Solutions

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DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. Two letter-size formulae sheets, handwritten by you, may be used. Put your answers on the same sheet as the question. Use at least 5 significant digits in your computations and answers where possible. 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%) A 0.5 kW reversible pump will compress 3 kg/s of mercury from 100 kPa to ___2.3633___ MPa

2. (3%) If 2kg of tungsten at 100°C cools down to the ambient temperature of 20°C, it will release ___20.8___ kJ of heat and the entropy generated in the complete system will be ___8.22___ J/K.

3. (3%) The specific heat at constant volume of acetylene at 800 K is ___2.0864___ kJ/kg-K.

4. (3%) If the temperature of 2 kg of argon increases by 300°C, then its internal energy increases by ___187.2___ kJ.

5. (3%) Of the following purported heat engines, case 3 violates the first law, and case 2 violates the second law:
   1. $Q_H = 2$, $Q_L = 2$, $W = 0$.
   2. $Q_H = 2$, $Q_L = 0$, $W = 2$.
   3. $Q_H = 0$, $Q_L = 2$, $W = 2$.

6. (3%) You have saturated vapor in a well insulated piston cylinder combination. Out of (1) saturated vapor; (2) saturated liquid; (3) superheated vapor; (4) compressed liquid; (5) two-phase; (6) critical point; you can achieve the final states numbered 1,3,5 .

7. (3%) If an ideal adiabatic turbine with a pressure ratio of 5 and a mass flow of 2 kg/s produces 641 kW of power, then a corresponding real turbine with a turbine efficiency of 80% produces 512.8 kW.

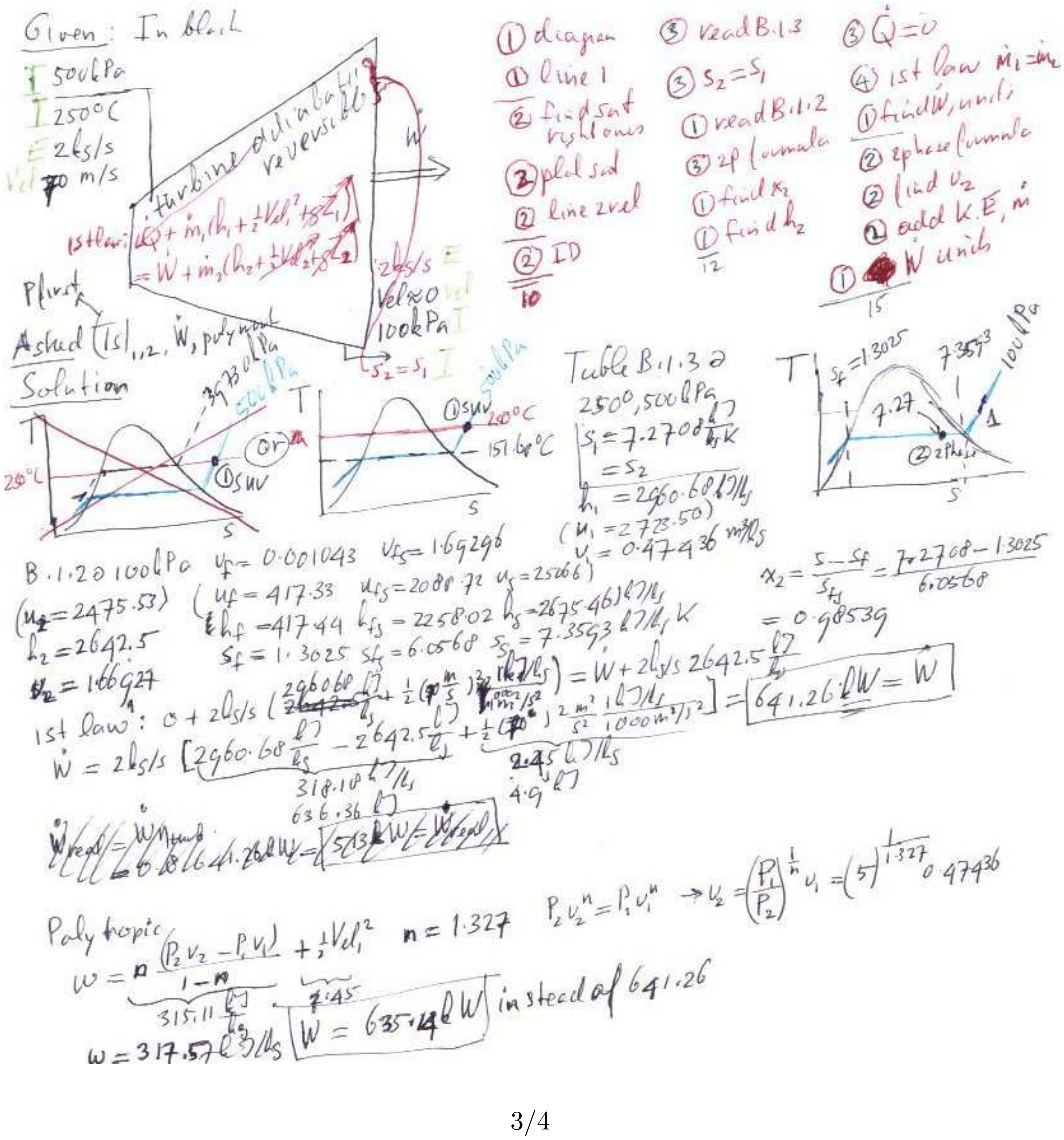
8. (3%) A refrigerator with a temperature of 5°C inside in a 25°C kitchen will need at least 71.904 J of electricity for every kJ of heat removed from the fridge.

9. (3%) At 2 km height in the atmosphere, the pressure is 80 kPa. In that case, a pot with boiling water will boil there at an accurate temperature of 93.34 °C.

10. (3%) Assume a substance with known properties. For each of the following combinations of data, enter a y if we can find the state of the substance from the data, or an n if not. (1) P, T: y. (2) P, V: n. (3) P, v: y. (4) ρ, v: n. (5) P, ρ: y.

11. (37%) A 2 kg/s stream of water at 500 kPa and 250°C enters an adiabatic reversible turbine at a speed of 70 m/s. The water leaves the turbine at 100 kPa with negligible velocity.
    1. Construct the initial phase in a very neat Ts diagram. To do so, draw the 500 kPa pressure line first, and take the construction from there. Mark 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.*
    2. After finding enough information to do so, construct the state of the exiting water in a separate Ts diagram, meeting the same requirements as the first. *State the phase.*
    3. Find the power produced by the turbine.
    4. Assuming instead that the process is polytropic with $n = 1.327$, use the polytropic work formula to compute the power and compare with the earlier exact value. For a fair comparison, you will need to compute the final specific volume in the polytropic formula from the polytropic relation. Also, do not forget to add the kinetic energy contribution.

You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*



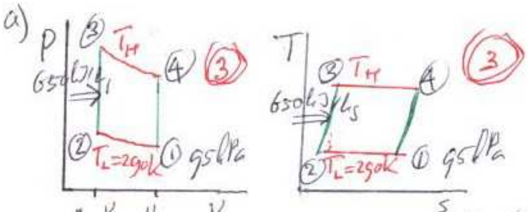
12. (33%) Consider an ideal Stirling cycle using standard air. Number the successive points such that 1 is the start of the compression stroke. It is given that at point 1 the air is at 290 K and 95 kPa (the lowest pressure). The compression ratio is 5. The heat added to raise the temperature in the first isochoric process is 650 kJ/kg.

Box your answers and use section numbers a, b, . . . , f.

(a) Draw both the numbered Pv and Ts diagrams of this cycle very neatly and large enough.
(b) Find the *specific* heat fluxes in each part of the cycle and find the peak temperature. Make sure you check your numbers, or you will get all the rest wrong, and that is a lot of credit to lose.
(c) What is the *specific* work performed per cycle?
(d) What is the thermal efficiency without regeneration? What is it with perfect regeneration?
(e) What is the peak pressure, and at which point?
(f) If the volume of air at point 1 is 0.5 L and the engine runs at 200 rpm, then what is the mass of air and the power produced?

You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*

a)



b) $q_{23} = 650\,kJ/kg = c_v(T_H - T_L) \Rightarrow 650\,kJ/kg = 0.717\frac{kJ}{kgK}(T_H - 290K) \Rightarrow$ [$T_H = 1196.55K$] ③

$T_H = (650\,kJ/kg / .717\frac{kJ}{kgK}) + 290K = 1196.55K = T_H$

$q_{23} = c_v(T_H - T_L) = q_{41}$ [$q_{23} = q_{41} = 650\,kJ/kg$] ③

$q_L = RT_L \ln\frac{v_1}{v_2} = 0.287\frac{kJ}{kgK}\,290K \ln 5$ $q_H = RT_H \ln\frac{v_4}{v_3} = 0.287\frac{kJ}{kgK}\,1196.55K \ln 5$

[$q_L = 133.95\,kJ/kg$ $q_H = 552.7\,kJ/kg$] ③

c) $w = q_H + q_{32} - q_L - q_{41} = q_H - q_L = (552.7 - 133.95)\,kJ/kg =$ [$418.75\,\frac{kJ}{kg} = w$] ③

d) $\eta_{th\,no\,reg} = \frac{w}{q_H + q_{23}} = 0.34817$ [$= 0.34817 = \eta_{th\,no\,reg}$] ③ ($q_{23}$ from fuel, q_{41} is lost)

$\eta_{th\,reg} = \frac{w}{q_H} = \frac{T_H - T_L}{T_H}$ = [$0.75765 = \eta_{th\,reg}$] ③ (q_{23} no longer from fuel)

e) $P_1v_1 = P_2v_2$ $P_2 = P_1\frac{v_1}{v_2} = 95\,kPa\;5 = 475\,kPa$ $\frac{P_3V_3}{T_3} = \frac{P_2V_2}{T_2}$

$P_3 = P_2\frac{T_3}{T_2} = 475\,kPa\,\frac{1196.55K}{290K} = 1959.87$ [$= 1959.9 = P_3$] ③

f) $P_1V_1 = mRT_1$ $95\,kPa\;0.0005\,m^3 = m\;0.287\frac{kJ}{kgK}\,290K$ [$m = 0.5707\;10^{-3}\,kg$] ③

$W_{cycle} = wm = 418.75\frac{kJ}{kg}\,0.5707\;10^{-3}\,kg = 0.23898\,kJ/cycle$

$\dot{W}_{200rpm} = 200\frac{cycle}{min}\;\frac{1\,min}{60\,s}\;0.23898\frac{kJ}{cycle} =$ [$= 0.79661\,kW = \dot{W}_{200rpm}$] ③