UNIVERSITI TEKNOLOGI PETRONAS

# FINAL EXAMINATION
# MAY 2024 SEMESTER

| | | |
|---|---|---|
| **COURSE** | : | **YBB1013 - INORGANIC CHEMISTRY I** |
| **DATE** | : | **9 AUGUST 2024 (FRIDAY)** |
| **TIME** | : | **9:00 AM - 12:00 NOON (3 HOURS)** |

## INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

**Note** :

i. There are **NINE (9)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. An atom $X$ has four electrons in its valence orbitals, and the electrons have the following set of quantum numbers:

$$n = 5, l = 1, m_l = -1, m_s = +\tfrac{1}{2}$$
$$n = 5, l = 1, m_l = 0, m_s = +\tfrac{1}{2}$$
$$n = 5, l = 1, m_l = +1, m_s = +\tfrac{1}{2}$$
$$n = 5, l = 1, m_l = -1, m_s = -\tfrac{1}{2}$$

i. Write the ground state electronic configuration for atom $X$.

[2 marks]

ii. Calculate the $Z_{eff}$ values difference between one of the valence electrons from **part (a)(i)** and an electron in atom $X$ with the following set of quantum numbers:

$$n = 4, l = 2, m_l = -2, m_s = +\tfrac{1}{2}$$

[5 marks]

b. Use Slater's rules to evaluate the following two possible electronic configurations for zirconium: [Kr]$5s^2\,4d^2$ and [Kr]$4d^4$. Choose the correct electronic configuration for zirconium and justify your answer.

[6 marks]

c. By using the Molecular Orbital theory, arrange the following molecule and ions in the order of increasing bond length. Justify your answers.

$$P_2^-,\quad P_2,\quad PS^-$$

[7 marks]

2. Consider the following molecules and ions:

| $Sr_2^+$ | CO | $OBr^-$ | HF | $NH_3$ |
|---|---|---|---|---|
| **I** | **II** | **III** | **IV** | **V** |

a. By using the Molecular Orbital theory, predict the existence of chemical formulas **I**, **II** and **III**. Justify your answers.

[8 marks]

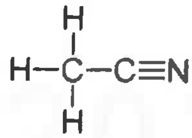
b. Compare the LUMO for molecules **II** and **III** by sketching their molecular orbital interactions. Label your diagrams.

[4 marks]

c. Based on the Molecular Orbital theory, differentiate the Molecular Orbital energy level diagrams for the diatomic molecule **IV** and polyatomic molecule **V** and show that the MO diagram for HF is consistent with its Lewis structure. Justify your answers.

[8 marks]

3. Consider the following molecules:

| | | | | |
|---|---|---|---|---|
| $CCl_2Br_2$ | $PCl_3F_2$ | $H_2C{=}CH_2$ | $SF_5H$ |  |
| **I** | **II** | **III** | **IV** | **V** |

a. Determine the geometries and draw the possible isomers of molecules **I** and **II**, if any, using perspective drawing.

[4 marks]

b. Determine the total number of planes of symmetry in **I** and **III** and illustrate your answers.

[4 marks]

c. Identify principal rotational axis for molecule **V** and sketch the axis to illustrate your answer.

[2 marks]

d. Determine **ALL** the symmetry elements and point group for molecule **IV**.

[4 marks]

e. If one of the hydrogens in acetonitrile (structure **V**) is replaced with a chlorine atom, describe the bonding in the molecule **V** by using the Valence Bond theory and the hybridization concept. Assume all atoms except hydrogen are hybridized. Draw and label the atomic orbitals and the hybrid orbitals to explain your answers.

[6 marks]

4. a. Given the following data in **TABLE Q4**, determine which metal has the higher density. Justify your answer by using calculation.

**TABLE Q4**

| **Metal** | **Rb** | **Ag** |
|---|---|---|
| Unit cell | BCC | FCC |
| Edge length, *a* | 0.562 nm | 0.409 nm |

[6 marks]

b. **FIGURE Q4** shows the unit cell of a crystalline solid with the stoichiometry of $M_xF_y$ where M is a metal and F is fluorine. Determine the values of **x** and **y**.

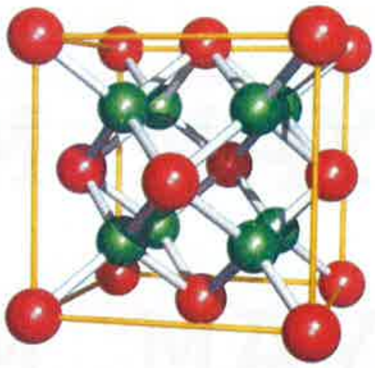


**FIGURE Q4**: $M_xF_y$ unit cell (M – red, F – green)

[4 marks]

c. Solids of $CaI_2$ and LiBr adopt cadmium iodide and sodium chloride crystal structures, respectively. By using the Born-Landé equation and data available in Appendices, determine which solid is most likely to possess covalent character in its bonding. Show your calculations clearly to justify your answer.

[10 marks]

5. a. Potassium metal and potassium chloride exist in a solid state at room temperature. Differentiate the type of bonding that exists in each of these solids.

[4 marks]

b. Oxygen-20 undergoes beta ($\beta^-$) emission while curium-243 decays by alpha ($\alpha$) emission. Write the nuclear equation for each of these changes and determine which nuclear reaction exhibits greater neutron-to-proton ratio change before and after nuclear reaction.

[6 marks]

c. A radioactive nuclide $\boldsymbol{A}$ undergoes a series of nuclear reactions according to scheme of $\alpha$, $\varepsilon$, $\beta^+$ to form nuclide $\boldsymbol{B}$. If the mass number and the atomic number of nuclide $\boldsymbol{B}$ are 170 and 69, respectively, determine nuclide $\boldsymbol{A}$. Show all the nuclear equations to justify your answer.

[6 marks]

d. Explain **TWO (2)** major differences between nuclear reactions and chemical reactions.

[4 marks]

-END OF PAPER-

## APPENDIX I (PERIODIC TABLE)

B = Solids   Hg = Liquids   Kr = Gases   Pm = Not found in nature

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 1.00794 | | | | | | | | | | | | | | | | | 2 He 4.002602 |
| 3 Li 6.941 | 4 Be 9.012182 | | | | | | | | | | | 5 B 10.811 | C 12.0107 | 7 N 14.00674 | 8 O 15.9994 | 9 F 18.9984032 | 10 Ne 20.1797 |
| 11 Na 22.989770 | 12 Mg 24.3050 | | | | | | | | | | | 13 Al 26.581538 | 14 Si 28.0855 | 15 P 30.973761 | 16 S 32.066 | 17 Cl 35.4527 | 18 Ar 39.948 |
| 19 K 39.0983 | 20 Ca 40.078 | 21 Sc 44.955910 | 22 Ti 47.867 | 23 V 50.9415 | 24 Cr 51.9961 | 25 Mn 54.938049 | 26 Fe 55.845 | 27 Co 58.933200 | 28 Ni 58.6534 | 29 Cu 63.545 | 30 Zn 65.39 | 31 Ga 69.723 | 32 Ge 72.61 | 33 As 74.92160 | 34 Se 78.96 | 35 Br 79.504 | 36 Kr 83.80 |
| 37 Rb 85.4678 | 38 Sr 87.62 | 39 Y 88.90585 | 40 Zr 91.224 | 41 Nb 92.90638 | 42 Mo 95.94 | 43 Tc (98) | 44 Ru 101.07 | 45 Rh 102.90550 | 46 Pd 106.42 | 47 Ag 107.87 | 48 Cd 112.411 | 49 In 114.818 | 50 Sn 118.710 | 51 Sb 121.760 | 52 Te 127.60 | 53 I 126.90447 | 54 Xe 131.29 |
| 55 Cs 132.90545 | 56 Ba 137.327 | 71 Lu 174.967 | 72 Hf 178.49 | 73 Ta 180.94.79 | 74 W 183.84 | 75 Re 186.207 | 76 Os 190.23 | 77 Ir 192.217 | 78 Pt 195.078 | 79 Au 196.56655 | 80 Hg 200.59 | 81 Tl 204.3833 | 82 Pb 207.2 | 83 Bi 208.58038 | 84 Po (209) | 85 At (210) | 86 Rn (222) |
| 87 Fr (223) | 88 Ra (226) | 103 Lr (262) | 104 Rf (261) | 105 Db (262) | 106 Sg (263) | 107 Bh (262) | 108 Hs (265) | 109 Mt (266) | 110 Ds (269) | 111 Rg (272) | 112 Cn (277) | 113 Uut (277) | 114 Uuq (277) | 115 Uup (277) | 116 Uuh (277) | | 118 Uuo (277) |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La 138.9055 | 58 Ce 140.116 | 59 Pr 140.50765 | 60 Nd 144.24 | 61 Pm (145) | 62 Sm 150.36 | 63 Eu 151.964 | 64 Gd 157.25 | 65 Tb 158.92534 | 66 Dy 162.50 | 67 Ho 164.93032 | 68 Er 167.26 | 69 Tm 168.93421 | 70 Yb 173.04 |
| 89 Ac 232.0381 | 90 Th 232.0381 | 91 Pa 231.03588 | 92 U 238.0289 | 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) |

## APPENDIX II (LIST OF ELEMENTS)

| Name | Symbol | Atomic number | Atomic weight | Name | Symbol | Atomic number | Atomic weight |
|---|---|---|---|---|---|---|---|
| actinium | Ac | 89 | 227.03[a] | mendelevium | Md | 101 | 258.10[a] |
| aluminium | Al | 13 | 26.98 | mercury | Hg | 80 | 200.59 |
| americium | Am | 95 | 243.06[a] | molybdenum | Mo | 42 | 95.94 |
| antimony | Sb | 51 | 121.75 | neodymium | Nd | 60 | 144.24 |
| argon | Ar | 18 | 39.95 | neon | Ne | 10 | 20.18 |
| arsenic | As | 33 | 74.92 | neptunium | Np | 93 | 237.05[a] |
| astatine | At | 85 | 209.99[a] | nickel | Ni | 28 | 58.69 |
| barium | Ba | 56 | 137.33 | niobium | Nb | 41 | 92.91 |
| berkelium | Bk | 97 | 247.07[a] | nitrogen | N | 7 | 14.01 |
| beryllium | Be | 4 | 9.01 | nobelium | No | 102 | 259.10[a] |
| bismuth | Bi | 83 | 208.98 | osmium | Os | 76 | 190.23 |
| bohrium | Bh | 107 | 264.12[a] | oxygen | O | 8 | 16.00 |
| boron | B | 5 | 10.81 | palladium | Pd | 46 | 106.40 |
| bromine | Br | 35 | 79.90 | phosphorus | P | 15 | 30.97 |
| cadmium | Cd | 48 | 112.41 | platinum | Pt | 78 | 195.08 |
| calcium | Ca | 20 | 40.08 | plutonium | Pu | 94 | 244.06[a] |
| californium | Cf | 98 | 251.08[a] | polonium | Po | 84 | 208.98[a] |
| carbon | C | 6 | 12.01 | potassium | K | 19 | 39.10 |
| cerium | Ce | 58 | 140.12 | praseodymium | Pr | 59 | 140.91 |
| caesium | Cs | 55 | 132.91 | promethium | Pm | 61 | 145.00[a] |
| chlorine | Cl | 17 | 35.45 | protactinium | Pa | 91 | 231.04 |
| chromium | Cr | 24 | 52.00 | radium | Ra | 88 | 226.03[a] |
| cobalt | Co | 27 | 58.93 | radon | Rn | 86 | 222.02[a] |
| copper | Cu | 29 | 63.55 | rhenium | Re | 75 | 186.21 |
| curium | Cm | 96 | 247.07[a] | rhodium | Rh | 45 | 102.91 |
| dubnium | Db | 105 | 262.11[a] | rubidium | Rb | 37 | 85.47 |
| dysprosium | Dy | 66 | 162.50 | ruthenium | Ru | 44 | 101.07 |
| einsteinium | Es | 99 | 252.08[a] | rutherfordium | Rf | 104 | 261.11[a] |
| erbium | Er | 68 | 167.26 | samarium | Sm | 62 | 150.35 |
| europium | Eu | 63 | 151.96 | scandium | Sc | 21 | 44.96 |
| fermium | Fm | 100 | 257.10[a] | seaborgium | Sg | 106 | 266.00[a] |
| fluorine | F | 9 | 19.00 | selenium | Se | 34 | 78.96 |
| francium | Fr | 87 | 223.02[a] | silicon | Si | 14 | 28.09 |
| gadolinium | Gd | 64 | 157.25 | silver | Ag | 47 | 107.87 |
| gallium | Ga | 31 | 69.72 | sodium | Na | 11 | 23.00 |
| germanium | Ge | 32 | 72.61 | strontium | Sr | 38 | 87.62 |
| gold | Au | 79 | 196.97 | sulfur | S | 16 | 32.07 |
| hafnium | Hf | 72 | 178.49 | tantalum | Ta | 73 | 180.95 |
| hassium | Hs | 108 | 269.13[a] | technetium | Tc | 43 | 98.00[a] |
| helium | He | 2 | 4.00 | tellurium | Te | 52 | 127.60 |
| holmium | Ho | 67 | 164.93 | terbium | Tb | 65 | 158.93 |
| hydrogen | H | 1 | 1.01 | thallium | Tl | 81 | 204.37 |
| indium | In | 49 | 114.82 | thorium | Th | 90 | 232.04 |
| iodine | I | 53 | 126.90 | thulium | Tm | 69 | 168.93 |
| iridium | Ir | 77 | 192.22 | tin | Sn | 50 | 118.71 |
| iron | Fe | 26 | 55.85 | titanium | Ti | 22 | 47.90 |
| krypton | Kr | 36 | 83.80 | tungsten | W | 74 | 183.84 |
| lanthanum | La | 57 | 138.91 | uranium | U | 92 | 238.03 |
| lawrencium | Lr | 103 | 262.11[a] | vanadium | V | 23 | 50.94 |
| lead | Pb | 82 | 207.19 | xenon | Xe | 54 | 131.30 |
| lithium | Li | 3 | 6.94 | ytterbium | Yb | 70 | 173.04 |
| lutetium | Lu | 71 | 174.97 | yttrium | Y | 39 | 88.91 |
| magnesium | Mg | 12 | 24.31 | zinc | Zn | 30 | 65.39 |
| manganese | Mn | 25 | 54.94 | zirconium | Zr | 40 | 91.22 |
| meitnerium | Mt | 109 | 268.14[a] | | | | |

## APPENDIX III (CONSTANT VALUES)

| | |
|---|---|
| $\Delta U(0\,\mathrm{K}) = -\dfrac{LA\lvert z_+\rvert\lvert z_-\rvert e^2}{4\pi\varepsilon_0 r_0}\left(1-\dfrac{1}{n}\right)$ | Born-Landé Equation |

| **TABLE 1**: Constants | |
|---|---|
| L ($N_A$) | $6.022 \times 10^{23}$ |
| $e$ | $1.602 \times 10^{-19}$ C |
| $\varepsilon_0$ | $8.854 \times 10^{-12}$ Fm$^{-1}$ |
| | |

| **TABLE 2**: Ionic radius (pm) | |
|---|---|
| $r$ ($Ca^{2+}$) | 114 |
| $r$ ($Li^{+}$) | 60 |
| $r$ ($Br^{-}$) | 196 |
| $r$ ($I^{-}$) | 220 |

**TABLE 3**: Value of the Born exponent, $n$, givan for an ionic compound MX in term of the electronic configuration of the ion $[M^+][X^-]$.

| Electronic configuration of the ions in an ionic compound MX | Examples of ions | $n$ (no units) |
|---|---|---|
| [He][He] | $H^-$, $Li^+$ | 5 |
| [Ne][Ne] | $F^-$, $O^{2-}$, $Na^+$, $Mg^{2+}$ | 7 |
| [Ar][Ar], or [3$d^{10}$][Ar] | $Cl^-$, $S^{2-}$, $K^+$, $Ca^{2+}$, $Cu^+$ | 9 |
| [Kr][Kr], or [4$d^{10}$][Kr] | $Br^-$, $Rb^+$, $Sr^{2+}$, $Ag^+$ | 10 |
| [Xe][Xe], or [5$d^{10}$][Xe] | $I^-$, $Cs^+$, $Ba^{2+}$, $Au^+$ | 12 |

**TABLE 4**: Madelung constants, $A$, for selected structure types.

| **Structure type** | **$A$ (no unit)** |
|---|---|
| Sodium chloride (NaCl) | 1.7476 |
| Caesium chloride (CsCl) | 1.7627 |
| Wurtzite ($\alpha$-ZnS) | 1.6413 |
| Zinc blende ($\beta$-ZnS) | 1.6381 |
| Fluorite ($CaF_2$) | 2.5194 |
| Rutile ($TiO_2$) | 2.408 |
| Cadmium iodide ($CdI_2$) | 2.355 |

**TABLE 5**: Lattice energy determined using the Born-Haber cycle (kJ.mol$^{-1}$)

| | |
|---|---|
| $CaI_2$ | –2056 |
| LiBr | –818 |