COPPERBELT UNIVERSITY

CHEMISTRY DEPATMENT

CH110/CH120/FO130– GENERAL CHEMISITRY – 2015/2016

Question 1 – Electromagnetic Radiation

a) Quanta and Photons[2]

(i) Give the three primary characteristics of waves and give the expression of their mathematical relationship and the units of each variable [5]. Zumdahland Zumdahl, 9th Edition –pp 324

ANSWER:

Wavelength, frequency and speed [1]. $c = \lambda \times \nu$ **[1] where c is the speed of light (** $3.00 \times 10^{8} ms^{-1}$ **) [1],** λ **is the wavelength in metres [1] and** ν **is frequency in Hertz (or** s^{-1}**) [1]**

(ii) Strontium salts such as $Sr(NO_3)_2$ and $SrCO_3$ when heated emit light with wavelength around 650 nm. What colour is this light and what is its frequency? [4]. Zumdahland Zumdahl, 9th Edition –pp 324.

ANSWER:

Red light [1]. Its frequency, from the relation $c = \lambda \times \nu$ **[1] is** $\lambda = \frac{3.00\times10^{8}}{6.50\times10^{-7}} = 4.62 \times 10^{14} Hz$ **[2]**

(iii) State the postulate that Planck made during his study of electromagnetic radiation profiles emitted by solid bodies heated to incandescence [1]. Write the mathematical expression of the postulate and clearly explain the meaning of each variable in the formula to the point of giving its units [7]Zumdahl and Zumdahl, 9th Edition, pp. 324

ANSWER:

Planck's postulate: In atomic oscillations or vibrations of hot incandescence bodies, energy can be gained or lost in whole number multiples of the quantity hv [2], that is, change in energy for a system ΔE **is represented by the equation** $\Delta E = nhv$ **[1] where** n **is an integer (1, 2, 3, …) [1] is Planck's constant (**$h = 6.63 \times 10^{-34} J \cdot s$**) [1] and** ν **is frequency in** $s^{-1} or\ Hz$ **of the electromagnetic**

radiation absorbed or emitted during atomic oscillations [1]. The units of ΔE is J [1]

(iv) In summary, Planck's observation is that energy occurs in ……….[1] called …………[1] and we energy is ………[1] Zumdahl and Zumdahl, 9th Edition, pp. 325

ANSWER:

Discrete units [1] called quanta [1] and we said energy is quantized [1]

b) Photoelectric Effect [2]

(i) Einstein during his study of the photoelectric effect called each discrete particle of light energy a …………[1]. Zumdahl and Zumdahl, 9th Edition, pp. 327.

ANSWER:

Photon [1]

(ii) Explain what is meant by the photoelectric effect. [2]Zumdahl and Zumdahl, 9th Edition pp. 327.

ANSWER:

The photoelectric effect refers to thephenomenon in which electrons are emitted from the surface of a metal when light strikes it. [2]

(iii) Give the mathematical relationship of kinetic energy of a photoelectron to the incident light particle in the photoelectric effect with a clear explanation of the terms of the equation [4]Zumdahl and Zumdahl, 9th Edition, pp. 328.

ANSWER:

$$\mathrm{KE}_{\text{electron}} = \tfrac{1}{2}mv^2 = h\nu - h\nu_0$$

Mass of electron | Velocity of electron | Energy of incident photon | Energy required to remove electron from metal's surface

(iv) From Einstein's theory of general relativity, give the relation for the apparent mass of a photon. [2]Zumdahl and Zumdahl, 9th Edition, pp. 328.

ANSWER:

$\boldsymbol{m = \frac{E}{c^2}}$ **[1] where E is the energy [½] and c is the speed of light [½]**

(v) At the conclusion of the study of the photoelectric effect, the phenomenon of the **dual** *nature of light* was demonstrated. Explain what is meant by this phenomenon. [1]Zumdahl and Zumdahl, 9th Edition, pp. 328.

ANSWER:

Light exhibits both wave properties and shows certain characteristics of particulate matter as well [1].

(vi) Who was the scientist who postulated that *matter has adual nature?* [1] Write the mathematical he formulated alongside his postulate? [2] Zumdahl and Zumdahl, 9th Edition, pp. 329.

ANSWER:

Louis de Broglie [1]. The equation he formulated is $\lambda = \frac{h}{mv}$ [½] where is Planck's constant [½], mv is momentum of the particle of matter [½] and is the wavelength of the matter wave of the particle [½].

(vii) Who was the scientist who postulated that *matter has adual nature?* [1] Write the mathematical he formulated alongside his postulate? [2] Zumdahl and Zumdahl, 9th Edition, pp. 329.

ANSWER:

Louis de Broglie [1]. The equation he formulated is $\lambda = \frac{h}{mv}$ [½] where h is Planck's constant [½], mv is momentum of the particle of matter [½] and is the wavelength of the matter wave of the particle [½].

(viii) A particle has a velocity that is 90.% of the speed of light. If the wavelength of the particle is 1.5 3 10215 m, calculate the mass of the particle [3] Zumdahl and Zumdahl, 9th Edition, Question 7.55 pp. 369.

ANSWER:

Using the de Broglie equation,$\lambda = \frac{h}{mv}$[1] where Planck's constant is$h = 6.63 \times 10^{-34} J \cdot s$, mass of a neutron is$m = 1.675 \times 10^{-27} kg$ [½] and velocity of the neutron is $v = 0.9c = 0.9 \times 3.00 \times 10^{8} ms^{-1}$ [½]. Thus, $\lambda = \frac{6.63\times10^{-34}}{1.65\times10^{-27}\times2.70^{8}} m = 1.49 \times 10^{-15} m$[1].

c) Atomic Spectrum of Hydrogen [2]

(ix) The hydrogen emission spectrum is called ……….[1]. Zumdahl and Zumdahl, 9th Edition, pp. 331.

ANSWER:

Line spectrum [1]

(x) What is the significance of the line spectrum of a hydrogenic atom[2]Zumdahl and Zumdahl, 9th Edition, pp. 369,

ANSWER:

It indicates that only certain energies are allowed for the electron in the hydrogen atom [2]

(xi) Calculate the longest and shortest wavelength of light emitted by electrons in the hydrogen atom that begin in the n=6 state and then fall into states with small values of n. [10]Zumdahl and Zumdahl, 9th Edition, Question 7.61 pp. 369.

(i)

ANSWER:

There are two equations for solving this problem, the first one is of energy emitted or absorbed by an electron $\Delta E = hv = \frac{hc}{\lambda}$ so that the wavelength of the emitted/absorbed radiation is $\lambda = \frac{hc}{\Delta E}$ [1]. Since h and c are constants, so that solving for the wavelength requires the value of ΔE. This calls for the use of Bohr's equation relating the energy levels that electron transitions and the emitted energy.

Thus, the second equation, enabling us get ΔE is $\Delta E = A\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ [1] where $A = 2.18 \times 10^{-18} J$ and $n_2 = 6$ and n_1 is the lower energy level to which the electron transitions to. The transition giving the longest wavelength is electron goes to the lower energy level $n_1 = 5$ while that giving the shortest wavelength is for electron energy level $n_1 = 1$.

The table below gives the values for the calculations

n_1	$\Delta E = A\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = A\left(\frac{n_2^2 - n_1^2}{n_1^2 \times n_2^2}\right)$	$\lambda = \frac{hc}{\Delta E}$
5	$\Delta E = 2.18 \times 10^{-18} J\left(\frac{36-25}{25 \times 36}\right)$ $\Delta E = 2.18 \times 10^{-18} J\left(\frac{11}{900}\right)$ $= 2.66 \times 10^{-20} J$ [2]	$\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{2.66 \times 10^{-20}} m$ $\lambda = \frac{19.89 \times 10^{-26}}{2.66 \times 10^{-20}}$ $= 7.47 \times 10^{-6} m$ **or 7.47 µm** [2]
1	$\Delta E = 2.18 \times 10^{-18} J\left(\frac{36-1}{1 \times 36}\right)$ $\Delta E = 2.18 \times 10^{-18} J\left(\frac{35}{36}\right) = 2.12 \times 10^{-18} J$ [2]	$\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{2.12 \times 10^{-18}} m$ $\lambda = \frac{19.89 \times 10^{-26}}{2.12 \times 10^{-18}}$ $= 9.38 \times 10^{-8} m$ **or 93.8 nm** [2]

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d) Wavelike properties of electrons [2]

(i) Who was the scientist who postulated that *matter has adual nature?* [1] Write the mathematical he formulated alongside his postulate? [2] Zumdahl and Zumdahl, 9th Edition, pp. 329.

ANSWER:

Louis de Broglie [1]. The equation he formulated is $\lambda = \frac{h}{mv}$ [½] where is Planck's constant [½], mv is momentum of the particle of matter [½] and is the wavelength of the matter wave of the particle [½].

(ii) Who was the scientist who postulated that *matter has adual nature?* [1] Write the mathematical he formulated alongside his postulate? [2] Zumdahl and Zumdahl, 9th Edition, pp. 329.

ANSWER:

Louis de Broglie [1]. The equation he formulated is $\lambda = \frac{h}{mv}$ [½] where h is Planck's constant [½], mv is momentum of the particle of matter [½] and is the wavelength of the matter wave of the particle [½].

(iii) A particle has a velocity that is 90% of the speed of light. If the wavelength of the particle is 1.5×10^{-15} m, calculate the mass of the particle [3] Zumdahl and Zumdahl, 9th Edition, Question 7.55 pp. 369, Question 7.55.

ANSWER:

Using the modified de Broglie equation, $m = \frac{h}{\lambda v}$ [1] where Planck's constant is $h = 6.63 \times 10^{-34} J \cdot s$, wavelength of a neutron is $\lambda = 1.5 \times 10^{-15} m$ [½] and velocity of the neutron is $v = 0.9c = 0.9 \times 3.00 \times 10^{8} ms^{-1}$ [½]. Thus, $\lambda = \frac{6.63\times10^{-34}}{1.5\times10^{-15}\times2.7\times10^{8}} m = 1.64 \times 10^{-27} kg$ [1].

(iv) Neutron diffraction is used in determining the structures of molecules. Calculate the de Broglie wavelength of a neutron moving at 1.00% of the speed of light. [3] Calculate the velocity of a neutron with a wavelength of 75 pm ($1\ pm = 10^{-12}$ m) [3]. Zumdahl and Zumdahl, 9th Edition, Question 7.54 pp. 369.

ANSWER:

Using the de Broglie equation, $\lambda = \frac{h}{mv}$ [1] where Planck's constant is $h = 6.63 \times 10^{-34} J \cdot s$, mass of a neutron is $m = 1.675 \times 10^{-27} kg$ [½] and velocity of the neutron is $v = 0.1c = 0.1 \times 3.00 \times 10^{8} ms^{-1}$ [½]. Thus, $\lambda = \frac{6.63\times10^{-34}}{1.675\times10^{-27}\times3.0\times10^{7}} m = 1.32 \times 10^{-14} m$ [1].

Using the modified de Broglie equation, $v = \frac{h}{m\lambda}$ **[1] where Planck's constant is** $h = 6.63 \times 10^{-34} J \cdot s$**, mass of a neutron is** $m = 1.675 \times 10^{-27} kg$ **[½] and wavelength of the neutron is** $\lambda = 7.50 \times 10^{-11} m$ **[½]. Thus,** $v = \frac{6.63\times10^{-34}}{1.675\times10^{-27}\times7.5\times10^{-11}} m = 5.28 \times 10^{3} ms^{-1}$ **[1].**

Question 2 – The Bohr Model of the atom

a) Distinguish between an orbit and an orbital of an atom [2]. Specify the scientists who formulated the concept of an atomic orbit and an atomic orbital, respectively. [2] What do we call the atomic model each of these scientists formulated. [2]

ANSWER:

Orbit – A circular path of an electron around a hydrogenic atom with a particular energy level. [1]

Orbital – A region of space where an electron is likely to be found in an atom. The region is characterised by a specific electron wave function. [1]

Concept of an atomic orbit was introduced by Neils Bohr in the Bohr Model of the atom [2] while the concept of orbital or electron wave function in an atom was introduced by Erwin Schrodinger in the Quantum Mechanical Model of an atom [2].

Question 3 – Quantum mechanical model of an atom

a) Quantum mechanics [2]

(i) What is the mathematical relation of the Heisenburg Uncertainty Principle? [2]Zumdahl and Zumdahl, 9th Edition, pp. 338.

ANSWER:

$$\Delta x \cdot \Delta(mv) \geq \frac{h}{4\pi}$$

Where Δx **is the position of the particle,** $\Delta(mv)$ **is the momentum of the particle and** h**is Planck's constant.**

(ii) State the Heisenberg Uncertainty Principle [2]Zumdahl and Zumdahl, 9th Edition, pp. 338.

ANSWER:

There is a fundamental limitation to just how precisely we can know both the position and momentum of a particle at a given time.

(iii) Fill in the space with one or two words in the two sentences that follow:

Applied to the electron, the Uncertainty Principle implies that ……………(1) the exact motion of an electron as it moves around the nucleus. It is therefore ………..(2) to assume that the electron is moving around the nucleus in a well defined ………..(3), as in the ………….(4) Model of an atom. [4]Zumdahl and Zumdahl, 9th Edition, pp. 338.

ANSWER:

(1) cannot know [1]

(2) not appropriate [1]

(3) orbit [1]

(4) Bohr [1]

b) Quantum numbers [2]

(i) Name the quantum numbers one gets by solving the Schrodinger equation for the hydrogen atom [3] Zumdahl and Zumdahl, 9th Edition, pp. 339.

ANSWER:

Principal quantum number, n

Angular momentum quantum number, l and

Magnetic quantum number, m_l

(ii) Which of the following sets of quantum numbers are notallowed? For each incorrect set, state why it is incorrect.Zumdahl and Zumdahl, 9th Edition, pp. 370. Question 7.74

a. $n = 3, \ell = 3, m_\ell = 0, m_s = -\frac{1}{2}$

b. $n = 4, \ell = 3, m_\ell = 2, m_s = -\frac{1}{2}$

c. $n = 4, \ell = 1, m_\ell = 1, m_s = +\frac{1}{2}$

d. $n = 2, \ell = 1, m_\ell = -1, m_s = -1$

e. $n = 5, \ell = -4, m_\ell = 2, m_s = +\frac{1}{2}$

f. $n = 3, \ell = 1, m_\ell = 2, m_s = -\frac{1}{2}$

ANSWER:

d. is not allowed because m_s can only be –½ or +½

e. is not allowed because l cannot take negative values.

f. is not allowed because m_l cannot be greater than l

c) Orbital shapes and energies [2]

(i) Explain what is meant by degenerate orbitals and the kind of atoms wherethey are found. [3] Zumdahl and Zumdahl, 9th Edition, pp. 345.

ANSWER:

These are orbitals with the same energy [1]. In a hydrogenic atom, all orbitals with the same shell are generate [1]. In polyelectronic atom, orbitals in the same subshell are degenerate [1].

(ii) Given the sublevels $E_{n_s}, E_{n_p}, E_{n_d}, E_{n_f}$ of a polyelectronic atom, state whether these are degenerate or not. If they are not degenerate, show how the quantum levels of the orbitals vary in energy. [2]Zumdahl and Zumdahl, 9th Edition, pp. 345.

ANSWER:

The levels are different sublevels belonging to the same shell of a polyelectronic atom. Such levels are not degenerate. [1] Their energy order is $\mathbf{E_{n_s} < E_{n_p} < E_{n_d} < E_{n_f}}$ **[1].**

d) Electron spin and Pauli principle [2]

(i) State the Pauli Exclusion Principle. Zumdahl and Zumdahl, 9th Edition, Glossary pp. 1147.

ANSWER:

In a given atom no two electrons can have the same set of four quant um numbers.

Xx

(ii)

e) Polyelectronic atoms-orbital energies [2]

(i) State the Hund's Rule. [2] Zumdahl and Zumdahl, 9th Edition, Glossary pp 1144.

ANSWER:

the lowest energy configuration for an atom is the one having the maximum number of unpaired electrons allowed by the Pauli Exclusion Principle in a particular set of degenerate orbitals, with a ll unpaired electrons having parallel spins.

Question 4 – Aufbau (building-up) principle

a) Electron configuration of atoms [3]

(i) State the Aufbau Principle [2]Zumdahl and Zumdahl, 9th Edition, Glossary, pp. 1139

ANSWER:

As protons are added one by one to the nucleus to build up the elements, electrons are similarly added to hydrogen-like orbitals.

b) Electron configuration of ions [4]

Question 5 – Periodic table revisited

a) Electronic structure of periodic table [3]

(i) Give the electron configuration of scandium (Sc), cadmium (Cd), Lanthanum (La) Francium (Fr). [4] Zumdahl and Zumdahl, 9th Edition, pp 352

Sc: $1s^22s^22p^63s^23p^64s^23d^1$ or $[Ar]4s^23d^1$

Cd: $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}$ or $[Kr]5s^24d^{10}$

La: $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^25d^1$ or $[Ar]6s^25d^1$

Fr: $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^{14}5d^{10}6p^67s^1$ or $[Rn]7s^1$

(ii) Complete the table of quantum numbers for the 3rd level of orbitals in the hydrogen atom [7]

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	m_l (magnetic quantum No.)	Number of orbitals	Max. No. of Electrons

ANSWER:

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	m_l (magnetic quantum No.)	Number of orbitals	Max. No. of Electrons
3	**0**	**3s**	**0**	**1**	**2**
	1	**3p**	**-1, 0, 1**	**3**	**6**
	2	**3d**	**-2, -1, 0, 1, 2**	**5**	**10**

(iii) From table in 5a(ii) above write the electronic configuration and name of the element with the first electron in sublevel [4.5]

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	Element with first electron in the sublevel		
			Electron configuration	Name element	Element group Name
3					

ANSWER:

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	Element with first electron in the sublevel		
			Electron configuration	**Name element**	**Element group Name**
3	**0**	**3s**	**$[Ne]3s^1$**	**Sodium (Na)**	**Alkali**
	1	**3p**	**$[Ne]3s^2 3p^1$**	**Aluminium (Al)**	**Group IIIA**
	2	**3d**	**$[Ar]4s^2 3d^1$**	**Scandium (Sc)**	**Transition metal**

(iv) From table in 5a(iii) above, use the electronic configuration identify and write the number of core and valence electrons of the element with the first electron in sublevel [3]

n	l (angular	Sublevel	Element with first electron in the

(principal quantum No.)	mom. quantum No.)	designation	sublevel		
			Electron configuration	No. of core electrons	No. of valence electrons
3					

ANSWER:

n (principal quantum No.)	**l (angular mom. quantum No.)**	**Sublevel designation**	**Element with first electron in the sublevel**		
			Electron configuration	**No. of core electrons**	**No. of valence electrons**
3	**0**	**3s**	**[Ne]$3s^1$**	**10**	**1**
	1	**3p**	**[Ne]$3s^23p^1$**	**10**	**3**
	2	**3d**	**[Ar]$4s^23d^1$**	**18**	**3**

(v) What is meant by valence electrons and core electrons of an atom? Use an aluminium atom as an example to explain these concepts. [4]
ANSWER:
Valence electrons are the electrons in the outermost principle quantum level of an atom [1], e.g. $3s^23p^1$ electrons of an aluminium atom in the shell n=3 are valence electrons.[1]
Core electrons are electrons in the inner quantum levels of an atom [1] e.g. $1s^22s^22p^6$ electrons of aluminium in the shells n=1 and n=2 are core electrons. These have a noble electron configuration. [1]

(vi) Complete the following two statements on a group and a period of the periodic table using concepts of atomic structure [2]
Elements in the same group (vertical column) of the periodic table have the same …….. (1) electron configuration.
Elements in the same block (or subshell) in the period (horizontal row) of the periodic table have the same …………. quantum number
ANSWER:
(1) Valence
(2) Principal

(vi) Complete the table of quantum numbers for the 4th level of orbitals in the hydrogen atom [10.5]

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	m_l (magnetic quantum No.)	Number of orbitals	Max. No. of Electrons

ANSWER:

n (principal quantum No.)	**l (angular mom. quantum No.)**	**Sublevel designation**	**m_l (magnetic quantum No.)**	**Number of orbitals**	**Max. No. of Electrons**
4	**0**	**4s**	**0**	**1**	**2**
	1	**4p**	**-1, 0, 1**	**3**	**6**
	2	**4d**	**-2, -1, 0, 1, 2**	**5**	**10**
	3	**4f**	**-3, -2, -1, 0, 1, 2, 3**	**7**	**14**

(vii) From table in 5a(vi) above write the electronic configuration and name of the element with the first electron in sublevel [6]

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	Element with first electron in the sublevel		
			Electron configuration	Name element	Element group Name
4					

ANSWER:

n (principal quantum No.)	**l (angular mom. quantum No.)**	**Sublevel designation**	**Element with first electron in the sublevel**		
			Electron configuration	**Name element**	**Element group Name**
4	**0**	**4s**	**[Ar]$4s^1$**	**Potassium (K)**	**Alkali**
	1	**4p**	**[Ar]$4s^23d^{10}4p^1$**	**Gallium (Ga)**	**Group IIIA**
	2	**4d**	**[Kr]$4s^23d^1$**	**Yttrium (Y)**	**Transition metal**
	3	**4f**	**[Xe]$5s^25d^14f^1$**	**Cerrium (Ce)**	**Lanthanide**

(viii) From table in 5a(vii) above, use the electronic configuration identify and write the number of core and valence electrons of the element with the first electron in sublevel [4]

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	Element with first electron in the sublevel		
			Electron configuration	No. of core electrons	No. of valence electrons
4					

ANSWER:

n (principal quantum No.)	l (angular mom. quantum No.)	Sublevel designation	Element with first electron in the sublevel		
			Electron configuration	**No. of core electrons**	**No. of valence electrons**
4	**0**	**4s**	**$[Ar]4s^1$**	**18**	**1**
	1	**4p**	**$[Ar]4s^23d^{10}4p^1$**	**18**	**13**
	2	**4d**	**$[Kr]5s^23d^1$**	**36**	**3**
	3	**4f**	**$[Xe]6s^25d^14f^1$**	**54**	**4**

<u>Question 6 – Periodic trends in atomic properties</u>

a) Atomic radius [1]

(i) Arrange the following groups of atoms in order of increasing size. Zumdahl and Zumdahl, 9th Edition, Question 7.105, pp. 372

a. Te, S, Se.

b. K, Br, Ni

c. Ba, Si, Fe

ANSWER:

a. S, Se, Te.

b. K, Ni, Br.

c. Si, Fe, Ba

(ii) Ionic radius [2]

(i) Predict the trend in the radius of following ions. Zumdahl and Zumdahl, 9th Edition, Question 7.105, pp. 372

(iii) Ionisation energies [5]

(iv) Electron affinity [x]

<u>Question 7 – Periodic table and chemistry</u>

a) Alkali metals [6]

b) Metals, non-metals and metalloids [4]

c) Halogens [3]

d) Noble gases [3]