Solutions to Problems in Thermodynamics

AP Physics B

Mr. DiBucci

{Solutions to Temp. + Ideal GAS}

DiBucci

1. Since the cross sectional area does not change: $\cancel{A_1}v_1 = \cancel{A_2}v_2 \therefore v_1 = v_2$

$P_1 + \rho g h_1 = P_2 + \rho g h_2$

$P_A + \rho g h_A = P_B + \rho g h_B$

$P_B - P_A = \rho g h_A - \rho g h_B$

$P_B - P_A = \rho g (h_A - h_B)$

$= (925\ kg/m^3)(9.8\ m/s^2)(0 - 4m)$

$$\boxed{P_B - P_A = -3.6 \times 10^4\ Pa}$$

---

2. $T_K = T_C + 273.15$

$T_C = \cancel{T_K}^{0} - 273.15$

$T_C = -273.15°C$

$273.15°C\left(\frac{9/5\ F°}{1\ C°}\right) = 491\ F°$

273.15°C Below Ice point; 491 F° Below Ice point

$32°F - 491\ F° = \boxed{-459\ °F}$

---

3) $\Delta l = \alpha l_0 \Delta T = (12\times10^{-6}\ 1/C°)(1km)(30°C - (-10°C))$

$= 4.8\times10^{-4}\ km = \boxed{.48m} \approx 48cm$

---

4) Over Flow $= \Delta V_{gas} - \Delta V_{TANK}$

$= \beta_g V_{0gas} \Delta T - \beta_{TANK} V_{0TANK} \Delta T$

same; same

$= (\beta_g - \beta_T) V_0 \Delta T = (\beta_g - 3\alpha_T) V_0 \Delta T$

$= [9.5\times10^{-4}\ 1/C° - 3(12\times10^{-6}\ 1/C°)](0.070m^3)(50°C - 20°C)$

$$\boxed{= 0.00192 m^3}$$

5) $64g\ SO_2 \left(\frac{1\,\cancel{mol}}{64\,g}\right)\left(\frac{6.02\times10^{23}}{1\,\cancel{mol}}\right) = \boxed{6.02\times10^{23}\ \text{molecules}}$

$2(16\,g/mol) + (32\,g/mol)$

---

6) $1.5\,\cancel{mol}\left(\frac{2g}{1\,\cancel{mol}}\right) = 3g = 0.003\,kg$

---

7) $230g\ CO_2\left(\frac{1\,mol}{44g}\right) = 5.23\,mol$

---

9) $\frac{P_2 \cancel{V_2}}{P_1 \cancel{V_1}} = \frac{\cancel{nR}T_2}{\cancel{nR}T_1} = \frac{195K}{305K} = \boxed{.639}$

switch

---

8) $\frac{P_2 V_2}{P_1 V_1} = \frac{\cancel{nR}T_2}{\cancel{nR}T_1}$

$P_2 = 2P_1$
$V_2 = 2V_1$

$\frac{(2\cancel{P_1})(2\cancel{V_1})}{\cancel{P_1}\cancel{V_1}} = \frac{T_2}{T_1}$

$4 = \frac{T_2}{T_1}$

$T_2 = 4T_1 = 4(293\,K)$

$T_2 = 1172K$

$\boxed{T_2 = 899°C}$

---

10) Convert to kelvin

$\frac{\cancel{P_2}V_2}{\cancel{P_1}V_1} = \frac{\cancel{nR}T_2}{\cancel{nR}T_1}$

$V_2 = V_1\left(\frac{T_2}{T_1}\right) = (1.5\,m^3)\left(\frac{348K}{303K}\right)$

$\boxed{V_2 = 1.72\,m^3}$

Solutions to Kinetic theory of GASSES

DIBUCCI

1. $\frac{\cancel{P_1} V_1}{\cancel{P_2} V_2} = \frac{\cancel{n_1 R} T_1}{\cancel{n_2 R} T_2} \Rightarrow \frac{V_1}{V_2} = \frac{T_1}{T_2} \Rightarrow V_2 = V_1 \frac{T_2}{T_1} = (1.50\,m^3)\left[\frac{348K}{303K}\right]$

$\boxed{V_2 = 1.72\,m^3}$

---

2) $15g\ N_2 \cdot \left(\frac{1\,mol}{28g}\right) = 0.536\,mol$

$PV = nRT \Rightarrow P = \frac{nRT}{V} = \frac{(0.536\,\cancel{mol})(8.315\,\frac{J}{\cancel{mol}\cdot K})(525K)}{(0.020\,m^3)}$

$P = 1.17\times10^5\,Pa = \boxed{1.2\times10^5\,Pa}$

---

3) $V_{RMS} = \sqrt{\frac{3K_BT}{m}} = \sqrt{\frac{3(1.38\times10^{-23}\,J/K)(278K)}{5.31\times10^{-26}\,kg}}$

$\boxed{= 465.6\,m/s}$

Use

$\boxed{1u = 1.66\times10^{-27}\,kg}$

$31.9988\,u\left(\frac{1.66\times10^{-27}\,kg}{1u}\right) = 5.31\times10^{-26}\,kg$

(OR)

$1\,mol\ O_2 = 32g = 0.032\,kg$

$1\ \text{molecule} = \frac{0.032\,kg}{6.02\times10^{23}} = 5.31\times10^{-26}\,kg$

---

4) $U = \frac{3}{2}nRT$ (TOTAL internal energy)

$1.75\times10^3 g\left(\frac{1\,mol}{4g}\right) = \underline{437.5\,mol}$

$U = \frac{3}{2}\left(8.315\,\frac{J}{\cancel{mol}\cdot \cancel{K}}\right)(437.5\,\cancel{mol})(373K)$

$\boxed{U = 2.04\times10^6\,J}$

12.4 Linear EXPANSION

15. $\Delta l = \alpha l_0 \Delta T$

$$\frac{\Delta l}{l_0} = \alpha \Delta T = (12\times10^{-6}\ 1/C^\circ)(120 F^\circ)\left(\frac{1C^\circ}{\frac{9}{5}F^\circ}\right) = 8\times10^{-4}\ m$$

12.5 Volume EXPANSION

31) $r_i = 9.5\times10^{-3}\,m$

$l_0 = 76\,m$

$T_0 = 24^\circ C$

$T_F = 78^\circ C$

$$\Delta V_w = \beta_w V_{0_w} \Delta T$$

$$\Delta V_{cu} = \beta_{cu} V_{0_{cu}} \Delta T$$

$$V_{0_{cu}} = \pi r_i^2 l_0$$

the hole expands As if it were solid

$$V_{needed} = \Delta V_w - \Delta V_{cu} = (\beta_w - \beta_{cu}) V_0 \Delta T$$

$$= \left(207\times10^{-6}\frac{1}{C^\circ} - 51\times10^{-6}\frac{1}{C^\circ}\right)\pi(9.5\times10^{-3}m)(76m)(54^\circ C)$$

$$= 1.8\times10^{-4}\,m^3$$

33) $\Delta V = \beta_0 V_0 \Delta T$

$$\Delta V = (280\times10^{-6}\ 1/C^\circ)(1 gal)(22C^\circ) = 6.2\times10^{-3}\,gal$$

at \$2 per gallon $\Delta\$ = \$0.01$ $\boxed{1 penny}$

14.2 IDEAL GAS Solutions

13) $\dfrac{P_o V_o = \cancel{n} \cancel{R} T_o}{P_f V_f = \cancel{n} \cancel{R} T_f}$

$\dfrac{\cancel{P_o}}{48.5 \cancel{P_o}} \cdot \dfrac{\cancel{V_o}}{\frac{1}{16} \cancel{V_o}} = \dfrac{T_o}{T_F}$

$\dfrac{16}{48.5} = \dfrac{T_o}{T_F} \Rightarrow T_F = T_o \dfrac{48.5}{16} = \boxed{924.5\,K}$

$=$

14) $4g\ H_2O \left(\dfrac{1\,mol}{18g}\right) = .22\,mol$

$PV = nRT$

$P = \dfrac{nRT}{V} = \dfrac{(8.31\,J/mol\,K)(.22\,mol)(388K)}{(0.030\,m^3)}$

$\boxed{= 23.6\,kPa}$

18) $\dfrac{\cancel{P_o} V_o = \cancel{n_o} \cancel{R} T_o}{\cancel{P_f} V_f = \cancel{n} \cancel{R} T_f} \Rightarrow \dfrac{V_o}{V_f} = \dfrac{T_o}{T_F} \Rightarrow \dfrac{\cancel{A} h_1}{\cancel{A} h_2} = \dfrac{T_o}{T_F}$

$h_2 = h_1 (T_F / T_o) = (.120m)\left(\dfrac{318\,K}{273\,K}\right)$

$\boxed{= .140\,m}$

Ideal GAS 14-2

26) $P_1 V_1 = n_1 R T_1$ $\qquad$ $P_2 V_2 = n_2 R T_2$

$$n_1 = \frac{P_1 V_1}{R T_2} \qquad n_2 = \frac{P_2 V_2}{R T_2}$$

$$n_1 = \frac{(5\times10^5 \text{ Pa})(2.0\text{ m})}{(8.315 \text{ J/mol k})(220\text{ k})} = 546.7\text{ mol} \qquad n_2 = \frac{(2\times10^5 \text{ PA})(5.8\text{ m}^3)}{(8.315 \text{ J/mol k})(580\text{ k})} = 240.5\text{ m}$$

$n_T = 546.7\text{ mol} + 240.5\text{ mol} = \underline{787.2\text{ mol}}$

$V_T = \underline{7.8\text{ m}^3}$

$m_1 = (546.7\text{ m})(20.2\text{ g/mol}) = 11.04\text{ kg}$ $\qquad$ $m_2 = 240.5\text{ mol}\left(\frac{20.2\text{ g}}{\text{mol}}\right) = 4.86\text{ kg}$

$m_1 \cancel{c} \Delta T_1 = -m_2 \cancel{c} \Delta T_2$

$11.04(T_F - 220) = -4.86(T_F - 580)$

$11.04T_F - 2428.8 = -4.86T_F + 2819$

$15.9\,T_F = 5248$

$\boxed{T_F = 330\text{ K}}$

B

$PV_T = n_T R T_F$

$$P = \frac{n_F R T_F}{V_F} = \frac{(787.2\text{ mol})(8.315 \text{ J/mol k})(330\text{ k})}{(7.8\text{ m}^3)}$$

$$\boxed{= 2.77\times10^5 \text{ Pa}}$$

14.3 Kinetic theory of Gasses Solutions

30) $T = 6\times10^3\ K$
$m = 1.67\times10^{-27}\ kg$

$$V_{rms} = \sqrt{\frac{3K_B T_K}{m}}$$

$$V_{rms} = \sqrt{\frac{3(1.38\times10^{-23}\frac{J}{K})(6\times10^3 K)}{1.67\times10^{-27}\ kg}}$$

$$\boxed{=1.22\times10^4\ m/s}$$

31)

$n = 2\ mol$
$V = 8.5\times10^{-3}\ m^3$
$P = 4.5\times10^5\ Pa$

$$KE_{Avg} = \frac{3}{2}K_B T$$

Find T
$PV = nRT$

$$T = \frac{PV}{nR} = \frac{(4.5\times10^5\ Pa)(8.5\times10^{-3}\ m^3)}{(2\ mol)(8.31\times J/mol\ K)}$$

$$\boxed{T = 230K}$$

$$KE_{Avg} = \frac{3}{2}(1.38\times10^{-23}\frac{J}{K})(230K)$$

$$\boxed{=4.76\times10^{-21}\ J}$$

33)
A) $\overline{V^2} \Rightarrow$

3^2
7^2
$+\ 9^2$
139

$$\frac{139}{3} = \boxed{46.3\frac{m^2}{s^2}}$$

B) $(\overline{V})^2 \Rightarrow$

3
7
9
19

$\frac{19}{3} = 6.33\frac{m}{s}$

6.33^2

$\boxed{=40.1\frac{m^2}{s^2}}$

37) $V_0 = 680\ m^3$ Ne
$P_0 = 1.01\times10^5\ Pa$
$T_0 = 293.2K$
$T_f = 294.3K$

$PV = nRT$

$$n = \frac{P_0 V_0}{R T_0} = \frac{(1.01\times10^5\ Pa)(680\ m^3)}{(8.31\frac{J}{mol\ K})(293.2K)}$$

$$n = 2.82\times10^4\ mol$$

Internal Energy

$$U_0 = \frac{3}{2}nRT_0 = \frac{3}{2}n(8.31)(293.2) = 1.0306\times10^8\ J$$

$$U_f = \frac{3}{2}nRT_f = \frac{3}{2}n(8.31)(294.3) = 1.0345\times10^8\ J$$

$$\boxed{3.90\times10^5\ J}$$

Solutions to Intro. to thermal Energy

1.

$$\frac{\Delta Q}{\Delta t} = KA\frac{\Delta T}{\Delta x}$$

$T_h = 100°c$

$T_L = 0°c$

$\Delta x = 0.17m$

$A = 4.44cm^2\left(\frac{(1m)^2}{(100cm)^2}\right) = 4.44\times10^{-4}m^2$

$K = ?$

$$K = \frac{\Delta Q\,\Delta x}{\Delta t\,\Delta T\,A}$$

$\Delta Q = m_I L_f$

$\Delta Q = (1\times10^{-3}kg)(3.33\times10^5\frac{J}{kg})$

$\Delta Q = 333J$

$$= \frac{(333J)(0.17m)}{(26s)(100c°)(4.44\times10^{-4}m^2)}$$

$$\boxed{= 49\frac{W}{m\,c°}}$$

2)

$$\boxed{\Sigma Q_{gain} = -\Sigma Q_{Lost}}$$

$$m_I L_f + m_I C_I \Delta T_1 + m_I C_w \Delta T_2 = -m_w C_w \Delta T_3$$

$$m_I\left[L_F + C_I \Delta T_1 + C_w \Delta T_2\right] = -m_w C_w \Delta T_3$$

$$m_I = \frac{-m_w C_w \Delta T_3}{L_F + C_I \Delta T_1 + C_w \Delta T_2}$$

$$= \frac{(.566kg)(4190\,J/kg\,c°)(6°c - 61°c)}{334\times10^3\frac{J}{kg} + (2000\,J/kg°c)(0_{c°} - (-19)_{c°}) + (4190\frac{J}{kg°c})(6-0)}$$

$$= \frac{1.30\times10^5\,J}{3.97\times10^5\,J/kg} = .327kg$$

$$\boxed{= 327g}$$

3. $m_{Fe} = 0.120 kg$ $T_{0,Fe} = 336°C$
$m_{cu} = 0.50 kg$ $T_{0,cu} = 20°C$ $T_F = ?$ system
$m_w = 0.20 kg$ $T_{0,w} = 20°C$

$$\Sigma Q_{gained} = -\Sigma Q_{lost}$$

$$m_w C_w \Delta T_w + m_{cu} C_{cu} \Delta T_{cu} = -m_{Fe} C_{Fe} \Delta T_{Fe}$$

$$(.2kg)(4190 \tfrac{J}{kg C°})(T_F - 20) + (.5)(390 \tfrac{J}{kg C°})(T_F - 20) = -(.12kg)(470 \tfrac{J}{kg C°})(T_F - 336)$$

$$(838 \tfrac{J}{kg C°})(T_F - 20) + (195 \tfrac{J}{kg C°})(T_F - 20) = (-56.4 \tfrac{J}{kg C°})(T_F - 336)$$

$$838 T_F - 1.68 \times 10^4 + 195 T_F - 3900 = -56.4 T_F + 1.90 \times 10^4$$

$$838 T_F + 195 T_F + 56.4 T_F = 1.9 \times 10^4 + 3900 + 1.68 \times 10^4$$

$$1089 T_F = 3.97 \times 10^4$$

$$\boxed{T_F = 36.4°C}$$

Heat AND Phase change: Latent Heat

57) $Q = mC_s\Delta T + mL_f$

$= (0.45kg)\left[(900\ J/kg\,C°)(660°_c - 130°_c) + (4\times10^5\ J/kg)\right]$

$\boxed{= 3.95\times10^5\ J}$

60) $m = \rho V = \rho A \cdot t = (917\ kg/m^3)(4.5\times10^{-4}\ m)(1.25\ m^2) = .516\ kg$

$Q = mC_I\Delta T + mL_F = m(C_I\Delta T + L_F)$

$= (.516\ kg)\left[(2\times10^3\ \frac{J}{kg\,C°})(0-(-12°)) + (33.5\times10^4\ J/kg)\right]$

$\boxed{= 1.85\times10^5\ J}$

62) $\Sigma Q_{gained} = -\Sigma Q_{lost}$

$m_w L_{v_w} = -m_p C_p \Delta T_p$

$m_w = -\frac{m_p C_p \Delta T_p}{L_{v_w}} = \frac{-(75\,kg)(3500\ \frac{J}{kg\,C°})(-1.5\,C°)}{22.6\times10^5\ J/kg}$

$\boxed{= .174\ kg}$

67) $\frac{1}{2}mV_0^2 + W_F = \frac{1}{2}mV_f^2$

$W_F = \frac{1}{2}mV_f^2 - \frac{1}{2}mV_0^2 = \frac{1}{2}m(V_f^2 - V_0^2) = -336.18\ J$

$Q = 336.2\ J = m_i L_F$

$m_i = \frac{336.2\ J}{33.5\times10^4\ J/kg} = 0.001\ kg$

$\boxed{1\times10^{-3}\ kg}$

CHAPTER 13 | *THE TRANSFER OF HEAT*

PROBLEMS

1. $\boxed{\text{SSM}}$ ***REASONING*** The heat conducted through the iron poker is given by Equation 13.1, $Q = (kA\,\Delta T)t/L$. If we assume that the poker has a circular cross-section, then its cross-sectional area is $A = \pi r^2$. Table 13.1 gives the thermal conductivity of iron as $79\ \text{J/(s}\cdot\text{m}\cdot\text{C}^\circ)$.

   SOLUTION The amount of heat conducted from one end of the poker to the other in 5.0 s is, therefore,

$$Q = \frac{(kA\Delta T)t}{L} = \frac{[79\ \text{J/(s}\cdot\text{m}\cdot\text{C}^\circ)]\pi\left(5.0\times10^{-3}\ \text{m}\right)^2(502\ ^\circ\text{C} - 26\ ^\circ\text{C})(5.0\ \text{s})}{1.2\ \text{m}} = \boxed{12\ \text{J}}$$

2. ***REASONING AND SOLUTION*** The rate at which energy is gained through the refrigerator walls is

$$\frac{Q}{t} = \frac{kA\Delta T}{L} = \frac{[0.030\ \text{J/(s}\cdot\text{m}\cdot\text{C}^\circ)]\left(5.3\ \text{m}^2\right)\left(2.0\times10^1\ \text{C}^\circ\right)}{0.075\ \text{m}} = 42\ \text{J/s}$$

   Therefore, the amount of heat per second that must be removed from the unit to keep it cool is $\boxed{42\ \text{J/s}}$.

3. ***REASONING AND SOLUTION*** The heat Q conducted during a time t through one side of the cubical box with walls of thickness L and cross-sectional area A is given by Equation 13.1:

$$Q = \frac{(kA\Delta T)\ t}{L}$$

   Since the cube has six faces, the total heat conducted through all six faces is $Q_{\text{total}} = 6Q$, or

$$Q_{\text{total}} = \frac{6(kA\Delta T)\ t}{L}$$

   Solving for the thermal conductivity, k, we have

$$k = \frac{Q_{\text{total}}L}{6A\Delta Tt} = \frac{(3.10\times10^6\ \text{J})(3.00\times10^{-2}\ \text{m})}{6(0.350\ \text{m})^2[21.0\ ^\circ\text{C} - (-78.5\ ^\circ\text{C})](24\ \text{h})}\left(\frac{1.00\ \text{h}}{3600\ \text{s}}\right) = \boxed{1.47\times10^{-2}\ \text{J/(s}\cdot\text{m}\cdot\text{C}^\circ)}$$

4. ***REASONING AND SOLUTION***

a. The heat lost by the oven is

$$Q = \frac{(kA\Delta T)t}{L} = \frac{[0.045\ \mathrm{J/(s\cdot m\cdot C^\circ)}](1.6\ \mathrm{m}^2)(160\ ^\circ\mathrm{C} - 50\ ^\circ\mathrm{C})(6.0\ \mathrm{h})\left(\dfrac{3600\ \mathrm{s}}{1\ \mathrm{h}}\right)}{0.020\ \mathrm{m}}$$

$$= \boxed{8.6\times10^{6}\ \mathrm{J}}$$

b. Now 1 J = 2.78×10^{-7} kWh, so Q = 2.4 kWh. At \$ 0.10 per kWh, the cost is $\boxed{\$\ 0.24}$.

---

14. ***REASONING AND SOLUTION*** The rate of heat transfer is the same for all three materials so

$$Q/t = k_pA\Delta T_p/L = k_bA\Delta T_b/L = k_wA\Delta T_w/L$$

Let T_i be the inside temperature, T_1 be the temperature at the plasterboard-brick interface, T_2 be the temperature at the brick-wood interface, and T_o be the outside temperature. Then

$$k_pT_i - k_pT_1 = k_bT_1 - k_bT_2 \qquad (1)$$

and

$$k_bT_1 - k_bT_2 = k_wT_2 - k_wT_o \qquad (2)$$

Solving (1) for T_2 gives

$$T_2 = (k_p + k_b)T_1/k_b - (k_p/k_b)T_i$$

a. Substituting this into (2) and solving for T_1 yields

$$T_1 = \frac{(k_p/k_b)(1+k_w/k_b)T_i + (k_w/k_b)T_0}{(1+k_w/k_b)(1+k_p/k_b) - 1} = \boxed{21\ ^\circ\mathrm{C}}$$

b. Using this value in (1) yields

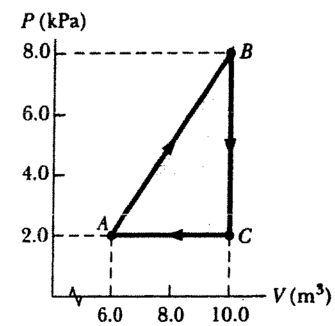
$$\boxed{T_2 = 18\ ^\circ\mathrm{C}}$$

Name Solutions per. ___ Date ______ DiBUCCI

The First Law of Thermodynamics DiBucci

1. A gas is taken through a cyclic process as described in the figure below.
   a. Find the net thermal energy transferred to the system during one cycle.
   b. If the cycle is reversed, what is the net thermal energy transferred in one cycle?

Work for 1cycle = Area enclosed By TRIANGLE



$W_{A\to B}$ is negative

$W_{B\to C} = 0$

$W_{C\to A}$ is positive $\quad |W_{A\to B}| > |W_{C\to A}|$

$\therefore$ TOTAL work is negative.

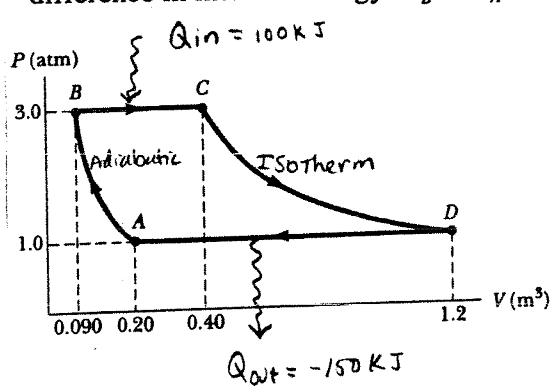
$W_{TOTAL} = -\frac{1}{2}bh = -\frac{1}{2}[10m^3 - 6m^3][8-2\ Pa]\times 10^3$

$W_T = -12000J = \boxed{-12KJ}$

$\Delta U_{cycle} = Q_{TOTAL} + W_{TOTAL} \qquad \Delta U_{cycle} = 0$

$Q_{TOTAL} = -W_{TOTAL} = -(-12\ KJ) = \boxed{+12KJ}$

2. A gas system goes through the process shown in the diagram below. From A to B the process is adiabatic, and from B to C the process it is isobaric with 100 kJ of heat flowing into the system. From C to D the process is isothermal, and from D to A the process is isobaric with 150 kJ of heat flowing out of the system. Determine the difference in internal energy $U_B - U_A$.



$W_{B\to C} = -[(3atm)(1.013\times 10^5 \frac{Pa}{Atm})][.4m^3 - .09m^3]$

$= -9.42\times 10^4 J = \underline{-94.2KJ}$

$\Delta U_{B\to C} = U_C - U_B = Q + W = 100KJ + (-94.2KJ)$

$\boxed{= 5.79KJ}$

$\Delta U_{D\to C} = \boxed{0J}$ (Isothermal)

$W_{D\to A} = -(1ATM(1.013\times 10^5 Pa/Atm)(.2m^3 - 1.2m^3) = +1.01\times 10^5 J = \underline{+101\ KJ}$

$\Delta U_{D\to A} = U_A - U_D = Q + W = (-150KJ) + (101KJ) = \boxed{-49KJ}$

$\Delta U_{A\to B} + \Delta U_{B\to C} + \Delta U_{C\to D} + \Delta U_{D\to A} = 0$

$\Delta U_{A\to B} = -[\Delta U_{B\to C} + \Delta U_{C\to D} + \Delta U_{D\to A}] = -[5.79KJ + 0KJ + (-49KJ)]$

$\boxed{= +43KJ}$ ANS

Solutions: Thermal Processes

DiBucci

7. ISOBARIC

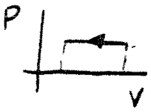
a) $V_0 = 7\times10^{-3}\,m^3$

$V_f = 2\times10^{-3}\,m^3$

$P = 1.5\times10^5\,Pa$

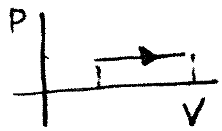
a) $W = -P\Delta V$

$= -1.5\times10^5\,Pa\,(2\times10^{-3}m^3 - 7\times10^{-3}m^3) = \boxed{+750\,J}$



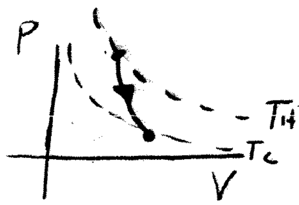
b) $W = -P\Delta V = -1.5\times10^5\,Pa\,(8\times10^{-3}m^3 - 2\times10^{-3}m^3)$

$W = \boxed{-900\,J}$



8) $\Delta U = +210\,J$

Adiabatic $Q = 0$



$\Delta U = \cancel{Q}^{\,0} + W$

$W = \Delta U = \boxed{+210\,J}$

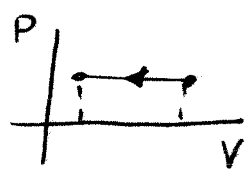
Work is Done on the system

9) $Q = +1500\,J$ ISOBARIC

$\Delta U = +4500\,J$

$\Delta V = -0.010\,m^3$

$P = ?$



$\Delta U = Q + W$

$\Delta U = Q - P\Delta V$

$\Delta U - Q = -P\Delta V$

$P\Delta V = Q - \Delta U$

$$P = \frac{Q - \Delta U}{\Delta V} = \frac{+1500\,J - (4500\,J)}{-0.010\,m^3} = \boxed{3\times10^5\,Pa}$$

Solutions: continued

10)
* each block $= (1.0\times10^4 Pa \times 2\times10^{-3} m^3) = 20$ Joules/block
* gas is expanding so work is negative

$$\left.\begin{aligned} W_{AB} &= -60 \text{ blocks}\left(\frac{20 \text{ Joules}}{\text{block}}\right) = -1200\text{ J} \\ W_{BC} &= -90 \text{ blocks}\left(\frac{20 \text{ Joules}}{\text{block}}\right) = -1800\text{ J} \end{aligned}\right\} = \boxed{-3\times10^3\text{ J}}$$

by the system

14)
$$W_{AB} = -3\times10^5 Pa\,(5\times10^{-3}m^3 - 2\times10^{-3}m^3)$$
$$\boxed{= -900\text{ J}}$$

$W_{BC} = 0\text{ J}$ (Isochoric)

$W_{CA} \Rightarrow$ USE AREA (Positive because ΔV is "$-$")

$= \text{AREA } \Delta + \text{AREA } \square$
$= \frac{1}{2}bh_1 + bh_2$

$$= \frac{1}{2}(5\times10^{-3} - 2\times10^{-3})(7\times10^5 - 3\times10^5) + (5\times10^{-3} - 2\times10^{-3})(3\times10^5 Pa)$$
$$= 600\text{ J} + 900\text{ J} = \boxed{+1500\text{ J}}$$

Solutions continued.

15) $V_0 = 1.4\times10^{-3}\,m^3$

$\beta = 69\times10^{-6}\ 1/c^\circ$

$T_0 = 20^\circ$

$T_F = 320^\circ C$

$P = 1.01\times10^5\,Pa$

$\Delta V = \beta V_0 \Delta T$

$W = -P\Delta V$

$W = -P\beta V_0 \Delta T$

$W = -(1.01\times10^5 Pa)(69\times10^{-6}\frac{1}{^\circ C})(1.4\times10^{-3}m^3)(320^\circ c - 20^\circ c)$

$\boxed{= -2.93\text{ Joules}}$

16) $P = 2.6\times10^5\,Pa$ <u>ISOBARIC</u>

$\Delta V = +6.2\times10^{-3}\,m^3$

$Q = ?$

$PV = nRT$

$P\Delta V = nR\Delta T$

$\Delta U = Q + W$

$3/2\, nR\Delta T = Q + (-P\Delta V)$

$3/2\,(P\Delta V) = Q - P\Delta V$

$3/2\, P\Delta V + P\Delta V = Q$

$Q = \frac{5}{2} P\Delta V = \frac{5}{2}(2.6\times10^5 Pa)(6.2\times10^{-3} m^3)$

$= {}^{+}4030\text{ J}$ heat flows into the gas.

Solutions continued.

15) $V_0 = 1.4 \times 10^{-3}\ m^3$

$\beta = 69 \times 10^{-6}\ 1/C°$

$T_0 = 20°$

$T_F = 320°C$

$P = 1.01 \times 10^5\ Pa$

$\Delta V = \beta V_0 \Delta T$

$W = -P \Delta V$

$W = -P \beta V_0 \Delta T$

$W = -(1.01 \times 10^5\ Pa)(69 \times 10^{-6} \frac{1}{°C})(1.4 \times 10^{-3}\ m^3)(320°C - 20°C)$

$\boxed{= -2.93 \text{ Joules}}$

16) $P = 2.6 \times 10^5\ Pa$ ISOBARIC

$\Delta V = +6.2 \times 10^{-3}\ m^3$

$Q = ?$

$PV = nRT$

$P\Delta V = nR\Delta T$

$\Delta U = Q + W$

$3/2\, nR\Delta T = Q + (-P\Delta V)$

$3/2\,(P\Delta V) = Q - P\Delta V$

$3/2\, P\Delta V + P\Delta V = Q$

$Q = \frac{5}{2} P\Delta V = \frac{5}{2}(2.6 \times 10^5\ Pa)(6.2 \times 10^{-3}\ m^3)$

$= +4030\ J$ heat flows into the gas.

* Introduction to thermo

Processes that utilize an Ideal gas

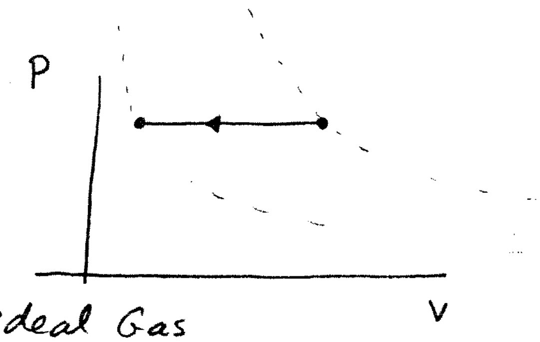
1. $\Delta U = Q + W$

$\Delta U = Q + [-P\Delta V]$

$\Delta U = 1510\,J + [(-7\times10^4 Pa)(0.06m^3 - 0.02m^3)]$

$\Delta U = -1290\,J$

2)



$PV = nRT$

$T_0 = 381K$ Isotherm

$T_F = 300K$ Isotherm

Ideal Gas

$n = 3.7\,mol$ $\quad$ $P = 6.4\times10^5\,Pa$

$T_0 = 381K$ $\quad$ $C_V = 11.16\ J/mol\cdot K$

$T_f = 300K$ $\quad$ $R = 8.314\ J/mol\,K$

	P	V	T	Q	W	ΔU
ISOBARIC	↔	↓	↓	+	+	−

a) First find $\Delta V \Rightarrow$ $PV = nRT$ if P is constant

$P\Delta V = nR\Delta T$

$\Delta V = \dfrac{nR\Delta T}{P} =$

$= \dfrac{(3.7mol)(8.314\ J/molK)(300-381)K}{6.4\times10^5 Pa}$

$= -3.9\times10^{-3}\,m^3$

$\therefore$ $W = -P\Delta V = -(6.4\times10^5 Pa)(-3.9\times10^{-3} m^3)$

$\boxed{= +2496\,J}$

B) $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}(3.7mol)(8.314\frac{J}{mol\,K})(-81K)$

$\boxed{\Delta U = -3737\,J}$

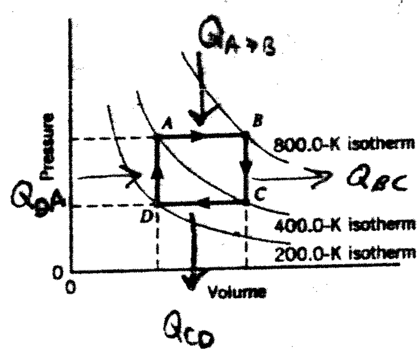
c) $\Delta U = Q + W \ \therefore\ Q = \Delta U - W = -6233\,J$

A. P. Physics B (Solution)

Thermodynamic Analysis of Heat Engines

The drawing refers to one mole of a monatomic ideal gas and shows a process that has four steps, two isobaric (A to B, C to D) and two isochoric (B to C, D to A). Complete the following table by calculating ΔU, W, and Q (including the algebraic signs) for each of the four steps.

$PV = nRT$
$n = 1$



Step	Comment	V	P	T	Q	W	ΔU
A → B	ISOBARIC (EXPANSION)	↑	↔	↑	+8310 J	-3324 J	+4986 J
B → C	Isochoric	↔	↓	↓	-4986 J	0 J	-4986 J
C → D	ISOBARIC (Contraction)	↓	↔	↓	-4155	+1662 J	-2493 J
D → E	ISOchoRIC	↔	↑	↑	+2493	0 J	+2493 J
	Totals				+1662 J	-1662 J	0 J

Check #2 Add column

* FOR TOTAL Cycle $\Delta U = Q + W = +1662 + (-1662) = 0$

Always a Net Flow of +Q

$\Delta U = 0$ for ANY complete cycle

Final comments: See Reverse SIDE for calculations

ANSWERS:

STEP	ΔU	W	Q
A → B	4990	-3320	8310
B → C	-4990	0	-4990
C → D	-2490	1600	-4150
D → A	2490	0 J	2490

* Work is always negative for a heat engine

* Thermodynamic Analysis of a heat engine   Solution continued

STEP A → B: ISOBARIC EXPANSION

$\Delta U = 3/2\, nR\Delta T$

$= 3/2\,(1\text{mol})(8.31\ \text{J/mol K})(800\text{K} - 400\text{K}) = \boxed{4985\text{ J}}$

$PV = nRT$

$P\Delta V = nR\Delta T$

$W = -P\Delta V = -nR\Delta T = -(1\text{mol})(8.31\ \text{J/mol K})(800\text{K} - 400\text{K}) = \boxed{-3324\text{ J}}$

$\Delta U = W + Q \Rightarrow Q = \Delta U - W = 4986\text{J} - (-3324\text{J}) = \boxed{8310\text{ J}}$

STEP B → C: ISOCHORIC

$\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2}(1\text{mol})(8.31\ \text{J/mol K})(400\text{K} - 800\text{K}) = \boxed{-4986\text{ J}}$

$W = 0$ (Isochoric $\Delta V = 0$)

$\Delta U = Q + \cancel{W}^{0} \quad Q = \Delta U = -4986\text{ J}$

STEP C → D: ISOBARIC Contraction

$\Delta U = 3/2\, nR\Delta T = (\frac{3}{2})(1\text{mol})(8.31\ \text{J/mol K})(200\text{K} - 400\text{K}) = \boxed{-2493\text{ J}}$

$W = -P\Delta V = -nR\Delta T = (-1\text{mol})(8.31\ \text{J/mol K})(200\text{K} - 400\text{K}) = \boxed{+1662\text{ J}}$

$\Delta U = W + Q$

$Q = \Delta U - W = -2493\text{J} - (+1662\text{J}) = \boxed{-4155\text{ J}}$

STEP D → A

$\Delta U = 3/2\, nR\Delta T = (3/2)(1\text{mol})\left(\frac{8.31\text{J}}{\text{mol}\cdot\text{K}}\right)(400\text{K} - 200\text{K})$

$= \boxed{+2493\text{ J}}$

$W = 0 \quad \Delta V = 0$ Isochoric

$Q = \Delta U - \cancel{W}^{0} = \Delta U = \boxed{+2493\text{ J}}$

{ Solutions to 15.5 Thermal Processes + Ideal gas }

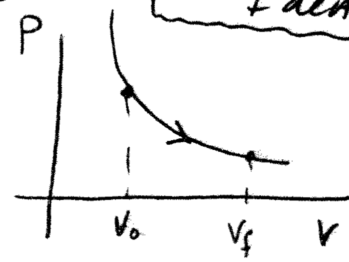
20) $n = 3$

$T_0 = 373K$

Process = Isothermal

$V_f = 4V_0$

$W = ?$



$$W = nRT \ln\left(\frac{V_0}{V_f}\right)$$

$$= (3)(8.31\ J/mol\,K)(373K) \ln\left(\frac{\cancel{V_0}}{4\cancel{V_0}}\right)$$

$$\boxed{= -1.29 \times 10^4\ J}$$

21) $n = 3$

$V_0 = 5.5 \times 10^{-2} m^3$

$V_f = 2.5 \times 10^{-2} m^3$

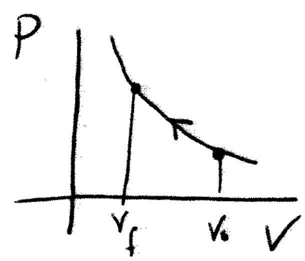
$W = {}^{+}6.1 \times 10^3\ J$

A) $\Delta U = ?$

B) $Q = ?$

C) $T = ?$

Process: Isothermal



$$W = nRT \ln\left(\frac{V_0}{V_f}\right)$$

A) $\boxed{\Delta U = 0}$ Isothermal process $\Delta U = 3/2\, nR\Delta T$ $\Delta T = 0$ $\Delta U = 0$

B) $\cancel{\Delta U}^{0} = W + Q$

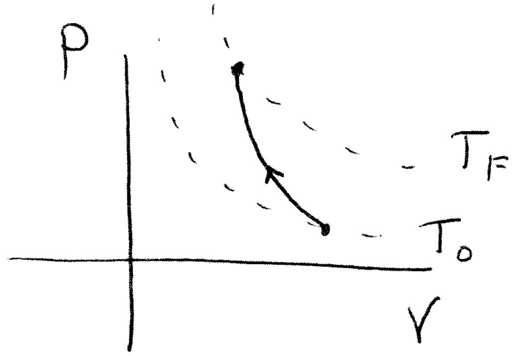
B) $Q = -W = \boxed{-6.1 \times 10^3\ J}$

C) $W = nRT \ln\left(\frac{V_0}{V_f}\right)$

$$T = \frac{W}{nR \ln\left(\frac{V_0}{V_f}\right)} = \frac{6.1 \times 10^3\ J}{3(8.31\ J/mol\,K) \ln\left(\frac{5.5}{2.5}\right)} = \boxed{310K}$$

24) $\gamma = 5/3$

Process: Adiabatic
Compression

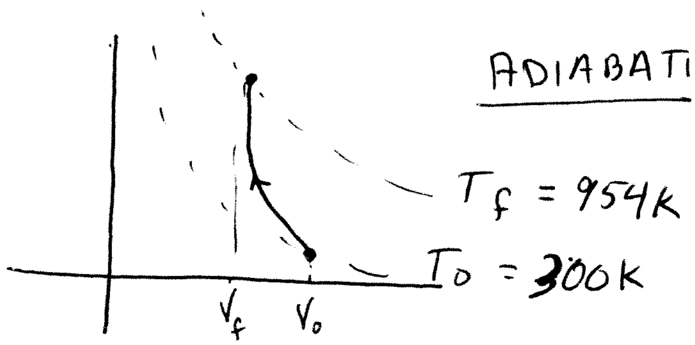


$$V_f = \frac{1}{2} V_0$$

$$P_0 V_0^{\gamma} = P_f V_f^{\gamma} \qquad \frac{P_f}{P_0} = \left(\frac{V_0}{V_f}\right)^{\gamma} = \left(\frac{V_0}{\frac{1}{2}V_0}\right)^{\gamma} = 2^{5/3}$$

$$\boxed{= 3.17}$$

27)



ADIABATIC Compression

$T_0 = 300K$

$T_f = 954K$

$\gamma = 7/5$

$\text{RATIO} = \frac{V_0}{V_f}$

$$PV = nRT$$

$$P = \boxed{\frac{nRT}{V}}$$

$$P_0 V_0^{\gamma} = P_f V_f^{\gamma}$$

$$\left(\frac{\cancel{nR}T_0}{V_0}\right) V_0^{\gamma} = \frac{\cancel{nR}T_f}{V_f} (V_f)^{\gamma}$$

$$T_0 \frac{V_0^{\gamma}}{V_0} = T_F \frac{V_f^{\gamma}}{V_f}$$

$$T_0 V_0^{\gamma - 1} = T_F V_f^{\gamma - 1}$$

$$\left(\frac{V_0}{V_f}\right)^{\gamma - 1} = \frac{T_F}{T_0} \Rightarrow \frac{V_0}{V_f} = \left(\frac{T_F}{T_0}\right)^{\frac{1}{\gamma - 1}}$$

work continues

$$= \left(\frac{954K}{300K}\right)^{\frac{1}{7/5 - 1}}$$

$$= \left(\frac{954\cancel{K}}{300\cancel{K}}\right)^{\frac{5}{2}}$$

$$\boxed{= 18}$$

Solutions to 15.5 (Continued)

22) $\Delta U = 0$ $\quad \cancel{\Delta U}^{0} = Q + W \therefore W = -Q = +nRT\ln(V_F/V_0)$

$$T = \frac{Q}{nR\ln(V_F/V_0)} = \boxed{434K}$$

23) $\Delta U = 0 \quad W = -nRT\ln(V_F/V_0) \quad \cancel{\Delta U}^{0} \quad Q = -W$

$Q = nRT\ln(V_F/V_0)$

$\ln(V_F/V_0) = \dfrac{Q}{nRT}$ $\qquad \ln(V_F/V_0) = 2.08$

$$\boxed{V_F/V_0 = 8.0}$$

25) $W = -nRT\ln(V_F/V_0)$ Isothermally

$W = 3/2\, nR\Delta T$ adiabatically

$$-\cancel{n}\cancel{R}T_0\ln(V_F/V_0) = 3/2\,\cancel{n}\cancel{R}(T_F - T_0)$$

$$\ln(V_F/V_0) = \frac{3/2(T_F - T_0)}{-T_0} =$$

$$\frac{V_f}{V_0} = e^{\frac{3/2(T_F - T_0)}{-T_0}} = \boxed{11.81}$$

26) $\dfrac{V_f}{V_0} = \dfrac{P_0}{P_F} = \dfrac{(P_0 + \rho g h)}{P_0} = 2$ $\qquad \Delta U = 0$

$Q = -W$

$Q = -(-nRT\ln(V_F/V_0))$

$$Q = nRT\ln(V_F/V_0) = \boxed{+0.59J}$$

* Thermodynamic Analysis of a heat Engine   Solution continued

STEP A → B: ISOBARIC EXPANSION

$\Delta U = 3/2\, nR\Delta T$

$= 3/2\,(1\,mol)(8.31\,J/mol\,K)(800K - 400K) = \boxed{4985\,J}$

$PV = nRT$

$P\Delta V = nR\Delta T$

$W = -P\Delta V = -nR\Delta T = -(1\,mol)(8.31\,J/mol\,K)(800K - 400K) = \boxed{-3324\,J}$

$\Delta U = W + Q \Rightarrow Q = \Delta U - W = 4986J - (-3324J) = \boxed{8310\,J}$

STEP B → C: ISOCHORIC

$\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2}(1\,mol)(8.31\,J/mol\,K)(400K - 800K) = \boxed{-4986\,J}$

$W = 0$ (Isochoric $\Delta V = 0$)

$\Delta U = Q + \cancel{W}^{0} \quad Q = \Delta U = -4986\,J$

STEP C → D: ISOBARIC contraction

$\Delta U = 3/2\, nR\Delta T = (\frac{3}{2})(1\,mol)(8.31\,J/mol\,K)(200K - 400K) = \boxed{-2493\,J}$

$W = -P\Delta V = -nR\Delta T = (-1\,mol)(8.31\,J/mol\,K)(200K - 400K) = \boxed{+1662\,J}$

$\Delta U = W + Q$

$Q = \Delta U - W = -2493J - (+1662J) = \boxed{-4155\,J}$

STEP D → A

$\Delta U = 3/2\, nR\Delta T = (3/2)(1\,mol)(\frac{8.31J}{mol.K})(400K - 200K)$

$= \boxed{+2493\,J}$

$W = 0 \quad \Delta V = 0$ Isochoric

$Q = \Delta U - \cancel{W}^{0} = \Delta U = \boxed{+2493\,J}$

{ Solutions to 15.5 Thermal Processes + Ideal gas }

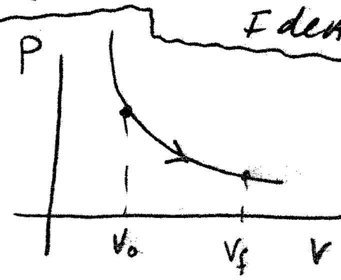
20) $n = 3$

$T_0 = 373K$

Process = Isothermal

$V_f = 4V_0$

$W = ?$



$$W = nRT \ln\left(\frac{V_0}{V_f}\right)$$

$$= (3)(8.31\ J/mol\,K)(373K)\ln\left(\frac{V_0}{4V_0}\right)$$

$$\boxed{= -1.29\times10^4\,J}$$

21) $n = 3$

$V_0 = 5.5\times10^{-2}\,m^3$

$V_f = 2.5\times10^{-2}\,m^3$

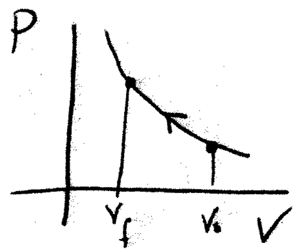
$W = {}^{+}6.1\times10^3\,J$

A) $\Delta U = ?$

B) $Q = ?$

c) $T = ?$

Process: Isothermal



$$W = nRT \ln\left(\frac{V_0}{V_f}\right)$$

A) $\boxed{\Delta U = 0}$ Isothermal process $\Delta U = 3/2\, nR\Delta T$ $\quad \Delta T = 0$, $\Delta U = 0$

B) $\cancel{\Delta U}^{\,0} = W + Q$

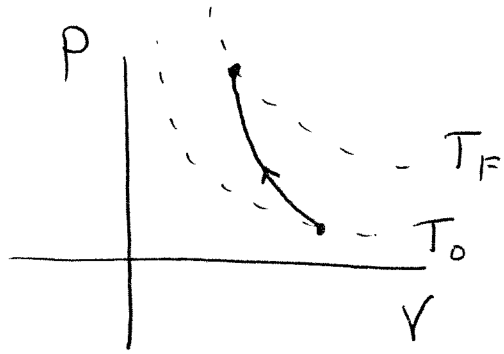
B) $Q = -W = \boxed{-6.1\times10^3\,J}$

c) $W = nRT\ln\left(\frac{V_0}{V_f}\right)$

$$T = \frac{W}{nR\ln\left(\frac{V_0}{V_f}\right)} = \frac{6.1\times10^3\,J}{3(8.31\,J/mol\,K)\ln\left(\frac{5.5}{2.5}\right)} = \boxed{310K}$$

24) $\gamma = 5/3$

Process: Adiabatic Compression

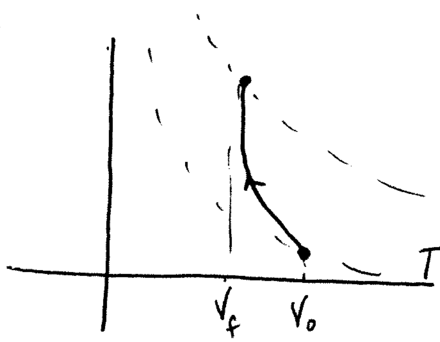


$$V_f = \frac{1}{2} V_0$$

$$P_0 V_0^{\gamma} = P_f V_f^{\gamma} \qquad \frac{P_f}{P_0} = \left(\frac{V_0}{V_f}\right)^{\gamma} = \left(\frac{V_0}{\frac{1}{2}V_0}\right)^{\gamma} = 2^{5/3}$$

$$\boxed{= 3.17}$$

27)



ADIABATIC compression

$T_0 = 300K$

$T_f = 954K$

$\gamma = 7/5$

$\text{RATIO} = \dfrac{V_0}{V_f}$

$$PV = nRT$$

$$P = \boxed{\frac{nRT}{V}}$$

$$P_0 V_0^{\gamma} = P_f V_f^{\gamma}$$

$$\left(\frac{\cancel{nR}T_0}{V_0}\right) V_0^{\gamma} = \frac{\cancel{nR}T_f}{V_f}(V_f)^{\gamma}$$

$$T_0 \frac{V_0^{\gamma}}{V_0} = T_F \frac{V_f^{\gamma}}{V_f}$$

$$T_0 V_0^{\gamma-1} = T_F V_f^{\gamma-1}$$

$$\left(\frac{V_0}{V_f}\right)^{\gamma-1} = \frac{T_F}{T_0} \Rightarrow \frac{V_0}{V_f} = \left(\frac{T_F}{T_0}\right)^{\frac{1}{\gamma-1}}$$

WORK continued

$$= \left(\frac{954K}{300K}\right)^{\frac{1}{7/5-1}}$$

$$= \left(\frac{954\cancel{K}}{300\cancel{K}}\right)^{\frac{5}{2}}$$

$$\boxed{= 18}$$

Solutions to 15.5 (Continued)

22) $\Delta U = 0$ $\quad \cancel{\Delta U}^{0} = Q + W \quad \therefore \quad W = -Q = +nRT\ln(V_F/V_0)$

$$T = \frac{Q}{nR\ln(V_F/V_0)} = \boxed{434K}$$

23) $\Delta U = 0 \quad W = -nRT\ln(V_F/V_0) \quad \cancel{\Delta U}^{0} \quad Q = -W$

$$Q = nRT\ln(V_F/V_0)$$

$$\ln(V_F/V_0) = \frac{Q}{nRT}$$

$$\ln(V_F/V_0) = 2.08$$

$$\boxed{V_F/V_0 = 8.0}$$

25) $W = -nRT\ln(V_F/V_0)$ Isothermally

$W = 3/2\, nR\Delta T$ adiabatically

$$-\cancel{n}\cancel{R}T_0\ln(V_F/V_0) = 3/2\,\cancel{n}\cancel{R}(T_F - T_0)$$

$$\ln(V_F/V_0) = \frac{3/2(T_F - T_0)}{-T_0} =$$

$$\frac{V_f}{V_0} = e^{\frac{3/2(T_F - T_0)}{-T_0}} = \boxed{1.81}$$

26) $\dfrac{V_f}{V_0} = \dfrac{P_0}{P_F} = \dfrac{(P_0 + \rho g h)}{P_0} = 2$ $\quad \Delta U = 0$

$Q = -W$

$Q = -(-nRT\ln(V_F/V_0))$

$$Q = nRT\ln(V_F/V_0) = \boxed{+0.59J}$$

28) STEP A→B: ISOBARIC EXPANSION

$\Delta U = 3/2\, nR\Delta T$

$= 3/2\,(1\text{mol})(8.31\ \text{J/mol K})(800\text{K} - 400\text{K}) = \boxed{4985\ \text{J}}$

$PV = nRT$

$P\Delta V = nR\Delta T$

$W = -P\Delta V = -nR\Delta T = -(1\text{mol})(8.31\ \text{J/mol K})(800\text{K} - 400\text{K}) = \boxed{-3324\ \text{J}}$

$\Delta U = W + Q \Rightarrow Q = \Delta U - W = 4986\text{J} - (-3324\text{J}) = \boxed{8310\ \text{J}}$

STEP B→C: ISOCHORIC

$\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2}(1\text{mol})(8.31\ \text{J/mol K})(400\text{K} - 800\text{K}) = \boxed{-4986\ \text{J}}$

$W = 0$ (Isochoric $\Delta V = 0$)

$\Delta U = Q + \cancel{W}^{\,0} \quad Q = \Delta U = -4986\text{J}$

STEP C→D: ISOBARIC Contraction

$\Delta U = 3/2\, nR\Delta T = (\frac{3}{2})(1\text{mol})(8.31\ \text{J/mol K})(200\text{K} - 400\text{K}) = \boxed{-2493\ \text{J}}$

$W = -P\Delta V = -nR\Delta T = (-1\text{mol})(8.31\ \text{J/mol K})(200\text{K} - 400\text{K}) = \boxed{+1662\ \text{J}}$

$\Delta U = W + Q$

$Q = \Delta U - W = -2493\text{J} - (+1662\text{J}) = \boxed{-4155\ \text{J}}$

STEP D→A

$\Delta U = 3/2\, nR\Delta T = (3/2)(1\text{mol})(8.31\ \frac{\text{J}}{\text{mol K}})(400\text{K} - 200\text{K})$

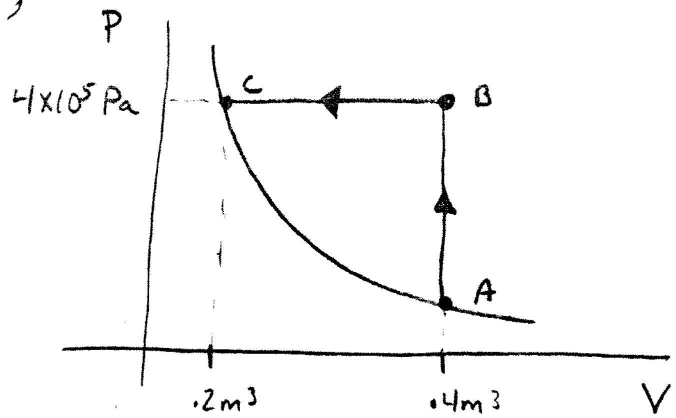
$= \boxed{+2493\ \text{J}}$

$W = 0 \quad \Delta V = 0$ Isochoric

$Q = \Delta U - \cancel{W}^{\,0} = \Delta U = \boxed{+2493\ \text{J}}$

30)

$PV = nRT$



A → B Isochoric (V is constant)

$W_{A \to B} = 0$

$\Delta U = \cancel{W}^{0} + Q_{AB}$

$\Delta U = Q_{AB}$

B → C ISOBARIC (P is constant)

$W_{B \to C} = -P\Delta V = -4 \times 10^5 \text{Pa}(.2m^3 - .4m^3)$

$= {}^{+}8 \times 10^4 \text{J}$

A → B → C Temperature does not change

if $\Delta T_{ABC} = 0$ then $\Delta U_{ABC} = 0$

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

$\Delta U_{ABC} = W_{ABC} + Q_{ABC}$

work is only done during B → C

$\Delta U_{ABC} = (\cancel{W_{AB}} + W_{BC}) + Q_{ABC}$

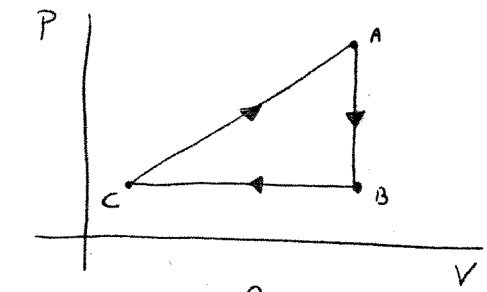
$\Delta U_{ABC} = W_{BC} + Q_{ABC}$ But $\Delta U_{ABC} = 0$

$0 = W_{BC} + Q_{ABC}$

$Q_{ABC} = -W_{BC} = \boxed{-8 \times 10^4 \text{J}}$

Heat is given off.

P.619 #9 WALKER 3rd ed.



1st Law of Thermodynamics

$W = -P\Delta V$ (ISOBARIC)

	Q	W	ΔU
A→B	-53 J	(a)	(b)
B→C	-280J	+130J (contracting)	(c)
C→A	(e)	-150J (expanding)	(d)

a) $W_{A\to B} = \boxed{0J}$ Isochoric.

b) $\Delta U_{A\to B} = Q + \cancel{W}^0 = Q = \boxed{-53\,J}$

c) $\Delta U_{B\to C} = Q + W = (-280J) + (+130J) = \boxed{-150J}$

d) $\Delta U_{cycle} = 0$ $\quad \Delta U_{C\to A} + \Delta U_{B\to C} + \Delta U_{A\to B} = 0$

$\Delta U_{C\to A} = -\Delta U_{B\to C} - \Delta U_{A\to B}$

$= -(-150J) - (-53J) =$

$= 150J + 53J = \boxed{+203\,J}$

e) $\Delta U_{C\to A} = W + Q$

$Q = \Delta U_{C\to A} - W = 203J - (-150J) = \boxed{+353\,J}$

Thermodynamics Review #1

P.623 #88 WALKER 3rd ed.

$n = 1\,mol$

A→B Isothermal

$\Delta U = 0$ $\quad W_{A\to B} = -nRT \ln(V_F/V_i)$

$W_{A\to B} = -PV \ln(V_F/V_i)$

$W_{AB} = -(600\times10^3\,Pa)(.75\times10^{-3}\,m^3)\ln\left(\frac{4.5}{.75}\right)$

$W_{AB} = \boxed{-806\,J}$

$\Delta \cancel{U}^0 = Q + W$

$Q = -W$ $\quad Q_{AB} = -W_{AB} = \boxed{+806\,J}$

B→C ISOBARIC $\quad P\Delta V = nR\Delta T$

$W_{B\to C} = -P\Delta V = -(100\times10^3\,Pa)(.75-4.50)\times10^{-3}\,m^3 \boxed{= +375\,J}$

$\Delta U_{B\to C} = 3/2\, nR\Delta T$

$\Delta U_{B\to C} = 3/2\, P\Delta V = 3/2(100\times10^{+3}\,Pa)(.75-.45)\times10^{-3}\,m^3 \boxed{= -562.5\,J}$

$Q_{B\to C} = \Delta U_{BC} - W_{BC}$

$= -562.5J - (+375J) = \boxed{-937.5\,J}$

C→A

Isochoric $(W = 0J)$ $\quad \Delta P V = nR\Delta T$

$\Delta U = 3/2\, nR\Delta T.$

$\Delta U = 3/2\, V\Delta P = 3/2(.75\times10^{-3}\,m^3)(600-100)\times10^3\,Pa$

$\boxed{= +562.5\,J}$

$\Delta U = Q + \cancel{W}^0$

$Q = \Delta U = \boxed{562.5\,J}$

b) $e = \frac{|W|}{Q_H} = \frac{|(-806J)+(375J)|}{(806J)+(563J)} = \boxed{0.31}$

Thermodynamic Review   AP Physics - B   Thermo Review # 2

a) Use Ideal gas equation for pts. 1+2

$$\frac{P_1V_1 = nRT_1}{P_2V_2 = nRT_2} \qquad \frac{T_1}{T_2} = 1 \qquad \boxed{T_1 = T_2 \therefore \text{ Step } 1\to 2 \text{ is an } \underline{\text{Isothermal process}}}$$

$$\frac{(2\,Atm)(1\,m^3)}{(1\,Atm)(2\,m^3)} = \frac{T_1}{T_2}$$

$PV = nRT$ = Constant (for Isotherm)

Def. of work for Isothermal process

b) $W = nRT \ln\left(\frac{V_0}{V_f}\right) = PV \ln\left(\frac{V_0}{V_f}\right) = (2\,atm)(1\,m^3)\ln\left(\frac{1\,m^3}{2\,m^3}\right)$

$= 2(1.013\times10^5\,PA)(1\,m^3)\ln(1/2) = \boxed{-1.40\times10^5\,J}$

$\Delta U = Q + W = 0$

$\boxed{Q = -W}$

c) $\underline{\text{IsoBaric}}$, $W = -P\Delta V = -(1\,ATM)(1\,m^3 - 2\,m^3) = 1.013\times10^5\,PA\,(+1\,m^3)$

$\boxed{= +1.013\times10^5\,J}$

d) $\underline{\text{Isochoric}}$, $W = 0\,J \because \Delta V = 0$, $\Delta U = 3/2\, nR\Delta T = 3/2(1\times10^2\,mol)(8.31\,\frac{J}{mol\cdot K})(\Delta T)$ Find

$\underline{*\ T \text{ at pt. } 3}$

$P_3V_3 = nRT_3$

$$T_3 = \frac{P_3V_3}{nR} = \frac{(1\,Atm)(1.0\,m^3)}{(1\times10^2\,mol)(8.315\,\frac{J}{mol\,K})} = \frac{(1.013\times10^5\,Pa)(1\times10^3\,m^3)}{(1\times10^2\,mol)(8.315\,J/mol\cdot K)}$$

$\boxed{= 122\,K}$

$\underline{*\ T \text{ at pt. } 1}$

$P_1V_1 = nRT_1$

$$T_1 = \frac{P_1V_1}{nR} = \frac{2(1.013\times10^5\,Pa)(1\,m^3)}{(1\times10^2\,mol)(8.31\,J/mol\cdot K)} = \boxed{243\,K}$$

$*\ 3\to1 \quad \Delta T = 243\,K - 122\,K = \boxed{121\,K} \quad \therefore \quad \Delta U = 3/2\, nR\Delta T$

$\Delta U = 3/2\,(1\times10^2\,mol)(8.31\,\frac{J}{mol\cdot K})(121\,K)$

$\boxed{\Delta U = 1.51\times10^5\,J}$

(heat must be Absorbed SAme Amount)

$\underline{*\text{ for } \underline{\text{ANY}} \text{ Process}}$

molar heat capacity at constant volume

$\Delta U = nC_V\Delta T$

$$C_V = \frac{\Delta U}{n\Delta T} = \frac{1.51\times10^5\,J}{(1\times10^2\,mol)(121\,K)} = \boxed{12.5\,\frac{J}{mol\,K}}$$

e) $W_{TOTAL} = W_{1\to2} + W_{2\to3} + W_{3\to1} = (-1.40\times10^5\,J) + (+1.013\times10^5\,J) + 0\,J$

$\boxed{= -3.87\times10^4\,J}$

"$-$" sign indicates work is done BY the gas

f+g) $\Delta U = 0$ for any complete cycle $\therefore$ $\Delta U = W + Q$ (First Law of thermodynamics)

$Q = -W$

$Q = -(-3.87\times10^4\,J) = \boxed{+3.87\times10^4\,J}$

Thermodynamic cycle: Solution UTILIZING MOLAR HEAT capacities

DiBucci

A→B ISOBARIC EXPANSION

$\Delta V = 0.5 m^3$, $\Delta P = 0$, $P\Delta V = nR\Delta T$

$$\Delta T = \frac{P\Delta V}{nR} = \frac{(4\times10^4 Pa)(0.5 m^3)}{(1 mol)(8.32 J/mol\,K)} = \boxed{2.4\times10^3 K}$$

constant pressure

$$Q = nC_p\Delta T = (1 mol)(20.78 J/mol\,K)(2.4\times10^3 K) = \boxed{+4.99\times10^4 J}$$

$$\Delta U = 3/2\, nR\Delta T = 3/2\,(1 mol)(8.32 J/mol\,K)(2.4\times10^3 K) = \boxed{3.0\times10^4 J}$$

$$W = -P\Delta V = (4\times10^4 Pa)(0.5 m^3) = \boxed{-2\times10^4 J}$$

B→C ISOTHERMAL EXPANSION

$\Delta V = 1 m^3$, $\Delta P = -2.0\times10^4 Pa$, $\Delta T = 0$ (Def) $\therefore \Delta U = 0$

Pick any point to Determine T   I used pt. B

$$T = \frac{PV}{nR} = \frac{(4\times10^4 Pa)(1 m^3)}{(1 mol)(8.32)} = \boxed{4.81\times10^3 K}$$

$$W = -nRT\ln(V_f/V_o) = -1(8.32)(4.81\times10^3 K)\ln\left(\frac{2 m^3}{1 m^3}\right)$$

$$\boxed{W = -2.77\times10^4 J}$$

$$Q = \cancel{\Delta U}^{\,0} - W = \boxed{+2.77\times10^4 J}$$

C→D ISOBARIC CONTRACTION

$$\Delta P = 0,\ \Delta V = -1.5 m^3,\ \Delta T = \frac{P\Delta V}{nR} = \frac{(2\times10^4 Pa)(-1.5 m^3)}{(1 mol)(8.32)}$$

$$\boxed{\Delta T = -3.61\times10^3 K}$$

$$Q = nC_p\Delta T = (1 mol)(20.78 J/mol\,K)(-3.61\times10^3 K) = \boxed{-7.49\times10^4 J}$$

$$\Delta U = 3/2\, nR\Delta T = \boxed{-4.5\times10^4 J}$$

$$W = -P\Delta V = -(2\times10^4 Pa)(-1.5 m^3) = \boxed{+3\times10^4 J}$$

(over)

D → A (Isochoric process)

$\Delta P = +2\times10^4\ Pa$, $\Delta V = 0$,

$PV = nRT$

$\Delta P V = nR\Delta T$

$\Delta T = \frac{\Delta P V}{nR} = \frac{(2\times10^4 Pa)(.5 m^3)}{(1)(8.32)}$

$\boxed{\Delta T = 1.2\times10^3 K}$

$\boxed{W = 0}$ Isochoric

$\Delta U = 3/2\, nR\Delta T = 3/2(1)(8.32)(1.2\times10^3 K) = \boxed{1.50\times10^4\ J}$

$Q = nC_V\Delta T = 1(12.45\ J/mol(K))(1.2\times10^3 K) = \boxed{1.50\times10^4 J}$

Constant Volume

TOTALS

$Q_T = Q_{AB} + Q_{BC} + Q_{CD} + Q_{DA} = (5\times10^4 J) + (2.77\times10^3 J) + (-7.49\times10^4) + (1.5\times10^4)$

$= \boxed{1.78\times10^4\ J}$

$W_T = (-2\times10^{+4} J) + (-2.77\times10^{+4}) + (3\times10^4 J) + (0\ J)$

$\boxed{= +1.78\times10^4 J}$

$\Delta U_T = Q_T + W_T = \boxed{0\ J}$

Carnot's Principle

DiBucci

50) $e_{max} = 1 - \frac{620}{950} = .347$

$e = \frac{3}{5} e_{max} = \boxed{.21}$

51) $e = 1 - \frac{200}{500} = .6$

$W = e Q_H = (.6)(5000 J) = \boxed{3000 J}$

52) $e = 1 - \frac{T_c}{T_H}$ $\quad e - 1 = -\frac{T_c}{T_H}$ $\quad \frac{T_c}{T_H} = 1 - e$ $\quad T_H = \frac{T_c}{1-e}$

$T_H = \frac{300K}{1-.4} = \boxed{500K}$

53)
A) $e = 1 - \frac{T_c}{T_H}$ $\quad T_H = \frac{T_c}{1-e}$ (See # 52) $\quad T_H = \frac{378K}{1-.7} = \boxed{1260K}$

B) $e = 1 - \frac{Q_H}{Q_L}$ $\quad Q_H = \frac{Q_L}{1-e} = \frac{5230J}{1-.7} = \boxed{1.74 \times 10^4 J}$

54) $e = 1 - \frac{Q_L}{Q_H}$

$e = 1 - \frac{1}{1.5} = \boxed{.33}$

$e = 1 - \frac{T_L}{T_H}$ $\quad \frac{T_L}{T_H} = 1 - e$

$\frac{T_H}{T_L} = \frac{1}{1-e} = \boxed{1.49}$

Solutions : Heat Engines

DiBucci

43) $e = 1 - \frac{Q_L}{Q_H} = 1 - \frac{5.6\times10^3 J}{2.41\times10^4 J} = .77$

$e = \frac{W}{Q_H} \Rightarrow W = e \cdot Q_H = (.77)(2.41\times10^4 J) = \boxed{1.85\times10^4 J}$

44.) $W_o = e_o Q_H$

$W_A = e_A Q_H$

$\frac{W_A}{W_o} = \frac{e_A}{e_o}\frac{\cancel{Q_H}}{\cancel{Q_H}} = \frac{.20}{.14} = \boxed{1.4}$

45) $e = \frac{W}{Q_H} = \frac{W}{W+Q_L} = \frac{16{,}600 J}{16{,}600 J + 9{,}700} = \boxed{.631}$

46) $e = \frac{W}{Q_H}$ $\quad Q_H = \frac{W}{e} = \frac{5500 J}{.64} = \boxed{8593 J}$

$Q_L = Q_H - W = 8593 J - 5500 J = \boxed{3093 J}$

47) $W_p = \Delta U = mg\Delta h = (58 kg)(9.8 m/s)(950 m) = \boxed{5.4\times10^5 J}$

$e = \frac{W}{Q} = \frac{5.4\times10^5 J}{4.5\times10^6 J} = \boxed{0.12}$

48) $e_A = 1 - \frac{Q_{L,A}}{Q_H}$ $\quad e_B = 2e_A$

$e_B = 1 - \frac{Q_{L,B}}{Q_H}$ $\quad 1 - \frac{Q_{L,B}}{Q_H} = 2\left(1 - \frac{Q_{L,A}}{Q_H}\right)$

$\frac{Q_H - Q_{LB}}{\cancel{Q_H}} = \frac{2Q_H - 2Q_{LA}}{\cancel{Q_H}}$

$-Q_{LB} = Q_H - 2Q_{LA}$

$Q_{LB} = 2Q_{LA} - Q_H = 2(.72Q_H) - Q_H$

$\boxed{Q_{LB} = .44 Q_H}$

Solutions: molar Heat capacities

DiBucci

33. $Q = nC_p \Delta T =$

$= n\left(\frac{5}{2}R\right)\Delta T = (1.5\text{ mol})\left(\frac{5}{2}\right)(8.31\text{ J/mol K})(77\text{K}) = \boxed{2400\text{ J}}$

34. $Q = -750\text{ J}$

$n = 5\text{ mol}$

A) Isochoric

$Q = nC_v \Delta T$

$\Delta T = \frac{Q}{nC_v} = \frac{Q}{n\left(\frac{3}{2}\right)R} = \frac{-750\text{ J}}{5\left(\frac{3}{2}\right)(8.31)} = \boxed{-12\text{ K}}$

B) ISOBARIC

$Q = nC_p \Delta T$

$\Delta T = \frac{Q}{nC_p} = \frac{-750\text{ J}}{(5)\left(\frac{5}{2}\right)(8.31)} = \boxed{-7.22\text{K}}$

35) $Ar \Rightarrow 39.9\ \frac{g}{mol}$

$\Delta T = +75\text{K}$

$Q = ?$

ISOBARIC

$Q = nC_p \Delta T$

$n = (8g)\left(\frac{1\text{ mol}}{39.9\text{ g}}\right) = \boxed{.2\text{ mol}}$

$Q = (.2\text{ mol})\left(\frac{5}{2}R\right)\Delta T$

$= (.2\text{ mol})\left(\frac{5}{2}\right)\left(8.31\ \frac{J}{mol\,K}\right)(+75\text{K})$

$= \boxed{+311.6\text{ Joules}}$

36)

$n = 3$

Isochoric $V = 1.5 m^3$

$Q = +5.24 \times 10^3 J$

a) $\Delta T = ?$

$Q = n C_V \Delta T$

$Q = n(\frac{3}{2}R)\Delta T$

$\Delta T = \frac{Q}{n(\frac{3}{2}R)} = \boxed{1.4 \times 10^2 K}$

B) $\Delta U = Q + \cancel{W}^{0}$

$\Delta U = Q$

$\Delta U = 5.24 \times 10^3 J$

c) $\Delta P V = nR\Delta T$

$\Delta P = \frac{nR\Delta T}{V} = \boxed{2.33 \times 10^3 Pa}$

38)

$Q = n C_p \Delta T$

$Q = n(\frac{5}{2}R)\Delta T$

$W = -P\Delta V$

$W = -nR\Delta T$

$\left|\frac{Q}{W}\right| = \left|\frac{\cancel{n}\frac{5}{2}\cancel{R}\cancel{\Delta T}}{-nR\Delta T}\right|$

$\boxed{= 5/2}$

39) $P_{ower} = \frac{Q}{t} \Rightarrow t = \frac{Q}{Power}$

$Q = n C_p \Delta T \quad C_p = \frac{5}{2}R$

$P\Delta V = nR\Delta T$

$Q = (\frac{5}{2}R) n\Delta T = (\frac{5}{2}\cancel{R})(\frac{P\Delta V}{\cancel{R}}) = 5/2\, P\Delta V$

$\therefore t = \frac{\frac{5}{2}P\Delta V}{} = \frac{5/2\,(2.5 \times 10^5 Pa)(.2(1 \times 10^{-3} m^3))}{} = \boxed{12.5 s}$