Chemical Engineering Thermodynamics 141 -- Fall 2008
Tuesday, October 2, 2008
Midterm I - 70 minutes
100 Points Total
Closed Book and Notes

(15 points)   1. Consider an ideal gas with constant heat capacities. Indicate whether the enthalpy
(H) and the entropy (S) of the system increase, decrease or remain unchanged during
the following processes:

A) condensing saturated vapor;

B) adiabatic reversible compression of a superheated vapor;

C) Joule-Thomson throttling.

(30 points)   2. A closed insulating cylinder is fitted with a non-conducting, frictionless floating
piston which divides the cylinder into Sections A and B. The two sections contain air
with equal number of moles, n_0, and initially at the same conditions, $T_1 = 300$ K and
$P_1 = 1$ atm. An electrical heating element $\dot{Q}$ in Section A is activated and the air
temperatures slowly increase: T_A in Section A because of heat transfer and T_B in
Section B because of adiabatic compression by the slowly moving piston. Assume air
to be an ideal gas with $C_p = \dfrac{7}{2} R$. If the final pressure P_2 is 1.25 atm, calculate:

A) T_B, temperature in Section B;

B) T_A, temperature in Section A;

C) Q/n_A, heat absorbed per mole of gas A.

Data: R= 82.06 cm^3. atm.mol^{-1}.K^{-1}

(25 points)   3.   A car driving along the road accidentally runs over a nail, puncturing one tire. The tire was initially inflated to an absolute pressure of 3.378 bar, and the air inside had an initial temperature of 320 K. For simplicity we assume the volume remains constant at 45 L as the tire deflates. If the tire deflates until its internal pressure is 1.035 bar:

A)   What is the temperature of the air that remains in the tire immediately after?

B)   How many moles of gas have escaped the tire?

You may treat air as an ideal gas with a constant pressure heat capacity of 7/2 R. Assume good mixing and that the tire deflation is adiabatic.

(30 points)   4.   Consider a cycle that consists of the following reversible processes:
   (i)   Isothermal compression from P_1 to P_2
   (ii) Constant-volume heating from P_2 to P_3
   (iii) Isothermal expansion from P_3 to P_4
   (iv) Constant-volume cooling from P_4 to P_1

Assume constant heat capacity, and that the working fluid obeys the **van der Waals** equation of state:

$$P = \frac{RT}{V-b} - \frac{a}{V^2}$$

A)   Draw the paths on a qualitative P-V diagram. Label each state 1, 2, 3, and 4 according to their respective pressures. Also label the isotherms T_H and T_C for the hotter temperature and the colder temperature, respectively.

B)   For step i, calculate ΔU, Q, and W in terms of experimentally accessible variables. Use the sign convention $\Delta U = Q - W$, and leave these quantities in molar units.

C)   Show that:

$$\frac{(V_2 - b)}{(V_1 - b)} = \frac{(P_4 - P_1)}{(P_3 - P_2)}$$

Table A.1: Conversion Factors

Quantity	Conversion
Length	$1\ m = 100\ cm$ $= 3.28084(ft) = 39.3701(in)$
Mass	$1\ kg = 10^3\ g$ $= 2.20462(lb_m)$
Force	$1\ N = 1\ kg\ m\ s^{-2}$ $= 10^5(dyne)$ $= 0.224809(lb_f)$
Pressure	$1\ bar = 10^5\ kg\ m^{-1}\ s^{-2} = 10^5\ N\ m^{-2}$ $= 10^5\ Pa = 10^2\ kPa$ $= 10^6(dyne)\ cm^{-2}$ $= 0.986923(atm)$ $= 14.5038(psia)$ $= 750.061(torr)$
Volume	$1\ m^3 = 10^6\ cm^3$ $= 35.3147(ft)^3$ $= 264.172(gal)$
Density	$1\ g\ cm^{-3} = 10^3\ kg\ m^{-3}$ $= 62.4278(lb_m)(ft)^{-3}$
Energy	$1\ J = 1\ kg\ m^2\ s^{-2} = 1\ N\ m$ $= 1\ m^3\ Pa = 10^{-5}\ m^3\ bar = 10\ cm^3\ bar$ $= 9.86923\ cm^3(atm)$ $= 10^7(dyne)\ cm = 10^7(erg)$ $= 0.239006(cal)$ $= 5.12197 \times 10^{-3}(ft)^3(psia) = 0.737562(ft)(lb_f)$ $= 9.47831 \times 10^{-4}(Btu)$
Power	$1\ kW = 10^3\ W = 10^3\ kg\ m^2\ s^{-3} = 10^3\ J\ s^{-1}$ $= 239.006(cal)\ s^{-1}$ $= 737.562(ft)(lb_f)\ s^{-1}$ $= 0.947831(Btu)\ s^{-1}$ $= 1.34102(hp)$

Table A.2: Values of the Universal Gas Constant

$R = 8.314\ J\ mol^{-1}\ K^{-1} = 8.314\ m^3\ Pa\ mol^{-1}\ K^{-1}$
$= 83.14\ cm^3\ bar\ mol^{-1}\ K^{-1} = 8{,}314\ cm^3\ kPa\ mol^{-1}\ K^{-1}$
$= 82.06\ cm^3(atm)\ mol^{-1}\ K^{-1} = 62{,}356\ cm^3(torr)\ mol^{-1}\ K^{-1}$
$= 1.987(cal)\ mol^{-1}\ K^{-1} = 1.986(Btu)(lb\ mole)^{-1}(R)^{-1}$
$= 0.7302(ft)^3(atm)(lb\ mol)^{-1}(R)^{-1} = 10.73(ft)^3(psia)(lb\ mol)^{-1}(R)^{-1}$
$= 1{,}545(ft)(lb_f)(lb\ mol)^{-1}(R)^{-1}$