × 105 Pa)(5 × 10-3m2) = 500 N

1 point(s) earned: 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

> 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

Part(ii)

1 point(s) earned: For showing the calculation of the temperature and a correct answer with units

PV = nRT

T = PV/nR = (1.0 × 105 Pa) (0.10 m3) / (2)(8.31 J/mol · K) = 602 K

1 point(s) earned: For indicating that temperature characterizes the average speed or average kinetic energy or RMS velocity of the molecules

Part B

Part (i)

1 point(s) earned: For identifying that the temperature increases due to increasing volume and constant pressure

1 point(s) earned: For relating temperature change with internal energy change

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.

Part(ii)

1 point(s) earned: For calculating the work done in process ABC (i.e., the area under the line)

$W_{AB} = -(1.0 \times 10^5\ Pa)(0.10\ m^3 - 0.04\ m^3) = -6000\ J$ and $W_{BC} = 0$

1 point(s) earned: For calculating T_A and T_C (or ΔT between the states) and using them to determine internal energy change

$T_A = P_A V_A / nR = (1.0\times 10^5\ Pa)(0.04\ m^3)/(2 mol)(8.31\ J/mol\cdot K) = 241 K$ $T_C = P_C V_C / nR = (0.5\times 10^5\ Pa)(0.10\ m^3)/(2 mol)(8.31\ J/mol\cdot K) = 301 K$ $\Delta U = \Delta K_{per molecule}\, n N_0 = (3/2) k_B \Delta T n N_0$ $\Delta U = (3/2)(1.38\times 10^{-23}\ J/K)(301\ K - 241\ K)(2 mol)(6.02\times 10^{23}) = 1500 J$

Alternately, ΔU can be calculated directly from the given data

$\Delta U = (3/2) nR\Delta T = (3/2)(P_C V_C - P_A V_A) = (3/2)((0.5\times 10^5\ Pa)(0.10\ m^3) - (1.0\times 10^5\ Pa)(0.04\ m^3)) = 1500 J$

1 point(s) earned: 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

$Q = \Delta U - W = 1500\ J - (-6000\ J)$

$Q = 7500\ J$

Thermodynamics Practice

0	1	2	3	4	5

The student response earns 5 of 5 point(s)

Part (i)

1 point(s) earned: For identifying that the temperature increases due to increasing volume and constant pressure

1 point(s) earned: For relating temperature change with internal energy change

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.

Part(ii)

1 point(s) earned: For calculating the work done in process ABC (i.e., the area under the line)

WAB = -(1.0 × 105 Pa)(0.10 m3 - 0.04 m3) = -6000 J and WBC = 0

1 point(s) earned: For calculating TA and TC (or ΔT between the states) and using them to determine internal energy change

T A = P A V A /nR=(1.0× 10 5 Pa)(0.04 m 3)/(2mol)(8.31 J/mo1·K)=241K T C = P C V C /nR=(0.5× 10 5 Pa)(0.10 m 3)/(2mol)(8.31 J/mo1·K)=301K ΔU=Δ K permolecule n N 0 =(3/2) k B ΔTn N 0 ΔU=(3/2)(1.38× 10 −23 J/K)(301 K−241 K)(2mol)(6.02× 10 23)=1500J

Alternately, ΔU can be calculated directly from the given data

ΔU=(3/2)nRΔT=(3/2)(P C V C − P A V A) =(3/2)((0.5× 10 5 Pa)(0.10 m 3)−(1.0× 10 5

Pa)(0.04 m 3))=1500J

1 point(s) earned: 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

$Q = \Delta U - W = 1500\ J - (-6000\ J)$

$Q = 7500\ J$

Part C

1 point(s) earned: 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 ΔKtotal = (3/2)nRΔT as shown below

Δ K total =(3/2) k B ΔTn N 0 or Δ K total =(3/2)nRΔT Δ K total =(3/2)(1.38× 10 −23 J/K)(241 K−301 K)(2mol)(6.02× 10 23 mo 1 −1) Δ K total =−1500J

0	1 ✔

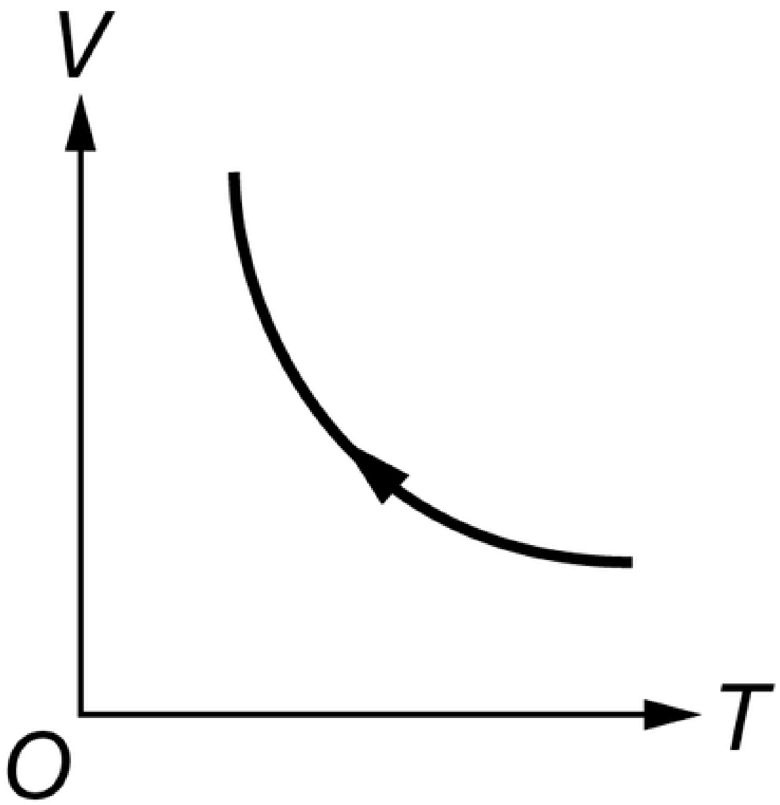
The student response earns 1 of 1 point(s)

1 point(s) earned: 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 ΔKtotal = (3/2)nRΔT as shown below

Δ K total =(3/2) k B ΔTn N 0 or Δ K total =(3/2)nRΔT Δ K total =(3/2)(1.38× 10 −23 J/K)(241 K−301 K)(2mol)(6.02× 10 23 mo 1 −1) Δ K total =−1500J

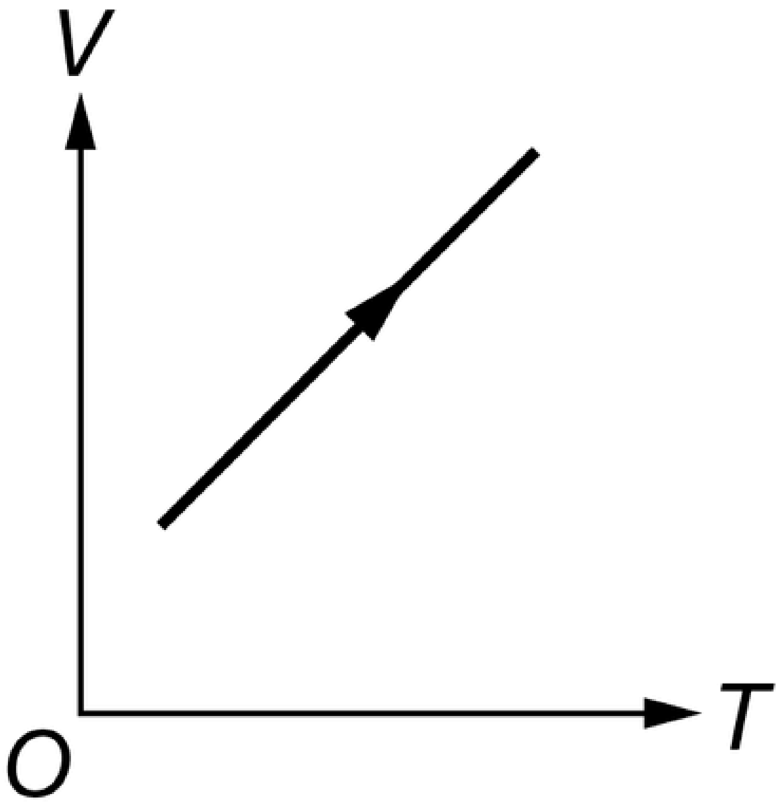
44. One mole of an ideal gas undergoes an isobaric expansion. Which of the following graphs of volume as a function of temperature in kelvin could represent this process?

(A)



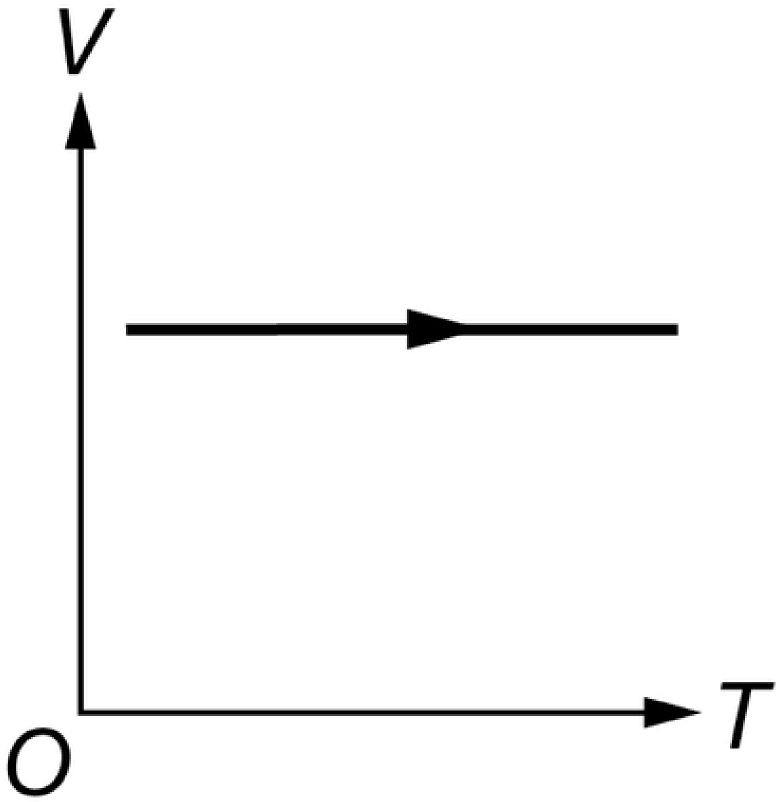
Thermodynamics Practice

(B)

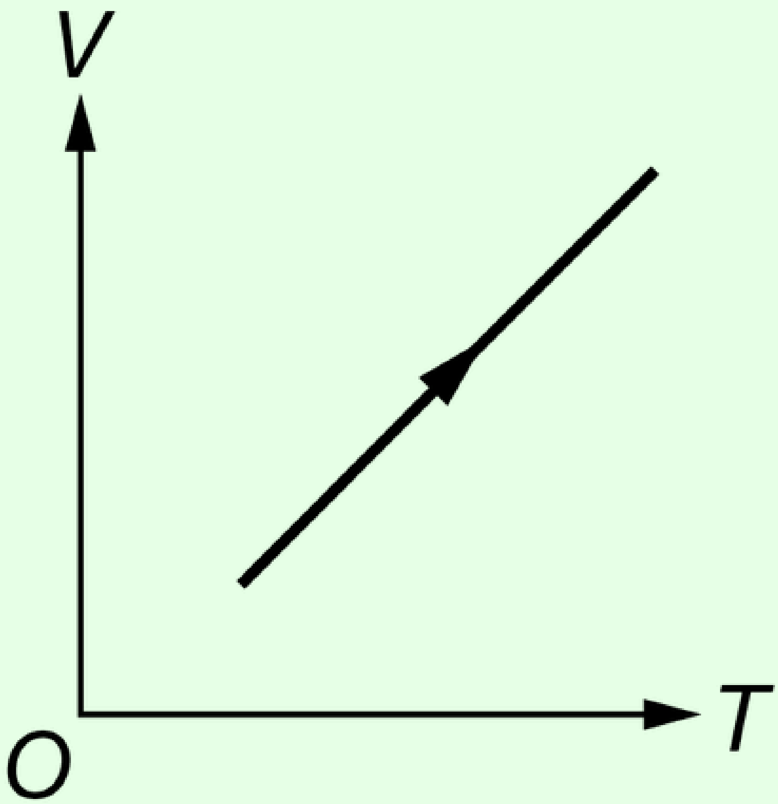


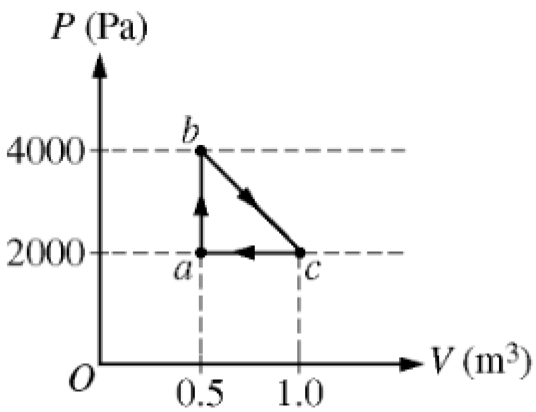
Thermodynamics Practice

C



(D)





A sample of an ideal gas is taken through the cycle *abca*, as shown in the *PV* diagram above.

45. What is the change in internal energy of the gas for the process *bc* ?

(A) -1500 J

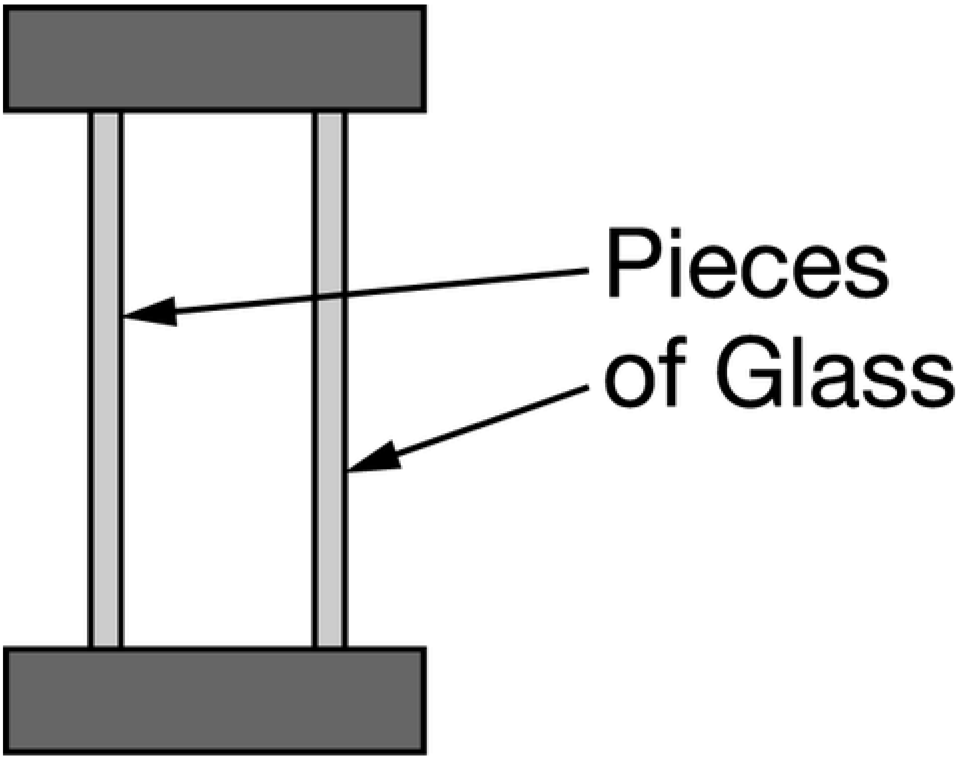
(B) -500 J

(C) 0 J ✓

(D) +500 J

(E) +1500 J

46.



A student wants to conduct an experiment to determine the rate at which windows transfer energy to the outside air in the winter. The student investigates windows that are made from two parallel pieces of glass with a space in between, as shown in the figure. The student decides to investigate how the spacing between the pieces of glass affects the transfer of energy. Which additional criteria should the student use when selecting windows for the experiment? Select two answers.

Thermodynamics Practice

(A) Select windows with different areas.

(B) Select windows with the space between the pieces of glass filled with different gases.

(C) Select windows with pieces of glass made from the same type of glass. ✔

(D) Select windows with pieces of glass made from the same thickness of glass. ✔