THE COPPERBELT UNIVERSITY
SCHOOL OF MATHEMATICS AND NATURAL SCIENCES

CHEMISTRY DEPARTMENT

SESSIONAL EXAMINATIONS 2017/2018

DATE: 13 AUGUST 2018

COURSE: GENERAL CHEMISTRY

COURSE CODE: CH 110

TIME ALLOWED: THREE (03) HOURS

INSTRUCTIONS TO CANDIDATES:

1. This paper comprises **eight** questions printed on pages 2 to 8.
2. Candidates are expected to attempt any **five** questions.
3. Each question carries **twenty** marks.
4. Candidates are reminded to **clearly present** their answers.
5. All the parts of a question should be answered **strictly in continuation.**

QUESTION 1: ACIDS AND BASES [20 MARKS]

(a) Answer the following questions

(i) What is the Arrhenius definition of an acid? Give an example of an acid according to this theory. [2]

ANSWER:

Acid - produces positively charged hydrogen ions, H^+ in water solution. [1]

Example: Any one among but not limited HCl, HNO_3, H_2SO_4, CH_3COOH, etc [1]

(ii) What is the Arrhenius definition of a base? Give an example of a base according to this theory. [2]

ANSWER:

Base - produces hydroxide ions, OH^- in water solution. [1]

Example: Any one amongbut not limited to NaOH, $Ba(OH)_2$, $Al(OH)_3$, NH4OH, KOH [1]

(b) When ethanoic acid is added to water, it reacts reversibly to give ethanoate ions and hydroxonium ions.

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

Use this reaction to explain the meaning of the terms conjugate acid and conjugate base, clearly picking out the conjugate pairs. [4]

ANSWER:

Conjugate acid - the particle formed when a base accepts a proton. [1]

- **CH_3COOH is the acid .... CH_3COOH is its conjugate base [1]**

Conjugate base - the particle that remains after an acid gives up a proton [1]

- **H_2O is the base .... H_3O^+ is its conjugate acid [1]**

(c) Which of the following conditions indicate a *basic* solution at 25°C? [2]

(i) $pOH = 11.21$

(ii) $pH = 9.42$

ANSWER:

(i) $\mathbf{pOH = 11.21}$ **- Acidic [1]**

(ii) $\mathbf{pH = 9.42}$ **- Basic [1]**

(d) Use the following equations to help you to explain what is meant by the statement that "water is amphoteric". [2]

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$
$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

ANSWER:
In the first equation water (H_2O) is donating a proton to ammonia (NH_3)thereby behaving as an acid. [1]

In the second equation, water (H_2O) is behaving as a base by accepting a proton from HCl. [1]

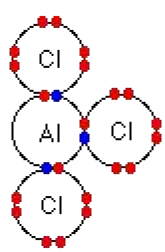
(e) Answer the following questions

(i) Define the terms Lewis acid and Lewis base. [2]

ANSWER:
A Lewis acid is an electron-pair acceptor [1]
A Lewis base is an electron-pair donor [1]

(ii) Draw a dots-and-crosses diagram of a molecule of aluminium chloride, $AlCl_3$, showing outer electrons only. Would you expect this to behave as a Lewis acid, a Lewis base, or neither, or both? Explain your answer. [3]

ANSWER:



[2]

$AlCl_3$ would behave as a Lewis acid because the central metal aluminium is electron deficient and would accept a pair of electrons from the base [1]

(f) Calculate the concentration of acetic acid, CH_3COOH, whose pH and K_a are 3.40 and 1.7×10^{-5}, respectively. [3]

ANSWER:

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+ \;\; \therefore K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]} = \frac{[H^+]^2}{[CH_3COOH]}$$

Since $pH = 3.40$ then $[H^+] = 10^{-3.40} = 3.98 \times 10^{-4} mol\, dm^{-3}$ [1]
Substituting this concentration in the above equation gives

$$K_a = \frac{[H^+]^2}{[CH_3COOH]} \; or\; 1.7 \times 10^{-5} mol\, dm^{-3} = \frac{(3.98 \times 10^{-4} mol\, dm^{-3})^2}{[CH_3COOH]} \quad [1]$$

$$[CH_3COOH] = 9.32 \times 10^{-3} mol\, dm^{-3} \quad [1]$$

QUESTION 2: THERMOCHEMISTRY **[20 MARKS]**

(a) Answer the following questions

(i) What is thermochemistry? [1]

ANSWER:
Study of the changes in heat energy that accompany chemical and physical changes

(ii) State first law of thermodynamics [1]

ANSWER:
First Law of Thermodynamics states that energy is neither created nor destroyed, but changes from one form to another.

(b) Copy the table of state functions below into your answer booklet and complete its second and third columns as shown for (i) [5]

State function	The function is an extensive one (True or False)	Its S.I. units are
(i) Volume	True	m^3
(ii) Density	**False**	$kg\ m^{-3}$
(iii) Internal Energy	**True**	kJ
(iv) Molar Internal Energy	**False**	$kJ\ mol^{-1}$
(v) Enthalpy	**True**	kJ
(vi) Molar Enthalpy	**False**	$kJ\ mol^{-1}$

(c) Answer the following questions relating to Hess's Law

(i) State Hess's Law [1]

ANSWER:
Hess's Law states that the overall enthalpy changes in a reaction is equal to the sum of the enthalpy changes for the individual steps in the process.

(ii) The enthalpy of combustion of N_2 are given in the reaction equations below

$$\tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2 \longrightarrow NO(g) \qquad \Delta H_f^o = 90\ kJ/mol$$
$$\tfrac{1}{2}N_2(g) + O_2 \longrightarrow NO_2(g) \qquad \Delta H_f^o = 33.18\ kJ/mol$$

Use these equations to derive and calculate the heat of combustion of the reaction $NO(g) + \tfrac{1}{2}O_2 \longrightarrow NO_2(g)$. [4]

ANSWER:

$$NO \longrightarrow \tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2 \qquad -90.25 \quad [1]$$
$$\tfrac{1}{2}N_2 + O_2 \longrightarrow NO_2 \qquad +33.18 \quad [1]$$
$$NO + \tfrac{1}{2}O_2 \longrightarrow NO_2 \quad [1] \qquad -57.05KJ/mol \quad [1]$$

(iii) The enthalpy of combustion of solid carbon to form carbon dioxide is −393.7 kJ/mol carbon, and the enthalpy of combustion of carbon monoxide to form carbon dioxide is −283.3 kJ/mol CO. Use these data to calculate Δ*H* for the reaction [3]

$$2C(s) + O_2(g) \longrightarrow 2CO(g)$$

ANSWER:

Thermochemical reactions given are:

$$\boldsymbol{C(s) + O_2(g) \longrightarrow CO_2(g) \qquad \Delta H_1 = -393.3\ kJ/mol}$$

$$\boldsymbol{CO(g) + ½O_2(g) \longrightarrow CO_2(g) \qquad \Delta H_2 = -283.3\ kJ/mol}$$

To get required thermochemical equation, double both equations [1]

$$\boldsymbol{2C(s) + 2O_2(g) \longrightarrow 2CO_2(g) \quad 2 \times \Delta H_1 = 2\ mol \times (-393.3\ kJ/mol) = -786.6\ kJ}$$

$$\boldsymbol{2CO(g) + O_2(g) \longrightarrow 2CO_2(g) \quad 2 \times \Delta H_2 = 2\ mol \times (-283.3\ kJ/mol) = -566.6\ kJ}$$

Reverse the doubled second thermochemical equation [1]

$$\boldsymbol{2CO_2(g) \longrightarrow 2CO(g) + O_2(g) \quad -2 \times \Delta H_2 = 2\ mol \times (\mp 283.3\ kJ/mol) = +566.6\ kJ}$$

Sum doubled enthalpy of first equation double reversed enthalpy of the second equation to enthalpy of final equation (ΔH_3). [1]

$$\boldsymbol{2C(s) + 2O_2(g) \longrightarrow 2CO_2(g) \quad 2 \times \Delta H_1 = 2\ mol \times (-393.3\ kJ/mol) \quad = -786.6\ kJ}$$

$$\boldsymbol{+\ 2CO_2(g) \longrightarrow 2CO(g) + O_2(g) \quad -2 \times \Delta H_2 = 2\ mol \times (\mp 283.3\ kJ/mol) = +566.6\ kJ}$$

$$\boldsymbol{2C(s) + 2O_2(g) + 2CO_2(g) \longrightarrow 2CO_2(g) + 2CO(g) + O_2(g) \quad \Delta H_3 = -786.6\ kJ + 566.6\ kJ}$$

That is

$$\boldsymbol{2C(s) + O_2(g) \longrightarrow 2CO(g) \quad \Delta H_3 = -220.0\ kJ}$$

(iii) The bombardier beetle uses an explosive discharge as a defensive measure. The chemical reaction involved is the oxidation of hydroquinone by hydrogen peroxide to produce quinone and water:

$$C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2O(l)$$

Calculate Δ*H* for this reaction from the following data [5]

$$C_6H_4(OH)_2(aq) \longrightarrow C_6H_4O_2(aq) + H_2(g) \qquad \Delta H = +177.4\ kJ$$
$$H_2(g) + O_2(g) \longrightarrow H_2O_2(aq) \qquad \Delta H = -192.2\ kJ$$
$$H_2(g) + ½O_2(g) \longrightarrow H_2O(g) \qquad \Delta H = -241.8\ kJ$$
$$H_2O(g) \longrightarrow H_2O(l) \qquad \Delta H = -43.8\ kJ$$

ANSWER:

1. **We designate the above four thermochemical reactions as R_1, R_2, R_3 and R_4 while the required reaction is designated as R_5. Their corresponding enthalpies are ΔH_1, ΔH_2, ΔH_3, ΔH_4 and ΔH_5. We show this below:**

$$\mathbf{R_1\ is}\ \mathrm{C_6H_4(OH)_2(aq) \longrightarrow C_6H_4O_2(aq) + H_2(g)}\quad \mathbf{and}\quad \mathbf{\Delta H_1} = +\,177.4\ \mathrm{kJ}$$
$$\mathbf{R_2\ is}\ \mathrm{H_2(g) + O_2(g) \longrightarrow H_2O_2(aq)}\quad \mathbf{and}\quad \mathbf{\Delta H_2} = -\,192.2\ \mathrm{kJ}$$
$$\mathbf{R_3\ is}\ \mathrm{H_2(g) + ½O_2(g) \longrightarrow H_2O(g)}\quad \mathbf{and}\quad \mathbf{\Delta H_3} = -\,241.8\ \mathrm{kJ}$$
$$\mathbf{R_4\ is}\ \mathrm{H_2O(g) \longrightarrow H_2O(l)}\quad \mathbf{and}\quad \mathbf{\Delta H_4} = -\,43.8\ \mathrm{kJ}$$
$$\mathbf{R_5\ is}\ \mathrm{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2O(l)}\ \mathbf{and}\ \mathbf{\Delta H_5} =\ ?$$

2. **Overall evaluation using Hess's Law gives**
   $\boldsymbol{R_5 = R_1 - R_2 + 2R_3 + 2R_4}$ **(2 marks for worked the reactions)**
   and $\mathbf{\Delta H_5 = \Delta H_1 - \Delta H_2 + 2\Delta H_3 + 2\Delta H_4}$ **(3 marks for calculating enthalpies that evaluates to)**
   $$\mathbf{\Delta H_5 = +\,177.4 - (-\,192.2) + 2(-\,241.8) + 2(-\,43.8) = -\,201.6}$$

3. **Stepwise, the first combination of reactions is** $\boldsymbol{R_1^{'} = R_1 - R_2}$ **whose enthalpy is** $\boldsymbol{\Delta H_1^{'}} = \mathbf{\Delta H_1 - \Delta H_2}$ **gives us**
   $$\mathbf{R_1\ is}\ \mathrm{C_6H_4(OH)_2(aq) \longrightarrow C_6H_4O_2(aq) + H_2(g)}\quad \mathbf{and}\quad \mathbf{\Delta H_1} = +\,177.4\ \mathrm{kJ}$$
   $$\underline{\boldsymbol{R_1^{'}}\ \mathbf{is}\ \mathrm{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2(g) + O_2(g)}}$$
   $$\mathbf{and}\quad \boldsymbol{\Delta H_1^{'}} = +\,177.4\ \mathrm{kJ} + (+\,192.2\ \mathrm{kJ}) = +\,369.6\ \mathrm{kJ}$$

The resulting thermochemical reaction is

$$\mathbf{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2(g) + O_2(g)}\ \boldsymbol{\Delta H_1^{'}} = \mathbf{+\,369.6\ kJ}\qquad \textbf{[1]}$$

4. **The second combination of chemical equations gives**
   $$\boldsymbol{R_2^{'} = (R_1 - R_2) + 2R_3},\ \textbf{that is, } \boldsymbol{R_2^{'} = R_1^{'} + 2R_3}$$
   whose enthalpy is
   $\boldsymbol{\Delta H_2^{'}} = \mathbf{(\Delta H_1 - \Delta H_2) + 2\Delta H_3}$ **or** $\boldsymbol{\Delta H_2^{'}} = \boldsymbol{\Delta H_1^{'}} + \mathbf{2\Delta H_3}$
   $$\boldsymbol{R_1^{'}}\ \mathbf{is}\ \mathrm{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2(g) + O_2(g)}$$
   $$\mathbf{2R_3\ is}\ \mathbf{2}\mathrm{H_2(g)} + \mathbf{2} \times \mathrm{½O_2(g) \longrightarrow}\ \mathbf{2}\mathrm{H_2O(g)}$$

$$\boldsymbol{R_2^{'} = R_1^{'} + 2R_3 is}\ \mathrm{C_6H_4(OH)_2(aq) + H_2O_2(aq) +}\ \mathbf{2}\mathrm{H_2(g)} + \mathbf{2} \times \mathrm{½O_2(g)}$$
$$\longrightarrow \mathbf{2}\mathrm{H_2O(g) + C_6H_4O_2(aq) + 2H_2(g) + O_2(g)}$$

Or

$$\boldsymbol{R_2^{'} is}\ \mathrm{C_6H_4(OH)_2(aq) + H_2O_2(aq) +}\ \cancel{\mathbf{2}\mathrm{H_2(g)}} + \cancel{\mathbf{2} \times \mathrm{½O_2(g)}}$$
$$\longrightarrow \mathbf{2}\mathrm{H_2O(g) + C_6H_4O_2(aq) +}\ \cancel{\mathrm{2H_2(g)}} + \cancel{\mathrm{O_2(g)}}$$

The reaction of the second addition $\boldsymbol{R_2^{'}}$ **is**

$$\mathbf{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow 2H_2O(g) + C_6H_4O_2(aq)}$$

and its enthalpy is $\boldsymbol{\Delta H_2^{'} = \Delta H_1^{'}} + \mathbf{2\Delta H_3 = +\,369.6 + (2 \times -\,241.8 = -\,114.0)}$

Thus thermochemical equation of the second addition is

$$\mathbf{C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow 2H_2O(g) + C_6H_4O_2(aq)}\quad \boldsymbol{\Delta H_2^{'}} = \mathbf{-\ 114.0}\quad \textbf{[1]}$$

5. **Finally, the third combination of reactions is**
   $$\boldsymbol{R_5 =\ (R_1 - R_2 + 2R_3) + 2R_4\ or\ R_5 = R_2^{'} + 2R_4}$$

whose sum of enthalpies is

$$\Delta H_5 = (\Delta H_1 - \Delta H_2 + 2\Delta H_3) + 2\Delta H_4 \text{ or } \Delta H_5 = \Delta H_2' + 2\Delta H_4$$

Thus

$$R_2' \quad C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow 2H_2O(g) + C_6H_4O_2(aq) \quad \Delta H_2' = -114.0\text{ kJ}$$

$$+\ 2R_4 \text{ is } 2H_2O(g) \longrightarrow 2H_2O(l) \qquad 2\Delta H_4 = 2(-43.8\text{ kJ}) = -87.6\text{ kJ}$$

$$R_5 \text{ is } C_6H_4(OH)_2(aq) + H_2O_2(aq) + 2H_2O(g) \longrightarrow 2H_2O(g) + C_6H_4O_2(aq) + 2H_2O(l) \quad \Delta H_5 = -201.6\text{ kJ}$$

or

$$R_5 \text{ is } C_6H_4(OH)_2(aq) + H_2O_2(aq) \cancel{+\ 2H_2O(g)} \longrightarrow \cancel{2H_2O(g)} + C_6H_4O_2(aq) + 2H_2O(l) \quad \Delta H_5 = -201.6\text{ kJ}$$

That is

$$R_5 \text{ is } C_6H_4(OH)_2(aq) + H_2O_2(aq) \longrightarrow C_6H_4O_2(aq) + 2H_2O(l) \qquad \Delta H_5 = -201.6\text{kJ} \qquad [2]$$

The enthalpy of reaction is -201.6 kJ **[1]**

QUESTION 3: ATOMIC THEORY AND PERIODICITY [20 MARKS]

(a) Which metal in each of the following sets will be drawn into a magnetic field the most? [4]

(i) Zn Mn V (ii) Ca Cu Cd (iii) Sc Cu V (iv) Ti Tl Ga

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.84

(i) Mn (has 5 unpaired electrons) (ii) Cu (has 1 unpaired electron)
(iii) V (has 3 unpaired electrons) (iv) Ti (has 2 unpaired electrons)

(b) What is wrong with each of the following ground state configurations? [4]

(i) $1s^2\ 2p^6\ 3d^{10}\ 4f^{14}$ (ii) $1s^2\ 2s^2\ 2p^4\ 3s^2\ 3p^6$ (iii) $[Xe]\ 6s^2\ 5d^{10}\ 4f^{15}$

(iv) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{14}$

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.75

(i) The 2*s*, 3*s*, 3*p*, etc. subshells are missing.
(ii) The 2*p* subshell is not completely filled.
(iii) There are too many electrons in the 4*f* subshell.
(iv) There are too many electrons in the 3*d* subshell.

(c) How many unpaired electrons are present in the ground state of an atom if there are five electrons in each of the following subshells? There are no other unpaired electrons. [3]

(i) 3*p* subshell (ii) 3*d* subshell (iii) 4*f* Subshell

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.77

(i) One **(ii) Five** **(iii) Five**

(d) Identify the element from each of the following *partial* configurations of neutral atoms: **[2]**

(i) $...3d^{10}\ 4p^{5}$ (ii) $...7s^{2}\ 6d^{1}\ 5f^{14}$

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.67

(i) Br **(ii) Lr**

(e) Calculate the energy of a photon of light of wavelength 4.340×10^{-7} m, corresponding to a line in the visible spectrum of hydrogen. **[3]**

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.18

$$E = \frac{hc}{\lambda} \qquad [1]$$

$$\mathrm{E} = \frac{(6.63 \times 10^{-34}\ \mathrm{J \cdot s})\left(3.00 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}}\right)}{4.340 \times 10^{-7}\ \mathrm{m}} \qquad [1]$$

$$\mathrm{E} = 4.58 \times 10^{-19}\ \mathrm{J} \qquad [1]$$

(f) Answer each the following questions using one sentence only:

(i) What is the difference, if any, between an *s* subshell and an *s* orbital? **[2]**

(ii) What is the difference, if any, between a *p* subshell and a *p* orbital? **[2]**

ANSWER – Source: Fundamentals of Chemistry by David E. Goldberg Question 4.6

(i) Because the *s* subshell contains only one orbital, there is no difference.

(ii) A *p* subshell contains three *p* orbitals.

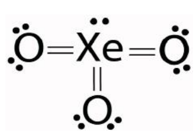
QUESTION 4: CHEMICAL BONDING & MOLECULAR GEOMETRY [20 MARKS]

(a) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. Draw the complete Lewis electron-dot diagram for each of these molecules.

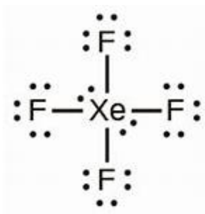
(i). XeO_3 [2] (ii) XeF_4 [2]

ANSWER:

(i). XeO_3



[2]

(ii) XeF_4  **[2]**

(b) On the basis of the Lewis electron-dot diagrams you drew for part (a), predict the following:

(i) The geometric shape of the XeO_3 molecule. [1]

ANSWER: Trigonal pyramidal **[1]**

(ii) The geometric shape of the XeF_4 molecule. [1]

ANSWER: Square planar **[1]**

(iii) The hybridization of the valence orbitals of xenon in XeO_3 [1]

ANSWER: sp^3 **[1]**

(iv) The hybridization of the valence orbitals of xenon in XeF_4. [1]

ANSWER: sp^3d^2 **[1]**

(c) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction. [3]

ANSWER: Polar, XeO_3 has net polarity **[3]**

(d) Explain why the CH_2F_2 molecule is polar, whereas the CF_4 molecule is not. [2]

ANSWER:

CH_2F_2: has two different kind of bonds C-H and C-F, has net polarity **[1]**

CF_4 : all the bonds are the same C-F, has no net polarity **[1]**

(e) Calculate the formal charges of atoms in;

(i) XeO_3 [2] (ii) XeF_4 [2]

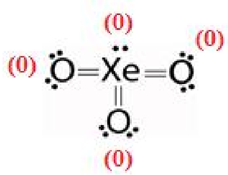
ANSWER:

(i) XeO_3 [2]

Formal charge(FC) = Valence e^-s – unbonded e^-s – ½bonded e^-s **[½]**

O (FC) = 6 – 6 - 4/2 =0 **[½]**

Xe (FC) = 8 - 2 - 12/2 =0 [½]

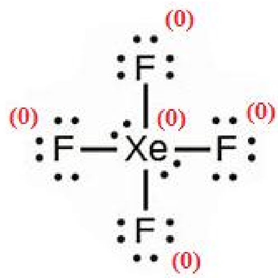


(ii) XeF_4 [2]

ANSWER:

O (FC) = 8 – 4 - 8/2 =0 **[½]**

Xe (FC) = 7 - 6 - 2/2 =0 **[½]**



[1]

(f) List the three possible molecular geometries which have sp^3 hybridized orbitals. [3]

ANSWER: **Tetrahedral, Trigonal pyramid and Bent** **[3]**

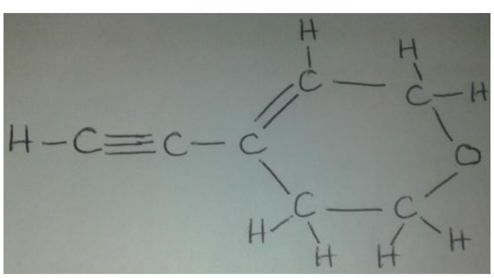
QUESTION 5: ORGANIC CHEMISTRY **[20 MARKS]**

(a) State whether each of the following statements is true or false [2]

(i) 3-propyl heptane and n-decane are structural isomers **[True]** **[1]**

(ii) A series of compounds whose structures differ from each other by a specific structural unit is called a homologous **[True]** **[1]**

(b) Copy the following molecule in your answer booklet and label all the sp and sp^2 hybridized carbon atoms. [4]



Carbon atoms 1 and 2 are sp hybridized **[2]**

Carbon atoms 3 and 4 are sp^2 hybridized **[2]**

(c) Answer the following questions based on the structures of organic compounds given below:

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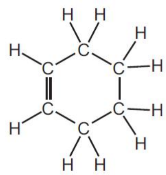

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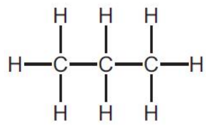

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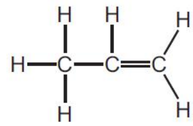

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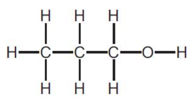

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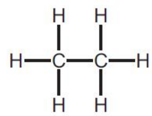

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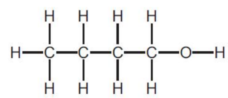

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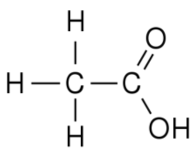
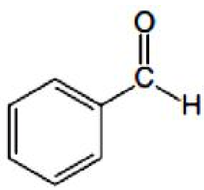
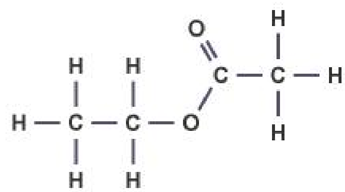


W



X



(i) Which **two** of these compounds are alcohols? **S and U** **[2]**

(ii) Which **two** of these compounds are saturated hydrocarbons? **Q and T** **[2]**

(iii) Identify any **two** of these compounds that are not hydrocarbons? [2]

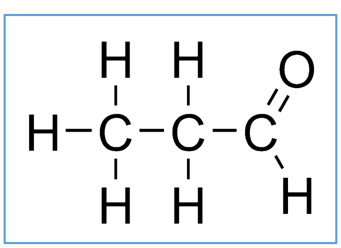
S, U, V, W, X (any two of these) **[2]**

(iv) Which **one** of these compounds is a ketone? **None** **[1]**

(v) Suggest the name of the main product when compound R reacts with hydrogen bromide **2-Bromo propane** **[2]**

(vi) Suggest the names of the products when compound Q completely reacts with oxygen **Carbon dioxide and Water** **[2]**

(d) Write down the structural formula and the name of an aldehyde that is an isomer of acetone (propanone) [1]

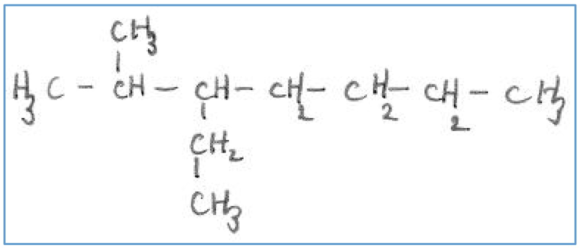


[½]

Propanal **[½]**

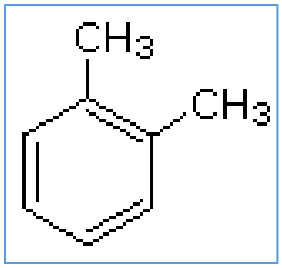
(e) Draw the structures of the following organic molecules [2]

(i) 2-methyl-3-ethyl heptanes



[1]

(ii) 1,2-dimethyl benzene



[1]

QUESTION 6: REACTIONS IN SOLUTION **[20 MARKS]**

(a) Define the following

(i) Titrant [1]

ANSWER:
This is a solution of known concentration which is added (titrated) to another solution to determine the concentration of a second chemical species. **[1]**

(ii) Standard solution [1]

ANSWER:
This is a solution whose concentration is known to a great degree of precision and correctness, it is also called a titrant. **[1]**

(b) Answer the following questions

(i) What is the difference between an end point and the equivalence point in a titration? [2]

ANSWER:
The equivalent point is that point in a titration where just enough titrant has been added to react all the analyte present. **[1]**

The end point in a titration is a point where a physical change, such as a colour change of an indicator occurs. This is used to signal the equivalence point **[1]**

(ii) What is the difference between a direct titration and a back titration? [2]

ANSWER:

In a direct titration, the titrant reacts directly with the analyte. **[1]**

In a back titration, a known excess of a reagent that reacts with the analyte is added and the excess reagent is then titrated **[1]**

(c) Answer the questions below

(i) Calculate the molarity of silver nitrate solution when 117.40 g of silver nitrate is dissolved in a litre of solution. [3]

ANSWER:

Molar mass of $AgNO_3$ = 169.9 g/mol **[1]**

Moles of $AgNO_3$ = $\frac{117.40g}{169.90\ g/mol}$ = 0.691 mol **[1]**

Molarity of $AgNO_3$ = $\frac{0.691\ mol}{1.0\ L}$ = 0.691 M **[1]**

(ii). Calculate the amount of sodium hydroxide in milligrams for a 0.500 mol/L sodium hydroxide solution whose volume is 100 mL. [3]

ANSWER:

Molar mass of NaOH = 40.0 g/mol **[1]**

Amount of $\mathrm{NaOH} = 0.1\mathrm{L} \times \frac{0.500\ \mathrm{mol}}{\mathrm{L}} \times \frac{40.0\ \mathrm{g}}{\mathrm{mol}} = 2.00\ \mathrm{g}$ **[2]**

(d) A 0.500 g sample containing sodium dihydrogen phosphate is titrated with sodium hydroxide:

$$\mathrm{OH^- + H_2PO_4^- \longrightarrow HPO_4^{2-} + H_2O}$$

If 23.06 mL of 0.0985 M sodium hydroxide is required for the titration, what is the percentage of NaH_2PO_4 in the sample? [4]

ANSWER:

% NaH_2PO_4in sample = $\frac{(volume)(molarity)(Molar\ mass)\ (100\%)}{mass\ of\ sample}$ **[1.5]**

= $\frac{(23.06mL)\left(\frac{0.0985mol}{L}\right)\left(\frac{120g}{mol}\right)\ (100\%)}{500mg}$ **[1.5]**

= 54.5 % NaH_2PO_4 **[1]**

(e) A 0.3147 g sample of primary standard grade $Na_2C_2O_4$ was dissolved in dilute H_2SO_4 and titrated with a solution of $KMnO_4$. The end point was observed after the addition of 31.67 mL of the titrant. Use the unbalanced reaction in acidic media is given below to write the balance redox reaction. [4]

$$C_2O_4^{2-} + MnO_4^- \longrightarrow Mn^{2+} + CO_2 + H_2O$$

ANSWER:

1. **Unbalanced oxidation half reaction is**
   $\mathbf{C_2O_4^{2-} \longrightarrow CO_2}$ **[½]**
2. **Mass balanced oxidation half reaction is**
   $\mathbf{C_2O_4^{2-} \longrightarrow 2CO_2}$ **[½]**
3. **Charge balanced oxidation half reaction is**
   $\mathbf{C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-}$ **[½]**
4. **Unbalanced reduction half reaction is**
   $\mathbf{MnO_4^- \longrightarrow Mn^{2+}}$ **[½]**
5. **Mass balanced oxidation half reaction is**
   $\mathbf{8H^+ + MnO_4^- \longrightarrow Mn^{2+} + 4H_2O}$ **[½]**
6. **Charge balanced oxidation half reaction is**
   $\mathbf{8H^+ + MnO_4^- + 5e^- \longrightarrow Mn^{2+} + 4H_2O}$ **[½]**
7. **Balancing electrons in half reactions requires that Equation 3 is multiplied by 5 while Equation 6 is multiplied by 2 and the resulting equations added to give**
   $\mathbf{5C_2O_4^{2-} + 16H^+ + 2MnO_4^- + 10e^- \longrightarrow 10CO_2 + 10e^- + 2Mn^{2+} + 8H_2O}$ **[½]**
8. **Canceling the electrons on both sides of Equation 7 gives the balanced redox reaction**

   $\mathbf{5C_2O_4^{2-} + 16H^+ + 2MnO_4^- \longrightarrow 10CO_2 + 2Mn^{2+} + 8H_2O}$ **[½]**

QUESTION 7: GASES **[20 MARKS]**

(a) The pressure of a gas is measured as 49 torr. Represent this pressure in both atmospheres and pascals. [4]

ANSWER – Source Zumdahl 8th Edition Example 5.1

Since 760 torr = 1 atm,

$$\mathbf{49\ torr \times \frac{1\ atm}{760\ torr} = 6.4 \times 10^{-2} atm}$$ **[2]**

Since 1 atm = 101,325 Pa

$$\mathbf{6.4 \times 10^{-2} atm \times \frac{101325\ Pa}{1\ atm} = 6.5 \times 10^{3} Pa}$$ **[2]**

(b) State the two gas laws below, give each law's mathematical representation and sketch a graphical plot of the mathematical relation that you give for each law. [6]

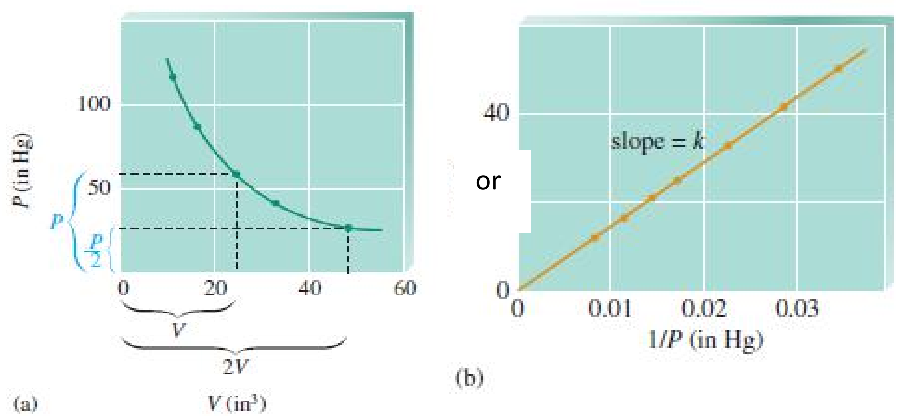
(i) Boyle's Law (ii) Avogadro's Law

ANSWER: [3 marks each part – Total 6]

(i) **Boyle's Law: Pressure of ideal gas at constant temperature is inversely proportional to its value. [1]**

Mathematical relation is PV=k or P=k/V or V=k/P. [1]

Graphical plot – either (a) or (b). [1]



(ii) **Avogadro's Law: Volume of an ideal gas at constant pressure and temperature is directly proportional to its number of moles. [1]**

Mathematical relation is V=kn or V/n=k. [1]

Graphical plot similar to (b) but with an x-axis of ninstead of 1/P [1]

(c) Quicklime (CaO) is produced by thermal decomposition of calcium carbonate ($CaCO_3$). Calculate the volume of carbon dioxide (CO_2) at STP produced from the decomposition of 152 g of $CaCO_3$. [6].

ANSWER – Source Zumdahl and Zumdahl 8th Edition Example 5.12.

[1 mark for decomposition equation, 1 mark for molar volume, 2 marks for moles of $CaCO_3$, 3 marks for CO_2 volume – Total 7 marks]

Decomposition equation is $\mathrm{CaCO_3}(s) \longrightarrow \mathrm{CaO}(s) + \mathrm{CO_2}(s)$ [1]

The molar volume of a gas at STP is 22.42 L (or Ideal Gas Law Equation) [1]

Since the molar mass of CaCO3 is 100.09g, its number of moles is

$$152\ \mathrm{g\ CaCO_3} \times \frac{1\ \mathrm{mol\ CaCO_3}}{100.09\ \mathrm{g\ CaCO_3}} = 1.52\ \mathrm{mol\ CaCO_3} \quad [2]$$

The decomposition equation shows that for each mole $CaCO_3$ produces a mole of CO_2 or 22.42 L of CO_2. Therefore the volume of 1.52 moles of CO_2 produced is

$$1.52\ \mathrm{mol\ CaCO_3} \times \frac{22.42\ \mathrm{L\ CaCO_3}}{1\ \mathrm{mol\ CaCO_3}} = 34.1\mathrm{L\ CaCO_3} \quad [2]$$

(d) Answer the following questions on Dalton's Law.

(i) The partial pressure of oxygen was observed to be 156 torr in air with a total atmospheric pressure of 743 torr. Calculate mole fraction of O_2 present. [2]

ANSWER: Source – Zumdahl and Zumdahl 8th Edition; Example 5.16

[1 mark mole fraction equation, 1mole fraction – Total 2 marks]

The mole fraction of O_2 is given as

$$\chi_{O_2} = \frac{P_{O_2}}{P_{TOTAL}} = \frac{152 \text{ torr}}{743 \text{ torr}} = 0.21 \qquad [2]$$

(ii) The mole fraction of nitrogen in the air is 0.7808. Calculate the partial pressure of N_2 in air when the atmospheric pressure is 760 torr. [2]

ANSWER – Source Zumdahl and Zumdahl 8th Edition Example 5.17.

[1 mark partial pressure equation, 1 mole fraction – Total 2 marks]

The partial pressure of N_2 is given as

$$P_{N_2} = \chi_{N_2} \times P_{TOTAL} = 0.7808 \times 760 \text{ torr} = 593 \text{ torr} \qquad [2]$$

QUESTION 8: CHEMICAL EQUILIBRIUM [20 MARKS]

(a) Calculate the value of the equilibrium constant, K_c at 127 ^{O}C for the reaction given below. [2]

$$\frac{1}{2}N_2\,(g) + \frac{3}{2}H_2\,(g) \rightleftharpoons NH_3\,(g)$$

where $[NH_3] = 3.1 \times 10^{-2}$ mol/L

$[N_2] = 8.5 \times 10^{-1}$ mol /L

$[H_2] = 3.1 \times 10^{-3}$ mol /L

ANSWER:

$$K_c = \frac{[NH_3]}{[N_2]^{1/2}[H_2]^{3/2}} = \frac{[3.1\times10^{-2}]}{[8.5\times10^{-1}]^{1/2}[3.1\times10^{-3}]^{3/2}} = 1.9 \times 10^2 \qquad [2]$$

(b) For the reaction for the formation of nitrosylchloride: $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ the pressures were:

P_{NOCl} = 1.2 atmospheres

$P_{NO} = 5.0 \times 10^{-2}$ atmosphere

$P_{Cl2} = 3.0 \times 10^{-1}$ atmosphere

(i) Calculate K_p at 25^{O}C [2]

ANSWER:

$$K_c = \frac{P^2_{NOCl}}{P^2_{NO}P_{Cl_2}} = \frac{(1.2)^2}{(5.0\times10^{-2})^2(3.0\times10^{-1})} = 1.9 \times 10^3 \qquad [2]$$

(ii) Using K_p calculated at (i), obtain the value of K_c at 25^{O}C for the reaction

$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ [2]

ANSWER:

$K_p = K_c(RT)^{\Delta n}$ **where** Δn **is the difference between the sums of the coefficients in the gaseous products and reactants, that is,** $\Delta n = 2 - (2+1) =- 1\ mol$**.**

$T = (25 + 273) = 298\ K$ **and** $R = 0.08205\ 74$

Thus $K_p = K_c(RT)^{-1} = \frac{K_c}{RT}$

Solving for K$_c$ gives

$$K_c = K_pRT = (1.9 \times 10^3)(0.08206)(298) = 4.6 \times 10^4$$ **[2]**

(c) Answer the questions below.

(i) Write the reaction quotient for the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ [1]

ANSWER:

$$Q = \frac{[NH_3]_0^2}{[N_2]_0[H_2]_0^3}$$ **[1]**

(ii) For the synthesis of ammonia at 500 ^{O}C, $K_c = 6.0 \times 10^{-2}$. Predict the direction in which the system will shift to reach equilibrium in the following cases:-

(1) [NH$_3$]$_O$ = 10×10^{-3}M; [N$_2$]$_0$= 1.0×10^{-5}M; [H$_2$]$_0$= 2×10^{-3}M [1]

ANSWER:

$$Q = \frac{(1.0 \times 10^{-3})^2}{(1.0 \times 10^{-5})(2.0 \times 10^{-3})^3} = 1.3 \times 10^7$$

Since $Q >>> K(6.0 \times 10^{-2})$**, to obtain equilibrium, the concentrations of products must be decreased and the concentrations of reactants decreased. ∴ the system will shift to the left,** $N_2 + 3H_2 \leftarrow 2NH_3$

[1]

(2) [NH$_3$]$_O$= 2.0×10^{-4}M; [N$_2$]$_0$= 1.50×10^{-5}M; [H$_2$]$_0$= 3.54×10^{-1}M [1]

ANSWER:

$$Q = \frac{(2.0 \times 10^{-4})^2}{(1.5 \times 10^{-5})(3.54 \times 10^{-1})^3} = 6.01 \times 10^{-2}$$

In this case K=Q, so the system is at equilibrium; therefore no shift will occur. **[1]**

(3) [NH$_3$]$_O$= 1.0×10^{-4}M; [N$_2$]$_0$= 5.0 M; [H$_2$]$_0$= 1.0×10^{-2}M [1]

ANSWER:

$$Q = \frac{(1.0 \times 10^{-4})^2}{(5)(1.0 \times 10^{-2})^3} = 2.0 \times 10^{-3}$$

Here $K >>> Q$, thereforethe system will shift to the left to attain equilibrium by increasing the concentration of the product and decreasing the reactant concentrations, $N_2 + 3H_2 \rightarrow 2NH_3$ [1]

(d) The reaction for the formation of gaseous hydrogen fluoride from hydrogen and fluorine has

$K_c = 1.1 \times 10^2$at a certain temperature. In one experiment, 3 moles of each component was added to the 1.5 litre flask. Calculate the equilibrium concentrations of all species. [6]

ANSWER:

(i) Balanced equation is $H_2(g) + F_2(g) \rightleftharpoons 2HF(g)$ [½]

(ii) Equilbrium expression is $K_c = 1.15 \times 10^2 = \frac{[HF]^2}{[H_2][F_2]}$ [½]

(iii) Initial concentrations: $[HF]_0 = [H_2]_0 = [F_2]_0 = \frac{3\ mol}{1.5\ L} = 2.0\ M$ [½]

(iv) Value of Q: $Q = \frac{[HF]^2}{[H_2][F_2]} = \frac{(2)^2}{(2)(2)} = 1$. Since Q<<<K, the system must shift to the right to reach equilibrium. [½]

(v) What change in the concentrations is necessary? [½]

Initial Concentration (Mol/L)	Change (Mol/L)	Equilibrium Concentration (Mol/L)
$[H_2]_0 = 2$	$-x$	$2 - x$
$[F_2]_0 = 2$	$-x$	$2 - x$
$[HF]_0 = 2$	$+2x$	$2 + 2x$

(vi) What is the value of x?

$$K_c = 1.15 \times 10^2 = \frac{[HF]^2}{[H_2][F_2]} = \frac{(2+2x)^2}{(2-x)^2}$$

Therefore, $\sqrt{1.15 \times 10^2} = \frac{(2+2x)}{(2-x)}$ $and\ x = 1.528$ [½]

(vii) The equilibrium concentrations are:

$[H_2] = [F_2] = 2M - x = 0.472M\ and\ [HF] = 2M + 2x = 5.056$ [3]

(e) Answer the questions below.

(i) State Le Chaterlier's Principle. [1]

ANSWER:

Le Châtelier's principle states that when a system in chemical equilibrium is disturbed by a change of temperature, pressure, or a concentration, the system shifts in equilibrium composition in a way that tends to counteract this change of variable. [1]

(ii) Arsenic can be extracted from its ores, first reacting the ore with oxygen (called roasting) to form $As_4\ 0_6$ which is then reduced by carbon:

$$As_40_6(s) + 6C(s) \rightleftharpoons As_4(g) + 6CO\ (g)$$

In which direction will the equilibrium position shift in response to the following conditions

(1) Addition of carbon monoxide [1]

ANSWER:

Equilibrium position shifts to the left. [1]

(2) Addition or removal of carbon or tetra arsenic hexoxide (As_4O_6) [1]

ANSWER:

Since amount of pure solid has no effect on equilibrium position,there will be shift. [1]

(3) Removal of gaseous arsenic (As_4) [1]

ANSWER:

Equilibrium position shifts to the right. [1]

TABLE OF FUNDAMENTAL CONSTANTS

Quantity	symbol	Value	Power of ten	Units
Speed of light	c	2.9979	10^8	$m\ s^{-1}$
Elementary charge	e	1.602	10^{-19}	C
Faraday's constant	$F=N_Ae$	9.6485	10^4	$C\ mol^{-1}$
Boltzmann's constant	k	1.380 65	10^{-23}	$J\ K^{-1}$
Gas constant	$R=N_Ak$	8.314 47		$J\ K^{-1}\ mol^{-1}$
		8.314 47	10^{-2}	$L\ bar\ K^{-1}\ mol^{-1}$
		8.205 74	10^{-2}	$L\ atm\ K^{-1}\ mol^{-1}$
		6.236 37	10	$L\ Torr\ K^{-1}\ mol^{-1}$
Planck's constant	h	6.626 08	10^{-34}	Js
Avogadro's constant	N_A	6.022 14	10^{23}	mol^{-1}
Atomic mass unit	m_u	1.660 54	10^{-27}	Kg
Mass				
Electron	m_e	9.109 38	10^{-31}	Kg
Proton	m_p	1.672 62	10^{-27}	Kg
neutron	m_n	1.674 93	10^{-27}	kg
Rydeberg constant	R_H	1.097 37	10^7	m^{-1}
1 atm = 760 mmHg = 760 Torr = 1.01325 x 10^5 Nm^{-2} = 1.01325 x10^5 Pa= 1.01325 bar				

The Periodic Table

1	2											3	4	5	6	7	0
1 **H** 1.01				Atomic Number **Element** Atomic Mass													2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.71	29 **Cu** 63.55	30 **Zn** 65.37	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** 98.91	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.40	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.30
55 **Cs** 132.91	56 **Ba** 137.34	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.21	77 **Ir** 192.22	78 **Pt** 195.09	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.98	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 **Uut** (284)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (291)	117 **Uus** (Unknown)	118 **Uuo** (294)

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)