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. (5%) Helium in an adiabatic container is compressed reversibly from 25°C to 300°C. The work that must be done to do so is ___856.4___ kJ/kg.

2. (5%) One of the following heat pumps is possible, one does not satisfy the first law, and one does not satisfy the second law. Which is the one that is possible?
   (a) $W = 0$, $Q_H = 1$, $Q_L = 1$
   (b) $W = 1$, $Q_H = 0$, $Q_L = 1$
   ((c)) $W = 1$, $Q_H = 1$, $Q_L = 0$

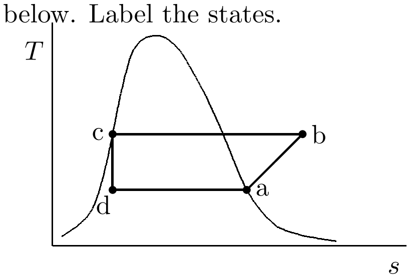
3. (5%) If a pump compresses 3kg/s of liquid with a constant density of 2000 kg/m^3 from 100 kPa to 1000 kPa, it will need ___1.35___ kW of power. Ignore irreversible effects and height and velocity changes.

4. (5%) A 2 kg iron cast piece cools down from its 1800 K melting point to the ambient temperature of 300 K. The total change in its entropy is ___-1.505___ kJ/K.

5. (5%) If the heat engine in your car burns the fuel at 1000 K and dumps its heat to the surroundings at 300 K, then the most power it can possibly produce out of 10 kW of combustion heat is ___7___ kW.

6. (5%) You have a substance in an insulated container. What is possible by compressing (increasing the pressure of) the substance, reversibly or irreversibly,
   ((a)) You can change saturated liquid into two-phase.
   (b) You can change saturated vapor into two-phase.
   (c) You can change superheated vapor into two-phase.

7. (5%) *Neatly* draw the $T - s$ diagram for the reversible cycle described below. Label the states.
   - 1-2 isobaric increase in temperature from saturated vapor.
   - 2-3 isothermal cooling to saturated liquid.
   - 3-4 reversible adiabatic pressure reduction to the same temperature as it started out at in 1.
   - 4-5 constant pressure heating to saturated vapor.



8. (32%) Air enters an adiabatic reversible turbine at 727°C and 1 MPa. In the turbine it expands to 10°C.

   (a) Find the exit pressure.

   (b) Find the specific work output of the turbine.

   (c) Under a certain approximation, you can use a work formula to find the work. What is the approximation? How does the work found this way compare to the work you found above?

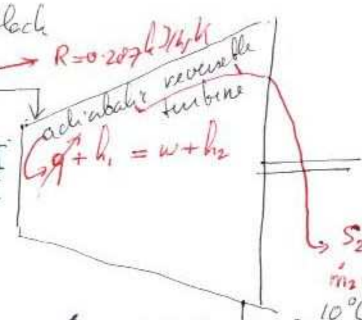
   Ignore kinetic and potential energy changes in the air.

   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

Air → $R = 0.287$ kJ/kg K

727°C
1 MPa I
1000 K I



$s_2 = s_1$ I
$\dot m_2 = \dot m_1 = ??$ E?
10°C I

Ignore kinetic and potential energy changes

(3) A7.1 (2) c_p, c_v, k const
(4) interpolate (2) formula
(4) s-formula (2) sol w (6)
(4) $s_2 = s_1$ (2) units + comps
(2) compute P_2
(4) 1st law
(3) $q = 0$

$s^\circ_{T_1} = 8.13493$ kJ/kg K

Asked: P_e, w, Work formula approx + result

Solution: A.7.1 @ 1000 K: $h_1 = 1046.22$ kJ/kg

@ 10°C = 283 K:

$g = 283$	$g_1 = 280$	$g_2 = 290$	
$d = h$	$d_1 = 280.39$	$d_2 = 290.43$	$h_2 = 283.402$
$d = s^\circ_T$	$d_1 = 6.79998$	$d_2 = 6.83521$	$s^\circ_{T_2} = 6.810549$

$$d = d_1 + \frac{g - g_1}{g_2 - g_1}(d_2 - d_1)$$

$$s_2 - s_1 = 0 = s^\circ_{T_2} - s^\circ_{T_1} - R \ln \frac{P_2}{P_1}$$

$$0 = 6.810549 \frac{\text{kJ}}{\text{kg K}} - 8.13493 \frac{\text{kJ}}{\text{kg K}} - 0.287 \frac{\text{kJ}}{\text{kg K}} \ln \frac{P_2}{1000 \text{ kPa}}$$

$$\ln \frac{P_2}{1000 \text{ kPa}} = -4.61456 \qquad P_2 = 1000\, e^{-4.61456} \text{ kPa} = \underline{9.906 \text{ kPa}}$$

$$w = h_1 - h_2 = 1046.22 \frac{\text{kJ}}{\text{kg}} - 283.402 \frac{\text{kJ}}{\text{kg}} = \underline{762.8 \frac{\text{kJ}}{\text{kg}}}$$

If c_p, c_v, k constant, then polytropic with $n = k = 1.4$ from A.5, since isentropic.

$$w = \frac{(P_2 v_2 - P_1 v_1)n}{1-n} = \frac{nR(T_2 - T_1)}{1-n} = \frac{1.4 \cdot 0.287\,(10 - 727)}{1 - 1.4} = \underline{720.22 \frac{\text{kJ}}{\text{kg}}}$$

9. (33%) A piston-cylinder configuration contains 2 kg of water at 20°C and a quality of 2%. The piston is pushed in at a rate so that the water stays at 20°C until the volume becomes 0.002 m^3. This compression process can be taken to be reversible.

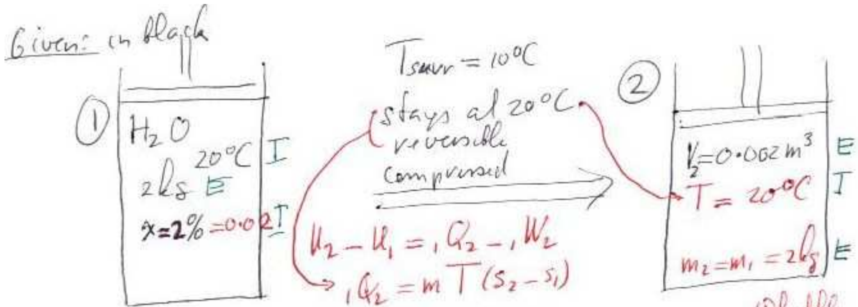
   (a) Construct the final phase in the Ts diagram, marking all lines and points used to do it with their values. Do not put more info in the diagram than is needed to construct the phase. State the phase. Also show the process as a fat curve (maybe straight) in the diagram.

   (b) Find the heat transfer and work during the process to five significant digits.

   (c) Assuming that the environment is at 10°C, what is the net entropy generated by irreversible processes?

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



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

${}_1Q_2 = m T (s_2 - s_1)$

Asked. Ts for ②, process, ${}_1Q_2$, ${}_1W_2$, S_{gen}

①bubble ①line 1 ①sat val ①plat ①line 2 ①TD ①process ③B.1.1 ④u_1, s_1 ④B.1.4 $T_2 = T_1$ ... ⑤${}_1Q_2$ ⑤1st law ⑤2nd law

Solution $v_2 = \frac{V_2}{m} = \frac{0.002\,m^3}{2\,kg} = 0.001\,\frac{m^3}{kg}$

② is compressed liquid

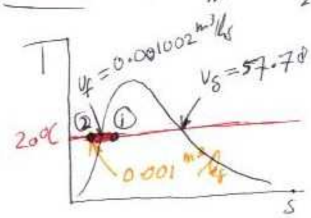


Table B.1.4 @ 20°C, 0.001 $\frac{m^3}{kg}$

$u_2 = 83.64\,\frac{kJ}{kg}$ $s_2 = 0.2955\,\frac{kJ}{kg\,K}$

Table B.1.1 @ 20°C and $x_1 = 0.02$

$u_1 = u_f + x_1 u_{fg} = 83.94\,\frac{kJ}{kg} + 0.02 \cdot 2318.98\,\frac{kJ}{kg} = 130.3196\,\frac{kJ}{kg}$

$s_1 = s_f + x_1 s_{fg} = 0.2966\,\frac{kJ}{kg\,K} + 0.02 \cdot 8.3706\,\frac{kJ}{kg\,K} = 0.464012\,\frac{kJ}{kg\,K}$

${}_1Q_2 = m T (s_2 - s_1) = 2\,kg\,(20 + 273)\,K\,(0.2955 - 0.464012)\,\frac{kJ}{kg\,K}$

$= -98.748032\,kJ$

${}_1W_2 = {}_1Q_2 + U_1 - U_2 = -98.748032 + 2\,kg\,(130.3196 - 83.64)\,\frac{kJ}{kg}$

$= -5.388832\,kJ$

${}_1S_{2gen} = S_2 - S_1 - \frac{{}_1Q_2}{T_{surr}} = m(s_2 - s_1) - \frac{{}_1Q_2}{T_{surr}}$

$= 2\,kg\,(0.2955 - 0.464012)\,\frac{kJ}{kg\,K} + \frac{98.748032\,kJ}{(273 + 10)\,K}$

$= 0.01191\,\frac{kJ}{K}$