EDO UNIVERSITY IYAMHO

Department of Electrical/Electronic Engineering

EEE 315 Physical Electronics

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Lectures: Tuesday, 8am – 10 am & Wednesday, 1pm – 2pm, Engineering Drawing Studio,
Phone: (+234) 8032107220; Office hours: Wednesday, 8.30am to 9.30am,
Office: First room by the left, right wing, ground floor, Engineering & Medical. Sc. Building.

Teaching Assistants: *None*

General overview of lecture: This lecture is intended to give students an introduction to the course-physical electronics and the basic understanding of atoms and its structure. It covers the basic definitions pertaining the particles in an atom, the various atomic models, mathematical analysis of the Bohr model of an atom, the valence electron, free electrons in materials and line spectral of hydrogen atom.

Prerequisites: Students are expected to have good knowledge of atomic physics/chemistry and be familiar with some concepts such as free electrons, emissions, atomic model, excitation etc. Students are also expected to have basic mathematical analytic skills in science and related areas.

Learning outcomes: At the end of this course, it is expected that students:

i. will have a better understanding of the electronic structure of electronic materials,
ii. will have a better understanding of the mathematical base of electronics,
iii. will be able to explain the basis for the classification of elements and materials,
iv. will be able to explain the difference between valence electron and a free electron,
v. will understand the meaning of intrinsic and extrinsic semiconductor as well as doping,
vi. will be able to explain the meaning of line spectral in relation to hydrogen atom.

Assignments: In this course, we shall have three (3) assignments for each student and a Test after the midway of the semester. The assignments are systematically structured to prepare the students for the Test and the examination at the end of the semester.

Grading: The continuous assessment of this course will have a total of 30% with attendance accounting for 10%, assignment accounting for 10% and Test accounting for 10%. The semester examination will account for 70% of the grade/mark.

Textbook: The recommended textbook for this class are as stated:

1. Title: *Principles of Electronics*
   Authors: V.K. Mehta and Rohit Mehta
   Publisher: S. Chand & Company Ram Nagar, New Delhi-110 055 (Multicolour Illustrative Edition)

2. Title: *Semiconductor Physical Electronics*
   Authors: Sheng S. Li

Publisher: Springer (Second Edition)
ISBN 10: 0-387-28893-7
ISBN 13: 978-0387-28893-2

3. Title: *Semiconductor Physics and Devices- Basic Principles (Fourth Edition)*
Author: Donald A. Neamen
Publisher: McGraw-Hill Publishers
ISBN: 1-558600-320-4

Main Lecture: Below is a description of the contents.

1. Introduction

Electronics as a word is gotten from the fact of the availability of electron in every material. Therefore electronics is mainly about the use of these electrons in devices and machine to achieve some particular result. Electronics is that aspect of electrical engineering that is saddled with the use of the production, flow and control of electron (electricity) as well as their behavior and effects in vacuum (empty compartment), gaseous environment, semiconductors and with devices using such electrons. Electronics is usually associated with low voltage current.

Electronic devices

An electronic device is one that permits current to run through a material either in a vacuum or gas or semiconductor. These devices exhibit certain important characteristics and actions that permits their use in a certain ways in various industries.

Common function/behaviour of electronic devices

(i) Rectification. This is the transformation of alternating signals usually referred to as AC such as power, voltage current etc. into a direct current signals. These transformation is usually with high efficiency. Example of such a device is the diode.
(ii) Amplification. This is a way by which the strength of a signal is increase from one level to another e.g. from a weak signal to a strong signal. This usually achieve by electronic device known as amplifier. An example of such a device that can amplify is the transistor in a common emitter configuration.
(iii) Control. Electronic devices are able to guide and monitor the behavior of some other devices by regulating some of the properties of those devices find wide applications in automatic control. The control of current, voltage, frequency etc. by electronic devices can be used to control the action of some other devices as the motor
(iv) Signal attenuation. Electronic device that can act on an input signal to reduce the strength or power of a signal is called an attenuator. In an attenuator, the output signal strength is lower than the input signal.

2. Atoms and Their Structure

Every object or material is made up of very minute particles known as atoms. The atoms are the smallest entity and the unit of all matters. The atom is made up of a nucleus with positive charge proton located at the center of the atom called nucleus and moving around it in an orbit is the negatively charged particles known as the electrons. Also located at the nucleus of the atom is the neutron which is no charge. In other to have a good understanding of the principles of current and voltage and their behavior, a reasonable fundamental knowledge of the atom and its structure is needed. The easiest form of atom is that of the hydrogen which is basically composed of one **proton** and one **electron**.

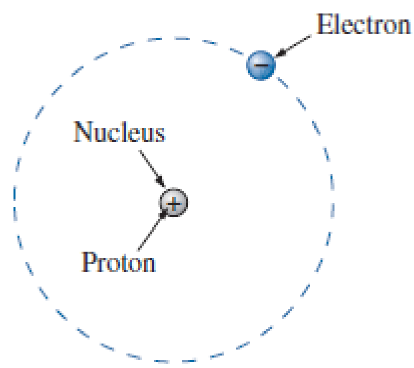


Figure 1: Structure of an atom

(Source: Dr. Ibrahim Aljubouri, Engineering Collage Electrical Engineering Dep)

(a) Nucleus. It is located at the core part of an atom and holds the *protons* and the *neutrons*. The proton is particle that is positively charged, while the neutron is a particle that has no charge, but possesses a mass that is the same as that of the proton. This make the nucleus of an atom to be entirely positive in charge. The total number of protons and neutrons is the atomic weight. The electrons is of negligible weight in relation to the weight of protons or neutrons.

Therefore, Atomic weight = no. of protons + no. of neutrons

(b) The Orbit (Shell). This is the outer portion of the atom which contains only the electrons. The electron has a negative charge with a negligible mass. This charge is equal and opposite to that of the proton. Again, in an ordinary condition, electrons are equal to proton in an atom. Therefore, the atomic number is the number of electrons or protons in an atom. The revolving numbers of electron in an orbit is mathematically given as $2n^2$.

Where n = number of the orbit in an atom.

Structure of Elements

It is an established fact that the atom comprise of three basic particles namely the proton, the neutron and the electron. The variation in the properties and behavior of various elements is a result of the difference in the number as well as the arrangement of these atomic particles within the various atoms. For example, the arrangement of copper atom varies significantly from that of carbon and so there is a difference in the properties of the two element.

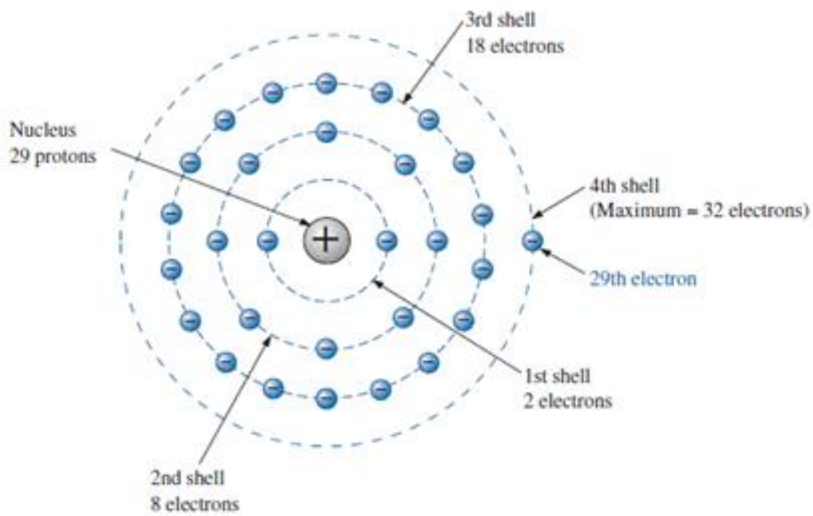


Figure 2: Structure of copper atom

(Source: Dr. Ibrahim Aljubouri, Engineering Collage Electrical Engineering Dep)

The atomic structure can be easily built up if we know the atomic weight and atomic number of the element. Thus taking the case of copper atom,

Atomic weight = 64
Atomic number = 29
Therefore, No. of protons = No. of electrons = 29
and No. of neutrons = 64 - 29 = 35

Copper is about the about commonest metal in use in the industries especially in those that deal with electrical and electronics devices. An analysis of the atomic structure of copper will show why it is versatile in industrial applicability. From Figure 2.2, it possess 29 electrons orbiting the nucleus, and the last electron (29th electron) stands alone in its last shell, the 4th shell

Note

1. The 4th shell can contain a total of $2n^2 = 2(4)^2 = 32$ electrons, but unfortunately this shell is having only a single electron. This renders the outermost shell to be incomplete.
2. This makes the atom to be unstable as atoms with complete octet (in line with $2n^2$) are usually stable and therefore can react with other atoms and element under certain conditions.
3. This particular electron in the outermost shell is far from the nucleus with less exerting force from the nucleus as compare with the electrons in the lower shells closer to the nucleus. This force on the outermost orbit is given by Coulomb's law as follows:

$$F = k\frac{Q_1Q_2}{r^2} \text{ (N)}$$

Where F is in newton (N),
k = a constant = 9.0×10^9 N·m^2/C^2,
$Q1$ and $Q2$ are the charges in coulombs
r = distance between the two charges in meters.

The above equation shows that the coulombic force between the nucleus and the electron in the outermost shell is inversely proportional to the distance between the two particles. The implication of this is that as the distance between them increases, the force F become weaker in holding the electron to the atom. So, when a little external force is applied to the outermost shell electron by way of absolving enough energy from the environment, it will leave the parent atom by breaking the weak force from the nucleus to become a free electron. There are nearly 1.4 x 10^{24} free electrons in 1 cubic in. of copper at room temperature. Atoms of different elements exhibit varying degree of properties depending on the arrangement of the electrons in the shells and the number of electrons in the outermost shell.

Basic Parameter of Electron (Charged Particles)
The basic parameters of an electron is as follows
(i) Charge on an electron, e = 1.602 x10^{-19} c
(ii) Mass of an electron, m = 9.11 x10^{-31} kg
(iii) Radius of an electron, r = 1.9 x 10^{-15} m
(iv) Radius of an atom, r = 10^{-15} m
(v)The ratio e/m of an electron is 1.77 x10^{-11} c/kg.

The implication of this is that the mass of an electron is very little as compared to its charge. As a result of this property of electron, the mobility of the electron is very high and can be easily influenced by both the electric and the magnetic fields.

1. Valence Electrons

The valence electrons are the electrons in the outermost or last shell in an atom. The outermost shell usually can accommodate a maximum of 8 except the first shell. The force of attractions between the valence electrons and the nucleus is usually smaller than the force between the lower level octet shells.

On the basis of the above,

(i) If the valence electrons in an atom is less than half octet, the element is most cases a metal and a conductor.

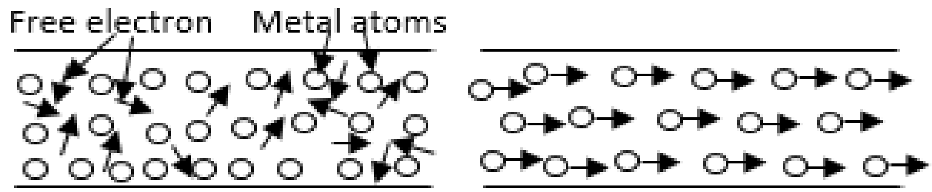
(*ii*) If the valence electrons in an atom is greater than half octet, the element is most cases a non-metal and an insulator.

(*iii*) If the valence electrons in an atom is half an octet (*i.e.* exactly 4), the material stands in between metals and non-metals.

2. Free Electrons

Valence electron which moves randomly in an atom are called free electrons. The diagrammatic representation is as shown in Figure.

The free electrons can be removed easily from the atom by free electron acquiring a little amount of external energy. The free electrons determine to a very large extent a material's electrical conductivity.



(a) Free electron in an un-energised material (b) Free electron in conduction

Figure 3: Free electrons

2.2. Atomic Models

(a) Thomson's Atomic Model

The model postulated the following:

- An atom looks like a sphere with a mass of positive charge and the negatively charged electrons embedded in the sphere.
- Both the positively and negatively charged particles are equal in magnitude and this makes the atom to be electrically neutral.
- This atomic model present an atom as a spherical plum pudding.

Limitations of Thomson's Atomic Model

- The atomic model did not show how the positively charged mass holds the negatively charged electrons in its mass. Again, it did not explain the stability of the atom.
- The model did not show or discuss the nucleus of an atom.
- It could not explain the Rutherford scattering experiment.

(b) Rutherford atomic model

This model postulated the following

- An atom is made up of particles which are positively charged. Most parts of the atomic mass was centered in a very little portion of the atom called the nucleus. This nucleus was later discovered to consist of the neutron and proton.
- The nucleus of an atom is encircled by electrons which are negatively charged and revolves round the nucleus at the center in a fixed circular pathway called the orbit with a very high speed.
- Like the Thomson model, it explained the electrical neutrality of an atom as the electrons are negatively charged particle and the densely concentrated nucleus is positively charged. An electrostatic force of attractions holds the nucleus and electrons in the orbit together.
- The nucleus size of the atom is very little as compare to the size of an atom in totality.

(c) Bohr's Atomic Model

Neils Bohr, a Danish Physicist in 1913 gave an atomic model that is summarized as follows:

i. An atom is made up nucleus which is positively charged and a circular orbit with electrons of negative charge revolving in the orbit.
ii. The electrons are only permitted in a certain orbit (n = 1, 2, 3 …) *i.e.* orbits of certain radii are allowed.

iii. The atom can only possess a certain level of discrete energies i.e. the energy of the orbit is quantized.

iv. The electron stationary state determined by the fact that the angular momentum of the electron in this state is quantized and it is an integral multiple of h/2π. Thus

$$mvr = \frac{nh}{2\pi}$$

where n is an integer.

Bohr's Atomic Model Calculations

In deriving these equations, let

ε_o = Permittivity of free space = 8.854 x10^{-12} farad/m

h = Planck's constant = 6.625 x 10^{-34} J-s

Z = Atomic number (For Hydrogen Z = 1)

m = Mass of electron

n = Number of orbit

k = Constant

v = Linear velocity

r = Distance of electron from the nucleus

1. **Radius of orbit**

$$r = \frac{\varepsilon_o n^2 h^2}{\pi m e^2} \approx \frac{n^2 h^2}{4\pi^2 m k Z e^2}$$

Where n = 1, 2, 3 …

2. **Energy**

Potential Energy = Coulomb Potential

$$U = -\frac{e^2}{4\pi\varepsilon_o r}$$

Kinetic Energy

$$= \frac{1}{2}mv^2$$

Total Energy (TE)

$$E_n = -\frac{me^4}{8{\varepsilon_o}^2 n^2 h^2}$$

3. Wave number

$$\frac{1}{\lambda} = R_H\left(\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right)$$

$R_H = \frac{me^4}{8{\varepsilon_o}^2 h^3 c} = 10.97 \times 10^6\ m^{-1}$ this is called Rydberg's constant

Wave number $v = \frac{1}{\lambda}$

4. Total distance covered by electron in one revolution $d = 2\pi r$

And

From (3) $r = \frac{\varepsilon_o n^2 h^2}{\pi m e^2}$

$$\therefore d = \frac{2\varepsilon_o n^2 h^2}{m e^2}$$

2.4 The Hydrogen Line spectrum

Radiations from atoms of low-pressured gas under the influence of intense potential difference consisting of a set of distinct electromagnetic wavelength is referred to as line spectrum. It is essentially a movement of electron from higher energy levels to lower energy levels in an atom. A set of distinct wavelengths arriving an energy level from a higher level are known as "series." This is as shown in the Figure below.

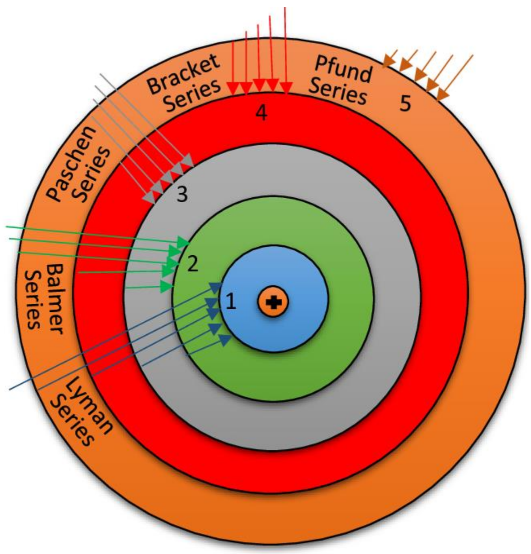


Figure 4: hydrogen atom line spectral

The Limitation of the Bohr model of one-electron atom

1. Bohr's model can only account for an atom that possesses one electron (hydrogen). It could not validly be extended to a two or more electron atoms to arrive at the same analysis from those of hydrogen.
2. The model fails to account for the mutual actions between electrons in the same atom.
3. The model could not account for the uncertainty principle.

Solved Example

Determine the energy of an electron moving from n= 3 to n= 1. Comment on the direction of movement of the energy involved.

Solution:

$$\Delta E = E_R\left(\frac{1}{{n_2}^2} - \frac{1}{{n_1}^2}\right) = 2.18 \times 10^{-18}\, J\left(\frac{1}{{n_i}^2} - \frac{1}{{n_f}^2}\right)$$

$$\Delta E = 2.18 \times 10^{-18}\, J\left(\frac{1}{3^2} - \frac{1}{1^2}\right)$$

$$\Delta E = 2.18 \times 10^{-18}\, J \left(\frac{1}{9} - 1\right)$$
$$\Delta E = -1.94 \times 10^{-18}\, J$$

Energy was radiated as the value of the energy is negative in sign and electrons transited from a higher energy level (n= 3) to lower energy level (n =1). As a result, energy is lost.