# UNIVERSITY OF SWAZILAND

FINAL EXAMINATION

ACADEMIC YEAR 2017/2018

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TITLE OF PAPER: Atomic Structure, Chemical Bonding and Chemistry of s- and p-Block Elements

COURSE CODE: CHE221

TIME ALLOWED: THREE (3) HOURS

INSTRUCTIONS:

1. There are six (6) questions. Answer any four (4) questions. Each question is worth 25 marks.
2. Begin the solution to each question on a new page

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A periodic table and a table of constants have been provided with this examination paper.

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**Question One**

a) Calculate the energies of the n=1 and n=2 states of the hydrogen atom in joules per atom and in kilojoules per mole. What is the difference in energy ($\Delta E$) of the two states in J/atom? Calculate the wavelength, $\lambda$, (in nanometers) that corresponds to $\Delta E$. **[8]**

b) In fireworks displays, Mg is oxidized by $KClO_4$ giving rise to white flashes. One product of the reaction is KCl. Write a balanced equation for the reaction. **[2]**

c) Given that the angular function of an orbital is proportional to $\cos^2\theta$, determine the orientation of the orbital.

**[15]**

**Question Two**

a) Manganese is found as $MnO_2$ in deep ocean deposits.

(i) Depict the electron configuration of this element using the noble gas notation and an orbital box diagram
(ii) Using an orbital gas diagram, show the valence electrons for $Mn^{4+}$.
(iii) Is $Mn^{4+}$ paramagnetic? Explain your answer.

**[5]**

b) Answer the questions below about the elements A and B, which have the ground state electron configurations shown.

A = $[Kr]5s^2$ B = $[Kr]4d^{10}5s^25p^5$

i) Is element A a metal, nonmetal or metalloid? What about element B?
ii) Which element has the greater ionization energy?
iii) Which element has a larger ionization energy?
iv) Which element has the more negative electron attachment enthalpy?
v) Which is more likely to form a cation?
vi) Which is a likely formula for a compound formed between A and B?

**[8]**

c) Calculate the effective nuclear charge, Z*, for an outermost electron in atoms O, F and Ne. Relate Z* values to the expected trend in their relative atomic radii and first ionization energies.

[12]

**Question Three**

a) For each of the molecules or ions below, draw a Lewis structure and determine the formal charge on each atom. [4]

i) $NO_2^+$ ii) $N_2H_4$

b) Draw Lewis structures for each of the following molecules or ions. Describe the **electron pair geometry**, **molecular geometry** and the nature of **hybridization** around the central atom.

i) $ClF_3$ ii) $ClF_5$ [10]

c) Consider the molecular species $N_2$, $N_2^+$ and $N_2^-$. Using molecular orbital theory, compare these species with regard to their i) magnetic properties, ii) bond orders, and iii) bond lengths and bond strengths.

[11]

**Question Four**

a) Ethanol, $CH_3CH_2OH$, and dimethyl ether, $CH_3OCH_3$, have the same molecular formula but a different arrangement of atoms. Predict which of these compounds has the higher boiling point. Use suitable diagrams to illustrate your answer. [4]

b) Give a sketch of the Born-Haber cycle for the formation of $Al_2O_3(s)$ from its constituent elements in their standard states. [8]

c) Silicon and carbon have the same solid-state crystal structure. However, diamond is an insulator and silicon is a semiconductor. Explain why there is a difference. [3]

d) Aluminum has a density of 2.699 g/cm$^3$, and the atoms are placed in a face-centered cubic crystal lattice. What is the radius of an aluminium atom? [10]

### Question Five

a) Give the formulas and Lewis structures of nitrogen oxides corresponding to the oxidation states +II, +III, +IV and +V. **[10]**

b) One way to prevent any $SO_2$ from reaching the atmosphere is to scrub the exhaust gases with slaked lime, $Ca(OH)_2$, followed by oxidation of the resulting sulphite to sulphate. Give the balanced reactions involved in the process. **[3]**

c) Give balanced chemical equations depicting the reactions of oxides with water to form the following acids:

i) $H_3PO_4$ ii) $HNO_3$ iii) $H_2SO_4$ iV) $H_2CO_3$

**[12]**

### Question Six

a) Consider the halides $BCl_3$, $AlCl_3$, $CCl_4$, $SiCl_4$, $SnCl_4$, $PbCl_4$.

i) Name each of the halides
ii) Briefly describe the chemical reactions, if any, which take place when these halides are mixed with water. If appropriate, each case should be accompanied by a balanced chemical reaction.

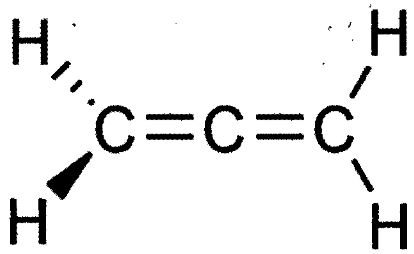
**[14]**

b) Aluminium and beryllium are examples of two elements that exhibit a diagonal similarity relationship. Two of their similarities are that they form similar carbides and that both of their oxides are amphoteric. Illustrate the two similarities by giving balanced reactions for the following processes:

i) Reactions of carbides of Be and Al with water
ii) Reactions of oxides Be and Al with an aqueous solution of sodium hydroxide

**[8]**

c) With the help of suitable diagram, illustrate how pi-type atomic orbitals overlap to form two adjacent pi bonds in the allene molecule, whose structre is shown below.




**[3]**

# PERIODIC TABLE OF THE ELEMENTS

## GROUPS

| PERIODS | 1 IA | 2 IIA | 3 IIIB | 4 IVB | 5 VB | 6 VIB | 7 VIIB | 8 VIII | 9 VIII | 10 VIII | 11 IB | 12 IIB | 13 IIIA | 14 IVA | 15 VA | 16 VIA | 17 VIIA | 18 VIIIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.008 H 1 | | | | | | | | | | | | | | | | | 4.003 He 2 |
| 2 | 6.941 Li 3 | 9.012 Be 4 | | | | | | | | | | | 10.811 B 5 | 12.011 C 6 | 14.007 N 7 | 15.999 O 8 | 18.998 F 9 | 20.180 Ne 10 |
| 3 | 22.990 Na 11 | 24.305 Mg 12 | TRANSITION ELEMENTS | | | | | | | | | | 26.982 Al 13 | 28.0855 Si 14 | 30.9738 P 15 | 32.06 S 16 | 35.453 Cl 17 | 39.948 Ar 18 |
| 4 | 39.0983 K 19 | 40.078 Ca 20 | 44.956 Sc 21 | 47.88 Ti 22 | 50.9415 V 23 | 51.996 Cr 24 | 54.938 Mn 25 | 55.847 Fe 26 | 58.933 Co 27 | 58.69 Ni 28 | 63.546 Cu 29 | 65.39 Zn 30 | 69.723 Ga 31 | 72.61 Ge 32 | 74.922 As 33 | 78.96 Se 34 | 79.904 Br 35 | 83.80 Kr 36 |
| 5 | 85.468 Rb 37 | 87.62 Sr 38 | 88.906 Y 39 | 91.224 Zr 40 | 92.9064 Nb 41 | 95.94 Mo 42 | 98.907 Tc 43 | 101.07 Ru 44 | 102.906 Rh 45 | 106.42 Pd 46 | 107.868 Ag 47 | 112.41 Cd 48 | 114.82 In 49 | 118.71 Sn 50 | 121.75 Sb 51 | 127.60 Te 52 | 126.904 I 53 | 131.29 Xe 54 |
| 6 | 132.905 Cs 55 | 137.33 Ba 56 | 138.906 *La 57 | 178.49 Hf 72 | 180.948 Ta 73 | 183.85 W 74 | 186.207 Re 75 | 190.2 Os 76 | 192.22 Ir 77 | 195.08 Pt 78 | 196.967 Au 79 | 200.59 Hg 80 | 204.383 Tl 81 | 207.2 Pb 82 | 208.980 Bi 83 | (209) Po 84 | (210) At 85 | (222) Rn 86 |
| 7 | (223) Fr 87 | 226.025 Ra 88 | (227) **Ac 89 | (261) Rf 104 | (262) Ha 105 | (263) Unh 106 | (262) Uns 107 | (265) Uno 108 | (266) Une 109 | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide series | 140.115 Ce 58 | 140.908 Pr 59 | 144.24 Nd 60 | (145) Pm 61 | 150.36 Sm 62 | 151.96 Eu 63 | 157.25 Gd 64 | 158.925 Tb 65 | 162.50 Dy 66 | 164.930 Ho 67 | 167.26 Er 68 | 168.934 Tm 69 | 173.04 Yb 70 | 174.967 Lu 71 |
| ** Actinide series | 232.038 Th 90 | 231.036 Pa 91 | 238.029 U 92 | 237.048 Np 93 | (244) Pu 94 | (243) Am 95 | (247) Cm 96 | (247) Bk 97 | (251) Cf 98 | (252) Es 99 | (257) Fm 100 | (258) Md 101 | (259) No 102 | (260) Lr 103 |

Numbers below the symbol of the element indicates the atomic numbers. Atomic masses, above the symbol of the element, are based on the assigned relative atomic mass of $^{12}C$ = exactly 12; ( ) indicates the mass number of the isotope with the longest half-life.

SOURCE: International Union of Pure and Applied Chemistry, I. Mills, ed., *Quantities, Units, and Symbols in Physical Chemistry*, Blackwell Scientific Publications, Boston, 1988, pp 86-98.

## Fundamental Physical Constants (six significant figures)

| | |
|---|---|
| Avogadro's number | $N_A$ = $6.02214 \times 10^{23}$/mol |
| atomic mass unit | amu = $1.66054 \times 10^{-27}$ kg |
| charge of the electron (or proton) | $e$ = $1.60218 \times 10^{-19}$ C |
| Faraday constant | $F$ = $9.64853 \times 10^{4}$ C/mol |
| mass of the electron | $m_e$ = $9.10939 \times 10^{-31}$ kg |
| mass of the neutron | $m_n$ = $1.67493 \times 10^{-27}$ kg |
| mass of the proton | $m_p$ = $1.67262 \times 10^{-27}$ kg |
| Planck's constant | $h$ = $6.62607 \times 10^{-34}$ J·s |
| speed of light in a vacuum | $c$ = $2.99792 \times 10^{8}$ m/s |
| standard acceleration of gravity | $g$ = 9.80665 m/s$^2$ |
| universal gas constant | $R$ = 8.31447 J/(mol·K) |
| | = $8.20578 \times 10^{-2}$ (atm·L)/(mol·K) |

# Rydberg constant = $1.097 \times 10^{7}$ m$^{-1}$

## SI Unit Prefixes

| p | n | μ | m | c | d | k | M | G |
|---|---|---|---|---|---|---|---|---|
| pico- | nano- | micro- | milli- | centi- | deci- | kilo- | mega- | giga- |
| $10^{-12}$ | $10^{-9}$ | $10^{-6}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ | $10^{3}$ | $10^{6}$ | $10^{9}$ |

## Conversions and Relationships

### Length
**SI unit: meter, m**

1 km = 1000 m
= 0.62 mile (mi)
1 inch (in) = 2.54 cm
1 m = 1.094 yards (yd)
1 pm = $10^{-12}$ m = 0.01 Å

### Volume
**SI unit: cubic meter, m$^3$**

1 dm$^3$ = $10^{-3}$ m$^3$
= 1 liter (L)
= 1.057 quarts (qt)
1 cm$^3$ = 1 mL
1 m$^3$ = 35.3 ft$^3$

### Pressure
**SI unit: pascal, Pa**

1 Pa = 1 N/m$^2$
= 1 kg/m·s$^2$
1 atm = $1.01325 \times 10^{5}$ Pa
= 760 torr
1 bar = $1 \times 10^{5}$ Pa

### Mass
**SI unit: kilogram, kg**

1 kg = $10^3$ g
= 2.205 lb
1 metric ton (t) = $10^3$ kg

### Energy
**SI unit: joule, J**

1 J = 1 kg·m$^2$/s$^2$
= 1 coulomb·volt (1 C·V)
1 cal = 4.184 J
1 eV = $1.602 \times 10^{-19}$ J

### Math relationships

$\pi = 3.1416$
volume of sphere = $\frac{4}{3}\pi r^3$
volume of cylinder = $\pi r^2 h$

### Temperature
**SI unit: kelvin, K**

0 K = −273.15°C
mp of $H_2O$ = 0°C (273.15 K)
bp of $H_2O$ = 100°C (373.15 K)
$T$ (K) = $T$ (°C) + 273.15
$T$ (°C) = [$T$ (°F) − 32]$\frac{5}{9}$
$T$ (°F) = $\frac{9}{5}T$ (°C) + 32