For Examiners' use only:

Question	1-4	5-7	8-9	10-12	Total
Mark	/16	/11	/18	/15	/60

CHEM 113 TEST

ANSWERS.

Monday, 27 April, 2009

Name (Print clearly): ....

Student ID No: ....

Signature: ....

Instructions:

Attempt **all** questions. Enter answers in the spaces provided (continue on the back of the **opposite** sheet if necessary).

Total marks: 60 Time allowed: 60 minutes

Note:

At the end of this paper is:

1. a periodic table, and
2. a sheet containing physical chemistry formulae.

[Please check that both of these pages are provided before starting to answer the test paper!]

1. (6 marks)

(a) Define the meaning of the word 'isotope' (1 mark)

Atoms having the same atomic number (protons) but mass numbers (neutrons).

(b) Give the number of neutrons and the number electrons in one atom of the boron isotope ${}^{11}_{5}B$. (1 mark)

Number of neutrons = 6

Number of electrons = 5

(c) Write down the full electron configuration for this atom. (1 mark)

$1s^2 2s^2 2p^1$

(d) If the ${}^{11}_{5}B$ isotope of boron accounts for 80.1% of neutral B and the ${}^{10}_{5}B$ isotope accounts for the remainder, **calculate** the average molar mass for B to three significant figures. (3 marks)

$$\left(\frac{80.1}{100} \times 11\right) + \left(\frac{19.9}{100} \times 10\right)$$

$$= 8.81 + 1.99$$

$$= 10.801$$

2. (4 marks)

(a) Write **ALL** the possible values for the angular momentum quantum number, $\boldsymbol{l}$, for the electron shell with principal quantum number $\boldsymbol{n} = \mathbf{3}$

l = 0, 1, 2

(b) For a d subshell, write **ALL** the possible values for the magnetic quantum number $\boldsymbol{m_l}$

m_l =
d subshell ⇒ $l = 2$
$-2, -1, 0, 1, 2$

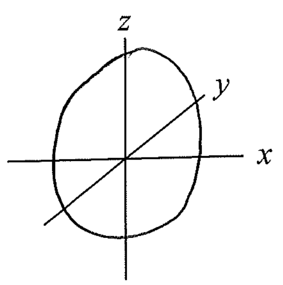
(c) Write **ALL** the possible values for the electron spin quantum number $\boldsymbol{m_s}$

m_s = $+1/2, -1/2$

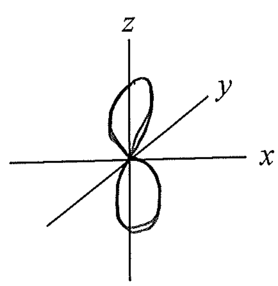
3. (3 marks)

On the axes given below, sketch the shapes (or 'boundary surface' diagrams) of:

(a) the 3s orbital



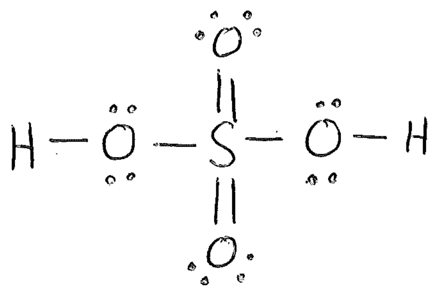
(b) the 2p_z orbital



4. (3 marks)

Draw the Lewis structure for sulfuric acid, H_2SO_4, then select, from the possibilities below, the number of single bonds, double bonds, lone pairs.

(a) 3, 3, 7 (b) 6, 1, 6 (c) 4, 2, 8 (d) 5, 1, 9.



5. (4 marks)

For the following redox reaction in an **acidic** solution, complete and balance the oxidation and reduction half-reactions and write the balanced equation for the full reaction.

$$MnO_4^- + I^- \rightarrow I_2 + Mn^{2+}$$

$$10 I^- \rightarrow 5 I_2 + 10 e^- \quad (ox)$$

$$16 H^+ + 10 e^- + 2 MnO_4^- \rightarrow 2 Mn^{2+} + 8 H_2O \quad (Red)$$

$$\Rightarrow \quad 10 I^- + 16 H^+ + 2 MnO_4^- \rightarrow 5 I_2 + 2 Mn^{2+} + 8 H_2O$$

6. (4 marks)

A helium gas thermometer is found to have a volume of 100.0 cm^3 when placed in an ice-water bath at 0 °C. When the same thermometer is immersed in boiling liquid chlorine, the volume of helium at the same pressure is found to be 87.2 cm^3. Calculate the temperature of the boiling point of chlorine in Kelvin (K).

[0 °C = 273 K]

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\Rightarrow T_2 = \frac{V_2 T_1}{V_1} = \frac{87.2 \times 273}{100} = 238K \ (-35°C)$$

7. (3 marks)

How many H_2O molecules are there in a snowflake weighing 10 mg?

Avogadro's number: $N_A = 6.022 \times 10^{23}$ mol^{-1}

M(O) = 16.0 g mol^{-1}; M(H) = 1.00 g mol^{-1}

Mass of 1 mole H_2O = 18.00g = 6.022×10^{23} H_2O molecules.

So x molecules of H_2O = $\frac{6.022 \times 10^{23}}{18.00}$

$\Rightarrow$ x molecules of H_2O = 3.34×10^{22} molecules/gram

$\Rightarrow$ 3.34×10^{20} molecules H_2O in 10 mg snowflake.

$\left(n = \frac{m}{M} \Rightarrow n = \frac{0.01}{18} = 5.55 \times 10^{-4} \text{ mol} \times 6.022 \times 10^{23} = 3.34 \times 10^{20} \right)$

8. (3 marks)

The first law of thermodynamics may be written as

$$\Delta U = q + w$$

Briefly explain the meaning of each of the terms that appear in the above expression.

ΔU is the change in the internal energy of the system
q is the heat supplied to the system
w is the work done on the system by the surroundings

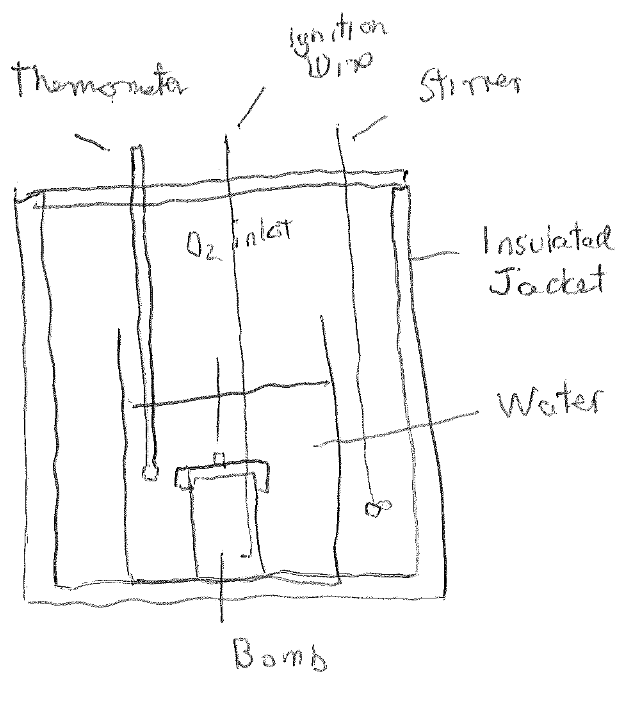
9. (15 marks)

A sample of liquid cyclohexane, $C_6H_{12}(l)$, of mass 0.842 g was mixed with excess oxygen and burned in a **constant-volume** calorimeter at 25 °C. It was observed that, after the combustion was over, the temperature of the calorimeter and its contents had increased by 3.91 °C (this information will not be required until part (e)).

(a) (3 marks)

Sketch a constant-volume calorimeter, labelling its essential features.

See Fig 6.8 Chang
Essential features:
Bomb
Thermometer
Water around bomb
Insulated jacket



(b) (2 marks)

Write a balanced equation for the combustion of cyclohexane given that the products are $CO_2(g)$ and $H_2O(l)$.

$C_6H_{12}(l) + 9O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

(c) (3 marks)

Use the following information to calculate the standard enthalpy change, $\Delta H°$, for the combustion of liquid cyclohexane.

Substance	$\Delta H_f°$ (kJ mol^{-1})
$C_6H_6(l)$	49.0
$C_6H_{12}(l)$	–156.0
$C_6H_{14}(l)$	–198.7
$CO(g)$	–110.5
$CO_2(g)$	–393.5
$H_2(g)$	0
$H_2O(g)$	–241.8
$H_2O(l)$	–285.8
$O(g)$	249.4
$O_3(g)$	142.2

$\Delta H° = 6\Delta H_f°(CO_2(g)) + 6\Delta H_f°(H_2O(l)) - \Delta H_f°(C_6H_{12}(l))$

$= 6 \times -393.5 + 6 \times -285.8 - (-156.0)$

$= -3919.8$ kJ mol^{-1}

(d) (3 marks)

Calculate the standard internal energy change, $\Delta U°$, for the combustion of liquid cyclohexane. (R = 8.314 J mol^{-1} K^{-1})

[Hint: Use your answers to parts (b) and (c) above. If you were unable to obtain an answer in (c), use the **incorrect** value of –4 000 kJ mol^{-1} here.]

$\Delta H° = \Delta U° + RT \Delta n_{gas}$

$\Delta n_{gas} = 6 + 0 - 1 - 9 = -3$

$\Delta U° = \Delta H° - RT \Delta n_{gas}$

$= -3919.8 - 8.314 \times 10^{-3} \times 298.15 \times -3$

$= -3919.8 + 7.4$

$= -3912.4$ kJ mol^{-1}

(e) (4 marks)

Calculate the heat capacity of the complete calorimeter, including the water it contains. [$M(C_6H_{12})$ = 84.2 g mol^{-1}]

[Hint: Use your answer to part (d) above. If you were unable to obtain an answer in (d), use the **incorrect** value of –4 000 kJ mol^{-1} here.]

$-\Delta U = C \Delta T$

$n(C_6H_{12}) = \frac{0.842}{84.2} = 0.01$ mol

$0.01 \times 3912.4 = C_{cal} \times 3.91$

$C_{cal} = 10.0$ kJ K^{-1}

note C is +ve

Top equation follows from the fact we have an isolated system

$0 = \Delta U_{sys} = \Delta U_{rxn} + C\Delta T$

10. (2 marks)

Explain why the symbol $\rightleftharpoons$ is used to denote chemical equilibrium.

= denotes equilibrium while the arrowheads denote that the equilibrium is dynamic in nature, ie, opposite processes occurring at equal rate so that no net change takes place.

(Go to question 11 on the next page.)

11. (6 marks)

The following questions, (a) to (e), each give an *equilibrium equation* and a *change* that may be made to such a system at equilibrium. You should use one of the following **letters** (A, B, C or D) to indicate how the (equilibrium) **system responds** to the change:

(A) Net occurrence of forward reaction

(B) No net reaction occurs

(C) Net occurrence of reverse reaction

(D) Cannot say

Only if you answer **D** for a particular question, you should then indicate the **additional information** that you would require in order to decide whether A, B or C in fact occurs.

(a) $Ca(HCO_3)_2(aq) \rightleftharpoons CaCO_3(s) + H_2O(l) + CO_2(g)$

Change: $CO_2(g)$ is *removed* at constant volume and temperature

System response: A Additional information:

(b) $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

Change: $CaCO_3(s)$ is *added* at constant pressure and temperature

System response: B Additional information:

(c) $CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$

Change: He(g) is *added* at constant volume and temperature

System response: B Additional information:

(d) $2NO_{(g)} + O_2(g) \rightleftharpoons 2NO_2(g)$

Change: Volume is *increased* at constant temperature

System response: C Additional information:

(e) $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

Change: Temperature is *decreased*

System response: D Additional information: Sign of $\Delta_r H$

12. (7 marks)

At a particular temperature, the (thermodynamic) equilibrium constant is $K = 400$ for the reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

11.0 mol of $H_2(g)$ and 11.0 mol of $I_{2(g)}$ are mixed and the above equilibrium is established at the temperature for which the given K is valid. The total pressure of the equilibrium system is 2.20 atm.

Calculate the equilibrium partial pressures of $H_2(g)$, $I_2(g)$ and $HI(g)$.

11.0 + 11.0 = 22.0 mols of species are initially present.

Because of 2:2 reaction stoichiometry, this amount does not change ⇒ 22.0 mols present at equilibrium. Hence:

Equilibrium amounts : $n_{H_2} = (11.0 - x)$ mol, $n_{I_2} = (11.0 - x)$ mol, $n_{HI} = (0 + 2x)$ mol } by reaction stoichiometry

⇒ equilibrium pressures ; $P_{H_2} = \left(\frac{11.0 - x}{22.0} \times 2.20\right)$ atm

$P_{I_2} = \left(\frac{11.0 - x}{22.0} \times 2.20\right)$ atm

$P_{HI} = \left(\frac{2x}{22.0} \times 2.20\right)$ atm

(because of Dalton's law : $P_x = (\text{mol fraction of } X)\, P_{tot}$

Equilibrium constant : $K = \frac{(a_{HI})^2}{(a_{H_2})(a_{I_2})} = \frac{\left(P_{HI}/1\text{ atm}\right)^2}{\left(P_{H_2}/1\text{ atm}\right)\left(\frac{P_{I_2}}{1\text{ atm}}\right)}$

$\Rightarrow 400 = \frac{\left(\frac{2x}{22.0} \times 2.20\right)^2}{\left(\frac{11.0 - x}{22.0} \times 2.20\right)^2} = \frac{4x^2}{(11-x)^2} \Rightarrow 100(11-x)^2 = x^2$

$\Rightarrow x = 10$

$\Rightarrow P_{H_2} = P_{I_2} = 0.10$ atm, $P_{HI} = 2.00$ atm