MODULE 2 STRUCTURE OF THE NUCLEUS AND ELECTRONIC CONFIGURATION

UNIT 1 MAGNETIC MOMENT (OR MAGNETIC DIPOLE MOMENT)

CONTENTS

1.0 INTRODUCTION

In this unit we would treat magnetic dipole moment and angular momentum.

2.0 A OBJECTIVE

At end of this unit you will be able to:

- explain what is meant by magnetic dipole moment and angular momentum.

2.0 B How to Study this Unit

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.

4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENT

3.1 Magnetic Moment

In Bohr's model of hydrogen atom, he says that electrons which are negatively charged revolve round the nucleus of an atom which is positively charged in certain allowed orbits. Therefore if a negative charge (i.e an electron) and a positive charge (i.e the nucleus) are kept apart from one another at a distance say r as shown in fig. 6 below

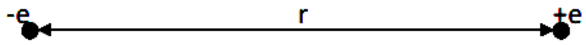


Fig. 6

This arrangement is called **an electric dipole moment or magnetic dipole moment or simply magnetic moment symbol μ.**

The magnitude of the dipole is given by multiplying the size of one of the charge q by the distance apart. i.e $\mu = q \times r$

3.2 Angular Momentum of an Atom

In Bohr's model of an atom, he says the allowed orbits are those for which the angular momentum of the electron is equal to an integral multiple of $\frac{h}{2\pi} = \hbar$.

i.e $L = mvr = n\hbar$. The quantity mv is called the momentum and r is the distance of the electron from the nucleus (or radius of the allowed orbit).
The product mv x r (i.e momentum times distance of the electron from the nucleus of an atom) is called the angular momentum of an atom.
Where m is the mass of the electron and v is the velocity of the electron round the nucleus.

The product mv x r is called the moment of momentum.

What is the Angular Momentum Quantum Number?

There are four quantum numbers that make up the address for an electron. Of the four quantum numbers, our focus for this lesson is the **angular momentum quantum number**, which is also known as the **secondary quantum number** or **azimuthal quantum number**.

The **angular momentum quantum number** is a quantum number that describes the *shape* of an orbital. We can think about it this way - for our homes, each one has its own architecture. In the subatomic level, the 'home' of electrons is an orbital, and each orbital has its own shape. The symbol that is used when we refer to the angular momentum quantum number is:

Symbol

ℓ

Electrons occupy a region called *shells* in an atom. The angular momentum quantum number, *l*, divides the shells into subshells, which are further divided into orbitals. Each value of *l* corresponds to a particular subshell. The lowest possible value for *l* is 0. The following table shows which subshells correspond to the angular momentum quantum number:

Angular Momentum Quantum Number, ℓ	Name of Subshell
0	s
1	p
2	d
3	f

The angular momentum quantum number can also tell us how many nodes there are in an orbital. A ***node*** is an area in an orbital where there is zero probability of finding electrons. *The value of l is equal to the number of nodes*. For example, for an orbital with an angular momentum of *l* = 3, there are 3 nodes.

Relationship with the Principal Quantum Number

It is important to point out that there is a relationship between the principal quantum number and the angular momentum quantum number. To recap, the **principal quantum number** tells us what principal shells the electrons occupy. It determines the energy level and size of the shell and uses the symbol *n* and is any positive integer.

In comparison, the **angular momentum quantum number** tells us which subshells are present in the principal shell. It also describes the shape of an orbital. Since it is a number, its values range from 0 to n-1 and cannot be greater than *n*. The following table shows the relationship between the two quantum numbers:

Principal Quantum Number, *n*	**Angular Momentum Quantum Number, ℓ** ℓ **= 0, 1, 2… n-1**	**Subshells**
1	$\ell = 0$	s (1 subshell)
2	$\ell = 0$ $\ell = 1$	s p (2 subshells)
3	$\ell = 0$ $\ell = 1$ $\ell = 2$	s p d (3 subshells)
4	$\ell = 0$ $\ell = 1$ $\ell = 2$ $\ell = 3$	s p d f (4 subshells)

We can think about the relationship between these two quantum numbers as this: The principal quantum number is the number of the floors, and the angular momentum quantum numbers are the rooms in each floor. The floor contains the rooms, and each room has its own unique appearance.

It is important to note that the value of *l* never exceeds *n* and its greatest value is equal to *n-1*. Let us go over a few examples to further understand this relationship.

Angular Momentum Basic Equation

In linear momentum we use the equation P = mv. The angular momentum equivalent is:

$$L = I\omega$$

Where L is angular momentum, I is the moment of inertia, and omega is the angular velocity. The angular velocity can be related to the linear velocity, v, if you know the radius, r, from the center of rotation by using the equation w = v/r. However, the moment of inertia for any object is determined by three factors: its mass, its shape, and the axis of rotation.

Sample Moments of Inertia

The moment of inertia of a point mass moving in a circle of radius r:

$$I = mr^2$$

The moment of inertia of a disc:

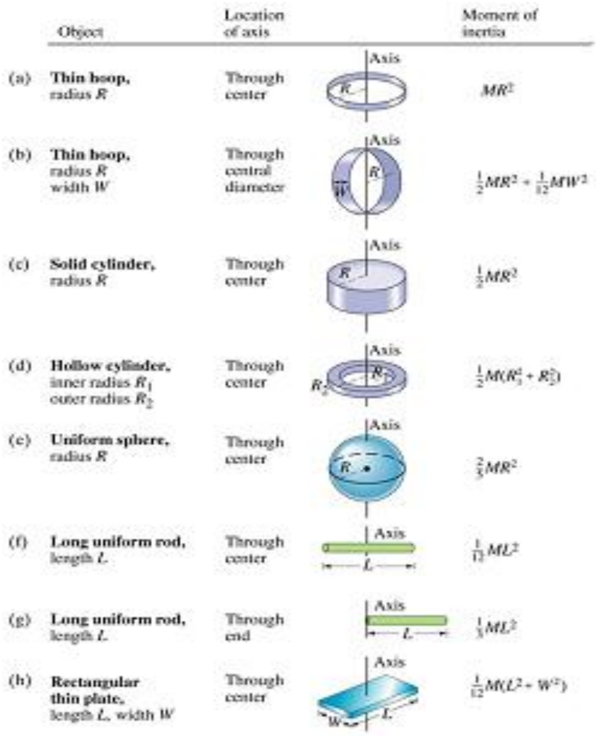
$$I = mr^2/2$$

The moment of inertia of a thin rod about its center:

$$I = mL^2/12$$

The moment of inertia of a thin rod about its end:

$$I = mL^2/3$$



Point Mass Problems

The easiest types of angular momentum problems are those that involve a **point mass** rotating around a center of axis. Examples of point mass problems can be anything from a ball on a string to planetary sized bodies. Using the linear momentum equation, and substituting in the moment of inertia of a rotating point mass, we get L = $m\ r\ v$. So, these problems depend on mass, radius, and linear velocity.

Activity 1

What is the angular momentum around the catcher of a baseball thrown at 40 m/s? The weight of the baseball is 145 grams and on a wild pitch the catcher has extended his arm 1.25 m from his center of rotation.

Solution

L = *m r v* = (.145 kg)(1.25 m)(40 m/s) = 7.25 kgm^2/s

Activity 2

A ball is rotating on a string 5 ft from the end of a hollow pipe with a linear velocity of 10 ft/s. The string continues down the pipe to the other end. What would the new linear velocity of the ball be if you pulled the string 3 ft, thereby shortening the turning radius of the ball?

Activity 3

By what percentage does the linear velocity of the Earth increase as it moves from its furthest distance away from the Sun to its closest approach? Perihelion (when Earth is closest to the Sun) = 91.4 million miles and Aphelion (when Earth is farthest from the Sun) = 94.5 million miles.

4.0 CONCLUSION

In this unit you have known what is magnetic dipole moment and the angular momentum of an atom.

5.0 Answer to Activities

Activity 2

Since linear momentum is conserved between the two states (as long as we ignore friction, the weight of the string and the diameter of the pipe) the new L and old L are going to be equal.

L(old) = L(new)

m r v (old) = *m r v* new)

m(5)(10) = *m*(5-3)(*v*)

The masses cancel out, leaving:

50 = 2v

v = 25 ft/s

Activity 3

Although it seems like a very different problem, we can use the very same approach as the ball on the string problem, above.

L(slow) = L(fast)

$m\ r\ v$ (slow) = $m\ r\ v$ (fast)

$m(94.5)(v) = m(91.4)(v)$

6.0 SUMMARY

Magnetic dipole moment is when two charges of equal magnitude but oppositely charge are separated by a distance, the product of one of the charge and the distance separating them is the dipole moment.

7.0 TUTORS MARKED ASSIGNMENTS

1. What is meant by a dipole moment?
2. Define angular momentum of an atom.

8.0 REFERENCES/FURTHER READINGS

Bueche, F. J. & Hecht, E. (2006). *College physics*. Schaum's Outline Series. New York: McGraw-Hill.

Duncan, T. (1982). *Physics. A textbook for Advanced Level Students*

Duncan, T. (2000), Advanced physics (5^{Th} edition). Hodder Murray.

Gautreau, R. & Savin, W. (1978). Theory and problems of modern Physics. Schaum's Outline Series.

Geddes, S. M. (1981). *Advanced physics*. London: Macmillan Education Ltd.

Gibbs, K (2011). *Advanced physics, 2^{nd} ed*. Cambridge: Cambridge University Pres

Halladay, Resnick & Walker, (2003), Fundamentals of Physics. Enhanced problems version (6^{TH} ed.).

http://web.sahra.arizona.edu/programs/isotopes/types/radioactive.html

IGNOU (2005). *Electricity and Magnetism Physics* PHE-07, New Delhi, India. London: John Murray (Publishers) Ltd..

McKenzie, A.E.E (1973). *A second course of electricity*. Cambridge: The University Press.

Philip, M. (1992), Advanced chemistry. Cambridge Low Price Editions.

Raymond A. S, Robert, J. B (2000), Physics For scientists and Engineers (5^{TH} edition),.Saunders College Publishing.

Vuille, C., Serway, R. A. & Faughn, J. S. (2009). *College physics*, 8^{th} ed. Belmont, USA: Brooks/Cole.

UNIT 2 ELECTRON SPIN

CONTENTS

1.0 INTRODUCTION

In this unit you will learn about the spin of the electron in an atom and the spin quantum number that are used to describe the property of an atom.

2.0A OBJECTIVES

At the end of this unit you will know the spin and the spin quantum number of an atom.

2.0 B How to Study this Unit:

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENT

3.1 Electronic Spin

Electronic spin is defined as the property of an electron which gives rise to its angular momentum about an axis within the electron.

Electrons have a magnetic field and behave like tiny bar magnets. When electric charges (or electrons) move round in a circle (around the nucleus) a magnetic field is set up. As electrons move round the nucleus of an atom, they also spin around their axes. The spin is used to describe their magnetic properties. The electrons have only two different spins, namely, spin up or spin down. The spin of an electron is described by the spin quantum number m_s.

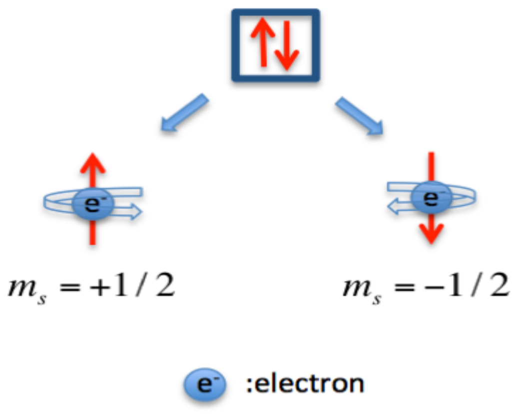
For spin up $m_s = +\frac{1}{2}$ (↑) or spin down $m_s = -\frac{1}{2}$ (↓)

3.2 Spin Quantum Number

Let's think about an electron in an atom; first, imagine a spinning top. A top can spin clockwise or counter-clockwise. In the same way, an electron occupying an orbital behaves like a spinning top.

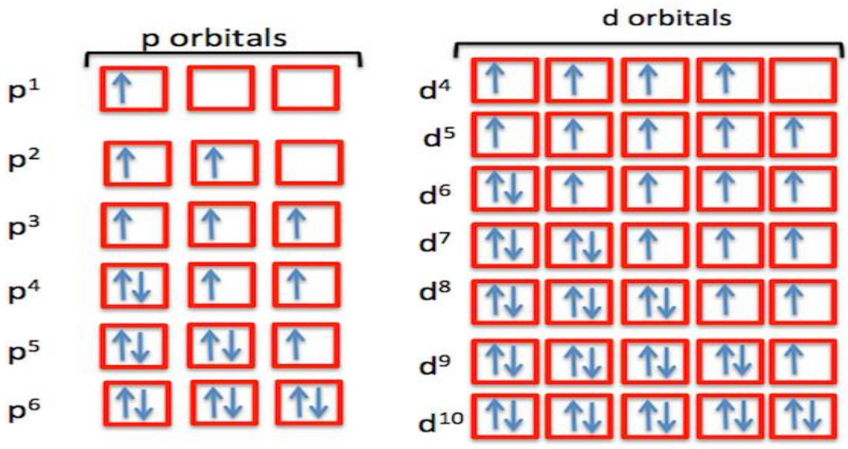
The spin quantum number, also known as the fourth quantum number, is a number value that describes the orientation of an electron occupying an orbital. The symbol that we will use for the spin quantum number is *ms*.

Let's visualize the spin quantum number. The value of *ms*=+1/2 is shown by an arrow pointing upwards and is also said to be spin up. The value of *ms*=-1/2 is shown by an arrow pointing downwards and is also said to be spin down.



How do electrons enter orbitals? This is important when determining the sign of *ms*. Electrons singly occupy orbitals first and then they pair up, as shown in the following illustration. Each box represents one orbital, and an orbital can only have a maximum number of two electrons.

There are three 'p' orbitals and on the left side, it is shown how the 'p' orbitals are filled. There are five 'd' orbitals and on the right side, it is shown how 'd; orbitals are filled as the number of electrons increase.

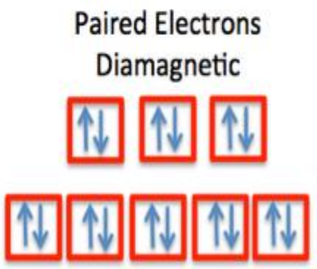


As we can see, in one orbital, the orientation of the two electrons are always the opposite of each other. One electron will be spin up, and the other electron is spin down. If the last electron that enters is spin up, then *ms* = +1/2. If the last electron that enters is spin down, then the *ms* = -1/2.

Paramagnetism and Diamagnetism

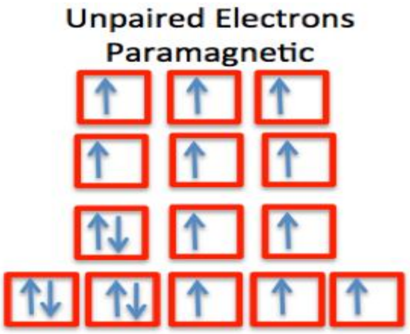
The spin of an electron makes it behave like a small magnet, in that the spin determines the magnetic property of an atom. Electrons are very small particles and their movement is limited. However, this movement still creates a small magnetic field.

For example, in an atom, all the electrons are paired in the orbitals. The spins, since they have values with opposite signs (+1/2 and -1/2), cancel each other out. We can therefore say that the atom is diamagnetic. Diamagnetic atoms have all of their electrons paired, and in each orbital, if you add their spins, the total will be zero, and they repel magnetic fields.



Now let's look at an atom that contains unpaired electrons in their orbitals. These unpaired electrons are alone in their orbitals.

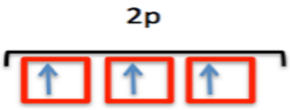
We can say therefore that these atoms with unpaired electrons are paramagnetic. Paramagnetic atoms have unpaired electrons, and they are attracted to a magnetic field. The electron in the orbital has a net spin, so the spins do not get cancel each other out. In effect, the whole atom will have a net spin.



Determining the Spin Quantum Number

Let's go over the following examples so that we can determine the value of the spin quantum number based on the information given in the question:

- Example 1: What is the correct value for *ms* for the last electron that enters the orbitals below? Is this atom paramagnetic or diamagnetic?



Answer: The correct value for *ms* = +1/2 since the last electron entering has a spin up orientation. None of the electrons are paired, so this shows that the atom is paramagnetic.

4.0 CONCLUSION

In this unit you have learnt about the electron spin and the spin quantum number of and electron in the atom.

5.0 SUMMARY

The spin of an electron in an atom can have a value of + ½ or - ½.
And the magnetic spin quantum number can be $m_s = +\frac{1}{2}$ or $m_s = -\frac{1}{2}$.

6.0 TUTORS MARKED ASSIGNMENT

1. What are the possible spins numbers of the in electron in an orbital?
2. What are the two possible directions which the spins can point at.

7.0 REFERENCES/FURTHER READING

Bueche, F. J. & Hecht, E. (2006). *College physics*. Schaum's Outline Series. New York: McGraw-Hill.

Duncan, T. (1982). *Physics. A textbook for Advanced Level Students*

Duncan, T. (2000), Advanced physics (5^{Th} edition). Hodder Murray.

Gautreau, R. & Savin, W. (1978). Theory and problems of modern Physics. Schaum's Outline Series.

Geddes, S. M. (1981). *Advanced physics*. London: Macmillan Education Ltd.

Gibbs, K (2011). *Advanced physics, 2^{nd} ed*. Cambridge: Cambridge University Pres

Halladay, Resnick & Walker, (2003), Fundamentals of Physics. Enhanced problems version (6^{TH} ed.).

http://web.sahra.arizona.edu/programs/isotopes/types/radioactive.html

IGNOU (2005). *Electricity and Magnetism Physics* PHE-07, New Delhi, India. London: John Murray (Publishers) Ltd..

McKenzie, A.E.E (1973). *A second course of electricity*. Cambridge: The University Press.

Philip, M. (1992), Advanced chemistry. Cambridge Low Price Editions.

Raymond A. S, Robert, J. B (2000), Physics For scientists and Engineers (5^{TH} edition),.Saunders College Publishing.

Vuille, C., Serway, R. A. & Faughn, J. S. (2009). *College physics*, 8^{th} ed. Belmont, USA: Brooks/Cole.

UNIT 3 PAULI EXCLUSION PRINCIPLE

CONTENTS

1.0 INTRODUCTION

In this unit you will learn the Pauli Exclusion Principle. The electronic configuration of elements and Hund's rule.

2.0 A OBJECTIVES

At the end of this unit, you should be able to know:

- The order which the electrons fill the orbital in an atom.
- Rules for filling orbitals
- Hund's rule
- How to write the electronic structure of element if the numbers of electrons are provided.

2.0 B How to Study this Unit:

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENT

3.1 Pauli Exclusion

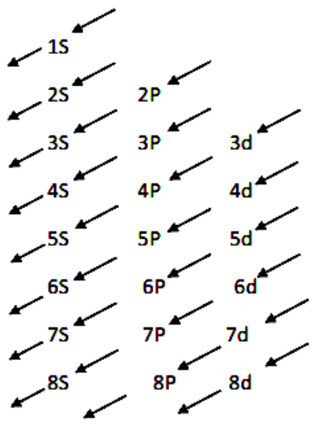
The Pauli exclusion states that when two electrons go into the same orbital, one electron has spin $m_s = +\,{}^1/_2$ and the other has $m_s = -\,{}^1/_2$. It is then said that their spins is paired. Pauli Exclusion Principle therefore states that ‘’it is impossible for two electrons with the same spin quantum number to be in the same orbit”.

3.2 Electronic Configuration

Is the orbital and spin arrangement of electrons in the atom, specifying the quantum numbers of the electrons in the atom in a given state. Also called electronic structure. These arrangements follow three rules:

1. Electrons go into orbital’s with the lowest energy.
2. The Pauli exclusion principle has two versions:
   i. It is impossible for two electrons with the same spin quantum number to be in the same orbital.
   ii. An orbital can contain a maximum of two electrons.
3. Hund’s rule: Electrons will fill a set of degenerate orbital by keeping their spin parallel.

The aufbau method is a way of building up electron structure using the above three rules. The summary of the aufbau method is shown below:



Following the arrows, the electronic structure for the first few elements are:

H = $1S^1$
He = $1S^2$
Li = $1S^2, 2S^1$
Be = $1S^2, 2S^2$
B = $1S^2, 2S^2, 2P^1$ and so on.

Example: Write down the electronic structure of:

i. Nickel, atomic number 28
ii. Zinc, atomic number 30

Solution

i. $1S^2$, $2S^2$, $2P^6$, $3S^2$, $3P^6$, $4S^2$, $3d^8$

ii. $1S^2$, $2S^2$, $2P^6$, $3S^2$, $3P^6$, $4S^2$, $3d^{10}$

4.0 CONCLUSION

In this unit you have learnt the filling of electrons in orbitals. Rules for filling the electrons in the orbitals. How to write the electronic structure of an element.

5.0 SUMMARY

- Electrons fill orbitals in the order: 1s, 2s, 2p, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, …………….
- Rules for filling orbitals:
  - i. As far as possible, electrons will go in the orbital with the lowest energy
  - ii. The Pauli exclusion principle says that: It is impossible for two electrons with the same spin quantum number to be in the same orbital.
  - iii. Hund's rule says that: Electrons will start to fill a set of degenerate orbitals keeping their spins parallel.
- Electrons structures are shown by writing down the list of orbitals with the number of electrons as a superscript. For example, the 11 electrons of sodium are arrange in the order $1s^2$, $2s^2$, $2p^6$, $3s^1$.

6.0 TUTORS MARKED ASSIGNMENT

Write down the electronic structure of:

1. Carbon, atomic number 6
2. Sodium, atomic number 11
3. Chromium, atomic number 24.

7.0 REFERENCES/FURTHER READING

Bueche, F. J. & Hecht, E. (2006). *College physics*. Schaum's Outline Series. New York: McGraw-Hill.

Duncan, T. (1982). *Physics. A textbook for Advanced Level Students*

Duncan, T. (2000), Advanced physics (5Th edition). Hodder Murray.

Gautreau, R. & Savin, W. (1978). Theory and problems of modern Physics. Schaum's Outline Series.

Geddes, S. M. (1981). *Advanced physics*. London: Macmillan Education Ltd.

Gibbs, K (2011). *Advanced physics, 2nd ed*. Cambridge: Cambridge University Pres

Halladay, Resnick & Walker, (2003), Fundamentals of Physics. Enhanced problems version (6TH ed.).

http://web.sahra.arizona.edu/programs/isotopes/types/radioactive.html

IGNOU (2005). *Electricity and Magnetism Physics* PHE-07, New Delhi, India. London: John Murray (Publishers) Ltd..

McKenzie, A.E.E (1973). *A second course of electricity*. Cambridge: The University Press.

Philip, M. (1992), Advanced chemistry. Cambridge Low Price Editions.

Raymond A. S, Robert, J. B (2000), Physics For scientists and Engineers (5TH edition),.Saunders College Publishing.

Vuille, C., Serway, R. A. & Faughn, J. S. (2009). *College physics*, 8th ed. Belmont, USA: Brooks/Cole.

UNIT 4 X – RAY SPECTRA

CONTENTS

1.0 INTRODUCTION

In this unit you will learn what are X – rays and how they are produced. You will also learn the energies and quality of X – rays produced.

2.0 A OBJECTIVES

At the end of this unit you would what are X –rays, how they are produced, the energy spectrum and quality of X – rays produced.

2.0 B How to Study this Unit:

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENT

3.1 Production of X – Ray

X – ray are high – energy photons that are produced when electrons jump (or make transition) from one atomic orbit to another. This transition occurs when photoelectric effect (or free electrons) of high energy (in order of thousands electro volt) penetrate deep into atoms and knock out electrons from deep energy levels.

The fall of electrons from higher energy levels into the gaps left by the knocked out electrons cause the emission of high energy X – rays. Another method of production of X – rays is when fast electrons are stopped by a metal target.

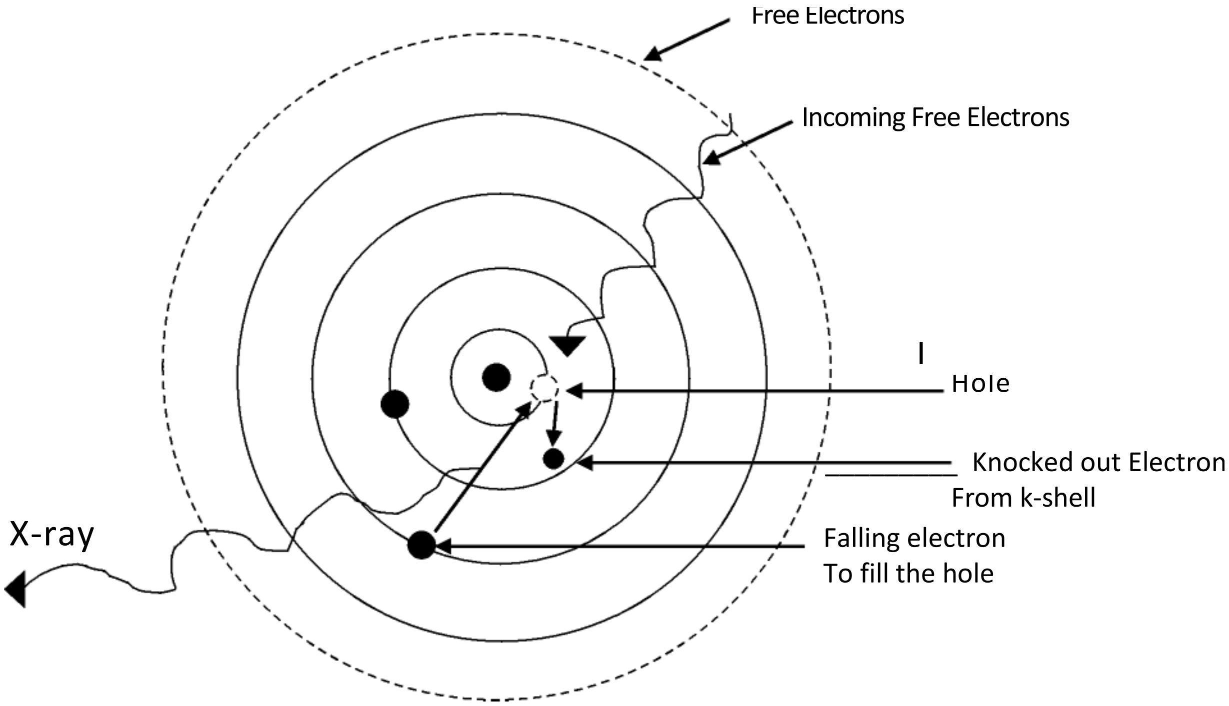


Fig. 7 X-ray production

3.2 X – Ray Spectra

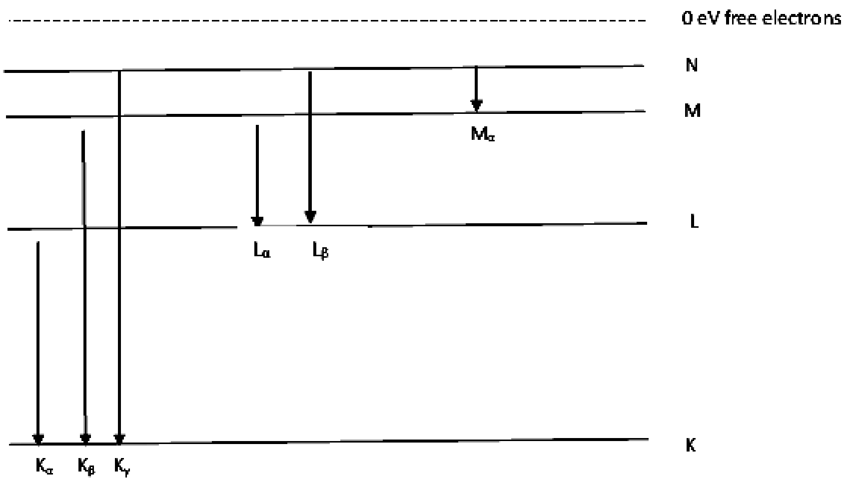


Fig. 8 X – ray spectra

K – Series X – ray are produced when an electron is knocked out of the lowest K – shell.

K_α are X – ray produced when electron from L – shell move in to fill the gap in K – shell.

Kβ are X – ray produced when the electron from M – shell move in to fill the gap in K – shell.

K_γ are X – ray produced when electrons from N – shell move in to fill the gap in K – shell.

The same for the L and M – series. Hence an X – ray spectra is formed.

4.0 CONCLUSION

In this unit you have learnt about X –rays, how they are produced, the energy spectra of X- rays and the quality of X –ray produced.

5.0 SUMMARY

- X –rays are produced due to electron transition from one orbital to another or when fast moving electron are stopped by a metal target.
- The energy and quality of X – rays produced depends on the energy level which the electrons transition takes place.

6.0 TUTORS MARKED ASSIGNMENT

1. Briefly describe the modes of X – rays production.
2. State two factors which the quality and energy of X – rays produced depend.

7.0 REFERENCES/FURTHER READING

Bueche, F. J. & Hecht, E. (2006). *College physics*. Schaum's Outline Series. New York: McGraw-Hill.

Duncan, T. (1982). *Physics. A textbook for Advanced Level Students*

Duncan, T. (2000), Advanced physics (5Th edition). Hodder Murray.

Gautreau, R. & Savin, W. (1978). Theory and problems of modern Physics. Schaum's Outline Series.

Geddes, S. M. (1981). *Advanced physics*. London: Macmillan Education Ltd.

Gibbs, K (2011). *Advanced physics, 2nd ed*. Cambridge: Cambridge University Pres

Halladay, Resnick & Walker, (2003), Fundamentals of Physics. Enhanced problems version (6TH ed.).

http://web.sahra.arizona.edu/programs/isotopes/types/radioactive.html

IGNOU (2005). *Electricity and Magnetism Physics* PHE-07, New Delhi, India.

London: John Murray (Publishers) Ltd..
McKenzie, A.E.E (1973). *A second course of electricity*. Cambridge: The University Press.
Nelkon & Parker (1995), Advance Level Physics (7TH ed). Heineman Educational Books Nigeria Ltd.
Philip, M. (1992), Advanced chemistry. Cambridge Low Price Editions.
Raymond A. S, Robert, J. B (2000), Physics For scientists and Engineers (5TH edition).Saunders College Publishing.
Vuille, C., Serway, R. A. & Faughn, J. S. (2009). *College physics*, 8th ed. Belmont, USA: Brooks/Cole.

UNIT 5 WAVE – PARTICLE DUALITY

CONTENTS

1.0 INTRODUCTION

In this unit you would learn about the Wave – Particle duality that is the behavior of matter as particle and as wave.

2.0 A OBJECTIVES

At the end of this unit you will be able to:

- explain how matter exhibit both particle and wave properties; and
- state the De Broglie's equation which connects the wave – particle duality of matter.

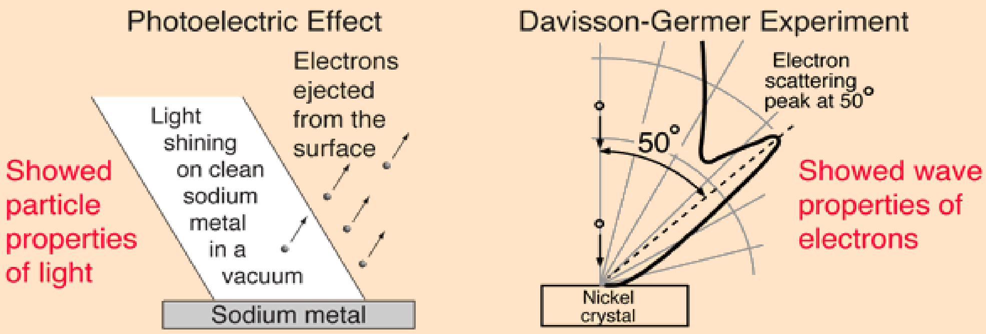
2.0 B How to Study this Unit:

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENT

3.1 Wave – Particle duality of Matter

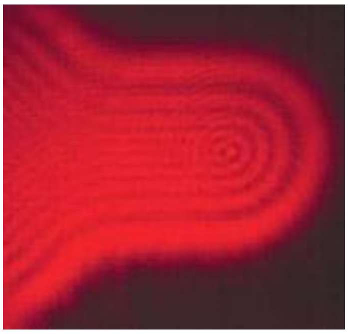
Publicized early in the debate about whether light was composed of particles or waves, a wave-particle dual nature soon was found to be characteristic of electrons as well. The evidence for the description of light as waves was well established at the turn of the century when the photoelectric effect introduced firm evidence of a particle nature as well. On the other hand, the particle properties of electrons were well documented when the DeBroglie hypothesis and the subsequent experiments by Davisson and Germer established the wave nature of the electron.



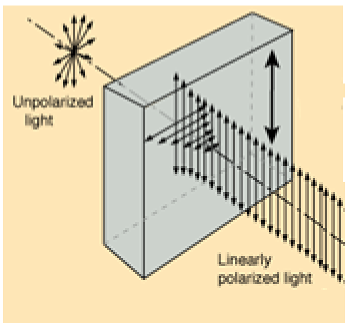
Wave-Particle Duality: Light

Does light consist of particles or waves? When one focuses upon the different types of phenomena observed with light, a strong case can be built for a wave picture:

Interference



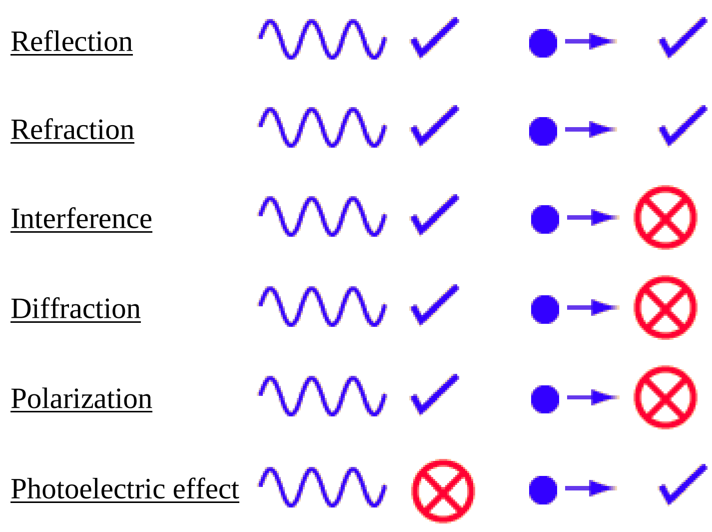
Diffraction



Polarization

By the turn of the 20th century, most physicists were convinced by phenomena like the above that light could be fully described by a wave, with no necessity for invoking a particle nature. But the story was not over.

Phenomenon	Can be explained in terms of waves.	Can be explained in terms of particles.



Most commonly observed phenomena with light can be explained by waves. But the photoelectric effect suggested a particle nature for light. Then electrons too were found to exhibit dual natures.

Wave – particle duality means that matter exhibit wave properties and particle properties. (Wave properties are diffraction, interference, reflection, refraction, polarization, and superposition and the particle properties are mass, momentum etc.)

As a wave, applying Planck's energy equation : E = hf = hc/λ where c is the velocity of light, h is the Planck's constant and λ is the wavelength of the wave.

As a particle, Applying Einstein's energy – mass equation: $E = mc^2$. Combining the gives:

$$\frac{hc}{\lambda} = mc^2$$

$$\lambda = \frac{hc}{mc^2}$$

$$\lambda = \frac{h}{mc}$$

But as a particle of mass m moving with speed v behaves like waves of wavelength $\lambda = \frac{h}{mv} = \frac{h}{p}$ where P = mv, that is momentum.

The equation $\lambda = \frac{h}{mv} = \frac{h}{p}$ is called De Broglie equation which sums up the wave – particle duality of matter.

4.0 CONCLUSION

In this unit you have learnt:

- Matter exhibit both wave and particle behaviors, as a wave it can deflect, reflect, diffract, interfere, superimpose, wavelength, etc and as a particle it has mass, momentum, kinetic energy, etc.
- The De Broglie equation which connects the wave –particle duality is:

5.0 SUMMARY

- Wave – particle duality means matter exhibit both wave and particle properties.
- De Broglie equation sums up this wave – particle duality.

6.0 TUTORS MARKED ASSIGNMENT

1. Explain what is meant by wave – particle duality of matter.
2. List the particle and wave properties of matter.

7.0 REFERENCES/FURTHER READING

Bueche, F. J. & Hecht, E. (2006). *College physics*. Schaum's Outline Series. New York: McGraw-Hill.

Duncan, T. (1982). *Physics. A textbook for Advanced Level Students*

Duncan, T. (2000), Advanced physics (5^{Th} edition). Hodder Murray.

Gautreau, R. & Savin, W. (1978). Theory and problems of modern Physics. Schaum's Outline Series.

Geddes, S. M. (1981). *Advanced physics*. London: Macmillan Education Ltd.

Gibbs, K (2011). *Advanced physics, 2^{nd} ed*. Cambridge: Cambridge University Pres

Halladay, Resnick & Walker, (2003), Fundamentals of Physics. Enhanced problems version (6^{TH} ed.).

http://web.sahra.arizona.edu/programs/isotopes/types/radioactive.html

IGNOU (2005). *Electricity and Magnetism Physics* PHE-07, New Delhi, India. London: John Murray (Publishers) Ltd..

McKenzie, A. E. E (1973). *A second course of electricity*. Cambridge: The University Press.

Philip, M. (1992), Advanced chemistry. Cambridge Low Price Editions.

Raymond A. S, Robert, J. B (2000), Physics For scientists and Engineers (5^{TH} edition),.Saunders College Publishing.

Vuille, C., Serway, R. A. & Faughn, J. S. (2009). *College physics*, 8^{th} ed. Belmont, USA: Brooks/Cole.