THE COPPERBELT UNIVERSITY
SCHOOL OF MATHEMATICS AND NATURAL SCIENCES

CHEMISTRY DEPARTMENT

Test Two for 2020/2021

DATE: May 2021

COURSE: GENERAL CHEMISTRY

COURSE CODE: CH 110

Proposed solutions

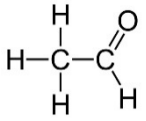
TIME ALLOWED: TWO (02) HOURS

INSTRUCTIONS TO CANDIDATES:

1. This paper comprises **FOUR** questions
2. Candidates are expected to attempt **ALL** questions.
3. Each question carries **TWENTY FIVE** marks.
4. Candidates are reminded to **CLEARLY PRESENT** their answers.
5. All the parts of a question should be answered **IN CONTINUATION**

QUESTION 1 THERMOCHEMISTRY [25 MARKS]

(a) Acetaldehyde (Ethanal) has a fruity aroma, and is naturally contained in foods such as fruits and fruit juice. Ethanal (CH_3CHO) has the structure shown. Gaseous ethanal burns by the equation



$CH_3CHO(g) + 2½O_2(g) \rightarrow 2H_2O(g) + 2CO_2(g)$ or

$CH_3CHO(g) + 2½(O=O) \rightarrow 2(O-O) + 2(O=C=O)$

(i) Use the mean bond enthalpy data to calculate the enthalpy change which occurs when all the bonds in the reactants shown in the above equation are broken [5]

$4 \times C-H = 4 \times 413 =$ 1652 [1]

$1 \times C-C = 1 \times 347 =$ 347 [1]

$1 \times C=O = 1 \times 736 =$ 736 [1]

2735

$2½ \times O=O = 2.5 \times 498 =$ 1245 [1]

$\Delta H = \Sigma BE_{(bonds\ broken)} =$ +3980 [1]

(ii) Calculate the enthalpy change which occurs when all the bonds in the products shown in the above equation are formed [3]

$4 \times H-O = -4 \times 464 = -1856$ [1]

$4 \times C-O = -4 \times 736 = -2944$ [1]

$\Delta H = \Sigma BE_{(bonds\ formed)} = -4800$ kJ [1]

(iii) Hence, calculate the enthalpy change for the complete combustion of ethanal as shown in the equation above [2]

$\Delta H_{rxn} = \Sigma BE_{(bonds\ broken)} + \Sigma BE_{(bonds\ formed)}$ [1]

$\Delta H_{rxn} = 3980 + (-4800)$

$\Delta H_{rxn} = -820$ kJ [1]

(b) The ***standard enthalpy of formation*** (ΔH_f^0) is the heat change that results when one mole of a compound is formed from its elements in their standard states.

(i) Write the equation for standard enthalpy of formation (ΔH_f^0) of calcium hydroxide, $Ca(OH)_2(s)$ [3]

$Ca(s) + H_2(g) + O_2(g) \rightarrow Ca(OH)_2(s)$ 3

(ii) Calculate the enthalpy of formation (ΔH_f^0) of calcium hydroxide, $Ca(OH)_2(s)$ using the following balanced thermochemical equations [12]

(i) $H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H^0 = +286$ kJ

(ii) $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$ $\Delta H^0 = -64$ kJ

(iii) $Ca(s) + \frac{1}{2}O_2(g)$ 'n $CaO(s)$ $\Delta H^0 = -634$ kJ

- *Reverse equation* (i) $H_2(g) + \frac{1}{2}O_2(g)$ 'n $H_2O(l)$ $\Delta H^0 = -286$ kJ [3]
- *Take equation* (ii) *as it is* $CaO(s) + H_2O(l)$ 'n $Ca(OH)_2(s)$ $\Delta H^0 = -64$ kJ [3]
- *Take equation* (iii) *as it is* $Ca(s) + \frac{1}{2}O_2(g)$ 'n $CaO(s)$ $\Delta H^0 = -634$ kJ [3]
- Add the equations $Ca(s) + H_2(g) + O_2(g) \rightarrow Ca(OH)_2(s)$ $\Delta H_f^0 = -984$ kJ [3]

QUESTION 2. ATOMIC STRUCTURE AND PERIODICITY [25 MARKS]

(a) Fill each blank space with an appropriate word in the sentences that follow. [5]

(i) Which form of electromagnetic radiation has the longest wavelengths?

(ii) How many unpaired electrons are in the orbital notation for the Fe^{3+} ion?

(iii) According to Heisenberg's uncertainty principle, if one attempts simultaneously to measure the position and momentum of an electron, the more exactly the position is measured, the greater will be the_____in the momentum measurement.

(iv) The maximum number of electrons that can be accommodated in a sublevel for which $l = 3$ is_____.

(v) The ground state electron configuration for arsenic is_____.

ANSWERS:

(i) Radio Waves
(ii) 5
(iii) Error
(iv) 14
(v) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^3$

(b)

(i) A line in the spectrum of atomic mercury has a wavelength of 254 nm. When mercury emits a photon of light at this wavelength, what is the frequency of the light? [3]

Ans:

We have the equation $C = \vartheta \times \lambda$

$\lambda = 254$ nm, $C = 3 \times 10^8$ m/s, $\vartheta = ?$

$\vartheta = C/\lambda$ $\quad \frac{3 \times 10^8}{2.54 \times^{10-7}} S^{-1} = 1.181 \times 10^{15} S^{-1} = 1.181 \times 10^{15}$ Hz

Note: Equation: 1Mark; Derivation: 1Marks; Answer: 1 Mark

(ii) Why is it much harder to explain the line spectra of polyelectronic atoms and ions than it is to explain the line spectra of hydrogen and hydrogen-like ions? [2]

Ans: For hydrogen and hydrogen-like (one electron) ions, all orbitals with the same value of n have the same energy. For polyatomic atoms/ ions, the energy of the orbitals also depends on the value of angular momentum (l). Because there are more nondegenerate energy levels for polyatomic atoms/ions as compared with hydrogen, there are many more possible electronic transitions resulting in more

complicated line spectra.

(c)

(i) How many orbitals in an atom can have the designation 5p, $3dz^2$, 4d, n = 5, n = 4? [2.5]

5p= 3; $3dz^2$ = 1; 4d = 5; n = 5= 25; n =4 = 16

(ii) Complete the following table using your knowledge of isotopes and ions. [2.5]

Ans:

(S.No.	Symbol ${}^{A}_{Z}X$	Atomic Number	Mass Number	Number of Electrons	Number of Protons	Number of Neutrons
I	${}^{109}_{47}Ag$	47	109	47	47	62

Note: Each answer carries 0.5 Mark

(d)

(i) Give two examples of elements for each category. [4]

a) Noble gases
b) Halogens
c) Alkali metals
d) Alkaline earth metals

Ans: He; Ne; Ar; Kr; Xe; Rn --- Nobel gases
F; Cl; Br; I, At; Ts ------ Halogens
Li; Na; K; Rb; Cs; Fr ------ Alkali metals
Be; Mg; Ca; Sr; Ba; Ra ------- Alkaline earth metals

Note: Any two examples from above answer. Each answer carries 0.5 Mark

(ii) Compare the following elements with respect to the characteristics listed below: [1]

a. Sodium b. Boron c. Aluminum d. Carbon

Which has the largest atomic radius_____.

Which has the largest Ionization energy _____.

Ans: A & D

Note: Each answer carries 0.5 Mark

(e)

(i) Which elements are most likely to undergo the same kinds of reactions, those in a group or those in a period? Explain your answer. [2]

Ans: Elements are arranged in groups (vertical columns) based on their physical and chemical characteristics. So, those in the same family/group will share the same kinds of reactions.

(ii) This group of the periodic table contains highly reactive nonmetal. Give your answer with correct reason. [2]

Ans: The halogens are group 7 and are the most highly reactive nonmetals since they have 7 valence electrons.

(iii) Among copper, chromium, chlorine and sodium, which one is p-block element? [1]

Ans: Chlorine

QUESTION 3. CHEMICAL BONDING & MOLECULAR GEOMETRY [25 MARKS]

(a) Two elements *X* and *Y* occur in the same period and their atoms have two and seven valence electrons respectively. Write down the electronic structure of the most probable compound between *X* and *Y*. Will the bond between *X* and *Y* be predominantly ionic or covalent?

Answer: XY_2; Ionic [2]

(b) Predict the geometry of the following molecules using VSEPR theory. [3]

(i) CCl_4
(ii) $AlCl_3$
(iii) H_2Se

Answer: (i)Tetrahedral (ii) Trigonal planar (iii) Bent

(c) Classify the bonds in the following as ionic, polar covalent or covalent: [3]

(i) HCl
(ii) NaCl
(iii) NCl_3

Answer: HCl - Polar covalent, NaCl - Ionic and NCl_3 – Covalent

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

Answer: Tetrahedral, Trigonal pyramid and Bent

(e) Use the following data to estimate ΔH_f° for potassium chloride. [4]

$K(s) + \frac{1}{2}Cl_2 \rightarrow KCl(s)$

Lattice energy: -690 kJ/mol
Ionization energy for K: 419 kJ/mol
Electron Affinity of Cl: -349 kJ/mol
Bond energy of Cl_2: 239 kJ/mol
Enthalpy of sublimation for K: 64 kJ/mol

Answer:

Sublimation of K(s): $K(s) \rightarrow K(g)$ $\Delta H_1 = 64$ kJ

Ionization of K(g): $K(g) \rightarrow K^+(g) + e^-$ $\Delta H_2 = 419$kJ

Bond breaking of $\frac{1}{2}Cl_2$: $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$ $\Delta H_3 = 239/2 = 119.5$kJ

Electron Affinity of Cl: $Cl(g) + e^- \rightarrow Cl^-(g)$ $\Delta H_4 = -349$ kJ

Lattice energy: $K^+(g) + Cl^-(g) \rightarrow NaCl(s)$ $\Delta H_5 = -690$ kJ

$\Delta H_f^\circ = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$

$H_f^\circ = 64 + 419 + 119.5 + (-349) + (-690)$

$H_f^\circ = -436.5$ kJ/mol

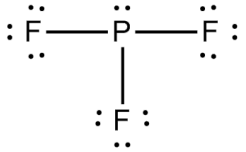
(f) For each of the following molecules: PF_3 and $COCl_2$:

(i) Draw the Lewis Structure. [2]
(ii) Determine the geometry of the molecule. [2]
(iii) Sketch the molecule to show the dipoles. [2]
(iv) Indicate if the molecule is polar or non polar. [2]

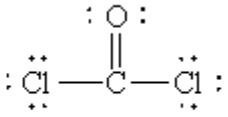
(v) Determine the number of lone pairs of electrons on each atom. [2]

Answer:

(i) Structure for PF_3



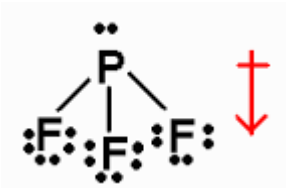
Structure of $COCl_2$



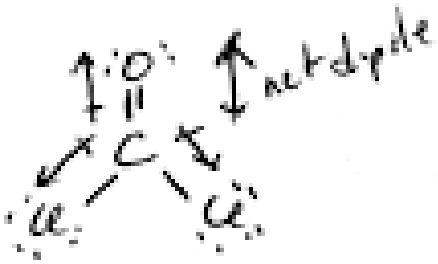
(ii) PF_3: Trigonal pyramidal

$COCl_2$: Trigonal planar

(iii) Sketch for PF_3



Sketch for $COCl_2$



(iv) PF_3: Polar

$COCl_2$: Polar

(v) PF_3: one pair

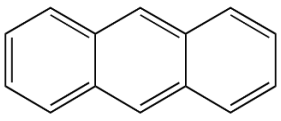
$COCl_2$: zero pair

QUESTION 4. ORGANIC CHEMISTRY [25 MARKS]

(a) How many carbon-carbon sigma bonds are present in each of the following molecules? [3]

(i) 2-butyne,

(ii) anthracene (that is, three fused benzene rings in a straight line), as shown below



(iii) 2,3-dimethylpentane

Answer: Source - Chung Question 24.50

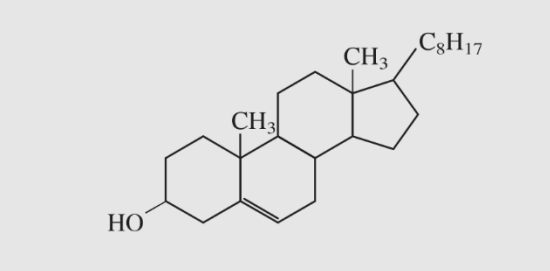
(i) The butyne structure is $CH_3 - C \equiv C - CH_3$ has 3 carbon-carbon sigma bonds.[1]

(ii) The anthracene structure given above in (ii) has 16 carbon-carbon sigma bonds [1]

(iii) The structure of 2,3-dimethylpentane given below has 6 carbon-carbon sigma bonds

$CH_3 - CH(CH_3) - CH(CH_3) - CH_2 - CH_3$ [1]

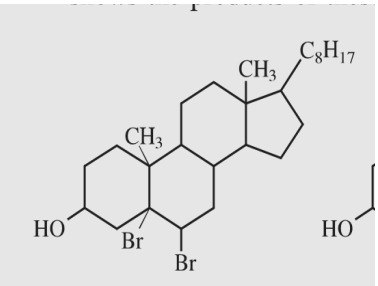
(b) Cholesterol is a major component of gallstones, and it is believed that the cholesterol level in the blood is a contributing factor in certain types of heart disease. From the following structure of the compound, predict its reaction with (a) Br_2, (b) H_2 (in the presence of a Pt catalyst), (c) CH_3COOH [8]



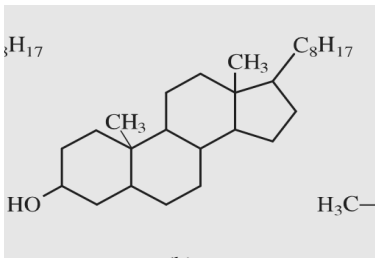
Answer: Source - Chung Example 24.5

There are two functional groups in cholesterol: the hydroxyl group and the carbon-carbon double bond. [2]

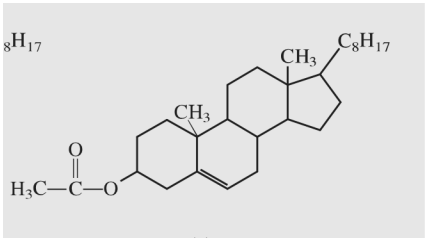
(i) The reaction with bromine results in the addition of bromine to the double-bonded carbons, which become single-bonded [1] as shown in the figure below [1]



(ii) This is a hydrogenation reaction. Again, the carbon-carbon double bond is converted to a carbon-carbon single bond. [1] as shown in the figure below [1]



(iii) The acid reacts with the hydroxyl group to form an ester and water [1] as shown in the figure below [1]



(c) Classify each of the following molecules according to their functional groups [7]

(i) $CH_3 - O - CH_2 - CH_3$ Ether

(ii) $CH_3 - CH_2 - NH_2$ Amine

(iii) $CH_3 - CH_2 - CHO$ Aldehyde

(iv) $CH_3 - CO - CH_2 - CH_3$ Ketone

(v) HCO_2H Carboxylic acid

(vi) $CH_3 - CH_2 - CH_2 - OH$ Alcohol

(vii) Ph - CH_2 - $CH(NH_2)CO_2H$ (where Ph is phenyl group) Amino acid

Answer: Source - Chung Question 24.36 [1 mark each answer]

(d) Discuss how you can determine compounds might be alkanes, cycloalkanes, alkenes, or alkynes, without drawing their formulas: (i) C_6H_{12}, (ii) C_4H_6, (iii) C_5H_{12}, (iv) C_7H_{14}, (v) C_3H_4 [5]

Answer – Source Chung Question 24.16

No.	½ mark per cell	
	General formula	Compound class
(i)	C_nH_{2n}	Alkene or cycloalkane

(ii)	C_nH_{2n-2}	Alkyne
(iii)	C_nH_{2n+2}	Alkane
(iv)	Like (i)	Alkene or cycloalkane
(v)	Like (ii)	Alkyne

(e) State whether it is true or false that the molecule I - CBr_2 - CH_2 - CH_3 is chiral? [1] Justify your answer [1]

Answer: Source - Chung

False [1]. It has no asymmetric carbon atom, that is, a carbon atom bonded to four different functional groups. [1]

TABLE OF FUNDAMENTAL CONSTANTS

Average Bond Energy of selected covalent bonds	
Bond	Bond Energy ($kJ\ mol^{-1}$)
N ≡ N	944
H – H	436
C – H	413
C – C	347
C = O	7360
O = O	4980
O – H	464

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 8.314 47 8.205 74 6.236 37	 10^{-2} 10^{-2} 10	$J\ K^{-1}\ mol^{-1}$ $L\ bar\ K^{-1}\ mol^{-1}$ $L\ atm\ K^{-1}\ mol^{-1}$ $L\ Torr\ K^{-1}\ mol^{-1}$
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 = $1.01325 \times 10^{5}\ Nm^{-2}$ = 1.01325×10^{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 **Nh** (284)	114 **Fl** (289)	115 **Mc** (288)	116 **Lv** (291)	117 **Ts** (Unknown)	118 **Og** (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)