This problem set is designed to give you practice with the properties of a simple compressible pure substance and the use of tables, charts or models to determine properties and analyze processes. In addition, it gives you some exercise with the concepts of work, heat, and heat transfer, as well as their characteristics. All problem numbers such as “3.91” refer to the 6th edition of Sonntag. In this and future homework, when you write down the value of a property obtained from the text, please state the Table or Figure number, and the page number where you got the information. This helps us follow your reasoning as we are grading. Citing the source this way will also be required on exams. Problems 7-8 (especially 8) could be quite time-consuming, so you are urged to start on them well in advance!

1. Is there any difference between the intensive properties of saturated liquid at a given temperature and the liquid of a saturated mixture at the same temperature? Explain.

2. A 500-L tank stores nitrogen gas at 160 K. The maximum pressure it can take is 6.5MPa. What is the maximum mass of nitrogen the tank can take? Which is the most accurate, and how different in percent are the other two? Compare the results to those given by the computer software.
   a) Nitrogen tables, Table B.6
   b) Ideal Gas EOS
   c) Generalized compressibility chart, Fig. D.1

3. 3.91 (Compare the results to those given by the computer software.)

4. 4.68

5. 4.75 (hint: simple math).

6. 4.108

7. An ideal gas sits inside a cylinder. The piston is moved in and out by varying the external pressure \( P_{\text{ext}} \). The motion is so slow, and the materials involved are such good heat conductors, that the temperature everywhere remains undetectably different from room temperature at all times. There is friction between the piston and the cylinder; the coefficient of static friction and the coefficient of kinetic friction are the same.
   a. The frictional force of the cylinder on the piston is shown, labeled “f”. At the moment depicted, is \( P_{\text{ext}} \) greater than, equal to, or less than \( P_{\text{gas}} \)?
   b. Plot \( P_{\text{gas}} \) vs. \( V \) as \( V \) is reduced from a value of \( V_1 \) to a value of \( V_2 \).
   c. On the same sketch, plot \( P_{\text{ext}} \) vs. \( V \) as \( V \) is reduced from \( V_1 \) to \( V_2 \).
   d. If you were to plot \( P_{\text{gas}} \) vs. \( V \) as \( V \) is later increased from \( V_2 \) to \( V_1 \), would the curve be different or the same as your answer to (b)? Explain briefly.
   e. On the same sketch, plot \( P_{\text{ext}} \) vs. \( V \) as \( V \) is increased from \( V_2 \) to \( V_1 \).
   f. The amount of work done on the piston by \( P_{\text{ext}} \) during (e) can be represented by the area of a certain region on your diagram. Indicate this with an equation. Indicate this graphically.
(i.e., draw this area and cross-hatch it). State whether the amount of work in question is positive, negative, or zero.

g. Indicate graphically the amount of work done on the piston by $P_{ext}$ during a complete cycle.

Is it positive, negative, or zero?

8. You are about to step into your ES181 final exam. You have been up studying most of the night, and as you enter the room you are provided with a styrofoam cup that you can fill with black coffee. It is essential to put that caffeine to work as soon as possible, but it's currently too hot to drink (100 ºC). Milk is also available in a refrigerator (4 ºC) in the room, and you are faced with the choice of either (1) adding the milk immediately to the coffee and then waiting for the mixture to cool to drinkable temperature (say 52 ºC) or (2) waiting for the coffee to cool a bit while the milk sits in the refrigerator, and then adding the milk to bring the temperature down. You cannot add enough milk to the coffee to bring it immediately from 100 ºC down to drinkable temperature, because there is not enough milk to go around (also, that would leave so little room for coffee that it wouldn't help you as much; besides, it would take all the fun out of the problem).

(a) Construct qualitative arguments about the benefits and drawbacks of methods 1 and 2 described above. For example, how does adding milk change the rate of heat transfer by each of the heat transfer modes discussed in Ch 4.8? Limit your answer to one or two sentences for each case.

(b) What is the dominant heat-loss mechanism at the beginning of the "experiment"? You may assume steady-state heat transfer; this is justified by the explanatory note at the bottom. For the sake of definiteness, assume: 1) The styrofoam cup is 2.5 mm thick and its shape is a cylinder with a diameter of 6 cm and height 9 cm. 2) You put 200 ml of coffee in the cup and have access to 40 ml of milk. 3) The room and walls are at 20 ºC. 4) The specific heat of coffee and milk are 1 calorie per degree and are independent of temperature. You will need to make other assumptions, such as numerical values for coefficients and emissivities. State all such assumptions explicitly and explain why you chose the values that you did and cite the source of all data that you look up.

(c) Consider only the dominant heat-loss mechanism from part (b). How long will it be before you can drink your coffee by each of the two methods? Again state all assumptions explicitly and explain why you chose the values that you did. Is this an upper limit or a lower limit, given the existence of other heat loss mechanisms?

Notes:
Thermal conductivity of foam $\approx$ Thermal conductivity of air because the way foam insulation works is to entrap the air and prevent convection.
There are three paths of heat transfer from the coffee to the room that are occurring in parallel; in part (b) you are required to figure out which of these three paths transports the most heat. The paths you must choose a "winner" from are:

1. Radiative heat transfer out of the top (Styrofoam is opaque to infrared radiation so there is no radiative cooling through the walls);
2. Convective heat transfer out of the top (the formulae for convection INCLUDE the contribution from conduction, so whenever convection is occurring in a fluid conduction through that fluid is NOT a separate mechanism);
3. Conductive heat transfer through the wall of the cup, IN SERIES with convective transfer from the outer surface of the wall to the room. (In principle, convective heat transfer from the outer surface of the cup to the room is also in parallel with radiative heat transfer from the outer surface to the cup to the room, but it's got to be negligibly small. It goes as $T^4$ and if it's significant for the cool-enough-to-hold walls of the cup then it must be overwhelming for the too-hot-to-touch surface of the liquid).

You may decide whether to hold the cup up in the air, thereby permitting convection out of the bottom as well as out of the sides, or whether to leave it on the table, which can be thought of as a really good insulator thereby shutting off heat transfer from the bottom.

Explanation of steady-state assumption. Immediately after pouring the coffee into the cup, there is an initial transient of a few seconds over which the outer surface of the Styrofoam goes from room temperature up to some steady state elevated temperature. At this steady state temperature, the rate of heat transfer by convection from the outer surface to the air equals the rate of heat transfer by conduction through the wall of the cup (there is only one temperature at which these two rates are equal and you need to solve for it). Over a much longer time scale (many minutes), the coffee actually gets cooler. Because of this, the temperatures discussed in the beginning of this paragraph aren't *truly* steady state; however, because the time scale over which the coffee cools is so much longer, a snapshot of the instantaneous temperature profile for the true problem is indistinguishable from a snapshot of the instantaneous profile in an equivalent case in which you were adding heat to the coffee (say an immersion resistive heater was dunked into it) at the same rate at which it was escaping, thereby keeping the coffee temperature exactly at 100 °C forever. Indistinguishable temperature profiles imply indistinguishable heat transfer rates. (This is called the "quasi-stationary" or "pseudo steady-state" approximation). When part (b) asks "What is the dominant heat loss mechanism at the beginning of the experiment", it means AFTER this initial transient of a few seconds has gone away so that the steady state profile is establishes, but BEFORE enough heat has left the coffee to make its temperature drop significantly below 100 °C.