Chemistry 2740 Spring 2016 Test 1

Time: 50 minutes
Marks: 31
Aids allowed: calculator, 8.5×11-inch formula sheet
Useful data is given on the reverse of this page.
Instructions: You can answer the questions in any order, but make sure that you clearly label each of your answers with the question number in your exam booklet(s).

1. The tidal volume, the volume of air taken in during a normal breath, is approximately 0.5 L for an adult. What is the work done to expand the chest by this much if the atmospheric pressure is 90 kPa (a typical atmospheric pressure in Lethbridge)? How much work would be done in one day if you average 15 breaths a minute? [4 marks]

2. The rotational partition function for a diatomic molecule is

$$q_{\text{rot}} = \frac{2Ik_BT}{\sigma\hbar^2},$$

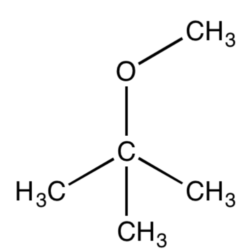
where I is the moment of inertia (a constant for a given molecule), $\hbar$ is shorthand for $h/2\pi$, and σ is a symmetry number, which has the value 1 for a heteronuclear, and 2 for a homonuclear diatomic molecule.

   (a) Calculate the rotational contribution to the molar internal energy for a diatomic molecule. [5 marks]

   (b) In class, we found that the translational contribution to the internal energy was $\frac{3}{2}RT$. It turns out that, for most molecules at room temperature, vibrations contribute negligibly to the internal energy. Add the translational and rotational contributions to get the molar internal energy of a diatomic molecule, then calculate the molar constant-pressure heat capacity of a diatomic molecule. Compare your result to the constant-pressure heat capacity of oxygen. [5 marks]

   Bonus: Why don't the vibrations contribute much to the internal energy for most diatomic molecules at room temperature?

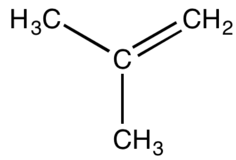
3. 2-methoxy-2-methylpropane (MMP, for short) has the chemical formula $C_5H_{12}O$ and the structure:



MMP is used as an anti-knocking agent in gasoline.

(a) The standard enthalpy of combustion of liquid MMP is $-3368.97\,\text{kJ mol}^{-1}$. What is the standard enthalpy of formation of this compound? [6 marks]

(b) MMP is made industrially by reacting methanol with 2-methylpropene, C_4H_8,



over a catalyst at constant pressure. In some plants, the reaction is carried out with all reactants and products in the liquid state. This requires a high (but still constant) pressure since 2-methylpropene has a low normal boiling point. (We will talk about the effect of pressure on boiling point later in this course.) Calculate the molar enthalpy change of this reaction. [3 marks]

(c) The excess heat from a reaction in a chemical plant is often used to make steam, which can then be used for other purposes (often for heating). An MMP plant makes 50 t (50 000 kg) of MMP per day. Assume that 80% of the heat of reaction can be used to make steam at 130 °C from liquid water initially at 90 °C. What mass of steam can be produced in one day? Give your answer in tonnes. The molar mass of MMP is $88.15\,\text{g mol}^{-1}$. [8 marks]

Useful data

$R = 8.314\,472\,\text{J K}^{-1}\text{mol}^{-1}$
$1\,\text{m}^3 = 1000\,\text{L}$
$1\,\text{t} = 1000\,\text{kg}$
To convert degrees Celsius to Kelvin, add 273.15.

Properties of water
Specific heat capacity (liquid) = $4.184\,\text{J K}^{-1}\text{g}^{-1}$
Heat of vaporization at the boiling point = 2257 J/g
Specific heat capacity at constant pressure (steam) = $1.874\,\text{J K}^{-1}\text{g}^{-1}$

Standard thermodynamic data at 298.15 K		
Species	$\frac{\Delta_f H^\circ}{\text{kJ mol}^{-1}}$	$\frac{C_{p,m}}{\text{J K}^{-1}\text{mol}^{-1}}$
$CH_3OH_{(l)}$	−239.1	81.6
$C_4H_{8(l)}$ (2-methylpropene)	6.1	121.3
$CO_{2(g)}$	−393.51	37.1
$H_2O_{(l)}$	−285.830	75.40
$O_{2(g)}$	0	29.35