IB Paper 4: Thermodynamics
Hints on Examples Paper 2

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Physical principles are in **bold**; assumptions are *emphasised*.

Q1. Determining the dryness fraction at turbine exit χ_4 requires many steps: look up $s_3 = s_{\mathrm{g}}(p_3)$ and $h_3 = h_{\mathrm{g}}(p_3)$, look up $s_{\mathrm{f4}}(p_1)$ and $s_{\mathrm{g4}}(p_1)$, solve for *isentropic* dryness fraction χ_{4s} such that $s_3 = s_{4s} = \chi_{4s}s_{\mathrm{g4}} + (1 - \chi_{4s})s_{\mathrm{f4}}$, evaluate $h_{4s} = \chi_{4s}h_{\mathrm{g4}} + (1 - \chi_{4s})h_{\mathrm{f4}}$, use the definition of *isentropic efficiency* $\eta = (h_3 - h_4)/(h_3 - h_{4s})$ to calculate h_4, and finally solve for the real dryness fraction in $h_4 = \chi_4 h_{\mathrm{g4}} + (1 - \chi_4)h_{\mathrm{f4}}$. For part (c), consider how to use all pieces of information given in the question.

Q2. For part (e), Think about what sets the maximum possible efficiency for a *Carnot engine*, and how this applies to our reheated steam cycle.

Q3. Pay attention to the value of c_p that the question asks for: a Table lookup is needed at these high temperatures. Calculating the pinch point requires a **First Law** analysis for a control volume from the pinch point to either end of the heat exchanger; $T_{\mathrm{steam}} = T_{\mathrm{sat}}(p = 20\,\mathrm{bar})$ at the pinch point. Part (c): what does the special case of the ratio of entropy changes being unity mean?

Q4. Use the R-134A table, Databook p.7, or the chart on the following page. The method is conceptually identical to Q1. Once again, take care to get *isentropic efficiencies* the correct way up!

Q5. In part (f), use the saturation temperature in the condensor, not the peak temperature. To get the COP_{R} as a function of efficiency for a *Carnot engine* we must analyse running it in reverse.

Q6. Here, we must use the R-143A tables, because the chart has no isentropic lines in the vapour dome. Remember that throttles exchange no heat or work with the surroundings, and are *isenthalpic*.

S1. Make sure to distinguish between the universal gas constant, which is always $\overline{R} = 8.31\,\mathrm{kJ\,kmol^{-1}\,K^{-1}}$, and the specific gas constant $R = \overline{R}/M$ with units $\mathrm{kJ\,kg^{-1}\,K^{-1}}$. The former is on a molar basis, the latter on a mass basis.

Q7. Review the definitions of specific humidity, relative humidity, and dew point, Lecture §9.

Q8. On the T–s diagram, consider that extracting heat will reduce entropy. Get $p_{\mathrm{v1}} = \phi_1 p_{\mathrm{sat}}(T_1)$, then use the **humidity equation** (not in Databook) $\omega_1 = \frac{M_{\mathrm{H_2O}}}{M_{\mathrm{Air}}}\frac{p_{\mathrm{v1}}}{p - p_{\mathrm{v1}}}$ to get specific humidity. If 30% of the water is removed, while the air flow stays the same, $\omega_2 = 0.7\omega_1$, and perform the same steps in reverse. When looking up $T_{\mathrm{sat}}(p_{\mathrm{v2}})$ use temperature tables because they have better resolution. Applying the **First Law** to the cooler, treat the air as a *perfect gas* with $\Delta h = c_p \Delta T$, while steam/water enthalpies are $h_{\mathrm{g}}(T_2)$ and $h_{\mathrm{f}}(T_2)$ at exit, and $h(p_1, T_1)$ at inlet is superheated.

Q9. If the reaction is rich, then there is excess fuel and CO is produced; If the reaction is lean, then excess air leaves O_2 remaining. Determine which by comparing to the stoichiometric air-fuel ratio.

Q10. Lecture §10.7 gives examples of combustion calculations. Starting with the **First Law** applied to the adiabatic combustion chamber, there is no net enthalpy flow. Manipulate this into three enthalpy changes which sum to zero: (a) vapourising and heating the reactants to T_0, (b) products minus reactants for burning at $T_0 = \mathrm{const.}$, (c) heating the products from T_0 to T_2. At low temperatures in (a), can assume the gases are *perfect* with c_p values from the Databook p.12, and add on the heats of vapourisation. At high temperatures in (c), this assumption is invalid and we must use molar enthalpies from Databook p.13. The combustion term (b) is calorific value of H_2, Databook p.11 multiplied by the mass of fuel consumed (the reaction is rich so some is left over).