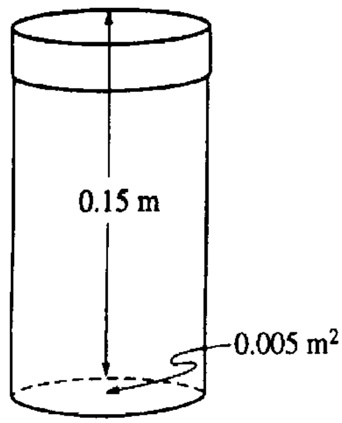
IDEAL GAS LAW

1996 Q7

The inside of the cylindrical can shown above has cross-sectional area 0.005 m^2 and length 0.15 m. The can is filled with an ideal gas



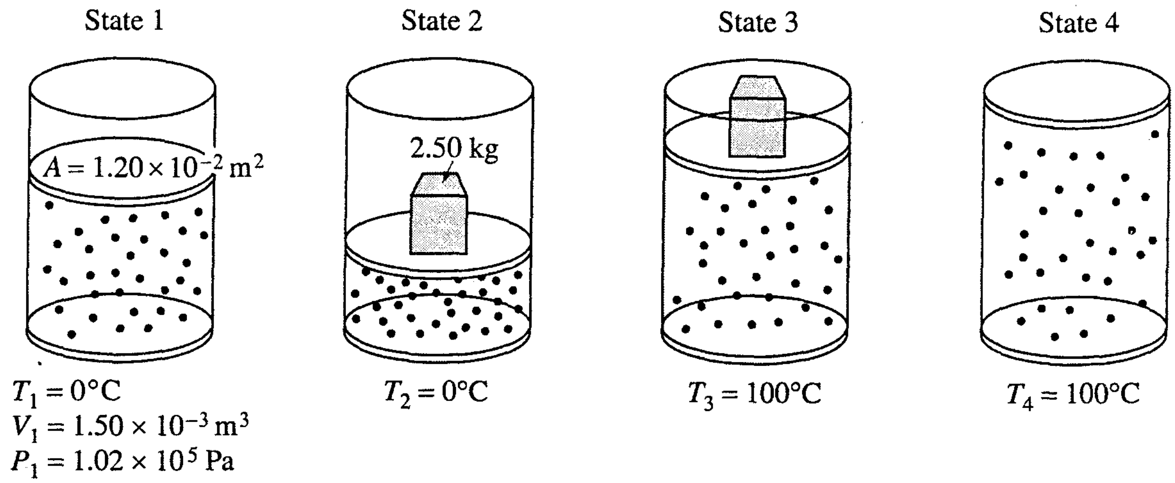
and covered with a loose cap. The gas is heated to 363 K and some is allowed to escape from the can so that the remaining gas reaches atmospheric pressure (1.0×10^5 Pa). The cap is now tightened, and the gas is cooled to 298 K.

(a) What is the pressure of the cooled gas?

(b) Determine the upward force exerted on the cap by the cooled gas inside the can.

(c) If the cap develops a leak, how many moles of air would enter the can as it reaches a final equilibrium at 298 K and atmospheric pressure? (Assume that air is an ideal gas.)

2001B6



Note: Figures not drawn to scale.

A cylinder is fitted with a freely moveable piston of area 1.20×10^{-2} m^2 and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume 1.50×10^{-3} m^3, pressure 1.02×10^5 Pa, and the cylinder is in contact with a water bath at a temperature of 0° C. The gas is then taken through the following four-step process.

- A 2.50 kg metal block is placed on top of the piston, compressing the gas to state 2, with the gas still at 0°C.
- The cylinder is then brought in contact with a boiling water bath, raising the gas temperature to 100° C at state 3.
- The metal block is removed and the gas expands to state 4 still at 100° C.
- Finally, the cylinder is again placed in contact with the water bath at 0° C, returning the system to state 1.

(a) Determine the pressure of the gas in state 2.

(b) Determine the volume of the gas in state 2.

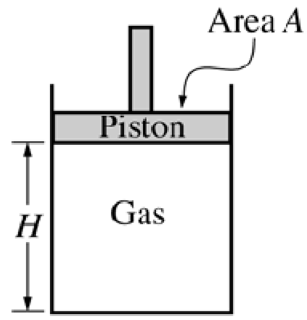
(c) Indicate below whether the process from state 2 to state 3 is isothermal, isobaric, or adiabatic.

_____Isothermal _____Isobaric _____Adiabatic
Explain your reasoning.

(d) Is the process from state 4 to state I isobaric? _____Yes _____No
Explain your reasoning.

(d) Determine the volume of the gas in state 4.

2005 Q6

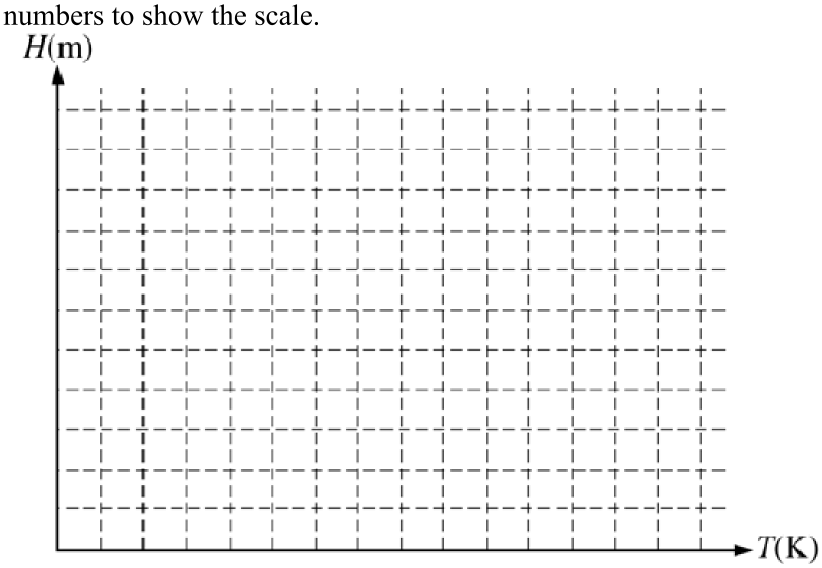


An experiment is performed to determine the number n of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area A. The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure P remains constant. Measurements are made of the temperature T of the gas and the height H of the bottom of the piston above the base of the cylinder and are recorded in the table below. Assume that the thermal expansion of the apparatus can be ignored.

T (K)	H (m)
300	1.11
325	1.19
355	1.29
375	1.37
405	1.47

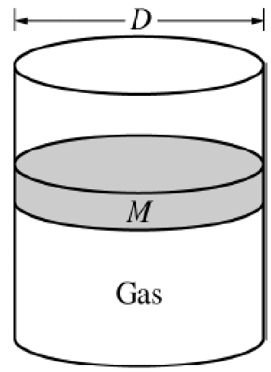
(a) Write a relationship between the quantities T and H, in terms of the given quantities and fundamental constants, that will allow you to determine n.

(b) Plot the data on the axes below so that you will be able to determine n from the relationship in part (a). Label the axes with appropriate numbers to show the scale.



(c) Using your graph and the values $A = 0.027\ m^2$ and $P = 1.0$ atmosphere, determine the experimental value of n.

2007B Q5



The cylinder above contains an ideal gas and has a movable, frictionless piston of diameter D and mass M. The cylinder is in a laboratory with atmospheric pressure P_{atm}. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Initially, the piston is free to move but remains in equilibrium. Determine each of the following.

i. The force that the confined gas exerts on the piston

ii. The absolute pressure of the confined gas

(b) If a net amount of heat is transferred to the confined gas when the piston is fixed, what happens to the pressure of the gas?

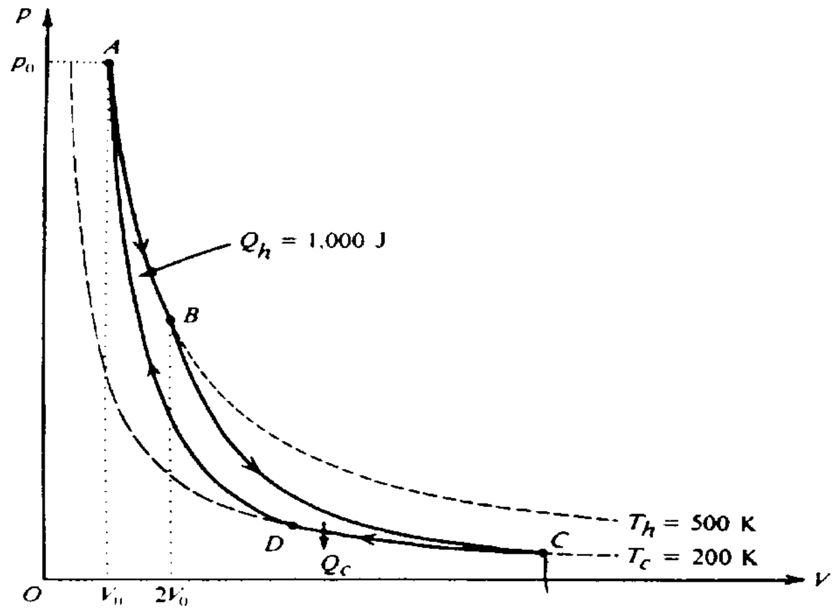
____ Pressure goes up. ____ Pressure goes down. ____ Pressure stays the same.

Explain your reasoning.

(c) In a certain process the absolute pressure of the confined gas remains constant as the piston moves up a distance x_0. Calculate the work done by the confined gas during process.

P-V DIAGRAMS

1983 Q4



The *pV*-diagram above represents the states of an ideal gas during one cycle of operation of a reversible heat engine. The cycle consists of the following four processes.

Process	Nature of Process
AB	Constant temperature (T_h = 500 K)
BC	Adiabatic
CD	Constant temperature (T_c = 20O K)
DA	Adiabatic

During process *A B*, the volume of the gas increases from V_0 to $2V_0$ and the gas absorbs 1,000 joules of heat.

(a) The pressure at *A* is p_0. Determine the pressure at *B*

(b) Using the first law of thermodynamics, determine the work performed by or on the gas during the process *AB*.

(c) During the process *AB*, does the entropy of the gas increase, decrease, or remain unchanged? Justify your answer.

(d) Calculate the heal Q_c given off by the gas in the process *CD*.

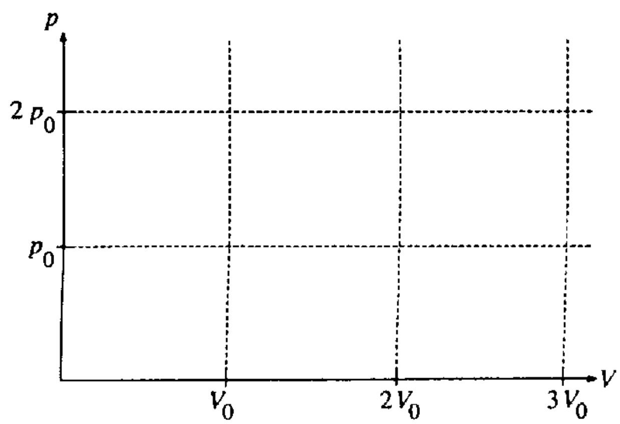
(e) During the full cycle *ABCDA*, is the total work the gas performs on its surroundings positive, negative, or zero? Justify your answer.

1989 Q4

An ideal gas initially has pressure p_0, volume V_0, and absolute temperature T_0. It then undergoes the following series of processes:

I. It is heated, at constant volume, until it reaches a pressure 2 p_0.
II. It is heated, at constant pressure, until it reaches a volume $3V_0$.
III. It is cooled, at constant volume, until it reaches a pressure p_0.
IV. It is cooled, at constant pressure, until it reaches a volume V_0.

(a) On the axes below
 i. draw the pV diagram representing the series of processes;
 ii. label each end point with the appropriate value of absolute temperature in terms of T_0.



(b) For this series of processes, determine the following in terms of p_0 and V_0.

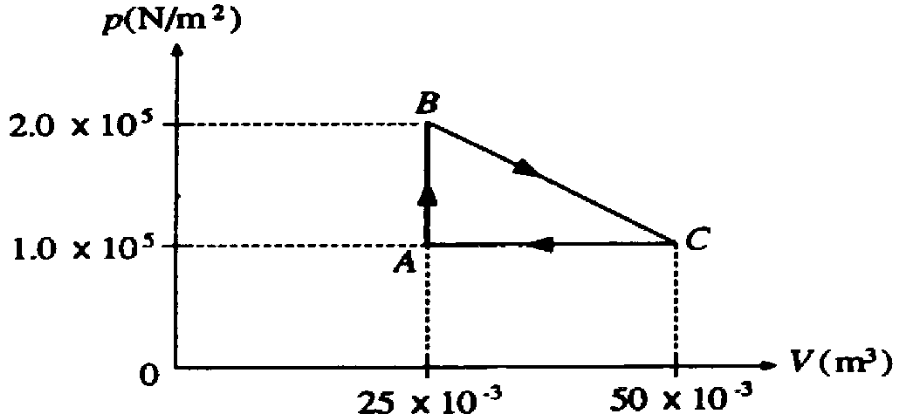
 i. The net work done by the gas

 ii. The net change in internal energy

 iii. The net heat absorbed

(c) Given that $C_p = 5/2\ R$ and $C_v = 3/2\ R$, determine the heat transferred during process 2 in terms of p_0 and V_0.

1990 Q4



One mole of an ideal monatomic gas, initially at point A at a pressure of 1.0×10^5 newtons per meter squared and a volume of 25×10^{-3} meter cubed, is taken through a 3-process cycle, as shown in the pV diagram above. Each process is done slowly and reversibly. For a monatomic gas, the heat capacities for constant volume acid constant pressure are, respectively, $C_v = (3/2)R$ and $C_p = (5/2)R$, where R is the universal gas constant, 8.32 J/mole • K.

Determine each of the following:

(a) the temperature of the gas at each of the vertices, A, B, and C, of the triangular cycle

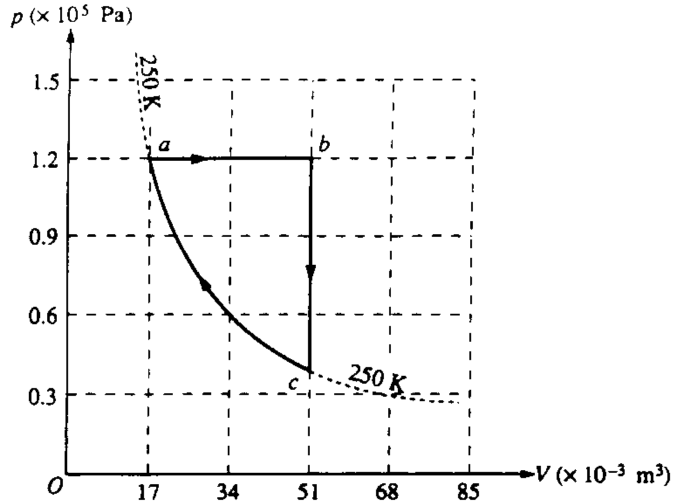
(b) the net work done by the gas for one cycle

(c) the net heat absorbed by the gas for one full cycle

(d) the heat given off by the gas for the third process from C to A

(e) the efficiency of the cycle

1993 Q5



One mole of an ideal monatomic gas is taken through the cycle *abca* shown on the diagram above. State *a* has volume $V_a = 17 \times 10^{-3}$ cubic meter and pressure $Pa = 1.2 \times 10^5$ pascals, and state *c* has volume $V_c = 51 \times 10^{-3}$ cubic meter. Process *ca* lies along the 250 K isotherm. The molar heat capacities for the gas $C_p = 20.8$ J/mole K, and $C_r = 12.5$ J/mole K. Determine each of the following.

(a) The temperature T_b of state *b*

(b) The heat Q_{ab} added to the gas during process *ab*

(c) The change in internal energy $U_b - Ua$

(d) The work W_{bc} done by the gas on its surroundings during process *bc*

The net heat added to the gas for the entire cycle is 1,800 joules. Determine each of the following.

(e) The net work done by the gas on its surroundings for the entire cycle

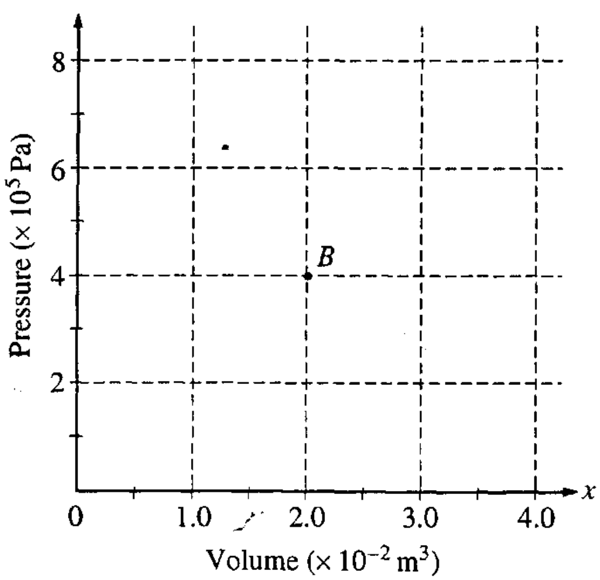
(f) The efficiency of a Carnot engine that operates between the maximum and minimum temperatures in this cycle

1999 Q7 (10 points)

A cylinder contains 2 moles of an ideal monatomic gas that is initially at state *A* with a volume of 1.0×10^{-2} m^3 and a pressure of 4.0×10^5 Pa. The gas is brought isobarically to state *B*, where the volume is 2.0×10^{-2} m^3. The gas is then brought at constant volume to state *C*, where its temperature is the same as at state *A*. The gas is then brought isothermally back to state *A*.

(a) Determine the pressure of the gas at state *C*.

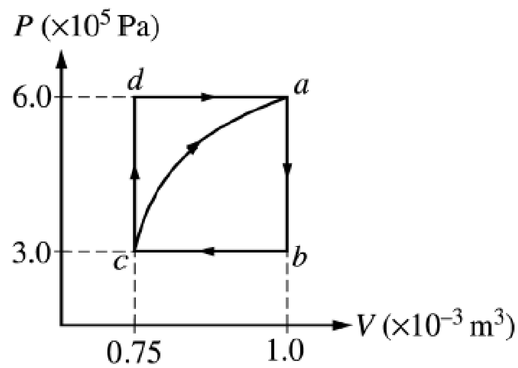
(b) On the axes below, state *B* is represented by the point *B*. Sketch a graph of the complete cycle. Label points *A* and *C* to represent states *A* and *C*, respectively.



(c) State whether the net work done by the gas during the complete cycle is positive, negative, or zero. Justify your answer.

(d) State whether this device is a refrigerator or a heat engine. Justify your answer.

2003 Q5 (10 points)



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 internal energy, $U_a - U_c$, between states *a* and *c*.

(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

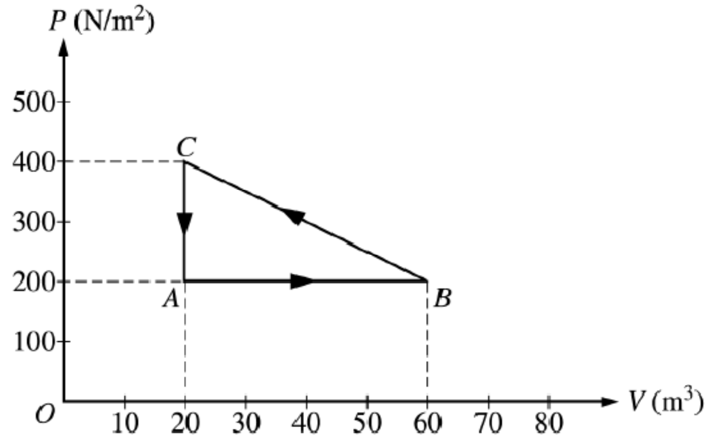
ii. Calculate the amount added or removed.

(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

2003B Q5 (10 points)



One mole of an ideal gas is taken around the cycle $A \rightarrow B \rightarrow C \rightarrow A$ as shown on the PV diagram above.

(a) Calculate the temperature of the gas at point A.

(b) Calculate the net work done on the gas during one complete cycle.

(c)

i. Is heat added to or removed from the gas during one complete cycle?

____ added to the gas ____ removed from the gas

ii. Calculate the heat added to or removed from the gas during one complete cycle.

(d) After one complete cycle, is the internal energy of the gas greater, less, or the same as before?

____ greater ____ less ____ the same

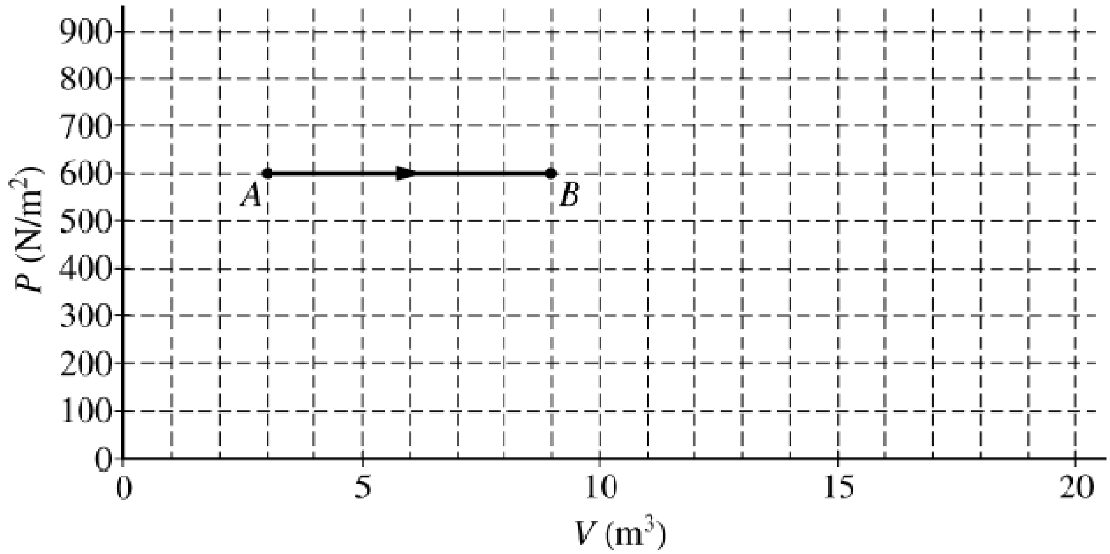
Justify your answer.

(e) After one complete cycle, is the entropy of the gas greater, less, or the same as before?

____ greater ____ less ____ the same

Justify your answer.

2004 Q5 (10 points)



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, $P_A = P_B = 600\ \text{N/m}^2$, $V_A = 3.0^3$ and $V, = 9.0\ \text{m}^3$.

(a)

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

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

iii. Calculate the heat 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 *C* 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*.

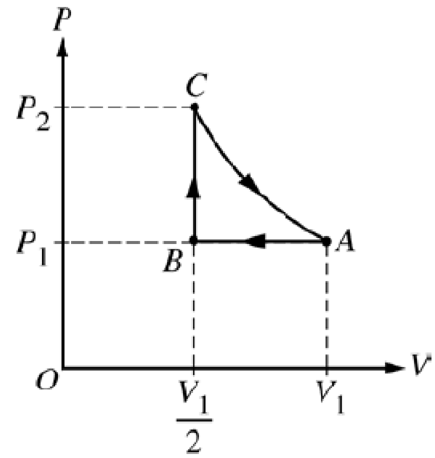
i. Draw a line or curve on the diagram to represent this process.

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

________add to_______removed from

Justify your answer.

2004B Q5



One mole of an ideal gas is initially at pressure P_1, volume V_1, and temperature T_1, represented by point *A* on the *PV* diagram above. The gas is taken around cycle *ABCA* shown. Process *AB* is isobaric, process *BC* is isochoric, and process *CA* is isothermal.

(a) Calculate the temperature T_2 at the end of process AB in terms of temperature T_1.

(b) Calculate the pressure P_2 at the end of process BC in terms of pressure P_1.

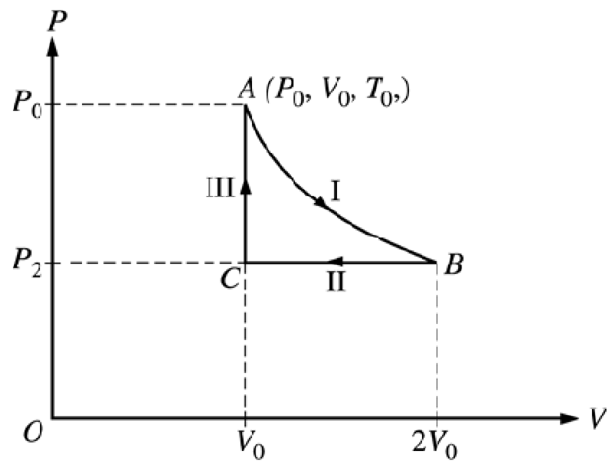
(c) Calculate the net work done on the gas when it is taken from *A* to *B* to *C*. Express your answer in terms of P_1 and V_1.

(d) Indicate below all of the processes that result in heat being added to the gas.

____ *AB* ____*BC* ____*CA*

Justify your answer.

2006B Q5 (10 points)



A sample of ideal gas is taken through steps I, II, and III in a closed cycle, as shown on the pressure *P* versus volume V diagram above, so that the gas returns to its original state. The steps in the cycle are as follows.

I. An isothermal expansion occurs from point *A* to point *B*, and the volume of the gas doubles.
II. An isobaric compression occurs from point *B* to point *C*, and the gas returns to its original volume.
III. A constant volume addition of heat occurs from point *C* to point A and the gas returns to its original pressure.

(a) Determine numerical values for the following ratios, justifying your answers in the spaces next to each ratio.

i. $\frac{P_B}{P_A} =$

ii. $\frac{P_C}{P_A} =$

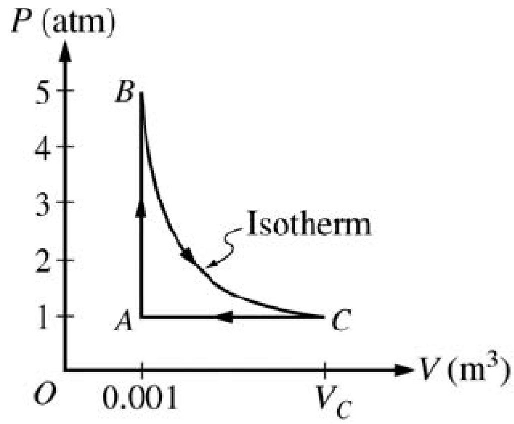
iii. $\frac{T_B}{T_A} =$

iv. $\frac{T_C}{T_A} =$

(b) During step I, the change in internal energy is zero. Explain why.

(c) During step III, the work done on the gas is zero. Explain why.

2008 Q5 (10 points)



A 0.03 mol sample of helium is taken through the cycle shown in the diagram above. The temperature of state *A* is 400 K.

(a) For each process in this cycle, indicate in the table below whether the quantities *W*, *Q*, and ΔU are positive (+), negative (–), or zero (0). *W* is the work done on the helium sample.

Process	*W*	*Q*	ΔU
$A \rightarrow B$			
$B \rightarrow C$			
$C \rightarrow A$			

(b) Explain your response for the signs of the quantities for process *AB*.

(c) Calculate V_C.

1986 Q5

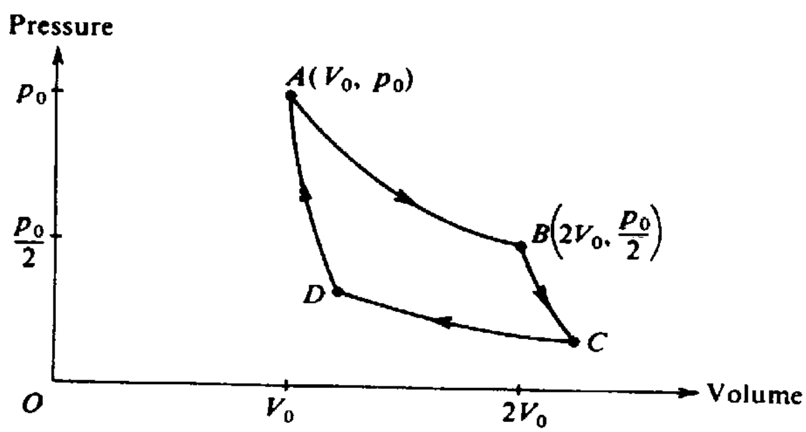
A proposed ocean power plant will utilize the temperature difference between surface seawater and seawater at a depth of 100 meters. Assume the surface temperature is 25° Celsius and the temperature at the 100-meter depth is 3° Celsius.

(a) What is the ideal (Carnot) efficiency of the plant?

(b) If the plant generates useful energy at the rate of 100 megawatts while operating with the efficiency found in part (a), at what rate is heat given off to the surroundings?

(c) A nuclear power plant operates with an overall efficiency of 40 percent. At what rate must mass be converted into energy to give the same 100-megawatts output as the ocean power plant above? Express your answer in kilograms per second.

The diagram below represents the Carnot cycle for a simple reversible (Carnot) engine in which a fixed amount of gas, originally at pressure p_0 and volume v_0,, follows the path ABCDA.



(d) In the chart below, for each part of the cycle indicate with +, −, or 0 whether the heat transferred ***Q*** and temperature change ΔT are positive, negative, or zero, respectively. (***Q*** is positive when heat is added to the gas, and ΔT is positive when the temperature of the gas increases.)

	Q	ΔT
AB		
BC		
CD		
DA		

HEAT ENGINES

1991 Q3

A heat engine consists of an oil-fired steam turbine driving an electric power generator with a power output of 120 megawatts. The thermal efficiency of the heat engine is 40 percent.

(a) Determine the time rate at which heat is supplied to the engine.

(b) If the heat of combustion of oil is 4.4×10^7 joules per kilogram, determine the rate in kilograms per second at which oil is burned.

(c) Determine the time rate at which heat is discarded by the engine.

(d) If the discarded heat is continually and completely absorbed by the water in a full tank measuring 200 meters by 50 meters by 10 meters, determine the change in the temperature of the water in 1 hour.

(Density of water is 1.0×10^3 kg/m3; specific heat of water is 4.2×10^3 J/kg°C.)

1995 Q5

A heat engine operating between temperatures of 500 K and 300 K is used to lift a l0-kilogram mass vertically at a constant speed of 4 meters per second.

(a) Determine the power that the engine must supply to lift the mass.

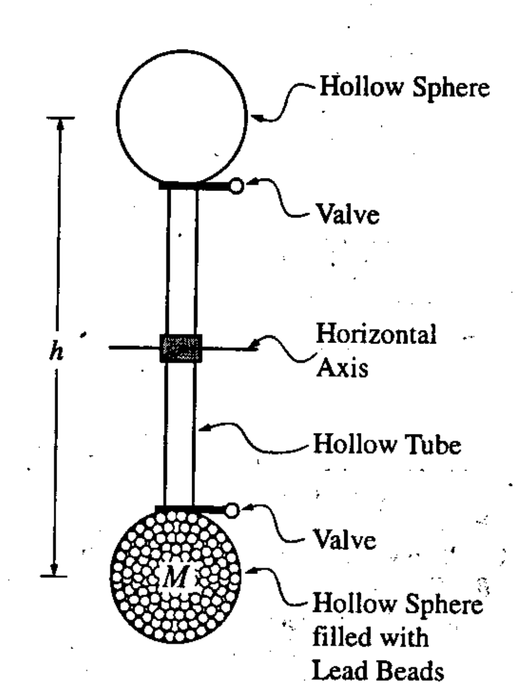
(b) Determine the maximum possible efficiency at which the engine can operate.

(c) If the engine were to operate at the maximum possible efficiency, determine the following.

i. The rate at which the hot reservoir supplies heat to the engine

ii. The rate at which heat is exhausted to the cold reservoir

1998 Q3 (10 points)



Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass *M* and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance *h*. What minimum amount of work must the student do to accomplish this?

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00\ m$, and $c = 128$ J/(kg ·K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical <u>cumulative</u> temperature increase after the 100 repetitions.

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.