DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. Put your answers on the same sheet as the question, Use many digits in your computation. You must give the units of your answers. You must write clearly. Encircle the right answer number in multiple choice. To correct, erase the wrong circle as well as you can and encircle the corrected answer number twice. Best possible answer for multiple choice. For questions asking a number, putting the clear correct formula(s) below the question might result in partial credit even if the answer is wrong. *Not following those requirements will result in reduced or no credit.*

1. (3%) What would you normally best model as a control volume:

   (a) An isolated lake
   ((b)) A stretch of river
   (c) A mountain

2. (3%) If you have saturated liquid in an insulated container and you increase the temperature reversibly,

   ((a)) it turns into compressed liquid
   (b) it turns into two-phase
   (c) it turns into superheated vapor

3. (3%) Air in the room is heating up at a rate of 2°C/min. Its internal energy is changing at a rate of __1.434__ kJ/kg-min.

4. (3%) Engine oil is being compressed by the reversible oil pump from 1 bar to 2.5 bar. The work needed by the pump is __0.16949__ kJ/kg. Ignore kinetic and potential energy.

5. (3%) Half a kg of lead cools from 100°C down to the ambient temperature of 25°C. The net entropy generated during this process is __0.00176754__ kJ/K.

6. (3%) If liquid water at standard ambient conditions flows with a velocity of 5 m/s through a pipe with a 3 cm diameter, the amount of water flowing through the pipe will be 3.534 kg/s.

7. (3%) Helium enters a reversible adiabatic turbine at 1Mpa and 300 K and comes out at 120 K at the same height and velocity that it entered. The work produced by the turbine is 934.41 kJ/kg.

8. (3%) A heat engine extracting heat from a 100°C underground geothermal reservoir on a 25°C day can produce up to 0.201 kJ of work for each kJ of heat extracted.

9. (3%) If the ambient pressure is 75 kPa, then water boils at 91.77 °C.

10. (3%) Suppose that it is -10°C outside and 25°C inside your house. Then a resistance heater using 2 kW of electricity would add 2 kW of heat to your house while an ideal heat pump using 2 kW of electricity would add 17 kW.

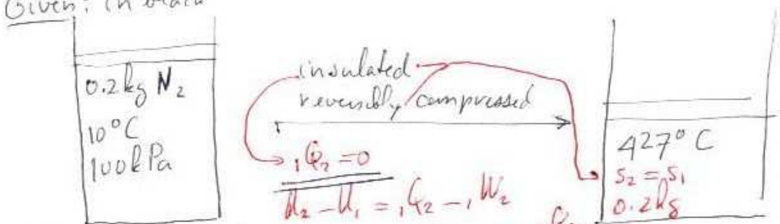
11. (35%) An insulated piston-cylinder combination contains 0.2 kg diatomic nitrogen at 10°C and 100 kPa. The nitrogen is now reversibly compressed until its temperature is 427°C.

   (a) Find the final pressure, the heat transfer, and the work.

   (b) Find the same quantities but now assuming that the specific heats of nitrogen are constant at their 25°C values.

You must show the derivations and reasoning completely and correctly for full credit. You must give units for your answers. Most accurate procedure only unless stated otherwise.

Given: in black



${}_1Q_2 = 0$

$U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Asked: P_2, ${}_1Q_2$, ${}_1W_2$ ~~${}_1S_{gen_2} = m(s_2 - s_1) - \frac{{}_1Q_2}{T_{surr}}$~~

Solution $s_2 - s_1 = 0 = s^o_{T_2} - s^o_{T_1} - R\ln(P_2/P_1)$

A.8 ∋ oxygen and 10°C = 283 K: $R = 0.2968 \frac{kJ}{kg\,K}$

$g = 283$ $\quad S_1 = 250$ $\quad S_2 = 300$

$d = u$ $\quad d_1 = 185.50$ $\quad d_2 = 222.63$ $\quad u_1 = 210.0058$ kJ/kg

$d = s^o_T$ $\quad d_1 = 6.6568$ $\quad d_2 = 6.8463$ $\quad s^o_{T_1} = 6.78187$ kJ/kg K

and 427°C = 700 K: $u_2 = 528.09$ $\quad s^o_{T_2} = 7.7415$

$0 = s^o_{T_2} - s^o_{T_1} - R\ln P_2/P_1 = 7.7415 - 6.78187 - 0.2968 \ln \frac{P_2}{100\text{ kPa}}$

$\ln\left(\frac{P_2}{100\text{ kPa}}\right) = 3.2332$ $\quad P_2 = 100\text{ kPa}\; e^{3.2332} = \underline{2536.2069 \text{ kPa}}$

1st law: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$ $\quad {}_1W_2 = U_1 - U_2 = m(u_1 - u_2)$

$= 0.2\text{ kg}\,(210.0058 - 528.09)\frac{kJ}{kg} = \underline{-63.6168 \text{ kJ}} = {}_1W_2$

For constant specific heats: $n = k = 1.4$ $\quad c_v = 0.745$ kJ/kg K

$\left(\frac{P_2}{P_1}\right) = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \left(\frac{700}{283}\right)$ $\quad \underline{P_2 = 2380.07 \text{ kPa}}$ → 2403 from s-equation

$P_1 = 100$ kPa

${}_1W_2 = U_1 - U_2 = m\,c_v(T_2 - T_1) = 0.2\text{ kg}\;\frac{kJ}{kg\,K}(427 - 10)\text{K}$

$= \underline{62.133 \text{ kJ}}$ (or use $m\frac{P_2v_2 - P_1v_1}{1-k} = m\frac{R(T_2 - T_1)}{1-k} = \frac{0.2968(417)}{1-1.4}0.2 = 61.8828$)

(4) $s_2 = s_1$
~~$m_2 = m_1$~~
(4) ${}_1Q_2 = 0$ (circled)
~~1st law~~
~~eq for s~~

(2) A.7.1
(4) interpolate u, s^o_T
(4) eq for s
(2) find P_2
(5) 1st law, find W_2
(1) $m_2 = m_1$

(3) A.5 R/k, c_v as needed
(3) CC find P_2
(3) CC find W

12. (35%) An reversible isothermal compressor takes in 2 kg/s of water at 500 kPa and 200°C. It exits the compressor with an entropy of 3kJ/kg-K. Kinetic and potential energy can be neglected.

    (a) Construct the initial phase of the water in the Pv diagram. Construct the final phase of the water in the Ts diagram. Mark all lines and points used to do it with their values. Do not put more info in the diagrams than is needed to construct the phases. State the phases. Show the process in the Pv diagram.

    (b) Find the heat transfer from the water and the work required by the compressor.

    (c) If the surroundings are at 27°C, then what is the total entropy generated? Is the second law violated or not? Why?

You must show the derivations and reasoning completely and correctly for full credit. You must give units for your answers. Most accurate procedure only unless stated otherwise.

Given: in black

2 kg/s H_2O, 500 kPa, 200°C → [reversible isothermal compressor] → $s_2 = 3$ kJ/kgK, 200°C; $\dot W$, $\dot Q$; ~~ΔKE~~ ~~ΔPE~~

$\dot Q = T(s_2 - s_1)$

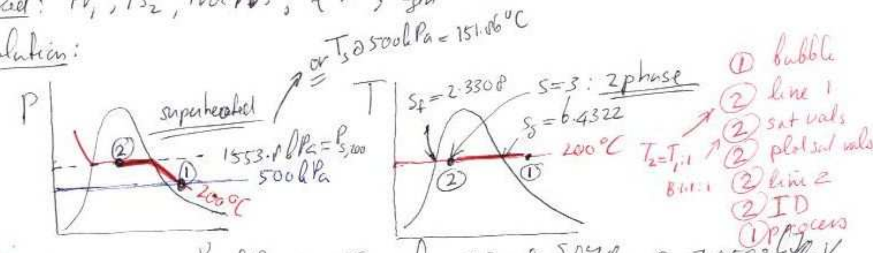
$\dot Q + \dot m(h_1 + \ldots) = \dot W + \dot m(h_2 + \ldots)$

$\dot S_{gen} = \dot m(s_2 - s_1) - \dot Q/T_{surr}$

$T_{surr} = 27°C = 300$ K

Asked: Pv_1, Ts_2, Proc Pv, $\dot Q$, $\dot W$, $\dot S_{gen}$

Solution:



② Table B.1.3 @ 500 kPa, 200°C: $h_1 = 2855.37$ kJ/kg, $s_1 = 7.0592$ kJ/kgK

Table B.1.1 @ 200°C s_f, s_g above $h_f = 852.43$ kJ/kg $h_g = 2793.18$ kJ/kg

⑤ $\dot Q = \dot m q = \dot m T(s_2 - s_1) = 2\,\text{kg/s}\,(200 + 273)\text{K}\,(3 - 7.0592)\frac{\text{kJ}}{\text{kgK}}$

$= -3840$ kJ

② $s_2 = s_f + x(s_g - s_f) \Rightarrow 3\frac{\text{kJ}}{\text{kgK}} = 2.3308\frac{\text{kJ}}{\text{kgK}} + x(6.4322 - 2.3308)\frac{\text{kJ}}{\text{kgK}}$

$\Rightarrow x = 0.16316$

② $h_2 = h_f + x(h_g - h_f) = 852.43\frac{\text{kJ}}{\text{kg}} + 0.16316(2793.18 - 852.43)\frac{\text{kJ}}{\text{kg}}$

$= 1169.09$ kJ/kgK

⑤ 1st law: $\dot Q + \dot m h_1 = \dot W + \dot m h_2 \Rightarrow -3840\text{ kJ} + 2\frac{\text{kg}}{\text{s}}\,2855.37\frac{\text{kJ}}{\text{kg}}$

$= \dot W + 2\,\text{kg/s}\,1169.09\frac{\text{kJ}}{\text{kg}} \Rightarrow \dot W = -467.44$ kW

⑤ 2nd law: $\dot S_{gen} = \dot m(s_2 - s_1) - \frac{\dot Q}{T_{surr}} = 2\,\text{kg/s}\,(3 - 7.0592)\frac{\text{kJ}}{\text{kgK}} + \frac{3840\text{ kJ/s}}{300\text{ K}}$

② analyze: $= 4.6816\frac{\text{kW}}{\text{K}}$ $\quad \dot S_{gen} > 0$ so 2nd law OK.