

Last Name _____ First name _____
Student ID# _____ Lecture section: _____

APS 104S, term test – Chemistry, Jan. 28 2010, 6:00 pm

1. (30 pts) The composition of air 79.0 mol% N₂ and 21.0 mol% O₂. An internal combustion engine burns pure propane (C₃H₈). If air is fed to the engine to provide the necessary (stoichiometric) O₂ to ensure complete combustion to CO₂ and H₂O, calculate:
 - (a) (10 pts) The volume of air at 15 °C and 1.02 bar, needed for the complete combustion of 1 mol of propane.
 - (b) (10 pts) The mol% and partial pressure of N₂ in the exhaust, which leaves the engine at 200°C and 1.00 bar.
 - (c) (10 pts) To calculate the volume of air you have assumed the air behaves like an ideal gas. What are the assumptions of the ideal gas model and give one reason (described in terms of the molecules of a gas) why these assumptions might not hold in a real gas.

Answers:



Need 5 moles of oxygen to burn 1 mole of propane and 1 mole air only 21% oxygen.

$$n_{\text{air}} = \# \text{ moles propane} * \# \text{moles oxygen per mole propane} * \text{moles oxygen per mole air}$$
$$= 1 * 5 / 0.21 = 23.8 \text{ mol air per mol of C}_3\text{H}_8 \text{ required.}$$

$$V_{\text{air}} = nRT/P = 23.8 \text{ mol} * 0.0831 \text{ bar} * \text{L/(mol*k)} * 288 \text{ K} / 1.02 \text{ bar} = 558 \text{ L}$$

(b) consider total moles of gas in exhaust after combustion of 1 mole of propane:

	<u>moles</u>
O ₂	0 (all consumed)
C ₃ H ₈	0 (all consumed)
N ₂	[1*5/0.21]*0.79 = 18.8 (no moles of air*79% since air is 79% N ₂)
CO ₂	3
H ₂ O	4
total	25.8

$$\text{mol \% N}_2 = (18.8 / 25.8) * 100 = 72.8 \%$$

$$P_{\text{N}_2} = n * P_{\text{T}} = 0.728 * 1.00 \text{ bar} = 0.728 \text{ bar}$$

(c) Assumptions are that the molecules are point sources and that they don't interact. In a real gas there might be interactions between the molecules such that they do interact thus invalidating the ideal gas law assumptions.

2. (40 pts) You are interested in compressing 10L of air, initially at a temperature of 25°C and 1 bar, to a final pressure of 10 bar using a piston-cylinder device. You decided to evaluate two different paths. Path 1: isothermal reversible compression. Path 2: adiabatic reversible compression. Assume that c_v (or as in the book $C_{v,m}$) is $3/2R$ for air.
- (15 pts) Calculate the final volume and work for path 1.
 - (15 pts) Calculate the final volume and work for path 2.
 - (10 pts) Explain why there is a difference in the work calculated for the 2 paths (consider the motion of molecules in your argument), and select the most efficient path.

Answers:

(a) At the final conditions of the isothermal compression, $T_f = T_i = 298K$, $P_f = 10$ bar, and the value of “n” can be calculated from the initial conditions:
 $n = P_i V / RT = 1 \text{ bar} * 10\text{L} / (0.0831 \text{ bar} * \text{L} / (\text{K} * \text{mol}) * 298\text{K}) = 0.403 \text{ mol}$

$$\text{Final volume, } V_f = nRT/P_f = 0.403 \text{ mol} * 0.0831 \text{ bar} * \text{L} / (\text{K} * \text{mol}) * 298\text{K} / 10\text{bar} = 1\text{L}$$

$$\begin{aligned} \text{The work for an isothermal reversible process} &= -nRT \ln(V_f/V_i) \\ W &= -0.403 \text{ mol} * 8.31 \text{ J} / (\text{mol} * \text{K}) * 298\text{K} * \ln(1\text{L}/10\text{L}) = 2.30E+3 \text{ J} = 2.30 \text{ kJ} \end{aligned}$$

(b) For an adiabatic, reversible process $T_f = T_i * (P_f/P_i)^{(R/C_p)}$
 $C_p = C_v + R = 3/2R + R = 5/2R$, $R/C_p = 2/5 = 0.4$, then:

$$\begin{aligned} (c) \quad T_f &= T_i * (P_f/P_i)^{(R/C_p)} = 298\text{K} * (10\text{bar}/1\text{bar})^{0.4} = 748\text{K} \\ V_f &= nRT_f/P_f = 0.403 \text{ mol} * 0.0831 \text{ bar} * \text{L} / (\text{K} * \text{mol}) * 748\text{K} / 10\text{bar} = 2.51\text{L} \end{aligned}$$

$$\begin{aligned} \text{For an adiabatic process, } W &= \Delta U = nC_v\Delta T = 0.403 \text{ mol} * 3/2 * 8.31 \text{ J} / (\text{mol} * \text{K}) * (748 - 298)\text{K} \\ W &= 2.22E+3 \text{ J} = 2.26 \text{ kJ} \end{aligned}$$

(d) In the adiabatic process, as we compress the gas, the molecules are pushed against each other and this causes an increase in kinetic energy and temperature. This, in turn, increases the number of collisions against the walls, which helps increasing the pressure, with less work than in the isothermal case. In the isothermal case one “cools down” the gas as the compression progresses. If the goal is simply reach a high pressure, then the adiabatic path requires less work, in which case is the more efficient. If the goal is to reduce the volume, the isothermal is the most efficient because with similar work (about 2.5 kJ) the isothermal path reaches less than half of the final volume of the adiabatic path.

3. (30 pts) Using the enthalpy of reactions indicated in the table below, obtain:
- (10 pts) The standard enthalpy of formation of $\text{SO}_{3(g)}$ ($\Delta H^\circ_f \text{ SO}_{3(g)}$) at 25°C and 1.0 atm.
 - (10 pts) The standard internal energy of formation of $\text{SO}_{3(g)}$ ($\Delta U^\circ_f \text{ SO}_{3(g)}$) at 25°C and 1.0 atm.
 - (10 pts) Under what condition would the enthalpy of formation of $\text{SO}_{3(g)}$ be the same at 100°C as at 25°C? Explain your answer

Reactions	$\Delta H^\circ, \text{ kJ/mol}$
(I) $\text{S}_{(s)} + \text{O}_{2(g)} \rightarrow \text{SO}_{2(g)}$	-296.90
(II) $2\text{SO}_{2(g)} + \text{O}_{2(g)} \rightarrow \text{SO}_{3(g)}$	-196.56

Answers

(a)



This is for 2 moles of SO_3 so must divide by 2 to get enthalpy of formation per mole

$$\Delta H^\circ_f \text{ SO}_{3(g)} = -395.18 \text{ kJ/mol}$$

(b)

Δn per one mole of SO_3 generated is -0.5 moles since go from 3/2 mol gas in reactants \rightarrow 1 mole of gas in products.

$$\begin{aligned} \Delta U^\circ_f \text{ SO}_{3(g)} &= \Delta H^\circ_f \text{ SO}_{3(g)} - \Delta n_{(g)} * RT^\circ = -395.8 \text{ kJ} - (-0.5 \text{ mol}) * 8.31 \times 10^3 \text{ J/(mol*K)} * 298 \text{ K} \\ &= -394.6 \text{ kJ per mol of } \text{SO}_{3(g)} \text{ formed.} \end{aligned}$$

(c) The only way that this heat of reaction would still be the same is if the heat capacity of the reactants and products is balanced. That balance is expressed in the term $\Delta C_p = \sum v_i C_p = 0$. Otherwise, at a different T the enthalpy would have to be calculated using the heat capacities of all the reactants and products.