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%) If heat leaks into your -10°C freezer at a rate of 100 J/s from your 20°C house, the rate of entropy generation by that process is 0.03893 W/K

2. (5%) The values $Q_H = 2$, $Q_L = 2$, and $W = 0$
   (a) are fine for a heat engine.
   (b) are fine for a heat pump.
   (c) are impossible.

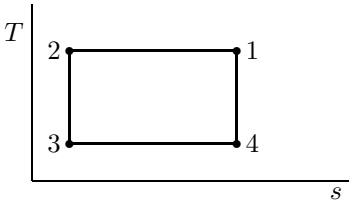
3. (5%) Air is compressed isentropically from 1000 K to 1500 K. Assuming (incorrectly) that the specific heats are constant at their 25°C values, the work done will be 358.75 (or 502) kJ/kg

4. (5%) If you heat 2 L of lead from 27°C to its melting point of 327°C, you will increase its entropy by 2.0437 kJ/K.

5. (5%) If heat leaks into your -10°C freezer at a rate of 100 J/s from your 20°C house, the absolute minimum electrical power it will need to operate is 11.407 W?

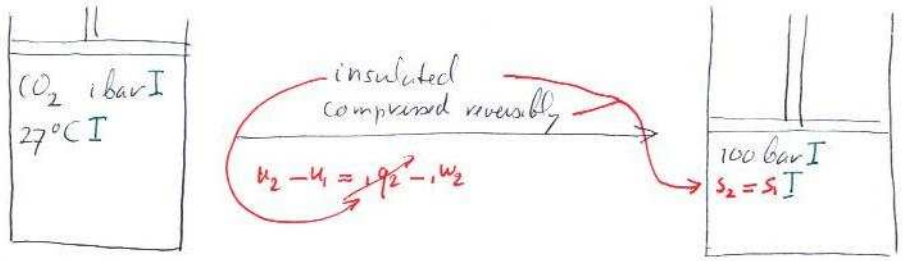
6. (5%) You have water in an insulated piston cylinder combination. Gently or wildly,
   (a) You can change saturated liquid into saturated water and vice-versa.
   (b) You can change saturated vapor into saturated liquid by compressing the vapor, but not vice-versa.
   (c) You can change saturated liquid into saturated vapor by expanding the water, but not vice-versa.
   (d) Whatever you do, it is not possible to change either one into the other in an insulated system.

7. (5%) *Neatly* draw the $T - s$ diagram for the reversible cycle described below. Assume an ideal gas. Label each state and state what sort of proces this is: Carnot Cycle .
   - 1-2 isothermal heat removal.
   - 2-3 reversible adiabatic pressure reduction.
   - 3-4 polytropic expansion with $n = 1$;
   - 4-1 polytropic temperature increase with $n = k$.



8. (32%) An insulated piston cylinder combination contains carbon dioxide at 1 bar and 27°C. The carbon dioxide is reversibly compressed to 100 bar. Find the final temperature and the specific work that must be done to compress the carbon dioxide.

   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.




Asked: $T_2$, ${}_1w_2$

Solution: $s_2 - s_1 = s^0_{T_2} - s^0_{T_1} - R\ln\frac{P_2}{P_1}$ A.8 $R = 0.1889\ \frac{kJ}{kg\,K}$

A.8 ② 300 K $u_1 = 157.70\ \frac{kJ}{kg}$ $s^0_{T_1} = 4.8631\ \frac{kJ}{kg\,K}$

$$0 = s^0_{T_2} - 4.8631\ \frac{kJ}{kg\,K} - 0.1889\ \frac{kJ}{kg\,K}\ln\frac{100}{1}$$

$$s^0_{T_2} = 5.73302\ \frac{kJ}{kg\,K}$$

A.8 ③ $s^0_{T_2} = 5.73302$ interpolated

$s = 5.73302$ $s_1 = 5.6976$ $d_1 = 700$ K $d_1 = 493.97\ kJ/kg$

$s_2 = 5.7761$ $d_2 = 750$ K $d_2 = 531.40\ kJ/kg$

$T_2 = 722.56$ K $u_2 = 505.37\ \frac{kJ}{kg}$

$= 450$ °C

${}_1w_2 = u_1 - u_2 = -347.66\ kJ/kg$

work that must be done 347.66

④ $s_2 = s_1$

④ formula for $s_2 - s_1$ ② compute $s^0_{T_2}$ → 1 : $T_2$

④ $R$, ② $R$, option A.5

④ $s^0_{T_1}$, $u_1$ from A.8

④ reverse lookup $s^0_{T_2}$ ④ interpolate ③ interpolate $T_{2,cc}$

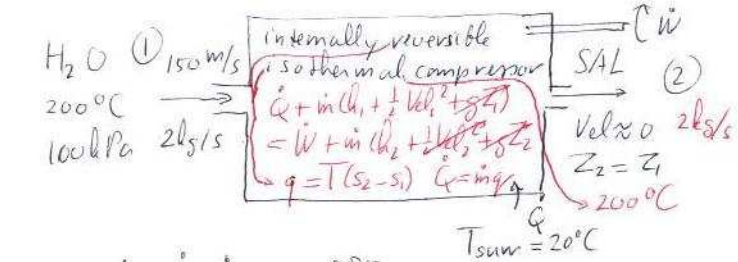
⑤ 1st law, spec ④ ${}_1q_2 = 0$ ① compute ${}_1w_2$

9. (33%) Water at 200°C and 100 kPa enters an internally reversible isothermal compressor at 150 m/s and 2 kg/s. It exits as saturated liquid at negligible velocity and at the same height. Find the rate of heat removal from the water, the power required to run the compressor, and the entropy generated if the heat is absorbed by cooling water at an average temperature of 20°C.

   You must construct all phases that are not given in the $Ts$-diagram, marking all lines and points used to do it with their values. Unambiguously number the phases in the diagram.

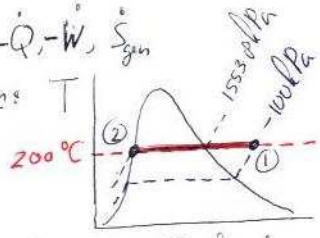
   Also show the process as a fat curve in the diagram.

   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.




Asked $-\dot{Q}, -\dot{W}, \dot{S}_{gen}$

Solutions




According to diagram, ① is superheated vapor. Use B.1.3 @ 100 kPa, 200°C

$h_1 = 2875.27 \frac{kJ}{kg}$ $s_1 = 7.8342 \frac{kJ}{kg\,K}$

Table B.1.1 @ 200°C, f-values: $h_2 = 852.43 \frac{kJ}{kg}$ $s_2 = 2.3300 \frac{kJ}{kg\,K}$

$q = T(s_2 - s_1)$ $\dot{Q} = \dot{m} T (s_2 - s_1) = 2 \frac{kg}{s} (200 + 273) K (2.3300 - 7.8342) \frac{kJ}{kg\,K}$

$= -5206.2\ kW$ $-\dot{Q} = 5206.2\ kW$

1st law $-5206.2\ kW + 2 \frac{kg}{s} \left(2875.27 + \frac{1}{2} \frac{150^2\ m^2/s^2}{1000\ m^2/s^2}\right) kJ/kg$

$= \dot{W} + 2 \frac{kg}{s}\ 852.43\ kJ/kg$

$\dot{W} = -1138.03$ $-\dot{W} = 1138.03$ (velocity adds 22)

2nd law $\dot{S}_{gen} = \dot{m}(s_2 - s_1) - \frac{\dot{Q}}{T_{surr}} = 2 \frac{kg}{s} (2.3300 - 7.8342) \frac{kJ}{kg\,K} + \frac{5206.2\ kW}{(20 + 273) K}$

$= 6.7618 \frac{kW}{K}$

phase 1: diagram ① $h_1, s_1$ in B1.3 ② 2nd law ⑤
line 1 ① $h_2, s_2$ in B1.1 ④ units and computations ④ e.g. kelvin, $m^2/s^2$
sat value ① isothermal heat ⑤
plot ① 1st law ⑥
line 2 ① compute ⑦
process line ②