Middle East Technical University
Department of Chemical Engineering
ChE204 Thermodynamics I (Section 2)
2013 - 2014 Spring Semester
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February 28, 2014

PROBLEM SET 1

Problems 1, 2, 6 and 7 are homework due March 7

1) Explain briefly whether the following statements are true or false.

a. An adiabatic system can exchange no energy with its environment, can neither influence it nor be influenced by it.

b. The ratio of two extensive properties of a homogeneous system is also an extensive property.

c. Heat and work are both transient phenomena. Systems never possess heat or work, but either or both cross the system boundary when a system undergoes a change of state.

d. A homogeneous system is a system which is composed of a single chemical species.

e. The two-property rule states that the thermodynamic state of any system of given mass can be fixed by specifying two properties.

f. An adiabatic process is a process during which the temperature of a system remains constant.

2) State whether the heat transfer, Q, and work, W, are positive, negative or zero for each of the following processes. The words in *italics* define the system.

a. *A mixture of ice and water* is contained in a vertical cylinder closed at the top by a piston; the upper surface of the piston is exposed to the atmosphere. The piston is held stationary while a flame, applied to the base of the cylinder, causes some of the ice to melt.

b. As under (a), but the piston is allowed to move so as to keep the mixture pressure constant.

c. *A mixture of ice and water* is contained in an insulated vertical cylinder closed at the top by a non-conducting piston; the upper surface is exposed to the atmosphere. The piston is held stationary while the mixture is stirred by means of a paddle-wheel protruding through the cylinder wall. As a result some of the ice melts.

d. As under (c), but the piston is allowed to move so as to keep the mixture pressure constant.

e. A well-insulated, sealed vessel contains one gram of fuel-oil and some oxygen gas. The oil ignites, causing a rise in the temperature of the *vessel and its contents*.

f. The *water and water vapour* in a rigid metallic container; the container is set on a stove and the pressure and temperature of its contents rise.

g. The system in the previous example bursts its container and explodes into a cold atmosphere.

3) A system consisting of a block of copper is initially at room temperature (25°C) in an adiabatic container (*state A*). A second piece of copper is placed in contact with the system within the container. After a period of time the system is in *state B*. Examination of the second piece of copper then shows that its temperature has increased. The system next falls freely and adiabatically. It is in *state C* when half the fall is completed and it is still falling. In the next state (*state D*) the system is resting on a piece of melting ice. In *state E* the ice has melted completely. The system is then restored to *state A*.

Determine whether the energy effects on the system were heat or work in the following processes. Also determine the signs (- or +) of these effects.

a. From *state A* to *state B*.

b. From *state B* to *state C*.

c. From *state D* to *state E*.

4) A pot of water is boiling on an electric stove. Place boundaries around the pot so as to make it part of;

a. An open system.

b. A closed system.

c. An isolated system.

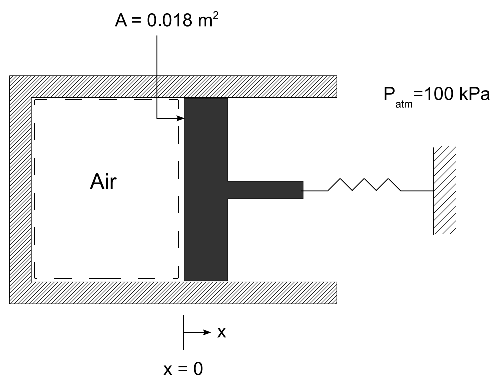
5) An ice cube is dropped into a heavily insulated jar of warm water and the jar is closed with a well-insulated cover. Draw the boundaries within the closed jar which designate;

a. A system experiencing a positive heat effect.

b. A system experiencing a negative heat effect.

c. A system experiencing no heat effect.

6) Air is trapped in a piston-cylinder assembly oriented horizontally as shown in the figure. Initially, P_1=100 kPa, V_1=2 L, and the face of the piston is at x=0. The spring exerts no force on the piston in the initial position. The atmospheric pressure is 100 kPa, and the area of the piston face is 0.018 m^2. The air expands slowly until its volume is V_2= 3 L. During the process, the spring exerts a force on the piston that varies with x according to F = kx, where k = 16.2 × $10^3 N/m$. There is no friction between the piston and the cylinder wall. Determine the final pressure of the air, in kPa, and the work done by the air, in kJ.



7) The following table lists the volumes of 1 gram of water and 1 gram of mercury as functions of temperature.

T(°C)	Volume of 1 gram H_2O (cm^3)	Volume of 1 gram Hg (cm^3)
0	1.0001329	0.0735560
1	1.0000733	0.0735694
2	1.0000321	0.0735828
3	1.0000078	0.0735961
4	1.0000000	0.0736095
5	1.0000081	0.0736228
6	1.0000318	0.0736362
7	1.0000704	0.0736496
8	1.0001236	0.0736629
9	1.0001909	0.0736763
10	1.0002719	0.0736893
20	1.0015678	0.0738233
30	1.0043408	0.0739572
40	1.0078108	0.0740910
50	1.012074	0.0742250
60	1.017046	0.0743592
70	1.022694	0.0744936
80	1.028987	0.0746282
90	1.035904	0.0747631
100	1.043427	0.0748981

a. Discuss why water would not be an appropriate thermometer fluid between 0°C and 10°C.

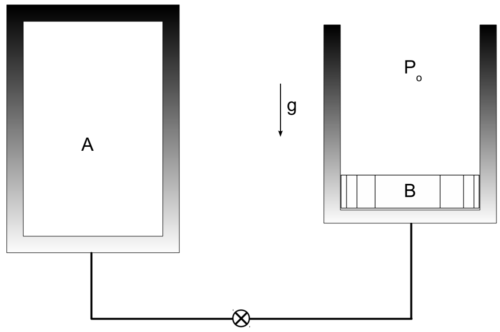
b. Because of the slightly nonlinear temperature dependence of the specific volume of liquid mercury, there is an inherent error in using a mercury filled thermometer that has been calibrated against an ideal gas thermometer at only 0°C and 100°C. Using the data in the table, prepare a graph of the error, ΔT, as a function of temperature.

c. Prepare a graph of the error, ΔT, as a function of temperature for a thermometer using water as the thermometer fluid.

d. When the temperature is actually 4°C, what is the reading on the mercury thermometer? On the water thermometer?

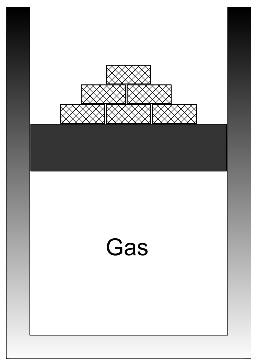
e. Why does a common mercury thermometer consist of a large-volume mercury-filled bulb attached to a capillary tube?

8) Tank A has a volume of 0.1 m^3 and contains helium at 3 bar, 25°C. Cylinder B contains a frictionless piston of a mass such that a pressure of 1.3 bar inside the cylinder is required to raise the piston. The valve connecting the tank and the cylinder is now opened, allowing helium to flow into the cylinder. Eventually, the helium is at a uniform state of 1.3 bar, 25°C throughout. Calculate the work done by helium during this process.



9) Consider as a system the gas contained in the cylinder as shown in the figure below. The cylinder is fitted with a frictionless piston on which a number of small weights are placed. The initial pressure is 200 kPa and the initial volume of the gas is 0.04 m^3.

a. Let a Bunsen burner be placed under the cylinder, and let the volume of the gas increase to 0.1 m^3 while the pressure remains constant. Calculate the work done by the system during the process.



b. Consider the same system and initial conditions, and a final volume of 0.1 m^3, but at the same time the Bunsen burner is under the cylinder and the piston is rising, let weights be removed from the piston at such a rate that, during the process, the temperature of the gas remains constant.

c. Consider the same system, but during the heat transfer let the weights be removed at such a rate that $PV^{1.3}$ = constant describes the relation between pressure and volume during the process. Again the final volume is 0.1 m^3. Calculate the work done.

d. Consider the system and the initial state given in the first three examples, but let the piston be held by a pin so that the volume remains constant. In addition, let heat be transferred from the system until the pressure drops to 100 kPa. Calculate the work done.

10) A vessel of volume V contains n moles of gas at high pressure. Connected to the vessel is a capillary tube and stopcock. When the stopcock is opened slightly, the gas leaks slowly into a cylinder equipped with a nonleaking, frictionless piston in which the pressure remains constant at the atmospheric value P_0.

a. Show that, after as much gas as possible has leaked out, an amount of work

$$W = P_0(n\overline{V}_0 - V)$$

has been done, where $\overline{V}_0$ is the molar volume of the gas at atmospheric pressure and temperature.

b. How much work would be done if the gas leaked directly into the atmosphere?