Homework #4

Solutions

Carter 5.3, 5.4, 5.9, 6.7, 6.8, 6.13

Schroeder 4.7, 4.8, 4.14, 4.21 abc

Additional Problems 1–3

Carter

5.3 a. $u = u_0 + c_v T - \frac{a}{v}$

$$u - u_0 + \frac{a}{v} = c_v T$$

$$T = \frac{u - u_0}{c_v} + \frac{a}{v c_v}$$

$$\eta = \left(\frac{\partial T}{\partial v}\right)_u = \frac{-a}{v^2 c_v}$$

Clearly, $\eta = 0$ if $a = 0$.

b. $h = u + Pv$

We know

$u = u_0 + c_v T - \frac{a}{v}$

Eqn of state for Vander Waals:

$$P + \frac{a}{v^2} = \frac{RT}{v-b}$$

$$P = \frac{RT}{v-b} - \frac{a}{v^2}$$

Combining

$$h = u_0 + c_v T - \frac{a}{v} + \left(\frac{RT}{v-b} - \frac{a}{v^2}\right) v$$

$$h = u_0 + c_v T - \frac{a}{v} + \frac{RTv}{v-b} - \frac{a}{v}$$

$$h = u_0 + c_v T - \frac{2a}{v} + \frac{RTv}{v-b}$$

c.

$$\mu = \left(\frac{\partial T}{\partial p}\right)_h \qquad \text{(Carter (5.9))}$$

$$-\frac{1}{c_p}\left(\frac{\partial h}{\partial p}\right)_T = \left(\frac{\partial T}{\partial p}\right)_h = \mu \qquad \text{(Carter pg 74)}$$

$$\mu = -\frac{1}{c_p}\left(\frac{\partial h}{\partial p}\right)_T = -\frac{1}{c_p}\left(\frac{\partial h}{\partial V}\right)_T \left(\frac{\partial V}{\partial p}\right)_T$$

But $h = u + pv$ so $\left(\frac{\partial h}{\partial V}\right)_T = \left(\frac{\partial u}{\partial V}\right)_T + p + v\left(\frac{\partial p}{\partial V}\right)_T$

$$\left(\frac{\partial u}{\partial V}\right)_T = -c_v \left(\frac{\partial T}{\partial v}\right)_u \qquad \text{(Carter (5.2))}$$

$$= -c_v \eta = -c_v \cdot -\frac{a}{v^2 c_v} = \frac{a}{v^2} \qquad \text{(Carter pg. 71)}$$

$$\mu = -\frac{1}{c_p}\left(\frac{a}{v^2} + p + v\left(\frac{\partial p}{\partial V}\right)_T \left(\frac{\partial V}{\partial p}\right)_T\right). \text{ Using } p = \frac{RT}{v-b} - \frac{a}{v^2}$$

$$\mu = -\frac{1}{c_p}\left(\frac{a}{v^2} + \frac{RT}{v-b} - \frac{a}{v^2} + v\left(\frac{\partial p}{\partial V}\right)_T\right)\left(\frac{\partial V}{\partial p}\right)_T$$

$$= -\frac{1}{c_p}\left(\frac{RT}{v-b}\right)\cdot\left(\frac{\partial V}{\partial p}\right)_T - \frac{v}{c_p}$$

But $\left(\frac{\partial V}{\partial P}\right)_T = -\kappa V$, so

$$\mu = -\frac{1}{c_p}\left(\frac{RT}{V-b}\right)\cdot -\kappa V - \frac{V}{c_p}$$

$$\boxed{\mu = \frac{\kappa V}{c_p}\frac{RT}{(V-b)} - \frac{V}{c_p}}$$

d. $\kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T = -\frac{1}{V}\frac{1}{\left(\frac{\partial P}{\partial V}\right)_T}$

$$\left(\frac{\partial P}{\partial V}\right)_T = -\frac{RT}{(V-b)^2} + \frac{2a}{V^3}$$

$$\kappa = \frac{-1}{\left(-\frac{RT}{(V-b)^2} + \frac{2a}{V^3}\right)V} = \boxed{\frac{1}{\left(\frac{RTV}{(V-b)^2} - \frac{2a}{V^2}\right)}}$$

e. If $a=b=0$, $\kappa = \frac{1}{\frac{RTV}{V^2}} = \boxed{\frac{V}{RT}}$

$$\mu = \frac{\kappa V}{c_p}\frac{RT}{V} - \frac{V}{c_p} = \frac{V}{RT}\cdot\frac{1}{c_p}\cdot RT - \frac{1}{c_p} = \boxed{0}$$

5.4 a. $\left(\frac{\partial h}{\partial T}\right)_v = \left(\frac{\partial h}{\partial T}\right)_p + \left(\frac{\partial h}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_v$

(Clint Eastwood Relation)

$= c_p + \left(\frac{\partial h}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_v$

Note:

$\beta = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_p$

$\kappa = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$

$\left(\frac{\partial h}{\partial T}\right)_v = c_p + \left(\frac{\partial h}{\partial p}\right)_T \cdot \frac{\beta}{\kappa}$

$= c_p - c_p \left(\frac{\partial T}{\partial p}\right)_h \cdot \frac{\beta}{\kappa}$ (Carter pg. 74)

$\boxed{\left(\frac{\partial h}{\partial T}\right)_v = c_p\left(1 - \frac{\mu\beta}{\kappa}\right)}$

b. $\left(\frac{\partial h}{\partial v}\right)_T = \left(\frac{\partial h}{\partial p}\right)_T \left(\frac{\partial p}{\partial v}\right)_T = \left(\frac{\partial h}{\partial p}\right)_T \cdot -\frac{1}{v\kappa}$

$= -c_p \mu \cdot \frac{-1}{v\kappa} = \boxed{\frac{c_p \mu}{v\kappa}}$

c. $\left(\frac{\partial T}{\partial v}\right)_h = \left(\frac{\partial T}{\partial p}\right)_h \left(\frac{\partial p}{\partial v}\right)_h = \mu\left(\frac{\partial p}{\partial v}\right)_h = \frac{\mu}{\left(\frac{\partial v}{\partial p}\right)_h}$

Clint Eastwood relation on denominator:

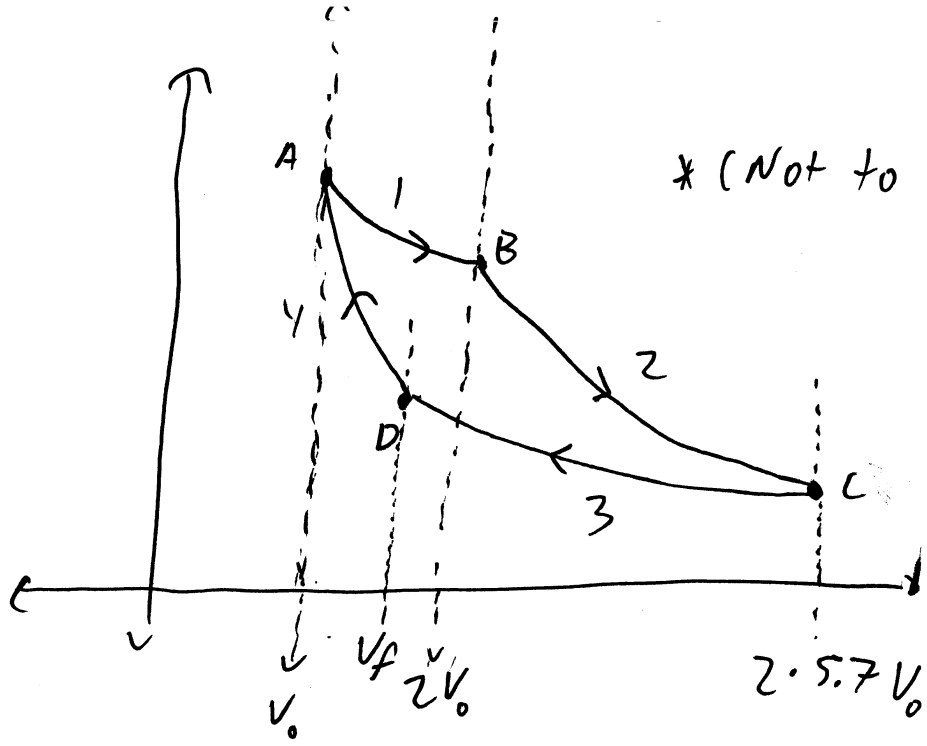
$\left(\frac{\partial v}{\partial p}\right)_h = \left(\frac{\partial v}{\partial p}\right)_T + \left(\frac{\partial v}{\partial T}\right)_p \left(\frac{\partial T}{\partial p}\right)_h$

$$\left(\frac{\partial V}{\partial P}\right)_h = -V\kappa + V\beta\mu$$

So

$$\boxed{\left(\frac{\partial T}{\partial V}\right)_h = \frac{\mu}{V(\mu\beta - \kappa)}}$$

5.9



* (Not to scale.)

1 = isothermal at $T = T_0$

2 = adiabatic

3 = isothermal at $T = T_f$

4 = adiabatic

($\gamma = \frac{5}{3}$ for a monatomic ideal gas)

$$\Delta U = 0 = W_{net} + Q_1 + \cancel{Q_2}^{\,0} + Q_3 + \cancel{Q_4}^{\,0}$$

If we define W_{net} as the work done BY the gas (the output work, in other words) this becomes

$$0 = -W_{out} + Q_1 + Q_3$$

$$W_{out} = Q_1 + Q_3$$

First, let's compute T_f & V_f in terms of known quantities.

We know $U(D) = U(C)$, since

$T(D) = T(C)$. Therefore $\Delta U(2) = \Delta U(4)$

But $Q_2 = Q_4 = 0 \Longrightarrow$

$W_2 = W_4$ From $pV^\gamma =$ constant, we have:

$$\int_{V_0}^{V_f} \frac{K_4}{V^{5/3}}\,dV = \int_{2V_0}^{2\cdot 5.7 V_0} \frac{K_2}{V^{5/3}}\,dV$$

$$K_4\left[+\frac{3}{2}V^{-2/3}\right]_{V_0}^{V_f} = K_2\left[+\frac{3}{2}V^{-2/3}\right]_{2V_0}^{2\cdot 5.7 V_0}$$

Assume V_f is some multiple of V_0;

e.g. $V_f = aV_0$. Then

$$K_4\left((aV_0)^{-2/3} - (V_0)^{-2/3}\right) = K_2\left((2\cdot 5.7 V_0)^{-2/3} - (2V_0)^{-2/3}\right)$$

The V_0s cancel, yielding:

$$a^{-2/3} = 1 + \frac{K_2}{K_4}\left((2\cdot 5.7)^{-2/3} - 2^{-2/3}\right)$$

But $K_4 = P_A V_A^\gamma = nRT_0 V_0^{\gamma-1}$

and $K_2 = P_B V_B^\gamma = \frac{nRT_0}{2V_0}\cdot(2V_0)^\gamma = nRT_0 2^{\gamma-1} V_0^{\gamma-1}$

So $\frac{K_2}{K_4} = \frac{nRT_0 2^{\gamma-1} V_0^{\gamma-1}}{nRT_0 V_0^{\gamma-1}} = 2^{\gamma-1} = 2^{2/3}$

Therefore

$$a^{-2/3} = 1 + 2^{2/3}\left(2^{-2/3}\cdot 5.7^{-2/3} - 2^{-2/3}\right)$$

$$a = 5.7 \Rightarrow \underline{\underline{V_f = 5.7 V_0}}$$

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

$$\underline{\underline{T_f = T_0 \cdot \left(\frac{V_0}{V_f}\right)^{\gamma-1}}} = \underline{\underline{T_0 \cdot \left(\frac{1}{5.7}\right)^{2/3}}}$$

Now we can compute Q_1 & Q_3 easily: $\Delta U_1 = 0$ (isotherm) $\Rightarrow$

$$Q_1 = -W_1 = \int_{V_0}^{2V_0} \frac{nRT_0}{V}\,dV = nRT_0 \ln 2$$

$$Q_3 = -W_3 = \int_{2\cdot 5.7V_0}^{5.7V_0} \frac{nRT_0\cdot\left(\frac{1}{5.7}\right)^{2/3}}{V}\,dV$$

$$= \frac{nRT_0}{(5.7)^{2/3}} \ln\left(\frac{1}{2}\right) = -\frac{nRT_0}{(5.7)^{2/3}} \ln 2$$

$$W = Q_1 + Q_3 = 9\cdot 10^5\ \text{J}$$

$$nRT_0 \ln 2 \left(1 - \frac{1}{(5.7)^{2/3}}\right) = 9\cdot 10^5$$

$$n = 1000\ \text{mol}, \quad R = 8.315\ \text{J/mol}\cdot\text{K}$$

$$T_0 = 227\ K$$

$$T_f = \frac{T_0}{(5.7)^{2/3}} = 71.3\ K$$

6.7 1 & 2 are simply shorthand for the conditions at states 1 & 2.

a. $$\Delta S = \int_1^2 \frac{dQ}{T} = \int_1^2 \frac{dU + P\,dV}{T}$$

$$= \int_1^2 \frac{n C_v\, dT}{T} + \int_1^2 \frac{nRT}{VT}\, dV$$

$$\boxed{\Delta S = n C_v \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{V_2}{V_1}\right)}$$

b. $$V_1 = \frac{nRT_1}{P_1} \qquad V_2 = \frac{nRT_2}{P_2}$$

$$\frac{V_2}{V_1} = \frac{\cancel{n}RT_2}{P_2} \cdot \frac{P_1}{\cancel{nR}T_1} = \frac{T_2 P_1}{T_1 P_2}$$

$$\Delta S = n C_v \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{T_2}{T_1} \cdot \frac{P_1}{P_2}\right)$$

$$= n C_v \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{P_1}{P_2}\right)$$

$$= n(C_v + R) \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{P_1}{P_2}\right)$$

$$\boxed{\Delta S = n C_p \ln\left(\frac{T_2}{T_1}\right) + nR \ln\left(\frac{P_1}{P_2}\right)}$$

6.8 Using our result from 6.7:

a. [redacted]

$$\Delta S = n C_p \ln\left(\frac{T_2}{T_1}\right) + n R \ln\left(\frac{P_1}{P_2}\right)$$

$$\Delta s = C_p \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{P_1}{P_2}\right)$$

$P_1 = P_2$ (isobaric) So:

$$\Delta s = C_p \ln\left(\frac{T_2}{T_1}\right)$$

$$\boxed{\Delta s = C_p \ln\left(\frac{V_2}{V_1}\right)}$$

$P_1 V_1 = n R T_1$

$P_2 V_2 = n R T_2$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \Rightarrow \frac{V_2}{V_1} = \frac{T_2}{T_1}$$

b. $$\Delta s = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right)$$

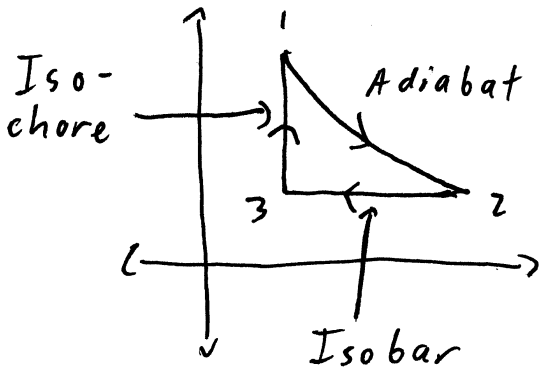
Isothermal $\Rightarrow T_1 = T_2$

$$\boxed{\Delta s = R \ln\left(\frac{V_2}{V_1}\right)}$$

c. a. is larger by $(C_p - R) \ln\left(\frac{V_2}{V_1}\right)$

$$= C_v \ln\left(\frac{V_2}{V_1}\right).$$

6.13



Path $\overline{12}$: $\Delta Q = 0$ by definition.

$\Rightarrow \boxed{\Delta S = 0}$

Path $\overline{23}$:

Use our result from 6.7 b.

$$\Delta S = n C_v \ln\left(\frac{T_2}{T_1}\right) + n R \ln\left(\frac{V_2}{V_1}\right)$$

Let's rewrite this in terms of P & V instead of T & V:

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

$$\Delta S = n C_v \ln\left(\frac{P_2 V_2}{P_1 V_1}\right) + n R \ln\left(\frac{V_2}{V_1}\right)$$

$$\Delta S = n C_v \ln\left(\frac{P_2}{P_1}\right) + n C_p \ln\left(\frac{V_2}{V_1}\right)$$

Now we just need P_2 in terms of P_1, V_1.

$$P_2 V_2^{\gamma} = P_1 V_1^{\gamma} \qquad P_2 = P_1 \cdot \left(\frac{V_1}{V_2}\right)^{\gamma}$$

Monatomic ideal gas $\Rightarrow \gamma = \frac{5}{3}$

$$P_2 = P_1 \cdot \left(\frac{2}{4}\right)^{5/3} = 0.315\, P_1$$

$$\Delta S \text{ for } \overline{23} = n C_v \ln\left(\frac{P_3}{P_2}\right) + n C_p \ln\left(\frac{V_3}{V_2}\right)$$

$$P_3 = P_2 \; ; \quad V_3 = \frac{1}{2} V_2 .$$

$$\Delta S_{\overline{23}} = n C_v \cdot 0 \; + \; n C_p \cdot \ln\left(\frac{1}{2}\right)$$

$C_p = \frac{5}{2} R$ for a monatomic ideal gas.

$$\Delta S_{\overline{23}} = 1000\,\text{mol} \cdot \frac{5}{2} \cdot 8.315\ \text{J/mol·K} \cdot -0.693$$

$$\boxed{\Delta S_{\overline{23}} = -14408\ \text{J/K}}$$

$$\Delta S \text{ for } \overline{31} = n C_v \ln\left(\frac{P_1}{P_3}\right) + n C_p \ln\left(\frac{V_1}{V_3}\right)$$

But $V_1 = V_3$ & $P_3 = P_2 = 0.315\, P_1$

So

$$\Delta S_{\overline{31}} = n \cdot C_v \cdot \ln\left(\frac{P_1}{0.315 P_1}\right)$$

$$= 1000 \cdot \frac{3}{2} R \cdot 1.155\ \text{J/K}$$

$$\boxed{\Delta S_{\overline{31}} = 14408\ \text{J/K}}$$

Clearly,

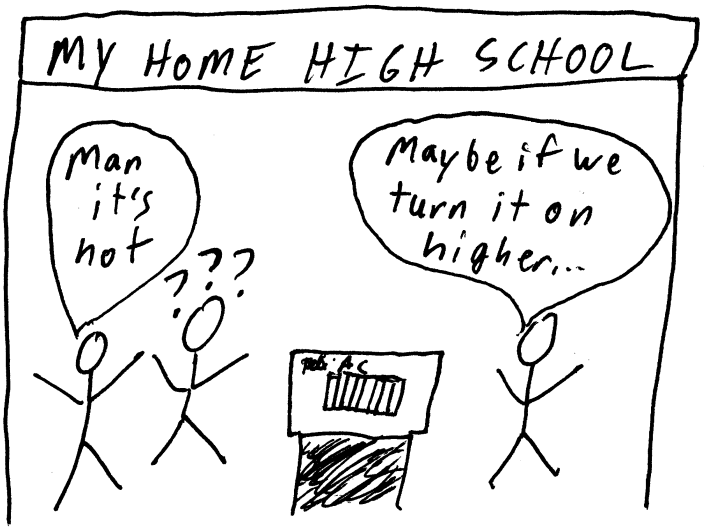
$\Delta S_{\overline{23}} +$

$\Delta S_{\overline{31}} +$

$\Delta S_{\overline{12}} = 0$

Schroeder

4.7 The waste heat is always greater than the heat removed from the cold reservoir. If the air conditioner is in the middle of a building, it has no place to dump the waste heat except right back into the room! this means that the air conditioner's net effect will be to INCREASE the room's temperature.



(not kidding)

4.8 Temporarily, yes, as the cold air already in the fridge mixes with the surroundings. But after the kitchen and the refrigerator's interior equalize in temperature, it's basically the same thing as having an air conditioner with nowhere to dump its waste heat (since, all along, the fridge has been dumping its waste heat into the kitchen).

4.14

a. COP usually = $\frac{\text{Benefit}}{\text{cost}}$

Benefit = Q_h (you want to heat the house)

Cost = W (Energy you must expend)

$$COP = \frac{Q_h}{W}$$

b. By conservation of energy

$Q_h = Q_c + W$ for a full cycle.

$$COP = \frac{Q_h}{Q_h - Q_c} = \frac{1}{1 - \frac{Q_c}{Q_h}}$$

Always > 1, since

$Q_h > 0$ & $Q_c > 0$ & $Q_h > Q_c$.

c. The entropy of the universe can never decrease.

Thus the entropy expelled during the cycle must be ≥ the entropy absorbed: $\frac{Q_h}{T_h} \geq \frac{Q_c}{T_c} \Rightarrow \frac{T_c}{T_h} \geq \frac{Q_c}{Q_h}$

Since $\frac{Q_c}{Q_h} \leq \frac{T_c}{T_h}$,

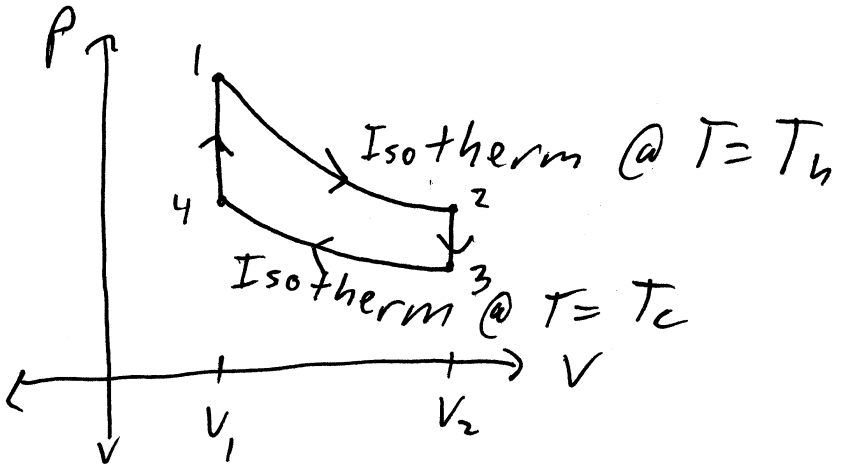
$1 - \frac{Q_c}{Q_h} \geq 1 - \frac{T_c}{T_h}$, which means

the COP $\leq \frac{1}{1 - T_c/T_h} = \frac{T_h}{T_h - T_c}$.

d. For an electric heater, all the electrical energy (W) is converted to heat (Q_h), so $W = Q_h$

$COP = 1$. An ideal heat pump, however, always has a $COP > 1$. (E.g. a heat pump operating between 25°C & 0°C could have a COP as high as $\frac{298}{298 - 273} = 12$!).

4.21 a.



Note: W here refers to work done BY the gas = $+\int P\,dV$.

b. Power stroke ($\overline{12}$):

$$W_{12} = \int_{V_1}^{V_2} \frac{NkT_h}{V}\,dV = NkT_h \ln\left(\frac{V_2}{V_1}\right)$$

Compression stroke ($\overline{34}$):

$$W_{34} = \int_{V_2}^{V_1} \frac{NkT_c}{V}\,dV = -NkT_c \ln\left(\frac{V_2}{V_1}\right)$$

Net work = $W_{12} + W_{34}$

$$= Nk(T_h - T_c)\ln\frac{V_2}{V_1}$$

Heat input during power stroke:

$T = 0 \Rightarrow \Delta U = 0$

so $Q_{12} = W_{12} = NkT_h \ln\left(\frac{V_2}{V_1}\right)$

During step $\overline{41}$ $W = 0$, so

$$Q_{41} = \Delta U_{41} = \frac{f}{2} N k (T_h - T_c)$$

Total heat input:

$$Q_h = N k T_h \ln\left(\frac{V_2}{V_1}\right) + \frac{f}{2} N k (T_h - T_c)$$

$e = \frac{W}{Q_h}$ Easier to compute $\frac{1}{e}$:

$$\frac{1}{e} = \frac{Q_h}{W} = \frac{N k T_h \ln(V_2/V_1) + f/2\, N k (T_h - T_c)}{N k (T_h - T_c) \ln(V_2/V_1)}$$

$$\frac{1}{e} = \frac{T_h}{T_h - T_c} + \frac{f}{2 \ln(V_2/V_1)}$$

$$e = \frac{1}{\frac{T_h}{T_h - T_c} + \frac{f}{2 \ln(V_2/V_1)}}$$

But $\frac{T_h}{T_h - T_c} = \frac{1}{e_c}$, where e_c = efficiency of Carnot engine.

Thus

$$e = \frac{e_c}{1 + e_c \cdot \frac{f}{2 \ln (V_2/V_1)}} < e_c$$

For example: if $f = 5$ (5 degrees of freedom), $\frac{V_2}{V_1}$ = compression ratio = 10, and $\frac{T_h}{T_c} = 2$, we have

$$e_c = \frac{2T_c - T_c}{2T_c} = \frac{1}{2}$$

$$e = \frac{e_c}{1 + e_c \cdot \frac{5}{2 \ln 10}} = \sim .32 < e_c$$

c. With an ideal regenerator, the heat input during step $\overline{41}$ comes for free, because it's exactly the same $\left(\frac{f}{2} N k (T_h - T_c)\right)$ as the heat output during step $\overline{23}$.

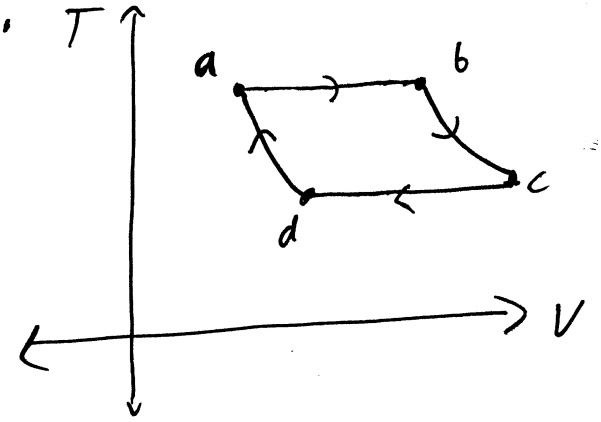
Therefore only Q_{21} counts in computing e. If we run through the calculations again, we find

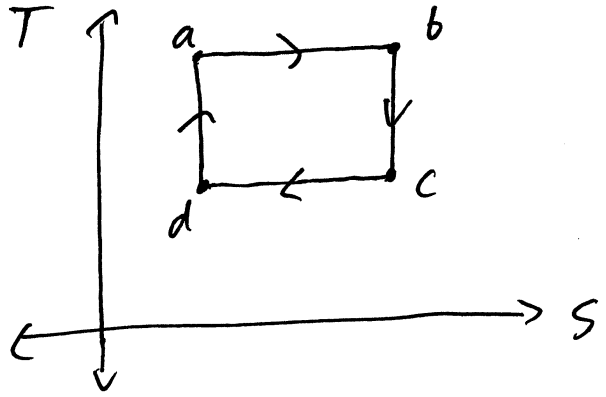
$$\frac{1}{e} = \frac{N_A T_h \cancel{\ln(V_2/V_1)}}{\cancel{N_A}(T_h - T_c)\cancel{\ln(V_2/V_1)}} = \frac{T_h}{T_h - T_c}$$

$$= \frac{1}{e_{Rc}} \quad \text{so} \quad \boxed{e = e_c .}$$

Additional Problems

1.





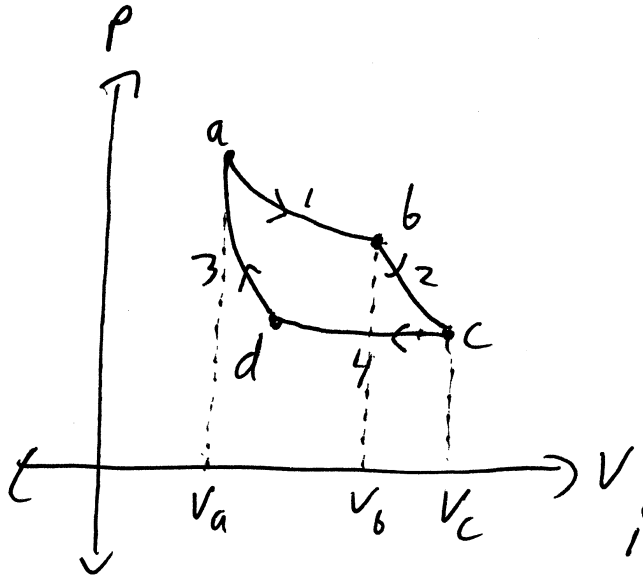
$pV^{\gamma} = \text{constant}$

$TV^{\gamma-1} = \text{constant}$

$T = \frac{k}{V^{\gamma-1}}$

$dS = \frac{dQ}{T}$

2.



2 & 3 are adiabats ($dS = 0$).

1 & 4 are isotherms ($\Delta U = 0$)

So $\Delta S_{net} = \Delta S_1 + \Delta S_4$.

$$\Delta S_1 = \int_1 \frac{dQ}{T_1} = \int_1 \frac{dU}{T_1}^{\to 0} + \frac{P\,dV}{T_1}$$

$$= \int_{V_a}^{V_b} \frac{nRT_1}{V} \cdot \frac{1}{T_1}\, dV = nR \ln\left(\frac{V_b}{V_a}\right)$$

$$\Delta S_4 = \int_4 \frac{nRT_4}{V} \cdot \frac{1}{T_4}\, dV = \int_{V_c}^{V_d} \frac{nR}{V}\, dV$$

$$= nR \ln\left(\frac{V_d}{V_c}\right)$$

Now we just need V_d, V_c in terms of V_b, V_a. Adiabatic Equations:

$$T_1 V_b^{\gamma-1} = T_2 V_c^{\gamma-1}, \quad T_1 V_a^{\gamma-1} = T_2 V_d^{\gamma-1}$$

(path 2) (path 3)

Dividing these two equations, we see that

$$\frac{T_1 V_b^{\gamma-1}}{T_1 V_a^{\gamma-1}} = \frac{T_2 V_c^{\gamma-1}}{T_2 V_d}$$

$$\left(\frac{V_b}{V_a}\right)^{\gamma-1} = \left(\frac{V_c}{V_d}\right)^{\gamma-1} \Longrightarrow \frac{V_c}{V_d} = \frac{V_b}{V_a}$$

So $\Delta S_4 = nR \ln\left(\frac{V_a}{V_b}\right) = -nR \ln\left(\frac{V_b}{V_a}\right)$

$$= -\Delta S_1$$

In other words

$$\Delta S_{net} = \Delta S_4 + \Delta S_1 = 0. \checkmark$$

Since every state function has a net change of 0 around a closed cycle, this might lead us to conclude that S is a state function. By itself, however, this example is not sufficient to PROVE that S is a state function.

3. $\Delta S = \int \frac{dQ}{T}$

$$\Delta S_{net} = \int_{253\,K}^{273k} \frac{C_{p(s)}}{T} dT + \frac{L_f}{273K} + \int_{273}^{373} \frac{C_{p(l)}}{T} dT + \frac{L_v}{373}$$

$$+ \int_{373}^{673} \frac{C_{p(g)}}{T} dT$$

$$= C_{p(s)} \ln\left(\frac{273}{253}\right) + \frac{L_f}{273} + C_{p(l)} \ln\left(\frac{373}{273}\right)$$

$$+ \frac{L_v}{373} + C_{p(g)} \ln\left(\frac{673}{373}\right)$$

$C_{p(s)}$ = Heat capacity of solid water (ice)

$= 2.30\ J/g\cdot K = 2.30\ kJ/kg\cdot K$

$C_{p(l)}$ = Heat capacity of liquid water

$= 4.18\ J/g\cdot K = 4.18\ kJ/kg\cdot K$

$C_{p(g)}$ = Heat capacity of gaseous water (steam) $= 2.01\ J/g\cdot K = 2.01\ \frac{kJ}{kg\cdot K}$

$L_f = 333\ J/g = 333\ kJ/kg$

$L_v = 2257\ J/g = 2257\ kJ/kg$

$$\Delta S_{net} = 0.175 + 1.22 + 1.305$$

$$+ 6.05 + 1.186 \text{ kJ/k}$$

$$= \boxed{9.94 \cdot 10^3 \text{ J/k}}$$