# IB Paper 4: Thermodynamics
# Hints on Examples Paper 1

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

S1. The **Second Law** for a control volume is $\dot{m}\Delta s = \int \mathrm{d}\dot{Q}/T + \dot{S}_\mathrm{irrev}$ with $\dot{S}_\mathrm{irrev} \geq 0$ . The right-hand side shows there are two mechanisms, but only heat extraction with $\dot{Q} < 0$ decreases entropy.

Q1. **Conservation of mass** yields an equation containing $V_\mathrm{B}$ and the densities at A and B. Can we assume incompressible flow? If we assume air is an *ideal gas* then we can use the equation of state to check if density is constant. To solve for the heat transfer we consider energy flows and use the **First Law** for a control volume. Finally, we use the **Second Law** to get at the increase in entropy due to irreversibility.

Q2. Air can be treated as a *perfect gas.* The "physical reasoning" questions are asking for a comparison of terms in the **availability** change, $\dot{W}_{x12,\mathrm{max}} = b_1 - b_2 = h_1 - h_2 - T_0(s_1 - s_2)$ , see Lecture §2.4. Without further information, we must assume *inviscid*, frictionless flow in the heat exchanger. In part (e), each heat engine will have the *Carnot efficiency*, $\mathrm{d}\dot{W}_x = (1 - T_0/T)\,\mathrm{d}\dot{Q}$ . To integrate and get total work, we must put $\mathrm{d}\dot{Q}$ in terms of $\mathrm{d}T$ by applying the **First Law** to a small element.

Q3. Throttles may be assumed *adiabatic.* Energy flow which is unavailable for work must go somewhere: it is rejected to the environment. So the area required in (a) is equal to $\dot{Q}_0$ , see Lecture §2.4 again.

Q4. For an *adiabatic* control volume around the entire heat exchanger, the **First Law** states that there is no net enthalpy flow. This fixes the coolant exit enthalpy, and for a *perfect gas*, the temperature. Similarly, we can use the net **availability** flow to determine if available power is being created or destroyed inside the control volume. The question states that the flow is *inviscid*, which rules out irreversibility due to friction or mixing.

Q5. Take great care with definitions of *isentropic efficiency.* The ideal power to compress to a given pressure ratio is less than the actual power, and vice-versa for a turbine. Because irreversibility generates entropy, we expect $T_2 > T_{2s}$ and $T_4 > T_{4s}$ . Apply the **First Law** to each component of the gas turbine in turn to get the required quantities.

Q6. There is a comprehensive worked example for this question in Lecture §3.6. To get the maximum power from the exhaust flow, we would use a reversible process to bring it to the dead state. Part (f) is an accounting exercise — the biggest opportunity for improvement lies in the biggest wastage. The highest thermal efficiency is achieved when the net work is equal to the available power increase in the combustor. Think back to the *Carnot cycle* which sets upper limits on efficiency.

Q7. Watch out for different values of $c_p$ , and hence varying $\gamma$ . Jet engines produce *no net work*, that is the compressor and turbine works balance. This means the turbine exit pressure is greater than atmospheric, producing thrust. Apply the **First Law** to the nozzle to obtain the jet velocity.

Q8. At first, $v_1 = v_\mathrm{g}(p_1)$ , and mass is volume over specific volume. Then, **conservation of mass** implies $v_2 = v_1 = \chi_2 v_{\mathrm{g}2}(p_2) + (1 - \chi_2)v_{\mathrm{f}2}(p_2)$ and we must solve for $\chi_2$ . One method for parts (c) and (b) is to solve simultaneously equations for **conservation of mass** and *constant volume.*

Q9. Recall that throttle valves are *adiabatic.* For a *perfect gas* this also means *isothermal*, but is steam a perfect gas? In part (b), 'the bled steam' refers to the state at throttle inlet.

Q10. See Lecture §6.6 for a worked example. What are the implications of a large value for part (d)?