AME 436	Assigned: Friday 1/29/2016
Problem Set #1	• Due Friday 2/5/2016 at 4:30 pm in drop-off box in OHE 430N (back room of the OHE 430 suite of offices, where the Xerox machine is located) • Hard copies are preferred but you can email your assignment to the graders at ame436usc@gmail.com if you're off campus. Emailed files must be a single .pdf file, not 10 or 20 .jpg images! • DEN students submit through the usual channels.

<u>Problem #1 (25 points)</u>

a) For the following fuel/oxidant combinations and presumed products balance the following reactions and calculate the stoichiometric fuel to oxidant ratios on a molar basis and on a mass basis:

Fuel + oxidant	Presumed products
H_2 + air	H_2O and N_2
CH_4 + air	CO_2, H_2O and N_2
CH_4 + N_2O	CO_2, H_2O and N_2
C_8H_{18} + NH_4NO_3 (ammonium nitrate)	CO_2, H_2O and N_2
Lithium + air	Li_2O and N_2

Use the property data in the table below.

Species	Δh_f^o (kJ/mole)	Molecular mass (g/mole)	Species	Δh_f^o (kJ/mole)	Molecular mass (g/mole)
CH_4	-74.87	16	O_2	0.00	32
H_2O	-241.84	18	N_2O	81.55	44
H_2	0.00	2	CO_2	-393.51	44
CO	-110.54	28	C_8H_{18}	-250.29	114
NH_4NO_3	-365.56	80	N_2	0.00	28
Li	0	7	Li_2O	-595.8	30

b) For the stoichiometric fuel/oxidant/product combinations above, calculate the heating value in Joules per kg of fuel. **Watch units – kilojoules vs. Joules, kilograms vs. grams, moles vs. kilograms.**

<u>Problem #2 (10 points)</u> (from a previous year's midterm exam)

It is proposed to "reform" propane (C_3H_8) by burning it in air under very rich conditions so that the products are CO, H_2 and N_2 rather than the usual CO_2, H_2O and N_2. (This CO and H_2 mixture will then be used in a fuel cell rather than an engine, but that's not part of this problem.) Below are the property values for the reactants and products.

	C_3H_8	O_2	N_2	CO	H_2
Δh_f^o (kJ/mole)	-104.70	0	0	-110.54	0
Molecular mass (g/mole)	44	32	28	28	2

a) Write down the stoichiometric reaction, i.e., find **a**, **b**, **c** and **d** for the reaction

$$1\ C_3H_8 + \mathbf{a}\ \text{air} \rightarrow \mathbf{b}\ CO + \mathbf{c}\ H_2 + \mathbf{d}\ N_2$$

b) What is the stoichiometric mass fraction (f) of this propane-air mixture with this set of assumed products (CO, H_2, N_2)?
c) What is the heating value of propane (in J/kg) with this set of assumed products?
d) What are the molecular mass (in g/mole) and gas constant (in J/kgK) of the product mixture?
e) What is the C_P of the product mixture if the mixture-averaged specific heat ratio $\gamma = 1.35$? Recall $C_P = \gamma R/(\gamma-1)$ and $R = \Re/M$ where $\Re$ is the universal gas constant and M is the mixture-averaged molecular mass.
f) What is the constant-pressure adiabatic flame temperature of this mixture if the reactants are at 298K?

Problem #3 (10 points) (from a previous year's midterm exam)

Consider a mixture of 30 mole % H_2O and 70 mole % He (helium) at **2000K and 3 atm**. Assume that the H_2O dissociates into H_2 and O_2 but no other products of dissociation (e.g. H, OH, O) occur. (Helium does not dissociate and thus does not participate in any equilibrium reactions.)

	H_2	O_2	He	H_2O
Δh_f^o (kJ/mole)	0	0	0	-241.83
Molecular mass (g/mole)	2	32	4	18
K (equilibrium constant) at 2000K	1	1	1	3492

a) Write down ALL relations needed to solve for the mole fractions of H_2O, H_2, and O_2 and He (that means you need as many equations as unknowns) at 2000K and 3 atm.
b) Solve these equations. Hint: it's not as bad as it seems; you can simplify the algebra a lot since $X_{H2} \ll 1$ and $X_{O2} \ll 1$.

Problem #4 (35 points)

For a carbon monoxide-oxygen (not air!) mixture with equivalence ratio 0.4, initial temperature 600K and initial pressure 10 atm:

a) Assuming constant specific heats and all CO burns to form CO_2, determine the constant volume adiabatic flame temperature for this mixture. The average of C_v of the CO / O_2 mixture at 600K is 735 J/kgK.
b) Determine the final pressure.
c) Repeat Problem 3a assuming the combustion products are CO, O, O_2, O_3 and CO_2 using GASEQ. The procedure is as follows:

1. At the top of the page, under "Problem type" select "adiabatic T and composition at const v"

2. Under "Reactants" enter "CO" and hit return
3. Under "Reactants" enter "O2" and hit return
4. In the list of reactants click on "CO" then enter the number of moles of CO needed to obtain an equivalence ratio of 0.4
5. In the list of reactants click on "O2" then enter the number of moles of O_2 needed to obtain an equivalence ratio of 0.4
6. In the box below the reactants box, enter the reactant temperature and pressure (600K, 10 atm in this case)
7. Under "Products" enter "CO" and hit return; repeat for O, O_2, O_3 and CO_2
8. Click on the "calculate" button

d) Why is the flame temperature and pressure so much lower in part c) than in a)? (There are two main reasons, both of which were discussed in class).

e) Show that the equilibrium concentrations of CO, O_2 and CO_2 predicted by GASEQ are consistent with a hand calculation (an example of which is shown in the Lecture 3 notes, page 9). You can get the thermodynamic data table at:

http://ronney.usc.edu/AME436/GasThermoData.xls).

f) Using the property data in the Excel spreadsheets, calculate the internal energy per unit mass of the reactants and compared this calculation to the value reported by GASEQ.

g) Using the property data in the Excel spreadsheets, calculate the internal energy per unit mass of the products and compared this calculation to the value reported by GASEQ. (Note that the internal energy per unit mass is the same before and after combustion, which must be the case for constant-volume combustion.)

h) Calculate the entropy per unit mass of these combustion products and compare this calculation to the value reported by GASEQ.

i) Using GASEQ, expand these products back to 10 atm. The procedure is as follows:
   1. Click the "R<<P" button to make the products of combustion become the reactants for the expansion.
   2. At the top of the page, under "Problem type" select "Adiabatic compression/expansion"
   3. Uncheck "Frozen chemistry"
   4. In the products property list, enter "10" in the pressure box
   5. Click on the "calculate" button

j) Calculate the entropy per unit mass of these expanded products and compare this calculation to the value reported by GASEQ. (Note that of course it's the same as the entropy per mass before expansion).

Problem #5 (20 points)

Hydrazine (N_2H_4) is a liquid rocket fuel that decomposes exothermically to form a mixture of gaseous N_2, H_2 and NH_3

N_2H_4 (liquid) → ??? N_2 (gas) + ??? H_2 (gas) + ??? NH_3 (gas)

Note that there is no hydrazine in the products. Thermodynamic data:

	N_2(g)	H_2(g)	NH_3(g)	N_2H_4 (liq)
Δh_f^o (J/mole)	0	0	-4.61 x 10^4	5.06 x 10^4
Molecular mass (kg/mole)	0.028	0.002	0.017	0.032
C_P (J/mole K) (temperature-averaged)	31.91	29.52	46.01	n/a
K_i (equilibrium constant) at 298 Kelvin (dimensionless)	1	1	739.6	n/a

a) What is the heating value of hydrazine "fuel" in J/kg if the combustion products are only N_2 and H_2 only (no NH_3)?

b) Estimate the constant-pressure adiabatic flame temperature of hydrazine if the combustion products are only N_2 and H_2 only (no NH_3) and the initial temperature is 300K.

c) If these combustion products are expanded and cooled to a temperature of 298 K and total pressure of 0.1 atm, what is the mole fraction of NH_3 **at equilibrium** in the products? You need to use the equilibrium constraint equations to determine the solution, but you can check your answer using GASEQ.