EML 3002 ME Tools
Homework

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

Contents

1 Due 9/4

1. A Stirling engine uses a cylinder with a diameter of 2 cm closed by a piston. What must the pressure inside the cylinder be so that the net upward force on the piston is 50 N? The ambient pressure is 100 kPa.

2. (Use English units only, no SI.) A hundred gallon tank holds 2 lb (or rather lbm, pound mass) of oxygen. What is the specific volume v in ft^3/lbm? What is the specific volume $\bar{v}$ in ft^3/lb mol? (Note that by the definition of "lb mol" the Molar Mass M is either in kg/kmol or lbm/lb mol.)

3. A manometer is filled with *light* oil. The difference in the height of the oil at the two sides is 10 cm. What is the pressure difference between the two sides? If the same pressure difference is measured using mercury instead of light oil, what would be the difference in height between the two sides?

4. A pressurized container holds 3 kg of steel immersed in 2 L of water. The pressure inside the container is 300 kPa and the temperature 23°C.

   - What is the combined volume of the water and steel?
   - What is the combined mass?

2 Due 9/9

1. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) R-134a at 20°C and 1 MPa, in the Tv diagram. Put in the pressure first.

   (b) R-134a at −20°C and 100 kPa, in the Pv diagram. Put in the temperature first.

2. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) Water at 100°C and 500 kPa, in the PT diagram. Put in the temperature first.

   (b) R-134a at 0°C and 350 kPa, in the Tv diagram. Put in the temperature first.

   (c) Ammonia at −10°C and 150 kPa, in the Pv diagram. Put in the temperature first.

   (d) Ammonia at −10°C and 150 kPa, in the Tv diagram. Put in the temperature first.

3. Construct the phase of R-134a at −10 F and 18 psia in the Pv diagram. Use the English-units tables only. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is. State the specific volume of the substance. Note: use the english units tables in appendix F or G in the far back of the book. No conversion to SI units! In case you do not have a compressed liquid table, you will have to use saturated liquid values. Make sure you get the temperature right!

4. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) Ammonia, at −10°C and 150 kPa, in the Pv diagram. Put in the temperature first. State the specific volume of the substance.

   (b) Ammonia, at 20°C and 100 kPa, in the Pv diagram. Put in the temperature first. State the specific volume of the substance.

3 Due 9/11

1. Find the phase of the substance under the given conditions and the requested data:

   (a) R-134a at 1,000 kPa and 0.03 m^3/kg. Construct the phase in the Tv diagram. Find the temperature T and the quality x if defined.

   (b) R-134a at 40°C and 0.01 m^3/kg. Construct the phase in the Tv diagram. Find the pressure P and the quality x if defined.

   (c) R-134a at 40°C and 50% quality. Find the phase, the pressure P and the specific volume.

2. Water in a piston/cylinder configuration boils at 110°C. There is standard atmospheric pressure above the piston and the piston has a mass of 30 kg. What is the diameter of the piston?

3. A piston/cylinder combination contains R-134a at $x = 1$ and 1318.1 kPa. Find the exact phase it is in, the temperature, and specific volume.

   (a) The piston is then pulled up in an isothermal process until the distance from the bottom of the cylinder is doubled. Construct the final phase in the Tv diagram. Label the lines with their values. Find the final temperature, pressure, specific volume, and quality if defined.

   (b) Repeat if *instead* the piston is pushed into the cylinder until it is twice as close to the bottom of it as it was.

4. A steel tank with a volume of 5 m^3 contains saturated R-134a at 10°C. The liquid is then boiled away and disappears at 50°C. What is the final pressure? How much liquid was boiled away?

4 Due 9/16

1. Determine whether the ideal gas approximation is good or reasonable for the following conditions. State why or why not. Use both the qualitative rules and the Lee-Kessler diagram.

   (a) Oxygen at 30°C, 3 MPa

   (b) Methane at 30°C, 3 MPa

   (c) Water at 30°C, 3 MPa

   (d) R-134a at 30°C, 3 MPa

   (e) R-134a at 30°C, 100 kPa

2. A rigid tank holds 4 m^3 of air at 6 bar and 100°C. To cool it down a bit, 2 kg of air is allowed to escape. This lowers the temperature by 25°C. What is the final pressure?

3. In the ideal Diesel cycle, the combustion proceeds isobarically. Assume that the air-fuel mixture can be approximated as plain air, and that the initial volume is 0.5 L and the final volume 1.3 L, while the initial pressure and temperature are 7 MPa and 700°C. What is the mass of the air, and the final temperature in degrees centrigrade?

4. (Refer to figure P3.73 / P 3.53 / P 2.80 in the book.) A rigid tank A of volume 2 m^3 is connected by a valve to another tank B with twice the volume. Initially, tank A holds nitrogen at 100 kPa and 250 K, and tank B nitrogen at 200 kPa and 300 K. Then the valve is opened and the combined tanks come to a uniform state at a temperature of 280 K. What is the pressure in the tanks then?

5 Due 9/18

1. A piston-cylinder configuration contains 2 kg of air at standard atmospheric pressure and 25°C. The piston is held by a linear spring. The air is now heated until the volume becomes 4 m^3 and the pressure 200 kPa. What is the final temperature in °C? What is the work done in the process? Show the work done also graphically in the PV diagram.

2. A steel container with a volume of 300 L contains 3 kg of water at 20 °C. The water is heated. What is the temperature at which all liquid water is gone, to five digits accurate? What is the work done by the water in the process? Show the process in the Pv diagram and so identify the work done graphically.

3. A constant pressure cylinder contains 2 kg water at 4 bar that is cooling down. The water is just starting to condense at the start of the process. At the end of the process the volume is half that at the start.

   (a) Find the initial phase.

   (b) Construct the final phase in the Pv diagram. Label all lines to do so with their values. Do not put more in the diagram than is needed to construct the phase.

   (c) Find the final temperature and volume to 5 digits accurate.

   (d) Find the work done by the substance in the process.

   (e) Show the work done graphically in the Pv diagram. How about the sign?

4. Consider a Stirling cycle with ideal-gas nitrogen as the working substance. The nitrogen is kept in a piston/cylinder combination during the entire cycle.

   - At the start of the cycle, the volume is 0.2 m^3 of nitrogen at 5 bar and 127°C. The nitrogen is now allowed to isothermally expand to a pressure of 100 kPa. (Heat must be added during the expansion to keep the temperature at 127dg.) What is the final volume? What is the work done by the nitrogen in this process?
   - Next the nitrogen is allowed to cool to room temperature, 27°C, while kept at the volume that you just computed. Find the work done by the nitrogen in this second process?
   - Next the nitrogen is compressed back to 0.2 m^3, but sufficiently slowly that it stays at the room temperature of 27°C. What is the work done by the nitrogen in this process?
   - Next the nitrogen is heated back to 127°C while being kept at volume 0.2 m^3, thus returning to the original state and completing the cycle. What is the work done during this final process?
   - What is the *net* work produced by the nitrogen during the complete cycle?
   - Show the process in a very neat PV diagram and graphically indicate the work.

6 Due 9/23

1. Two cubic meters of a gas at 200 kPa expands polytropically with $n = 5/3$ to standard atmospheric pressure. What is the work done by the gas in the process?

2. A piston cylinder combination contains 2 kg of air at the ambient temperature of 25°C and at the unknown ambient pressure. To provide a source of cooling on this hot Florida day, the piston is now pulled up until the air reaches a temperature of -100°C. It can be assumed that the process is a polytropic one with $n = 1.4$. What is the work that must be done *on* the air in the cylinder to pull up the piston and produce the cold air? The piston must also do work on the air outside the cylinder, which remains at the ambient pressure. What is the expression for that work?

3. Air in a piston/cylinder combination with an initial volume of 1 m^3 is initially kept at a pressure of 150 kPa by the weight of the piston and the atmospheric pressure. Due to being heated, it expands to 2 m^3, at which time the piston hits against a linear spring. The air then continues to expand to 4 m^3 while the pressure increases to 300 kPa due to the increasing spring force. Find the work done by the air in the complete process. Draw the PV diagram very neatly and graphically show the two parts of the work done by the air.

4. One type of a multistep process is a cycle. Consider the idealized car engine cycle, called Otto cycle. Assume that in state 1, the air-fuel mixture has been taken in and is still at 100 kPa and 27°C ambient conditions. Then the air is compressed until state 2, where the volume is one tenth of the intake volume. Assume that this compression stroke is polytropic with $n = 1.4$. Then from state 2 to state 3, an isochoric 2,500°C increase in temperature takes place. Finally, from state 3 to state 4, the power stroke, the air expands polytropically with $n = 1.4$ until the volume returns to the original intake volume value. Finally, for the process from 4 back to 1, a true car engine would dump the hot air to the exhaust and take in fresh cool air. However, the Otto cycle assumes that the air at step 4 is isochorically cooled down from 4 to 1 to the original intake temperature.

   Model the air-fuel mixture as pure air. Find the pressure, specific volume, and temperature at each of the 4 stages of the cycle. Then find the *net* specific work produced in the complete cycle.

   Also show the cycle and the work graphically in a very neat Pv diagram.

7 Due 10/2

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. 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. *Use British units throughout.*

4. There is 2 kg of water at 500 kPa and 200°C in a piston/cylinder combination. The water is expanded to 100 kPa in a process that is polytropic with $n = 1.3$. Construct the initial phase in a Pv diagram. Label the lines with their values. Find out enough info about state 2 without guessing its phase to construct the final phase in a second Pv diagram. Then find the final temperature and the heat lost in the expansion.

8 Due 10/7

1. Hot 500°C copper with a volume of 2 L is dumped in 200 L light 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 internal 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 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.

4. In an ideal diesel cycle, the combustion is assumed to be isobaric. The working fluid is assumed to be air. Assume that at the start of the combustion the temperature is 1000 K, the pressure 7 MPa, and that 1800 kJ/kg of heat is added.

   - What is the final temperature, and the work done by the air?
   - What are these same quantities if you use table A.5 values only?

9 Due 10/9

1. Air in a 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?

2. 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.

3. Part of a Stirling engine cycle is an isochoric heat addition. Assume that the substance is 2kg of air and the pressure and temperature before the heat addition are 1000 kPa and 27°C. The pressure is raised to 3000 kPa. Find the heat transfer using

   (a) properties from Table A.7.1

   (b) the heat capacity from Table A.5

4. 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.

10 Due 10/14

1. 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.

2. 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.

3. 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. Assume that nitrogen is an ideal gas.

4. 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.

11 Due 10/16

1. A mixing chamber takes in a stream of R134-a at 1 MPa and 12°C and a second stream at 1MPa and 60 °C. The first stream has twice the mass flow of the second; $\dot{m}_1 = 2\dot{m}_2$. No data is given about the stream 3 exiting the mixing chamber. Therefor, you will need to make two approximations typical for mixing chambers. One is that the pressure changes across the chamber are negligible. You are asked to find the exit temperature and the exit quality if it is defined. Construct all phases that are not given in a Pv diagram. Label the lines with their values.

2. An adiabatic turbine receives 12kg/s of steam at 10 MPa and 450°C at a velocity of 80 m/s. The steam exits the turbine at a pressure of 10 kPa, with a quality of 92%, at a velocity of 50 m/s. Find the kinetic energy change of the water, the produced power, and the diameter of the entrance pipe.

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. 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.

12 Due 10/28

1. Some car driving 60 mph on the highway uses 8 L of fuel per hour. The heating value HV of the fuel is about 42.4 MJ/kg and the density is 750 kg/m^3. If the thermal efficiency of the engine is 25%, then what is the power available at the crankshaft axis in bhp?

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	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 HP?	useful RC?
5	4	3				
5	3	2				
5	5	0				
5	0	5				
0	5	-5				

For the last case, in case you conclude that the second law is violated, state *which* of the two formulations is violated.

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.

13 Due 10/30

1. You want to keep your house at 25°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 its 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 that 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?

14 Due 11/4

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-134a as refrigerant. Heat is absorbed from the outside at -10°C. It is delivered to the heated space at 40°C. Assume that the R-134a enters the hot-side heat exchanger as saturated vapor and exits it as saturated liquid.
   1. 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.
   2. Find the quality of the R-134a at the beginning and end of the isothermal heat addition process at -10°C.
   3. 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.

15 Due 11/6

1. A solar-heated house uses a box of dry sand of $3 \times 4 \times 0.5$ m 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 is 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) Show why the first process is polytropic with $n = 1$ and the second with $n = 1.667$.

   (c) Use the polytropic formulae to get the final temperature T_3. It should be 143.06 K.

   (d) Use the first law and heat formulae to get the specific work in the first step from 1 to 2.

   (e) Compute the same work directly from the appropriate polytropic work formula and compare results.

   (f) Use the first law and heat formulae to get the specific work in the second step from 2 to 3.

16 Due 11/13

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 an adiabatic 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. (The one for the work will be covered next lecture, and can for now be found in the book.)

3. Three kg/s of R-134a 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-134a. Now assume that this heat is provided by a reversible heat pump that takes in heat from the surroundings that is at 300 K. What is the power needed by the heat pump?

   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-134a), is not constant but varies from about 0°C to 60°C. Instead, write the general 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. The heater pumps heat at a rate of 50 kW out of a reservoir at 500 K, while it pumps the remaining heat out of 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?

17 Due 11/18

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 adiabatic and reversible. Find the exit temperature, power, and heat flow. *Do not compute any volumes, specific or not, when solving this question.*

3. 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.

4. Air is blown into a well insulated turbine at 1227°C and 1 MPa and exits at 100kPa. The isentropic efficiency is 85%. Find the work produced by the turbine and the total entropy generated.

18 Due 12/2

Open-ended design question:

How could you, based on your knowledge of efficiencies and thermo, improve the performance of the lab Stirling engine with primarily thermodynamic (as opposed to mechanical) improvements? Discuss in detail. Explain the thermodynamics background behind your proposals clearly.

While your proposed improvement(s) must be thermodynamic in nature to qualify for credit in a thermo class, you must also discuss *how* to actually make the improvement in the lab engine. Include a design drawing.

Note that normally "performance" should be taken to be efficiency. If you take "performance" to be "produced power," the obvious (and correct) answer is: "make the engine bigger or build two of them." That trivial answer gets no credit. What we really want to see is *nontrivial*, creative (if at all possible), effective, fully explained and researched, improvements. There is some flexibility in what you define as "efficiency", but you better argue your case solidly!

Come to think of it, it is *your* responsibility to convincingly argue, to *any* reasonably fair grader, that your modifications will work, to a nontrivial extent. It is *not* up to the *grader* to prove your idea(s) *wrong*. It is up to you to prove it/them *right*. Your evidence should be able to convince even the most sceptical, but scientifically fair, judge.

To do so, please remember two key facts from physics and one from this class:

- Under the same P, V, and T, different gasses have the same number of molecules (as in $PV = n\bar{R}_u T$). The mass of the gases will be different depending on what the molecular mass is. But who cares what the mass is; the mass of the gas is negligible compared to the mass of the engine anyway. So you must compare gas properties on a *molar* (number of molecules), not *mass* basis. The numbers in table A.5 are on a mass basis (note the kg in the bottom) and are not suitable for comparisons of working gases in engines.

- All ideal gases have the *same translational* kinetic internal energy $\frac{3}{2}k_\mathrm{B}T$ per molecule, (not per unit mass). And it is this translational kinetic energy that produces the pressure. For noble gases, the translational kinetic energy is all there is. However, diatomic gasses like air, hydrogen, nitrogen, and oxygen have at normal temperatures another $k_\mathrm{B}T$ of *rotational* kinetic energy per molecule. A more complex molecule like water has another $\frac{1}{2}k_\mathrm{B}T$. A flappy (i.e big and flexible) molecule may have much more internal kinetic and potential energy still. It does not help creating pressure.

- The efficiency of an ideal Stirling cycle with complete regeneration is

  $$\eta_\mathrm{th} = 1 - \frac{T_\mathrm{L}}{T_\mathrm{H}}$$

  See any pressures in there? Heat conduction amounts? Gas or other substance properties? If not, modifying these quantities can do *nothing* for the efficiency of the ideal engine. So if your proposal includes modifying any of these quantities, you must make clear what non-ideal effect will be improved by your modification.

Your proposal should be neat, easy to read, and formulated in a logical order: abstract, background, theoretical justification of the proposal, proposed implementation method with design drawing, and references.

An abstract is *not* an introduction. It *must* summarize what your final proposal is, and how it is to be implemented.

All sources used in your project must be referenced and fairly credited for their contributions. Violations of this rule are unethical. You are still responsible for understanding and verifying the claims you find in literature and on the web.

Any nontrivial claim made in your text must either give a freely available reference that verifies the claim, or you must prove the claim yourself. Not doing so will lead to major grade reduction.

All references cited in the text must be listed in alphabetical order in a references section at the end of the document (with author names, title, link, if any). This may also include other references you looked at and found helpful.

A couple of typed single-spaced pages plus a design drawing and a list of references is typical. And about the most Dr. Van Dommelen will look at.

19 Due 12/4

1. Consider a Stirling engine that uses helium as the working fluid. The helium enters the compression process at 100 kPa and 27°C and is compressed to 600 kPa. After the compression it is isochorically heated to 1200 K.
   (a) There is no regeneration, heat is exchanged with the surroundings. Compute the heat transfer in *all four* processes. From that find the specific work produced per kg passing through and the thermal efficiency. (Base the thermal efficiency on the work divided by the *total* heat put *into* the substance. Heat will come out by itself.)
   (b) If ideal regeneration is added, what is the specific work and thermal efficiency then?

2. A car engine has a compression ratio of 9. The heat added by the combustion of the fuel is 1800 kJ/kg. Typically, the air enters the cylinder at a vacuum compared to atmospheric, which produces bad "pumping losses." That reduces mpg. However, it can be minimized by switching to a high gear that keeps the engine rpm low. Then the air could be entering the cylinder with about atmospheric pressure, call it 85 kPa, and 300 K. Model the performance of such an engine using the ideal Otto cycle. Approximate the substance at all stages as air with constant specific heats. Take the given entrance conditions to apply at the start of the compression stroke.
   (a) Find the thermal efficiency of the engine;
   (b) From that, find the specfic work produced per kilogram air flowing through.
   (c) Car engines are typically rated by the volume of air that they take in per cycle. Assume the intake volume is 2 L. The actual volume at the start of the cycle is greater than that by a factor $r_v/(r_v - 1)$ because the minimum volume is not part of the stroke (the piston does not hit the end of the cylinder). Convert the volume to an intake mass using the given entrance conditions. Multiply the specific work by the mass to get the work per cycle.
   (d) From that, compute the power produced at 2000 rpm (revolutions per minute; note that a cycle requires 2 revolutions.) Convert to metric horsepower. You may observe that a real engine stops somewhat short of ideal.
   (e) Find the peak temperature and pressure in the engine. (Find the pressure and temperature before combustion first.) Note that the temperature presents a material problem.

3. A diesel engine has a compression ratio of 19:1. The heat transferred to the air during combustion is 1800 kJ/kg. At the beginning of the compression process the pressure is 100 kPa and the temperature is 27°C. Determine, assuming the ideal cycle:
   (a) The pressure and temperature at each point in the cycle.
   (b) The thermal efficiency.

(c) The mean effective pressure.

(d) The engine is a 6 cylinder one, with a bore (cylinder diameter) of 10 cm and a stroke (piston motion) of 11 cm. It runs at 2000 rpm. What is the power produced?