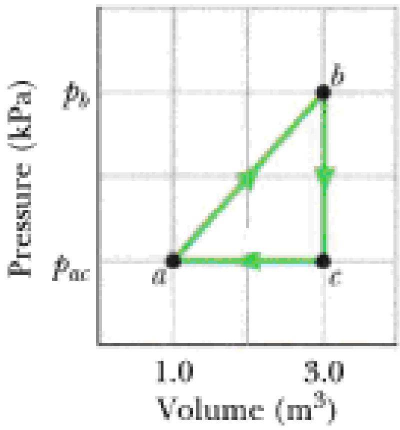
Chapter 19

••15 A sample of an ideal gas is taken through the cyclic process *abca* shown in Fig. 19-21. The scale of the vertical axis is set by $p_b = 7.5$ kPa and $p_{ac} = 2.5$ kPa. At point *a*, $T = 200$ K. (a) How many moles of gas are in the sample? What are (b) the temperature of the gas at point *b*, (c) the temperature of the gas at point *c*, and (d) the net energy added to the gas as heat during the cycle?



a) $PV = nRT \rightarrow n = P_aV_a/RT_a \rightarrow n = 2.5\times10^3\times1.0/(8.31\times200) = 1.5$ mol
b) $T_b = P_bV_b/nR = 7.5\times10^3\times3.0/(1.5\times8.31) = 1800$ K
c) $T_c = P_cV_c/nR = 2.5\times10^3\times3.0/(1.5\times8.31) = 600$ K
d) $Q_{net} = W_{net} = ½\,(3.0 - 1.0)\times(7500 - 2500) = 5000$ J $= 5.0$ kJ

•••16 An air bubble of volume 20 cm³ is at the bottom of a lake 40 m deep, where the temperature is 4.0°C. The bubble rises to the surface, which is at a temperature of 20°C. Take the temperature of the bubble's air to be the same as that of the surrounding water. Just as the bubble reaches the surface, what is its volume?

a) $P = P_0 + \rho gh = 1.013\times10^5 + 998\times9.8\times40 = 4.925\times10^5$ Pa
b) $P_aV_a/T_a = P_bV_b/T_b \rightarrow V_a = P_bV_b\,T_a/T_bP_a$
$V_a = 4.925\times10^5\times20\times(20+273)/[(4.0+273)\times1.013\times10^5)] = 103$ cm3

•18 Calculate the rms speed of helium atoms at 1000 K. See Appendix F for the molar mass of helium atoms.

$$v_{rms} = \sqrt{3RT/M} = \sqrt{3\times8.31\times1000/0.004} = 2496 \text{ m/s} = 2500 \text{ m/s}$$

•19 The lowest possible temperature in outer space is 2.7 K. What is the rms speed of hydrogen molecules at this temperature? (The molar mass is given in Table 19-1.)

$$v_{rms} = \sqrt{3RT/M} = \sqrt{3\times8.31\times2.7/0.00202} = 183 \text{ m/s}$$

•22 The temperature and pressure in the Sun's atmosphere are 2.00×10^6 K and 0.0300 Pa. Calculate the rms speed of free electrons (mass 9.11×10^{-31} kg) there, assuming they are an ideal gas.

$$v_{rms} = \sqrt{3RT/M} = \sqrt{3RT/N_A m} = \sqrt{3\times8.31\times2\times10^6/6.02\times10^{23}\times9.11\times10_{-31}} = 9.53\times10^6 \text{ m/s}$$

•25 Determine the average value of the translational kinetic energy of the molecules of an ideal gas at (a) 0.00°C and (b) 100°C. What is the translational kinetic energy per mole of an ideal gas at (c) 0.00°C and (d) 100°C?

$$\bar{\kappa} = \tfrac{1}{2} m v_{rms}^{2} = (m/2)(3RT/M) = 3mRT/2N_A m = 3RT/2N_A = 3kT/2N$$

(a) For T=273 K, $\bar{\kappa} = \frac{3}{2}\left(1.38\times10^{-23}\ \text{J/K}\right)(273\,\text{K}) = 5.65\times10^{-21}$ J .

(b) For $T = 373$ K, $\bar{\kappa} = 7.72\times10^{-21}$ J .

(c) $K_{\text{mole}} = N_A\bar{\kappa} = (6.02\times10^{23})(5.65\times10^{-21}\ \text{J}) = 3.40\times10^{3}$ J.

(d) $K_{\text{mole}} = (6.02\times10^{23})(7.72\times10^{-21}\ \text{J}) = 4.65\times10^{3}$ J.

•26 What is the average translational kinetic energy of nitrogen molecules at 1600 K? **What if the molecules are oxygen molecules?**

$$\bar{\kappa} = \frac{3}{2}(1.38\times10^{-23}\ \text{J/K})(1600\,\text{K}) = 3.31\times10^{-20}\ \text{J} .$$

1. The rms speed of an oxygen molecule at 0 °C is 460 m/s. If the molar mass of oxygen is 32 g and that of helium is 4 g, then the rms speed of a helium molecule at 0 °C is:

$(v_{rms2}/v_{rms1}) = (3RT/M_2)^{1/2} / (3RT/M_1)^{1/2} = (M_1/M_2)^{1/2} = (32/4)^{1/2} = 2.83$

➔ $v_{rms2} = 2.83\times v_{rms1}$ = **1300 m/s**

2. If the molecules in a tank of hydrogen have the same rms speed as the molecules in a tank of oxygen, then:

$v_{rms2} = v_{rms1}$ ➔ $(3RT_2/M_2)^{1/2} = (3RT_1/M_1)^{1/2}$ ➔ $T_2/T_1 = M_2/M_1 > 0$ since $M_2 > M_1$

a) the pressures are the same
b) the hydrogen is at the higher temperature
c) the hydrogen is at the greater pressure
d) the temperatures are the same
e) the oxygen is at the higher temperature

3. Ideal monatomic gas A is composed of molecules with mass m while ideal monatomic gas B is composed of molecules with mass 4m. The average translational kinetic energies are the same if the ratio of the temperatures T_A/T_B is:

$K = ½\, m\, v^2_{rms} = ½\, m[3RT/M] = 3/2\ RT/N_A$ ➔ if $K_1 = K_2$ then $CT_1 = T_2$ ➔ $T_A = T_B =$ **1**

4. Two ideal gases, each consisting of N monatomic molecules, are in thermal equilibrium with each other and equilibrium is maintained as the temperature is increased. A molecule of the first gas has mass m and a molecule of the second has mass 4m. Find The ratio of the changes in the internal energies $\Delta E_{4m}=\Delta E_m$.

$\Delta T_1 = \Delta T_2 = \Delta T$ and $N_1 = N_2 = N = nN_A$ ➔ $\Delta E_1/\Delta E_2 = n_1C_v\Delta T/\ n_2C_v\Delta T = (N_1/N_A)C_v\Delta T/\ (N_2/N_A)C_v\Delta T =$ **1**

5 Both the pressure and volume of an ideal gas of diatomic molecules are doubled. The ratio of the new internal energy to the old, both measured relative to the internal energy at 0 K, is

$E_2/E_1 = nC_vT_2 / nCvT_1 = n(5/2)RT_2 / n(5/2)RT_1 = nRT_2 / nRT_1 = P_2V_2 / P_1V_1 =$ **4**

6. An ideal gas of N monatomic molecules is in thermal equilibrium with an ideal gas of the same number of diatomic molecules and equilibrium is maintained as the temperature is increased. Find the ratio of the changes in the internal energies $\Delta E_{dia}=\Delta E_{mon}$.

$\Delta E_{dia}=\Delta E_{mon} = nC_{v(dia)}\,\Delta T / nC_{v(mon)}\Delta T = (5/2) / (3/2) =$ **5/3**

7. During a slow adiabatic expansion of a gas:

(an adiabatic process means Q = 0)

a) the pressure remains constant
b) energy is added as heat
c) work is done on
d) no energy enters or leaves as heat
e) the temperature is constant

8. Monatomic, diatomic, and polyatomic ideal gases each undergo slow adiabatic expansions from the same initial volume and the same initial pressure to the same final volume. The magnitude of the work done by the environment on the gas:

PV^γ = constant
➔ $W = \int PdV = constant\ \int dV/V^\gamma = \text{constant}(V_f^{1-\gamma} - V_i^{1-\gamma})/(1-\gamma)$, $\gamma_{mon} = 5/3$, $\gamma_{dia} = 7/5$, $\gamma_{pol} = 9/7$

a) is greatest for the polyatomic gas
b) is greatest for the diatomic gas
c) is greatest for the monatomic gas
d) is the same only for the diatomic and polyatomic gases
e) is the same for all three gases

9. Five mol of a monotomic ideal gas at $P_i = 6.0\times10^5$ Pa and $T_i = 27$ °C goes through a reversible adiabatic expansion. If its volume doubles, find a) P_f, b) T_f, c) ΔE_{int}, d)Q, and e) W.

a) $P_iV_i^\gamma = P_fV_f^\gamma$ ➔ $P_f = P_i(V_i/V_f)^\gamma = 6.0\times10^5[½]^{5/3} = 1.9\times10^5$ Pa

b) $T_iV_i^{\gamma-1} = T_fV_f^{\gamma-1}$ ➔ $T_f = T_i(V_i/V_f)^{\gamma-1}$ =(273+27)[½]$^{(5/3-1)}$ = 1.9×10^5 Pa = 189 K = −84 °C
c) $\Delta E_{int} = nC_v\Delta T$ = 5.0 (3R/2) (189 − 300) = −6918 J = −6.9 kJ
d) since the process is adiabatic then Q = 0
e) W = Q − ΔE_{int} = 6918 J = 6.9 kJ

10. During a reversible adiabatic expansion of an ideal gas, which of the following is NOT true?

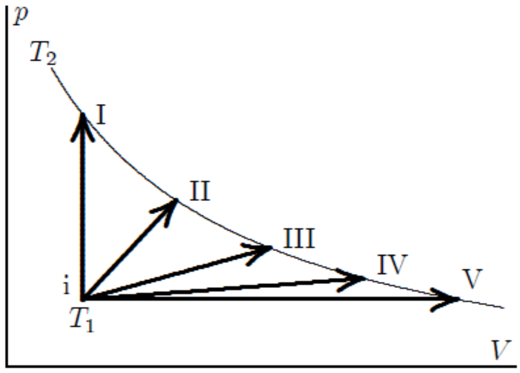
Ideal gas ➔ pV = nRT, adiabatic ➔ $TV^{\gamma-1}$ = constant & pV^{γ} = constant, Work = W = ∫p dV

a) pV^{γ} = constant   b) pV = nRT   c) $TV^{\gamma-1}$ = constant
d) W = ∫p dV   **e) pV = constant**

11. Which of the following is NOT a state variable?

a) Work   b) Internal energy   c) Entropy   d) Temperature   e) Pressure

12. An ideal gas is to be taken reversibly from state i, at temperature T_1, to any of the other states labeled I, II, III, IV, and V on the p-V diagram below. All are at the same temperature T_2. Rank the five processes according to the change in entropy of the gas, least to greatest.



a) I, II, III, IV, V   b) V, IV, III, II, I
c) I, then II, III, IV, and V tied   d) I, II, III, and IV tied, then V
e) I and V tied, then II, III, IV

13. An ideal gas, consisting of n moles, undergoes a reversible isothermal process during which the volume changes from V_i to V_f. The change in entropy of the thermal reservoir in contact with the gas is given by:

a) $nR(V_f - V_i)$ b) $nR\,ln(V_f - V_i)$ **c) $nR\,ln(V_i/V_f)$**   d) $nR\,ln(V_f/V_i)$
e) none of the above (entropy can't be calculated for a reversible process)

14. Two moles of an ideal gas expands reversibly and isothermally at temperature T until its volume is doubled. Find the change of entropy of this gas for this process. $\Delta S = nR\,ln(V_f/V_i) = 2\times8.31\times ln(2)$ = **11.5 J/K**

15. The maximum theoretical efficiency of a Carnot heat engine operating between reservoirs at the steam and at the freezing points temperatures of water is about: **(27 %)**

16. A perfectly reversible heat pump with a coe±cient of performance of 14 supplies energy to a building as heat to maintain its temperature at 27 ºC. If the pump motor does work at the rate of 1 kW, at what rate does the pump supply energy to the building as heat? $W + Q_L = W(1 + K) =$ **Q_H = 15 kW**

17. A certain heat engine draws 500 cal/s from a water bath at 27 ºC and transfers 400 cal/s to a reservoir at a lower temperature. Find the efficiency of this engine. **(20 %)**

18. A heat engine operates between 200K and 100K. In each cycle it takes 100 J from the hot reservoir, loses 25 J to the cold reservoir, and does 75 J of work. This heat engine violates:

a) both the first and second laws of thermodynamics
b) the first law but not the second law of thermodynamics
c) the second law but not the first law of thermodynamics
d) neither the first law nor the second law of thermodynamics
e) cannot answer without knowing the mechanical equivalent of heat

19. A block that slides on a rough surface slows down and eventually stops. The reverse process never occurs. That is, a block at rest never begins to move and accelerate on a rough surface without the action of an external agent. The second situation is forbidden because it would violate which of the following choices.

a) second law of thermodynamics
b) first law of thermodynamics
c) both the first and second laws of thermodynamics
d) conservation of momentum
e) conservation of total energy