Analysis II **Spring 2009**

Homework Problems

Do not print out this page. Keep checking for changes. Complete assignment will normally be available the day of the lecture one before the homework is due.

1 C2 Due 1/13

TBA

2 C3a Due 1/15

TBA

3 C3b Due 1/20

TBA

4 C3c Due 1/22

TBA

5 C4a Due 2/3

TBA

6 C4b Due 2/5

TBA

7 C5a Due 2/10

1. Construct the phases of the below states in *both* the Pv and Tv diagrams, labeling all lines with their values. *Make a separate diagram for each case, six diagrams in total.* Find the missing properties of T, P, v, u, h and x if applicable.
   (a) Water at 5000 kPa, $u = 800$ kJ/kg
   (b) Water at 5000 kPa, $v = 0.06$ m^3/kg
   (c) R-134a at 35°C, $v = 0.01$ m^3/kg
2. Water in a rigid container at 300°C, 1200 kPa has a mass of 0.75 kg. The water is cooled to 300 kPa. Find the final temperature, the work and the heat transfer in the process. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Show a Pv diagram of the process. So your solution must have a total of three diagrams.
3. There is 2 kg of liquid water at 300 kPa and 20°C in piston/cylinder combination. A linear spring on the piston exerts a force such that when the water is heated the pressure reaches 1 MPa with a volume of 0.2 m^3. Find the final temperature and the heat transfer in the process. Show a Pv diagram of the process.

4. A constant-pressure piston/cylinder has 2 lbm of water at 1100 F and 2.26 ft^3. It is now cooled to occupy 1/10 of the original volume. Find the heat transfer in the process. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Show a Pv diagram of the process.

8 C5b Due 2/12

1. Hot 500°C copper with a volume of 2 L is dumped in 200 L oil initially at 20°C. Assuming no heat transfer with the surroundings, what is the final temperature?
2. Carbon dioxide changes in temperature from 500 to 1300 K. Find the change in specific internat energy
   (a) using a constant C_v from table A.5
   (b) using the C_v evaluated from equation in A.6 at the average temperature.
   (c) Using the values listed in table A.8
3. Air in a piston cylinder at 600 kPa, 290 K has a volume of 0.01 m^3. An isobaric process produces 18 kJ of work. Find the final temperature of the air and the heat transfer input.
4. Air is kept inside a cylinder by a piston constrained by a linear spring. Initially there is 3 kg of air at 300 K and 160 kPa. It is then heated to 900 K to a final volume of twice the initial volume. Plot the process in a Pv diagram. Find the work done by the substance and heat added.

9 C5c Due 2/17

1. A steel tank contains 2 kg of carbon dioxide gas at 100 kPa, 1000 K that is heated to 1400 K. Find the heat transfer using
   (a) the heat capacity from Table A.5
   (b) properties from Table A.8
2. A insulated steel tank is divided into two parts of 3 m^3 each by an initially locked piston. Side A has air at 200 kPa, 300 K, and side B has air at 1.0 MPa, 1000 K. The piston is now unlocked so it is free to move, and it conducts heat so the air comes to a uniform temperature $T_A = T_B$. Find the mass in both A and B, and the final T and P.
3. A piston/cylinder contains helium at 500 K and 1200 kPa. It expands polytropically with $n = 1.667$ to a pressure of 100 kPa. Find the final temperature, the specific work and specific heat transfer in the process.
4. Air in a weighted piston/cylinder combination is being heated at a rate of 50 kW. At a certain time, the temperature is 25°C, the pressure 200 kPa, the volume 2 m^3 and the rate of volume change $\dot{V}$ is 0.2 m^3/s. What is the power produced by the air and what is the rate of change in temperature in °C/s at that time?

10 C6a Due 2/19

1. A stream of 0.3 kg/s of ammonia enters an insulated nozzle at 20°C, 800 kPa as superheated vapor at negligible velocity. The ammonia exits at 300 kPa with a velocity of 450 m/s. Determine the temperature (or quality, if saturated) and the exit area of the nozzle. Construct all phases that are not given in a Tv diagram. Label the lines with their values.
2. An compressor takes in normal nitrogen at 200 kPa, 27°C and sends it at 1000 K and 2 MPa into a heat exchanger. It exits the heat exchanger at 300 K. Find the specific work done by the compressor and the specific heat removal in the heat exchanger. Make an appropriate approximation for the type of process in the compressor and another for the one in the heat exchanger. Both assumptions are listed in the table in the book.

3. A stream of 2 kg/s of refrigerant R-134a enters a condenser at 600 kPa an 30°C. It exis as saturated liquid at 20°C. What is the cooling capacity in kW of the condenser? Construct all phases that are not given in a Pv diagram. Label the lines with their values.

4. Compressed liquid water at 10 MPa and 40°C enters a constant pressure steam generator through a 20 mm diameter pipe at the rate of 5 L/s. The water exits the generator at 350°C through a pipe of the same diameter. Show in the Pv diagram that the final phase of the water is indeed steam and find the rate of heat transfer to the water. Show a Pv diagram of the process.

11 C6b Due 2/24

1. An adiabatic turbine receives steam from two boilers. One boiler provides 10 kg/s at 5 MPa, 600°C and the other provides 20 kg/s at 800 kPa, 500°C. The steam exits the turbine at a pressure of 100 kPa, with a quality of 90%. Find the final temperature and the produced power.

2. A turbine takes in 2 kg/s neon at 27°C and 200 kPa with negligible velocity. The produced work is 75 kW and 30 kW of heat leaks into the turbine from the surroundings. The neon exits at 100 kPa and 230 K. Find the exit velocity of the neon.

3. Engine coolant (glycerine) enters the radiator of your car with a temperature of 100°C and exits it at 50°C. If the coolant must remove 30 kW of heat, what must be its mass flow rate through the radiator? If the heat is carried off by ambient air at about one atmosphere that has a temperature of 15 degrees before flowing through the radiator and 35 degrees after it, what is the volume flow of the air?

4. An adiabatic mixing chamber takes in two streams of water both at the ambient pressure of 100 kPa. On stream is 2 kg/s water at 50°C, and the other is water at 200°C. Pressure losses in the mixing chamber can be ignored, and the water comes out as saturated liquid. What is the mass flow rate of the incoming stream at 200°C? Construct all phases that are not given in a Pv diagram. Label the lines with their values. .

12 C6c Due 2/26

1. A stream of 0.5 kg/s R 134a at 20°C and $x = 0.9$ enters a mixing chamber through a throttle and is then mixed with a 2 kg/s stream at 100°C and 500 kPa. The R 134a exits the mixing chamber at 50°C and 500 kPa. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Find the heat going into the mixing chamber.

2. If high pressure steam is needed for some purpose in a power generation plant, it is often bled off from the high pressure side of the turbine. This is called cogeneration. Assume a well insulated turbine takes in 50 kg/s of steam at 10 MPa and 600°C, and that 10 kg/s at 400 kPa and 200°C is bled off, while the remaining steam exits at 100 kPa and a quality of 0.8. Construct the phase of the bled-off steam in the Tv diagram and so verify that it is indeed still steam. Find the power the turbine generates, and compare it to the power it would generate if no steam was bled off.

3. A stream of 2 kg/s of neon at 200°C and 100 kPa mixes with a stream of 3 kg/s of neon at 100°C and 100 kPa. The neon exits at 100 kPa and 50 kW of heat leaks out to the surroundings. Find the exit temperature.

4. Do 6.106 in the hardcover or 6.87 in the softcover.

13 C7a Due 3/17

1. Do 7.18 in the hardcover or 7.13 in the softcover.

2. For each of the cases below determine if the heat engine satisfies the first law, and if it does, if it satisfies the second law, and if it does, whether it is now a useful heat engine.

$\dot Q_H$	$\dot Q_L$	$\dot W$	1st law?	2nd law?	useful
5	4	3			
5	3	2			
5	5	0			
5	0	5			
0	5	–5			
–5	5	–10			
5	–5	10			
5	10	–5			

3. For each of the cases below determine if the heat pump or refrigeration cycle satisfies the first law, and if it does, if it satisfies the second law, and if it does, whether it is now a useful heat pump or refrigeration cycle.

$\dot Q_H$	$\dot Q_L$	$\dot W$	1st law?	2nd law?	useful
5	4	3			
5	3	2			
5	5	0			
5	0	5			
0	5	–5			
–5	5	–10			
5	–5	10			
5	10	–5			

4. Water at 25°C and 100 kPa enters an isobaric heat exchanger at a rate of 5 kg/s and is heated into saturated steam without droplets in it. The heat is provided by a heat pump with a coefficient of performance of 3. Determine the amount of power required by the heat pump.

14 C7b Due 3/24 (Moved)

1. You want to keep your house at 20°C. What is the maximum coefficient of performance of a heat pump if it is 10°C outside? What is it if it is -20°C outside? Assume that if it is -20°C outside, the amount of heat needed is four times the amount of heat needed when it is 10°C outside. How much more electricity would an ideal heat pump then require if it is -20°C outside instead of 10°C? Also, if it is 10°C outside, then how much more power would a resistance heater require compared to an ideal heat pump?

2. Suppose that you have a basin of 35°C warm water that you use to run a heat engine that cools it substance with air at 20°C. What is the maximum efficiency of the heat engine? What is the work you get out of each kJ of heat extracted from the basin. Repeat for the case the water is at 100°C. Comment on why efficient car engines run so hot.

3. Assume that your car engine burns 2 kg of fuel per hour in its cylinders at a temperature of 1500 K. The heating value of the fuel is 50 MJ/kg. Assume that the combustion heat is the equivalent of the heat $\dot Q_H$ in a heat engine. Assume that the engine rejects heat at an average temperature of 750 K through its exhaust, radiator, etcetera. Find the maximum amount of horsepower the engine can provide. But don't think you are going to get it from your car.

4. A Carnot refrigerator uses helium as refrigerant. It is 5°C inside the fridge and 20°C in the kitchen. The helium pressure decreases from 100 kPa to 90 kPa during the heat extraction from the fridge. How much heat is extracted from the fridge per kg of helium in each cycle, and what is the work required?

15 C8a Due 3/26

1. Construct the phase of
   (a) water if $s = 7.70$ kJ/kg K, $P = 25$ kPa, using the Ts diagram. Then find the values of h, T, and x if defined.
   (b) water, if $u = 3400$ kJ/kg and $P = 10$ MPa, using the Pv diagram. Then find the values of T, s, and x if defined

   In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points.

2. A Carnot-cycle heat pump uses R-22 as refrigerant. Heat is absorbed from the outside at -5°C. It is delivered to the heated space at 40°C. Assume that the R-22 enters the hot-side heat exchanger as saturated vapor and exits it as saturated liquid.
   (a) Show the cycle in the Ts diagram. List the entry to the hot side heat exchanger as 1, the exit of it as 2, and so on.
   (b) Find the quality of the R-22 at the beginning and end of the isothermal heat addition process at -5°C.
   (c) Determine the coefficient of performance for the cycle.

3. Two kilogram ammonia in a piston/cylinder at 50°C, 1000 kPa is expanded in a reversible isothermal process to 100 kPa.
   (a) Construct the initial phase of the ammonia in both the Ts and Pv diagrams. In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used.
   (b) Add the final state to the diagrams and then draw the process in them as a fat curve. (A "curve" might have straight parts.)
   (c) Find the work and heat transfer.

4. Water in a piston/cylinder at 400°C, 2000 kPa is expanded in a reversible adiabatic process. The specific work is measured to be 415.72 kJ/kg out.
   (a) Construct the initial phase of the water in both the Ts and Pv diagrams. In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used. Watch it: the temperature of the critical point is 374.1°C, less than 400°C.
   (b) Find a second intensive variable for the final state. Then use table B.1.2, not B.1.1 to find the saturated value(s) needed to figure out the phase.
   (c) Show the final state, and the process line as a fat curve, in the two diagrams.
   (d) Find the final pressure and temperature.

   Hardcovers have in B.1.3 $u = 2945.21$ listed incorrectly as 2045.21.

16 C8b Due 3/31

1. A solar-heated house uses a box of dry sand of $3 \times 4 \times 0.5$ to store solar heat. If during the night the sand cools from 35°C to 20°C, then how much heat is released to the 18°C house? What is the entropy generated in the total system by this process?

2. Three kg of liquid lead initially at 500°C is poured into a form. It then cools at constant pressure down to room temperature of 20°C as heat is transferred to the room. The melting point of lead is 327°C and the enthalpy change h_{if} between saturated solid and saturated liquid lead at 100 kPa is 24.6 kJ/kg. The specific heats are in Tables A.3 and A.4. Calculate the net entropy generated by this process in the complete system including the room.

3. Carbon dioxide at 400K and 30 kPa in an insulated cylinder is compressed to 625 kPa in a reversible process. Calculate the specific work and final temperature using
   (a) the exact data from table A.8.
   (b) the specific heat value from Table A.5. Do *not* use the polytropic formula to find T. Use the expression for the entropy change instead.

   Compare the results.

4. Helium is reversibly and isothermally compressed from 100 kPa and 20°C to 600 kPa, and then it expanded reversibly adiabatically back to 100 kPa.
   (a) Show this two-step process as a fat curve in both the Ts and Pv diagrams. Label the states as 1, 2, and 3.
   (b) Use the polytropic formulae to get the final temperature T_3. It should be 143.06 K.
   (c) Use the first law and heat formulae to get the specific work in the first step from 1 to 2.
   (d) Compute the same work directly from the appropriate polytropic work formula and compare results.
   (e) Use the first law and heat formulae to get the specific work in the second step from 2 to 3.

17 C8c Due 4/2

1. Two kg of hot saturated water vapor is in a cylinder closed by a weighted piston that pressurizes it to 200 kPa. Since the surroundings are at 20°C, the hot water cools down until the volume becomes half the original one.
   (a) Construct the final phase of the water in the Pv diagram. In the diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used.
   (b) Find the work done by the water.
   (c) Find the heat that has leaked out of the water.
   (d) Find the net entropy generated in the system and surroundings in the coold-down process.

2. A piston-cylinder contains 20 L of water at 200 kPa and 200°C. The piston is now pushed into the cylinder at a rate so that PV stays constant, while the pressure increases to 800 kPa. The heat that leaks out of the cylinder ends up in the 20°C surrounding room.
   (a) Construct the initial and final phases of the water in separate Pv diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used. In a third Pv diagram, show the process as a fat curve.
   (b) Find the work done by and heat added to the water in the process.
   (c) Does the total process satisfy the second law of thermo? Is it reversible?

3. Two kg of air at the ambient pressure of 100 kPa and at the ambient temperature of 15°C is confined within a steel container. A heating element within the tank now adds 100 kJ of heat to the air, and the air then ends up at 75°C. Find the net entropy generated by the process and comment on whether this process is possible. Use table A.5 values, do not use table A.7.1.

4. One kg of methane gas at 100 kPa and 20°C is compressed isentropically to 800 kPa. Calculate the final temperature using the polytropic relations. Then calculate the work done in the process. Calculate the work done directly, do *not* use the second law to do it.

18 C9a Due 4/7

1. A plane flies at an height where the ambient temperature is -45°C and the pressure 60 kPa with a true airspeed of 900 km/h. Air is flowing into a jet engine diffuser through an entrance area of 1 m^2 with a speed of 900 km/h and slows down to 20 m/s at the end of it. What is the temperature at the end of the diffuser, and what is the maximum possible pressure there? Use table A.7.1 values, not table A.5 ones.

2. An isothermal compressor compresses R-134a at 0°C and 200 kPa to saturated vapor. Construct the initial phase in the Pv and Ts diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used. Also show the final state in the diagrams, and the process between the two as a fat line. Find the specific heat transfer and work. Show the areas in the Pv and Ts diagrams that are equal to these.

3. Three kg/s of R-22 at 500 kPa flows as saturated vapor into an isobaric reversible heat exchanger where it is heated to 60°C. Show the process in a Ts diagram. There should be no need to construct the phases. Compute the heat that is added to the R-22. Now assume that this heat is provided by a reversible heat pump that takes in heat from the surroundings that is at 300 K.

   Warning: do *not* try to use the Carnot formula for the COP of the heat pump. It does not work since the high temperature, (the temperature of the R-22), is not constant but varies from about 0°C to 60°C. Instead, write the second law and use the fact that the generated entropy in the complete system is zero, because everything is reversible. That will give you the low heat flow. Then use the first law for the heat pump to find the work.

4. A completely reversible air heater receives a flow of 2 kg/s air at 400 K and 200 kPa and the air leaves at 600 K and 100 kPa. Heat at the rate of 50 kW is obtained from a reservoir at 500 K, while the remaining needed heat is obtained from the environment at 300 K. What is the heat obtained from the environment and what is the work needed to keep this reversible heater running?

19 C9b Due 4/9

1. Make 9.42 in the hardcover or 9.33 in the softcover. In addition to what is asked, construct the phases at 2, 3, and 4 in three separate Ts diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used.

2. R-134a at 1MPa and 30°C passes through an adiabatic expansion valve in which the pressure decreases to standard atmospheric pressure. Construct the initial phase in the Ts diagram. In the diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used. Then find the final quality and the entrpy generated.

3. Steam at 15 kPa and a quality of 90% enters a constant pressure condenser at a rate of 3 kg/s and exits it as saturated liquid. The heat is transferred to cooling water with an average temperature of 17°C. What is the entropy generated?

4. Air at 1000 kPa and 500 K enters an isobaric heat exchanger at a rate of 0.2 kg/s and exits at 300 K, having been cooled down by the ambient air at 300 K. Find the total rate of entropy generation. Use constant specific heats from table A.5, not table A.7.1.

20 C9c Due 4/14

1. You want to cool your cryogenics experiment by pumping pressurized liquid nitrogen through it. What is the power needed for a reversible pump that pressurizes 20 g/s of liquid nitrogen at 77.3 K from 200 kPa to 1MPa? Make appropriate approximations.

2. A typical specific heat ratio for the hot combustion gases entering the turbine of a jet engine is 1.25. For the gas constant, just use the one for air. Assume that the gases enter the turbine at 640 kPa and 927°C, and exit at the ambient pressure of 100 kPa at a rate of 2 kg/s. Also assume that the specific heat ratio is constant going through the turbine, and that the turbine is reversible. Find the exit temperature, power, and heat flow. *Do not compute any volumes, specific or not, when solving this question.*

3. An reversible isobaric heat exchanger heats a stream of carbon dioxide at 100 kPa from 300 to 500 K. It takes in heat from a 600 K reservoir. Find the work required, the heat taken from the reservoir, and the overall entropy generation.

4. Do 9.62 in the hardcover, 9.69 in the softcover. Use constant specific heats. You can write a separate first law for each stream, and then apply that the heat coming out of the nitrogen is the heat entering the oxygen. But it is simpler to write one first law for the entire thing.

21 C9d Due 4/23

Note: This homework is recommended but elective. It will not be graded.

1. A compressor takes in saturated steam (free of water droplets) at 1000 kPa and compresses it to 17.5 MPa and 650°C.

   (a) Show the process in both the Pv and Ts diagrams. Also show the process of the comparable ideal compressor in the diagrams. Also show and mark the 1000 kPa and 17.5 MPa isobars and the 650°C isotherm in the diagrams.

   (b) Find the enthalpy and entropy at 17.5 MPa by averaging between 15MPa and 20 MPa in B.1.3 for the following temperatures: 550°C, 600°C, and 650°C.

   (c) Find the isentropic efficiency.

   (d) Find the total entropy production.

2. Air is blown into a well insulated turbine at 1227°C and 5 atm and exits at 0.5 atm. The isentropic efficiency is 85%. Find the work produced by the turbine and the total entropy generated.

3. Air enters an adiabatic compressor with an isentropic efficiency of 70% at 100 kPa and 293 K, at the rate of 2 kg/s and exits at 473 K. What is the power required to run the compressor and its exit pressure. Use constant specific heats from A.5, not A.7.1. Note: this question is a bit tricky because the exit pressure is not given. Compute the quantities in the order asked, switching to the ideal compressor at the appropriate moment.