Queen Mary University of London

Thermodynamics 1 DEN107

Problem Set 04 (due week 6, Mon 2012Feb13)

Insert the SEMS homework coverpage as 1st page; this question sheet with original signatures as the 2nd page; then attach your solutions in subsequent pages. Your solutions are due before 3.30 pm on Monday February 13th 2012 in the cabinet outside the SEMS office.

By signing below I certify that I will not obtain the teaching assistant's (TA) signature for students other than myself, and that I will not forge the TA's signature on this page. Violators will be prosecuted in accordance to QMUL procedures. Please fill in the five items below.

Student Surname:	
Student Forenames:	
Student ID (9 digits):	
Student signature:	
TA confirms tutorial attendance (signature):	

50% of the assignment grade will be deducted if the TA signature above is missing

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IMPORTANT NOTE TO ALL DEN107 STUDENTS: Whenever solved solutions to the homework problems appear in the notes, do not just copy the solutions. Reproduce them in your own words and style of writing. Consider what other related follow-on or different questions may be asked, and how you would solve them. All this work is in preparation for the exam, as you will see later. Therefore it is required that you hand write the solutions to the problems.

Problem 1

(a) Draw the energy vs. entropy diagram for a general thermodynamic system A. On this diagram show the region of allowable non-equilibrium states, the line of stable equilibrium states, the region of non-allowable states, and the definition of temperature for system A at one point on the line of stable equilibrium states.

(b) Describe the four characteristics of a thermodynamic reservoir R. Draw the energy vs. entropy diagram for such a reservoir. On this diagram indicate the allowable states of the reservoir, the non-allowable states, and the definition of temperature for the reservoir on the line of stable equilibrium states.

(c) The thermodynamic system A of part (a):

- starts from an initial state A1 at 300 K, then receives 10 kJ of work bringing it to state A2; and then
- starting from state A2 receives 15 kJ of energy via a heat interaction with a reservoir R, where the temperature of the reservoir is $T^R = 500$ K, that finally brings system A to a final state A3 which is in mutual stable equilibrium with the reservoir R.

Re-draw the energy entropy diagram of part (a) illustrating the locations of states A1, A2 and A3 on the diagram.

Problem 2

(a) Use energy and entropy balances between a hot and a cold thermodynamic system, at infinitesimally different temperatures T^{H} and T^{C} respectively, to define the concept of specialized heat interaction between two systems. Write the energy and entropy balances, then derive and discuss the conditions required for a specialized heat interaction to occur between the two systems.

(b) Then use the same approach with a finite temperature difference between the two systems $T^{\mathrm{H}} > T^{\mathrm{C}}$, but where only an infinitesimal amount of energy dE is allowed to go from the hot to the cold system, to define the

concept of generalized heat interaction between two systems. Write the energy and entropy balances, then derive and discuss the conditions required for a generalized heat interaction to occur between the two systems.

(c) Discuss the extension from the theoretical concept of specialized heat interaction to the practical concept of generalized heat interaction, and the relation to entropy generated by irreversibility in generalized heat interactions.

(d) A wooden skewer is used to roast a marshmallow on an open fire. After 20 seconds over the fire the wooden skewer in the vicinity of the marshmallow is at about 360 K. The end of the wooden skewer held by the person roasting the marshmallow is at 335 K. Draw a graph of temperature of wooden skewer against its length, from the marshmallow end to the tip of the skewer held by the person roasting the marshmallow. Discuss the concept of specialized heat interaction at an arbitrary section of the skewer anywhere along its length. Discuss the concept of generalized heat interaction and entropy generated by irreversibility from the marshmallow end of the skewer to the coldest tip of its other end.

Problem 3

Two blocks of metal, A and B of mass m^{A} and m^{B} and specific heat capacity C^{A} and C^{B} obey the constitutive relations

$$\text{Energy } E: \qquad E_2 - E_1 = m\,C\,(T_2 - T_1)$$

$$\text{Entropy } S: \qquad S_2 - S_1 = m\,C\,\ln\left(\frac{T_2}{T_1}\right)$$

where T is temperature. Initially $T_1^{\mathrm{A}} > T_1^{\mathrm{B}}$.

(a) What is the adiabatic availability of metal block A in its initial state?

(b) The two blocks are allowed to interact and come to a mutual stable equilibrium via a heat interaction. Derive an expression for the final temperature of the two metal blocks. Derive an expression for the entropy generated by irreversibility.

(c) The two blocks start again from their initial states and interact via cyclic machinery X which extracts the maximum amount of work from the interaction. Derive an expression that gives the final temperature of the two blocks. Derive an expression that gives the maximum amount of work from this interaction.

(d) Evaluate the expressions in (b) and (c) for the following values of parameters:
m^{A}=10 kg, C^{A}=1.0 kJ/(kg.K), T_1^{A}=500 K, m^{B}=25 kg, C^{B}=1.0 kJ/(kg.K), and T_1^{B}=400 K.

Problem 4

A battery A starts from an initial state A_1 which is in mutual stable equilibrium with the local reservoir at temperature T^R =300 K. The properties at state A_1 are (E_1^A, S_1^A) =(20 kJ, 2 kJ/K).

(a) The battery starts from state A_1, receives work $W_{in,a}$ via an irreversible weight (adiabatic) process, and reaches a state A_2 with properties (E_2^A, S_2^A) =(1020 kJ, 4 kJ/K). What is the amount of work $W_{in,a}$ supplied by the adiabatic process? What is the entropy increase in this adiabatic process? How is this entropy generated?

(b) What is the maximum amount of work that can be extracted from battery A starting from state A_2 while it is allowed to interact with the reservoir R via cyclic machinery X? (In exam questions this may be stated as: what is the available energy Ω_2^{AR} of state A_2?)

(c) Compare $W_{in,a}$ to Ω_2^{AR} and explain any differences in the values.

(d) Is state A_2 an equilibrium or a non-equilibrium state?

(e) The battery starts again from state A_1, receives work $W_{in,e}$ via a reversible adiabatic process, and reaches a state A_4 with energy E_4^A= 1020 kJ. What is the amount of work $W_{in,b}$ supplied by the adiabatic process? What is the entropy increase in this adiabatic process?

(f) What is the available energy Ω_4^{AR} of state A_4?

(g) Compare $W_{in,b}$ to Ω_4^{AR} and explain any differences in the values.

(h) Is state A_4 an equilibrium or a non-equilibrium state?

Problem 5

Do example 03-12 from the lecture notes for:
T_1^{A} =500 K, T_1^{B} =550 K, and T_1^{C} =600 K, $C = C^{\mathrm{A}} = C^{\mathrm{B}} = C^{\mathrm{C}}$=1.2 kJ/(kg.K), and with T^{R} =298 K.
Hint: You will come to two equations with two unknown temperatures. Eliminate one of the two unknown temperatures and arrive at a cubic equation with unknown the other temperature. Use excel or MATLAB or other package to find ALL THREE possible solutions of the unknown temperature, accurate to two decimal places in temperature, e.g. T_3 =456.78 K. Plot a graph with x axis the unknown temperature and y axis the value of tehe cubic function to show the three temperature solutions.