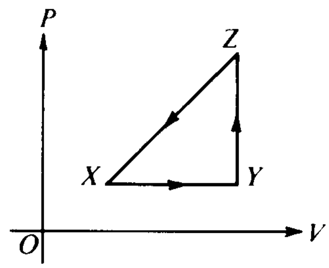
AP Physics Multiple Choice Practice – Thermodynamics

1. An ideal gas is made up of N diatomic molecules, each of mass M. All of the following statements about this gas are true EXCEPT:
   (A) The temperature of the gas is proportional to the average translational kinetic energy of the molecules.
   (B) All of the molecules have the same speed.
   (C) The molecules make elastic collisions with each other and with the walls of the container.
   (D) The average number of collisions per unit time that the molecules make with the walls of the container depends on the temperature of the gas.

Questions 2-3



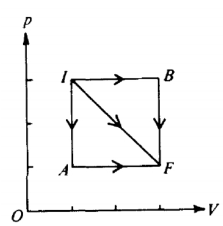
A thermodynamic system is taken from an initial state X along the path XYZX as shown in the PV-diagram.

2. For the process X→Y, ΔU is greater than zero and
   (A) Q < 0 and W = 0 (B) Q < 0 and W > 0 (C) Q > 0 and W < 0 (D) Q > 0 and W > 0

3. For the process Y→Z, Q is greater than zero and
   (A) W < 0 & ΔU = 0 (B) W = 0 & ΔU < 0 (C) W = 0 & ΔU > 0 (D) W > 0 & ΔU > 0

4. An ideal gas confined in a box initially has pressure p. If the absolute temperature of the gas is doubled and the volume of the box is quadrupled, the pressure is
   (A) p/8 (B) p/4 (C) p/2 (D) 2p

5. An ideal gas in a closed container initially has volume V, pressure P. and Kelvin temperature T. If the temperature is changed to 3T, which of the following pairs of pressure and volume values is possible?
   (A) 3P and V (B) 3P and 3V (C) P and V/3 (D) P/3 and V

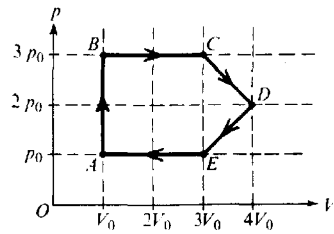


6. If three identical samples of an ideal gas are taken from initial state I to final state F along the paths IAF, IF, and IBF as shown in the pV-diagram above, which of the following must be true?
   (A) The heat absorbed by the gas is the same for all three paths.
   (B) The change in internal energy of the gas is the same for all three paths.
   (C) The expansion along path IF is adiabatic.
   (D) The expansion along path IF is isothermal.

7. If the average kinetic energy of the molecules in an ideal gas at a temperature of 300 K is E, the average kinetic energy at a temperature of 600 K is
   (A) E (B) $\sqrt{2}E$ (C) $2E$ (D) $4E$

8. A metal rod of length L and cross-sectional area A connects two thermal reservoirs of temperatures T_1 and T_2. The amount of heat transferred through the rod per unit time is directly proportional to
(A) A and L (B) A and 1/L (C) 1/A and L (D) 1/A and 1/L

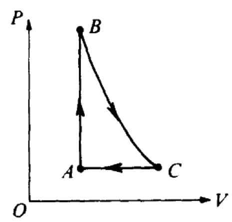
Questions 9-10



An ideal gas undergoes a cyclic process as shown on the graph above of pressure p versus volume V.

9. During which process is no work done on or by the gas?
(A) AB (B) BC (C) CD (D) EA

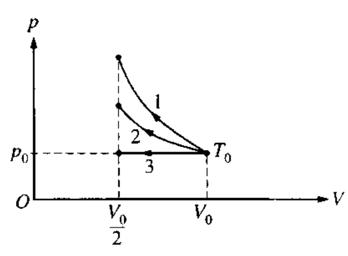
10. At which point is the gas at its highest temperature?
(A) A (B) B (C) C (D) D



11. Gas in a chamber passes through the cycle ABCA as shown in the diagram above. In the process AB, 12 joules of heat is transferred to the gas. In the process BC, no heat is exchanged with the gas. For the complete cycle ABCA, the work done by the gas is 8 joules. How much heat is added to or removed from the gas during process CA?
(A) 20 J is removed. (B) 4 J is removed. (C) 4 J is added. (D) 20 J is added.

12. If the gas in a container absorbs 275 joules of heat, has 125 joules of work done on it, and then does 50 joules of work, what is the increase in the internal energy of the gas?
(A) 450 J (B) 400 J (C) 350 J (D) 200 J

Questions 13-14

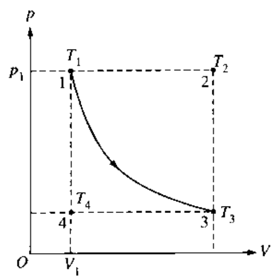


A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

13. Which of the following is true of the mechanical work done on the gas?
(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for all three processes.

14. Which of the following is true of the final temperature of this gas?
(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for all three processes.

15. In a certain process, 400 J of heat is transferred to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is
(A) 500 J (B) 300 J (C) –100 J (D) –300 J



16. **Multiple Correct.** 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? Select two answers:
(A) $T_1 < T_3$ (B) $T_1 < T_2$ (C) $T_1 = T_3$ (D) $T_1 = T_4$

17. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Doubles

18. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?
(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.

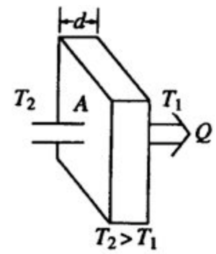
19. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v_2 is their average speed after the absorption of heat, what is the ratio v_2/v_1?
(A) 4 (B) 2 (C) $\sqrt{2}$ (D) 1/2

20. Two blocks of steel, the first of mass 1 kg and the second of mass 2 kg, are in thermal equilibrium with a third block of aluminum of mass 2 kg that has a temperature of 400 K. What are the respective temperatures of the first and second steel blocks?
(A) 400 K and 200 K (B) 200 K and 400 K (C) 400 K and 400 K (D) 800 K and 400 K

21. An ideal gas may be taken from one state to another state with a different pressure, volume, and temperature along several different paths. Quantities that will always be the same for this process, regardless of which path is taken, include which of the following?
I. The change in internal energy of the gas
II. The heat exchanged between the gas and its surroundings
III. The work done by the gas
(A) I only (B) II only (C) I and III only (D) II and III only

22. A square steel plate with sides of length 1.00 m has a hole in its center 0.100 m in diameter. If the entire plate is heated to such a temperature that its sides become 1.01 m long, the diameter of the hole will be
(A) 0.090 m (B) 0.099 m (C) 0.101 m (D) 0.110 m

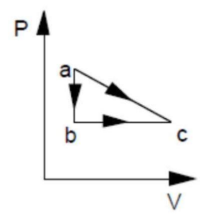
23. Which of the following will occur if the average speed of the gas molecules in a closed rigid container is increased?
(A) The density of the gas will decrease. (B) The density of the gas will increase.
(C) The pressure of the gas will increase. (D) The pressure of the gas will decrease.



24. In time t, an amount of heat Q flows through the solid door of area A and thickness d represented above. The temperatures on each side of the door are T_2 and T_1, respectively. Which of the following changes would be certain to decrease Q?
(A) Increasing A only (B) Decreasing d only
(C) Increasing d and $T_2 - T_1$ only (D) Decreasing A and $T_2 - T_1$ only

25. A gas with a fixed number of molecules does 32 J of work on its surroundings, and 16 J of heat are transferred from the gas to the surroundings. What happens to the internal energy of the gas?
(A) It decreases by 48 J. (B) It decreases by 16 J. (C) It increases by 16 J. (D) It increases by 48 J.

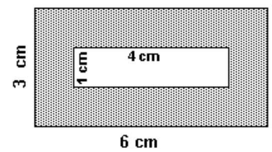
26. A mass m of helium gas is in a container of constant volume V. It is initially at pressure p and absolute (Kelvin) temperature T. Additional helium is added, bringing the total mass of helium gas to $3m$. After this addition, the temperature is found to be $2T$. What is the gas pressure?
(A) 2/3 p (B) 3/2 p (C) 3 p (D) 6 p



27. A gas can be taken from state a to c by two different reversible processes, $a \Rightarrow c$ or $a \Rightarrow b \Rightarrow c$. During the direct process $a \Rightarrow c$, 20.0 J of work are done by the system and 30.0 J of heat are added to the system. During the process $a \Rightarrow b \Rightarrow c$, 25.0 J of heat are added to the system. How much work is done by the system during $a \Rightarrow b \Rightarrow c$?
(A) 5.0 J (B) 10.0 J (C) 15.0 J (D) 20.0 J

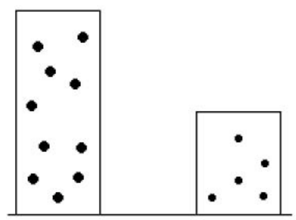
28. When an ideal gas is isothermally compressed:
(A) thermal energy flows from the gas to the surroundings.
(B) thermal energy flows from the surroundings to the gas.
(C) no thermal energy enters or leaves the gas.
(D) the temperature of the gas increases.

30. A 200 gram sample of copper is submerged in 100 grams of water until both the copper and water are at the same temperature. Which of the following statements would be true?
(A) the molecules of the water and copper would have equal average speeds
(B) the molecules of the water and copper would have equal average momenta
(C) the molecules of the water and copper would have equal average kinetic energies
(D) the water molecules would have twice the average speed of the copper molecules



31. A rectangular piece of metal 3 cm high by 6 cm wide has a hole cut in its center 1cm high by 4 cm wide as shown in the diagram at right. As the metal is warmed from 0^oC to 100^0C, what will happen to the dimensions of the hole?
    (A) both height and width will increase
    (B) both height and width will decrease
    (C) height will increase while width will decrease
    (D) height will decrease while width will increase

32. A gas is enclosed in a cylindrical piston. When the gas is heated from 0ºC to 100ºC, the piston is allowed to move to maintain a constant pressure. According to the Kinetic-Molecular Theory of Matter
    (A) the molecules continue to strike the sides of the container with the same energy
    (B) the number of molecules of gas must increase
    (C) the size of the individual molecules has increased
    (D) the average speed of the molecules has increased



33. Two containers are filled with gases at the same temperature. In the container on the left is a gas of molar mass *2M,* volume *2V,* and number of moles *2n.* In the container on the right is a gas of molar mass *M,* volume *V,* and moles *n*. Which is most nearly the ratio of the pressure of the gas on the left to the pressure of the gas on the right?
    (A) 1:1 (B) 2:1 (C) 4:1 (D) 8:1

34. A fan blows the air and gives it kinetic energy. An hour after the fan has been turned off, what has happened to the kinetic energy of the air?
    (A) it turns into thermal energy (B) it turns into sound energy
    (C) it turns into potential energy (D) it turns into electrical energy

35. According to the kinetic theory of gases, when the absolute temperature of an ideal gas doubles, the average kinetic energy of the molecules of the gas
    (A) quadruples (B) doubles (C) is cut in half (D) is quartered

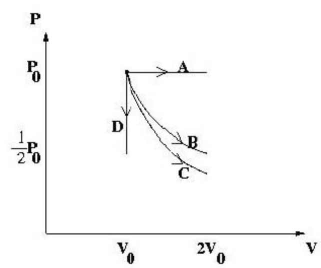
36. When gas escapes from a pressurized cylinder, the stream of gas feels cool. This is because
    (A) work is being done at the expense of thermal energy
    (B) of the convection inside the cylinder
    (C) pressurized cylinders are good thermal insulators
    (D) the moisture in the air condenses and cools

37. Two completely identical samples of the same ideal gas are in equal volume containers with the same pressure and temperature in containers labeled A and B. The gas in container A performs non-zero work W on the surroundings during an isobaric (constant pressure) process before the pressure is reduced isochorically (constant volume) to ½ its initial amount. The gas in container B has its pressure reduced isochorically (constant volume) to ½ its initial value and then the gas performs non-zero work W on the surroundings during an isobaric (constant pressure) process.

After the processes are performed on the gases in containers A and B, which is at the higher temperature?
(A) The gas in container A
(B) The gas in container B
(C) The value of the work W is necessary to answer this question.
(D) The value of the work W is necessary, along with both the initial pressure and volume, in order to answer the question.

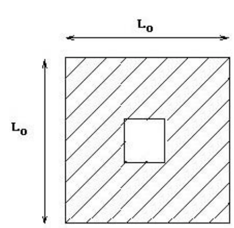
38. The volume of an ideal gas changes as the gas undergoes an isobaric (constant pressure) process starting from temperature 273 ^{O}C and ending at 546^{O}C. What is the ratio of the new volume of the gas to the old volume (V_{new}/V_{old})?
(A) $\frac{1}{2}$ (B) $\frac{2}{3}$ (C) $\frac{3}{2}$ (D) 2

39. A frozen hamburger in plastic needs to be thawed quickly. Which of the methods described provides the most rapid thawing of the burger?
(A) Place the burger itself in a metal pan at room temperature.
(B) Place the burger itself on the ceramic kitchen counter at room temperature.
(C) Place the burger in its package on the kitchen counter at room temperature.
(D) Place the burger in its package in a pot of non-boiling warm water.



40. **Multiple Correct.** The PV diagram shows four different possible reversible processes performed on a monatomic ideal gas. Process A is isobaric (constant pressure). Process B is isothermal (constant temperature). Process C is adiabatic. Process D is isochoric (constant volume). For which processes does the temperature of the gas decrease? Select two answers:
(A) Process A (B) Process B (C) Process C (D) Process D

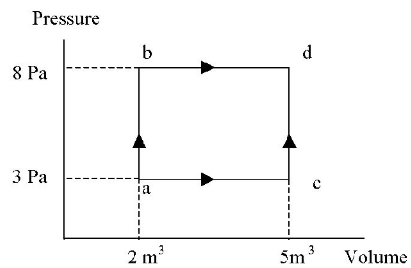
41. A pure 4-mole sample of a newly discovered monatomic ideal gas is sitting in a container at equilibrium in a 20.0ºC environment. According to the kinetic theory of gases, what is the average kinetic energy per molecule for this gas?
(A) 4.14×10^{-22} J (B) 2.02×10^{-21}J (C) 6.07×10^{-21} J
(D) The molar mass of the gas is needed to answer this question.



42. A uniform square piece of metal has initial side length L_0 . A square piece is cut out of the center of the metal. The temperature of the metal is now raised so that the side lengths are increased by 4%. What has happened to the area of the square piece cut out of the center of the metal?
(A) It is increased by 8 % (B) It is increased by 4 % (C) It is decreased by 4 % (D) It is decreased by 8 %

43. A monatomic ideal gas at pressure $P = 10^5$ Pa is in a container of volume $V = 12$ m^3 while at temperature $T =$ 50ºC. How many molecules of gas are in the container?
(A) 1.74×10^{27} (B) 2.69×10^{26} (C) 2888 (D) 447

44. Absolute zero is best described as that temperature at which
(A) water freezes at standard pressure.
(B) the molecules of a substance have a maximum kinetic energy.
(C) the molecules of a substance have a maximum potential energy.
(D) the molecules of a substance have minimum kinetic energy.



45. In the Pressure versus Volume graph shown, in the process of going from a to b 60 J of heat are added, and in the process of going from b to d 20 J of heat are added. In the process of going a to c to d, what is the total heat added?
(A) 80 J (B) 65 J (C) 56 J (D) 47 J

46. Which is not true of an isochoric process on an enclosed ideal gas in which the pressure decreases?
(A) The work done is zero. (B) The internal energy and temperature of the gas decreases.
(C) The heat is zero. (D) The rms speed of the gas molecules decreases.

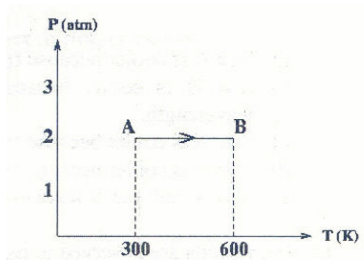
47. One mole of an ideal gas has a temperature of 100°C. If this gas fills the $10.0m^3$ volume of a closed container, what is the pressure of the gas?
(A) 0.821 Pa (B) 3.06 Pa (C) 83.1 Pa (D) 310 Pa

48. An ideal gas is enclosed in a container. The volume of the container is reduced to half the original volume at constant temperature. According to kinetic theory, what is the best explanation for the increase in pressure created by the gas?
(A) The average speed of the gas particles decreases, but they hit the container walls more frequently.
(B) The average speed of the gas particles is unchanged, but they hit the container walls more frequently.
(C) The average speed of the gas particles increases as does the frequency with which they hit the container walls.
(D) The average speed of the gas particles increases, overcoming the decreased frequency that they hit the container walls.

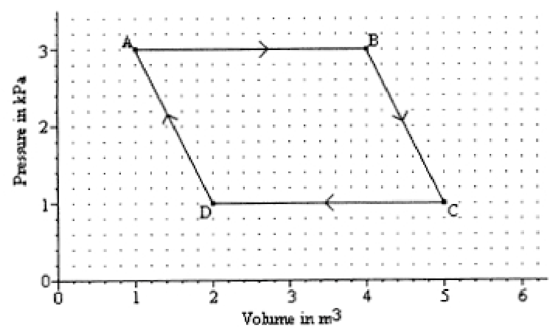
49. A mole of a monatomic ideal gas has pressure P, volume V, and temperature T. Which of the following processes would result in the greatest amount of energy added to the gas from heat?
(A) A process doubling the temperature at constant pressure.
(B) An adiabatic expansion doubling the volume.
(C) A process doubling the pressure at constant volume.
(D) A process doubling the volume at constant temperature.

50. An ideal gas in a closed container of volume 6.0 L is at a temperature of 100ºC. If the pressure of the gas is 2.5 atm, how many moles of gas are in the container?
(A) 0.0048 (B) 0.018 (C) 0.49 (D) 1.83

51. An ideal gas undergoes an isobaric expansion followed by an isochoric cooling. Which of the following statements *must* be true after the completion of these processes?
(A) The final pressure is less than the original pressure.
(B) The final volume is less than the original volume.
(C) The final temperature is less than the original temperature.
(D) The total quantity of heat, Q, associated with these processes is positive.



52. Two moles of a monatomic ideal gas undergoes the process from A to B, shown in the diagram above by the solid line. Using the sign convention that work is positive when surroundings do work on the system, how much work is done in the process AB?
(A) 5000 J (B) 1200 J (C) –1200 J (D) –5000 J



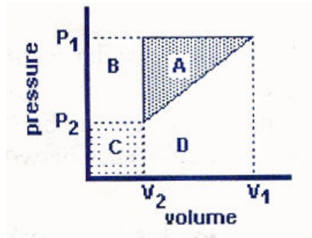
53. A sample of gas is caused to go through the cycle shown in the pV diagram shown above. What is the net work done by the gas during the cycle?
(A) 4,000 J (B) 6,000 J (C) 8,000 J (D) 12,000 J

54. A sample of an ideal monatomic gas is confined in a rigid 0.008 m^3 container. If 40 joules of heat energy were added to the sample, how much would the pressure increase?
(A) 320 Pa (B) 1,600 Pa (C) 3,333 Pa (D) 5,000 Pa

55. Hydrogen gas (H_2) and oxygen gas (O_2) are in thermal equilibrium. How does the average speed of the hydrogen molecules compare to the average speed of oxygen molecules?
(A) equal (B) 4 times greater (C) 8 times greater (D) 16 times greater

56. Hydrogen gas is contained in a rigid container. A second rigid container of equal volume contains oxygen gas. If the average rms velocities of the molecules in each container is the same, which of the following *must* be true?
(A) The oxygen gas would apply the greater pressure.
(B) The temperature of both gasses would be identical.
(C) There would be an equal pressure in each container.
(D) The oxygen gas would have the higher temperature.

57. A mole of ideal gas at STP is heated in an insulated constant volume container until the average velocity of its molecules doubled. Its pressure would therefore increase by what factor?
(A) 0.5 (B) 1 (C) 2 (D) 4



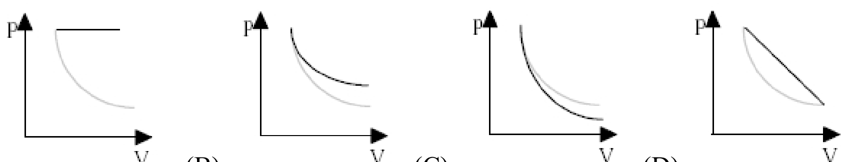
58. **Multiple Correct.** A sample of gas was first compressed from V_1 to V_2 at a constant pressure of P_1. The sample was then cooled so that the pressure went from P_1 to P_2 while the volume remained constant at V_2. Finally the sample was allowed to expand from V_2 back to V_1 while the pressure increased from P_2 back to P_1 as shown in the diagram. Which of the following statements are correct? Select two answers.

(A) The area A represents the energy that is lost by the gas in this cycle.
(B) The area A + D represents the "+" work done <u>on</u> the gas during the first compression.
(C) The area D represents the "+" work done <u>on</u> the gas during the final expansion.
(D) There was no energy lost or gained by the gas in this cycle.

59. **Multiple Correct.** One end of a metal rod of length L and cross-sectional area A is held at a constant temperature T_1. The other end is held at a constant T_2. Which of the statements about the amount of heat transferred through the rod per unit time are true? Select two answers.

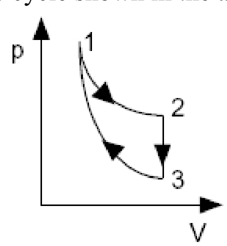
(A) The rate of heat transfer is proportional to A.
(B) The rate of heat transfer is proportional to $1/(T_1 - T_2)$.
(C) The rate of heat transfer is proportional to L.
(D) The rate of heat transfer is proportional to $(T_1 - T_2)$.

60. On all of the pV diagrams shown below the lighter curve represents isothermal process, a process for which the temperature remains constant. Which dark curve best represents an adiabatic process?



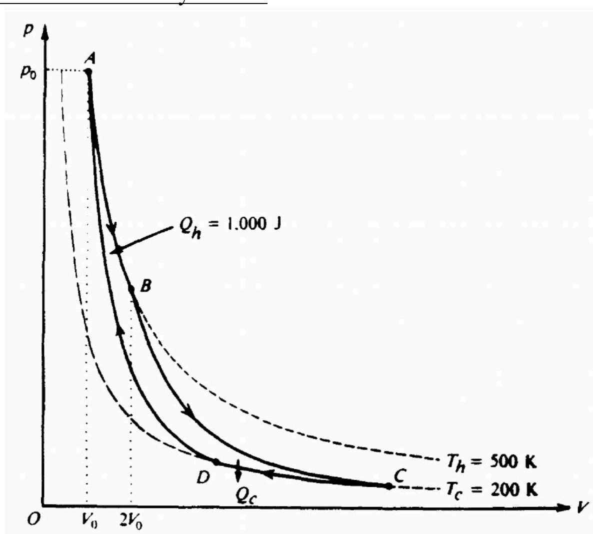
(A) (B) (C) (D)

61. Three processes compose a thermodynamic cycle shown in the accompanying pV diagram of an ideal gas.



Process 1→2 takes place at constant temperature (300 K). During this process 60 J of heat enters the system.
Process 2→3 takes place at constant volume. During this process 40 J of heat leaves the system.
Process 3→1 is adiabatic. T_3 is 275 K.

What is the change in internal energy of the system during process 3→1?
(A) –40 J (B) –20 J (C) +20 J (D) +40 J

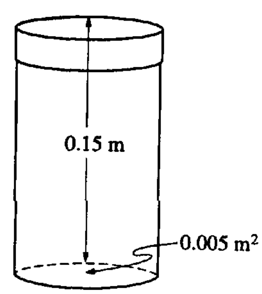


1983B4. The pV-diagram above represents the states of an ideal gas during one cycle of operation of a reversible heat engine. The cycle consists of the following four processes.

Process	**Nature of Process**
AB	Constant temperature (T_h = 500 K)
BC	Adiabatic
CD	Constant temperature (T_c = 200 K)
DA	Adiabatic

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

a. The pressure at A is $p_{o.}$ Determine the pressure at B.
b. Using the first law of thermodynamics, determine the work performed 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 heat Q_c given off by the gas in the process CD.
e. During the full cycle ABCDA is the total work the performed on the gas by its surroundings positive, negative, or zero? Justify your answer.



1996B7 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.

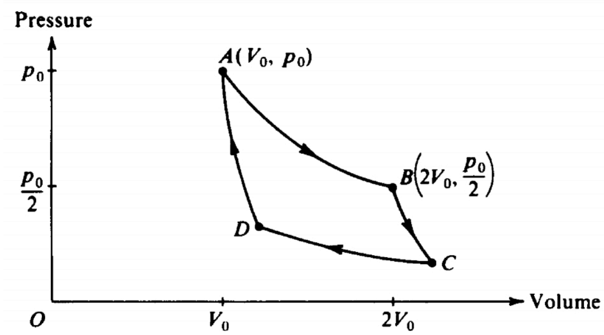
a. What is the pressure of the cooled gas?
b. Determine the upward force exerted on the cap by the cooled gas inside the can.
c. If the cap develops a leak, how many moles of air would enter the can as it reaches a final equilibrium at 298 K and atmospheric pressure? (Assume that air is an ideal gas.)

1986B5 (modified) 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?

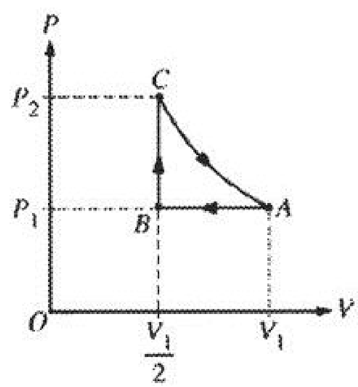
b. If the plant generates useful energy at the rate of 100 megawatts while operating with the efficiency found in part (a), at what rate is heat given off to the surroundings?

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



c. 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		



2004Bb5 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.

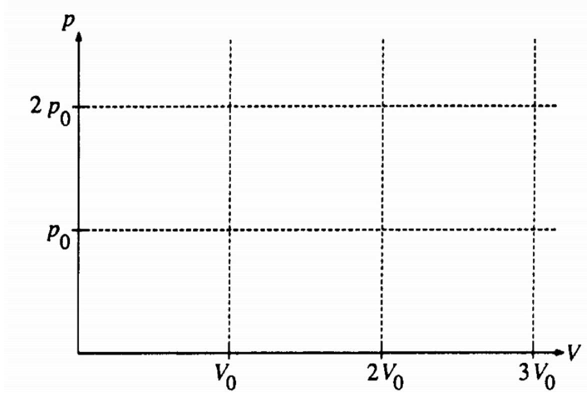
____ AB ____ BC ____ CA

Justify your answer.

1989B4 (modified) An ideal gas initially has pressure p_o, volume V_o, and absolute temperature T_o. It then undergoes the following series of processes:

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

a. On the axes below
i. draw the p-V diagram representing the series of processes;
ii. label each end point with the appropriate value of absolute temperature in terms of T_o.

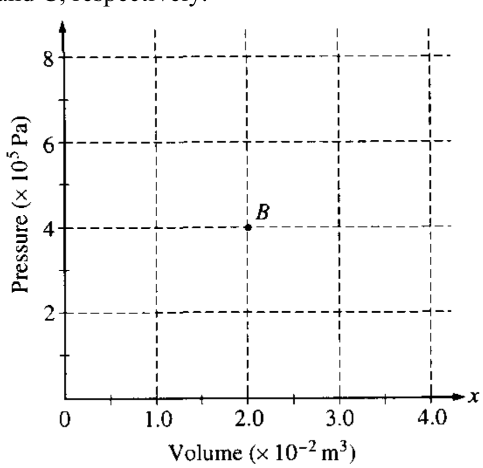


b. For this series of processes, determine the following in terms of p_o and V_o.
i. The net work done on the gas
ii. The net change in internal energy
iii. The net heat absorbed

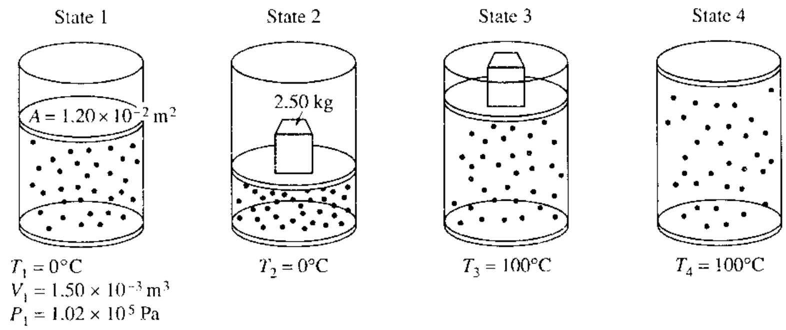
c. Determine the heat transferred during process 2 in terms of p_o and V_o.

1999B7. 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 on 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.



Note: Figures not drawn to scale.

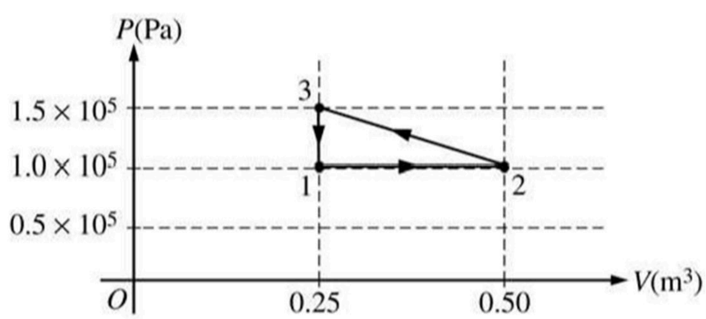
2001B6. A cylinder is fitted with a freely moveable piston of area 1.20×10^{-2} m^2 and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume 1.50×10^{-3} m^3, pressure 1.02×10^5 Pa, and the cylinder is in contact with a water bath at a temperature of 0°C. 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.

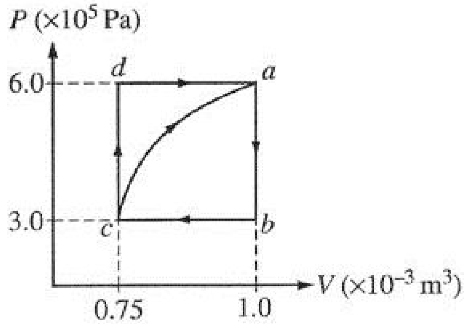
_____Isothermal _____Isobaric _____Adiabatic
Explain your reasoning.

d. Is the process from state 4 to state 1 isobaric? _____Yes _____No
Explain your reasoning.
e. Determine the volume of the gas in state 4.



2006B5 A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the PV diagram above.

a. Calculate the temperature of the gas when it is in the following states.
i. State 2
ii. State 3
b. Calculate the net work done on the gas during the cycle.
c. Was heat added to or removed from the gas during the cycle?
Added _____ Removed _____ Neither added nor removed _____
Justify your answer.



2003B5. 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.

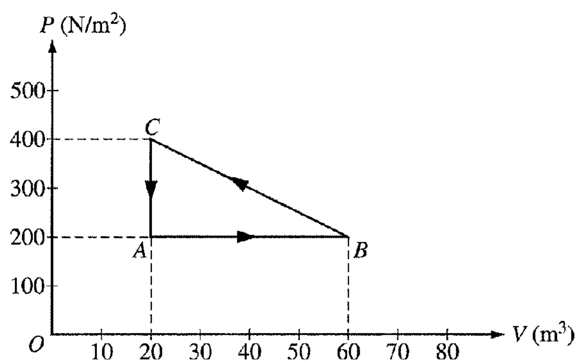
$Q_{c\to a}$ = 685 J along the curved path
$W_{c\to a}$ = –120 J along the curved path
$U_a - U_b$ = 450 J
$W_{a\to b\to c}$ = 75 J

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 ?*

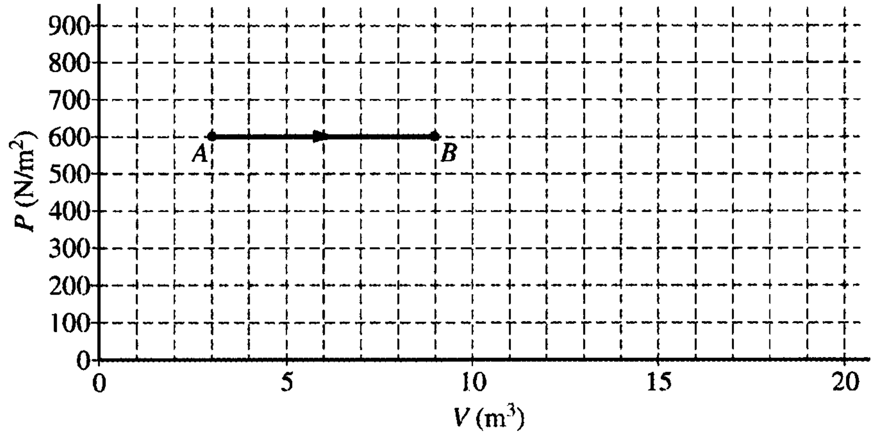
_____added to the gas _____removed from the gas
ii. Calculate the amount added or removed.

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.



2003Bb5. One mole of an ideal gas is taken around the cycle $A\to B\to C\to A$ 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.

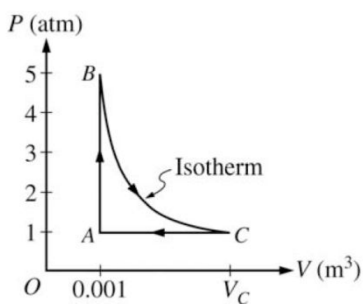


2004B5. The diagram above of pressure P versus volume V shows the expansion of 2.0 moles of a monatomic ideal gas from state A to state B. As shown in the diagram, $P_A = P_B = 600$ N/m^2, $V_A = 3.0$ m^3, and $V_B = 9.0$ m^3.

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?
_______added to _______removed from
Justify your answer.

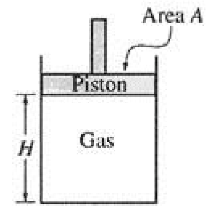


2008B5. A 0.03 mol sample of helium is taken through the cycle shown in the diagram above. The temperature of state A is 400 K.

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
$A \to B$			
$B \to C$			
$C \to A$			

b. Explain your response for the signs of the quantities for process A⇨B.
c. Calculate V_c.

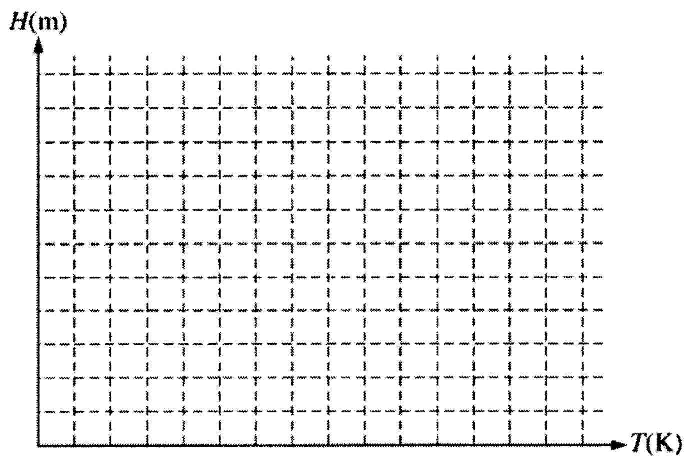


2005B6. An experiment is performed to determine the number n of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area A. The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure P remains 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.

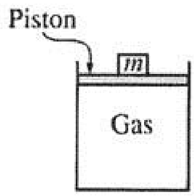
T (K)	H (m)
300	1.11
325	1.19
355	1.29
375	1.37
405	1.47

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.



Note: Figure not drawn to scale.

2005Bb6. You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

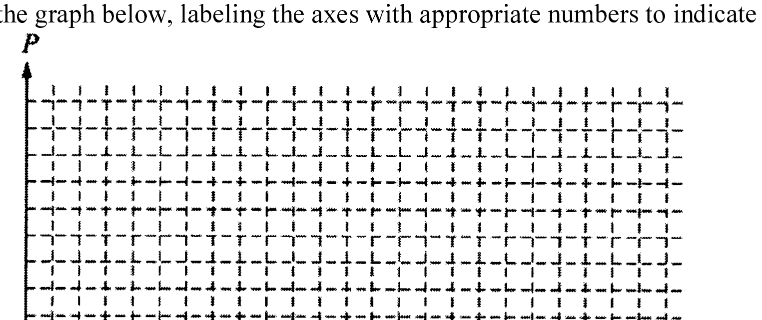
m (kg)	V (m^3)	$1/V$ (m^{-3})	P (Pa)
0	6.0×10^{-5}	1.7×10^4	
1	4.5×10^{-5}	2.2×10^4	
2	3.6×10^{-5}	2.8×10^4	
3	3.0×10^{-5}	3.3×10^4	
4	2.6×10^{-5}	3.8×10^4	

a. Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

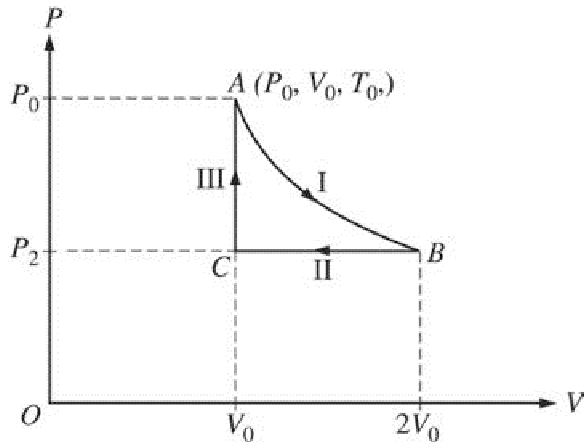
You also determine that $A = 3.0 \times 10^{-4}\ \text{m}^2$ and $T = 300$ K.

b. Calculate the value of P for each value of m and record your values in the data table above.

c. Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



d. Using your graph in part (c), calculate the experimental value of n.



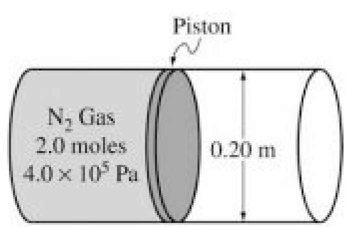
2006Bb5. A sample of ideal gas is taken through steps I, II, and III in a closed cycle, as shown on the pressure P versus volume V diagram above, so that the gas returns to its original state. The steps in the cycle are as follows.

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. $\dfrac{P_B}{P_A} =$ ii. $\dfrac{P_C}{P_A} =$ iii. $\dfrac{T_B}{T_A} =$ iv. $\dfrac{T_C}{T_A} =$

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.



2007B5. The figure above shows a 0.20 m diameter cylinder fitted with a frictionless piston, initially fixed in place. The cylinder contains 2.0 moles of nitrogen gas at an absolute pressure of 4.0×10^5 Pa. Nitrogen gas has a molar mass of 28 g/mole and it behaves as an ideal gas.

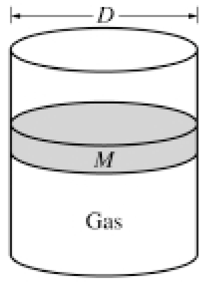
a. Calculate the force that the nitrogen gas exerts on the piston.
b. Calculate the volume of the gas if the temperature of the gas is 300 K.
c. In a certain process, the piston is allowed to move, and the gas expands at constant pressure and pushes the piston out 0.15 m. Calculate how much work is done <u>by the gas</u>.
d. Which of the following is true of the heat energy transferred to or from the gas, if any, in the process in part (c)?

_______Heat is transferred to the gas.

_______Heat is transferred from the gas.

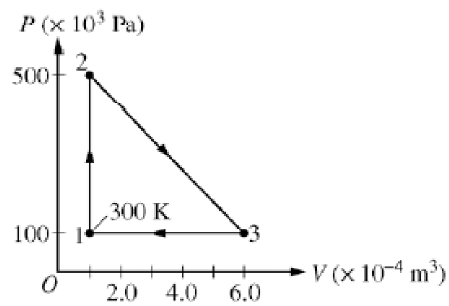
_______No heat is transferred in the process.

Justify your answer.

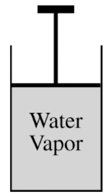


B2007b5. The cylinder above contains an ideal gas and has a movable, frictionless piston of diameter D and mass M. The cylinder is in a laboratory with atmospheric pressure P_{atm} . Express all algebraic answers in terms of the given quantities and fundamental constants.

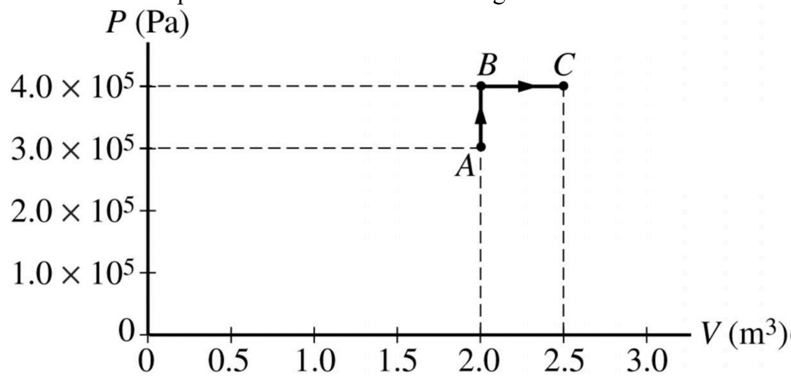
a. Initially, the piston is free to move but remains in equilibrium. Determine each of the following.
   i. The force that the confined gas exerts on the piston
   ii. The absolute pressure of the confined gas
b. If a net amount of heat is transferred to the confined gas when the piston is fixed, what 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_o. Calculate the work done by the confined gas during the process.



2008Bb6. A 0.0040 mol sample of a monatomic gas is taken through the cycle shown above. The temperature T_1 of state 1 is 300 K.
a. Calculate T_2 and T_3.
b. Calculate the amount of work done on the gas in one cycle.
c. Is the net work done on the gas in one complete cycle positive, negative, or zero?
   _____Positive _____Negative _____Zero
d. Calculate the heat added to the gas during process $1 \rightarrow 2$.



2009B4. The cylinder represented above contains 2.2 kg of water vapor initially at a volume of 2.0 m^3 and an absolute pressure of 3.0×10^5 Pa. This state is represented by point A in the PV diagram below. The molar mass of water is 18 g, and the water vapor can be treated as an ideal gas.



a. Calculate the temperature of the water vapor at point A.

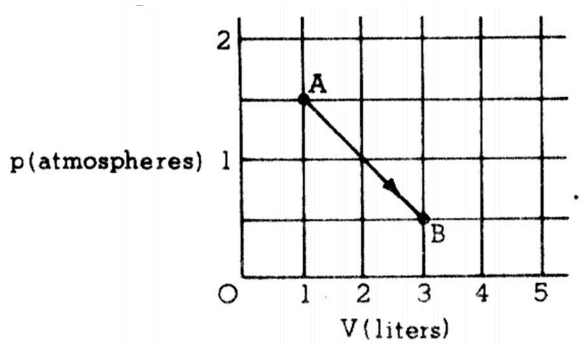
The absolute pressure of the water vapor is increased at constant volume to 4.0×10^5 Pa at point B, and then the volume of the water vapor is increased at constant pressure to 2.5 m^3 at point C, as shown in the PV diagram.

b. Calculate the temperature of the water vapor at point C.

c. Does the internal energy of the water vapor for the process $A \rightarrow B \rightarrow C$ increase, decrease, or remain the same?
____Increase ____Decrease ____Remain the same
Justify your answer.

d. Calculate the work done on the water vapor for the process $A \rightarrow B \rightarrow C$.

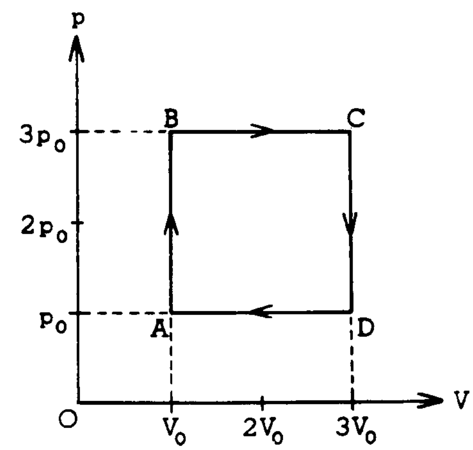
1974B6. One-tenth of a mole of an ideal monatomic gas undergoes a process described by the straight-line path AB shown in the p-V diagram below.



a. Show that the temperature of the gas is the same at points A and B.

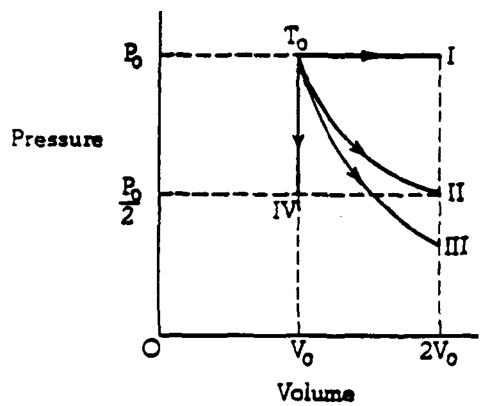
b. How much heat must be added to the gas during the process described by A $\rightarrow$ B?

c. What is the highest temperature of the gas during the process described by A $\rightarrow$ B?



1975B3. One mole of a monatomic ideal gas enclosed in a cylinder with a movable piston undergoes the process ABCDA shown on the p-V diagram above.

a. In terms of p_o and V_o calculate the work done on the gas in the process.
b. In terms of p_o and V_o calculate the net heat absorbed by the gas in the process.
c. At what two lettered points in the process are the temperatures equal? Explain your reasoning.
d. Consider the segments AB and BC. In which segment is the amount of heat added greater? Explain your reasoning.

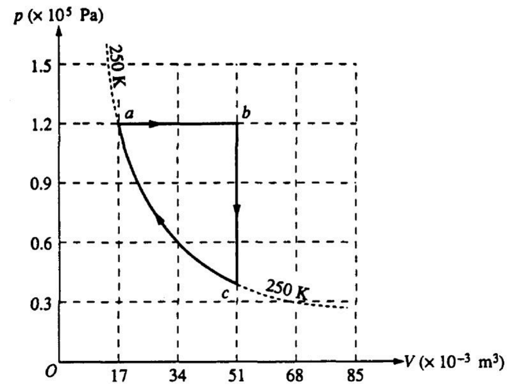


1979B5. Four samples of ideal gas are each initially at a pressure P_o and volume V_o, and a temperature T_o as shown on the diagram above. The samples are taken in separate experiment from this initial state to the final states I, II, III, and IV along the processes shown on the diagram.

a. One of the processes is isothermal. Identify which one and explain.
b. One of the processes is adiabatic. Identify this one and explain.
c. In which process or processes does the gas do work? Explain.
d. In which process or processes is heat removed from the gas? Explain.
e. In which process or processes does the root-mean-square speed of the gas molecules increase? Explain.

1991B3 (modified) 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.



1993B5. 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 $P_a = 1.2 \times 10^5$ pascals, and state c has volume $V_c = 51 \times 10^{-3}$ cubic meter. Process ca lies along the 250 K isotherm. 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 $U_b - U_a$

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 1,800 joules. Determine each of the following.

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

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

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1995B5. A heat engine operating between temperatures of 500 K and 300 K is used to lift a 10-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

ANSWERS - AP Physics Multiple Choice Practice – Thermodynamics

	Solution	Answer
1.	While *all* collisions are elastic and $K_{avg} \propto T$, the molecules move with a wide range of speeds represented by the Maxwellian distribution.	B
2.	For X⇨Y, the process is isobaric. Since the gas is expanding, $W < 0$ and since the temperature is increasing, $\Delta U > 0$ and $\Delta U = Q + W$ so $Q > 0$ (it is also true because process XY lies above an adiabatic expansion from point X)	C
3.	For Y⇨Z, the process is isochoric, which means no work is done ($W = 0$) and since the temperature is increasing, $\Delta U > 0$	C
4.	$PV \propto T$, or $P \propto T/V$ and if $T \times 2$ then $P \times 2$ and if $V \times 4$ then $P \div 4$ so the net effect is $P\times2\div4$	C
5.	$PV \propto T$ so to triple the temperature, the product of P and V must be tripled	A
6.	Changes in internal energy are path independent on a pV diagram as it depends on the change in temperature, which is based on the beginning and end points of the path and not the path taken	B
7.	$K_{avg} \propto T$	C
8.	$H = \dfrac{kA\Delta T}{L}$	B
9.	No work is done in an isochoric process, or a process where $\Delta V = 0$ (a vertical line on the pv graph)	A
10.	The temperature at any point is proportional to the product of P and V. Point A at temperature T_0 is at pressure × volume p_0V_0. Point C is at $3p_0 \times 3V_0 = 9T_0$ and point D is at $2p_0 \times 4V_0 = 8T_0$	C
11.	For the entire cycle, $\Delta U = 0$ and $W = -8$ J so $Q = \Delta U - W = +8$ J (8 J added). This means $Q_{AB} + Q_{BC} + Q_{CA} = +8\text{ J} = +12\text{ J} + 0\text{ J} + Q_{CA} = +8\text{ J}$	B
12.	$Q = +275$ J; $W = +125\text{ J} + (-50\text{ J}) = +75$ J; $\Delta U = Q + W$	C
13.	Work is the area under the curve, the line bounding the greatest area indicates the most work done	A
14.	Temperature rises as you travel up and to the right on a pV diagram. Since processes 1, 2 and 3 are at the same volume, the highest point is at the highest temperature	A
15.	$Q = +400$ J; $W = -100$ J; $\Delta U = Q + W$	B
16.	Isothermal means the temperature is constant. Points to the right or above are at higher temperatures.	B,C
17.	$P \propto T$ at constant volume. If $T \times 2$, then $P \times 2$. Since the mass and volume are unchanged, the density is unchanged as well	C
18.	If the collisions were inelastic, the gas would change its temperature by virtue of the collisions with no change in pressure or volume.	D
19.	related to average speed, $v_{rms} = \sqrt{\dfrac{3RT}{M}}$	C
20.	Being in thermal equilibrium means the objects are at the same temperature. Mass is irrelevant. The question describes the zeroth law of thermodynamics.	C

21. Changes in internal energy are path independent on a pV diagram as it depends on the change in temperature, which is based on the beginning and end points of the path and not the path taken. Different paths, with different areas under them will do different amounts of work and hence, different amounts of heat exchanged. A

22. In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. C

23. “rigid container□ = constant volume. If the speed increases, the temperature will increase, and if the temperature increases at constant volume, the pressure will increase. C

24. $H = \dfrac{kA\Delta T}{L}$ D

25. Q = –16 J; W = –32 J; ΔU = Q + W A

26. $P \propto nT/V$; if n × 3 then P × 3 and if T × 2 then P × 2, the net effect is P × 3 × 2 D

27. ΔU for each process is equal so $Q_{AC} + W_{AC} = Q_{ABC} + W_{ABC}$, or +30 J + (–20 J) = +25 J + W_{ABC} C

28. In any compression, work is done on the gas (W is +). Since the compression is isothermal, ΔU = 0 so Q = –W and heat leaves the gas. A

30. $K_{avg} \propto T$ C

31. In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. A

32. $K_{avg} \propto T$ D

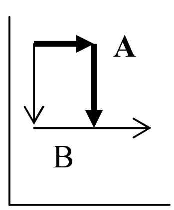
33. $P \propto n/V$ at constant temperature A

34. This question is a bit of a paradox as the energy form the fan giving the air kinetic energy is theoretically adding to the thermal energy of the air, But as the air lowers in temperature, this energy will dissipate into the walls and other outside areas of the room as thermal energy as well. A

35. $K_{avg} \propto T$ B

36. Gas escaping form a pressurized cylinder is an example of an adiabatic process. While the gas rapidly does work (W < 0), ΔU is negative since heat does not have time to flow into the gas in a rapid expansion. A

37. Since process A and B perform the same amount of work, they must have the same area under their respective lines. Since A does the work at a higher pressure, it does not have to move as far to the right as process B, which performs the work at a lower temperature. Since the end of process B lies farther to the right, it is at the higher temperature. B



38. At constant pressure $V \propto T$ (use absolute temperature) C

39. Metals are the best heat conductors and will conduct heat out of the hamburger quickly A

40. Consider the isothermal line as the “dividing line□ between process that increase the temperature of the gas (above the isotherm) and process that lower the temperature of the gas (below the isotherm). A similar analysis can be done to identify heat added or removed from a gas by comparing a process to an adiabat drawn from the same point. C,D

41. $K_{avg} = 3/2\ k_BT$ (use absolute temperature) C

42. In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. Since each side increases by 4%,the area increases by $(1.04)^2 = 1.08$ A

43. $pV = nRT$ and $n = N/N_A$ B

44. $K_{avg} \propto T$ (absolute) D

45. $Q_{abd} = +60\text{ J} + 20\text{ J} = +80\text{ J}$. W_{abd} = area, negative due to expansion = -24 J so $\Delta U = Q + W = +56$ J and $\Delta U_{abd} = \Delta U_{acd}$ and W_{acd} = area = -9 J so $Q_{acd} = \Delta U - W_{acd} = +56\text{ J} - (-9\text{ J})$ B

46. Since there is no area under the line (and no change in volume) W = 0. The temperature (and internal energy) decrease so Q cannot be zero ($Q = \Delta U - W$) C

47. $pV = nRT$ D

48. Pressure is the collisions of the molecules of the gas against the container walls. Even though the speed of the molecules is unchanged (constant temperature), the smaller container will cause the molecules to strike the walls more frequently. B

49. Q = 0 in adiabatic processes (choices B and D). $Q = \Delta U - W$. Choices A and C have the same ΔT and hence, same ΔU and since doubling the volume at constant pressure involves *negative* work, while doubling the pressure at constant volume does *no* work, $\Delta U - W$ is greater for the constant pressure process. (The constant temperature process has $\Delta U = 0$ and less work than the constant pressure process) A

50. $pV = nRT$ (watch those units!) C

51. Isochoric cooling is a path straight down on a pV diagram (to lower pressures) A

52. Work = area under the curve on a *pV diagram*. In the convention stated, work is negative for any expansion. Be careful with the graph since it is a graph of pressure vs. *temperature*. We can find the work by using $|W| = p\Delta V = nR\Delta T$ D

53. Work = area enclosed by the parallelogram. Since the work done *on* the gas is negative for a clockwise cycle and they are asking for the work done *by* the gas, the answer will be positive. B

54. At constant volume $\Delta U = Q = 3/2\ nR\Delta T$ where in an isochoric process $nR\Delta T = \Delta pV$ so $Q = 3/2\ \Delta pV$, or $\Delta p = 2 \times (+40\text{ J})/(3 \times 0.008\text{ m}^3)$ C

55. $v_{rms} = \sqrt{\dfrac{3RT}{M}}$ Since hydrogen is 16 times lighter and $v_{rms} \propto \dfrac{1}{\sqrt{M}}$, $v_H = 4 \times v_O$ B

56. $v_{rms} = \sqrt{\dfrac{3RT}{M}}$ since $M_O > M_H$ for them to have the same v_{rms} $T_O > T_H$ D

57. $v_{rms} = \sqrt{\dfrac{3RT}{M}}$ if v_{rms} is doubled, then T is quadrupled. If $T \times 4$ at constant volume, then $p \times 4$ D

58. The □ energy□ lost or gained would be the sum of the work done on the gas and the net heat adde to the gas, which is the change in internal energy of the gas. Since the gas returns to its original state, $\Delta U = 0$. A, B

59. $$H = \frac{kA\Delta T}{L}$$ A,D

60. An adiabatic expansion is shaped like an isotherm, but brings the gas to a lower temperature. C

61. $Q_{cycle} = Q_{12} + Q_{23} + Q_{31} = +60\text{ J} – 40\text{ J} + 0\text{ J} = + 20\text{ J}$ D
$W_{cycle} = \Delta U_{cycle} – Q_{cycle} = 0\text{ J} – (+20\text{ J}) = –20\text{ J} = W_{12} + W_{23} + W_{31}$
where $W_{12} = –Q_{12}$ since $\Delta U_{12} = 0$ and $W_{23} = 0$
so we have $–20\text{ J} = –60\text{ J} + 0\text{ J} + W_{31}$ which gives $W_{31} = +40\text{ J}$
Process 3⇨1 is adiabatic so $\Delta U_{31} = W_{31}$

1983B4

a. Since T is constant, $p_B V_B = p_0 V_0$ and $V_B = 2V_0$ gives $p_B = ½\ p_0$

b. $\Delta U = Q + W$, since AB is isothermal, $\Delta U = 0$ and $W = –Q = –1000$ J

c. The entropy of the gas increases because $\Delta S = Q/T$ and Q is positive (heat was added)

d. In a reversible (Carnot) engine $\dfrac{Q_H}{Q_C} = \dfrac{T_H}{T_C}$ giving $Q_c = 400$ J

e. Negative. In a clockwise cycle, the work done on the gas is negative. Or for the cycle $Q_{net} = +600$ J and $\Delta U = 0$ so $W = –Q = – 600$ J

1996B7

a. $p_1/T_1 = p_2/T_2$ gives $p_2 = 0.82$ atm $= 8.2 \times 10^4$ Pa

b. $F = p \times \text{Area} = 410$ N

c. Since volume and temperature are constant, we can use $p_1V = n_1RT$ and $p_2V = n_2RT$. SUbtractnig the two equations gives $\Delta pV = \Delta nRT$, or $\Delta n = \Delta pV/RT = 5.45 \times 10^{-3}$ mol

1986B5

a. $e_c = \dfrac{T_H - T_C}{T_H}$ (use absolute temperature) gives $e_c = 0.074$

b. $e = W/Q_H$, or $Q_H = W/e = (100\text{ MW})/(0.074) = 1350$ MW and $Q_C = Q_H – W = 1250$ MW (note Q may represent heat in Joules or rate in Watts)

c. AB is isothermal so $\Delta T = 0$. It is an expansion so W is – and $Q = –W$
BC is adiabatic so $Q = 0$. Temperature drops so ΔT is negative.
CD is isothermal so $\Delta T = 0$. It is a compression so W is + and $Q = –W$
BC is adiabatic so $Q = 0$. Temperature rises so ΔT is positive.

	Q	ΔT
AB	+	0
BC	0	–
CD	–	0
DA	0	+

2004B5B

a. Since $P_A = P_B$ and $V_A/T_A = V_B/T_B$ giving $T_B = T_2 = T_1/2$

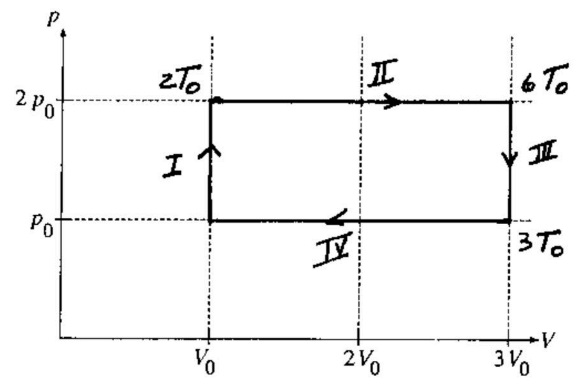
b. CA is an isotherm so $T_A = T_C$ so $P_AV_A = P_CV_C$; $P_1V_1 = P_2(V_1/2)$ giving $P_2 = 2P_1$

c. Work is the area under the line. No work is done from B to C so we just need the area under line AB.
Specifically, $W = –P\Delta V = –P_1(V_1/2 – V_1) = +½P_1V_1$

d. Heat was added in processes BC and CA, but not in AB.
BC: $W = 0$ so $\Delta U = Q$ and temperature rises so ΔU is positive
CA: $\Delta U = 0$ (isotherm) so $Q = –W$ and it is an expansion so W is negative and therefore Q is positive
AB: Compression so W is + and temperature drops so ΔU is negative and $Q = \Delta U – W$ which must be negative

1989B4

a.



b. i. The work done on the gas is the area enclosed. Area = width × height = $2V_0 \times P_0 = –2P_0V_0$ (negative since it is a clockwise cycle)

ii. $\Delta U = 0$ for any cycle

iii. since $\Delta U = 0$, $Q = –W = +2P_0V_0$

c. For process 2, $W = –P\Delta V = –2P_0 \times (3V_0 – V_0) = –4P_0V_0$

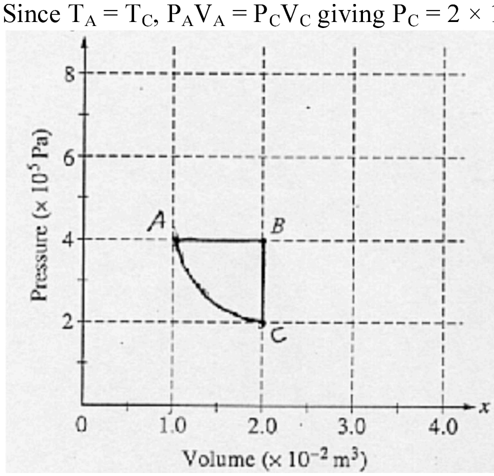
and $\Delta U = 3/2\ nR\Delta T = 3/2\ nR(6T_0 – 2T_0) = +6\ nRT_0 = +6P_0V_0$

$Q = \Delta U – W = +6\ P_0V_0 – (–4P_0V_0) = +10P_0V_0$

1999B7

a. Since $T_A = T_C$, $P_AV_A = P_CV_C$ giving $P_C = 2 \times 10^5$ Pa

b.



c. This is a clockwise cycle so the work done on the gas is negative.

d. This is a clockwise cycle so this is a heat engine.

2001B6

a. The additional pressure comes from the weight of the added block. $\Delta P = F/A = mg/A = 2.04 \times 10^3$ Pa and $P_2 = P_1 + \Delta P = 1.04 \times 10^5$ Pa

b. A constant temperature, $P_1V_1 = P_2V_2$, or $V_2 = P_1V_1/P_2 = 1.47 \times 10^{-3}$ m^3

c. Since the external pressure and the added weight do not change, the pressure remains constant, therefore the process from state 2 to state 3 is isobaric

d. For similar reasons as stated above, the process from state 4 to state 1 is also isobaric.

e. Comparing state 1 and state 4, which have equal pressures: $V_1/T_1 = V_4/T_4$, giving $V_4 = V_1T_4/T_1 = 2.05 \times 10^{-3}$ m^3

2006B5

a. i. $P_1 = P_2$ so $V_1/T_1 = V_2/T_2$ giving $T_2 = 746$ K

ii. $V_1 = V_3$ so $P_1/T_1 = P_3/T_3$ giving $T_3 = 560$ K

b. The net work done is the area enclosed by the triangle = ½ base × height = +6250 J (positive since the cycle is counterclockwise)

c. Since the cycle is counterclockwise, the work done on the gas is positive (more area under the process 2⇨3 in which positive work is done than in process 1⇨2 where negative work is done). In any cycle $\Delta U = 0$ so we have $Q = -W$, therefore Q is negative meaning heat is removed.

2003B5

a. $U_a - U_c = \Delta U_{ca} = Q_{ca} + W_{ca} = 685 \text{ J} + (-120 \text{ J}) = 565$ J

b. i/ii. Heat is removed. $\Delta U_{abc} = -\Delta U_{ca} = -565$ J since it is the opposite beginning and end points, the path doesn't matter. $Q = \Delta U - W = -565 \text{ J} - 75 \text{ J} = -640$ J

c. $W_{cda} = W_{cd} + W_{da} = 0 + -P\Delta V_{da} = -150$ J

d. Heat is added. $\Delta U = +565$ J and $W = -150$ J and $Q = \Delta U - W$

2003B5B

a. $pV = nRT$ so $T = pV/nR = (200 \text{ Pa})(20 \text{ m}^3)/(1 \text{ mol})(8.32 \text{ J/(mol-K)}) = 481$ K

b. The net work done is the area enclosed by the triangle = ½ base × height = +4000 J (positive since the cycle is counterclockwise)

c. i/ii. Heat is removed. In one cycle $\Delta U = 0$ so $Q = -W = -4000$ J

d. In a cyclic process $\Delta U = 0$ (the temperature returns to the same value)

e. The entropy is a function of the state of the gas, and after one complete cycle the gas has returned to its original state so the entropy is the same.

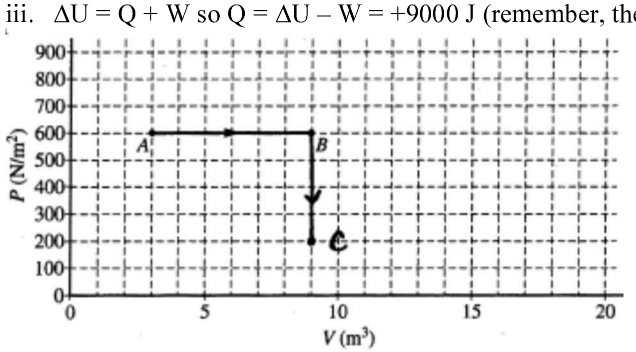
2004B5

a. i. $W = -P\Delta V = -3600$ J. The work done *by* the gas is the negative of the work done *on* the gas, +3600 J

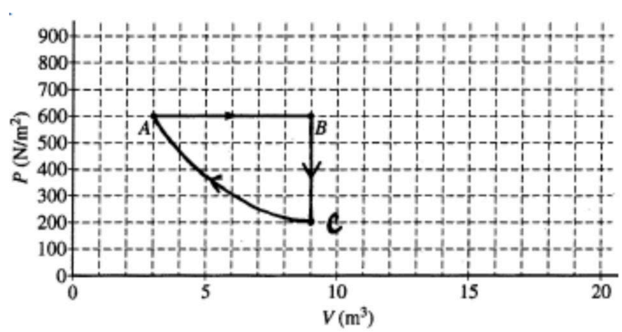
ii. $\Delta U = 3/2\, nR\Delta T$ and the temperatures can be found from $PV = nRT$ giving $T_A = 108$ K and $T_B = 325$ K so $\Delta U = 5400$ J

iii. $\Delta U = Q + W$ so $Q = \Delta U - W = +9000$ J (remember, the W in this equation is the work done *on* the gas)

b.



c.



ii. Heat is removed. In an isothermal process, $\Delta U = 0$ so $Q = -W$ and in a compression W is positive.

2008B5

a.

Process	W	Q	ΔU
$A \to B$	0	+	+
$B \to C$	–	+	0
$C \to A$	+	–	–

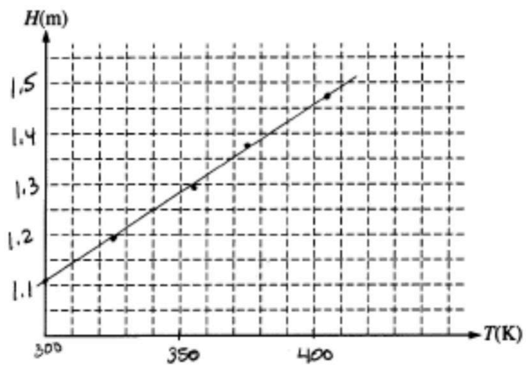
b. ⇨Since process AB is isochoric, $\Delta V = 0$ therefore $W = -P\Delta V = 0$ (also, there is no area under the line)
⇨At constant volume for a fixed number of moles, pressure is directly related to temperature and since the pressure increases, so does the temperature. ΔU is directly related to ΔT so it is positive.
⇨$Q = \Delta U - W$ and $W = 0$

c. Since $T_B = T_C$, $P_BV_B = P_CV_C$ so $V_C = P_BV_B/P_C = 0.005\ m^3$

2005B6

a. The volume of the cylinder = Area × height = AH. PV = nRT then becomes PAH = nRT so H = nRT/PA

b.



c. Calculating the slope of the line above and setting it equal to the slope from the equation of part a: nR/PA gives n = 1.11 moles

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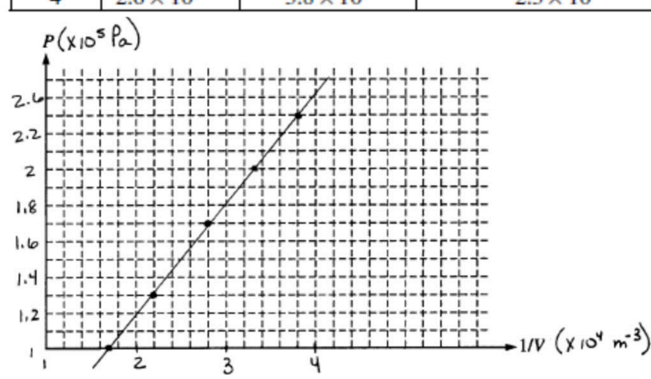
2005B6B

a. PV = nRT or P = (1/V)nRT

b. The total pressure is the atmospheric pressure plus the pressure due to the added mass $P = P_{atm} + mg/A$

m (kg)	V (m^3)	$1/V$ (m^{-3})	P (Pa)
0	6.0×10^{-5}	1.7×10^4	1.0×10^5
1	4.5×10^{-5}	2.2×10^4	1.3×10^5
2	3.6×10^{-5}	2.8×10^4	1.7×10^5
3	3.0×10^{-5}	3.3×10^4	2.0×10^5
4	2.6×10^{-5}	3.8×10^4	2.3×10^5

c.



d. From P = (1/V)nRT, the slope of the above line = nRT. Slope = 6.19 Pa-m^3 so n = .0025 moles

2006B5B

a. i. $T_A = T_B$ so $P_AV_A = P_BV_B$: $P_B/P_A = ½$
 ii. $P_B = P_C$ so $P_C/P_A = P_B/P_A = ½$
 iii. A and B are on the same isotherm so $T_B/T_A = 1$
 iv. $V_C = V_A$ so $P_C/P_A = T_C/T_A = ½$

b. Internal energy depends only on the temperature. Since step I is isothermal there is no change in temperature and thus no change in internal energy

c. $W = –P\ \Delta V$. In step III there is no change in volume, and thus no work done.

2007B5

a. $P = F/A$ so $F = PA = P(\pi R^2) = (4.0 \times 10^5\ \text{Pa})\pi(½\ 0.20\ \text{m})^2 = 1.3 \times 10^4\ \text{N}$

b. $PV = nRT$ gives $V = 1.2 \times 10^{-2}\ \text{m}^3$

c. $W_{\text{on the gas}} = –P\Delta V$ so $W_{\text{by the gas}} = +P\Delta V$ where $\Delta V = Ax = \pi R^2x$ and x = extra distance pushed by the piston giving $W_{by} = 1.9 \times 10^3\ \text{J}$

d. Heat is transferred to the gas. This is an expansion so W_{on} is negative. For the gas to expand at constant pressure, the temperature must also increase so ΔU is positive. $Q = \Delta U – W$.

2007B5B

a. i. For the piston to be in equilibrium, the gas must hold it up against its own weight and the external force due to the outside pressure: $F = P_{atm}A + Mg$ where $A = \pi R^2 = \pi(D/2)^2 = \pi D^2/4$ so we have $F = ¼P_{atm}\pi D^2 + Mg$
 ii. $P = F/A = F$ from above $\div ¼\pi D^2$ giving $P_{abs} = P_{atm} + 4Mg/\pi D^2$

b. Pressure goes up. If heat is added at constant volume, the temperature goes up and so must the pressure since $P \propto T$ at constant volume.

c. $W = Fx$ (from mechanics) $= (¼P_{atm}\pi D^2 + Mg)x_0$

2008B6B

a. $V_1 = V_2$ so $P_1/T_1 = P_2/T_2$ giving $T_2 = 1500\ \text{K}$; $P_1 = P_3$ so $V_1/T_1 = V_3/T_3$ giving $T_3 = 1800\ \text{K}$

b/c. The net work done is the area enclosed by the triangle = ½ base × height = –100 J (negative since clockwise)

d. For process 1⇨2 $W = 0$ so $Q = \Delta U = 3/2\ nR\Delta T = (1.5)(0.004\ \text{mol})(8.31\ \text{J/mol-K})(1500\ \text{K} – 300\ \text{K}) = 60\ \text{J}$

2009B4

a. $PV = nRT$ so $T = PV/nR$ and the number of moles $= (2.2 \times 10^3\ \text{g of}\ H_2O)/(18\ \text{g/mole}) = 122.2$ moles. This gives $T = (3 \times 10^5\ \text{Pa})(2\ \text{m}^3)/(122.2\ \text{moles})(8.31\ \text{J/mol-K}) = 591\ \text{K}$

b. The temperature is proportional to the product of P and V. $(PV)_A = 6 \times 10^5$ J and $(PV)_C = 10 \times 10^5$ J so $T_C/T_A = 10/6$ giving $T_C = 985\ \text{K}$

c. Since the temperature increases for process A⇨B⇨C and U is dependent on the temperature, U increases.

d. $W_{ABC} = W_{AB} + W_{BC} = 0 + –P\Delta V = –(4 \times 10^5\ \text{Pa})(2.5\ \text{m}^3 – 2\ \text{m}^3) = –2 \times 10^5\ \text{J}$

1974B6

a. $P_AV_A/T_A = P_BV_B/T_B$; $(1.5\ \text{atm})(1\ \text{L})/T_A = (0.5\ \text{atm})(3\ \text{L})/T_B$ giving $T_A = T_B$

b. Since $T_A = T_B$, $\Delta U_{AB} = 0$. W is the area under the line = –2 L-atm (negative for an expansion) and we have $Q = \Delta U – W = +2$ L-atm = +202.6 J

c. PV/T is constant so highest temperature is at the highest value of PV where P = 1 atm and V = 2 L. $PV = nRT$ gives $T = 243\ \text{K}$

1975B3

a. The work done on the gas is the area enclosed by the cycle = length×width = $–4p_0V_0$ (negative since clockwise)

b. In the cycle $\Delta U = 0$ so $Q = –W = +4p_0V_0$

c. Temperature is the same where the product p × V is the same: $A = p_0V_0$; $B = 3p_0V_0$; $C = 9p_0V_0$; $D = 3p_0V_0$; $T_B = T_D$

d. AB: $Q = \Delta U – W = 3/2\ nR\Delta T – 0$ and $\Delta T = 2T_0$; so $Q = +3nRT_0 = +3p_0V_0$
 BC: $Q = \Delta U – W = 3/2\ nR\Delta T – (–p\Delta V)$ and $\Delta T = 6T_0$; so $Q = 9p_0V_0 – (–6p_0V_0) = +15p_0V_0$
 $Q_{BC} > Q_{AB}$

1979B5

a. Process II is isothermal. An isothermal process is one in which the temperature is constant. Thus, from the ideal gas law, the product of pressure and volume is a constant. This condition is satisfied by process II.

b. Process III is adiabatic. In an adiabatic process, both the pressure and the volume must change. Thus, processes I and IV are eliminated. Since process II is isothermal, process III is the only possible adiabatic one.

c. The gas does work in processes I, II and III. Work is done by the gas whenever the volume increases. (negative work is done by the gas when the volume decreases as well)

d. In process IV, no work is done. Since the pressure decreases at constant volume, the temperature also decreases, giving ΔU is negative and with $W = 0$, $\Delta U = Q$ and therefore Q is negative. One could also use the adiabatic process as the dividing line between process in which heat is added and those for which heat is removed. On the adiabatic line, $Q = 0$. For any process from the same initial point that lies above the adiabat, heat is added and for any process that lies below the adiabat, heat is removed.

e. RMS speed is proportional to the kinetic energy which, in turn, is proportional to the temperature. Only in process I does the temperature increase.

1991B3

a. Power is the rate of useful work form an engine so W (which here represents the rate in MW) = 120 MW and $e = W/Q_H = 0.40 = 120\text{ MW}/Q_H$ giving $Q_H = 300$ MW

b. The rate of heat input from the combustion of oil is 300 Joules per second. Since oil provides 4.4×10^7 joules per kilogram burned we can divide to find the number of kg per second that must be combusted:
$\Delta m/\Delta t = (300 \times 10^6\text{ J/s}) \div (4.4 \times 10^7\text{ J/kg}) = 6.82\text{ kg/s}$

c. $Q_C = Q_H - W = 180$ MW

1993B5

a. Since $P_a = P_b$, $V_a/T_a = V_b/T_b$ giving $T_b = 750$ K

b/c. $\Delta U_{ab} = 3/2\ nR\Delta T = (1.5)(1\text{ mole})(8.32\text{ J/mol-K})(750\text{ K} - 250\text{ K}) = 6240\text{ J}$
$W_{ab} = -P\Delta V = -(1.2 \times 10^5\text{ Pa})(51 \times 10^{-3}\text{ m}^3 - 17 \times 10^{-3}\text{ m}^3) = -4080\text{ J}$
$Q = \Delta U - W = 10{,}320\text{ J}$

d. $W = -P\Delta V = 0$ (no area under the line)

e. In a cycle $\Delta U = 0$ so $W = -Q = -1800$ J

f. $e_c = \dfrac{T_H - T_C}{T_H} = 0.66$

1995B5

a. $P = Fv$ (from mechanics) $= mgv = (10\text{ kg})(10\text{ m/s}^2)(4\text{ m/s}) = 400\text{ W}$

b. $e_c = \dfrac{T_H - T_C}{T_H} = 0.4$ or 40%

c. i. With an efficiency of 0.4 and useful work done at the rate of 400 W we have $e = (W/t)/(Q_H/t)$ or $(Q_H/t) = 1000$ W
ii. $(Q_C/t) = Q_H/t) - (W/t) = 600$ W
