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Ministry of Education
& Technical Education
Central Administration
Of Book Affairs

Physics

General Secondary Certificate

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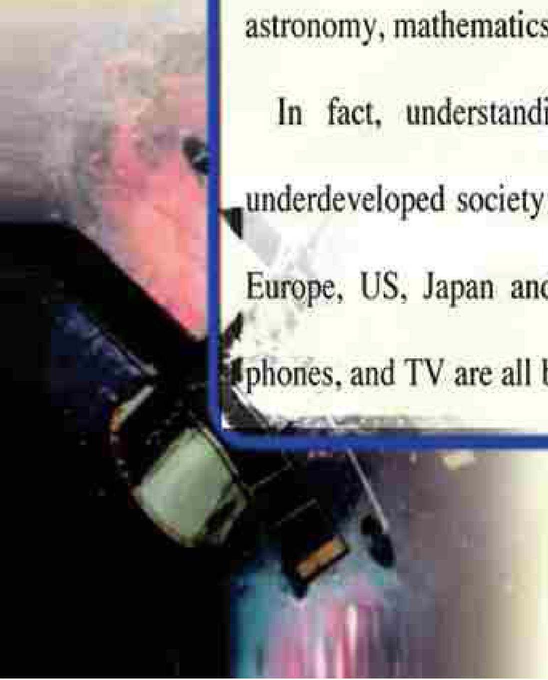
Foreword

Physics is the cornerstone of basic sciences. It deals with the understanding of nature and what goes around us, big and small in this universe. It is the root of all sciences. Interwined with it is chemistry which focuses on reactions between materials, biology which deals with living creatures, geology which is involved with the layers of the Earth, and astronomy which treats celestial objects. But in the end, physics remains the mother of all sciences and the basis for the tremendous present scientific and technological progress. Understanding physics means understanding the laws governing this universe. Such understanding has led to the current industrial development spearheaded by the West. The Arabs and Moslems were once the pioneers of civilization in the world when they realized the importance of understanding the laws of this universe. We owe them the discovery of most laws of physics centuries before the West. The foundations of medicine, physics, chemistry, astronomy, mathematics and music were all laid by Arab and Moslem scientists.

In fact, understanding physics and its applications converts a poor, and underdeveloped society into an affluent and developed one. This has taken place in Europe, US, Japan and South East Asia. Computers, satellites, cellular (mobile) phones, and TV are all byproducts of physics. Genetics is currently being looked into



intensively. It is targeted to use genetics, atoms and lasers in the computer of the future. It is a limitless world, enriched by imagination, where sky is the limit.

The scientific progress is a cumulative effort. This collective endeavor has led to where we are today. A scholar of physics must be acquainted with such accumulated knowledge in a short time, so that he could add to it within the limited span of his life. In studying what others have found, we must skip details and trials, and extract the end results and build on them.A global view is, therefore, more important at this stage than being drowned in minute details that could be postponed to a later stage of study.

This book is divided into 3 units. Unit 1 treats electricity, where (chapter 1) covers the electric current, Ohm's law, (chapter 2) covers the magnetic effects of electric current and measuring instruments, while (chapter 3) covers electromagnetic induction. Finally, chapter 4 deals with the circuits of alternating current Unit 2 gives an introduction to modern physics, where (Chapter 5) deals with wave particle duality, (Chapter 6) deals with atomic spectra, and (chapter 7) deals with lasers and their applications, while (chapter 8) covers modern electronics.

Suzanne Mubarak Science Exploration Center has carried out the preparation, and the typing of manuscript as well as the design of the artwork.

In the end, we want the student to take liking to physics. For this is the way to the future. We want the teacher to teach the subject of physics in an innovative way, to arouse the interest of the students by constantly referring to the use and applications of physics in the daily life. We hope that one day we will have great inventors and industrialists among today's students.

Committee for the preparation of this new version of the textbook.

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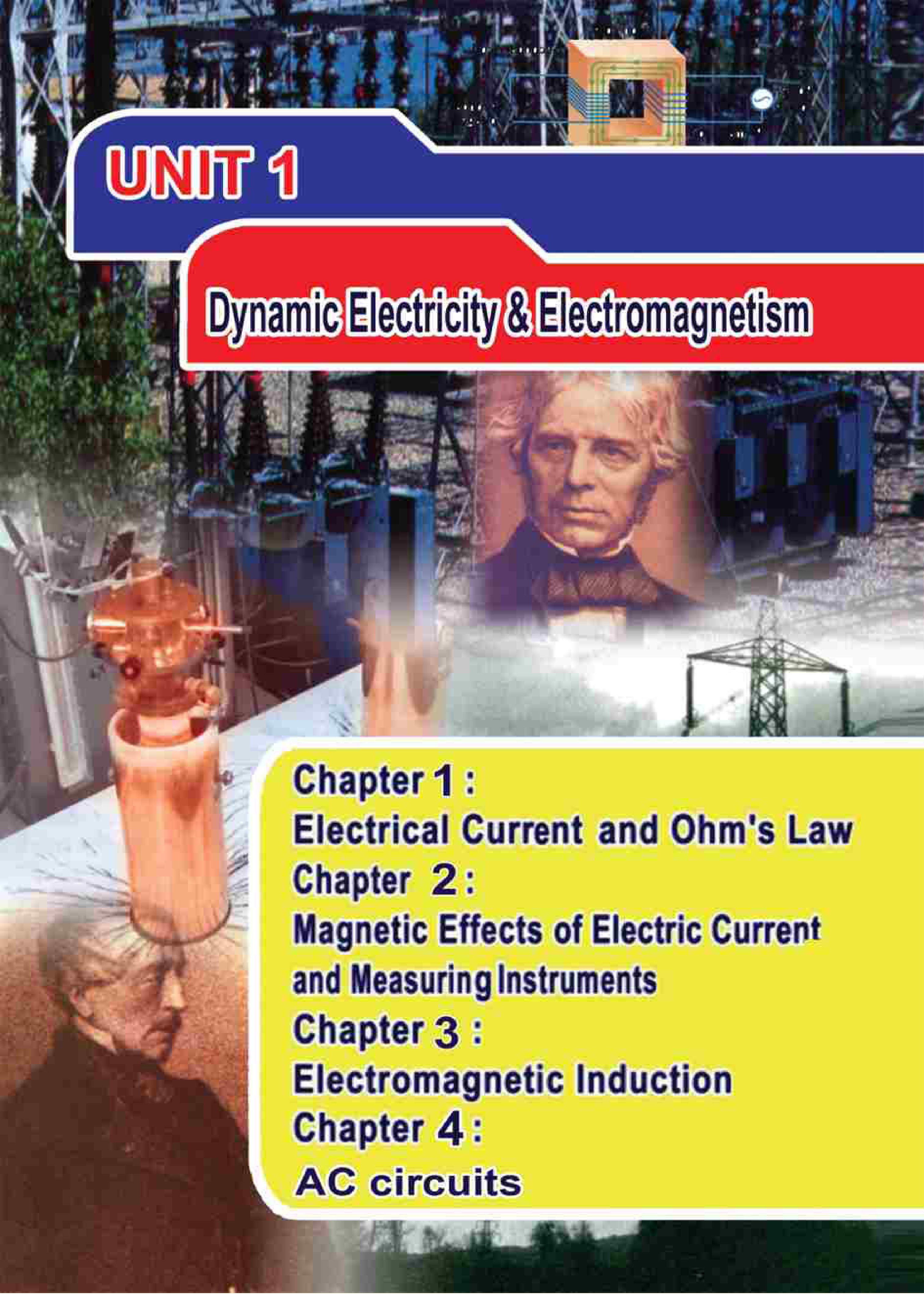
UNIT 1

Dynamic Electricity & Electromagnetism



Chapter 1 :
Electrical Current and Ohm's Law

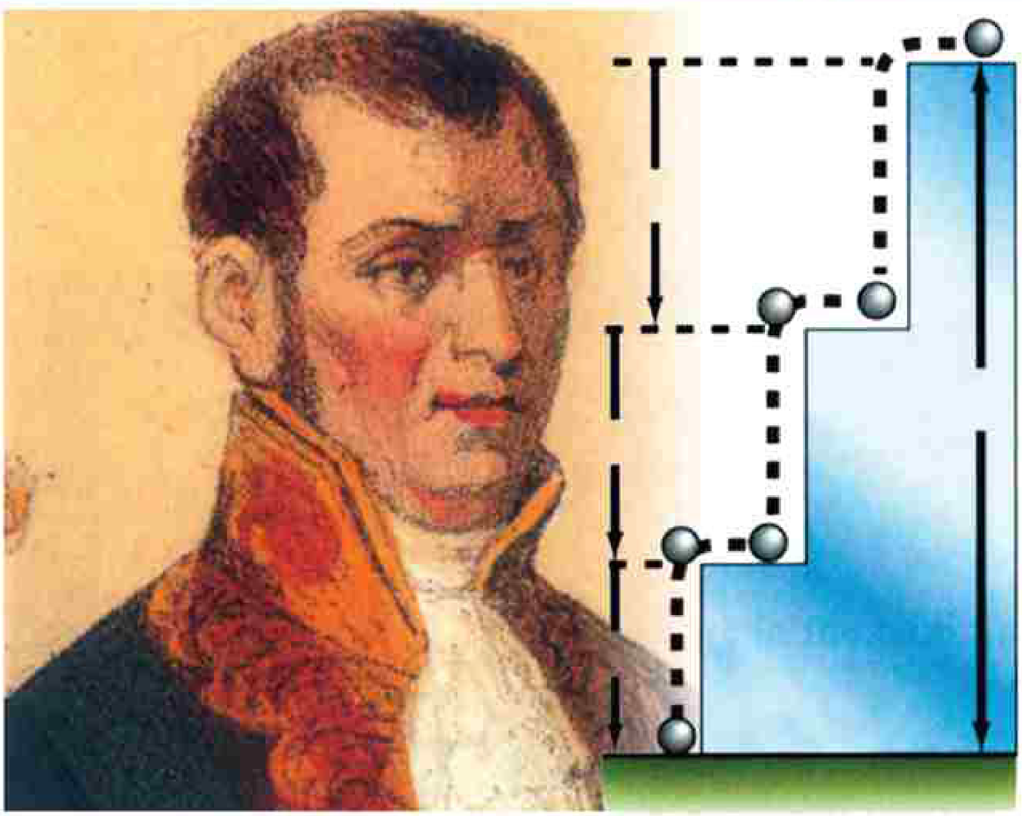
Chapter 2 :
Magnetic Effects of Electric Current and Measuring Instruments

Chapter 3 :
Electromagnetic Induction

Chapter 4 :
AC circuits

Dynamic Electricity & Electromagnetism

UNIT 1



Chapter 1:
Electrical Current and Ohm's Law

Chapter 1 Electric Current and Ohm's Law

Overview

We have learned from the previous study that:

1) The electric current is a flow of electric charges in a conducting material.

2) The intensity of an electric current I is given by the relation $I = \frac{Q}{t}$. where Q is the quantity of electricity (Coulomb-C), t is time (s) and I is measured in Amper (A).

   IA=Coulomb/sec (C/s).

3) The potential difference between two points: $V = \frac{W}{Q}$, where W is the work done (Joule), V is the potential difference in I Volt (V) = Joule/C.

Ohm

4) The emf of a source is the total work done to transfer unit charge (Coulomb) throughout the circuit outside and inside the source. It has unit of volt.

5) The resistance R is the opposition to the flow of the electric current and measured in Ohm (Ω) and depends on the length of the conductor, its cross sectional area and its material at constant temperature. It is given by the relation $R = \frac{\rho_e \ell}{A}$. Where ℓ is the length of the conductor (m), A is the cross

Ampere

sectional area (m^2) and (ρ_e) is the resistivity (Ωm).

The electrical conductivity of a certain material σ ($\Omega^{-1}m^{-1}$) is the reciprocal of the resistivity $\sigma = (\frac{1}{\rho_e})$.

6) **Ohm's Law** :

The current intensity in a conductor is directly proportional to the potential difference across its terminals at a constant temperature : $\boxed{V = IR}$

7) As a convention, the direction of flow of the electric current always goes from the positive terminal to the negative terminal outside the source into a closed electric circuit. It is opposite to the direction of motion of electrons. It is called the conventional direction of current.

Connecting resistors

Firstly: series connection

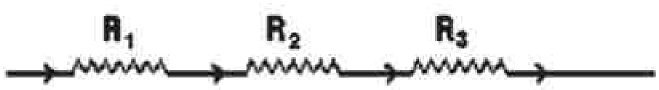


Fig (1 – 1)

Connection in series

Resistors are connected in series to obtain a higher resistance from a group of resistors (Fig1–1). The equivalent resistance of a group of resistors connected in series can be obtained in connecting these resistors in an electric circuit comprising a battery,an ammeter,a rheostat (variable resistor) and a switch (Fig 1-2). The circuit is closed and the rheostat is adjusted so that an appropriate current I Ampere is passed.

The voltage difference across each resistor is measured (V_1 across R_1, V_2 across R_2, V_3 across R_3) as well as the total voltage (V), which is equal to the sum of the voltage differences across the resistors in the series circuit .

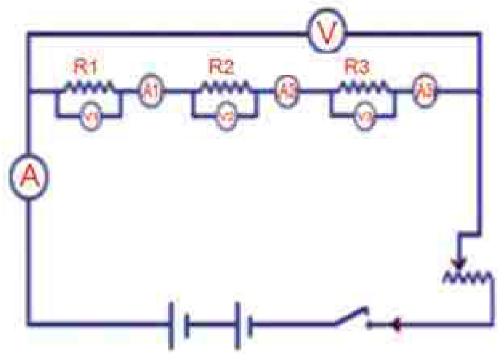


Fig (1 – 2)

Measuring the equivalent resistance in a series connection

$$V` = V_1 + V_2 + V_3$$

But $\because V = IR$

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

$$\boxed{IR` = IR_1 + IR_2 + IR_3}$$

$$R` = R_1 + R_2 + R_3 \qquad \textbf{(1-1)}$$

Thus, the equivalent resistance R` of a group of resistors connected in series equals the sum of these resistances. It is to be noted that the largest resistance in the combination determines the total resistance in a series connection. If N resistances are connected in series, each equal R then :

$$\boxed{R` = NR} \qquad \textbf{(1-2)}$$

Secondly: Parallel connection

The purpose of connecting resistors in parallel is to obtain a small resistance out of a bunch of large resistances (Fig 1 – 3). To obtain the equivalent resistance for a parallel connection, the combination is included in an electric circuit comprising a battery, an ammeter and a rheostat all connected as shown (Fig 1 – 4).

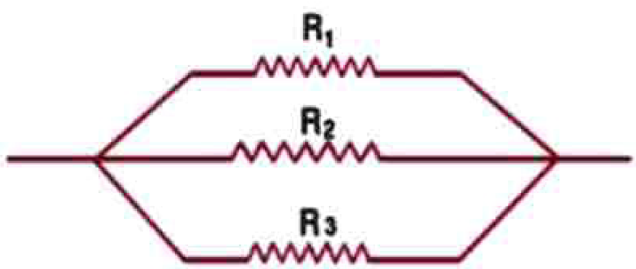


Fig (1 – 3)
Connection in parallel

We close the circuit and adjust the rheostat to obtain an appropriate current in the main circuit of intensity I (A), which can be measured by the ammeter. The total voltage difference can then be measured across the terminals of the resistances by a voltmeter (V). The current in each branch is measured (I_1 in R_1, I_2 in R_2, and I_3 in R_3). In a parallel connection, the total current is determined by the smallest resistance. This case is similar to the flow of water in pipes.

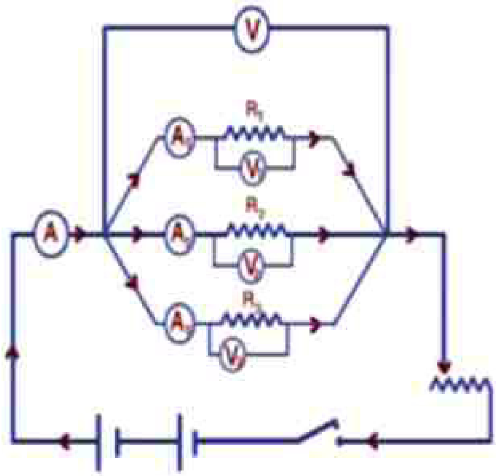


Fig (1 - 4)
Measuring the equivalent resistance in a parallel connection

It is to be noted that :

$$I = \frac{V}{R'} \ , \ I_1 = \frac{V}{R_1} \ , \ I_2 = \frac{V}{R_2} \ , \ I_3 = \frac{V}{R_3}$$

where R' is the equivalent resistance, and V is the voltage difference across resistors connected in parallel. The total current I is the sum of the branch currents. $I_1 + I_2 + I_3$.

Thus:

$$\frac{V}{R'} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\boxed{\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \qquad (1\text{-}3)$$

Hence, the reciprocal of the equivalent resistance R' is the sum of the reciprocal of resistances in the case of a parallel connection. In the case of two resistors in parallel, the equivalent resistance R' is given by :

$$\boxed{R' = \frac{R_1 R_2}{R_1 + R_2}} \qquad (1\text{-}4)$$

When N resistances are connected in parallel each equal to R,

$$\frac{1}{R'} = \frac{N}{R}$$

$$\boxed{R' = \frac{R}{N}} \qquad (1\text{-}5)$$

Ohm's Law for a closed circuit

We know that the emf of an electric cell (battery - source) is the total work done inside and outside the cell to transfer an electric charge of 1C in the electric circuit. If we denote the emf of a battery by V_B, the total current in the circuit by I, the external resistance by R and the internal resistance of the cell by r, then

$$V_B = IR + Ir$$

$$V_B = I(R + r)$$

$$I = \frac{V_B}{R + r} \qquad (1\text{-}6)$$

This is known as Ohm's law for a closed circuit, from which we find that the current intensity in a closed circuit that equals the total emf of the source divided by the total (external plus internal) resistance of the circuit.

$$I = \frac{\text{Total emf in the circuit}}{\text{Total resistance of the circuit}}$$

Relation between emf and voltage across a source

From Fig (1 – 5), we find

$$V = V_B - Ir$$

From this relation, we see that as I is decreased gradually in the circuit shown (Fig 1 – 5), by increasing the external resistance R, the voltage difference across the source increases.

When the current vanishes, the voltage difference across the source becomes equal to the emf of the source. Hence, we may define the emf of a source as the voltage difference across its poles when the current ceases in the circuit.

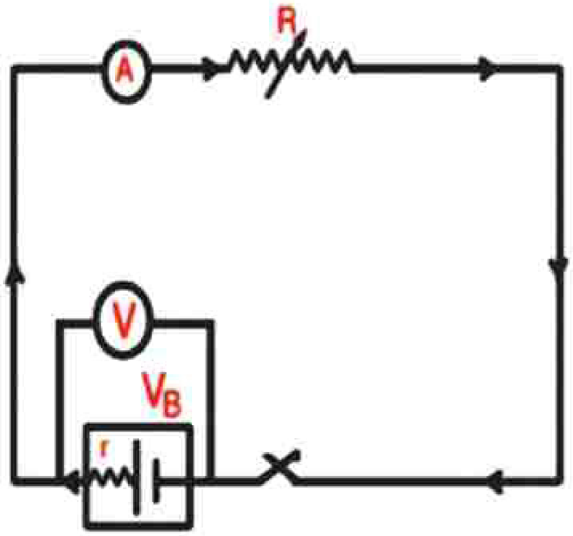


Fig (1-5)

Relation between the voltage difference and the emf of a source

Examples:

1) Three resistors 25Ω, 70 Ω and 85 Ω are connected in series to a 45 volt battery of a negligible internal resistance. Calculate:

   a) the current flowing in each resistor.

   b) The potential difference across each resistor.

Solution:

The total resistance of the circuit R is:

$$R = R1 + R2 + R3 = 25 + 70 + 85 = 180\ \Omega$$

The current flowing through the circuit is:

$$I = \frac{V_B}{R} = \frac{45}{180} = 0.25A$$

Since the resistors are connected in series, then the current flowing through each and all other parts of the circuit is the same, i.e., 0.25 A. Assume that the potential difference across R1 , R2, R3 are V1, V2, V3, respectively.

$$V_2 = IR_2 = 0.25 \times 70 = 17.5V$$

$$V_1 = IR_1 = 0.25 \times 25 = 6.25V$$

$$V_3 = IR_3 = 0.25 \times 85 = 21.25V$$

2) If the resistors in the previous example are connected in parallel to the same battery, calculate:

a) the current flowing in each resistor.

b) the total resistance.

c) the current through the circuit.

solution :

a) the voltage difference across each resistor = 45V, since they are connected in parallel and the battery is of negligible internal resistance. The current flowing through each resistor is calculated separately as follows :

$$I_1 = \frac{V}{R_1} = \frac{45}{25} = 1.8 \text{ A}$$

$$I_2 = \frac{V}{R_2} = \frac{45}{70} = 0.643 \text{ A}$$

$$I_3 = \frac{V}{R_3} = \frac{45}{85} = 0.529 \text{ A}$$

b)The total (equivalent or combined) resistance R is calculated as follows :

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{25} + \frac{1}{70} + \frac{1}{85}$$

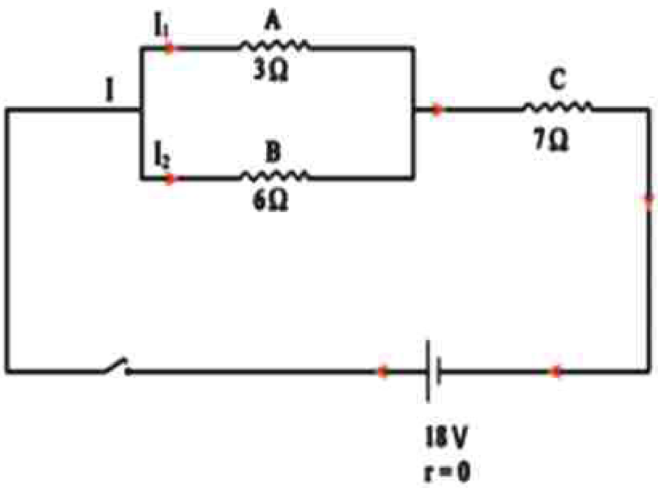
$$R' = 15.14\ \Omega$$

c) The current flowing through the circuit I is :

$$I = \frac{V}{R'} = \frac{45}{15.14} = 2.972 \text{ A}$$

It can be calculated also as the sum of the currents I_1 , I_2 , I_3 flowing through all resistors:

$$I = 1.8 + 0.643 + 0.529 = 2.972\ A$$



3) In the figure shown above two resistors A and B are connected in parallel. The combination is connected in series with a resistor C and a 18 volt battery of negligible internal resistance. If the resistances of A,B and C are 3Ω,6Ω,7Ω, respectively, calculate:

a) the total resistance.

b) the current flowing through the circuit.

c) the current through each of A and B.

Solution :

The equivalent resistance for the combination (A, B) is :

$$R' = \frac{R_1\, R_2}{R_1 + R_2} = \frac{3 \times 6}{3 + 6} = 2\ \Omega$$

The equivalent resistance for the combination (A,B)and(C) is :

$$R = R' + R_3 = 2 + 7 = 9\ \Omega$$

The current I flowing through the circuit is :

$$I = \frac{V}{R} = \frac{18}{9} = 2A$$

To calculate the current flowing through each of A and B, We should calculate the potential difference V' V across the combination (A, B):

$$V' = IR' = 2 \times 2 = 4V$$

Assuming the current flowing through A and B to be I1 and I2, respectively:

$$\therefore I_1 = \frac{V'}{R_1} = \frac{4}{3} = 1.333$$

$$\therefore I_2 = \frac{V'}{R_2} = \frac{4}{6} = 0.667$$

4) A cell of e.m.f. 2V and internal resistance 0.1 Ω is connected to a circuit of external resistance 3.9 Ω. Calculate the current flowing through the circuit.

Solution:

$$I = \frac{V_B}{R + r} = \frac{2}{3.9 + 0.1} = 0.5A$$

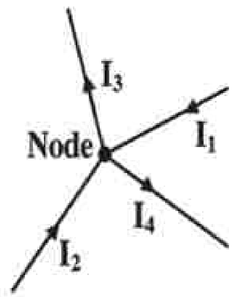
Kirchhoff's laws

Some electric circuits are too complicated to be managed by applying Ohm's law. For such cases there are a set of relations called **Kirchhoff's laws** which enable one to analyze arbitrary circuits.

Kirchhoff's First Law:"based on conservation of electric charge"

You know that the electric current through metallic conductors is a stream of negative free electrons (electric charges) flowing from one point to another and these charges do not accumulate at any point along their path through the conductor. According to this Kirchhoff has formulated his first law (**Kirchhoff's current law**) as follows:

"At any node (junction) in an electrical circuit, the sum of currents flowing into the node is equal to the sum of currents flowing out of that node"



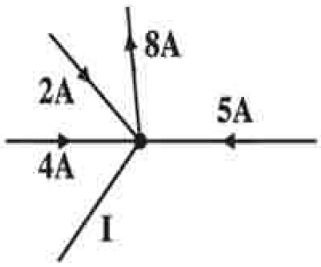
As shown in figure: $\sum I_{in} = \sum I_{out}$

$I_1 + I_2 = I_3 + I_4$

$I_1 + I_2 - I_3 - I_4 = 0$

"or the algebraic sum of electric currents meeting at a point (a node) in a closed circuit equals zero". This can be expressed as: $\sum I = 0$

Example: Calculate the intensity and the direction of the electric current (I) illustrated in the given figure.



Solution:

According to Kirchhoff's fist law:

Total electric currents flowing to a node = Total electric currents leaving the node

$4 + 5 + 2 = 8 + I$

Out of this: $I = 3$ A going out of the node

Kirchhoff's Second Law:"based on conservation of energy"

The electromotive force of a closed electric circuit expresses the work done or the energy required to transfer a unit electric charge once round the whole circuit.

On the other hand, the potential difference expresses the work done to transfer a unit electric charge across a component in the circuit. $V = I R$

This has been formulated by Kirchhoff in his second law (**Kirchhoff's voltage law**) as follows:

"The algebraic sum of the electromotive forces in any closed loop is equivalent to the algebraic sum of potential differences within that loop"

It can be expressed mathematically as:

$$\sum V_B = \sum I R$$

In analyzing circuits using Kirchhoff's laws, it is helpful to keep in mind the following guidelines.

1- You must assign directions of currents through the different branches. These directions are not the actual directions. Don't worry if you guess incorrectly the direction of a particular unknown current. If the answer resulting from the analysis come out positive, your suggested direction is correct. If negative, the actual current direction in this branch is opposite to the assumed direction.

2- Apply the junction rule (first law) to as many junctions in the circuit as possible.

3- For each closed loop, we assume a certain positive direction and its opposite is negative.

4- Kirchhoff's second law can be applied to more than one closed loop. If it agrees with the assumed current direction considered positive. If it goes the other way round considered negative.

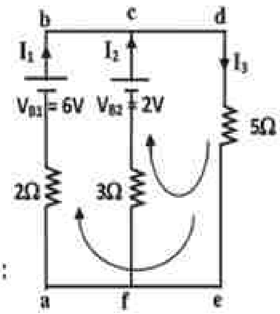
5- The direction of the electromotive force is from the positive pole to the negative pole. If it agrees with the assumed current direction considered positive. If it goes the opposite direction considered negative.

Examples based on Kirchhoff's law

Example (1): In the given circuit calculate:

1- The intensity of current through each branch.
2- The potential difference between the points **a** and **b**

Solution



Assign the directions of current as shown in the circuit.

Applying Kirchhoff's first law at the point (c):

$$I_1 + I_2 = I_3 \quad \rightarrow \quad (1)$$

Applying Kirchhoff's second law to the closed path (loop) (**a b d e a**):

$$\sum V_B = \sum I R$$

$$6 = 2 I_1 + 5 I_3 = 2I_1 + 5 (I_1 + I_2)$$

$$6 = 7 I_1 + 5 I_2 \quad \rightarrow \quad (2)$$

Applying Kirchhoff's second law to the closed path (loop) (**c d e f c**):

$$2 = 3 I_2 + 5 I_3 = 3I_2 + 5 (I_1 + I_2)$$

$$2 = 5 I_1 + 8 I_2 \quad \rightarrow \quad (3)$$

From equations (2) and (3), the coefficient of one of the two unknown currents is unified by multiplying equation (2) x 5 and equation (3) x 7

$$30 = 35 I_1 + 25 I_2$$

$$14 = 35 I_1 + 56 I_2$$

Subtracting the last two equations:

$$16 = -31 I_2$$

$$I_2 = -0.516 \text{ A}$$

The negative sign means that the actual direction of current I_2 is opposite to the assumed direction in figure.

Substituting in equation (3)

$$2 = 5 I_1 + 8 \times (-0.516)$$

$I_1 = 1.226$ A

The positive sign means that the assumed direction of current I_1 is correct.

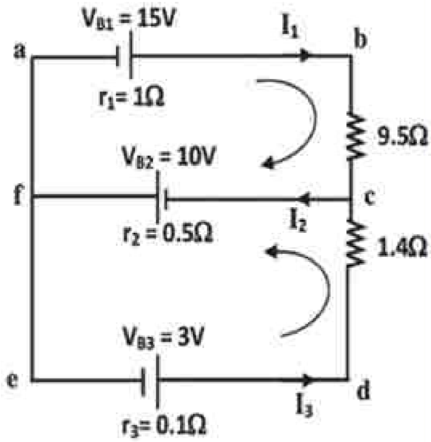
Substituting in equation (1), we find that: $I_3 = 0.71$ A

To find the voltage across **ab**:

$$V = V_B - Ir$$

$$V = 6 - (1.226 \times 2) = 3.55 \text{ V}$$

Example (2): In the given circuit find the current intensities: I_1, I_2 and I_3



Solution

Applying Kirchhoff's first law at the point (c):

$$I_1 + I_3 = I_2 \quad \rightarrow \quad (1)$$

Applying Kirchhoff's second law to the closed path (loop) (a b c f a)

$$\sum V_B = \sum I R$$

$$15 + 10 = (1 + 9.5)\ I_1 + 0.5\ I_2 \qquad \text{multiplying x 2}$$

$$50 = 21\ I_1 + I_2 \quad \rightarrow \quad (2)$$

Applying Kirchhoff's second law to the closed path (loop) (**f c d e f**)

$$\sum V_B = \sum I R$$

$$3 + 10 = 0.5\ I_2 + (0.1 + 1.4)\ I_3 \qquad \text{multiplying x 2}$$

$$26 = I_2 + 3 I_3 \quad \rightarrow \quad (3)$$

From equations (1) and (2),

$$50 = 20\,(I_2 - I_3) + I_2 = 22\ I_2 - 21\ I_3 \quad \rightarrow \quad (4)$$

Multiplying equation (3) x 7 and adding it to equation (4)

$$182 = 7\ I_2 + 21\ I_3$$

$$50 = 22\,I_2 - 21\,I_3 \quad \rightarrow \quad (4)$$

By addition: $232 = 29\,I_2$ $\quad I_2 = 8\text{ A}$

Substituting in equation (2)

$$50 = 21\,I_1 + 8$$

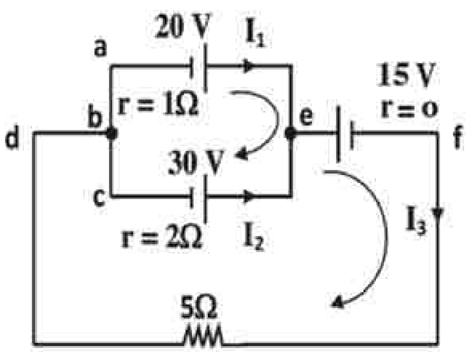
$$I_1 = 2\text{ A}$$

Substituting in equation (1), we find that: $I_3 = 6\text{ A}$

N.B. All the assigned directions are correct since all current intensities are positive

Example (3): In the circuit shown in figure, find:

1- The intensity of current through each battery.
2- The terminal voltage of each battery.
3- The potential difference across the resistor 5 Ω.



Solution:

Assume directions of current as shown in figure

Applying Kirchhoff's first law at the point (e):

$$I_1 + I_2 = I_3 \quad \rightarrow \quad (1)$$

Applying Kirchhoff's second law to the closed path (loop) (**a e c b a**)

$$\sum V_B = \sum I\,R$$

$$20 - 30 = 1 \times I_1 - 2 \times I_2$$

$$-10 = I_1 - 2I_2 \quad \rightarrow \quad (2)$$

Applying Kirchhoff's second law to the closed path (loop) (**a ef d b a**)

$$20 - 15 = 1 \times I_1 + 5 \times I_3$$

$$5 = I_1 + 5\,(I_1 + I_2)$$

$$5 = 6I_1 + 5\,I_2 \quad \rightarrow \quad (3)$$

Solving equations (2) and (3), by multiplying equation (2) x 5 and equation (3) x 2

$$-50 = 5 I_1 - 10 I_2$$

$$10 = 12 I_1 + 10 I_2$$

Adding the two equations:

$$-40 = 17 I_1$$

$$I_1 = -2.35 \text{ A}$$

The direction of the current I_1 is opposite to the assumed direction. i.e. The battery 20 V is in a state of charging.

Substituting in (2), we find that: $I_2 = -3.82$ A i.e. the battery 30 V is in a state of discharge.

And the current $I_3 = 1.46$ A

Terminal voltage of the battery 20 V:

$$V_1 = V_B + I r = 20 + (2.35 \times 1) = 22.35 \text{ V}$$

Terminal voltage of the battery 30 V:

$$V_2 = V_B - I r = 30 - (3.82 \times 2) = 22.36 \text{ V}$$

$$V_3 = 15 \text{V}$$

$$V_R = 5 \times 1.46 = 7.3 \text{ V}$$

In a Nutshell

Basic Laws:

- If charge Q flows across a section through a circuit in time t, the current intensity is given by:

$$I = \frac{Q}{t}$$

- If work done to transfer Q (Coulomb) is (W Joule), the voltage (or potential) difference in volts (V) is :

$$V = \frac{W}{Q}$$

- Ohm's law : If the voltage difference across a conductor is V(V) and current I (A) flows then:

$$R = \frac{V}{I}\ \Omega$$

Where R is the resistance of the conductor (also called resistor)

- Resistivity (ρ_e) at a constant temperature:

$$\rho_e = \frac{RA}{l}$$

Where R is the resistance (Ω), A is the cross sectional area (m2), and ℓ is the length (m).

- Conductivity ($\Omega^{-1}m^{-1}$).

$$\sigma = \frac{1}{\rho}$$

- In a series connection:

$$R = R1 + R2 + R3 + \dots$$

- For N equal resistances is series each r, R = Nr

- In a parallel connection:

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

- For N equal resistances each R:

$$R' = \frac{R}{N}$$

- Ohm's law for a closed circuit:

$$I = \frac{V_B}{R' + r}$$

where V_B is the emf of the source, r is its internal resistance and R is the external resistance.

Kirchhoff's First Law

The sum of currents flowing into a node in electric circuit is equal to the sum of currents flowing out of that node

$$\sum I = 0$$

Kirchhoff's Second law

The algebraic sum of the electromotive forces in any closed loop is equivalent to the algebraic sum of potential differences in that loop

$$\sum V_B = \sum IR$$

Questions and Drills

I) Complete

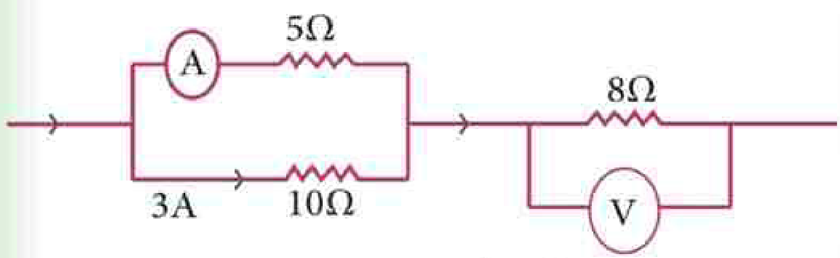
1) When a current of intensity 3A passes through a point in an electric circuit, the electric charge passing through one minute equals..........

2) The voltage difference in volt required to let a current of 3A pass through a 6 Ω resistor equals...............

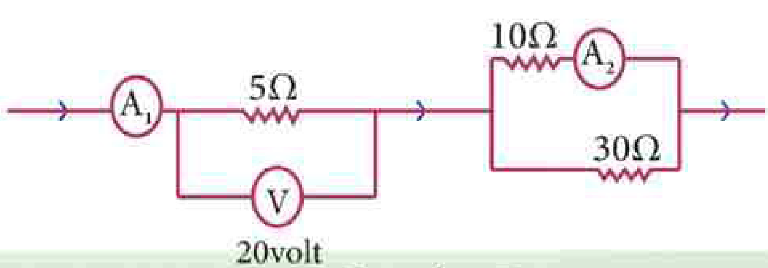
3) If the voltage difference across a 2 Ω resistor is 6V, the current intensity is..........

4) If two equal resistances 1 Ω each are connected in series, the equivalent resistance is ...., but if they are connected in parallel, it is ....

5) The emf is measured in the same unit as ....



Question 6



Question 7

6) In the circuit shown :

a) the ammeter reading is ....

b) the voltmeter reading is ....

7) In the circuit shown

a) the ammeter reading A_1 is ....

b) the ammeter reading A_2 is ....

II) Choose the right answer:

Four lamps 6Ω each are connected in parallel. The combination is connected to a 12V battery with a negligible internal resistance:

1) The current in the battery equals..........

a) 8A b) 6A c) 4A d) 2A e) 72A

2) The total charge leaving the battery in 10s is...............

a) 80C b) 60C c) 40C d) 20C e)2C

3) The current in each lamp is ....

a) $\frac{3}{2}$ A b) 8A c) $\frac{3}{2}$ A d) 1A e) 2A

4) The voltage difference across each lamp is..........

a) 3V b) 12 V c) 6 V d) 2 V e) 4 V

5) The total resistance of the four equal lamps is...........

a) $\frac{2}{3}$ Ω b) 24Ω c) $\frac{3}{2}$ Ω d) 6Ω e) 12Ω

6) If the 4 lamps are connected in series, the total resistance is.............

a) $\frac{3}{2}$ Ω b) 24Ω c) $\frac{2}{3}$ Ω d) 6Ω e) 12Ω

III) Essay Questions:

1) Show how to prove that the equivalent resistance of 3 resistors connected in series is given by:

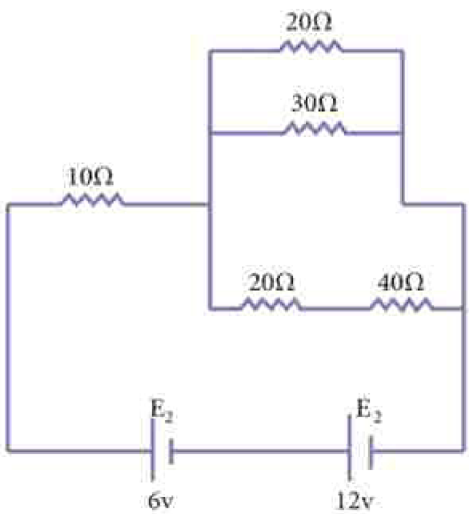
   $R = R_1 + R_2 + R_3$

2) Show that the reciprocal of the equivalent resistance of 3 resistors connected in parallel is equal to the sum of the reciprocals.

3) What are the factors determining the resistance of a conductor?

IV) Drills:

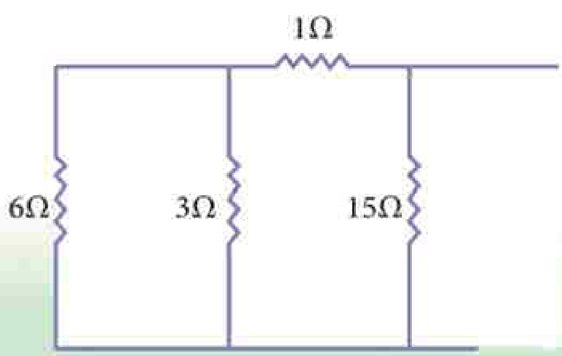
1) Calculate the total resistance in the circuit shown and also the total current intensity if the internal resistance of each cell is 2 Ω. (0.75 A, 20Q)



Drill 1

30Ω

2) Determine the equivalent resistance of a bunch of the resistors shown.



Drill 2

3) The circuit shown in Fig (1 – 5) consists of a 15 V battery, an external resistance 2.7Ω and a switch. If the internal resistance of the battery is 0.3Ω, determine :

a) the reading of the voltmeter when the switch is open, assuming that the voltmeter resistance is infinite. (15 V)

b) the reading of the voltmeter when the switch is closed. (13.5)

4) A student wound a wire of a finite length as a resistor. Then, he made another of the same material but half the diameter of the first wire and double the length. Find the ratio of the two resistances. (1:8)

5) A copper wire 30 m long and $2 \times 10^{-6} m^2$ cross sectional area has a voltage difference of 3V across. Calculate the current if the copper resistivity is 1.79×10^{-8} Ω.m

(11.17 A)

6) A 5.7Ω resistor is connected across the terminals of a battery of 12Ω emf and 0.3Ω internal resistance. Calculate:

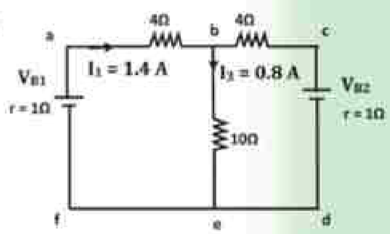
a) the current in the circuit . (2. A)

b) the voltage difference across the resistor. (11.4 V)

7) Analyze the given circuit in the opposite diagram using Kirchhoff's laws to find:

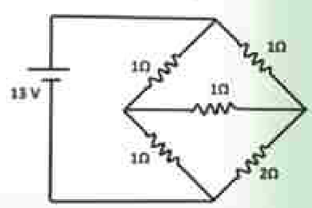
a) V_{B1} and V_{B2}
b) The voltage drop across eb

Answers: (V_{B1}= 15 V, V_{B2} = 5 V and V_{eb} = 8 V)



8) Find the equivalent resistance of the given resistance network using Kirchhoff's laws.

Answer: 1.18 Ω



Dynamic Electricity and Electromagnetism

UNIT 2

Chapter 2 : Magnetic Effects

Overview

In 1819, Hans Christian Oersted- a Danish physicist-brought a compass near a wire carrying an electric current. He noticed that the compass was deflected. When he turned the current off, the compass assumed its original position. The deflection of the compass-while current was flowing through the wire- indicated that it was being acted upon by an external magnetic field.This discovery started a chain of events that has helped shape our industrial civilization.

In this unit we are going to study the magnetic field of current- carrying conductors in the form of:

a) a straight wire. b) a circular loop. c) a solenoid.

Magnetic field due to current in a straight wire:

We can examine the pattern of the flux density surrounding a long straight wire carrying a direct current using iron filings sprinkled on a paper surrounding the wire in a vertical position.It will be noted that they become aligned in concentric circles around the wire, as shown in Fig (2 -1).

Oersted

Fig (2 – 1)
Pattern of iron filings around a wire carrying current

The figure shows that the circular magnetic flux lines are closer together near the wire and farther apart from each other as the distance from the wire increases.

As the electric current in the wire increases, the iron filings rearrange themselves after gently tapping the board such that the concentric circles become more crowded.

This indicates that the magnetic field due to the electric current passing through a straight wire increases with increasing the current intensity and vice verse.

The magnetic flux density **B** measured in Weber/m^2 or Tesla ($\mathbf{B} = \frac{\phi_m}{A}$ where ϕ_m is the magnetic flux, A is the area) a point near a long straight wire carrying current I can be determined using the formula:

$$B = \frac{\mu I}{2 \pi d} \qquad (2\text{-}1)$$

This relation is called Ampere's circuital law, where d is the normal distance between the point and the wire, and μ is the magnetic permeability of the medium (in air it is $4\pi \times 10^{-7}$ Weber/A.m.)Thus, B is inversely proportional to d and directly proportional to I. This is why it is advisable to live away from high voltage towers.

Ampere's right hand rule:

To determine the direction of the magnetic field resulting from an electric current in a wire, imagine that you grasp the wire with your right hand such that the thumb points in the direction of the current. The rest of the fingers around the wire give the direction of the magnetic field due to the current (Fig 2-2).

Fig (2 – 2)
Right hand rule

Examples:

Determine the magnetic flux density at a distance of 10cm in air from the center of a long wire carrying a current of 10A.

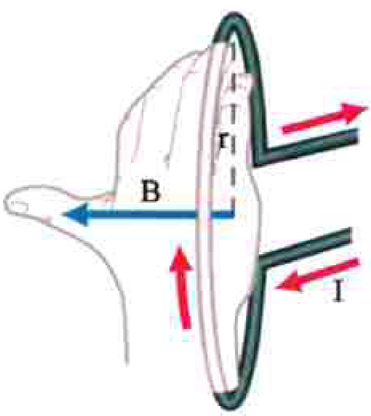
Solution:

$$B = \frac{\mu I}{2\pi d} = \frac{4\pi\times 10^{-7}\times 10}{2\pi\times 0.1} = 2\times 10^{-5} \text{ Tesla}$$

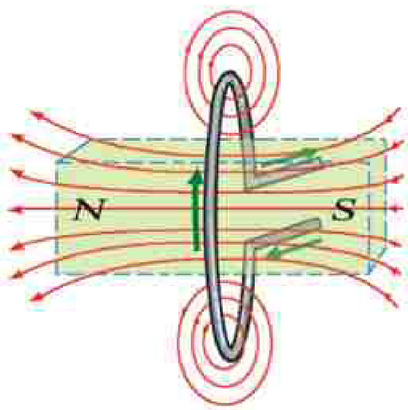
Magnetic field due to current in a circular loop:

If a wire is bent into a circular loop and caries current as shown in Fig. (2-3), the magnetic field is very similar to that of a short bar magnet. One face of the loop-where the direction of the current is clockwise upon looking at it-behaves as a south pole, and the other face-where the direction of the current is counter clockwise- behaves as a north pole.

a) field pattern



b) direction of the magnetic field at the center of the loop



c) polarity of the loop

Fig (2 – 3)

Magnetic field due to a circular loop

To study the magnetic field due to a circular loop (or a coil),iron filings are sprinkled on the board as shown in Fig (3 -10). Tapping it gently, the filings arrange themselves as shown in figure, from which we can notice that:

1. the flux lines near the center of the loop are no longer circular.
2. the magentic flux density changes from point to point.
3. the magnetic flux lines at the center of the loop are straight parallel lines perpendicular to the plane of the coil. This means that the magnetic field in this region is uniform.

The flux density at the center of a circular loop of N turns and radius r carrying current I is given by :

$$B = \frac{\mu N I}{2r} \qquad (2\text{-}2)$$

From this relation, the magnetic flux density at the center of a circular loop depends on three parameters:

1. number of turns of the circular loop where $B \propto N$.
2. current intensity passing through the circular loop where $B \propto I$.
3. radius of circular loop where $B \propto \frac{1}{r}$.

- Right-hand screw rule:

To determine the direction of the magnetic field at the center of a circular loop or coil, imagine a righthand screw being screwed to tie along the wire in the direction of the current. The direction of fastening of the screw gives the direction of the magnetic flux at the center of the loop (Figs. 2-4, 2-5)

Thus, a circular loop carrying current acts as a magnetic dipole.

It is to be noted that no single poles exist in nature. They always exist in N - S pairs.

Thus circular loop carrying current may be considered a solid disc having two circular poles as a bar magnet (Fig 2-3)

Fig (2 – 4)
Right hand screw direction of screwing.

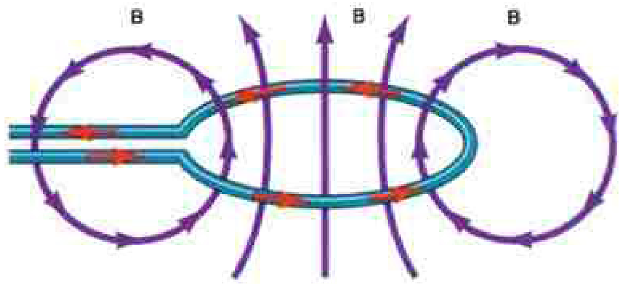


Fig (2 – 5)
A circular loop carrying current in the direction of screwing.

Examples:

Determine the magnetic flux density at the center of a circular loop of radius 11cm carrying a current of 1.4 A. if the wire loop consists of 20 turns and $\mu_{air} = 4\pi \times 10^{-7}$ Weber/Am

solution:

$$B = \frac{\mu NI}{2r} = \frac{4\pi \times 10^{-7} \times 20 \times 1.4}{2 \times 0.11}$$

$$= \frac{4 \times 22 \times 10^{-7} \times 20 \times 1.4}{7 \times 2 \times 0.11} = 16 \times 10^{-5} \text{ Tesla}$$

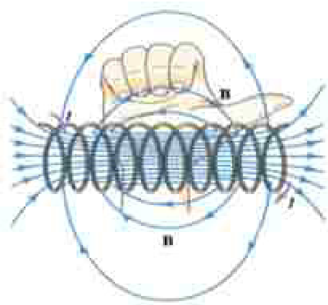
Magnetic field due to current in a solenoid:

When an electric current is passed through a solenoid (a long spiral or cylindrical coil) as shown in Fig(2-6), the resultant magnetic flux is very similar to that as a bar magnet. As shown in Fig(2-6A), the magnetic flux lines make a complete circuit inside and outside the coil,i.e., each line is a closed path. The side at which the flux emerges is the north pole, the other side where the magnetic flux reenters is the south pole. The magnetic flux density in the interior of a solenoid carrying an electric current depends on :

1) the current intensity passing through the coil where $B \propto I$.

2) the number of turns per unit length where $B \propto n$:

a) field pattern



b) polarity of the coil using Ampere's right hand rule.

Fig (2 – 6)

Magnetic field due to a solenoid carrying current

$$\therefore B \propto nI$$

$$B = \mu nI$$

where μ is the permeability of the core material. In this case, it is air

This relation may be rewritten as follow:

$$B = \mu \frac{N}{\ell} I \qquad (2\text{-}3)$$

Where N is the number of tuns of a solenoid of length ℓ. To determine the polarity of a solenoid carrying current we have the right screw rule considering that the solenoid consists of concentric turns (Fig 2-6b).

Examples:

1) A long solenoid has 800 turns and carries a current of 0.7A. Find the magnetic flux density at a point on the axis of a solenoid knowing that its length is 20 cm.

Solution :

$$B = \frac{\mu N I}{\ell} = \frac{4 \times 22 \times 10^{-7} \times 800 \times 0.7}{7 \times 0.2}$$

$$= 3.52 \times 10^{-3} \text{ Tesla}$$

2) A solenoid is constructed by winding 800 turns of wire on a 20 cm iron core. What current is required to produce a flux density of 0.815 Tesla at the center of the solenoid ? The permeability of iron is 1.63 10^{-2} Weber/Am

Solution :

$$B = \mu \frac{NI}{\ell}$$

$$0.815 = \frac{1.63 \times 10^{-2} \times 800 \times I}{0.2}$$

$$I = \frac{0.815 \times 0.2}{1.63 \times 10^{-2} \times 800} = 0.0125 \text{ A}$$

Force due to magnetic field acting on a straight wire carrying current.

If we place a straight wire carrying current between the poles of a magnet,a force results which acts on the wire and is perpendicular to both the wire and the field (Fig 2-7). The direction of the force is reversed if we reverse the current or the magnetic field. In all cases, the force is perpendicular to both electric current and the magnetic field. In case the wire is allowed to move due to this generated force, the direction of motion is perpendicular to both the electric current and the magnetic field. The direction of the force with which a magnetic field acts on a current- carrying wire perpendicular to the field can be obtained by applying Fleming's left hand rule.

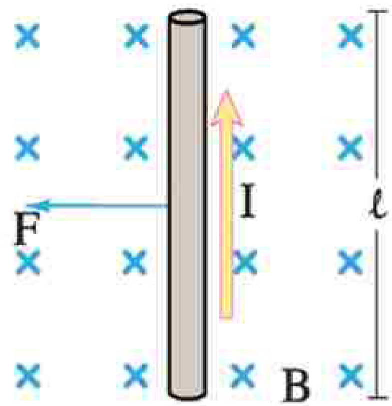


Fig (2 – 7)
Force due to a magnetic field acting on a straight wire carrying current, mark"x" denotes the direction into the paper.

Fleming's left hand rule

Form your left hand fingers as follows: the pointer and thumb perpendicular to each other and to the rest of the fingers. Make the pointer point to the direction of the magnetic flux, and the rest of the fingers- except the thumb- in the direction of the current. Then, the thumb points to the magnetic force or motion (Fig 2-8).

Fig (2 – 8)
Fleming's left hand rule.

It is found that the force acting on a wire carrying current flowing perpendicularly to a

magnetic field depends on the following factors:

1) the length of the wire ℓ , as the force is directly proportional to the length of the wire F & ℓ
2) the current intensity I, as the force is directly proportional to the current in the wire I i.e. F & I.
3) the magnetic flux density B, as the force is directly proportional to the magnetic flux density. Thus: F & BI ℓ

$$\therefore F = \text{const} \times BI\ell$$

The unit for magnetic flux density is Tesla. It generates a force of 1 N on 1 m long wire carrying a current of 1A.

Weber/m2 = N/Am.

$$\boxed{F = BI\ell} \quad (2\text{-}4)$$

$$B = \frac{F}{I\ell}$$

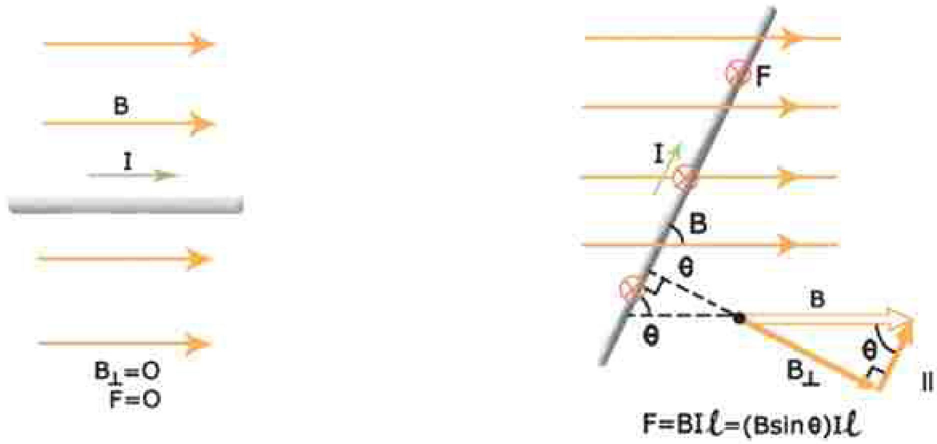
Tesla: The unit of the magnetic flux density

It is the magnetic flux density, which will exert a force of one Newton on a current carrying wire of one meter length perpendicular to the field when the current is one ampere. In general, if a wire of length ℓ makes an angle θ with the field "B" (Fig 2-9), then B can be analyzed into two components, one parallel to the current in the wire namely, B cos θ, and the other perpendicular to the direction of the current in the wire namely, B sin θ. In this case:

$$F = BI\ell \sin\theta$$

From this relation, we see that the force F vanishes when $\theta=0$, i.e, when the wire and the magnetic field are parallel.

You can imagine what the direction of the force will be in different cases. The mark ⊙ means out of the page, and the mark ⊗ means into the page.



a) the force vanishes when θ = 0

(wire and magnetic field are parallel)

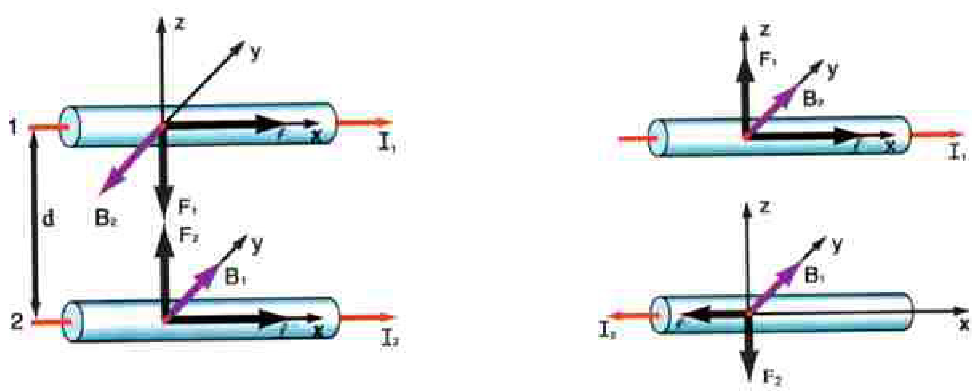
b) a force exists for θ other than zero

Fig (2 – 9)

A wire carrying current in a direction inclinded by an angle θ to the magnetic field.

The force between two parallel wires each carrying current.

When a current I_1 passes in a wire and a current I_2 passes in another parallel wire, a force results between the two wires. This force is attractive if the two currents flow in the same direction. The force is repulsive if the two currents flow opposite to each other. We can calculate this force as follows:



a) the two currents are in the same direction.

b) the two currents are in opposite directions.

Fig (2 – 10)

Force between two parallel wires each carrying current

$$B_2 = \frac{\mu_o I_2}{2\pi d}$$

$$F_1 = B_2 I_1 \ell$$

$$= \left(\frac{\mu_o I_2}{2\pi d}\right) I_1 \ell$$

$$F_1 = \frac{\mu_o I_1 I_2 \ell}{2\pi d}$$

Examples:

1) A 30 cm long wire supports a current of 4A in a direction perpendicular to a magnetic field. If the force developed on the wire is 6 N, find the magnetic flux density.

Solution:

$$F - BI\ell$$

$$6 = B \times 4 \times 0.3$$

$$B = \frac{6}{4\times0.3} = \frac{6}{1.2} = 5 \text{ Tesla}$$

2) If the wire in the previous example makes an angle 30° with respect to the field, find the force acting on the wire.

Solution:

$$F = BI\ell \sin\theta$$

$$= 5 \times 4 \times 0.3 \times \frac{1}{2} = 3 \text{ N}$$

Force and Torque acting on a rectangular coil carrying current placed in a magnetic field.

If we have a rectangular coil abcd (Fig 2-11), whose plane is parallel to the lines of a uniform magnetic flux, both ad and bc are parallel to the flux lines. The force acting on each wire is zero. As to both ab and cd, they are perpendicular to the flux lines. They will be acted upon by two forces equal in magnitude and opposite in direction and are parallel , each equal to $F=BI\ell_{cd}$, separated by a perpendicular distance ℓ_{ad} or ℓ_{bc} Thus, the coil is acted upon by a torque which will cause the coil to rotate around its axis.

The magnitude of the couple (torque) is equal to the force magnitude times the perpendicular spacing between the two equal forces:

$$\tau = BI\ell_{cd}\ell_{bc} = BIA$$

Where "A" is the area of the rectangle A= $\ell_{cd}\ell_{bc}$ if the rectangle consists of N turns , the total τ (read Taw) becomes:

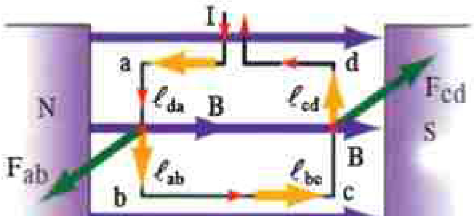
$$\boxed{\tau = BIAN = B\left|\overrightarrow{m_d}\right|} \quad (2-5)$$

Where $\tau\left|\overrightarrow{m_d}\right| IAN$ is the magnetic dipole moment which is a vector emanating from the north pole of the coil perpendicularly to area of the coil in the direction of advancing of a right hand screw, which is the direction of flow of the current. Thus, if the coil is perpendicular to the flux lines, m_d is along the flux lines and the couple is sero. If the plane of the coil is inclined with respect to the magenetic flux at an angle (Fig 2-11), then:

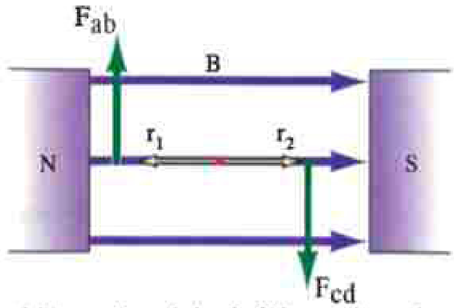
$$\boxed{\tau = BIAN \sin\theta} \quad (2-6)$$

Where θ is the angle between the normal to the plane of the rectangle (which is the direction of the magnetic dipole moment m_d and the magnetic flux lines).

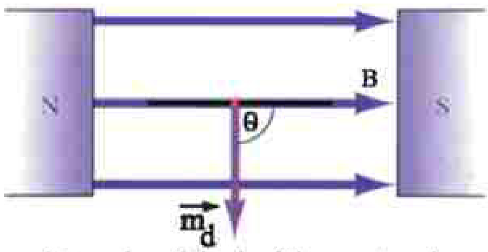
The concept of a couple in a coil carrying a current is used in many electrical measuring instruments and also in electric motors as that will be studied at the end of chapter 3.



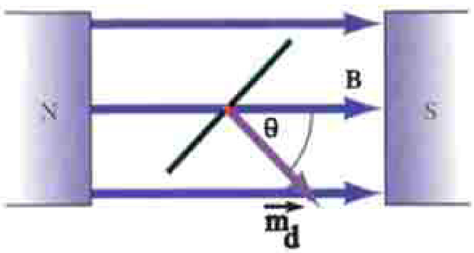
a) the coil is parallel to the magnetic field.



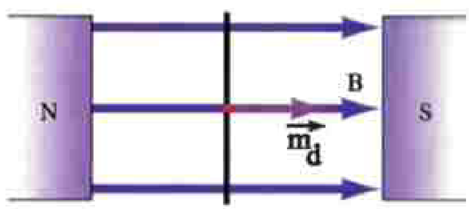
b) top view (plan)of the rectangle when the coil is parallel to the field.



c) top view (plan) of the rectangle when the magnetic dipole moment is perpendicular to the field.



d) top view (plan) of the rectangle when the magnetic dipole moment makes an angle θ with the field.



e) top view (plan) when the rectangle is perpendicular to the field or the magnetic dipole moment is parallel to the field and the couple is zero.

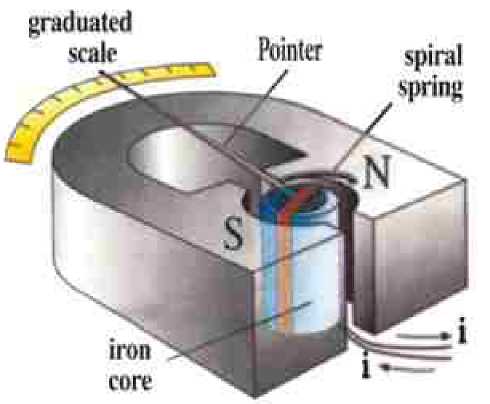
Fig (2 – 11)

A torque acting on a coil carrying a current

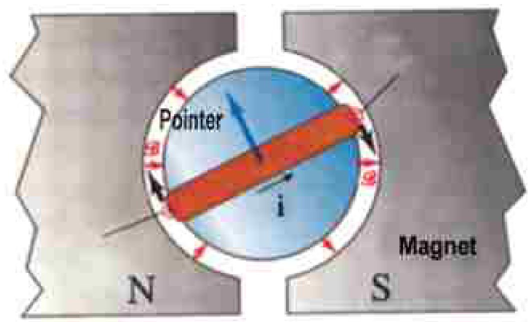
Applications: Measuning Instuments

The sensitive moving coil galvanometer

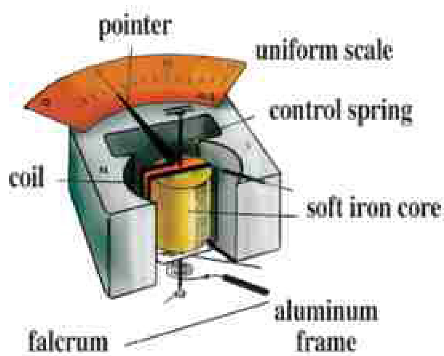
A sensutive moving coil galvanometer is an apparatus used to detect very weak currents in a circuit, measure their intensities and determine their polarities. Its principle of operation depends on the torque that is generated in a current -carrying coil moving in a magnetic field.



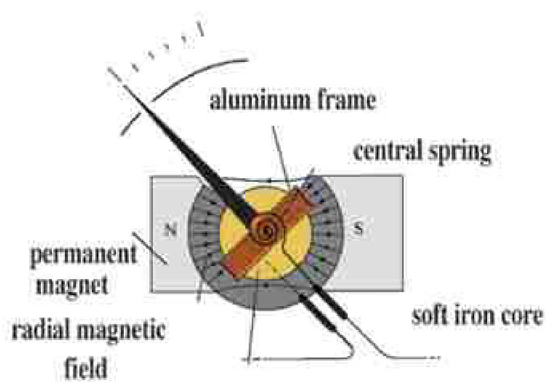
a) a simplified view of a galvanometer when the pointer is in the middle of the graduated scale



b) top view



c) a galvanometer converted to a milliammeter



d) top view

(Fig 2 – 12)
A moving coil galvanometer

The essential parts of this device are shown in Fig(2 -12). It consists of a rectangle of a thin wire coil wrapped around a light aluminum frame mountend on a soft iron core. The frame is pivoted on agate bearings. The assembly rotates between the poles of a U shaped (horse shoe) magnet. Its rotational motion is restrained by a pair of spiral control springs, which also serve as current leads to the coil. Depending upon the direction of the current being measured, the coil and pointer rotate either in clockwise or counterclockwise direction. The permanent magnet's poles are curved so that the magnetic flux lines are radially directed. Thus, the magnetic flux density is constant and perpendicular to the side of the rectangle irrespective of the angle of the coil. the deflection of the pointer is proportional to the current in the coil.

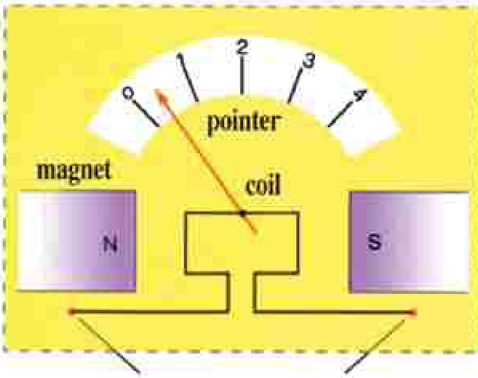
The current flows in the coil from the right side upwards, and emerges from the other side. Then the magnetic force generates a torque which makes the coil rotate clockwise. The pointer deflects until it settles at a certain reading when the torque is balanced with the spring torsion which is counterclockwise. Thus, at balance, we can read the current value. When the current is reversed, the pointer deflects in the opposite direction.

The galvanometer sensitivity:

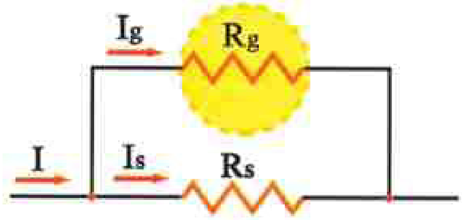
The galvanometer sensitivity is defined as the scale deflection per unit current intensity passing through its coil i.e, sensitivity = $\frac{\theta}{I}$ degree/micro ampere (deg/μA) .

Direct current (DC) ammeter :

An ammeter is a device which- through calibrated scales- is used to measure directly the electric current. A galvanometer is an ammeter of limited range due to its moving coil sensitivity. To extend the range of the galvanometer, it is necessary to add a very low resistance, called a shunt R_s to be connected in parallel with the galvanometer coil R_g as shown in Fig (2 -13).



a) a DC ammeter is a galvanometer whose pointer deflects in one direction



b) use of a shunt resistance

Fig (2 – 13)
The DC ammeter

Placing the parallel shunt assures that the ammeter as a whole will have a very low resistance, which is necessary if the current in the circuit is to be unaltered after connecting the ammeter in series.

Most of the current in the circuit passes through the shunt R_s, while only a small current I_g passes in the galvanometer coil R_g. If the maximum current to be measured is I, which is the full scale deflection (FSD), then

$$I = I_g + I_s$$

$$I_s = I - I_g$$

Because R_s and R_g are connected in parallel, the voltage difference across each is the same.

$$I_s R_s = I_g R_g$$

$$R_s = \frac{I_g R_g}{I_s}.$$

The two equations can be solved simultaneously to find R_s. Thus,

$$\mathbf{R_s = \frac{I_g R_g}{I - I_g}} \qquad (2\text{-}7)$$

Example:

A certain galvanometer has a resistance 2Ω, and a current of 5mA is required for full-scale deflection. What shunt resistance must be used to convert the galvanometer to an ammeter whose maximum range is 10 A?

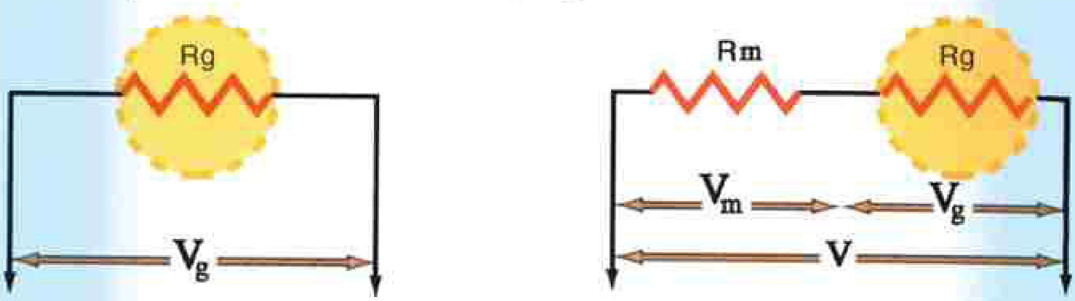
Solution:

$$R_s = \frac{I_s R_s}{I - I_s} = \frac{0.005 \times 2}{10 - 0.005}$$

$$R_s = \frac{0.01}{9.995} = 0.001\Omega$$

Direct current (DC) voltmeters:

A voltmeter is a device for measuring the potential difference across two points in an electric circuit. We shall discuss in this section how the galvanometer may be used to measure voltage. The positive terminal of the voltmeter must to connected to the positive terminal in the circuit. If the voltage difference is switched, the voltmeter connection must be inverted. The potential difference across a galvanometer is extremely small even when a large scale deflection occurs. Thus, if a galvanometer is to be used to measure the



a) the small coil resistance will not alter the value of the voltage to be measured in the curcuit

b) the use of a multiplier resistor Makes the resistance of the voltmeter high so it will not affect the voltage to be measured in the circuit

Fig (2 –14)
DC voltmeter

voltage,it must be converted to a high-resistance instrument.The voltmeter must draw a negligible current, so that it will not affect the voltage drop to be measured.To do this,a large multiplier resistor is connected in series with the galvanometer as shown in Fig. (2-14).The voltmeter is connected parallel across the two points between which the voltage difference is to be measured. Let us call the resistance of the galvanometer coil R_g and the multiplier resistance R_m which is connected in series parrallel with R_g. The maximum current that passes through it is I_g, which is the current needed for the full scale deflection (FSD) voltage V.

The voltage difference across the coil is :

$$V_g = I_g R_g$$

The maximum voltage drop to be measured is:

$$V = I_g R_g + I_g R_m = V_g + I_g R_m$$

$$\boxed{R_m = \frac{V - V_g}{I_g}} \qquad (2\text{-}8)$$

Example

A galvanometer has an internal resistance of 0.1Ω and gives a full scale deflection for a current of 1mA. Calculate the multiplier resistance necessary to convert this galvanometer to a voltmeter whose maximum range is 50V.

Solution

$$V_g = I_g R_g = 0.001 \times 0.1 = 1 \times 10^{-4}\ V$$

$$R_m = \frac{V - V_g}{I_g} = \frac{50 - 1 \times 10^{-4}}{1 \times 10^{-3}}$$

$$= 49999.9\ \Omega$$

The total resistance of the voltmeter is :

$$R_{total} = 49999.9 + 0.1 = 50000\ \Omega$$

Ohmmeter

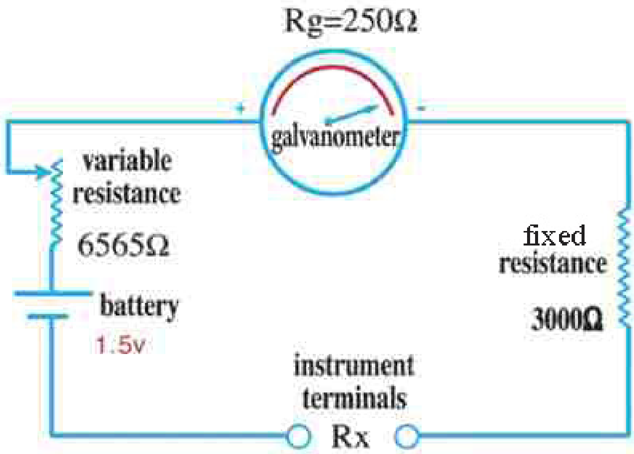


Fig (2 – 15)

A circuit for calibrating an ohmmeter

Measuring a resistance depends on measuring the current passing through it by an ammeter and the voltage drop across it by a voltmeter. If the current is I and the voltage drop is V, the resistance R from Ohm's law is R =V/I

If the voltage is fixed and known, we may remove the voltmeter from the circuit and calibrate the galvanometer to give the value of the resistance directly (Fig 2 -15).As the resistance is increased, the current in the circuit decreases,and consequently, the galvanometer reading.The Ohmmeter shown (Fig 2 -15) is actually a microammeter which reads 400µA as a full scale deflection (FSD).Its resistance is 250Ω connected in series with 3000Ω, a variable resistance whose maximum value is 6565Ω, and a 1.5 V battery of negligible internal resistance.When we short circuit (sc) the terminals of the instrument (R_X =0), current flows in the circuit.For this current to give FSD, the resistance in the circuit must be:

$$\frac{1.5}{400 \times 10^{-6}} = 3750 \ \Omega$$

The variable resistance must be adjusted to give FSD, when the variable resistance is 500 since 250+3000+500=3750Ω.

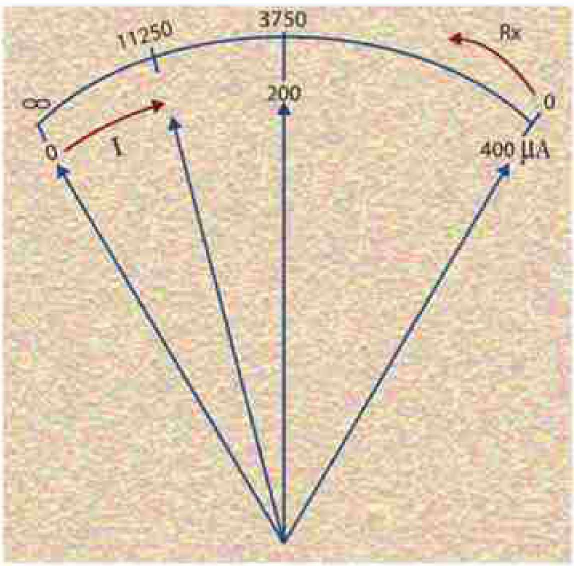
Now, if the unknown resistance is introduced into the circuit, the current flowing will be less, and the pointer will deflect short of FSD.

Thus, we may calibrate the instrument in terms of the resistance to be measured. If $R_x = 3750\Omega$, the current in the instrument is 200 μA, which is 1/2 the maximum current, and hence the deflection is 1/2 FSD.

If the resistance is doubled, i.e., 7500Ω., the deflection will be $\frac{1}{3}$ FSD. For three times the total resistance, i.e., 11250Ω, the deflection will be $\frac{1}{4}$ FSD corresponding to a current of 100μA. It is to be noted that the graduated scale used to measure the resistance (Fig 2-16) is opposite to the graduated scale for the current .

This means that the maximum deflection corresponds to zero resistance (short circuit or sc). As the resistance increases, the deflection decreases.

It is to be noted also that the scale is not linear. The spacings between the readings of the scale to the right are further apart than the readings to the left.



$R_x(\Omega)$	IμA
0	400
3750	200
11250	100
∞	0

Fig (2 – 16)

An ohmmeter has a nonlinear graduated scale

The instruments using a point, are called analog instruments. A combined instrument called multimeter can be switched around to measure voltage, curent and resistance (Fig 2-17).

Another set of instruments now exist which depend on reading numerals, denoting voltage, current a resistance on a small LCD (liquid crystal display) without the need for a pointer. Such instruments are called digital multimeters (Fig 2-18).

Fig (2 – 17)
Analog multimeter

Fig (2 – 18)
Digital multimeter

In a Nutshell

- Definitions and Basic Concepts:

- A megnetic field is produced around a current-carrying wire.
- The intensity of the magnetic field produced around a current-carrying wire, increases, by :
  a) getting closer to the wire.
  b) increasing the current.
- The direction of the magnetic field produced around a current-carrying straight wire is determined by Ampere's right-hand rule.
- The lines of force around a current-carrying wire forming a circular loop, resemble to a great extent those of a short bar magnet.
- The magnetic flux density at the center of a current-carrying circular loop depends on:
  a) the number of loop turns.
  b) the current intensity in the loop.
  c)the radius of the loop.
- The direction of the magnetic field at the center of a current-carrying loop is determined by the right-hand screw rule.
- The magnetic field produced by a current flowing through a solenoid (coil of several closely spaced loops) resembles to a great extent that of a bar magnet.
- The magnetic flux density at any point on the axis of a current-carrying a solenoid depends on :
  a) the current intensity.
  b) the number of turns per unit length.
- Right-hand screw rule is used to determine the polarity of a solenoid carrying a current.
- The unit of magnetic flux density is Web / m^2, (Tesla or N/Am).
- The force exerted by a magnetic field on a current-carrying wire placed in the field depends on:

a) the length of the wire.

b) the current intensity.

c) the magnetic flux density.

d) the angle between the wire and the direction of the magnetic field.

- A moving coil galvanometer is an instrument used to detect, measure and determine the polarity of very weak electric currents.
- The operation of a moving coil galvanometer is based on the torque acting on a current loop in the presence of a magnetic field.
- The sensitivity of a galvanometer is defined as the scale deflection per unit current intensity flowing through its coil.
- The ammeter is a device which is used through a calibrated scale to measure directly the electric current.
- To extend the range of the galvanometer, a low resistor known as a shunt is connected in parallel with the coil of the galvanometer.
- The total resistance of the ammeter (with the shunt) is very small, therefore, it does not appreciably change the current to be measured in a closed circuit.
- The voltmeter is a device used to measure the potential difference across two points of an electric circuit. It is basically a moving coil galvanometer having a very high resistance called a multiplier resistance connected in series with its coil.
- Since the total resistance of the voltmeter is very great, it does not affect much the flow of current through the element across which it is connected to measure its potential difference.
- The ohmmeter is an instrument which is used to measure an unknown resistance.
- An ohmmeter is basically a microammeter connected in series with a constant cell resistance, a variable resistance and a 1.5 volt battery. If its terminals are in contact (sc), the pointer gives full-scale deflection (FSD). If a resistor is inserted between its terminals, the current flowing decreases. Hence, the pointer's deflection decreases, and indicates directly the value of the inserted resistor through a calibrated scale.

Basic Laws :

- The magnetic flux density "B" at a point which is d (m) away from a wire carrying current I (A) is determined by the relation $B = \frac{\mu I}{2\pi d}$ Weber/m2 (or Tesla).
- The magnetic flux density B at the center of a circular loop of radius r, carrying current I and on N turns, is:

$$B = \frac{\mu N I}{2r} \text{ (Tesla)}$$

- The magnetic flux density at any point on the axis of a solenoid of length ℓ, number of turns N and carrying current I, is:

$$B = \frac{\mu I N}{\ell} \text{ (Tesla)}$$

- The magnetic force acting on a wire of length carrying current I and placed in a magnetic field of B flux density is:

$$F = B I \ell \sin\theta$$

Where θ is the angle between the wire and the direction of the magnetic field.

- The torque acting on a rectangular loop of face area A, number of turns n, carrying current I and placed parallel to a magnetic field of flux density B is:

$$T = B I A N = |\overline{m}_d| B \text{ (Nm)}$$

- Where $|\overline{m}_d|$ = IAN. The magnetic dipole moment $\overline{m}_d$ is a vector perpendicular to the plane of the coil.
- The value of the shunt of an ammeter is given from the relation: $R_s = \frac{I_g R_g}{I - I_g}$, where Rs is the shunt resistance, Ig is the maximum current in the galvanometer coil. Rg is the resistance of the galvanometer coil, and I is the full scale deflection (FSD) current.
- The multiplier resistance Rm in a voltmeter is given by the relation. $R_m = \frac{V - V_g}{I_g}$, where V is the FSD voltage, Vg is the voltage drop across the galvanometer coil and Ig is the current flowing in the galvanometer which corresponds to full scale deflection (FDS).

Questions and Drills

I) Essay questions:

1) State the parameters on which the magnetic flux density depends in each of the following cases:

   a) around a long current-carrying straight wire.

   b) at the center of a circular loop that carries current.

   c) at any point on the axis of a current-carrying solenoid.

2) What are the parameters affecting the magnitude of the force with which a magnetic field acts on a current-carrying wire placed at right angles to the field?

3) Prove that the force F acting on a long wire B of length carrying current I and placed at right angles to a magnetic field of flux density B is determined by the relation: $F = BI\ell$.

4) Prove that the torque τ acting on a loop of face area A, number of turns N, carrying a current I and placed parallel to a magnetic field of B flux density is $\tau = B\,I\,A\,N$

5) Describe with the aid of a labeled diagram the construction of the sensitive galvanometer and explain its basic operation.

6) Explain how the sensitive galvanometer is converted to be used as an ammeter. Deduce the required relation.

7) Explain how the sensitive galvanometer is converted to be used as a voltmeter. Deduce the required relation.

8) Give reasons for:

   a) mounting a soft iron cylinder inside the coil of the galvanometer.

b) the coil of the moving coil galvanometer is attached to a pair of spiral springs.

c) when the moving coil galvanometer is used as a voltmeter, a resistor of high resistance is connected in series with its coil.

d) an ammeter is connected in series with a circuit, but the voltmeter is connected parallel to it.

e) connecting a constant resistor inside the ohmmeter.

f) the cell connected to the ohmmeter should have a constant emf.

9) What is meant by each of: potential multiplier and shunt? What is the use of each? Deduce the rule related to each.

10) Explain how you can use the moving coil galvanometer to measure each of the electric current, the electromotive force and the electrical resistance.

II) Drills:

1) A coil of cross sectional area 0.2 m^2 is placed normal to a regular magnetic flux of density 0.04 Weber/m^2. Calculate the magnetic flux which passes through this coil. (0.008 Weber).

2) A wire of 10 cm length, carrying a current 5 A, is placed in a magnetic field of 1Tesla flux density. Calculate the force acting on the wire, when:

a) the wire is at right angles to the magnetic field. (0.5 N)

b) the angle between the wire and the field is 45°. (0.356 N)

c) the wire is parallel to the magnetic flux lines. (0)

3) A straight wire of diameter 2 mm carries a current of 5A. Find the magnetic flux density at a distance of 0.2 m from the wire. ($5x10^{-6}$ Tesla).

4) A circular loop of radius 0.1 m carries a current of 10 A. What is the magnetic flux density at its center? (the loop has one turn). (2π x 10^{-5} Tesla)

5) What is the magnetic flux density at a point on the axis of a solenoid of length 50 cm carrying a current of 2A and has 4000 turns? (0.02 Tesla).

6) A rectangular loop (12 x 10 cm) of 50 turns, carrying a current of 3 A, is placed in a magnetic field of 0.4 Tesla flux density, such that the plane of the loop is parallel to the field. Calculate the torque acting on the loop. (0.72 Nm)

7) A galvanometer's loop of 5 x 12 cm^2 and 600 turns is suspended in a magnetic field of 0.1 Tesla flux density. Calculate the current required to produce a torque of 1 Nm. (2.78 A).

8) A loop of cross-sectional area 0.2 m^2 and 500 turns,carrying a current of 10 A is placed at 30° between the normal to its plane and a magnetic field of 0.25 Tesla flux density. Calculate the torque acting on the loop. (125 Nm).

9) The coil of an ammeter is capable of carrying current up to 40 mA. If the resistance of the coil is 0.5Ω, and it is desired to use the ammeter for measureing a current of 1 A, What is the resistance value of the required shunt? (0.021Ω)

10) A galvanometer gives full scale deflection at current 0.02 A, and its terminal voltage is 5 V. What is the value of the multiplier resistance required to make it valid to measure potential differences up to 150 V? (7250Ω)

11) A voltmeter reads up to 150 V at full scale deflection. If the resistance of its coil is 50Ω and the current flowing is 4 x 10^{-4} A. Calculate the resistance of the potential multiplier connected to the coil? (374950Ω)

12) A galvanometer reads up to 5A and has a resistance of 0.1 Ω. If we want to increase its reading 10 times, what is the value of the required shunt resistor? (0.0111Ω).

13) An ammeter has resistance 30Ω. Calculate the value of the required shunt resistor to

(Decrease the sensitivity) to one third, and determine also the total resistance of the ammeter and the shunt resistor. (15 Ω, 10Ω).

14) A galvanometer of resistance 54Ω, when connected to a shunt (a), the current flowing through the galvanometer is 0.1 of the total current. But if connected to a shunt (b), 0.12 of the total current flows through the galvanometer. Find the resistances of a and b. (6 Ω, 7.364Ω)

15) A moving coil galvanometer of resistance 50 ohms gives full scale deflection at current 0.5A. How could it be converted to measure:

a) potential differences up to 200V? (350 Ω in series).

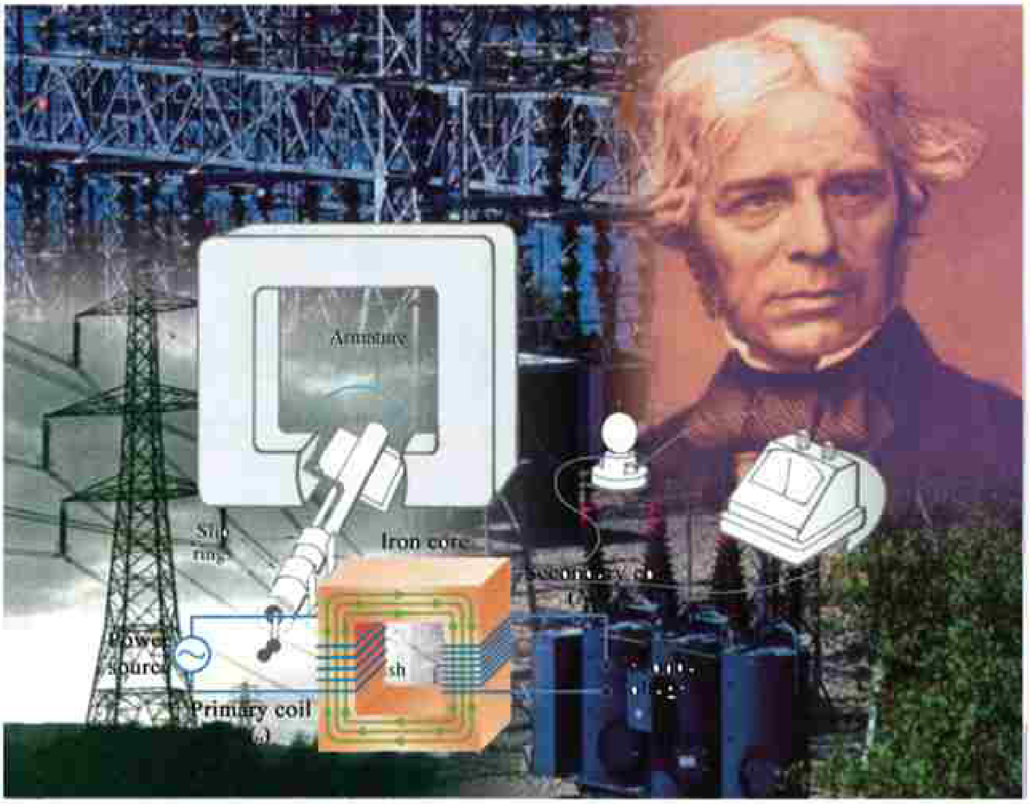
b) electric currents up to 2A? (16 2/3 Ω in parallel)

16) A milliammeter of resistance 5Ω has a coil capable of carrying a current of 15 mA. It is desired to use it as an ohmmeter using an electric cell of 1.5V having internal resistance 1Ω. Calculate the required standard resistor, and calculate the external resistance needed to make the pointer deflect to 10mA? Calculate the current that flows through it when connected to an external resistor of 400Ω ?

(94Ω, 50Ω, 3mA)

Dynamic Electricity & Electromagnetism

UNIT 1



Chapter 3: Electromagnetic Induction

Chapter 3 Electromagnetic Induction

Overview

It has been noticed that the passage of an electric current in a conductor produces a magnetic field. Soon after Oersted's discovery that magnetism could be produced by an electric current,a question arose, namely, could magnetic field produce an electric current ?

This problem was addressed by Faraday through a series of experiments which led to one of the breakthroughs in the field of physics, namely, the discovery of electromagnetic induction. On the basis of such a discovery, the principle of operation and function of most of the electric equipment - such as the electrical generators (dynamos) and transformers - depend.

Faraday's Experiment:

Faraday made a cylindrical coil of insulated copper wire, such that the coil turns were separated from each other. He connected the two terminals of the coil to a sensitive galvanometer having its zero reading at the mid point of its graduated scale, as shown in Fig (3-1) . When Faraday plunged a magnet into the coil, he noticed that the pointer of the galvanometer was deflected momentarily in a certain direction. On removing the magnet from

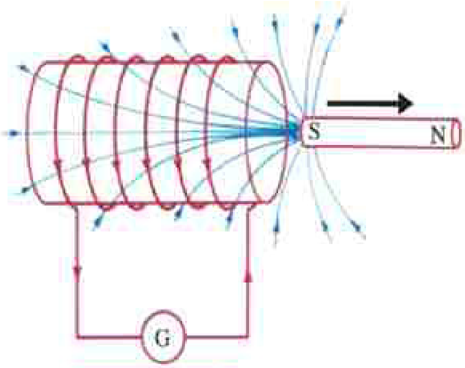


Fig (3-1a)

The magnet is plunged into the coil

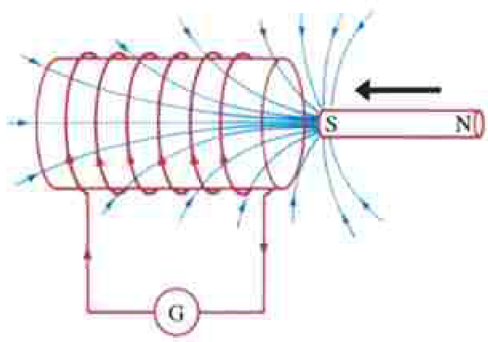


Fig (3-1b)

The magnet is pulled out of the coil

the coil, a deflection of the pointer was noticed in the opposite direction. This phenomenon is called "electromagnetic induction". According to this phenomenon, an electromotive force and an electric current are induced in the coil, when the magnet is plunged into or removed from the coil. As a result, Faraday concluded that the induced electromotive force and also the induced electric current were generatd in the circuit as a result of the time variation of the magnetic flux linked with the coil during the motion of the magnet.

Moreover, the action of the magnet is met by a reaction from the coil.If the magnet is plunged into the coil, the induced magnetic field acts in a way to oppose the motion of the magnet. If the magnet is pulled out, the induced magnetic field acts to retain (or keep) the magnet in. Faraday concluded that the induced emf and current were generated in the circuit as a result of the time variation of magnetic field lines as they cut the windings of the coil while the magnet was in motion.

Faraday's laws:

From the above Faraday's observations, one can conclude the following:

1) the relative motion between a conductor and a magnetic field in which there is time variation of the magnetic flux linked with the conductor, induces an electromotive force in the conductor. Its direction depends on the direction of motion of the conductor relative to the field.

2) the magnitude of the induced electromotive force is proportional to the rate by which the conductor cuts the lines of the magnetic flux linked with it, i.e., $emf \propto \frac{\Delta \phi_m}{\Delta t}$

where $\Delta\phi_m$ is the variation in the magnetic flux intercepted by the conductor through the time interval Δt

3) the magnitude of the induced electromotive force is proportional to the number of turns N of the coil which cut (or link with) the magnetic flux., i.e.,

$$emf \propto N$$

Thus, from the analysis of the above mentioned results, one can conclude the following relation:

$$emf = -N \frac{\Delta \phi_m}{\Delta t} \qquad (3-1)$$

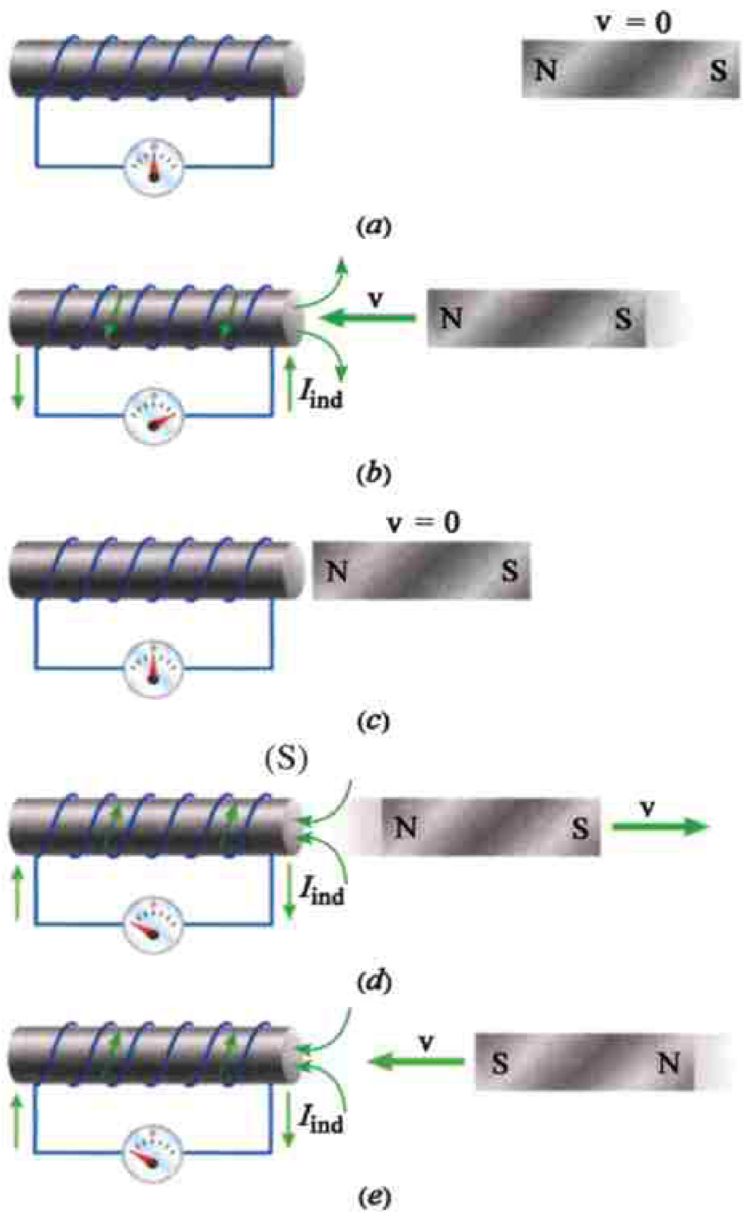


Fig (3 – 2)

Lenz's law

This is known as Farady's law of electormagnetic induction. The negative sign in the above relation indicates that the direction of the induced etectromotive force or the induced current tends to oppose the cause producing it. This rule is known as Lenz's rule.

Lenz's rule

The induced current must be in a direction such as to oppose the change producing it.

Fig (3 -2) illustrates a direct application of Lenz's rule :

As the North pole of the magnet is moved towards the coil,The induced electric current flows in the coil such that a North pole is formed at the coil end facing the North pole of the magnet (figure 3-2b) The repulsive force belween the .similar poles acts to resist the movement of the magnet towards the coil As the North pole of the magnet is moved away from the coil, the induced electric current flows in the coil such that a south pole is formed at the coil end facing the North pole of the magnet (figure 3-2d) The attractive force behween the different poles (south and North) acts to keep the magnet and resists the movement of the magnet away from the coil

The direction of the induced current in a straight wire:

In one of his several experiments, Faraday showed that the induced current in a straight wire flowed in a direction perpendicular to the magnetic field. Many years later. Fleming concluded a simple rule:

Fleming's right hand rule

Extend the thumb,pointer and the middle finger of the right hand, mutually perpendicular to each other. Let the pointer points to the direction of the field, and the thumb in the direction of motion, then the middle finger (with the rest of the fingers) will point to the direction of the induced current or voltage as shown in Fig (3 -3).

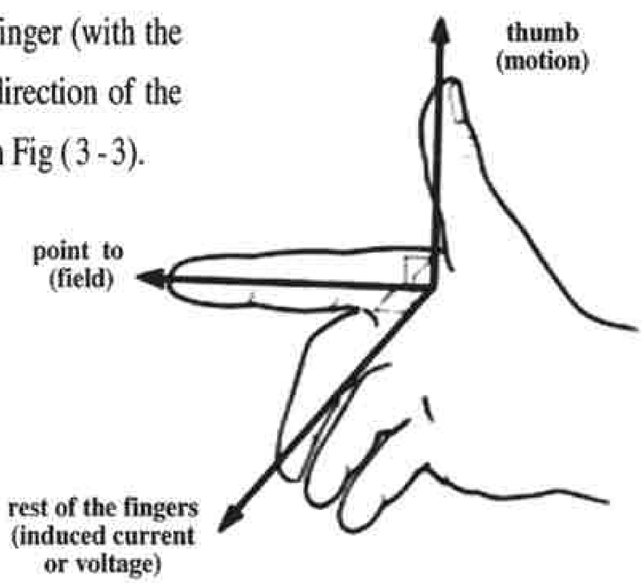


Fig (3 - 3)
Fleming's right hand rule

Mutual induction between two coils:

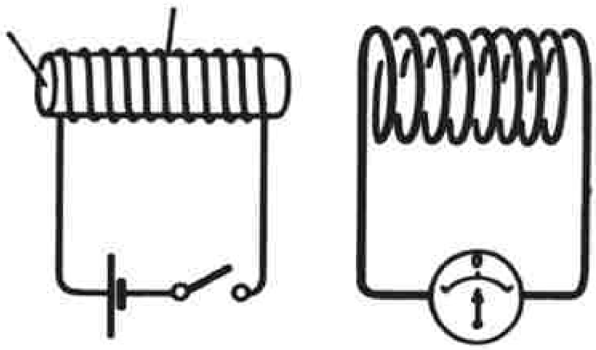


Fig (3 - 4A)
in case there is no current in the first coil, there is no emf in the second coil.

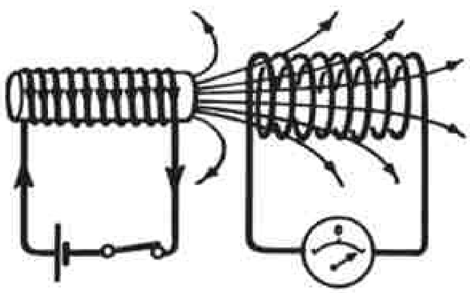


Fig (3 - 4b)
at the instant of closing the ciruit of the first coil, an emf is generated in the second coil.

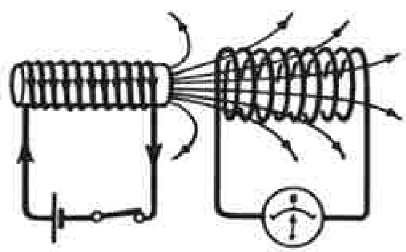


Fig (3 - 4c)
after the current in the primary is steady (the flux is steady) emf in the secondary coil: 0

If the two stationary coils are arranged such that one coil surrounds the other., i.e., one coil is plunged into the second one, or even one is placed in the neighborhood of the other as shown in Fig.(3 -4), then the variation in the intensity of the electric current in one of the two coils (opening and closing the switch) will induce an electromotive force in the other coil, according to Faraday's law. This induced electromotive force is proportional to the rate of change in the magnetic flux linked with the other coil. Since the magnetic flux is proportional to the intensity of current in the first coil.

$$(emf) \; \alpha \; \frac{\Delta I_1}{\Delta t}$$

$$(emf) = - M \frac{\Delta I_1}{\Delta t} \qquad (3\text{-}2)$$

where M is the coefficient of mutual induction (mutual inductance) of the two coils. Its unit is VsA^{-1} and is equivalent to what is called "Henry". Thus, the henry is the unit used to measure the inductance in general. The negative sign in equation (3 -2) follows from Lenz's rule, namely, that the direction of the induced electromotive force (or the direction of the induced current) is such as to oppose the cause producing it. The coefficient of mutual inductanc between two coils depends on the following factors.

1. the presence of an iron core inside the coil.
2. the volume of the coil and the number of its turns.
3. the distance separating them.

The transformer is considered as a clear example of mutual induction

Experiment to study mutual induction

One can study experimentally the mutual induction as follows:

Connect one of the two coils in a circuit which contains a battery, a switch and a rheostat. One coil is called the "primary coil", while the other coil - connected to a sensitive galvanometer with its zero point at the middle of its scale - is known as the "secondary coil". Fig(3 -5). Let us do the experiment as follows:

1) Close the circuit of the primary coil, while plunging the primary coil into the secondary coil. One notices a deflection in the galvanometer in a certain direction, indicating the generation of an induced electromotive force in the secondary coil due to the variation of the number of magnetic flux lines linked with the turns of the secondary coil. On taking away the primary coil from the secondary coil, one notices that the pointer of the sensitive galvanometer is deflected in the opposite direction.

2) Plunge the whole primary coil to reside in the secondary one, then increase the intensity of the current in the primary coil. Notice the deflection of the pointer of the galvanometer in a certain direction. Decrease the current in the primary, and notice that the deflection of the pointer takes place in the opposite direction. This indicates the generation of an induced electromotive force in the secondary coil on increasing or decreasing the intensity of the current in the primary coil.

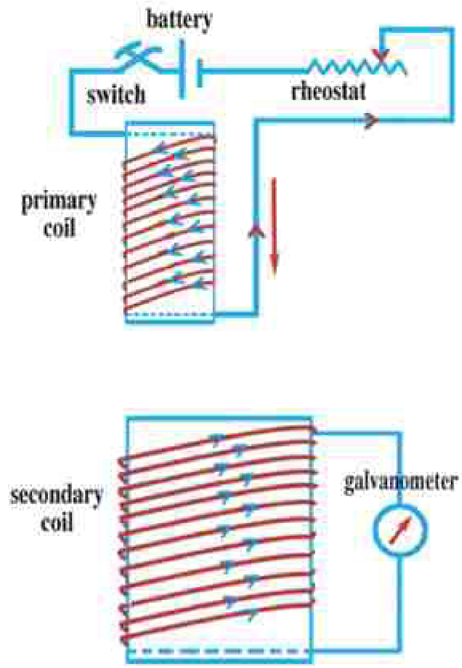


Fig (3 - 5)
Mutual inductance between two coils

3) With the primary coil inside the secondary one, close the circuit of the primary coil, a deflection is noticed in the galvanometer in a certain direction. Open the primary circuit, and notice that the deflection is in the opposite direction. This indicates that an electromotive force is induced in the secondary coil upon switching on or switching off the primary circuit.

The analysis of the above mentioned observations leads to the following conclusions:

I. The pointer of the sensitive galvanometer deflects in a certain direction in the following cases:

a) bringing the primary coil close to the secondary coil or when the primary coil is plunged inside the secondary one.

b) increasing the intensity of the current in the primary coil.

c) switching on the primary circuit.

In all cases above, there is a positive increase in magnetic flux linkage and the induced emf in the secondary coil increases as the affecting magntic field increases with time. The induced current is in opposing direction to that in the primary. In such a case, the induced magnetic field will be in a direction as to resist the increase in the affecting magnetic field.

II. The pointer of the galvanometer deflects in the opposite direction in the following cases:

a) on the withdrawal of the primary, or taking it far away from the secondary coil.

b) on decreasing the intensity of the current in the primary.

c) on switching off the primary circuit.

In the above cases, he intensity of the magnetic field affecting the secondary coil decreases and the magnetic flux linkage decreases. The induced emf in the secondary coil decreases as the affecting field decreases with time. The direction of the induced electromotive force (and the induced current) is in the forward direction, so as to produce a magnetic field in the same direction as the current in the primary. This in turn resists the decrease in the affecting magnetic field. All these observations clarify Lenz's rule, where the direction of the induced current is such as to resist (or to oppose) the time variation causing it.

Self induction of a coil:

One can understand what is meant by self induction of a coil by connecting the coil of a strong electromagnet (a coil of large number of turns) in series with a 6V battery, and a switch as shown in Fig (3 -6). Current passes in the considered coil, due to which a strong magnetic field is formed, since each turn acts as a small magnet. The magnetic flux links with the neighboring turns.

On switching off the circuit, it is noticed that an electric spark is passed between the two terminals of the switch. This is explained as follows.

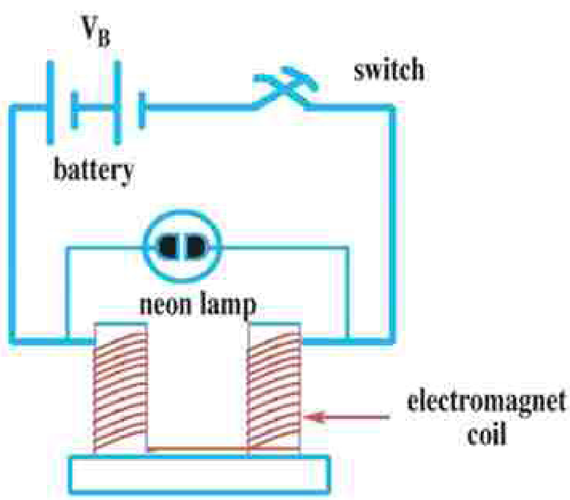


Fig (3 - 6)

Effect of self induction in a coil

When the coil circuit is switched off, the current ceases to pass in it, and this is associated with a decrease of the magnetic field of the neighboring turns to zero. This in turn is accompanied by a time variation of the flux linkage, i.e., each turn cuts the diminishing lines of the magnetic flux, and thus, an induced electromotive force is generated in the coil.

The induced electromotive force is formed in the turns of the coil as a whole as a result of the self induction of the coil itself. This induced electromotive force is generated due to the self induction of the coil on switching off or switching on the circuit following Lenz's rule. Thus, an induced electric current is generated in the same direction as the original current. When the circuit is switched off, to retain the existing current, a spark is formed between the two terminals of the switch. When the number of turns of the coil is large, the induced emf on switching off the circuit will be much larger than that of the battery, This causes a neon lamp connected in paralle1 between the two terminals of the switch to glow(a neon lamp requires a potential difference about 180V to glow).

Since the induced electromotive force is proportional to the rate of change of the current in the coil, then the emf induced by self induction is directly proportional to the rate of change of the current in the coil. That is :

$$(emf) \propto \frac{\Delta I}{\Delta t}$$

$$\therefore (emf) = - L \frac{\Delta I}{\Delta t} \qquad (3 - 3)$$

where L is a constant of proportionality known as the coefficiont of self induction (self inductance) of the coil, and the negative sign in equation (3 -3) indicates that the induced electromotivc force opposes the change causing it (Lenz's rule).

$$L = - \frac{emf}{\Delta I / \Delta t}$$

Thus, the self inductance of a coil is defined as:

It is the electromotive force induced in the coil when the current passing through it changes at a rate equals one Ampere per second. The self inductance is measured in the unit henry.

The Henry :

It is the self-inductance of a coil in which an emf of one volt is induced when the current passing through it changes at a rate of one Ampere per second $(vsA)^{-1}$.

The self inductance of a coil depends on:

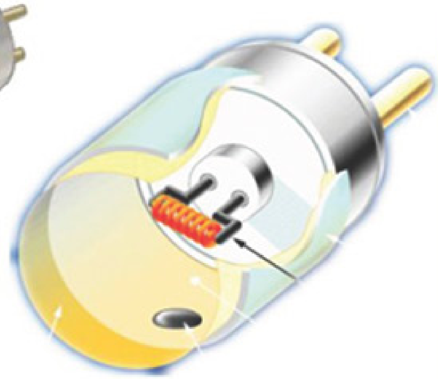
a) its geometry.

b) its number of turns.

c) the spacing between the turns.

d) the magnetic permeability of its core.

One application of self-induction is to start a fluorescent light bulb using a .solenoid with a large self-induction coefficient



Eddy Currents:

If the magnetic flux changes with time through a solid conductor ,currents will be induced in closed paths in the conductor. Such currents are called "eddy currents". The change in the intercepted magnetic flux is effected either by moving the solid in a suitable magnetic field or by subjecting the metallic solid to an alternating magnetic field(for example field due to an AC current). The eddy currents are associated with heating effects. Thus, they are useful in melting metals in what is called the induction furnaces.

Induced emf in a moving straight wire:

We place a straight wire of length ℓ perpendicular to a uniform magnetic field of magnetic flux density B (perpendicular to the paper inwardly) (Fig 11-7.) The wire is moved in a direction perpendicular to the field at velocity v, so that it is displaced a distance Δx in time Δt. the change in area is

$$\Delta A = \ell \Delta x$$

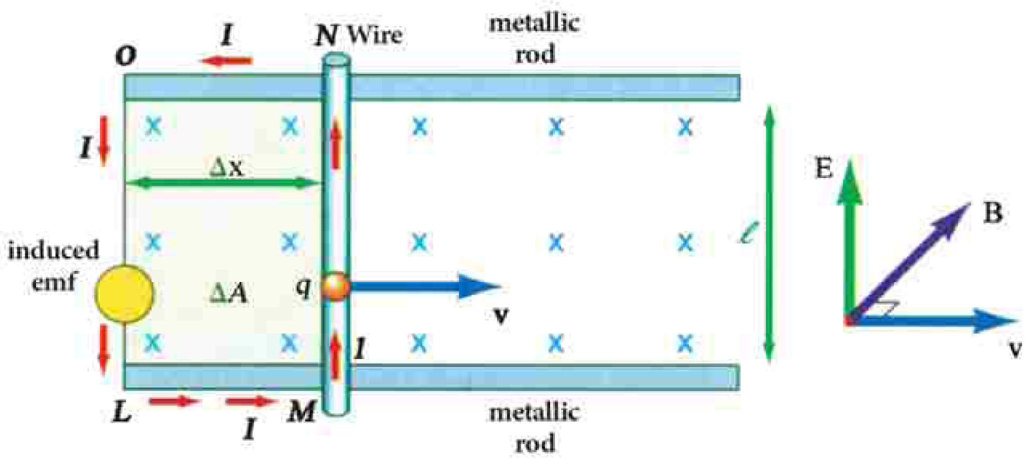


Fig (3-7)

Generation of an induced emf in a straight wire

The change in flux is

$$\Delta\Phi = B\Delta A \Delta = Bl \Delta x$$

The emf is determined from the relation

$$emf = \frac{\Delta}{\Delta t}$$

$$emf = \frac{Bl\Delta x}{\Delta t} = -Blv$$

The minus sign is required according to Lenz's rule. The emf is

$$emf = Blv \qquad (3\text{-}5)$$

If the angle between the direction of velocity and the Direction of the magnetic flux is θ, then

$$emf = Blv \sin\theta \qquad (3\text{-}6)$$

Alternating current generator:

The AC generator (or the dynamo) is a device which converts the mechanical energy into electrical energy. In a generator, a coil rotates in a magnetic field, and the resulting induced current can be transferred (or transmitted) by wires for long distances.

The simple electric generator consists as shown in Fig (3 -8) of four main parts :

a) a field magnet.

b) an armature.

c)two slip rings.

d) two brushes.

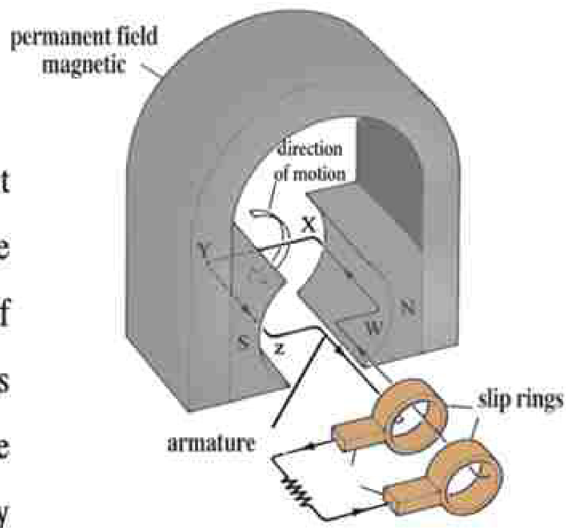


Fig (3 - 8)
A simplified schematic for an AC generator (dynamo)

The field magnet may be a permanent magnet or an electromagnet. The armature consists of a single loop of wire or coil of many turns suspended between the two poles of the field magnet. A pair of slip rings are connected, one to each end of the loop. They rotate with the loop in the magnetic field. The induced current in the coil passes to the external circuit through two graphite brushes, each touching one of the two corresponding slip rings. Fig (3 -9) shows the direction of rotation of the armature between the poles and the direction of the induced current at a certain instant. The loop rotates around its axis in a circle of radius r. Its linear velocity is

$$v = \omega r$$

where r is half the width of the coil since the coil is roting around its longitudenal axis where ω is the angular velocity equal to $2\pi f$, (where f is the frequency). Substituting for v in equation (3-6), we find:

$$emf = B\,\ell\,\omega\,r\sin\theta$$

Where θ is the angle between the direction of velocity and the magnetic flux density, or the angle between the normal to the surface M and B. When the coil is perpendicular to the flux, the induced emf is zero. Thus, the induced emf is given by

$$emf = 2\,B\,\ell\,\omega\,r\sin\theta$$

But the area of the armature A is

$$A = (\ell)\,(2\,r)$$

$$emf = BA\,\omega\sin\theta$$

If the number o turns is N, the instantaneous induced emf is

$$\boxed{emf = NBA\,\omega\sin\theta} \qquad (3\text{-}7)$$

From this relation, the induced emf changes according to a sine curve (sinusoidally) with time (Fig 11-10). The induced emf changes from a positive maximum at θ =90°, to zero at θ = 0. The maximum induced emf (noting sin 90°=1) is

$$\boxed{(emf)_{max} = NBA\,\omega = NBA\,(2\,xf)} \qquad (3\text{-}8)$$

We may express the instantaneous induced emf by

$$\boxed{emf = (emf)_{max}\sin\theta} \qquad (3\text{-}9)$$

Since θ = ω t = z xft. Thus:,

$$\boxed{emf = (emf)_{max}\sin 2\,xft} \qquad (3\text{-}10)$$

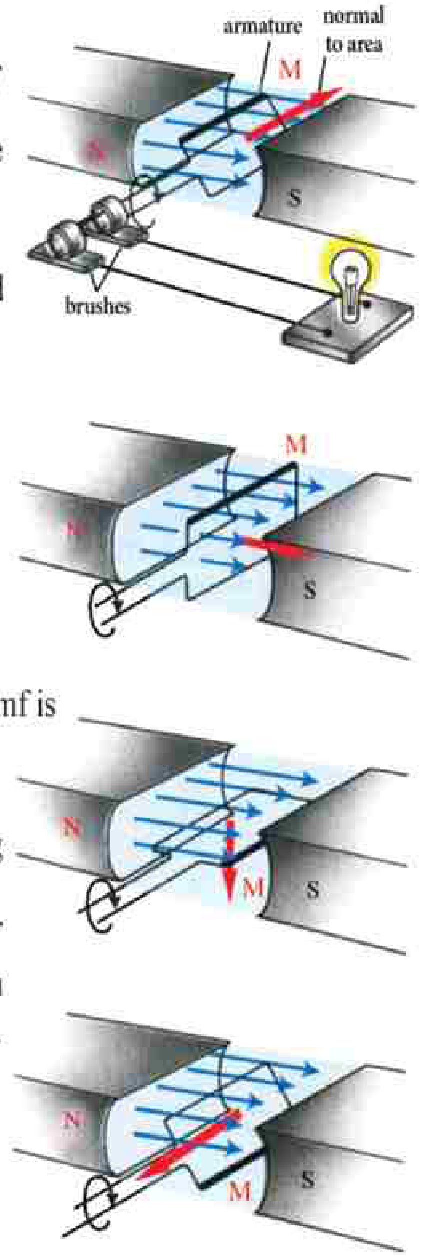


Fig (3-9)

Change of the direction of the induced current throughout one complete revolution of the armature

From Fig (3 -10), we see that the induced current changes direction every half a revolution. It follows a sine wave. From figure, we can also understand the meaning of f.

Throughout a complete revolution, the current increases from zero to a maximum, then decreases to zero, then reverses direction, and increases in the negative direction up to a negative maximum. Then, it heads back to zero. In one complete revolution, one complete oscillation has occurred. The number of oscillations per second is the frequency f. The frequecy of home use power is 50Hz

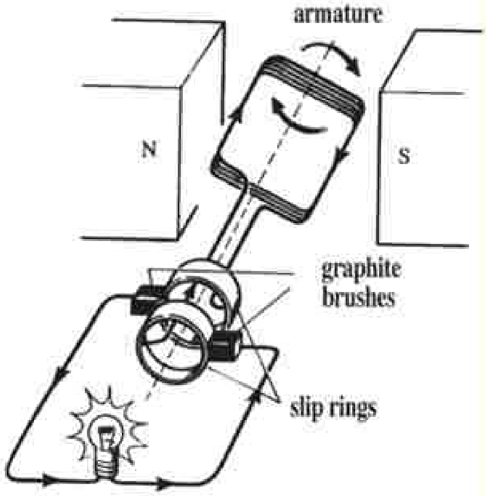


Fig (3 -10a)
AC generator

Example:

The coil of a simple AC generator consists of 100 turns, the cross sectional area of each is 0.21 m^2. The coil rotates with frequency 50 Hz (cycles/second) in a magnetic field of constant flux density $B = 10^{-3}$ Weber/m^2. What is the maximum induced emf generated? and what is the instantaneous value at $\theta = 30^\circ$?

Solution:

$$(emf)_{max} = NBA\,\omega = NBA\,(2\pi f)$$

$$= 100 \times 10^{-3} \times 0.21 \times 2 \times \frac{22}{7} \times 50 = 6.6\ V$$

Thus, the maximum induced emf generated equals 0.6 volts.

$$emf = (emf)_{max}\ \sin\theta = 6.6 \times \sin 30^\circ = 6.6 \times \frac{1}{2} = 3.3\ V$$

It is worth remembering that the induced current is directly proportional to the induced emf. Thus, the instantaneous value of the induced current is given by :

$$I = I_{max} \sin(2\pi f t)$$

This induced current reaches its maximum value when the induced emf reaches its maximum value, and it vanishes as the induced emf is zero.

Effective value of the alternating current:

It is worth mentioning that the average value of an AC current equals zero, because the AC current changes from (I_{max}) to ($-I_{max}$). through one complete cycle Neverthless, the electric energy is consumed as thermal energy due to the motion of electric charges, and the rate of the electric energy consumed is proportional to the square of the intensity of the current.

The effective value of the intensity of the alternating current is the value of the direct current which generates the same rate of thermal effect in a resistance (or the same power) as that generated by the considered AC current.

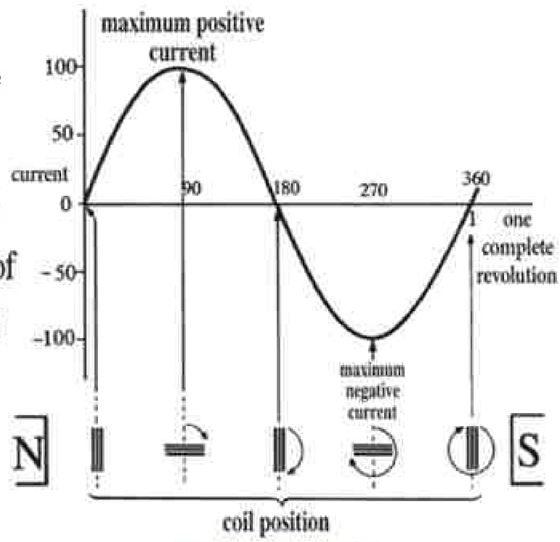


Fig (3 -10b)
The relation between current and angle of rotation(sine wave)

$$I_{eff} = 0.707\ I_{max} \quad (3\text{-}11)$$

The value I_{eff} is called the "effective value of the alternating current".

There is a similar relation for the effective electromotive force, that is :

$$(emf)_{eff} = 0.707\ (emf)_{max} \quad (3 - 12)$$

$$V_{eff} = 0.707\ V_{max}$$

Example:

If the effective intensity of current in a circuit equals 10 A, and the effective voltage is 240 volts,what is the maximum value for current and voltage ?

Solution:
Solution:

$$I_{eff} = 0.707\ I_{max}$$

$$\text{Also} \qquad I_{max} = \frac{10}{0.707} = 14.14\text{A}$$

$$V_{eff} = 0.707\ V_{max}$$

$$240 = 0.707\ V_{max}$$

$$V_{max} = \frac{240}{0.707} = 339.5\text{V}$$

Current rectification in the dynamo:

Many electrical processes, such as the production of some metals through the electrolysis of their compounds require unidirectional current or direct current. This process is called rectification. Also, an AC generator may be converted to a DC generator. To fulfil this purpose, one has to replace the two metallic rings by what is called a "commulator". The

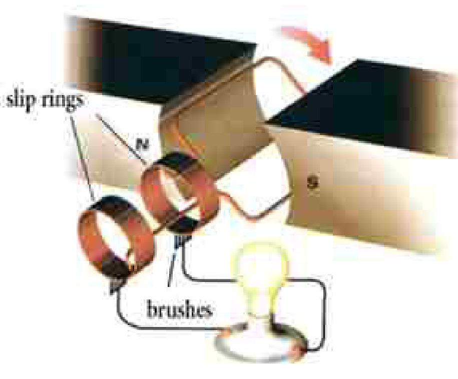


Fig (3 -11a)

AC generator

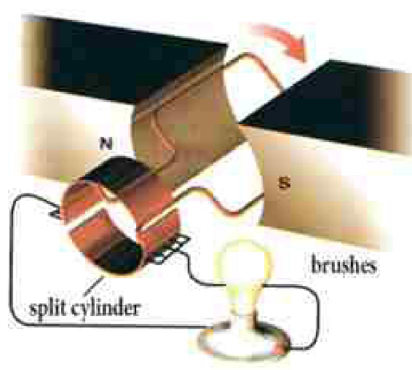


Fig (3 -11b)

DC generator

commutator consists of two halves 1 and 2 of a hollow metallic cylinder split in between, and are well insultated from each other as shown in Fig (3 -11).Two brushes F_1 and F_2 touch the two halves during the rotation of the coil. The external circuit is connected to the two brushes F_1 and F_2. It is necessary that the two brushes F_1 and F_2 touch the insulator between the two halves at the moment when the plane of the coil is perpendicular to the magnetic field, i.e, at the instant when the generated electromotive force in the coil is zero.

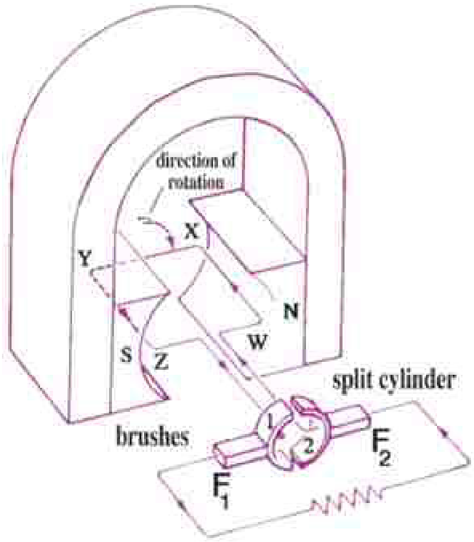


Fig (3 -11c)

Use of a split cylinder rectifies the current

Let us consider that the coil starts rotation in the direction shown (Fig. 3 -11c).During the first half rotation, brush F_1 touches the half cylinder (1), while brush F_2 touches the other half (2) of the cylinder. The current in such a case will pass in the coil in the direction w x y z. As a result, the current passes in the external circuit in the direction from F_1 to F_2 during the first half of the cycle. In the second half of the cycle, the electric current reverses its direction in the coil, i.e., the current passes in the coil in the direction z y x w. At the same time, brush F_1 will be in contact with the half(2), while F_2 will be in contact with the half(1), i.e., the two halves of the commutator reverse their position relative to the two brushes. In such a case, the current in the external circuit passes from, F_1 to F_2, which is the same direction as that in the first half of the cycle.

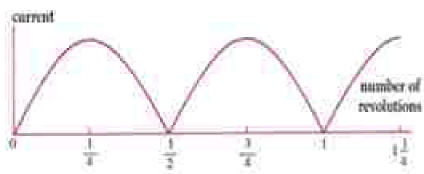


Fig (3 -11d)

Unidirectional current versus θ (sine wave)

Continuing the rotation, the brush F_1 acts as a positive pole, while F_2 acts as the negative pole of the dynamo. Accordingly, the current in the external circuit will be always in one direction as shown. It is noticed that using the commutator renders the induced emf in Fig (3 -11d) in one direction, but its value changes from zero up to a maximum value, then decreases again to zero during each half cycle of the coil rotation, but it is always in one direction.

To obtain a uni-directional current of approximately constant value, i.e., to obtain a nearly DC (value), many coils separated by small angles are used. A cylinder is used which is split into a number of segments, double the number of coils. Thus, the current in the external circuit is almost constant. This is the way to obtain a DC generator (Fig 3 -12).

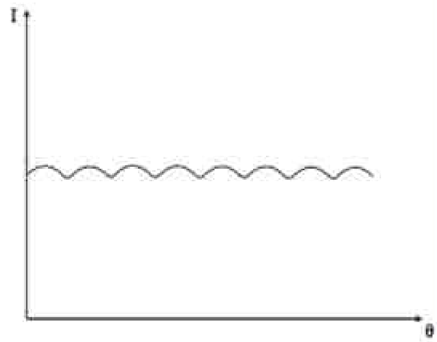


Fig (3 -12)
Nearly DC current

The transformer:

The electric transformer is a device whose function is based on the mutual induction between two coils, and is used to step up or to step down an AC voltage. Transformers are used to transfer the electric energy from generators at electric power stations. Such transformers are called step - up transformers, while the transformers used at the zones where the energy has to be distributed among buildings are called step-down transformers. The transformer as shown in Fig (3 -13) consists of two coils: a primary coil and a secondary coil. The two coils are wound around a soft iron core made of thin iron sheets

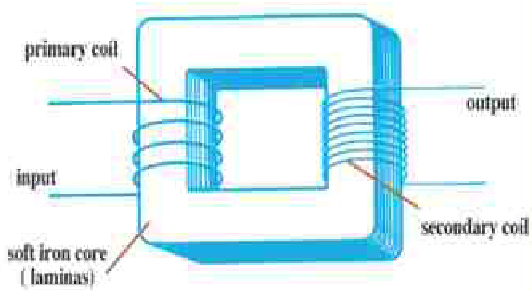


Fig (3 -13a)
Step UP transformer

(laminas) insulated from each other, to minimize the effect of eddy currents and to minimize the dissipated electric energy. When an electric current passes in the primary coil, a magnetic field is generated. The core makes the lines of such a field pass through the secondary coil.

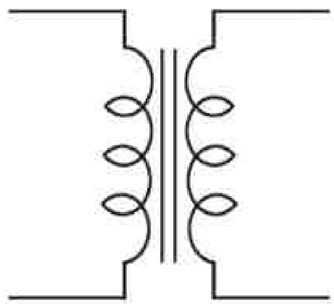


Fig (3-13b)
Transformer symbol

The relation between the two emfs in the two coils of the transformer:

When the primary coil is connectcd to a source of AC voltage, the variation in the magnetic field linked with the primary current generates an induced emf in the secondary coil having the same frequency. The induced emf in the secondary is determined from the relation:

$$V_s = -N_s \frac{\Delta \phi_m}{\Delta t}$$

where, N_s is number of turns of the secondary coil and $\frac{\Delta \phi_m}{\Delta t}$ is the rate of change of the mangetic flux linked between the primary through the secondary coil. The electromotive force in the primary is in turn related to the rate of change of the magnetic flux and is determined from the relation :

$$V_p = -N_p \frac{\Delta \phi}{\Delta t}$$

where, N_p is the number of turns of the primary coil. Assume that the wasted magnetic energy is negligible, i.e., there is no considerable loss in the magnetic flux, i.e., the whole resulting magnetic flux passes through the secondary coil (no stray lines). Dividing the above two relations one can get the following formula :

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad (3-13)$$

This equation shows the interrelation between the emf V_s in the secondary and V_p in the primary. If N_s is larger than N_p, one has a step-up transformer, where the emf in the secondary coil will be larger than the emf in the primary one. For example, if the number of turns of the secondary coil is twice that for the primary coil, one gets $V_s = 2V_p$.

While, for the case when N_s is less than N_p one gets a step-down transformer, where, in such a case V_s will be less than V_p.

The relation between the current intensities in the two coils of the transformer:

Let us assume that there is no loss in the electric energy in the transformer (almost zero resistance), then according to the law of conservation of energy, the electric energy made available by the source in the primary coil must equal that delivered to the load in the secondary coil.

$$V_p I_p t = V_s I_s t$$

From which the input power is equal to the output power, i.e,

$$V_p I_p = V_s I_s$$

Thus,

$$\therefore \frac{V_s}{V_p} = \frac{I_p}{I_s} \qquad (3 - 14)$$

From the equations (3 -13) and (3 -14),

$$\frac{I_s}{I_p} = \frac{N_p}{N_s} \qquad (3 - 15)$$

This shows that the intensity of the electric current in either of the two coils is inversely proportional to the number of its turns.

For example: if the number of turns of the secondary coil is twice that of the primary coil, then the intensity of current in the secondary coil equals half that in the primary coil.

From this argument, we see the importance of the use of the step-up transformer at the electric generating power station (power plant), where it is desired to raise the voltage to a very high value. This is associated with small values of currents, consequently, losses decrease in the electric energy during power transmission along great distances. This is because the loss in power equals I2R, where I is the intensity of the electric current passing through the wire, and R is the ohmic resistance of the wires. Therefore, if we succeed to decrease the intensity of the electric current passing through the transmission lines, by $\frac{1}{100}$, for example of its value in the primary coil through the use of a step-up transformer, the loss in energy is decreased by $\frac{1}{10000}$ of its value. At zones of energy distribution, one has to use step-down transformers, where the potential difference or voltage across the two terminals of the secondary coil is 220 Volt. This value represents the working household voltage for the electric lamps and most of the electric appliances used in our houses.

The uses of the electric transformer:

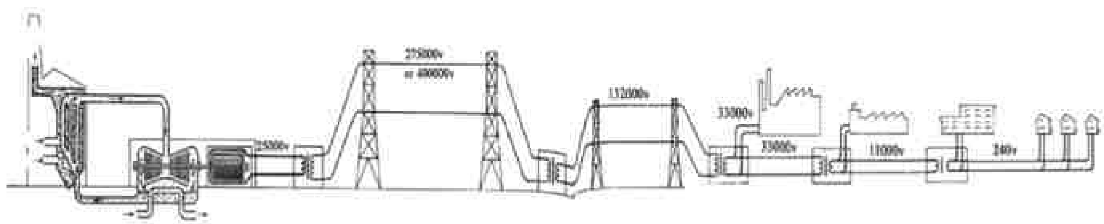


Fig (3-14)

Use of transformers in electric power transmission

Transformers are used to transfer electric energy from the generating power stations to zones of distribution across very long distances through metallic wires with no considerable loss in energy. Step-up used at the stations while step-down transformers are used at the distribution regions (Fig 3-14, 3-15). Transformers, are also used in some domestic appliances, such as electric bells and refrigerators.

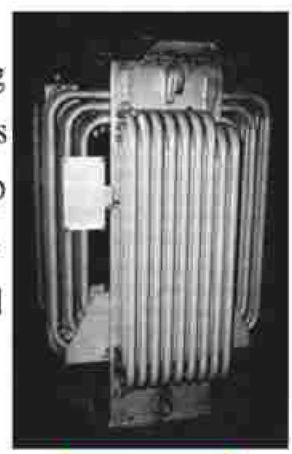


Fig (3-15)

Efficiency of the transformer:

If there is no loss in electric energy in the transformer, i.e., the electric energy generated in the secondary coil equals the electric energy available in the primary coil. The efficiency of the transformer is said to be 100% efficient. Such a transformer is not available in every day life, because loss in energy must take place for the following reasons:

1) Part of the electric energy is converted into thermal energy in the wires. To reduce such a loss, it is recommended to use metallic wires of least ohmic resistance.
2) Part of the electric energy is converted in the iron core into thermal energy due to eddy currents. To minimize such a loss, the core is made of thin insulated sheets of siliconic soft iron having high specific resistivty and which decreases the eddy currents.
3) Part of the energy is converted into mechanical energy consumed in the vibration of the molecules of the core. To minimize this effect, soft iron is used for the easiness with which its magnetic molecules move.

In general, if the lost energy represents 10% of the total original energy, the efficiency of the transformer is 90%. The efficiency of the transformer is defined as the ratio between the energy gained from the secondary coil to the energy given from the source to the primary coil within the same time, i.e.,

$$\eta = \frac{V_S \times I_S}{V_P \times I_P} = \frac{V_S \times N_P}{V_P \times N_S} \quad (3\text{-}16)$$

Examples:

1- A trandformer connected to a 240 V AC power source gives 900 V output emf with current intensity 4A. What is the intensity of the source current assuming that the efficiency of the transformer is 100%?

Solution:

$$\because \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

$$\therefore \frac{900}{240} = \frac{I_p}{4}$$

$$\therefore I_p = \frac{900 \text{ x } 4}{240} = 15 \text{ A}$$

2) An electric bell is connected to a transformer of efficiency 80% which gives 8 V output, while the input household voltage is 220 volts. What is the number of turns of the secondary coil if the number of turns of the primary coil is 1100 ? and what is the intensity of current in the secondary coil if the current in the primary coil is 0.1 A ?

Solution:

$$\eta = \frac{V_S \times I_S}{V_P \times I_P} = \frac{V_S \times N_P}{V_P \times N_s}$$

$$80 = \frac{8}{220} \text{x} \frac{1100}{N_S} \text{ x}100$$

$N_S = 50$ turns

$$\frac{I_S}{I_p} = \frac{N_P}{N_S}$$

$$\frac{I_S}{0.1} = \frac{1100}{50}$$

$I_S = 2.2$ A

DC motor:

It is a device which converts electric energy to mechanical energy. It operates on a DC source (battery) (Fig 3-17). It consists in its simplest form of a rectangular coil abcd comprising a large number of turns of insulated copper wire wound around a soft iron core made of thin insulated sheets to cut down on eddy currents.

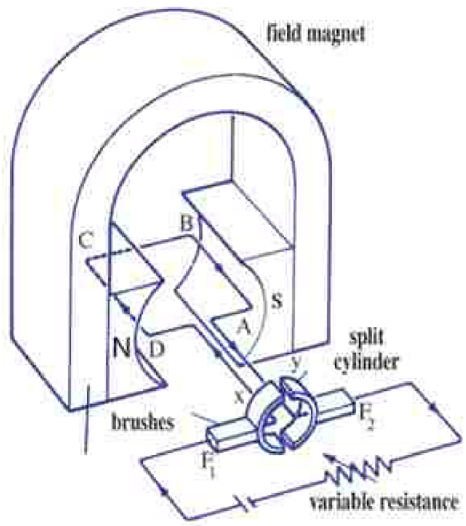


Fig (3-17)
DC motor

The core and the coil can rotate between the two poles of a strong horseshoe (U-shaped) field magnet. The two terminals of the coil are connected to two halves of a split cylinder (commutator). The two halves (x,y) are insulated from each other and capable of rotating around the axis of the coil.

The plane separating the two halves is perpendicular to the plane of the coil and the line connecting the two brushes is parallel to the lines of magnetic flux.

To operate the motor, the two brushes must be connected to the battery.

The motor and the galvanometer:

The principle of operation of the electric motor and that of the moving coil galvanometer are alike. The main difference is that the electric motor must rotate continuously in the same direction. The design of the electric motor necessitates that the two halves x,y of the cylinder must interchange positions relative to the two brushes F_1 and F_2 each half cycle. As a result, the electric current passing in the motor must reverse direction in the coil each half revolution.

Operation of a DC motor through one complete revolution:

Starting from a position at which the plane of the coil is parallel to the lines of the magnetic flux, and the brush F_1 - connected to the positive terminal of the battery - touches the half cylinder x, while F_2 - connected to the negative terminal of the battery - touches the half cylinder y as shown in Fig (3 -17). Thus, current passes in the coil in the direction dcba. Applying Fleming's left hand rule, one concludes that the wire ab is affected by a force in the upward direction, while the wire cd is affected by a force in the downward direction. The two produced forces (couple) form a torque, and the coil begins to rotate in the direction shown in the figure. As the coil rotates, the moment of the couple decreases gradually till it vanishes, when the coil plane becomes perpendicular to the lines of the magnetic flux. But the coil having gained a momentum will continue motion due to its inertia, which in turn pushes the coil to the other side. The two halves x and y of the commutator interchange position, such that the half cylinder x will be in touch with the brush F_2,while the brush F_1 will touch to other half cylinder y. Thus, the current in the coil will reverse direction and pass in the direction abcd. Applying "Fleming's left hand rule" for the new position of the coil shows that the force acting on the wire ab will be downward, while the force acting on the wire cd will be upwards. The obtained torque enables the coil to continue rotation in the same circular direction. The torque increases gradually to its maximum value when the plane of the coil becomes parallel to the lines of the magnetic flux. Then, it decreases to zero when the plane of the coil is perpendicular to the lines of magnetic flux. The inertia of the coil then causes it to continue rotating to the other side. This permits the two halves to interchange positions and with respect to the two brushes F_1 and F_2, and thus, the current in the coil is reversed once more. The coil continues rotating in the same circular direction making one complete revolution, and so on.

In order to increase the power of the motor, a number of coils may be used with equal angles between their planes. The two terminals, of each coil are connected to two opposite splits of a cylinder. The cylinder is split into a number of segments twice that of the number of the coils. During rotation, each two opposite segments touch the two brushes F_1 and F_2 when their corresponding coil is in position of largest torque.

In a Nutshell

Definitions and Basic Concepts:-

Electromagnetic induction : It is a phenomenon in which an induced electromotive force and also an induced current are generated in the coil on plunging a magnet into orwithdrawing a magnet out of a coil.

- The presence of a soft iron core inside a coil concentrates the lines of magnetic flux that link with the coil. This in turn increases the induced electromotive force and also the induced current.
- **Faraday's law for the induced emf : The induced emf generated in a coil by electromagnetic induction is proportional to the time rate by which the conductor cuts the lines of magnetic flux and is also proportional to the number of turns of the coil.**
- **Lenz's rule: the direction of the induced current generated by induction is such that to oppose the change in the magnetic flux producing it.**
- **Fleming's right hand rule: Place the thumb, the pointer and the middle finger(with the rest of the fingers) of the right hand mutually at right angles. If the pointer points in the direction of the magnetic field and the thumb in the direction of motion then the middle finger (with the rest of the fingers) will point in the direction of the induced current.**
- **Mutual induction:** It is the electromagnetic interaction between two coils kept close to each other (or one inside the other).An electric current with time varying intensity passing in one coil (primary coil)will produce in the second one (secondary coil) an induced current in a direction such that to oppose the variations of the current intensity in the primary coil.

- **Self-induction:** It is the electromagnetic effect induced in the same coil when the intensity of the current increases or decreases.This effect acts to resist such a change in the intensity of current.
- **Coefficient of self-induction :** It is measured numerically by the electromotive force generated by induction in the coil when the intensity of the current passing through it changes at a rate of 1A/s.
- **The unit of measuring the self induction (Henry):** It is the self induction of a coil in which an emf of 1V is induced when a current passes through it which changes at a rate of 1A/s.

$$H = \frac{V.S}{A}$$

- The self-induction of a coil depends on :

a) its geometry.
b) its number of turns.
c) the spacing between its turns.
d) the magnetic permeability of its core.

- **The Dynamo (AC Generator):** It is a device used to convert the mechanical energy to electric energy(AC current and voltage) when its coil rotates in a magnetic field.

The simple dynamo (AC generator) consists of :

a) field magnet (strong magnet).
b) a coil of insulated copper wire suspended between the two poles of the magnet.
c) two metallic rings in contact with two graphite brushes connected to an external circuit.

- **A commutator:** (cylinder split into a number of insulated segments) is used to obtain a DC current and voltage (DC generator).
- **The alternating current:** It is current which changes periodically its intensity and direction with time according to a sinusoidal curve.
- **The electric transformer:** It is an electric device used to step up or step down an emf through mutual electromagnetic induction.

- **The efficiency of the transformer:** It is the ratio between the output electric energy given in the secondary and that available to the primary.
- **The electric motor:** It is an electric device used to convert the electric energy into mechanical energy .

Basic laws:

- The induced emf genrated in a coil of N turns as a result of time variation of magnetic flux$\Delta\phi_m$ linked with the coil in an interval of time is given by the relation:

$$emf = -N\frac{\Delta\phi}{\Delta t}\cdot$$

The nagative sign indicates that the direction of the induced emf (and thus the current) is such as to oppose the cause producig it.

- The emf induced in a secondary coil due to the time variation in the lines of magnetic flux resulting from a primary coil linking with the secondary coil in a time interval Δt is given by the relation :

$$emf = -M\frac{\Delta I}{\Delta t}$$

where M is the coefficient of mutual induction.

- The emf induced by self induction as a result of the current ΔI passing through the coil in a time Δt is given by the relation :

where L is the coefficient of self induction of coil.

$$emf = -L\frac{\Delta I}{\Delta t}$$

- The emf induced in a straight wire of lengh $\Delta \ell$ moving with a uniform velovity Δv making an angle θ with a magnetic field of magnetic flux B is given by the relation:

$$emf = B \ell v \sin \theta$$

- The emf induced in the dynamo is given by the relation:

$$emf = NBA\ \omega \sin \theta$$

Where N is the number of turns, B is the magnetic flux density, A is the area of the face of the coil, θ is the angle confined between v and B, and B, and ω is the angular velocity given by the relation:

$$2x \text{ x } \frac{\text{Number ofrevolution}}{\text{time in sec onds}}$$

- The emf is maximum when $\theta° = 90°$ ($\sin 90° = 1$)

and minimum when θ = zero. ($\sin 0 = 0$)

- The relation between the effective value of the current I_{eff} and its max imum value I_{max} is given by:

$$I_{eff} = 0.707\ I_{max}$$

- The relation between the two electromotive forces in the two coil of the transformer.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- The relation between the two currents in the two coils of the transformer is:

$$\frac{I_s}{I_p} = \frac{N_P}{N_s} \qquad \text{or} \qquad \text{ie. } \frac{V_s}{V_p} = \frac{I_P}{I_s} = \frac{N_s}{N_P}$$

- The efficiency of the transformer η is given by the relation:

$$\eta = \frac{V_S \times I_S}{V_P \times I_P} = \frac{V_S \times N_P}{V_P \times N_s}$$

Questions & Drills

I) Put (√) against the right answer:

1) The pointer of a galvanometer whose terminals are connected to a solenoidal coil will be deflected if one withdraws the magnet quickly from the coil because:

a) the number of the coil turns is very large.

b) the coil intercepts the lines of the magnetic flux.

c) the number of the turns of the coil is small.

e) the number of turns of the coil is suitable.

2) The needle of the galvanometer whose terminals are connected to a solenoidal coil deflects on the withdrawal of the magnet in a direction opposite to that which occurs on plunging the magnet into the coil because:

a) an induced current is generated in a direction opposite to that on plunging the magnet.

b) an electric current is generated.

c) the number of the lines of magnetic flux decreases.

d) the number of the lines of the magnetic flux changes.

e) the number of flux lines remains constant.

3) The emf induced in a coil on plunging a magnet into or withdrawing it out of a coil differs according to the difference in :

a) [the intensity of the current - the length of the wire - the number of the lines of flux].

b) [magnet strength - the velocity with which the magnet moves- the number of turns of the coil].

c) [the cross sectional area of the coil - the mass of unit length - the material from which the wire is made].

d) [the length of the wire - the number of turns - the type of the magnet].

e) [the magnetic flux density - time - the intensity of the current].

4) A current passes in the primary coil, then this coil is plunged into a secondary coil whose terminals are connected to a galvanometer. The deflection of its needle will be in a direction:

a) opposite to the current in the primary coil.

b) points to zero reading

c) increasing.

d) same as the current in the primary coil

e) variable

5) Opening the primary circuit while the primary coil is inside the secondary one, leads to the generation of :

a) an induced forward current.

b) an electric field

c) an induced back current.

d) an AC current.

e) a magnetic field.

6) The slow rate of growth of the current in the solenoidal coil is due to the:

a) production of forward current.

b) production of a magnetic field.

c) production of a back induced current opposing (resisting) the original one.

d) production of a magnetic flux.

e) production of an electric field.

7) The ohmic resistors are made of double wound wires:

a) to decrease the resistance of the wire.

b) to increase the resistance of the wire.

c) to avoid self-induction.

d) to eliminate the resistance of the wire.

e) to facilitate the connection process.

8) The direction of the current produced in the dynamo coil can be determined using:

a) Fleming's left hand rule.

b) Lenz's rule.

c) Fleming's right hand rule.

9) The rate with which the coil intercepts the lines of magnetic field in the dynamo is maximum when:

a) the plane of the coil is perpendicular to the flux lines.

b) the plane of the coil is inclined to the lines by an angle 30°

c) the face area of the coil is minimum.

d) the face area of the coil is maximum.

e) the plane of the coil is parallel to the lines of the magnetic flux.

10) The intensity of the current in the two coils of the transformer is :

a) directly proportional to the number of the turns.

b) inversely proportional to the number of the turns.

c) depending on the temperature of the wire.

d) depending on the substance of the wire.

e) depending on the temperature of the air (ambient temperature).

11) The power of an electric motor to rotate increases on using:

a) larger number of turns.

b) several coils with angles between their planes.

c) several magnets

d) an insulated copper wire.

e) a current rectifier.

12) The ratio between the electric energy in the secondary to that in the primary is called:

a) the lost energy.

b) the given energy.

c) the efficiency of the transformer.

d) the working strength of the transformer.

e) the gained energy.

II) Define the following :

1- Electromagnetic induction.

2- Faraday's law of induction

3- Lenz's rule.

4- Fleming 's right hand rule.

5- Mutual induction.

6- Unit of measuring the mutual inductance.

7- Self induction.

8- Coefficient of self induction.

9- The Henry.

10- The induction coil.

11- The AC current.

12- The dynamo.

13- The electric motor.

14 - The transformer.

15- The efficiency of the transformer.

16- The back emf in the motor.

III) Essay questions:

1) What are the factors on which the emf induced in a conductor depends ? Mention the relation between the emf. and such factors.
2) State Faraday's law of the emf induced in a coil, then show how to verify this practically?
3) What is meant by mutual induction between two coils? and what is meant by the coefficient of mutual induction? How - using the mutual induction - one can verify Lenz's rule?
4) If a current passes through a coil, deduce an equation relating the induced emf in the coil and the rate of change of the current in the coil. From this, deduce a definition for the coefficent of self induction and the Henry.
5) When does the emf induced in a coil become maximum ? and when does it become zero?
6) Explain an experiment to show the conversion of the mechanical energy into electrical energy, and another experiment to show the opposite conversion. Then, state the rule used to define the direction of the current in the first case and the direction of motion in the second case.
7) Deduce the relation by which one can evaluate the instantaneous emf induced in an AC generator.
8) What are the modifications introduced to the AC generator to render it a unidrectional generator ?
9) Describe the structure of the electric transformer ? then explain the principle of its opertion. What is meant by saying that the efficiency of the transformer is 80%?.
10) What is meant by the efficiency of the transformer? What are the factors which lower such an efficiency and how to deal with them?
11) Draw a labelled diagram showing the structure of the motor and explain its operation.

IV) Give reasons

1) The core of an electic transformer is made of thin sheets insulated from each other.
2) A bar of soft iron will not be magnetized if a double wound wire carrying a current is wound around it.
3) A wire free to move in a magnetic field moves when a current passes through it.
4) The transformer is not suitable to convert DC voltage.
5) The electric motor rotates with uniform velocity.
6) The induced current dies out in a straight wire faster than in a coil with air core, and in a coil with air core faster than in a coil wound around an iron core.
7) The metallic cylinder used to obtain a unidirectional current in the dynamo is split into two halves completely insulated from each other.

V) Drills

1) A coil of 80 turns, and cross sectional area 0.2 m^2 is suspended in a perpendicular position to a uniform magnetic field. The average induced emf is 2 V when it rotates 1/4 revolution through 0.5 s. Find the magnetic flux density.

(0.0625T)

2- If the magnetic flux density between the two poles of the magnet of a dynamo is 0.7 Tesla, and the length of its coil is 0.4 m, find the velocity of motion in such a field to obtain an induced emf in the wire equal to 1V. (3.57m/s)

3) A coil of a dynamo consists of 800 turns each of face area 0.25 m^2. It rotates at a rate of 600 revolutions per minute, in a field of magnetic flux density 0.3 Tesla. Calculate the induced emf when the angle made between the normal to the coil and the magnetic flux is 30°. (1885v)

4) A rod of copper of length 30 cm moves with at velocity 0.5 m/s in a perpendicular direction to a magnetic field of density 0.8 Tesla. Calculate the emf induced in such a rod. (0.12v)

5) An antenna of length one meter fixed in a motor car, which moves at velocity 80km/hour in a direction perpendicular to the horizontal component of the Earth's magnetic field. An emf of 4×10^{-4} V is induced in the antenna. In such a case, calculate the magnetic flux density of the considerd horizontal field.

(18×10^{-6}T)

6) Calculate the coefficient of self-induction for a coil in which an emf of 10 V is induced if the passing current changes at a rate of 40 A/s

(0.25 Henry)

7) The mutual induction between two faces of opposite coils is 0.1 Henry and the intensity of current in one of them is 4 A. If this intensity drops to zero in 0.01s, find the emf induced in the other coil.

(40V)

8) A rectangular coil of dimensions 0.4m x 0.2m and of 100 turns rotates with a uniform velocity 500 revolutions per minute in a uniform field of magnetic flux density 0.1 Tesla. The axis of rotation in the plane of the coil is perpendicular to the field. Calculate the emf induced in the coil.

(41.89 V.)

9) A step-down transformer of efficiency 90% has a primary coil voltage of 200 V and that of the secondary is 9 V. If the intensity of the electric current in the primary is 0.5 A, and the number of turns of the secondary is 90 turns, what is the intensity of the current of the secondary coil, and what is the number of turns of the primary?

(10 A, 1800 turns)

10) A step-down transformer connected to an AC power source of 2500 V gives a current of 80 A.The ratio between the number of turns of the primary and the secondary coils is 20:1 Assuming that its efficiency is 80%, find the emf induced across the two terminals of the secondary, and find also the current in the primary coil.

(100V,4A)

Chapter 4 Alternating Current Circuits

In the previous chapter, we have studied the dynamo that generates the alternating current, which is the current that its intensity periodically changes; increasing from zero to maximum value then drops to zero through a half cycle. And then the current direction is reversed, and its intensity goes from zero to maximum and drops back to zero through the other half cycle. This variation is typically repeated each cycle.

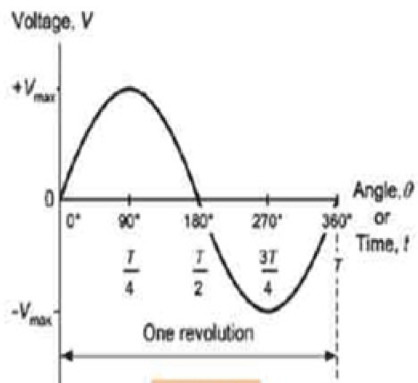


Figure (4 – 1)
Sinusoidal waveform of AC voltage or current

The alternating current is graphically represented by a sine waveform as shown in *figure (4-1)* ,since the current and the electromotive force vary their values and direction according to a sinusoidal function of angles from zero° to 360°.

Frequency of AC current: is the number of complete cycles made by the AC current in one second that is the same as the number of complete revolutions made by the dynamo coil that produce this current in one second.

The frequency of AC current used in Egypt is 50 Hz.

Advantages of AC current:

1- Its voltage can be stepped up or down ,using electric transformers.
2- The alternating electrical power can be efficiently transmitted through cables, over long distances from power plants to the consuming areas without much power loss, using **transformers.**
3- The AC current can be used in some processes but is not the appropriate choice in others such as the processes of electrolysis and electroplating.
4- AC current can be rectified into DC current.
5- Both AC current and DC current have thermal effect when flowing through a resistor since the heating effect is independent upon the current direction.

Measuring the alternating current

Hot Wire Ammeter:

Moving coil ammeters are not valid to measure the value of the alternating current, since its intensity and direction continuously changes. The operation of this ammeter requires a magnetic field affecting its coil that has constant intensity and direction till settling its pointer at a certain reading on the scale . Instead, the thermal effect of the alternating current is used to measure its effective value and the instrument here is known as hot wire ammeter.

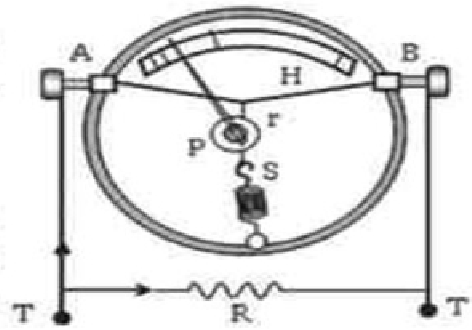


Figure (4 – 2)

Hot wire Ammeter

Construction and Operation:

Hot wire ammeter has a thin wire fixed tightly between two fixed ends A and B as shown in figure. The wire is made of platinum–iridium alloy that expands obviously when an electric current passes through it. A silk thread is permanently connected at the middle of the thin wire AB and wound around a pulley (P) that can rotate about its axis while the other end of the thread is anchored to a spring (S) that is fixed with the device wall. A pointer connected to the pulley moves along a non-uniform scale. A small resistance R is connected in parallel to the wire AB as a shunt.

Operation of Hot Wire Ammeter:

The hot wire ammeter is connected in series to the circuit through which the current to be measured passes. The wire AB gets heated due to the current and expands. Consequently, the tension in the wire decreases. The silk wire stretches the hot wire because of the tension in the spring on the other side, the pulley rotates a little and the pointer deflects along the scale. The pointer gives a definite reading when the temperature of the platinum – iridium wire becomes constant and the wire stops expanding. That is achieved when the rate of the heat radiated from the wire becomes equal to the rate of the heat generated in the wire. The pointer reading indicates the effective value of AC current.

Hot wire ammeter is calibrated by connecting it with a moving coil ammeter in series to a direct current circuit. It is essential to notice that the scale of hot wire ammeter is not uniformly divided. The scale divisions for equal increments of current increases as the value of current increases since the heat generated in a wire is directly proportional to the square of the current value passing through it ($Q \propto I^2$)

Disadvantages of hot wire ammeter:

1- Slow deflection of its pointer on passing the current and slow return to the zero position when the ammeter is disconnected from the circuit.
2- The platinum–iridium wire is affected by changes in atmospheric temperature that may lead to a zero-error in measurement. It is, however, requisite to make provision for this effect. This is done by mounting the working wire on a metal plate made of a metal having the same linear expansively as that of the working wire itself.

Alternating Current (AC) Circuits

1) AC current and AC voltage in a non-inductive Ohmic resistance:

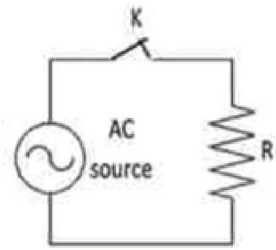


Figure (4 – 3)
AC circuit having a resistor

The figure (4 – 2) illustrates an AC circuit containing a current supply, a switch and a non-inductive ohmic resistor connected in series.

On closing the circuit, the instantaneous voltage across the resistor is given by the relation:

$$V = V_{max} \sin \omega t \; . . . . . \; (1)$$

Where V is the instantaneous voltage, V_{max} is the maximum voltage and ω t is the phase angle.

The instantaneous value of current is determined by the relation:

$$I = \frac{V}{R}$$

$$I = \frac{V_{max}}{R} \sin \omega t$$

$$I = I_{max} \sin \omega t \; . . . . . \; (2)$$

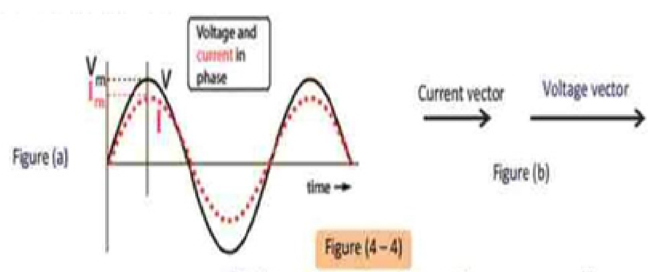


Figure (4 – 4)
AC voltage and current have the same phase

Comparing the equations (1) and (2), we find that both V and I in a non-inductive resistance have the same phase angle. This means that the current and voltage are synchronized and grow till they reach their maximum values simultaneously. In other words, voltage and current are in phase. They can be represented graphically as in figure (4-4a), or represented by two vectors having the same direction as in figure (4-4b).

2) AC current and AC voltage in an inductive coil of zero resistance:

The figure (4 – 5) illustrates an AC circuit containing a current supply, a switch and an inductive coil of zero ohmic resistance connected in series. On closing the circuit, the current grows gradually from zero to a maximum value at a rate $\frac{\Delta I}{\Delta t}$.

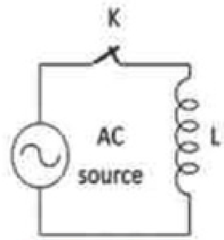


Figure (4 – 5)

AC circuit having an inductor

A reverse electromotive force is induced by self-induction across the coil of magnitude - L $\frac{\Delta I}{\Delta t}$ that opposes the change in the electric current.

The frequency of the induced emf is the same as the frequency of the AC supply but it acts in the opposite direction to the electromotive force of the supply.

By applying Kirchhoff's law

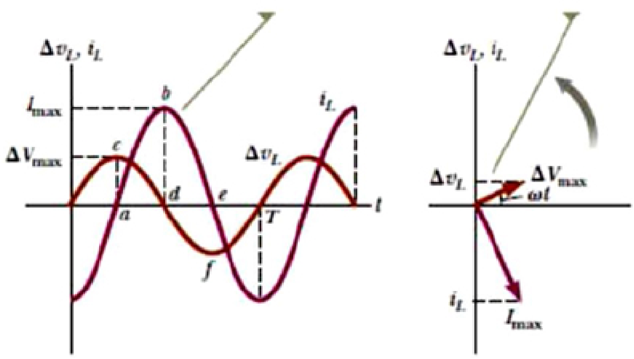
$$V - L\frac{\Delta I}{\Delta t} = I R$$

and by neglecting ohmic resistance of the circuit

The instantaneous voltage across the inductor is given by:

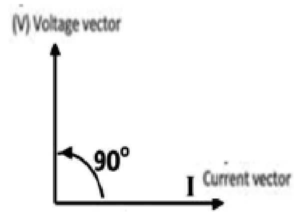
$$V = - L\frac{\Delta I}{\Delta t}$$

Given that I varies with the phase angle according to sine curve as indicated in figure (4 – 6 a), the value $\frac{\Delta I}{\Delta t}$ represents the slope of the tangent drawn to the curve. It reaches its peak value when the phase angle equals zero, and then it decreases gradually to reach zero when I reaches its peak value. When the value of the current decreases, the slope $\frac{\Delta I}{\Delta t}$ has a negative value. Thus, the curve representing the voltage takes the waveform indicated in figure (4 – 6 a)



It is obvious that the voltage **leads** the current by a phase angle 90^{o}.

Both current and voltage across an inductor can be represented by two vectors as in figure.

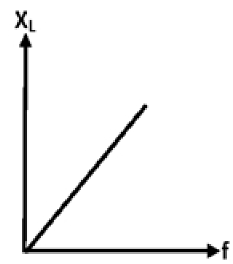


Finding the inductive reactance in a coil (X_L):

It is found that the inductive reactance in a coil is directly proportional to each of the frequency of the current flowing through the coil and its self-inductance.

The inductive reactance of a coil = 2 π x current frequency x self-inductance

$$X_L = 2\pi f L \quad \text{Ohm}$$



What is the inductive reactance?

It is the opposition to the flow of the AC current through a coil due to its self-inductance.

In this case the value of current (I) in an inductor = $\frac{\text{electromotive force}}{\text{inductive reactance}}$

The inductive reactance of inductor networking:

First: If the inductors are connected in series:

As that in case of resistors,

$X_L = X_{L1} + X_{L2} + X_{L3}$

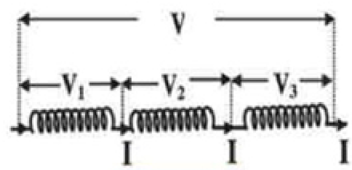


Figure (4 – 8)

Connection of inductors in series

If the inductive reactance is the same for all inductors, $X_L = n\,X_{L1}$

Second: If the inductors are connected in parallel:

$$\frac{1}{X_L} = \frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}$$

If the inductive reactance is the same for (n) inductors,

$$X_L = \frac{X_{L1}}{n}$$

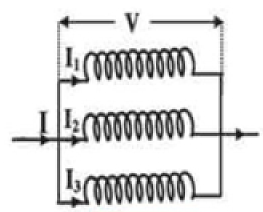


Figure (4 – 10)

Connection of inductors in parallel

Example: A coil of self-inductance 700 mH of negligible ohmic resistance is connected to an AC supply of electromotive force = 200 V and frequency 50 Hz. Calculate the value of current flowing through the coil.

Solution:

$$X_L = 2\pi f L = 2 \times \frac{22}{7} \times 50 \times 0.7 = 220\,\Omega$$

$$I = \frac{V}{X_L} = \frac{200}{220} = 0.9\,A$$

Capacitor: In its simplest form, a capacitor is two parallel metal plates separated by an insulating material. When the capacitor is connected to an electric source, the capacitor is charged so that one plate is positively charged and the other is negatively charged, and a potential difference (V) is generated between them. If the capacitance of the capacitor (C) is farads and the potential difference (V) is volts, then the amount of charge formed on one of the plates (Q) Coulomb is given by the relationship: Q=CV

Connecting a capacitor to a DC power source:

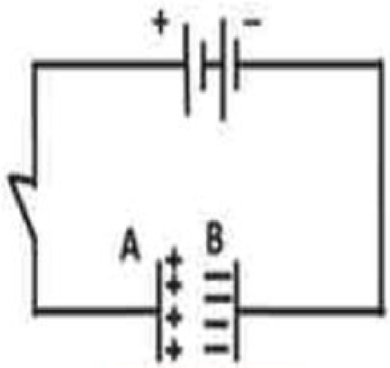


Figure (4 – 11)

A capacitor in DC circuit

When a capacitor is connected to a battery where plate (A) is connected to the positive electrode and plate (B) to the negative electrode as in the figure, negative electrons are displaced from the negative electrode of the battery to plate (B), so its voltage decreases and the negative charge of plate (B) affects plate (A), displacing negative electrons from it towards the positive electrode of the battery, so plate (A) is charged with a positive charge and its voltage rises.

When the potential difference between the two plates equals the potential difference between the battery electrodes, the charge transfer stops and the capacitor is charged. This means that an instantaneous current has passed through the circuit until the charging process is complete, after which it is no longer present.

Connecting the capacitor to an alternating current source:

When a capacitor is connected to an AC source, during the first half cycle of the source voltage, the capacitor is charged until the potential difference between its plates reaches a maximum value equal to the maximum value of the source impulse. When the source voltage emf starts to drop, the capacitor starts to discharge its charge to the source since the capacitor voltage is higher at that moment, so that when the source voltage emf reaches zero, the potential difference between the two plates of the capacitor has also reached zero.

In the second half of the cycle, the two plates of the capacitor are charged, but with a charge opposite to their charges in the first half of the cycle, until the potential difference between them reaches the maximum end of the driving force of the source, then the capacitor begins to discharge its charge when the emf of the source decreases until they both reach zero at the end of the second half of the cycle, as in Figure (4-12). This is repeated in the other cycles.

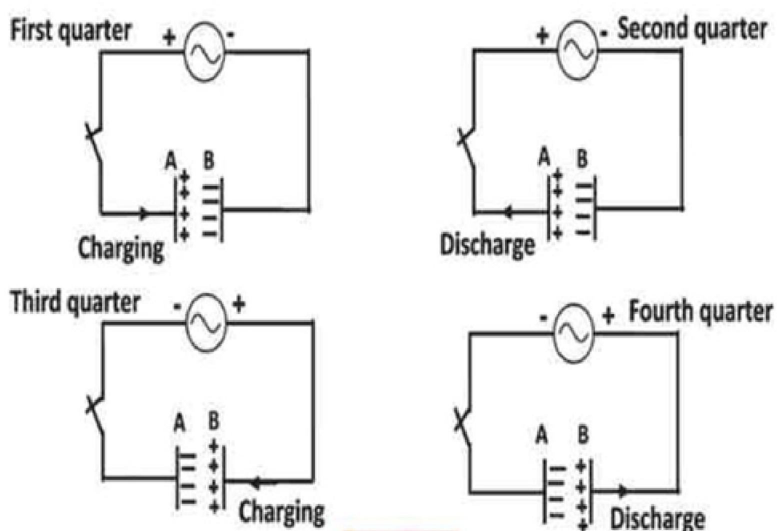


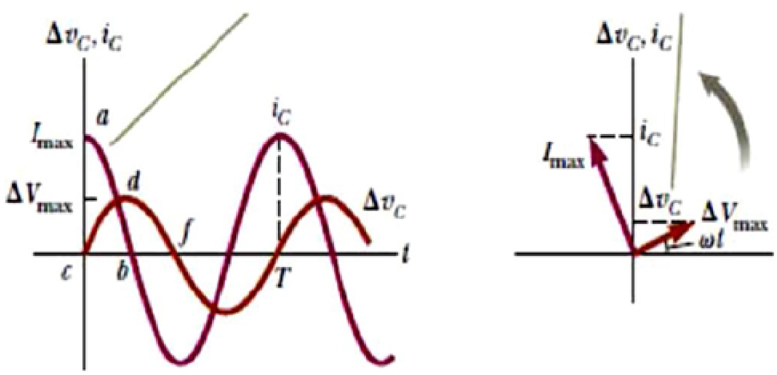
Figure (4 – 12)
A capacitor in AC circuit

This shows that an alternating current passes through a circuit with an alternating source and a capacitor. That is, the capacitor allows alternating current to pass through the circuit. The magnitude of the AC current at any instant is directly proportional to the rate of change in the amount of charge on the capacitor $\frac{\Delta Q}{\Delta t}$ or the potential difference between its plates $\frac{\Delta V}{\Delta t}$ since at any instant the amount of charge and the potential difference between the plates of the capacitor are in phase.

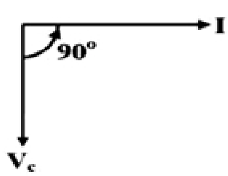
Since $I = \frac{\Delta Q}{\Delta t}$ and $Q = C\,V$

$$I = C\frac{\Delta V}{\Delta t}$$

Since V varies with phase angle as a sinusoidal curve, the expression $\frac{\Delta V}{\Delta t}$ is the slope of the tangent to the curve at any point, is maximum when the phase angle is zero, and gradually decreases until it reaches zero when V reaches a maximum. As V decreases, the slope of the tangent becomes a negative magnitude and the instantaneous current becomes a negative magnitude, so the curve I becomes as shown in Figure (4-13).



It is obvious that the voltage **lags** the current by a phase angle 90°. Both current and voltage across a capacitor can be represented by two vectors as in figure (4 –13b).

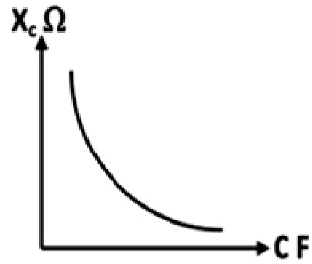


The capacitive reactance of a capacitor (X_C):

It is the opposition to the flow of the AC current in a capacitor due to its capacitance, and can be determined by the relation:

$$X_C = \frac{1}{2\pi f C} \qquad \Omega$$

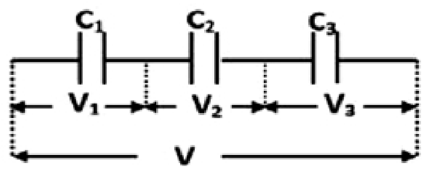
The capacitive reactance is inversely proportional with both the frequency of AC current and the capacitance of the capacitor.



Capacitor networking:

First: Capacitors in series:

If the capacitors are connected in series as shown in figure, capacitors are charged equally with a charge Q.



$$V = V_1 + V_2 + V_3$$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

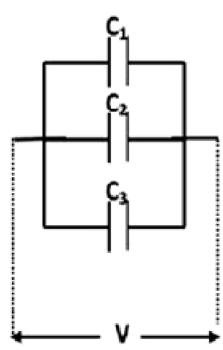
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

If the capacitance is the same for (n) capacitors,

$$C = \frac{C_1}{n}$$

Second: Capacitors in series:

If the capacitors are connected in parallel, the voltage across each capacitor is the same:



$$Q = Q_1 + Q_2 + Q_3$$

$$V\,C = V\,C_1 + V\,C_2 + V\,C_3$$

$$C = C_1 + C_2 + C_3$$

If the capacitance is the same for (n) capacitors,

$$C = n\,C_1$$

Example: Three capacitors of capacitance 20, 80 and 40 microfarad are connected in parallel then to an AC supply of electromotive force = 100 V and frequency 50 Hz. Calculate the value of current flowing through the circuit.

Solution:

$$\mathbf{C = C_1 + C_2 + C_3 = (20 + 80 + 40) \times 10^{-6} = 1.4 \times 10^{-4}\ Farad}$$

$$\mathbf{X_C = \frac{1}{2\pi f C} = \frac{1 \times 7 \times 10^4}{2 \times 22 \times 50 \times 1.4} = 22.72\Omega}$$

$$\mathbf{I = \frac{100}{22.72} = 4.4A}$$

Impedance

AC circuits containing ohmic resistors, inductors, and capacitors have impedance caused by the reactance of the coils and capacitors in addition to the resistance of the wires and circuit components. The sum of the combined reactance and resistance of the circuit is called the impedance and is symbolized by the symbol Z.

AC circuit contains ohmic resistance and inductive coil in series (RL-circuit):

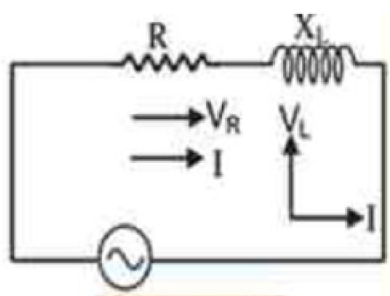


Figure (4 – 17)
RL circuit

In Figure 4-17. Since the current has the same phase in all components of the circuit because they are connected in series, while the potential difference across a component of the circuit may agree or disagree in phase with the current, the current and the potential difference across the ohmic resistance are in phase, while the potential difference across the coil is 90° in phase with the current. So the potential difference across the coil is 90° in phase with the potential difference across the ohmic resistor.

So the total potential difference V can be determined from the relationship:

$$V = \sqrt{V_R{}^2 + V_L{}^2}$$

$$\tan\theta = \frac{V_L}{V_R} = \frac{X_L}{X_R}$$

Since, $V_R = I\,R$ and $V_L = I\,X_L$

$$Z = \sqrt{R^2 + X_L{}^2}$$

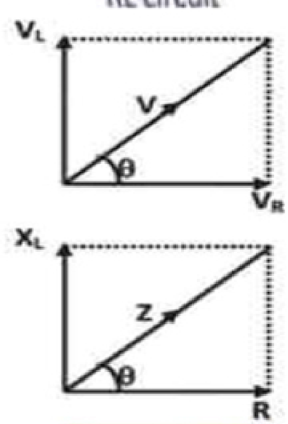


Figure (4 – 18)
Impedance of RL circuit

Example: An AC power supply of emf 80 V and frequency 50 Hz supplies a current to a coil of self-inductance $\frac{21}{220}$ *Henery* and a resistance 40 Ω in series. Find:

1- Impedance.

2- The voltage across each of the resistance and the coil. Is it correct to add these voltages algebraically?

Solution:

The inductive reactance: $X_L = 2\pi f L = 2 \times \frac{22}{7} \times 50 \times \frac{21}{220} = 30\ \Omega$

Impedance: $Z = \sqrt{R^2 + {X_L}^2} = \sqrt{(40)^2 + (30)^2} = 50\ \Omega$

$I = \frac{V}{Z} = \frac{80}{50} = 1.6\ A$

$V_R = 40 \times 1.6 = 64\ V$

$V_L = 30 \times 1.6 = 48\ V$

The algebraic sum of voltages: V = 64 + 48 = 112 V, This value is greater than the emf of the power supply. Because of this, voltages in the AC circuit is not added together algebraically.

But by addition of vectors:

$V = \sqrt{{V_R}^2 + {V_L}^2} = \sqrt{(64)^2 + (48)^2} = 80\ V$

AC circuit contains ohmic resistance and capacitors in series (RC-circuit):

The phase of the current in the resistor, coil, and capacitor is the same because they are connected in series, while the phase of the potential difference is different between them. In an ohmic resistor, the voltage and current are in phase, in a coil the voltage is 90° ahead of the current, and in a capacitor the voltage is 90° behind the current

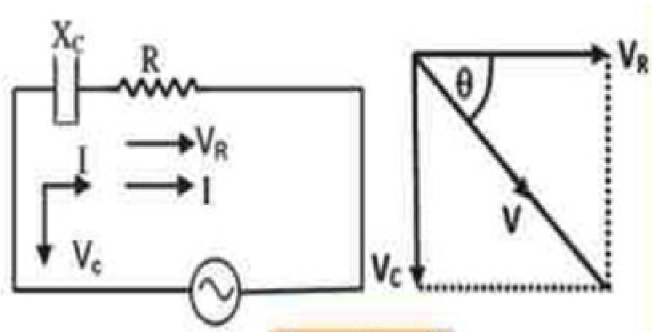


Figure (4 – 19)

RC circuit

So the total potential difference V is determined from the relationship: .

$$V = \sqrt{{V_R}^2 + {V_C}^2}$$

$$\tan\theta = \frac{-V_C}{V_R} = \frac{-X_C}{X_R}$$

Since, $V_R = I\,R$ $\quad and \quad$ $V_C = I\,X_C$

$$Z = \sqrt{R^2 + {X_C}^2}$$

AC circuit contains ohmic resistance, inductor and capacitors in series (LCR-circuit):

The current passing through the resistance, the inductor and the capacitor is the same since they are connected in series. On the other hand, the voltage across each component varies from one component to another:

In the ohmic resistance, the voltage is in the same phase with the current.

In the inductor, the voltage leads the current by a phase angle 90°

In the capacitor, the voltage lags the current by a phase angle 90°

And the resultant of the voltage vectors is:

$$V = \sqrt{{V_R}^2 + (V_L - V_C)^2}$$

Dividing by I:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\tan\theta = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$

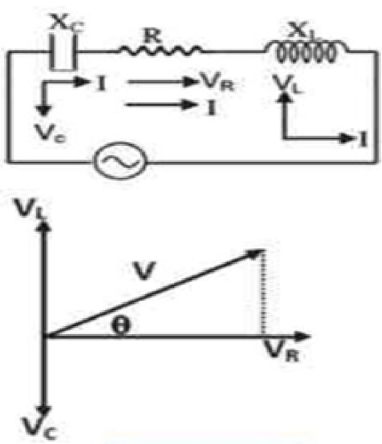
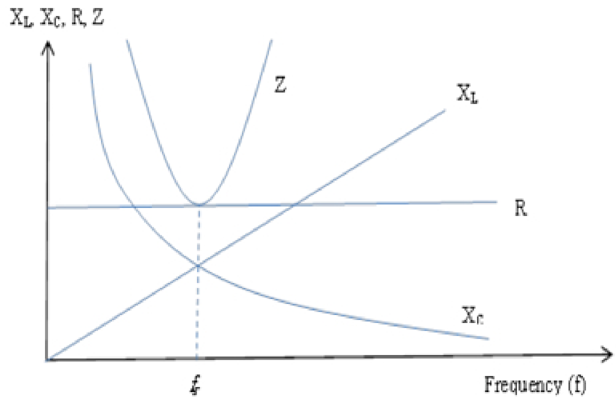


Figure (4 – 17)
LCR circuit

Note that:

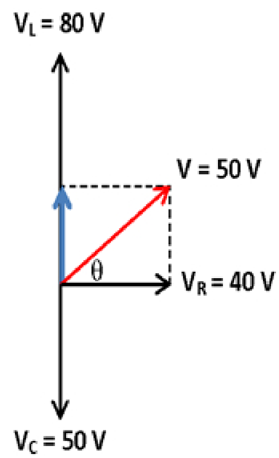
1- If $X_L > X_C$, the phase angle is positive and the circuit would have inductive characteristics. In other words, the voltage leads the current by a phase angle θ
2- If $X_L < X_C$, the phase angle is negative and the circuit would have capacitive characteristics. In other words, the voltage lags the current by a phase angle θ
3- If $X_L = X_C$, the phase angle = zero and the circuit would have characteristics of ohmic resistance. In other words, the voltage and the current have the same phase.
4- The coil and capacitor do not consume electrical power as a result of their inductive and capacitive reactions, respectively, because they store energy (power) as a magnetic field in the induction coil and an electric field in the capacitor, and then return it to the circuit as the AC cycle proceeds. Therefore, the power consumed in the circuit is due to the presence of ohmic resistance in the circuit.

The relation between each of resistance, reactance and impedance and the current frequency



Example: A current of 2 A passes through a series AC circuit containing a coil, a capacitor and a resistor. If the voltage across each of the coil, the capacitor and the resistor are 80 V, 50 V and 40 V respectively, answer:

1- Sketch the voltage vectors, and calculate the total voltage across the power supply.
2- Find the phase angle between the total voltage and the current. Deduce the characteristic of the circuit.
3- The power consumed as heat energy in the circuit.
4- Impedance of the circuit.



Solution

1- $V = \sqrt{{V_R}^2 + (V_L - V_C)^2} = \sqrt{(40)^2 + (80-50)^2} = 50\text{ V}$

2- $\tan\theta = \frac{V_L - V_C}{V_R} = \frac{80-50}{40} = \frac{3}{4}$

$\theta = 37^\circ$ the circuit would have inductive characteristics

The resistance $(R) = \frac{V_R}{I} = \frac{40}{2} = 20\ \Omega$

The consumed power in the circuit $= I^2 R = (2)^2 \times 20 = 80\text{ W}$

$Z = \frac{50}{2} = 25\ \Omega$

Oscillating circuit

An Oscillating circuit consists of an inductor L with a very small resistance and a capacitor, C. They can be connected together by a switch (b) as shown in the diagram.

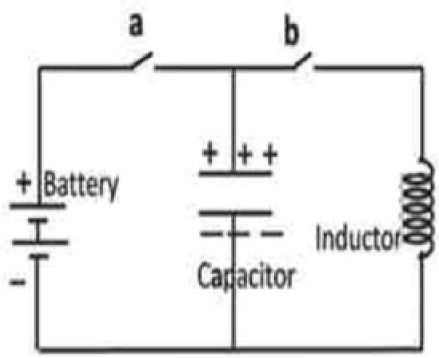


Figure (4 – 18)
Oscillator circuit

1-The capacitor stores energy in the form of an electric field due to the voltage difference between its plates, while the inductor stores energy in the form of a magnetic field .

2- When switch a is closed, the capacitor is connected to the battery and a current passes momentarily to start charging the capacitor until the potential difference between its plates equals the constant potential difference V and the current stops flowing to it.

3- When the capacitor is fully charged, switch a is opened and switch b is closed to connect the charged capacitor to the induction coil, the capacitor begins to discharge its charge q and an electric current I passes through the coil, generating a magnetic field in the coil that stores the energy that was stored in the electric field as magnetic energy.

4 -As the potential difference between the two plates of the capacitor C gradually decreases, the current through the coil increases, increasing the strength of the magnetic field around the coil .

5- As the potential difference between the two plates of capacitor C gradually decreases, the current through the coil increases, increasing the strength of the magnetic field around the coil.

The amount of charge on the capacitor plates is a maximum value

The potential difference across the capacitor is a maximum value

The intensity of the electric field between the plates of the capacitor is maximum

The electrical energy stored in the capacitor has a maximum value

The rate of change in current intensity is a maximum value

The capacitor discharge rate is zero

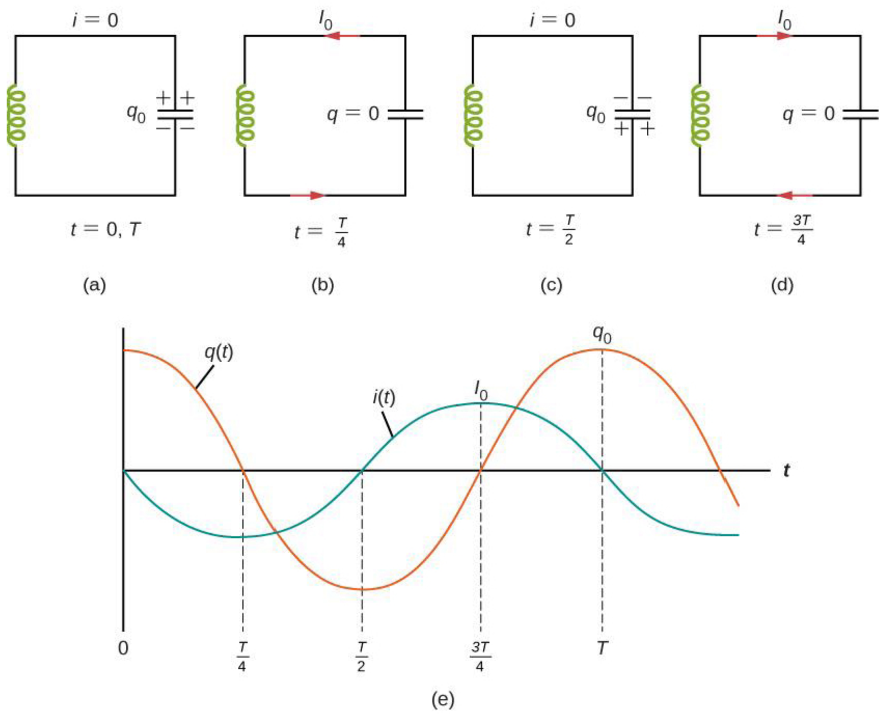
The rate of charge flow is zero

The rate of change in the amount of charge is zero

The current in the coil is zero

The strength of the magnetic field in the coil is zero

The magnetic energy stored in the coil is zero



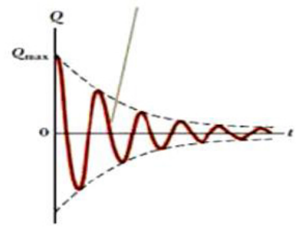
By the time the capacitor has discharged all of its charge, the current in the coil has - .reached its maximum value and so has the magnetic energy stored in the coil

The current in the coil then begins to decrease through the coil, creating a centrifugal - .force in the induction coil that keeps the current flowing in the original direction

This current charges the capacitor plates with a polarity opposite to their original - charge. The process of charging the capacitor continues until the current in the coil drops to zero and its magnetic field completely vanishes. The energy returns to the capacitor .again in the form of electrical energy

-

The capacitor now begins to discharge back through the coil and the whole process repeats. The polarity of the voltage changes as the energy passes back and forth between .the capacitor and the inductor, causing an alternating current to pass through their circuit ,Energy is constantly being exchanged between the two fields -



Due to the ohmic resistance in the coil and other wires, some of the energy is gradually converted into heat, the AC current in the circuit decreases, and the potential difference between the two plates of the capacitor gradually decreases until it is zero, stopping charging and discharging. The figure represents the decay of charge on the .capacitor plates over time

But if the capacitor can be fed with additional charge to compensate for its constant lack of it, .the charging and discharging processes can continue

The frequency of the alternating current in the oscillating circuit is calculated from the relationship:

This relationship was deduced by equating the inductive reactance of the coil and the capacitive reactance of the capacitor.

$$\therefore 2\pi f L = \frac{1}{2\pi f C} \qquad X_L = X_C$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The self-inductance coefficient of a solenoid L can be given by the relation:

$$L = \frac{\mu A N^2}{l} \quad Henry$$

Example 1: Find the frequency of current in an oscillator circuit if self-inductance of the coil is 16 µH and the capacitor capacitance is 4.9 mF.

Solution:

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{7}{2x\,22}\sqrt{\frac{1}{16\times10^{-6}\times4.9\times10^{-3}}} = \frac{7}{44}\times\frac{10^5}{4\times7} = 568.18\ Hz$$

Tuned or "Resonant" circuit

The resonant circuit is an LCR circuit containing a capacitor and an inductor.

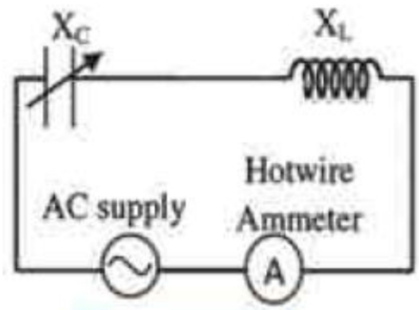


Figure (4 – 21)
Tuned circuit

Resonance phenomenon:

The phenomenon of resonance can be observed in sound, where the amplitude of vibration of two tuning forks increases significantly if their frequency is the same, and when the frequencies of the two tuning forks differ from each other, the amplitude of vibration decreases.

Similarly, in a circuit containing a variable-frequency AC source, a variable capacitor, an inductor, and a thermal ammeter, as shown in the figure. By changing the frequency of the electrical source, the effective value of the current in the circuit changes, decreasing if the difference between the source frequency and the circuit frequency is large, increasing as the source frequency approaches the circuit frequency, and the value of the current is greatest when the source frequency coincides with the circuit frequency. This state is achieved when the inductive reactance of the coil and the capacitive reactance of the capacitor are equal. The circuit can be

$$\mathbf{f} = \frac{\mathbf{1}}{\mathbf{2\pi\sqrt{L\,C}}}$$

The resonance circuit is used as a tuning circuit in radio receivers to select the radio station to be heard.

How the resonance circuit works in receivers or radios:

The resonance circuit in receivers or radios is connected to the receiver's antenna (aerial), where the waves of different radio stations reach the antenna, each of which has a specific frequency. These waves affect the antenna and generate currents that have the same frequency as the stations. The resonant circuit in the receiver only allows the current whose frequency matches the frequency of the circuit to pass through. When you want to listen to a particular radio station, you change the frequency of the circuit by changing the capacitance of the capacitor or the number of turns of the coil, and the current whose frequency corresponds to the frequency of the circuit passes to the receiver, and undergoes certain operations such as amplification, rectification, and separation of the current expressing the sound that passes to the receiver's speaker.

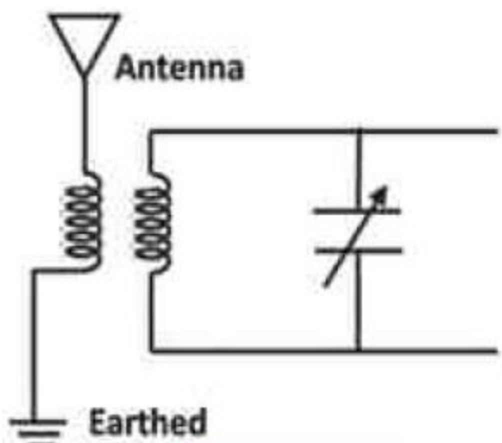


Figure (4 – 22)
Tuned circuit in radio receivers

In a Nutshell

1. The alternating current: is the current that changes its intensity periodically from zero to a maximum value, then drops back to zero in a half cycle. As it reverses its direction in the other half cycle, its intensity increases to maximum then back to zero value.

2. Hot wire ammeter: is the instrument used to measure either the effective value of the AC current or the intensity of direct current, based on the expansion of iridium-platinum wire due to the thermal effect of current.

3. Inductive reactance of a coil: is the opposition to the flow of the AC current in a coil due to self-inductance.

$$X_L = 2\pi f L \quad \text{Ohm}$$

4. The inductive reactance of inductors connected in series: $X_L = X_{L1} + X_{L2} + X_{L3}$

5. The inductive reactance of inductors connected in parallel: $\frac{1}{X_L} = \frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}$

6. Capacitive reactance in a capacitor: is the opposition to the flow of AC current in a capacitor due to its capacitance.

$$X_C = \frac{1}{2\pi f C} \quad \text{Ohm}$$

7. The capacitive reactance of inductors connected in series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

8. The capacitive reactance of inductors connected in parallel: $C = C_1 + C_2 + C_3$

9. Impedance of circuit: is the equivalent of reactance and resistance in the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

10. The frequency of the resonant circuit:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Questions and Drills

Q1: What is meant by each of the following...?

The inductive reactance – The capacitive reactance – Impedance – The oscillator circuit

Q2: Mention the factors that affect each of:

1- The inductive reactance   2– The capacitive reactance

3 – Frequency of an oscillator circuit   4– The impedance

Q3 : How is the total capacitance calculated for a number of capacitors connected together:

a) In series   b) In parallel

Q4 : Describe the construction of the oscillator circuit and explain its operation.

Q5 : Describe the construction of the tuned circuit and explain its operation in the radio receiver device.

Q6: Find the total capacitance of two capacitors of capacitance 24 and 48 microfarad connected together:

a) In series   b) In parallel

Q7: AC current of frequency 50 Hz passes through a resistor 12 Ω and an inductor of inductance $\frac{7}{440}$ *Henry* connected together in series. Find impedance of the circuit. (13 Ω)

Q8 : Calculate the value of current passing through an inductive coil of self-inductance $\frac{7}{275}$ *Henry* and ohmic resistance 6 Ω if the coil is connectedto:

a) A direct power supply of emf 6 Volt and negligible internal resistance.

b) An alternating power supply of emf 6 Volt and frequency 50 Hz. (0.6 A , 1 A)

Q9: Three identical capacitors, of capacitance 14 microfarad each, are connected in parallel then to a power supply of frequency 50 Hz. Calculate the total capacitive reactance.

Q10 : A resistor of 6 Ω, a capacitor of capacitive reactance = 80 Ω and a coil of self-inductance 0.28 Henry are connected together in series to an AC power supply of voltage 20 V and frequency 50 Hz. Find:

a) The potential difference between the capacitor plates.
b) The phase angle between the total voltage and current.
c) The maximum of the current value that can be reached in the circuit.

(160 V , 53°, 2.8 A)

Q11: A tuned circuit in a radio receiver consists of an inductive coil of inductance 10 millinery, a resistance 50 Ω and a capacitor of variable capacitance. Wireless waves of frequency 980 kHz hit the antenna and generate a voltage 10^{-4} Volt across the circuit. Find the capacitor capacitance and the current value at resonance.

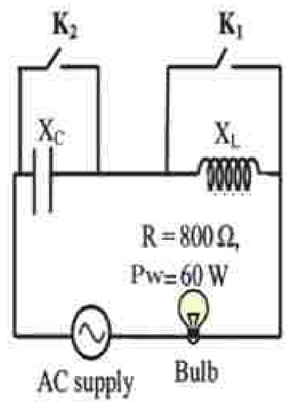
(2.635×10^{-12} F, 2×10^{-6} A)

Q12: A series circuit consists of a coil of inductive reactance 250 Ω, a resistance 100 Ω, a capacitor of variable capacitance and AC power supply of electromotive force 200 Volt and frequency $\frac{1000}{44}\,Hz$. Given that the current through the circuit reached its maximum value, find:

a) The capacitive reactance that caused the current to reach its maximum.
b) The potential difference between the terminals of the coil and the capacitor plates in this case.

(28×10^{-6}F, 500 V)

Q 13 : The circuit illustrated in figure contains an AC supply of frequency 50 Hz and electromotive force 220 Volt, a capacitor of capacitance 4 microfarad and an inductor of inductance 2.53 Henry. Find:

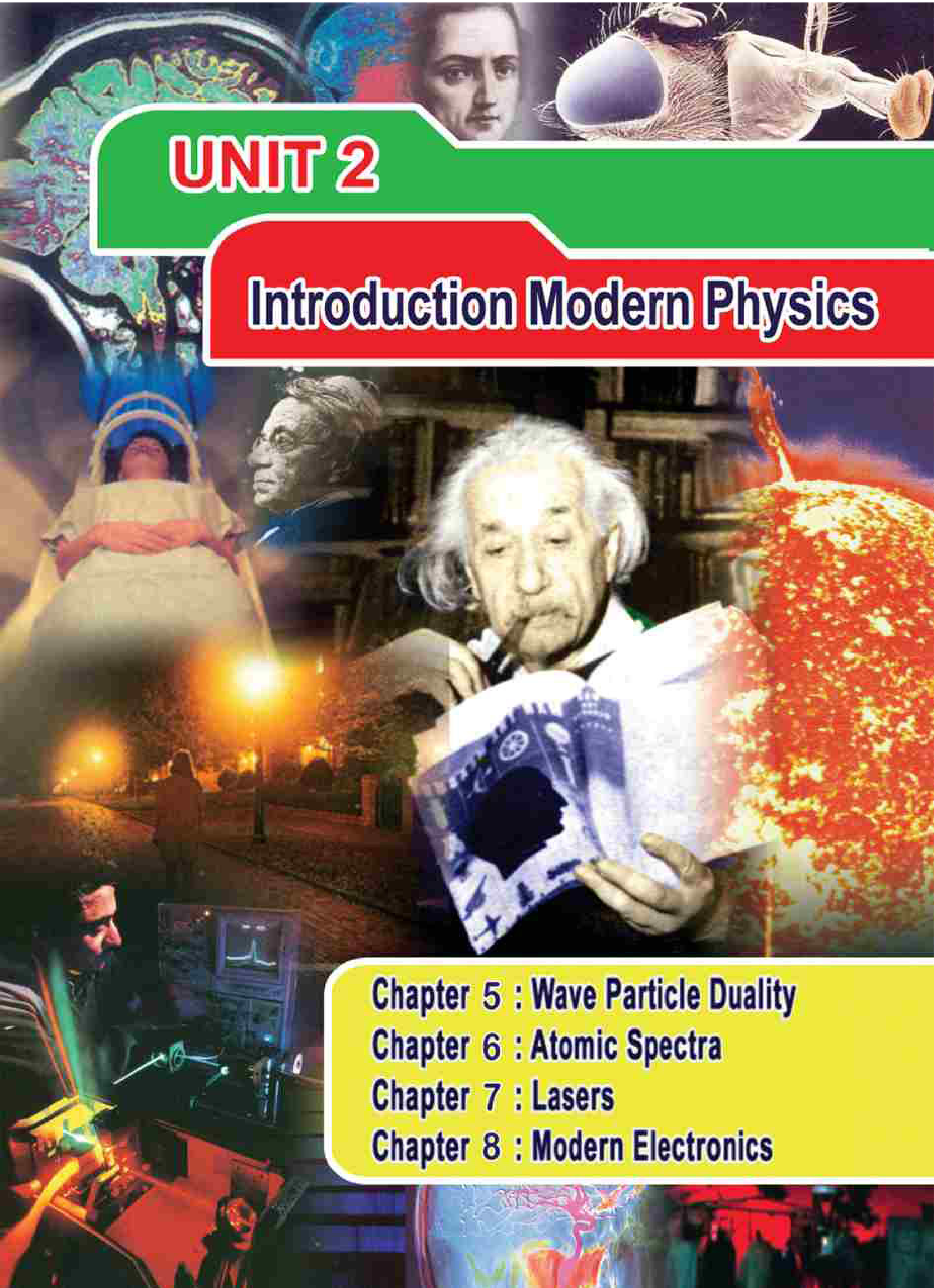


1- The capacitive reactance.
2- The inductive reactance.
3- What happens to the glowing of the electric bulb when only K_1 is turned on? Find the impedance.
4- What happens to the glowing of the electric bulb when only K_2 is turned on? Find the impedance.
5- What happens to the glowing of the electric bulb when both K_1 and K_2 are turned on? Find the impedance.

(795.4 Ω, 795.4 Ω, 1128 Ω, 800 Ω)

UNIT 2

Introduction Modern Physics



Chapter 5 : Wave Particle Duality

Chapter 6 : Atomic Spectra

Chapter 7 : Lasers

Chapter 8 : Modern Electronics

Chapter 5 Wave Particle Duality

Overview

Everything we have studied so far is under what is called "classical physics". This does not mean that it is unused physics, but rather that it explains our daily observations and usual experiences. As for the current unit, it includes some basic concepts of modern physics that are considered an important introduction to Quantum Physics. This branch of physics deals with a large group of scientific phenomena that we may not see directly in our daily life, but it deals with many phenomena of the universe that classical physics cannot explain, especially when we deal at the atomic or subatomic scale. This branch of physics also explains all electronic phenomena, which are the basis of modern electronics and communications systems, and it also explains chemical reactions at the molecular level, which the scientist Ahmed Zewail was able to photograph some of them using a high-speed laser camera, which qualified him to win the Nobel Prize in Chemistry in 1999.

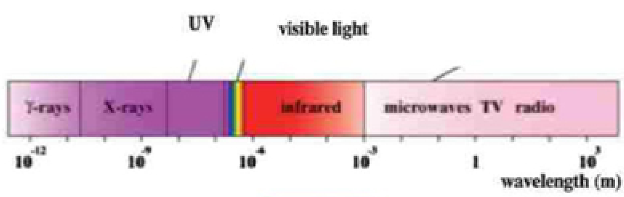


Fig (5-1)
Electromagnetic spectrum

Black Body Radiation

Our understanding of light so far is that it propagates in the form of electromagnetic waves. The properties of waves include reflection, refraction, interference, and diffraction. We also understand that visible light is a limited part of the electromagnetic spectrum (Figure 5-1). Electromagnetic waves differ in frequency and wavelength, but they propagate at a constant speed in a vacuum, which is $c = 3\times 10^{8}$ m/s. Electromagnetic waves do not need a materialistic medium for their propagation.

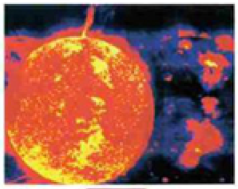


Fig (5-2)
The Sun as a source of em radiation

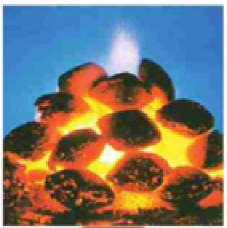


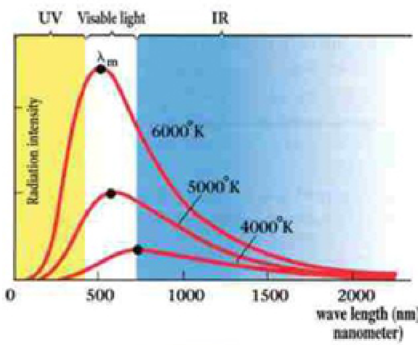
Fig (5-3)
A burnig charcoal emits em radiation

Fig (5-4a)
A glowing incandescent lamp emits em radiation

Fig (5-4b)
A lamp emitting less em radiation

We all notice that some hot objects radiate light and heat. Examples of these objects include the sun (Figure 5-2) and other stars, as well as a burning piece of coal (Figure 5-3), and the filament of an electric lamp (Figure 5-4). We also notice that the dominant color of the light emitted from all of these sources and others is variable.

When analyzing the electromagnetic radiation emitted by a source, we find that it does not radiate all wavelengths equally, but rather the intensity of the radiation varies with the wavelength. The curve that shows the intensity of the radiation for the wavelengths that make up the radiation is called Planck's Distribution curve (Figure 5-5). It has also been found in practice that the wavelength with the maximum radiation intensity λ_m is inversely proportional to the absolute temperature of the radiation source. This is known as Wien's Law. That is, the higher the absolute temperature of the radiation source, the shorter the wavelength with the maximum intensity. It is noted that at very long or very short wavelengths, the radiation intensity approaches zero.



Fig(5-5)
The wavelength at the peak is inversely proportional to temperature

For example, the temperature of the Sun at its surface is 6000 K, which makes the maximum radiation intensity fall at a wavelength of 5000 Å (0.5 micron), i.e. in the visible spectrum. Therefore, about 40% of the Sun's radiant energy is visible light, and about 50% is infrared radiation, while the rest of the radiation is distributed over the rest of the spectrum. By analyzing the radiation emitted by an incandescent light bulb (temperature 3000 K), we get the same Planck curve, which makes the maximum radiation intensity fall at a wavelength of about 1000 nm = 10^{-6} m = 10000 Å = 1 micron (Figure 5-5). Visible light usually represents about 20% of the radiation energy emitted by the lamp filament, and the rest is in the form of heat.

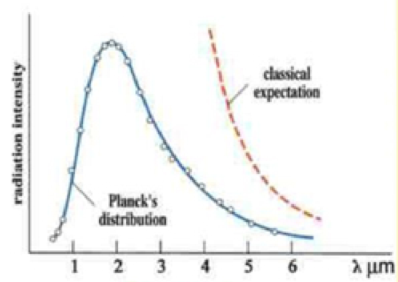


Fig (5-6)
Radiation decreases with increasing frequency in disagreement with classical expectations

These observations shown by the Planck curve cannot be explained using classical physics. It is known from classical physics that since radiation is electromagnetic waves, the intensity of radiation emitted by a hot body increases as the frequency increases. So why does the intensity of radiation decrease at high frequencies (Figure 5-6)? In 1900, the scientist Planck was able to explain this phenomenon, and found that this curve is repeated with all hot bodies that radiate a continuous spectrum of radiation, not only the sun, but also the earth and living organisms. However, the earth - as a non-glowing body - absorbs the sun's radiation, and then radiates it again. But because its temperature is much lower than the sun's, we find that the wavelength at the top of the curve is about 10 microns, which is in the infrared radiation range (Figure 5-7).

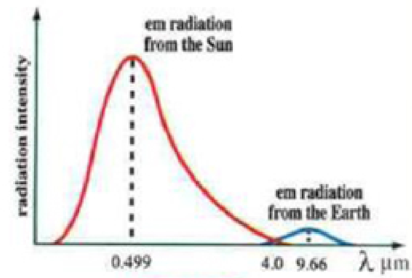


Fig (5-7)
Radiation from the Earth and from the Sun

There are satellites, airborne measuring devices, and ground-based devices that image the Earth's surface using different spectrum regions emitted by it, including infrared rays emitted from the Earth's surface in addition to visible light, as well as using microwaves used in radar (Figure 5-8). Scientists analyze these images to determine Earth Resources. This technology is called remote sensing. Egypt is considered a pioneer in this field.


Fig (5-8)
An image of southern Sinai taken by Land sat satellites

The radiation emitted by objects is also used in some military applications, such as night vision devices to detect moving objects in the dark due to the radiation they emit (Figure 5-9, 5-10).


Fig (5-9)
A night vision system


Fig (5-10)
An image taken by a night vision system

Thermal imaging is also used in the field of medicine, especially in the field of Tomography (Figure 5-11), embryology, and also in the field of forensic evidence discovery (Criminology), where the person's thermal effect remains for a period after he leaves the place.

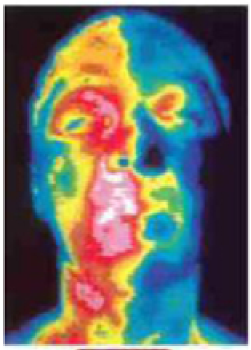


Fig (5-11)
A thermal image for the face and neck

This phenomenon is called "Black Body Radiation". The reason for this name is that a black body is a body that absorbs all radiation of different wavelengths falling on it. It is considered a perfect absorber, and then re-radiates it perfectly, i.e. it is also a perfect emitter. If we imagine a closed cavity with a small hole, what is inside this cavity appears black. This is because the radiation passing into the cavity remains mostly confined inside it due to many successive reflections, and only a small part comes out of it (Figure 5-12a, b).

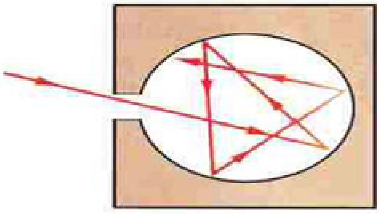


Fig (5-12a)
Radiation inside the cavity is trapped so it appears black

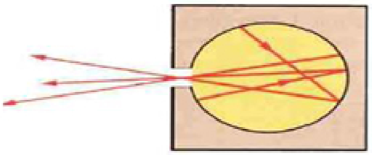


Fig (5-12b
A small part of energy leaks out of the hole which is called blackbody radiation

Planck's Explanation

Planck was able to explain the phenomenon of black body radiation by assuming something strange for his time, which is that the radiation emitted by a glowing body consists of small units or bursts of energy, each of which is called a quantum or photon. Thus, the radiation emitted by a glowing body is a huge flow of these photons. These photons are emitted by the oscillation of atoms, and the energy of these oscillating atoms is not continuous, but rather quantized or discontinuous, i.e. discrete. The energy levels take values E= n h ν, where h is Planck's constant $h=6.625 \times 10^{-34}$ J.s, and ν is the frequency.

The atom does not emit any radiation as long as it remains in one level. But whenever the atom moves from a high energy level to a lower energy level, it emits a photon with energy E= h ν. Thus, there are high-energy photons if ν is high and low-energy photons if ν is low.

As the frequency of radiation increases above the frequency of maximum radiation intensity in the Planck curve, the energy of its photons increases, and the number of emitted photons of this energy decreases. Since the radiation consists of billions of these photons, we do not observe these photons separately, but rather we observe the properties of the emitted radiation as a whole. These properties, which express the beam of photons, are the classical properties of waves.

Photoelectric effect and thermionic emission:

The metal contains positive ions and free electrons that can move inside the metal, but they cannot leave it because of the attractive forces that always pull them inward. This is called the surface potential barrier. However, some of these electrons can leave if we give them thermal or light energy. This is the idea of the cathode ray tube (CRT), which is used in television and computer screens (Figure 5-15).

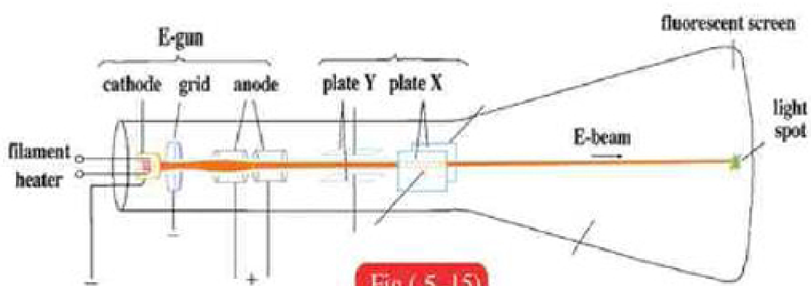


Fig (5-15)
Light spot on a fluorescent screen
(emits photons when struck by electrons)

This tube consists of a metal surface called the cathode (negative pole) that is heated by a heating filament. Some electrons are released from the cathode by the effect of heat, overcoming the forces of attraction at the surface. The emitted electrons are accelerated and organized by a positive pole called the anode. The electron beam is released from this part which is called the E-Gun, where it is captured by the fluorescent screen connected to the anode, causing a current in the external circuit. When these electrons collide with the screen, they emit light whose intensity varies from one point to another according to the intensity of the transmitted electrical signal that controls the intensity of the electron current by a special grid (negative voltage) that intercepts the path of these electrons.

The path of the E-beam electron beam can be directed by electric or magnetic fields to scan the screen point by point (Raster) until the image is completed (Figure 5-15).

Photoelectric effect:

When light falls on the cathode instead of heating the filament, an electric current also passes through the circuit of the photoelectric cell. This means that electrons are released by the light. The phenomenon of electrons being released due to light falling on a metal surface is called the photoelectric effect (Figure 5-14). This phenomenon cannot be explained by the classical theory of light. Since light is an electromagnetic wave, some of it can be absorbed by the metal, meaning that the light waves give energy to the electrons to be released? Then we face several problems in understanding what happens in practical observation. According to this classical conception, the intensity of the current or the release of electrons (which are called photoelectrons) depends on the intensity of the incident wave regardless of its frequency, and the kinetic energy of the released electrons (or their speed) must increase with increasing light intensity. Also, even if the light intensity is low, shining light on the metal for a long time is enough to give the electrons the energy needed to be released, regardless of the frequency of the incident light wave.

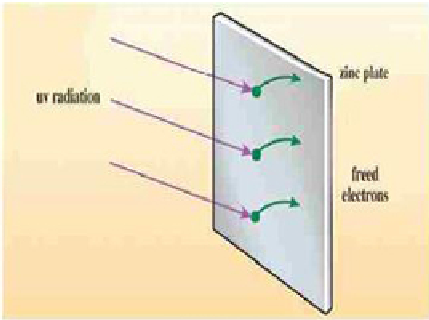


Fig (5-14a)
Electrons may be freed from a metal if given sufficient energy

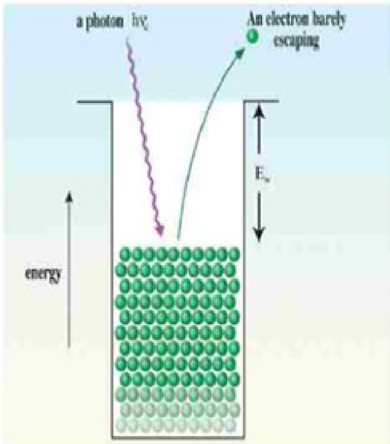


Fig (5-14b)
Minimum energy needed to free an electron is called work function

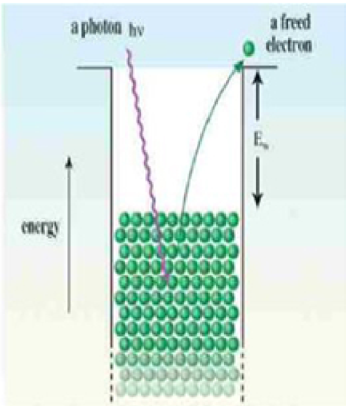


Fig (5-14c)
A more tightly bound electron needs higher energy to escape

However, scientific observation is completely different from these expectations based on classical theory. It has been observed that the emission of electrons from the metal depends primarily on the frequency of the incident wave and not on its intensity. These electrons are not emitted unless the frequency of the incident light is higher than a critical value ν_c, regardless of the intensity. However, if the frequency exceeds ν_c, the photoelectric current increases with the intensity (Figure 5-17).

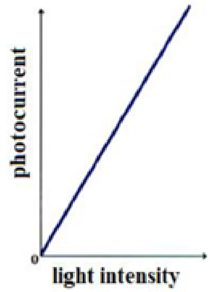


Fig (5-17b)
Photocurrent versus light intensity for $\nu > \nu_c$

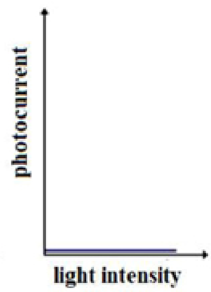
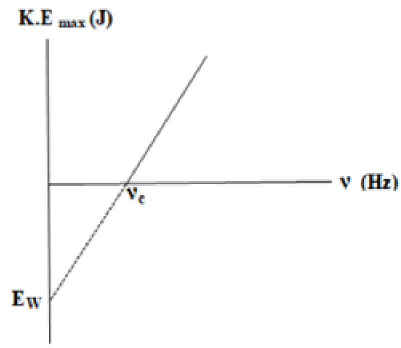


Fig (5-17a)
Photocurrent versus light intensity for $\nu < \nu_c$

The kinetic energy of the emitted electrons - and thus their speed - also depends on the frequency of the incident wave and not on its intensity. The emission of electrons occurs instantaneously. There is no need for time to collect the energy needed to liberate the electrons if the intensity of the light is weak. Rather, the electrons are emitted immediately, even if the intensity of the light is weak, but on condition that the frequency of the light is greater than the critical frequency ν_c.



Einstein's explanation

Einstein was able to explain these observations that the classical theory of light could not explain. Einstein won the Nobel Prize in Physics in 1921 for this explanation by discovering the law of the photoelectric effect.

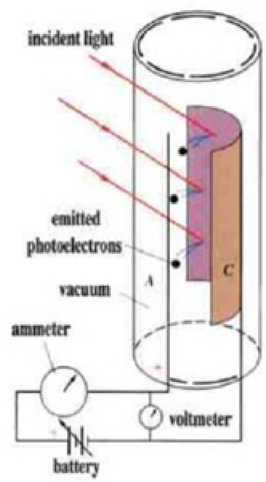


Fig (5-16)
Photoelectric current achieved by absorbing photons on a metal surface
(Photo electeric cell)

This explanation can be summarized as follows:

If a photon with energy $h\nu_c$ falls on a metal surface and this energy is greater than a certain limit called the work function and is symbolized by the symbol E_w and equals$h\nu_c$, which is the energy needed to liberate electrons from the metal surface (Figure 5-14), then this photon can barely liberate an electron from the surface of this metal, meaning that

$$E_w = h\nu_c \qquad (5-1)$$

If the energy of the incident photon is greater than that, the electrons are released and the energy difference appears in the form of kinetic energy (KE), i.e. they are released more quickly, and this kinetic energy increases with the increase in the frequency of the incident radiation. However, if $h\nu$ is less than E_W, the electron is not released regardless of the intensity of the light. Also, the release of electrons occurs instantaneously and there is no waiting period for energy to be collected, provided that the photon energy $h\nu$ is greater than E_W.

Accordingly, $h\nu_c$ (where ν_c is the critical frequency) depends on E_W, or the type of material, and does not depend on the intensity of light, or the time of exposure to light, or the potential difference between the cathode and the anode.

Einstein's equation can be written as follows:

$$\frac{1}{2}mv^2 = h\nu - h\nu_c \qquad (5-2)$$

Compton Effect:

It was observed that when a photon (from X-rays or gamma rays) falls on a free electron, the photon's frequency decreases and its direction changes, and the electron's speed increases and it changes its direction (Figure 5-18).

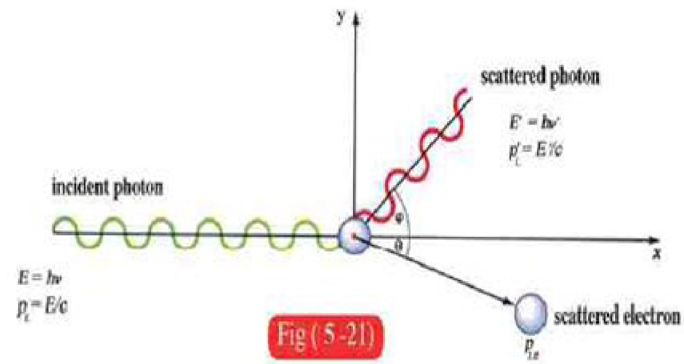


Fig (5-21)

Compton effect

This cannot be explained by the wave theory (classical), but can be explained by Planck's assumption that electromagnetic radiation is composed of photons, and that these photons can collide with electrons as billiard balls collide. Then the momentum must be conserved, meaning that the algebraic sum of the momentum before the collision equals the algebraic sum of the momentum after the collision, as well as the law of conservation of energy, meaning that:

$$(\text{Photon energy} + \text{electron energy})_{\text{before collision}} = (\text{Photon energy} + \text{electron energy})_{\text{after collision}}$$

Therefore, we must consider that the photon, like a particle, has momentum, just as the electron has momentum.

Photon Properties:

From all the above observations and experiments, the photon is an amount of energy concentrated in a very small size, and has momentum, and its energy is equal to hν, and it moves continuously at the speed of light c, which is constant regardless of the frequency. Einstein proved that mass and energy are related by his famous relation $E = mc^2$. That is, the loss of mass appears in the form of energy. This is the basis of the atomic bomb (Figure 5-19), where he found that the fission of the nucleus is accompanied by a very small loss of mass, but it turns into very large energy since the square of the speed of light is a very large amount ($c^2 = 9\times10^{16}\ m^2/s^2$).


Fig (5-19)
Atomic bomb

Therefore, the law of conservation of mass and the law of conservation of energy blend into the law of conservation of energy and mass together. This means that a photon with energy hν has a mass **equivalent to** this energy during its movement equal to $h\nu/c^2$. Since its speed is c, the momentum, which is the product of mass and velocity, becomes hν/c.

If a beam of photons falls on a surface and is reflected from it at a rate of Φ_L Photons/s, then if each photon falling on the surface and being reflected from it experiences a change in momentum equal to 2mc, and since the force exerted by the beam of photons on the surface it collided with is equal to the change in its momentum per second, then:

$$F = 2mc\Phi_L$$

$$F = 2\left(\frac{h\nu}{c}\right)\Phi_L = \frac{2P_w}{c} \qquad (5-3)$$

Where P_w is the power of the photon beam in Watts of incident light on the surface, this force is very small, so it does not noticeably affect a large surface such as a wall, for example, but it can affect a free electron due to its small mass and size, throwing it away. This is the explanation of the Compton Effect.

In the microscopic model, the photon can be imagined as a ball with a radius equal to the wavelength of the wave λ, oscillating at a frequency **ν**. The sum of these photons has an electric field and a magnetic field, and the two fields are perpendicular to each other and to the direction of propagation of the photon beam. Therefore, we consider that the photon beam carries the energy carried by the light beam. We can observe the wave properties in the behavior of the photon beam as a whole, and the wave intensity – and its measure is the intensity of the electric field or the intensity of the magnetic field accompanying the light beam - indicates the extent of the concentration of photons. That is, the wave motion is accompanied by a beam of photons in large numbers, and this is what is called the macroscopic model (i.e. large), meaning that the macroscopic and microscopic models are linked to each other.

If it is related to what happens at the level of the electron or the atom, we use the photon model, which is the microscopic model. But the wave property and the particle property of photons are interconnected. The important thing is to understand how to apply each in its position according to the size of the obstacle that obstructs the path of the light. If the obstacle has dimensions much larger than λ, we apply the macroscopic model, but if the obstacle is at the level of the atom or the electron, i.e. within the limits of λ, then we must deal with the microscopic model, i.e. the photon.

Example:

Calculate the force exerted by a beam of 1W when it reflects from the surface of a wall.

Solution:

$$\mathbf{F = \frac{2P_w}{c} = \frac{2 \times 1}{3 \times 10^8} = 0.67 \times 10^{-8} N}$$

This force is very small and hardly affects the wall.

The relation between the wavelength of a photon and the linear momentum:

$$\therefore \lambda = \frac{h}{P_L} \qquad (5-4)$$

The wavelength of a photon is equal to Planck's constant divided by the momentum P_L. It is noted that when a beam of photons falls on a surface, its reflection or transmission depends on comparing the wavelength λ and the distances between the atoms of the surface. If λ is much larger than the distances between them, the photons deal with this surface as a continuous one and reflect from it as in the wave theory. However, if the distances between them are close to the wavelength λ, the photons pass through the atoms. This is what happens, for example, in the case of X-rays passing through different media.

Example:

Calculate the equivalent mass and momentum of a photon if the wavelength λ=380nm

Solution

$$\nu = \frac{c}{\lambda} = \frac{(3 \times 10^{8} \mathrm{m/s})}{(380)(1 \times 10^{-9} \mathrm{m})} = 7.89 \times 10^{14} \mathrm{Hz}$$

$$m = \frac{E}{c^2} = h\nu/c^2 = \frac{(6.625 \times 10^{-34} \mathrm{Js})(7.89 \times 10^{14} \mathrm{s^{-1}})}{(3 \times 10^{8} \mathrm{m/s})^2}$$

$$= 5.81 \times 10^{-27} \mathrm{kg}$$

$$P_L = \frac{h}{\lambda} = \frac{(6.625 \times 10^{-34} \mathrm{Js})}{(380)(1 \times 10^{-9} \mathrm{m})} = 1.74 \times 10^{-27} \mathrm{kgm/s}$$

The wave nature of the particle:

In the universe, there is a great deal of symmetry in the universe. If waves have a particle nature, why can't particles have a wave nature? This symmetry (Wave-Particle Duality) was formulated by De Broglie in 1923 through an equation similar to the photon equation, that the particle has a wave nature with a wavelength:

$$\lambda = \frac{h}{P_L} \qquad (5-4)$$

Where P_L is the momentum of the particle.

But what does that mean?

We look at light as a huge collection of photons, all together having an accompanying wave that describes their collective behavior of propagation, reflection, refraction, interference, and diffraction, and the concentration of the photons determines the intensity of the wave. The photon behaves as if it carries the genetic characteristics of the wave in terms of frequency, wavelength, and speed.

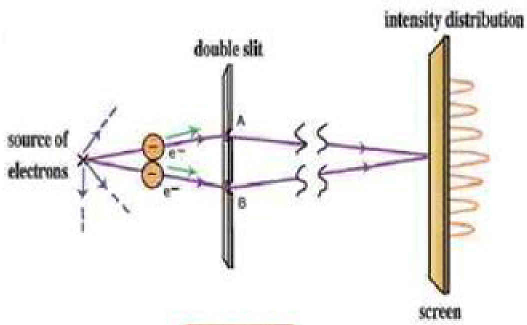


Fig (5-20a)
Diffraction of electrons through a double slit

By the same logic, we look at the electron beam as a huge collection of electrons all together having an accompanying wave that describes their collective behavior. As for each electron, it carries the genetic characteristics of the whole in terms of charge, mass, spin, and momentum. Accordingly, the accompanying wave has a wavelength. This means that the intensity of the accompanying wave also indicates the concentration of electrons, and the accompanying wave has the properties of propagation, interference, and diffraction, just like light (Figure 5-20).

But does this mean that we can use a beam of electrons as we use a beam of light? The answer is yes! The evidence for this is the invention of the electron microscope.

Electron Microscope:

The electron microscope is a laboratory device that depends on the wave nature of electrons. The electron microscope is similar to the light microscope in many ways. However, the optical microscope uses a light beam, while the electron microscope uses an electron beam. The main difference between them is the resolving power, where the electron microscope has a very large resolving power, because electrons can carry very high kinetic energy and therefore very short wavelengths (Equation 5-4), and therefore its magnification factor is very large, so that it can detect very small objects that ordinary light cannot detect (Figure 5-21). The speed of the electron accelerated by the electric field can be calculated from the relation:

$$eV = 1/2\ mv^2 \qquad (5\text{-}5)$$

Therefore, the wavelength of the electron beam can be a thousand or more times shorter than the wavelength of visible light. Therefore, the electron microscope has a greater resolution of fine details. The lenses used to focus the electron beam in the electron microscope are magnetic lenses, and are studied using electron optics.

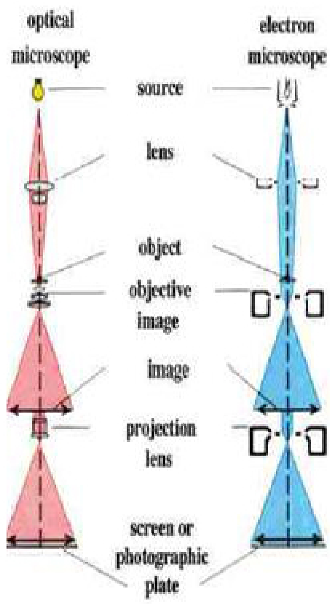


Fig (5-21a)
Electron microscope

Fig (5-21b)
Head of a fly as seen by an e-microscope

In a Nutshell

- Classical physics cannot explain many phenomena, particularly those in which light (or em radiation) interacts with electrons or atoms.
- Light or any em radiation consists of a huge collection of photons, each photon having energy $h\nu$, where h is Planck's constant and ν is the frequency.
- An evidence for photons is the photoelectric effect, where photocurrent depends on the intensity of incident light as long as the frequency is greater than a critical value ν_c. But if the frequency is less than ν_c, no photocurrent flows. The kinetic energy of the electron freed by the photoelectric effect depends on the frequency not on the light intensity.
- A photon has a mass, a linear momentum and a constant speed which is the speed of light. It has a size denoted by the wavelength. If a photon falls on a wall, it applies a small force on it, but if it falls on an electron, the electron will be thrown off due to its small mass and size.
- Compton effect proves the particle nature of photons, where a photon has mass, speed and linear momentum.
- A wave describes the collective behavior of photons.
- The wavelength of a photon is Planck's constant divided by the linear momentum. The same relation applies to a free particle, where the wavelength describes the wave nature of the particle ,i.e., the wave accompanying the particle.
- The electron microscope proves de Broglie relation for particles. It is used to detect diminutive particles.

Questions and Drills

I)Drills

1) Calculate the energy of a photon whose wavelength is 770 nm and find its mass and linear momentum?

(2.58×10^{-19} J , 0.29×10^{-35} kg , 0.86×10^{-27} kgm/s)

2) Calculate the mass of an X- ray photon and a γ ray photon if the wavelength of X-ray is 100 nm , and that of γ-ray is 0.05 nm

($m_X = 2.2 \times 10^{-35}$ kg , $m_\gamma = 4.4 \times 10^{-32}$ kg)

3) Calculate the wavelength of a ball whose mass is 140 kg which moves at velocity 40 m/s. Also, calculate the wavelength of an electron if it has the same velocity.

($\lambda = 1.18 \times 10^{-37}$ m , $\lambda_e = 1.8 \times 10^{-5}$ m)

4) A radio station emits a wave whose frequency is 92.4 MHz. Calculate the energy of each photon emitted from this station. Also, calculate the rate of photons ϕ_L if the power of the station is 100 kW.

($E = 612.15 \times 10^{-28}$ J , $\phi_L = 16.3 \times 10^{29}$ Photon/s)

5) An electron is under a potential difference 20 kV. Calculate its velocity upon collision with the anode from the law of conservation of energy. The electron charge is 1.6×10^{-19} C, its mass is 9.1×10^{-31} kg. Then calculate λ and P_L.

($v = 0.838 \times 10^{8}$ m/s , $\lambda = 0.868 \times 10^{-11}$ m , $P_L = 7.625 \times 10^{-23}$ kgm/s)

6) If the least distance detected with an electron microscope is 1nm, calculate the velocity of the electrons and the potential of the anode.

(velocity$= 0.725 \times 10^{6}$ m/s , V=1.5Volt)

7) Calculate the force by which an e-beam whose power is 100 kW affects an object

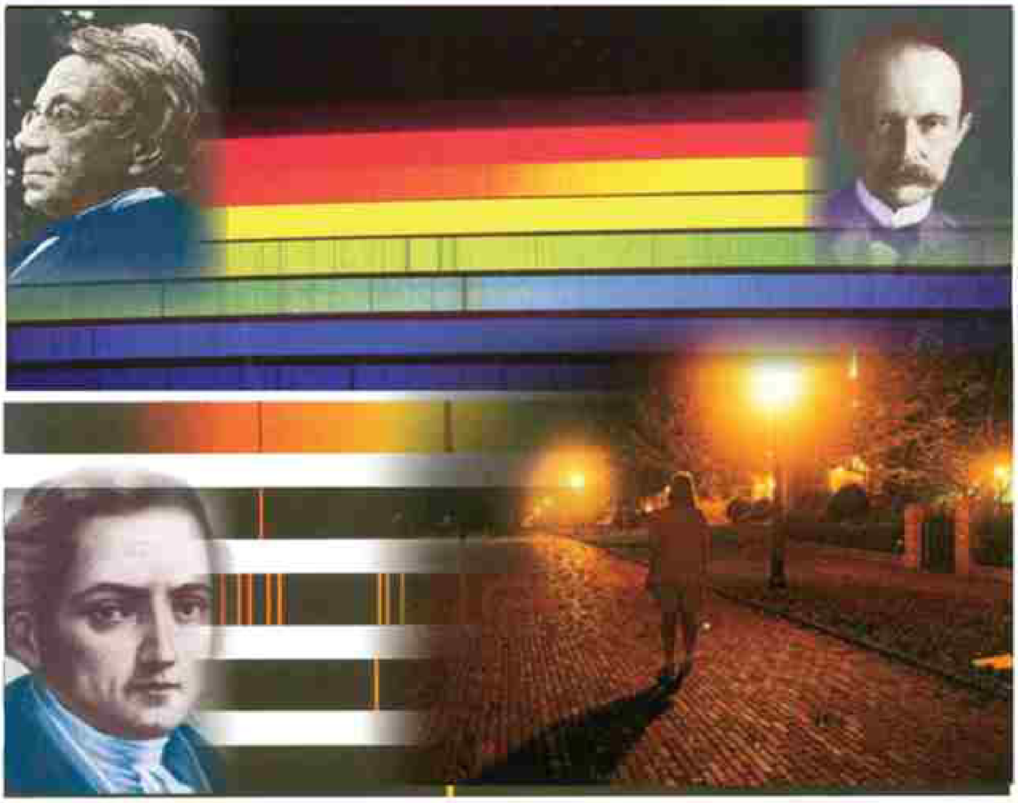
whose mass is 10 kg , what happens if the object is an electron and why ?

$0.67x10^{-3}N$

II) Essay questions

1) Show why the wave theory failed to explain the photoelectric effect, and how Einstein managed to interpret the experimental results of this phenomenon.
2) Show how to verify the particle nature of light from the blackbody radiation .
3) Explain the Compton effect and show how it proves the particle nature of light ?

Introduction to Modern Physics



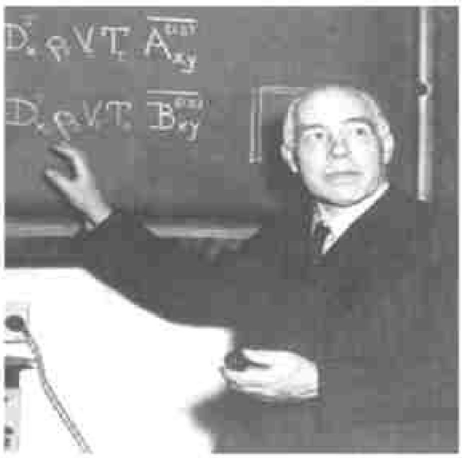
UNIT 2

Chapter 6: Atomic Spectra

Overview

The word atom goes back to a Greek origin, meaning the indivisible. Different models for the atom have been put forth since then by many great scientists based on many experimental evidences.

Bohr's Model (1913)



Bohr

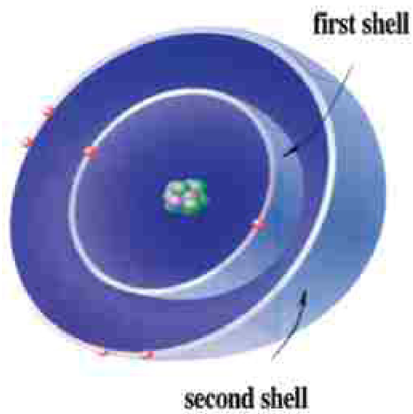


Fig (6-1a)
Bohr's Model

1) At the center of the atom there is a positively charged nucleus .
2) Negatively charged electrons move around the nucleus in shells. Each shell (loosely often called orbit) has an energy value. Electrons do not emit radiation as long as they remain in each shell (Fig 6 - 1).
3) The atom is electrically neutral, since the number of electrons around the nucleus equals the number of positive charges in the nucleus.

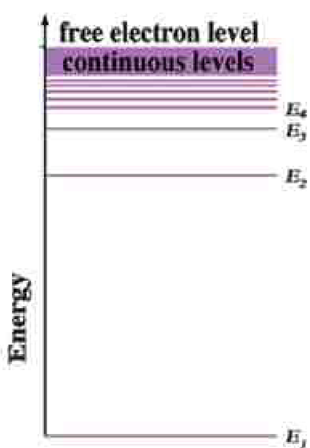


Fig (6-1b)
Energy levels

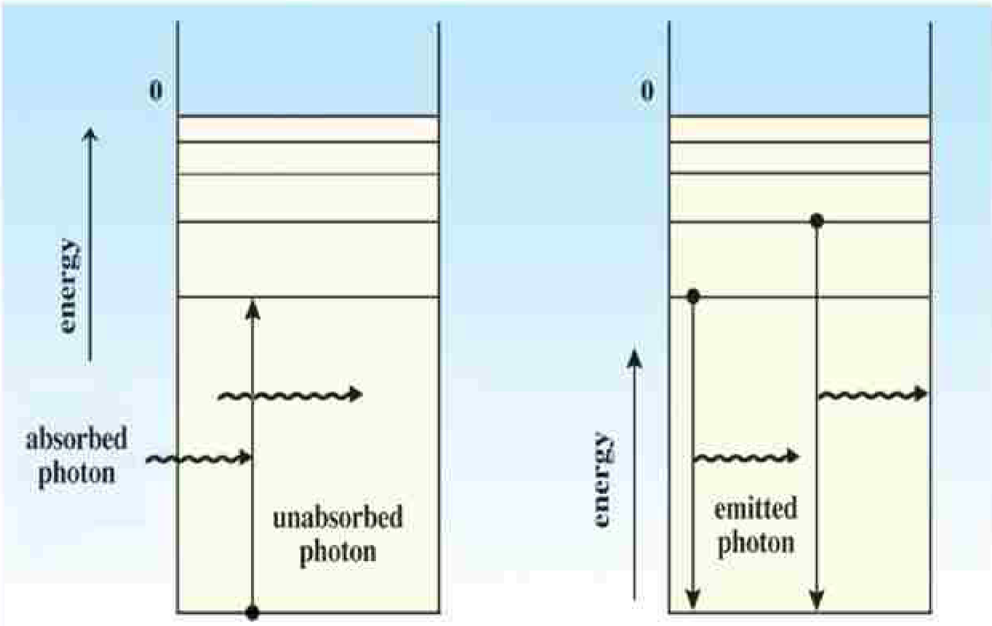


Fig (6- 2a)
Absorption of photons

Fig (6- 2b)
Emissin of photons

He then added three more postulates:

1) If an electron moves from an outer shell of energy E_2 to an inner shell of energy E_1 ($E_2 > E_1$), an amount of energy $E_2 - E_1$ is released in the form of a photon, whose energy $h\nu = E_2 - E_1$, where ν is the frequency of the emitted photon (Fig 6 - 2).

2) The electric (Coulomb's) forces and mechanical (Newton's) forces are at work in the atom.

3) We can estimate the radius of the shell by considering that the wave accompanying the electron forms a standing wave (calculate the shell radius for n = 1, 2, 3,)

The radius of the shell is given by :

$$n\lambda = 2\pi r_n \qquad \therefore r_n = \frac{n\lambda}{2\pi}$$

Emission of Light from Bohr's Atom.

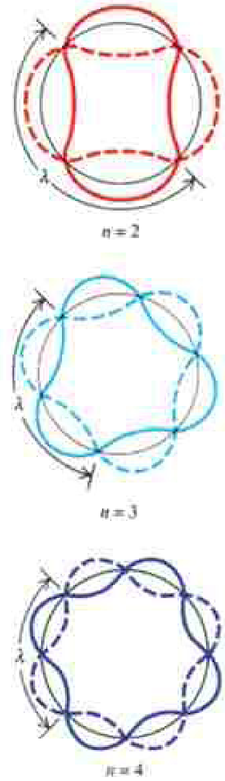


Fig (6 -3)

1) When hydrogen atoms are stimulated (given energy) not all of them are excited the same way. Thus, electrons in different atoms move from the first level K (n = 1) to different higher levels (n = 2, 3, 4..)
2) The energy of a shell in the hydrogen atom can be given by the relation
   $E_n = \frac{-13.6}{n^2}$ ev   where $1 eV = 1.6\times10^{-19}$ Joule
3) Electrons remain in excited levels (or states) only for a short period of time ,called lifetime (nearly 10^{-8}s), then they revert to the lowest level (ground state).
4) In going down from level E_2 to level E_1, the electron emits a photon whose energy
   $h\nu = E_2 - E_1$: where ν is the frequency of the photon and its wavelength is : $\lambda = \frac{c}{\nu}$
5) The line spectrum of hydrogen consists of a particular energy value, and hence a particular frequency.

Different series of atomic spectral lines for hydrogen are produced, and are arranged as follows (Fig 6 - 3):

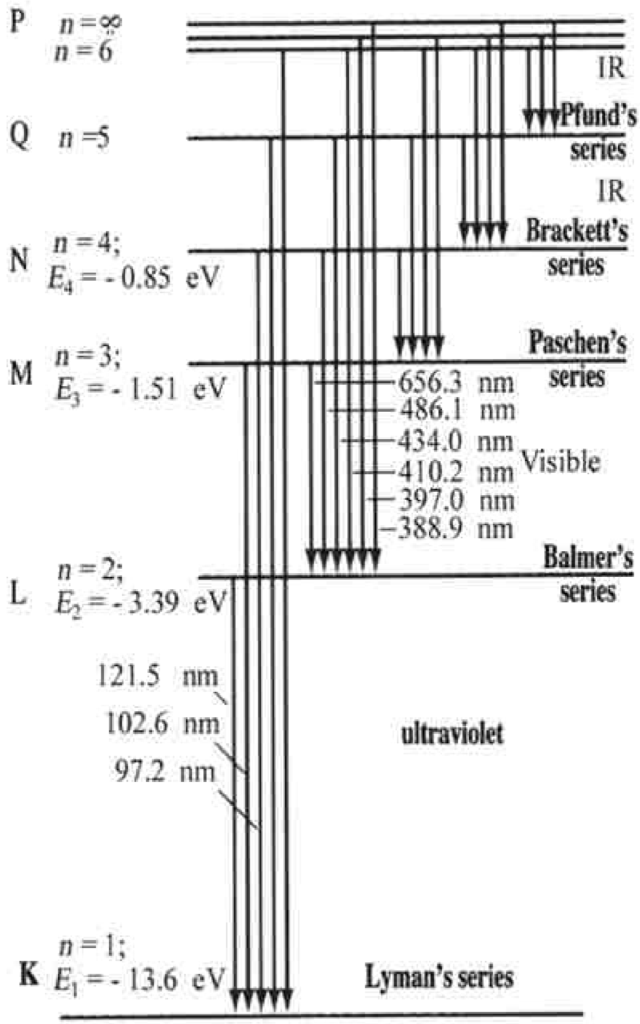


Fig (6-4a)

Atomic spectral series for hydrogen

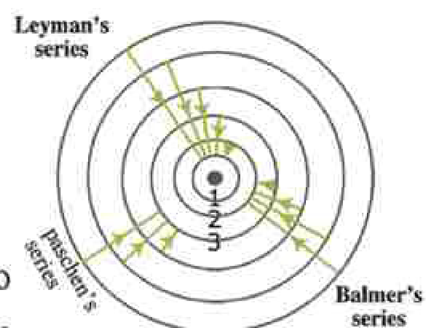


Fig (6-4b)

Atomic model for hydrogen spectrum spect

1) Lyman's series: where the electron moves down to level K (n = 1) from higher levels. This series lies in the ultraviolet range (short wavelengths and high frequencies).

2) Balmer's series: where the electron moves down to

level L (n = 2) from higher levels. This series lies in the visible range.

3) Paschen's series: where the electron moves down to level M (n = 3) from higher levels. This series lies in the infrared (IR) range.

4) Bracket's series: where the electron moves down to level N (n = 4) from higher levels. This series lies in the IR range.

5) Pfund's series: where the electron moves down to level O (n = 5) from higher levels. This series lies in the far IR and is the longest wavelengths (the lowest frequencies) among the line spectrum of hydrogen.

Spectrometer

To obtain a pure spectrum, a spectrometer is used (Fig 6 - 5). It consists of 3 parts :

1) a source of rays : a light source in front of which there is a slit whose width can be adjusted by a screw. This slit is at the focal point of a convex lens.

Fig (6-5a)
Spectrometer

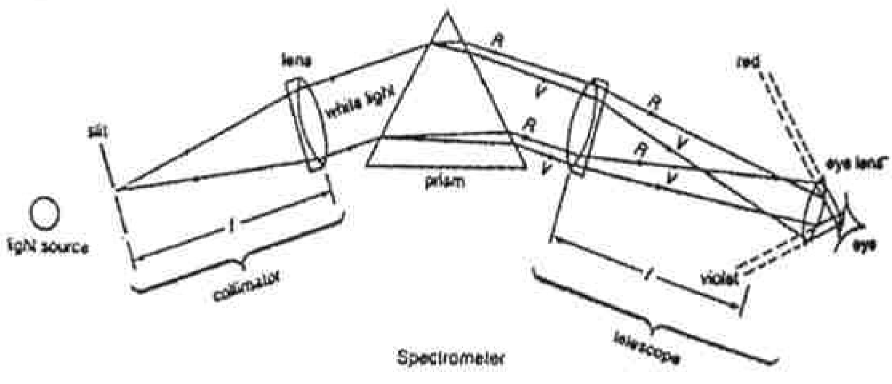


Fig (6-4b)
Spectrometer schematic

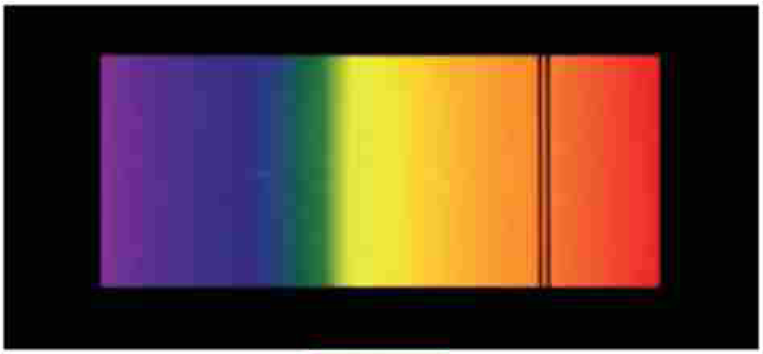


Fig (6-5c)
Use of a spectrometer to measure the temperature of the stars and their gases

2) a turntable on which a prism is placed.

3) a telescope consisting of two convex lenses (objective and eye piece).

Fraunhofer

To use the spectrometer for obtaining a pure spectrum, the slit is lit with bright light falling from the slit onto the prism at the minimum angle of deviation. The telescope is directed to receive the light passing through the telescope.The objective focuses the rays belonging to the same color at the focal plane of the lens . That is how we obtain a sharp (pure) spectrum.

From studying the line spectra of different elements whose atoms are excited , we notice different types of spectra (continuous and line) :

- the spectrum consisting of all wavelengths in a continuous manner is called the continuous spectrum.
- the spectrum occurring at specified frequencies and not continuously distributed is called the line spectrum.

Alternatively, they may be divided as emission and absorption spectra :

- the spectrum resulting from the transfer of excited atoms from a high level to lower level is called the emission spectrum.

- It was found experimentally that when white light passes through a certain gas, some wavelengths in the continuous spectrum are missing. These wavelengths are the same as those which appear in the emission spectrum of the gas (Fig 6 - 4) . This type of spectrum is called the absorption spectrum. Fraunhofer lines in the solar spectrum are examples of the absorption spectrum of the elements in the Sun, basically helium and hydrogen.

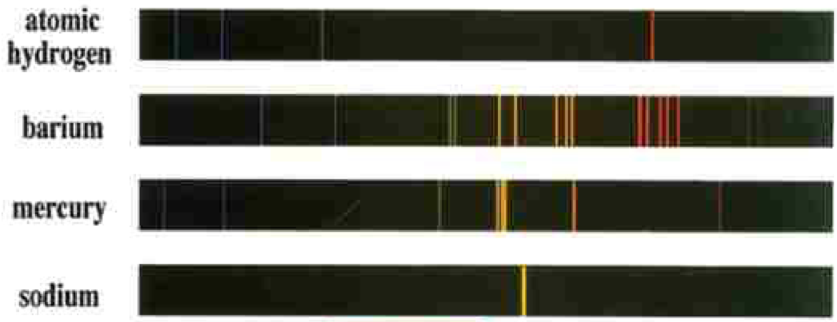


Fig (6 - 6)

Emission line spectra for some elements

X-rays

What are X-rays ?

They are invisible electromagnetic waves of short wavelength $(10^{-13} - 10^{-8} m)$ between uv and gamma rays. They were first discovered by Rontgen. He called it so (the unknown rays) because he did not know what they were .

Properties of X-rays:

- They can penetrate media easily .
- They can ionize gases .
- They diffract in crystals .
- They affect sensitive photographic plates .

target

Coolidge Tube

This is used to produce X-rays. When the filament is heated, electrons are produced and directed at the target under the influence of the electric field,which gives them high energy, depending on the voltage difference between the target and the hot filament. When an electron collides with the tungsten target, part- if not all- of its energy is converted to X-rays (Fig 6 - 7).

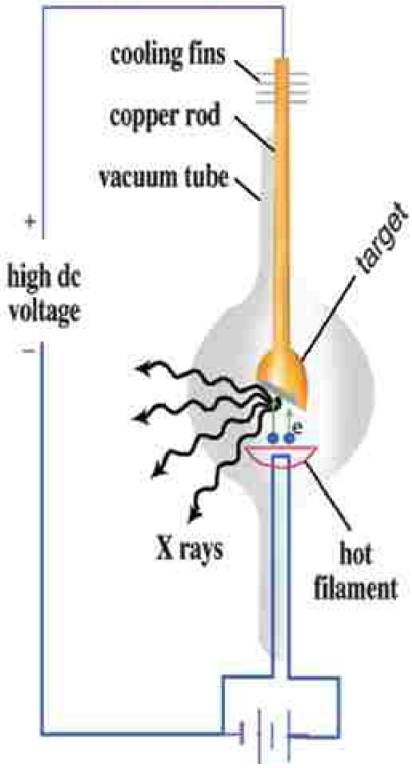


Fig (6- 7)
Coolidge tube

Spectrum of X-rays

Analyzing a beam of X-rays generated from a target to components of different wavelengths, we find that the spectrum consists of two parts :

a) the continuous spectrum of all wavelengths (within a certain range) regardless of the target material.

b) the line spectrum corresponding to certain wavelengths characteristic of the target material, called the characteristic X-ray radiation.

Interpretation of X-ray generation

a) characteristic radiation

The line spectrum is generated when an electron collides with an electron close to the nucleus of the target material atom. If the latter electron receives sufficient energy, it jumps to a higher level, or leaves the atom altogether, and is replaced by another electron from a higher level. The difference in energy appears as radiation with a definite wavelength. It is noted that:

1- the wavelength of the characteristic radiation does not depend on the voltage difference, but depends on the target element. The higher the atomic number of the target element, the shorter the wavelength of the characteristic radiation will be.

2- At low voltage differences, no characteristic radiation is produced.

3- The wavelength of the characteristic (often called hand) X- rays is found from the relation:

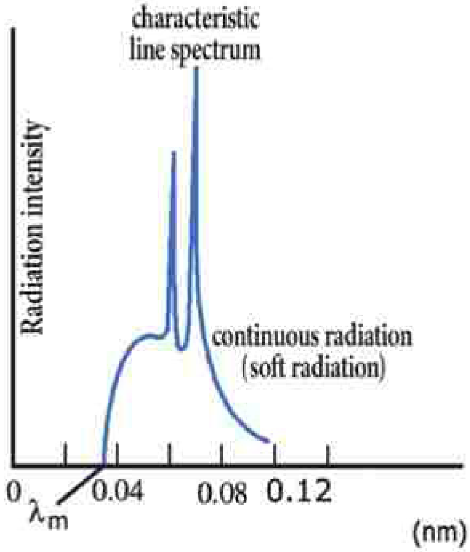


Fig (6-8)

Line and continuous spectra

$$h \times \frac{c}{\lambda} = \Delta E \qquad (6\text{-}1)$$

b) Continuous Radiation

This radiations is generated when the velocity of the colliding electrons is reduced upon passing through a retarding electric field due to the electrons of the target material. This energy decrease is due to repulsion, collision, and scattering. Hence, an electromagnetic radiations is generated based on Maxwell – Hertz theory. This radiation is continuous and is called soft (bremsstrahlung, i.e., braking radiation), i.e., the passing electron keeps losing energy continually due to the braking effect of the surrounding electrons, giving rise to electromagnetic radiation covering all different possible wavelengths, since the electron loses energy gradually. This is the origin of the continuous radiation of X-rays.

Important Applications of X-rays

1) One of the important features of X-rays is diffraction, as they penetrate materials. That is why X-rays are used in studying the crystalline structure of materials (Fig 6 - 9). The atoms in the crystal act as a diffraction grating (which is a generalization of diffraction from a double slit). Bright and dark fringes form, depending on the difference in the optical path.

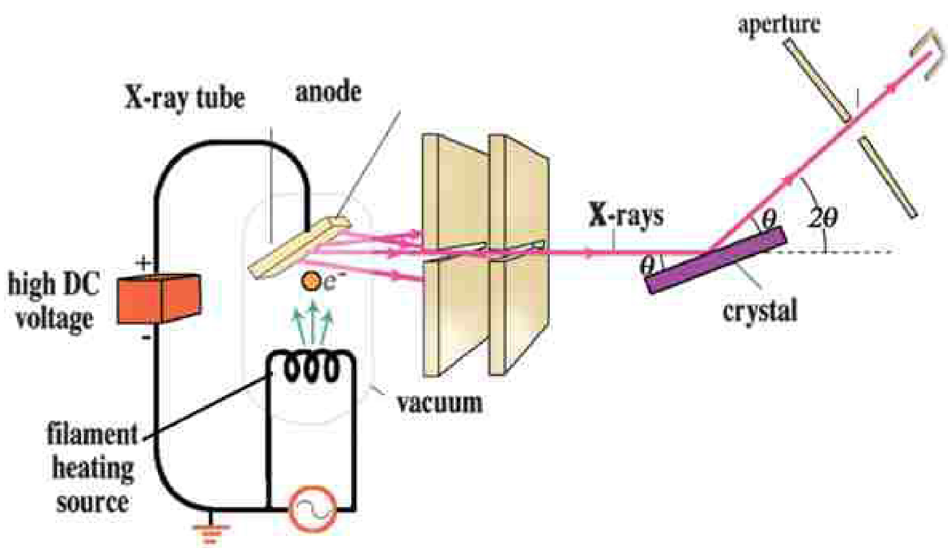


Fig (6- 9)

Use of X-rays in studying crystals

2) X- rays have a great penetrating power.

This is why they are used to detect defects in metallic structures.

3) X- rays are used in imaging bones and fractures and some other medical diagnosis (Fig 6-10).

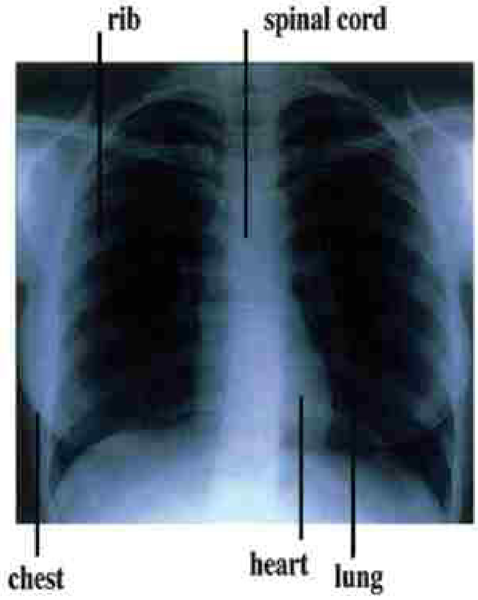


Fig (6-10)

An X-ray image for the chest

In a Nutshell

- Bohr's postulates and model of the hydrogen atom :

When an electron jumps from a high level to a lower level, it produces radiation in the form of a photon of frequency ν and energy $h\nu$, which is equal to the difference between the two levels

$$h\nu = E_2 - E_1,\ E_2 > E_1$$

- The line spectrum of hydrogen consists of 5 series. Each line corresponds to a definite energy difference, frequency and wavelength

Lyman	uv
Balmer	visible
Paschen	IR (infrared)
Brackett	IR
Pfund	far IR

- The spectrometer is an apparatus used to decompose light to its components (visible and invisible)
- X-rays are an invisible radiation of short wavelengths, first discovered by Rontgen (1895).He called them the unknown (X) rays
- X-ray diffraction is used in studying the crystalline structure, and also in the industrial and medical applications.

Questions and Drills

I) Essay question:

1- How could Bohr explain the spectrum of the hydrogen atom ?

2- What is the basis on which the hydrogen spectrum is classified into five series ?

3- Explain why Leyman's series has higher energies than Pfund's.

4- Explain how a spectrometer is used to obtian a sharp (pure) spectrum.

5- Explain how X-rays are generated in coolidge tube.

6- Make a comparison between continuos and characteristic X-rays.

7- Explain the mechanism for producing each of the characteristic line spectrum and the continuos spectrum for X-rays then make a comparison between them ?

8- Discuss some applications of X-rays.

II) Define.

1- the line spectrum.

2- the continuos spectrum.

3- the absorption spectrum.

4- the emission spectrum.

Introduction to Modern Physics

UNIT 2

Chapter 7: Lasers

Chapter 7 Laser

Overview

Rarely has any discovery left an impact on applied science as the discovery of laser has done. Soon after its discovery, laser has been introduced into optics, biology, chemistry, medicine and engineering especially communications.

The word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. In 1960, Maiman built the first laser out of chromium-doped Ruby. Later, He-Ne laser was manufactured along with other types of lasers.

Spontaneous Emission and Stimulated Emission

The atom has energy levels, the lowest of which is called ground state(E_1) in which the atom initially exists. The atom may be excited to one of higher states E_2, E_3 etc.

If we shine a photon with energy $hv = E_2 - E_1$ on the atom, the atom absorbs this photon and gets excited to E_2. Soon enough after a lifetime (nearly 10^{-8} s), the atom gets rid of this excitation energy in the form of a photon and goes back to its original state (Fig 7 -1).

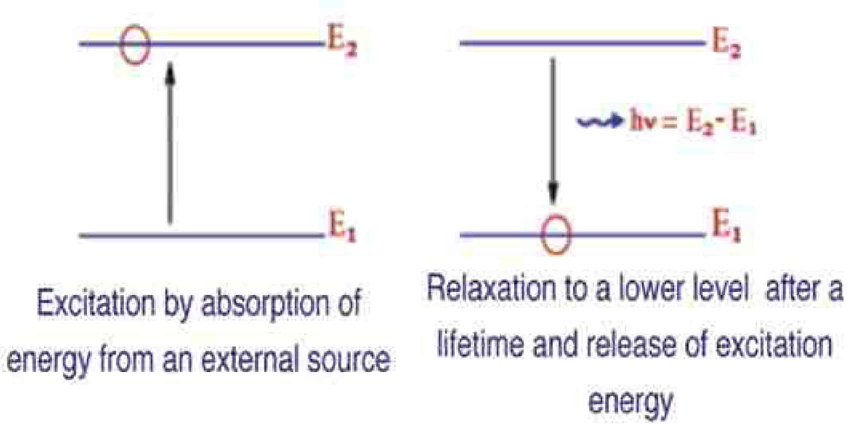


Fig (7-1)
Spontaneous emission

This type of radiation is called spontaneous radiation. It is the type of radiation common in ordinary light sources. The emitted photon has the same frequency and energy as the photon that caused the excitation . But the phase and direction are arbitrary. In 1917, Einstein showed that in addition to spontaneous radiation, there is another type of radiation, called stimulated emission (the dominant emission in lasers). If a photon of energy E_2-E_1 falls on an excited atom at level E_2 before the lifetime is over, this photon pushes the atom back to the ground state, and hence, the atom radiates the excitation energy in the form of a photon of the same frequency, phase and direction of the falling photon. (Fig 7–2).

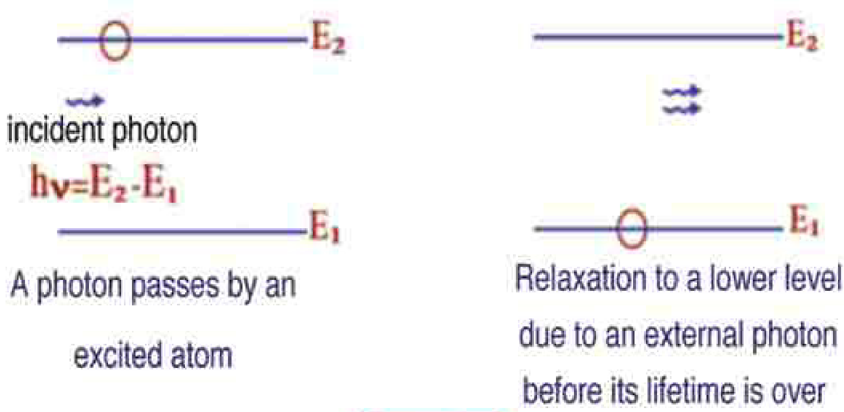


Fig (7-2)
Stimulated emission

Thus, throughout stimulated radiation, there are two types of photons; the stimulating and the stimulated photons moving together at the same frequency, phase and direction.

The emission of photons from the atoms of the material in this way renders these photons coherent and collimated for long distances. They are highly concentrated, and remain unspread and unscattered, unlike photons emitted spontaneously.

The following table gives a comparison between spontaneous and stimulated emissions :

	Spontaneous emission	Stimulated emissions
1	- occurs when the atom relaxes from an excited state to a lower state, emitting spontaneously the energy difference in the form of a photon without the effect of an external photon. It occurs after the lifetime interval is over.	- occurs where an external photon stimulates excited atoms to emit the energy difference is the form of a photon before the lifetime interval is over.
2	- The emitted photons have a wide range of wavelengths.	- The emitted photons are monochromatic (single) wavelength.
3	- The emitted photons propagate randomly	- The emitted photons are coherent and propagate in one direction as a collimated parallel beam.
4	- The intensity of photons decreases according to the inverse square law. This is called spreading. While collisions with particles is called scattering. In ordinary light sources both spreading and scattering occur.	- The intensity remains constant over long distances contrary to the inverse square law. It has been possible to send a laser beam to the Moon and receive it back, without much loseses, despite the long distance involved. Spreading effect is nil and limited scattering takes place.
5	- This is the dominant radiation in ordinary light sources.	- This is the dominant radiation in laser sources.

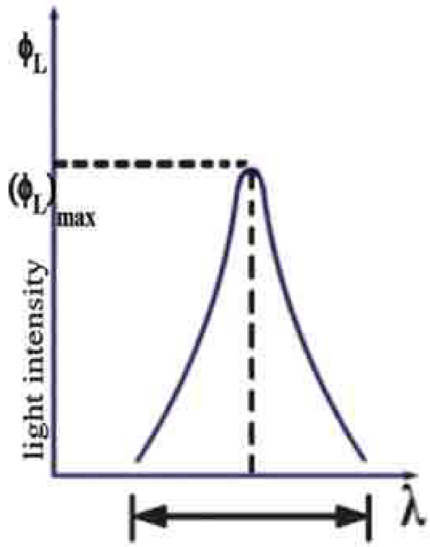


Fig (7 -3a)
Spectral width for an ordinary monochromatic light source

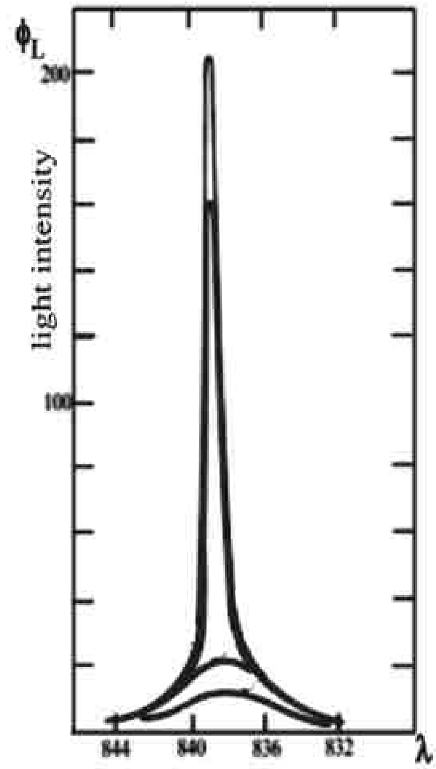


Fig (7-3b)
Spectral width for a laser source

Properties of a laser beam

1) **Monochromaticity:** Each line in the visible spectrum in ordinary light sources includes a band of wavelengths (this is why the ordinary color appears to have different shades to the naked eye). The intensity of each wavelength in this band width is shown in Fig (7 –3a). A laser source emits one spectral line with a very limited bandwidth and the intensity is concentrated at the wavelength of that spectral line Fig (7 –3b), hence it is called monochromatic.

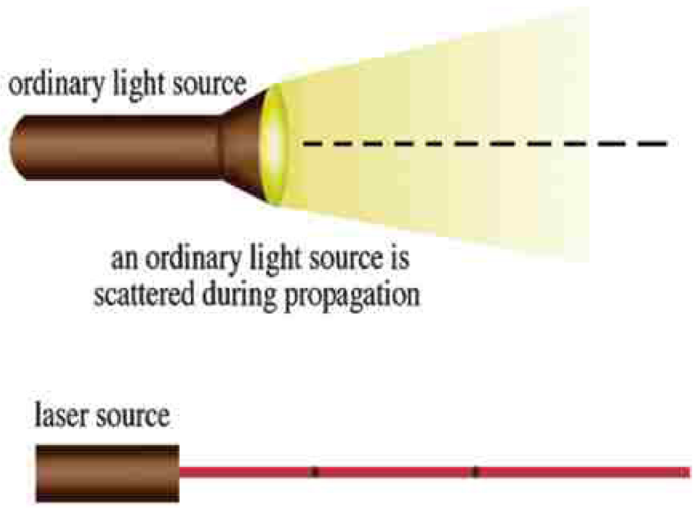


Fig (7 -4a)
Scattering of an ordinary light source and a laser

Fig (7 -4b)
Launching a laser beam from the Earth to a reflector on the surface of the Moon, 380000 km away

Fig (7-4c)
Measuring astronomical distances by a laser beam

Fig (7-4d)
Measuring the distance between the Moon and the Earth by the reflection of a laser beam from a reflector on the lunar surface

2) **Collimation :** In ordinary light sources, the diameter of the emitted light beam increases with distance , where in lasers, the diameter stays constant for long distances without much unscattering. Thus ,energy is transmitted without much losses .

3) **Coherence:** Photons of ordinary light sources propagate randomly or incoherently. They emanate at different instants of time, and have inconsistent and varying phase. In lasers, however, photons emanate coherently both in time and place, since they come out together at the same time sequence, and maintains the same phase difference throughout, during propagation over long distances. This makes radiation intense and focused.

4) **Intensity:** Light produced by ordinary sources is subject to the inverse square law, since the intensity of radiation falling on unit area decreases, the further away from the light source, due to spreading (Fig 7-4a). The laser rays falling on a unit surface are unspread. They maintain a constant intensity and are not subject to the inverse squarelaw.

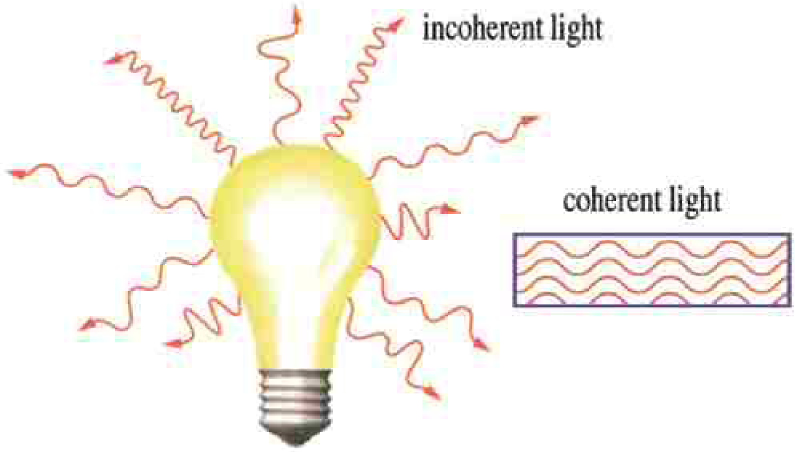


Fig (7-5)

Coherence

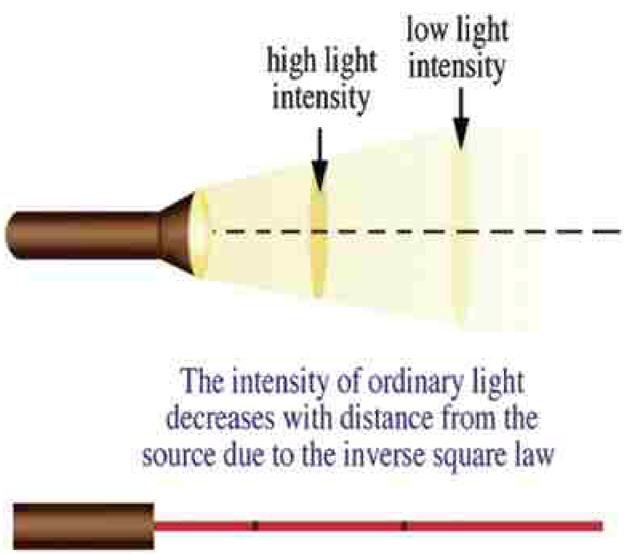


Fig (7-6)

Laser light maintains the same intensity as it propagates

Theory of the Laser Action:

Laser action depends on driving the atoms or molecules of the active medium into a state of population inversion, while maintaining a form of dynamic equilibrium. In this state, the number of atoms in the excited state exceeds the number of atoms in the lower state. Thus, when stimulated emission occurs, it will be amplified as photons are increased in number going back and forth in the active medium, due to multiple reflections between two enclosing mirrors. In so doing, more and more excited atoms are poised to generate stimulated emission, which is further amplified and so on. This is the origin of amplification of the laser (Fig 7–7), called laser action .

Main Components of a Laser

Despite the variations in size, type and frequency, three common elements must exist in any laser:

1) **Active medium:** This can be a crystalline solid (e.g. ruby), semiconductor (chapter15) a liquid dye, gas atoms (e.g. He – Ne laser), ionized gases (e.g. Argon laser), or molecular gases (e.g. CO_2 laser).

2) **Sources of energy responsible for exciting the active medium as follows :**

(a) excitation by electrical energy, either by using radio frequency (RF) waves or by using electric discharge under high DC voltage gas lasers:(HeNe – Ar – CO_2).

(b) excitation by optical energy, also known as optical pumping, which can be done either by flash lamps (e.g. in ruby laser) or using a laser beam as a source of energy (liquid dye laser).

(c) thermal excitation, by using the thermal effects resulting from the kinetic energy of gases to excite the active material (e.g. in He-Ne laser).

(d) excitation by chemical energy as chemical reactions between giving gases energy to stimulate atoms toward lasing (e.g. the reaction between hydrogen and fluorine or the reaction between Deuterium fluoride and CO_2) .

3) Resonant cavity is the container and the activating catalyst for amplification . It can be one of two types :

(a) external resonant cavity in the form of two parallel mirrors enclosing the active medium permitting multiple reflections leading to amplification as in gas lasers (Fig 7 – 7a).

b) internal resonant cavity where the ends of the active material are polished so as to act as mirrors as in ruby laser (Fig 7 – 7b). One of the two mirrors is semitransparent to allow some of the laser radiation to leak out (Fig 7 – 8).

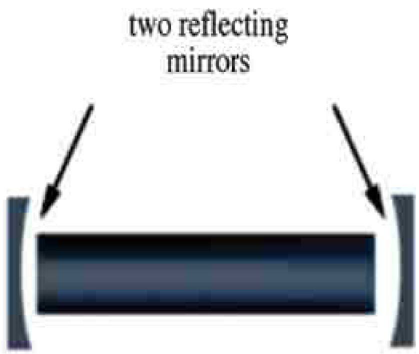


Fig (7 -7a)
External resonant cavity

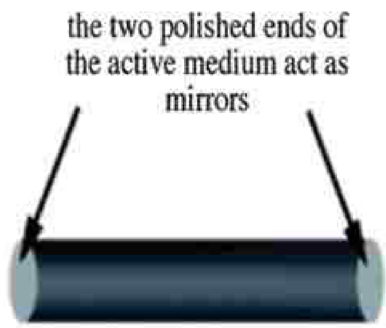


Fig (7 -7b)
Internal resonant cavity

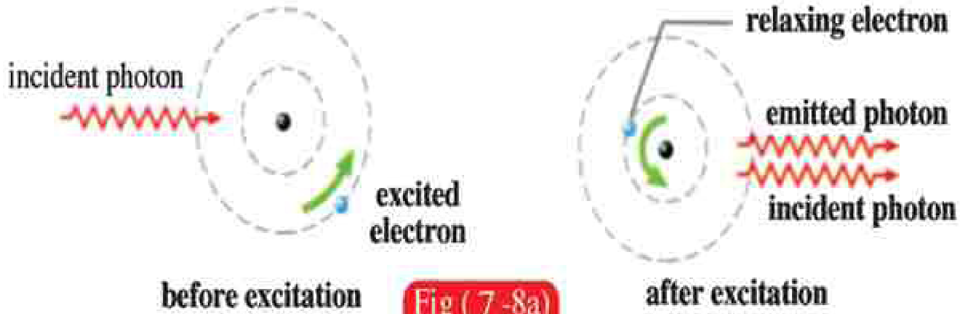


Fig (7 -8a)
Stimulated emission by an external photon

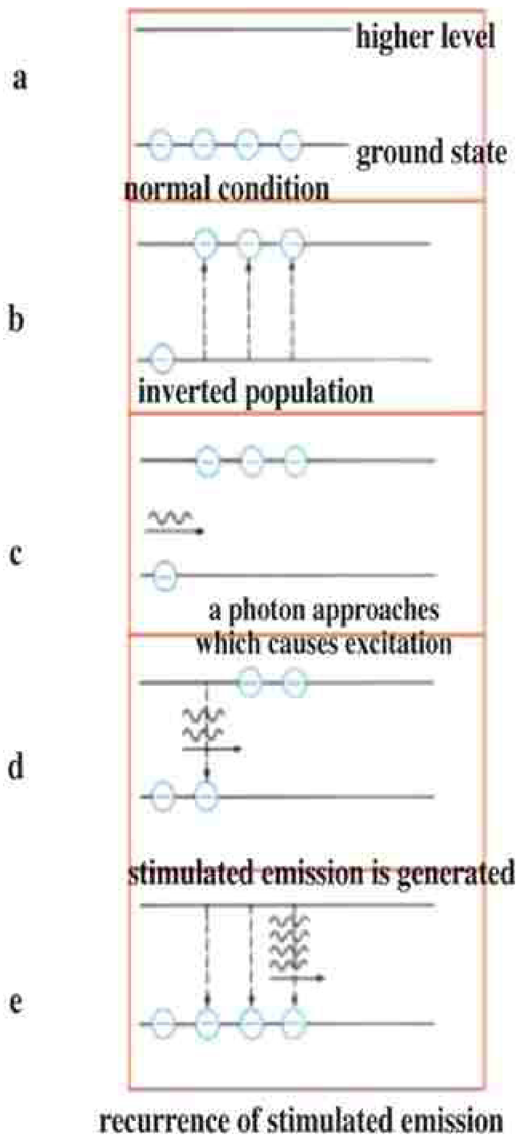


Fig (7 -8b)
Laser action

a

b

c

d

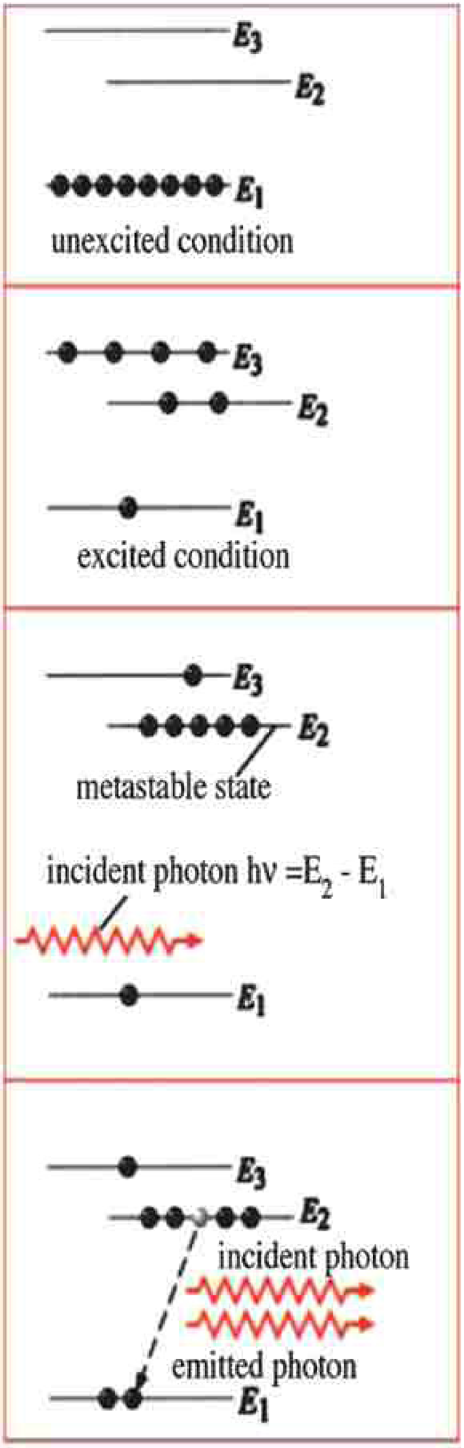


Fig (7-8c)

Population inversion through a third metastable state

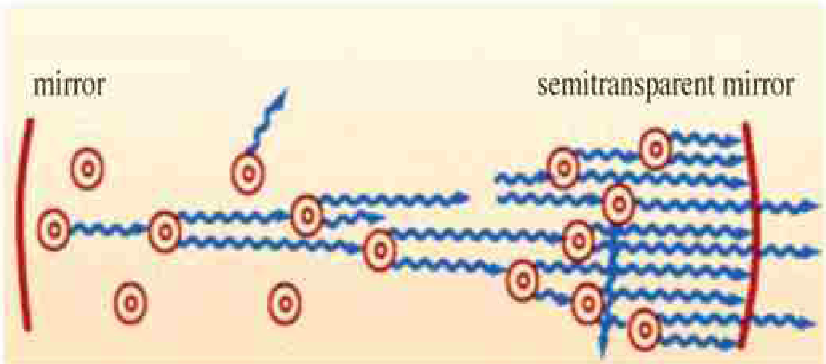


Fig (7-8d)

Multiple reflections between the two mirrors

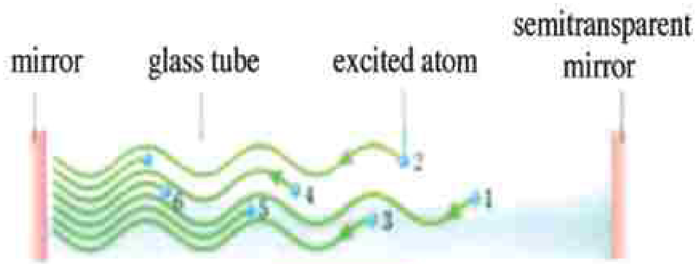


Fig (7-8e)

Amplification by multiple reflections

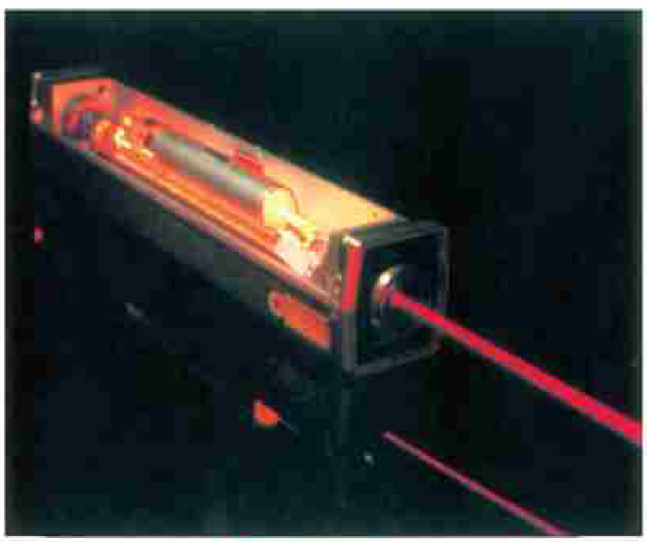


Fig (7-8f)

Output radiation from the semitransparent mirror

He-Ne LASER:

The helium-neon laser device consists of the following:

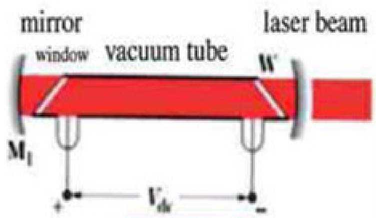


Fig (7-9a)
He – Ne laser schematic

A quartz glass tube containing a mixture of helium and neon gas atoms in a ratio of 10:1, respectively, under low pressure of about 0.6 mmHg (Figure 7-9a) (Figure 7-9b). These two elements have been selected due to the near equality of the energy values of the same meta-stable excited energy levels in their atoms.

At the ends of the tube are two parallel plane mirrors perpendicular to the tube axis, one of which has a reflection coefficient of 99.5% and the other is meta-transparent and has a reflection coefficient of 98%.

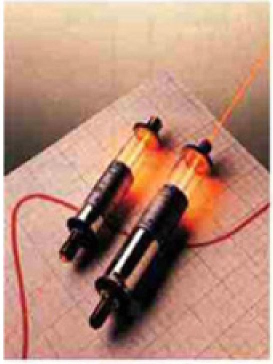


Fig (7-9b)
He – Ne laser

A high-frequency electric field feeds the tube from the outside to excite the helium and neon atoms, or a high continuous electric potential difference is applied to the two gases inside the tube to cause an electric discharge.

Device operation:

1- The electric potential difference inside the tube excites the helium atoms to higher energy levels, as shown in Figure (7-10a).
2- The excited helium atoms collide with the neon atoms. As a result of the convergence of the energy values of the meta-stable excitation levels between the two atoms, the neon atoms are excited.
3- The excited neon atoms accumulate in an energy level characterized by a relatively long lifetime (about 10^{-3} s), and this level is called the metastable state. Thus, the population inversion of the neon gas atoms is achieved.

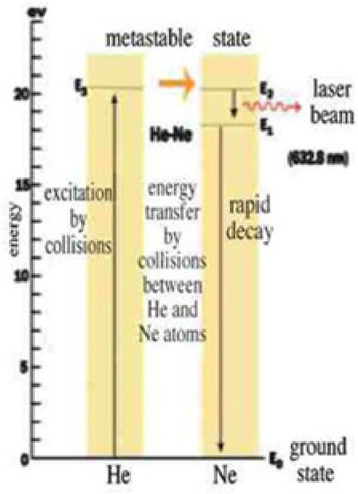


Fig (7-10a)
He – Ne laser energy levels

4- The first group of neon atoms that were excited automatically falls to a lower excitation energy level, thus emitting photons with energy equal to the difference between the energies of the two levels, and these photons spread randomly in all directions inside the tube.

5- The group of photons that are moving in the direction of the tube's axis encounters one of the two reflective mirrors on its way, so they bounce back inside the tube and cannot exit.

6- During the photons movement between the two mirrors inside the tube, they collide with some of neon atoms, which are in the meta-stable excitation level and have not yet reached their lifetime, prompting them to release photons with the same energy and direction as the photons that collided with them. This doubles the number of photons moving inside the tube between the two mirrors.

7- The previous step is repeated again, but with the new number of photons moving between the two mirrors, so this number doubles again, and so on until the radiation amplification process is completed.

8- When the radiation intensity inside the tube reaches a certain limit, part of it exits through the meta-transparent mirror in the form of a laser beam, and the rest of the radiation remains inside the tube to continue the process of stimulated emission and laser production.

9- As for the neon atoms that have fallen to the lower level, they lose the rest of their energy in multiple other forms after a short period and descend to the ground level to collide with other helium atoms, which provide them with energy to the meta-stable excitation level, and so on.

10- As for the helium atoms that lost their energy by colliding with the neon atoms and returned to the ground level, they return to be excited again by the electrical discharge inside the tube.

11- Figure (7-10b) shows the actual transitions between energy levels in the helium-neon laser.

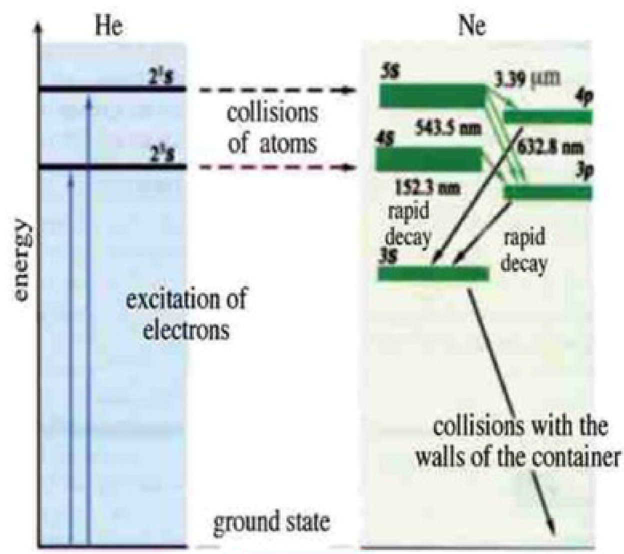


Fig (7-10b)
Transitions between energy levels in He-Ne laser

Applications of Lasers:

Laser beam covers many areas of the electromagnetic spectrum, from the visible light region to the ultraviolet and infrared ones. There are currently different types and sizes of lasers. Some lasers can focus light into a small point sufficient to melt and vaporize iron, and some are sufficient to pierce diamonds. On the other hand, there are other types of lasers that emit enough energy to destroy missiles and aircraft that may be used in what is called Star War.

Other important applications of lasers include the following:

a) Holography:

- Images of objects are formed by collecting light rays that leave the surface of the illuminated body carrying information from it to where the image is formed as a result of the difference in the light intensity of these rays from one point to another. Does the light intensity of these rays carry all possible information about the surface of the object?
- Let's take two rays representing two waves that left an illuminated body at two points on it. There is a difference in the amplitude of the two waves that appears as a difference in the light intensity. Because the light intensity is proportional to the square of the amplitude. But there is also a difference in the path length that the wave follows from each of the two points on the surface of the illuminated body to the photographic plate on which the image is recorded due to the presence of terrain (topography) on the surface of the body. Thus, the rays that leave the illuminated body carry - in addition to the difference between them in light intensity - a difference in the length of the path when they reach the photographic plate.
- In other words, there is a **phase difference between the light waves equal to ($\frac{2\pi}{\lambda}\times$ path difference).**
- The usual photographic plate records only the difference in light intensity, which causing the formation of the plane image (2D). Therefore, the plane images we obtain are the result of only part of the information that the light waves carry about the object.
- In 1948, the Hungarian scientist Gabor - who won the Nobel Prize - suggested a way to obtain the missing information we did not get. He suggested that the missing information can be extracted from the reflected rays from the body using other rays of the same wavelength,

which we call the Reference Beam, which is a beam of parallel rays that meets the beam of rays that leaves the illuminated body carrying the information, then the two beams meet at the photographic plate. As a result the phenomenon of light interference occurs between the two beams of rays. After developing the photographic plate, the resulting interference fringes appear, which an encrypted image that is called the Hologram.

- By illuminating the hologram with laser rays of the same wavelength and looking through it with the naked eye, we see a completely identical image of the body in its three dimensions without using lenses. This can only be achieved by using a light source with coherent wave photons. This is available only in laser beams. (Figure 7-11a) (Figure 7-11b)

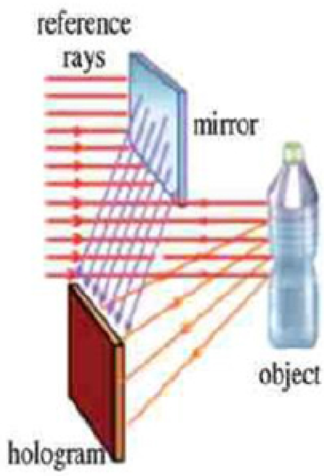


Fig (7 -11a)
Hologram formation

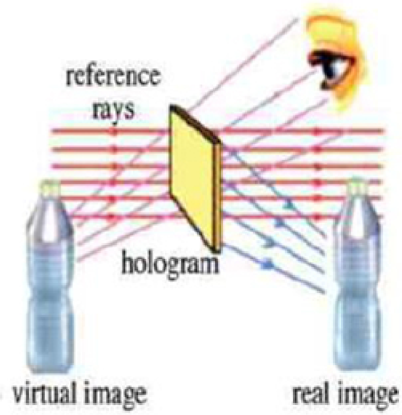


Fig (7 -11b)
Hologram as a grating

b) In medicine:

The eye retina contains light-sensitive cells. Sometimes the eye suffers from detachment of some parts of the retina. In this case, the affected parts lose their function unless treated quickly. The eye may be exposed to complete retinal detachment and the eye loses its ability to see. If this condition is addressed early, it is treated by performing an operation in which the detached parts of the retina fuse with the layer underneath.

In the past, this operation took a lot of time and effort, but the laser beams that are now used for this purpose have saved both time and effort, as the fusion process (Figure 7-12) takes place in small fractions of a second. In this process, a thin beam of laser is directed through the eye to the affected part, and the thermal energy of the laser beams works to complete the fusion process. Thus, the eye is protected from continued retinal detachment, and also from being exposed to loss of the ability to see. Laser is also used to treat cases of nearsightedness and farsightedness, thus eliminating the need for eye-glasses.

Fig (7-12)

Use of a laser beam in treating retinal detachment

Laser beams can also be used with optical fibers in diagnosis and treatment using medical endoscopes, Figure (13-7)

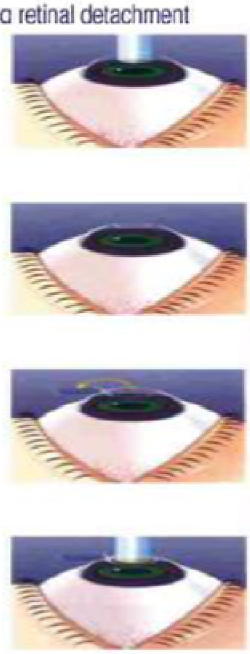


Fig (7-13)

Cornea treatment by a

c) In communications, where laser beams and optical fibers are used in communications as an alternative to telephone cables.

d) In industry, especially precision industries

e) In military fields such as: precision guidance of missiles, smart bo (LADAR)

f) Recording on compact discs (CDs)

g) Laser printer, where a laser beam is used to transfer information from the computer to a drum containing a light-sensitive material, then printing is done on paper using toner

h) Arts and light shows

i) Surveying work to accurately determine areas and dimensions.

j) Space research.

In a Nutshell

• Spontaneous emission:

It is the emission from one excited atom as it relaxes from a high energy level to a low energy level after its lifetime interval is over and under no external stimulus.

• Stimulated emission:

It is the emission from one excited atom as a result of a collision with an external photon, which has the same energy as the one that caused it to be excited. Photons at the end , come out in coherence ,i.e.,having the same phase, (direction and frequency).

• Properties of a laser beam :

1) spectral purity (monochromatic).

2) collimation (parallel rays).

3) coherence (same phase and direction).

4) concentration (high intensity and small diameter).

• Laser action :

1) the active medium must be in the state of population inversion .

2) emission of radiation for the excited atom through the stimulated emission.

3) amplification of stimulated emission through the resonant cavity

• Basic elements of a laser :

1) an active medium.

2) a source of energy (pumping).

3) a resonant cavity.

• He - Ne laser is a gas laser:

in which the active medium is a mixture of helium and neon in the ratio 10 : 1

- **Laser applications:**

1) 3D photography (holography).

2) medicine (e.g. treating retinal detachment).

3) communications.

4) industry.

5) military applications.

6) CD recording

7) printing

8) arts and shows

9) surveying

10) space research

Questions and Drills

1- What is meant by laser ?

2- Compare between spontaneous emission and stimulated emission operation - wise and feature - wise.

3- Laser light has special characteristics which distinguish it from ordinary light . Discuss this statement .

4- Discuss clearly the laser action .

5- What is meant by optical pumping and population inversion?

6- What is the role of the resonant cavity in laser operation ?

7- Lasers have 3 main components, what are they ?

8- On what basis have helium and neon been chosen as an active medium in He - Ne laser ?

9- What is the role of helium in He - Ne laser ?

10- Explain clearly how a laser beam is generated in He - Ne laser .

11- Explain how holography works using lasers .

12- Lasers are used extensively in medicine. Discuss one of its applications .

13- Lasers play an important role in missile guidance in modern warfare. Why is laser used as such?

Introduction to Modern Physics

UNIT 2

Chapter 8: Modern Electronics

Chapter 8 Modern Electronics

Overview:

The world witnesses a tremendous mushrooming in the field of electronics and communication to the point where they have become an insignia for this era. Electronics and communication are now indispensible in our life. TV, cellular (mobile) phone , computer, satellites and other systems are evidences for the vast progress in the applications of electronics and communications, whether in business, e-government, information technology(IT), entertainment or culture. They have become also an essential ingredient in modern warfare. Weapons do not fare from the point of view of fire power only, but guidance, surveillance, monitoring jamming and deception ,called electronic counter measures (or ECM) play an important role in combat. Also, in medicine whether in diagnois, prognosis, or operations, electronics plays a key role. In short, there is no single field in all walks of life where electronics has no part, starting from e -games to e– warfare. Therefore, you must attain a certain level of awareness about electronics – simplified as it may be, yet essential regardless of the prospective career you might end up with.

Pure Semiconductors:

There are three types of materials from the point of view of electrical conductivity. Conductors conduct electricity and heat easily (as in metals). Insulators do not conduct electricity and heat (as in wood and plastics). Semiconductors are in between. At absolute zero, they act as insulators, whereas as temperature increases ,their conductivity increases (as in silicon).

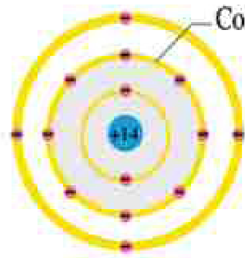


Fig (8-1)

A silicon atom

Silicon is one of the important and common elements in the universe. It exists in sand (SiO_2) and rocks of the Earth's crust. But crystals of pure silicon consist of silicon atoms bound together in covalent bonds. A crystal is a regular arrangement of atoms in the solid state. A silicon atom has four electrons in the outermost shell (Fig 8 – 1). Therefore, each silicon atom shares 4 electrons with 4 neighboring atoms, so that the outer shell of each is complete on sharing basis to contain 8 electrons each (Fig 8 – 2 a,b). We must distinguish here between two types of electrons in silicon. The first type is the innermost (tightly bound) electrons, which are strongly attracted to their parents atoms. The second type is the valence electrons, which have more freedom to move across interatomic distances. They exist in the outermost shell. At low temperatures (Fig 8 - 2c), all bonds in the crystal are intact (unbroken).

In this case – unlike metals – there are no free electrons. But as temperature increases,

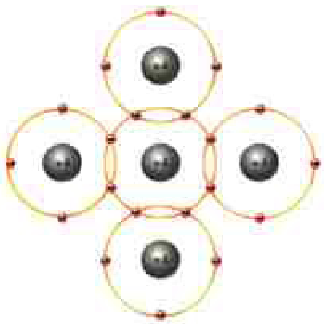


Fig (8 -2a)

Each atom shares electrons with its neighbors

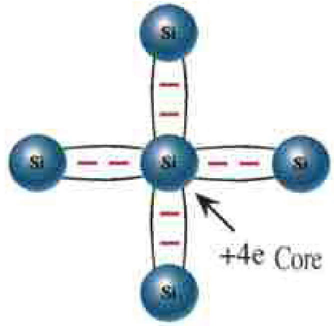


Fig (8 -2b)

Covalent bonds. We may represent a S_i atom (-14 e) around (+14 e) nucleus as a core (+4e) and (-4e) in the outer shell

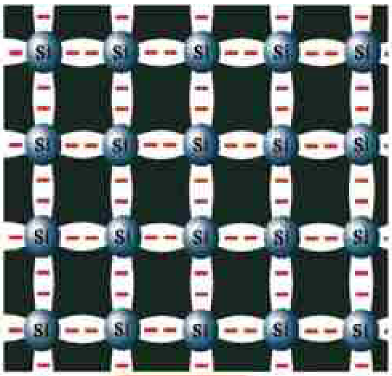


Fig (8 -2c)

Silicon crystal at T=0°K all bonds are intact

some bonds, are broken and electrons are freed. Such an electron leaves behind a vacancy in the broken bond.This vacancy is called a hole (Fig 8 – 3). Because the atom is neutral, then the absence of an electron entails the appearance of a positive charge. We, thus, say that the hole has a positive charge. We do not call a silicon atom which loses an electron from its bond an ion, because soon enough, this atom may capture a free electron or an electron from another bond to fill its own vacancy. Then, the atom returns neutral, and the

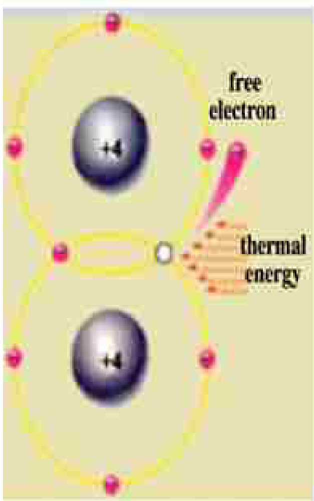


Fig (8-3a)

Breaking a bond requires energy

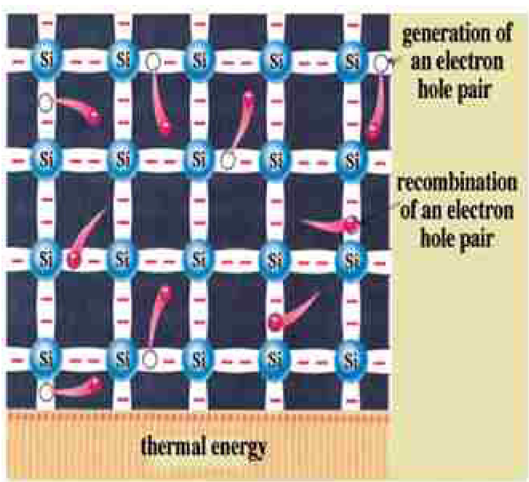


Fig (8 -3b)

As temperature increases more bonds are broken

broken bond is mended, and the hole shifts somewhere else, and so on.

As the temperature increases, the number of free electrons and holes increases, noting that the number of free electrons equals the number of free holes in a pure semiconductor. But a state of dynamic equilibrium is reached (called thermal equilibrium) at which only a small percentage of bonds are broken. The number of bonds broken per second will be equal to the number of bonds mended per second, so that a fixed number of free electrons and free holes remains constant at every temperature. But not the same electrons and same holes remain free.They reshuffle ,but their number stays constant.

Free electrons (a class of valance electrons) represent a third type of electrons in silicon. Such electrons in fact are still confined, but they are confined to the full size of the crystal itself, i.e., are limited by the so called surface of the crystal. Breaking a bond requires a minimum energy (thermal or optical). In the case of mending a bond (called recombination), energy is released (thermal or optical).

As the electrons move in a random motion ,so do the holes, since electrons in the bond move around randomly to fill in vacancies (voids) within the broken bonds (Fig 8 – 4).

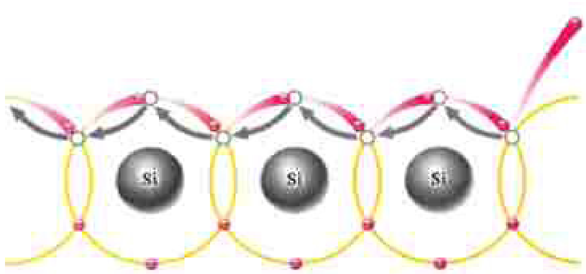


Fig (8-4a)

Holes move randomly between bonds

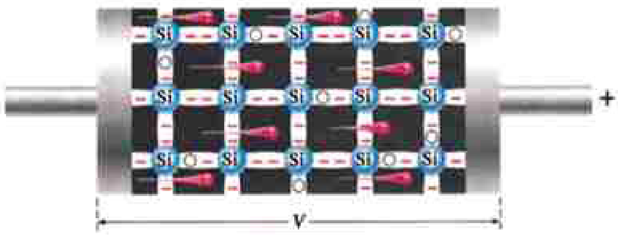


Fig (8-4b)

Motion of holes is equivalent to motion of electrons within bonds (in the opposite direction)

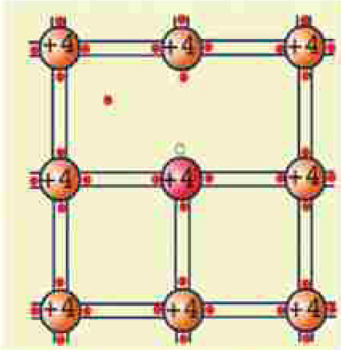


Fig (8-4c)

At a certain temperature, the number of free electrons and holes is constant

Doping:

Semiconductors are known to be sensitive to impurities and to temperature. Since silicon is tetravalent, the addition of an element as phosphorus (P) or antimony (Sb) or any other pentavalent element will cause such an impurity atom to replace a silicon atom in the crystal (Fig 8 – 5 a). Then, the phosphorus atom will try to do the same bonding with the neighbors as the silicon atom would do.

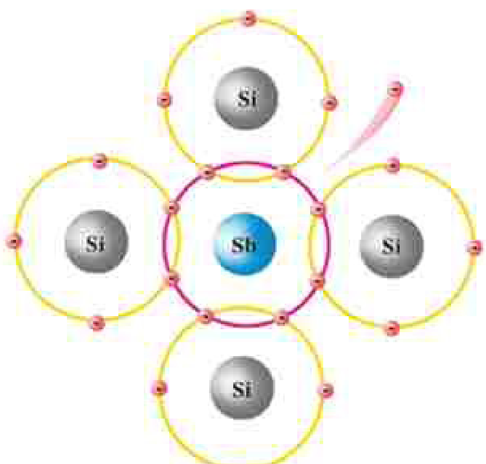
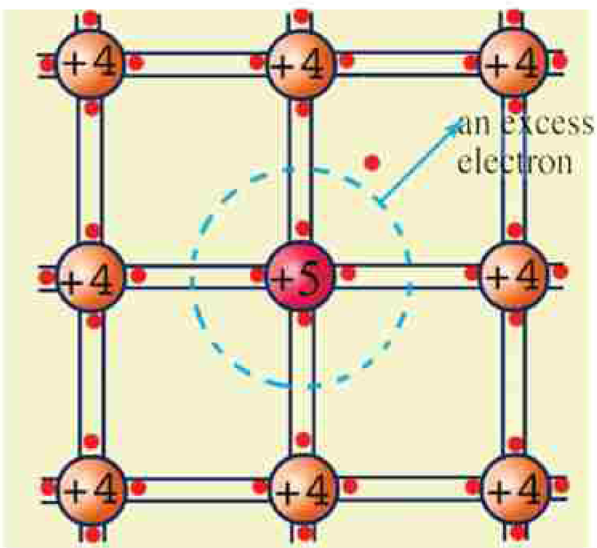


Fig (8-5a)

An antimony atom (pentavalent) replaces a silicon atom

Because the impurity atom has 5 electrons, four of them will take part in the bonding scheme, sparing one valence extra (excess) electron. The force of attraction on the excess electron which is left out is weak. Hence, it can easily be detached from its parent atom, which becomes a positive ion.This extra electron joins the stock of the free electrons in the crystal . In other words, the crystal has an added source of free electrons besides broken bonds, namely, impurity atoms. Such impurity atoms are called donors (givers). At thermal equilibrium, the sum of the positive charge equals the sum of the negative charge.

$$n = p + N_D^+ \qquad (8-1)$$



(Fig 8-5b)

Doping with a pentavalent atom provides an extra free electron. A pentavalent atom has a core (+5 e) and 5 electrons where N_D^+ is the positive donor ion concentration, n is the free electron density and p is the hole density. In this case, n > p and the material is called n–type. Conversely, if we add aluminum (Al) or boron (B) or any trivalent element, to pure silicon, the impurity atom replaces a silicon atom. Since the impurity atom now has 3 electrons in the outershell, it detaches an electron from a neighboring bond to complete its own bond creating an extra hole, becoming a negative ion. At thermal equilibrium ,

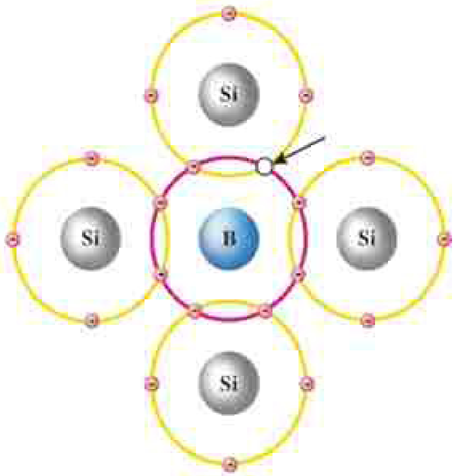


Fig (8 -6a)

A boron atom replaces a silicon atom

$$p = N_A^- + n \qquad (8-2)$$

where N_A^- is the negative impurity concentration. Thus, p>n. Such an atom is called acceptor (taker). In all cases, we have

$$np = n_i^2 \qquad (8-3)$$

where n_i is the electron or hole concentration in pure silicon, i.e., if n increases, p decreases and vice versa. This is called law of mass action. As an approximation, we may say :

in case of n-type

$$\boxed{n = N_D^+} \quad (8-4)$$

$$\boxed{p = n_i^2/N_D^+} \quad (8-5)$$

In case of p-type,

$$\boxed{p = N_A^-} \quad (8-6)$$

$$\boxed{n = n_i^2/N_A^-} \quad (8-7)$$

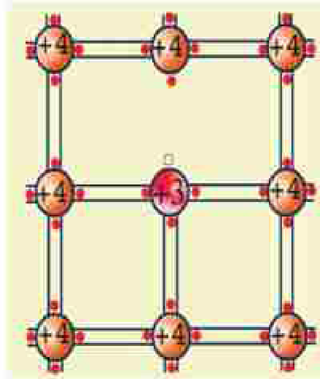


Fig (8 -6b)

Doping with a trivalent atom provides an extra hole. A trivalent atom has a core (+3e) and 3 electrons

Electronic Components and Devices

Electronic components and devices are the building blocks for all electronic systems (Fig 8 – 7). Some of these components are simple, e.g., resistor (R), inductor (L), capacitor (C). Some are more complex, such as pn junction (diode), transistor. There are also other specialized devices, such as optoelectronic and control devices. Semiconductors from which most of these devices are made are known to be sensitive to environmental conditions, such as light, heat, pressure, radiation and chemical pollution. That is why they are used as sensors or means for measuring external stimulii. Using these sensors, we can measure the intensity of incident light, temperature, pressure, humidity, pollution, radiation,etc.

Fig (8 -7a)

Resistors

Fig (8 -7b)

Diodes and transistors

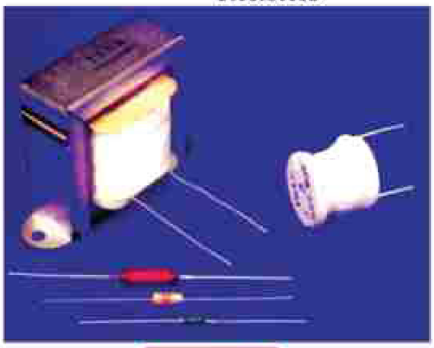


Fig (8 -7c)

Inductors

Fig (8 -7d)

Capacitors

Fig (8 -7e)

Transformers

Fig (8 -7f)

Switches

Fig (8 -7g)

A different set of components and devices
(Can you recognize some?)

pn junction:

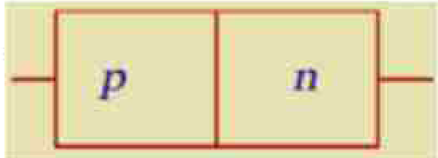


Fig (8-8)

A pn Junction

A pn junction (Fig 8 – 8) consists of an n–type region and a p-type region. The name pn stands for p-region and n-region not positive and negative. Also p,n regions are not two regions glued together but an n-material is converted in part to p-material or vice versa. Holes in the p–type region have high concentration, while holes in the n–type region have low concentration. Therefore, some holes diffuse from the p-type region to the n–type region. Also, some electrons diffuse from the n–type region (high concentration for electrons) to the p–type region (low concentration for electrons). Since each region is neutral (the sum of positive charge equals the sum of negative charge), the transfer of some electrons from the n–type region uncovers an equal number of positive donor ions, and the transfer of some holes from the p–type region uncovers an equal number of negative acceptor ions. This results in a middle region composed of positive ions on one side, and negative ions on the other, while no electrons or holes exist in this region. This region is called transition (depletion) region. In such a region, an electric field is set up, directed from the positive ions to the negative ions. This electric field causes a drift current to flow in a direction opposite to the diffusion current. At equilibrium, the forward current is balanced with a reverse current, so that the net current is zero (Fig 8 –9). If we apply an external voltage such that the p-type region is connected to the positive terminal of the battery

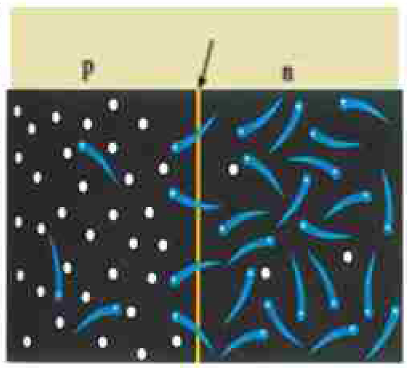


Fig (8-9a)

Electrons diffuse from n to p and holes from p to n

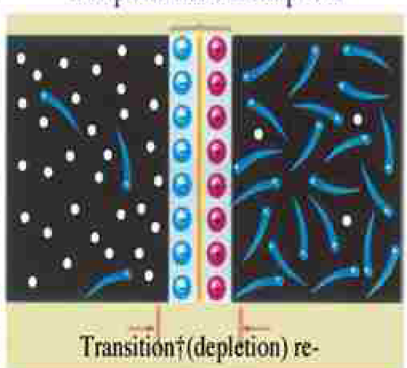


Fig (8-9b)

Transition region depleted from electrons and holes, only ions exist and the n-type region to the negative terminal of the battery, the field due to the battery is opposite to the internal field.in the transition region, and therefore, it weakens it. If we reverse the battery, then the two fields will aid each other. In the first case (forward bias), a net current will flow, and in the second case (reverse bias) current is almost zero (Fig 8-12). The action of the pn junction is like a switch, which is closed in the forward direction (conducting) and open (non conducting) in the reverse direction (Fig 8-13). We can make sure that the pn diode is functioning by using an ohmmeter, since the diode should have a small resistance in the forward direction and a large resistance in the reverse

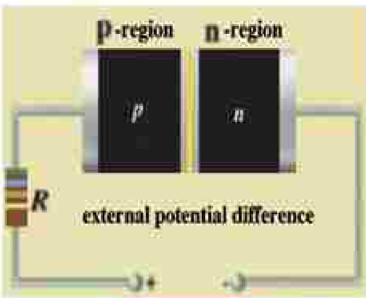


Fig (8-10a)
Forward Bios

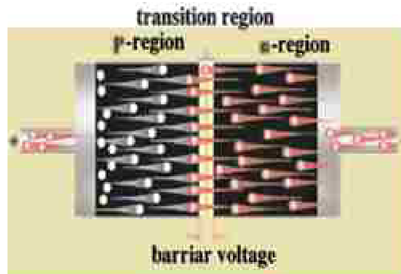


Fig (8-10b)
Motion of electrons and holes due to forward bias

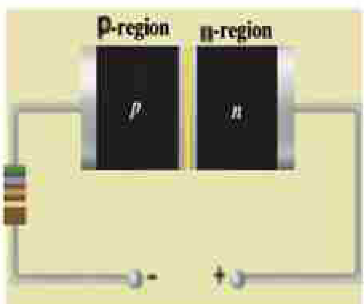


Fig (8-11a)
Diode in reverse bias

Fig (8-11b)
Motion of electrons and holes due to reverse bias

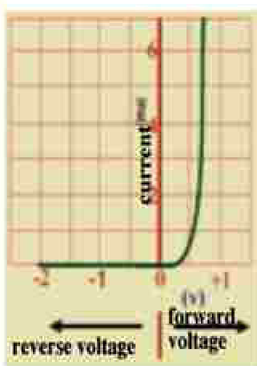


Fig (8-12)
I - V characteristic in a pn diode

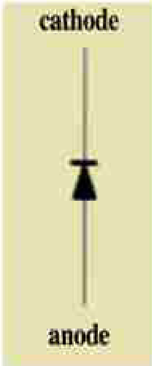


Fig (8-13a)
Diode symbol

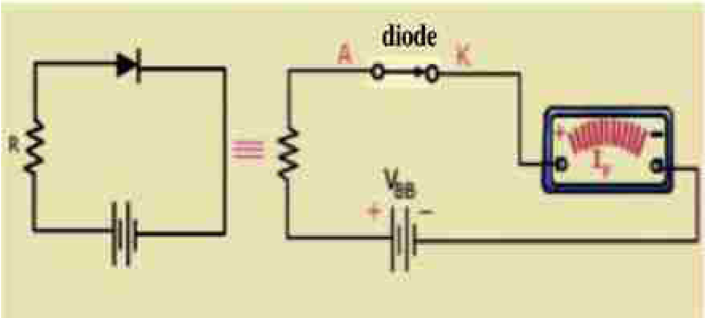


Fig (8-13b)
In forward bias the diode is like a closed switch

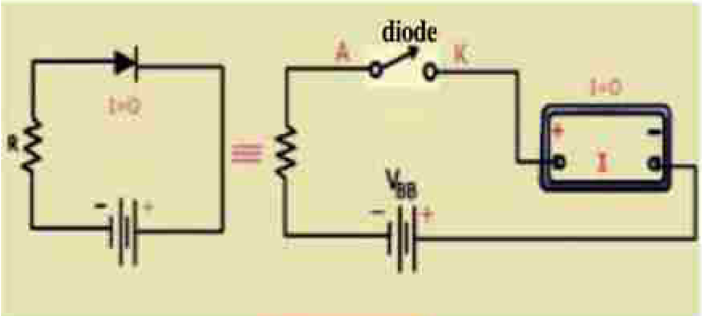


Fig (8-13c)
In reverse bias the diode is like an open switch

Learn at Leisure

Electronic tuning

To tune up a TV or radio onto a certain station, we need to adjust the value of a capacitor to set the frequency of the receiver to the frequency of the selected broadcast station. This condition is called resonance. In modern receivers, the capacitor is replaced by a reverse biased pn diode . The width of the transition region increases with increasing reverse bias (Fig 8 - 14). The increase of the width of the transition region entails an increase of the fixed ionic charge on both sides of the transition region with reverse voltage. This is tantamount to capacitor action. Thus, we can change the value of the capacitor by controlling the revese voltage. This is called electronic tuning (and the device is called a varactor).

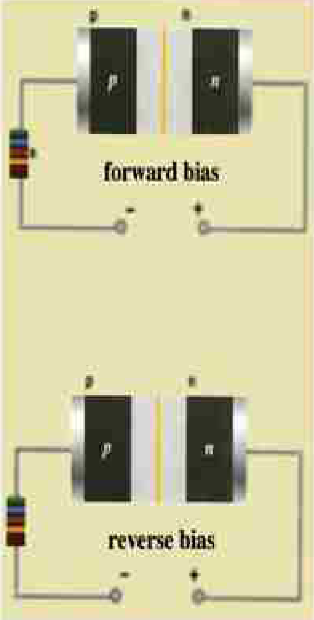


Fig (8-14)

The width of the transition region increases with increasing reverse bias

Transistor:

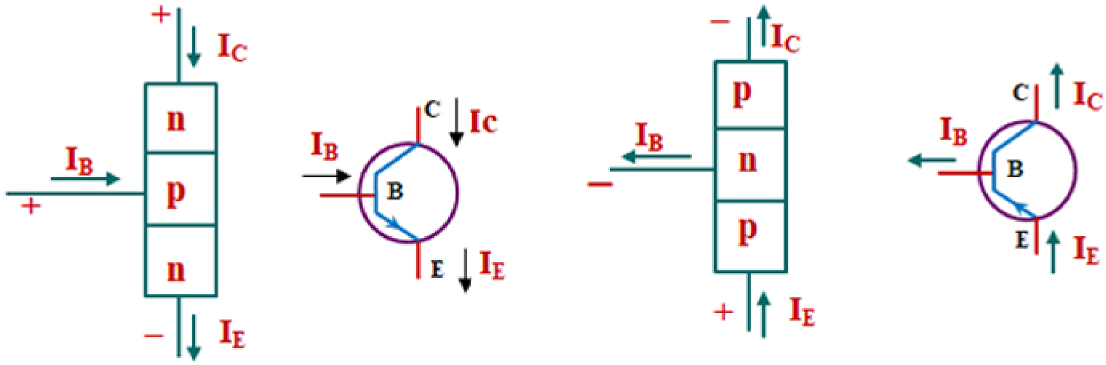
The transistor was invented in 1955 thanks to John Bardeen, William Shockley and Walter Brattain.

Bardeen, Schochley and Brattain

There are different types of transistors, and we will be content here with the BJT (Bipolar junction transistor) of the pnp and npn type, meaning that this type consists of a p region followed by n region and then p region or an n region followed by p region and then n region (Figure 8-15)

The first region is called the Emitter (E), the last the Collector (C) and the middle the Base (B), and the thickness of the base is very small.

A transistor can be connected in electronic circuits in several ways, including connecting it so that the base is common. For example, in the case of an npn transistor, the first np junction (emitter - base) is Forward biased, and the second pn junction (collector - base) is Reverse biased.



In this case, free electrons are released from the n-type emitter to the p-type base, where they diffuse for some time until they are picked up by the n-type collector, and because the electrons diffuse in a base full of holes, the recombination process that takes place in the base consumes a percentage of these electrons. Thus, if the electron current from the emitter is I_E, the current reaching the collector I_c is less than the emitter current as current I_B passes through the base circuit, thus

$$I_E = I_c + I_B$$

The constant $\propto_e$ is called the distribution constant and represents the ratio $\frac{I_C}{I_E}$ and its value is close to the one because the width of the base is very small, so only a small percentage of electrons are consumed in filling the positive holes, and the constant βe is called the current gain and represents the ratio $\frac{I_C}{I_B}$ and its value is very large.

The relation between the two transistor constants $\propto_e$ and β_e:

$$I_c = \propto_e I_E \quad , \quad I_B = (1 - \propto_e) I_E$$

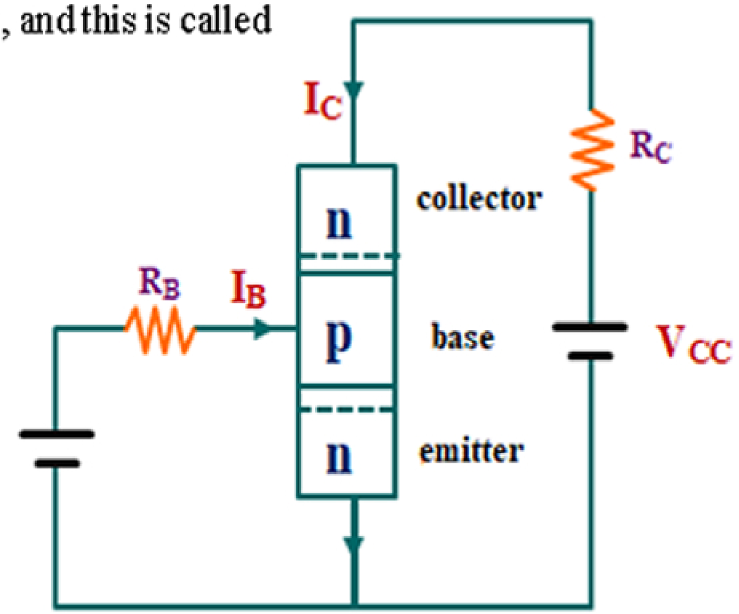
$$\beta_e = \frac{I_C}{I_B} = \frac{\alpha_e . I_E}{(1 - \alpha_e) I_E}$$

$$\therefore \quad \beta_e = \frac{\alpha_e}{1 - \alpha_e}$$

$$\therefore \quad \alpha_e = \frac{\beta_e}{1 + \beta_e}$$

Transistor as an amplifier:

The transistor can be connected so that the emitter is common, and it is then used as an amplifier of current and power, that is, if you put a small electrical signal such as the output from a microphone in the base current, its effect appears amplified in the collector current, and this is called transistor action.



Transistor as a switch:

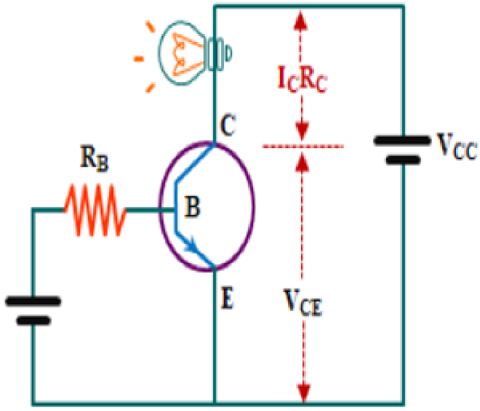
The transistor is connected so that the emitter is common.

In the collector circuit it is

$$V_{CC} = V_{CE} + I_C R_C$$

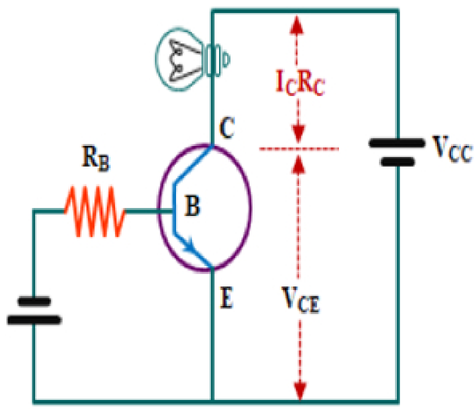
Where V_{CC} is the battery voltage, V_{CE} is the voltage difference between the collector and emitter, I_C is the collector current, and R_C is a resistor present in the circuit.

Transistor as a closed switch

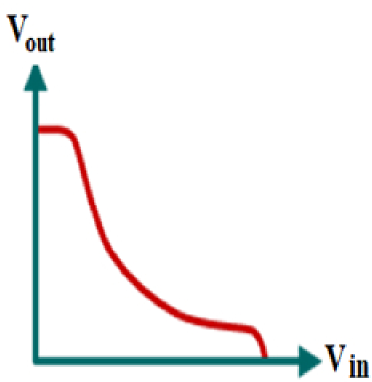


We find that as the collector current I_C increases, the potential difference I_CR_C between the two terminals of the resistor increases, and the value of V_{CE} decreases until it reaches its lowest value (about 0.2 V). If we consider the base to be the input V_{in} and the collector to be the output V_{out}, and the emitter is common (connected to its ground voltage) and the base voltage is positive and large, the collector current Ic is large and because the value of I_CR_C is large, the output voltage V_{CE} is small. The transistor thus functions as a closed switch.

Transistor as an open switch



If the base voltage is positive and the base voltage is small or negative, the collector current I_c is interrupted and the transistor acts as an open switch. But the value of I_CR_C is zero or very small, so the output voltage V_{CE} is large, almost equal to V_{CC}.



From the above, it is clear that the transistor in this case is a device that can function as a switch that can either conduct or not conduct current, and also as an inverter where the output V_{CE} is small when the input V_{in} is large, and the output V_{CE} is small when the input V_{in} is large.

Digital Electronics:

All electronic systems deal with natural quantities and convert them to electrical signals. As an example, a microphone converts sound to an electrical signal. A video camera converts an image to electrical signals. In TV, the image (video) and sound (audio) are transformed into electrical signals, then into electromagnetic waves. All this occurs at the transmitter. At the receiver, the em signal is transformed back into electrical (video and audio) signals. The electronics which deals with natural quantities is called analog electronics. A new branch of electronics has developed, namely, digital electronics. In this case, the electrical signal is not transmitted continuously (all values are allowed), but is coded, such that the signal is in terms of one of two possible values representing two states 0 or 1. So, if we want to represent 3, it can be written as 11_2, where subscript 2 denotes the binary system (not eleven).

$$3 = 1x2^0+1x2^1$$

as we may express 17 in decimal system as

$$17 = 7x10^0+1x10^1$$

similarly in the binary system, we use the weights of 2^0, 2^1, 2^2 ... instead of 10^0, 10^1, 10^2, ...Thus, each numeral, symbol and alphabet is coded with a binary code. Analog quantities may be encoded by an analog – digital converter (ADC). At the reciever, digital quantities are decoded into analog quantities using a digital to analog converter (DAC). Why do all this? In nature, there are unwanted spurious signals, called electrical noise. Noise is caused by the random motion of electrons. Electrons are charged particles. As they move randomly, they cause minute randomly varying currents. These currents interfere with and disturb the information - bearing signals. We notice that in weak radio stations, noise appears as a hiss, and in weak TV stations (or with a bad antenna an aerial) noise appears as spots (salt and pepper). Electrical noise marrs the useful signals, and is difficult to get rid of. In case of digital electronics, the information does not lie in the absolute value of the signal (which might be contaminated by noise), but lies in the code in terms of 0 or 1. It does not matter if the value corresponding to 0 or to 1 has some noise superimposed on it. What matters is the state (0 or 1). This is the main advantage of digital electronics. For this reason, it has permeated our modern life extensively, as in cellular (mobile) telephony, digital satellite TV, and CDs. What has increased the importance of digital electronics is the advent of the computer. Everything that is entered into the computer-whether numbers or letters-must be transformed into a binary code. Even images are divided into small elements, each called a pixel (picture element). These too must be encoded. The computer performs all arithmetic and logic operations using binary (Boolean) algebra. It also stores information in the binary code temporarily in the RAM (Random Access Memory) or permanently in the hard disk, by magnetizing in one direction for 0 and in the opposite direction for 1.

Logic Gates:

Modern applications of electronics, such as computer circuits and modern communication systems depend on digital circuits, called logic gates. These are the circuits that perform logic

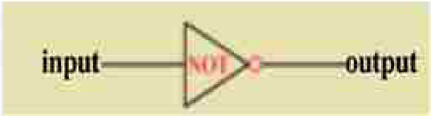


Fig (8-18a)
Not gate symbol

Fig (8-18b)
States of a NOT gate

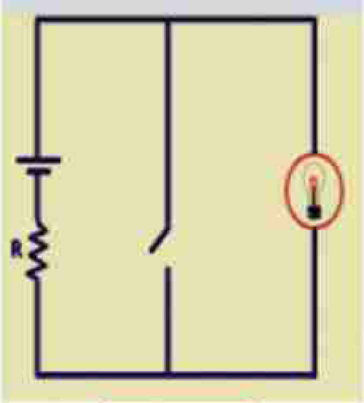


Fig (8-18c)
An equivalent drawing for a NOT gate. When the switch is closed (ON) the lamp is (OFF) and vice versa

operations, such as inversion (NOT), simultaneity or coincidence (AND) and optionality (OR)

They are based on Boolean (Binary) Algebra as follows :

1) **Inverter (NOT Gate)** (Fig 8 -18) has one input and one output, and has the following truth table:

input	output
1	0
0	1

2) **AND Gate:** (Fig 8 -19) has two inputs or more and one output and has the following truth table:

input	output
00	0
01	0
10	0
11	1

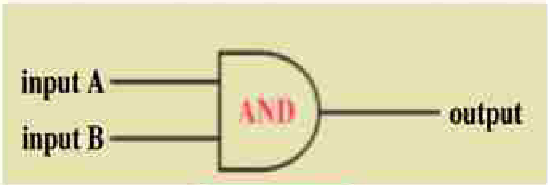


Fig (8-19a)

AND gate symbol

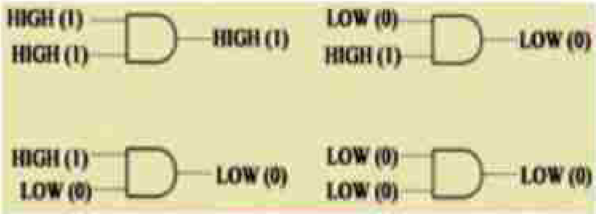


Fig (8-19b)

States of an AND gate

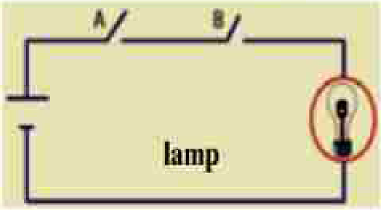


Fig (8-19c)

An equivalent drawing for an AND gate. The lamp does not glow until both switches are closed

Thus, there is no output (1) unless both inputs are (1) each, i.e., two conditions or more are met to satisfy an output (1). It can be represented by two switches in series. They both have to be closed at the same time for current to flow and the lamp to glow.

3) **OR Gate** has (Fig 8-20) two inputs or more and one output. One condition (1) may suffice to have an output (1).

input	Output
0 0	0
01	1
10	1
11	1

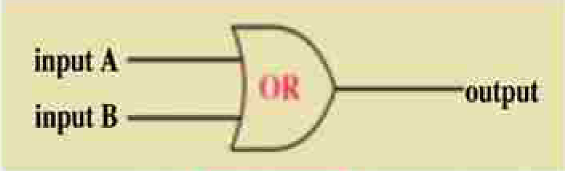


Fig (8-20a)
OR gate symbol

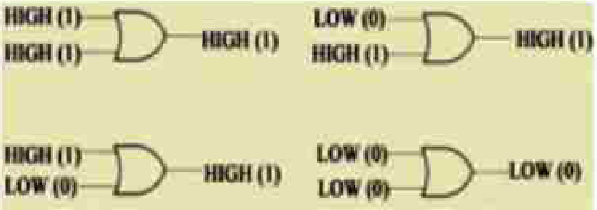


Fig (8-20b)
States of OR gate

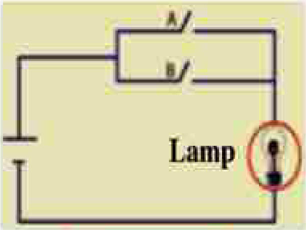


Fig (8-20c

An equivalent drawing for an OR gate.
One switch need be closed for the lamp to glow

This can be represented by two switches in parallel, one of them only need be closed to pass current.

All operations performed by the computer are based on these gates and others.

These gates can be implemented by transistors.

In a Nutshell

- A metallic crystal consists of positive ions and a cloud of free electrons roaming around the crystal in random motion. There is a force of attraction between the ions and the electron cloud. But the resultant of all forces of attraction on a single free electron is zero . If an electron tries to escape from the metal, a net force of attraction due to the atom layer at the surface pulls it in.
- A pure silicon (semiconductor) crystal consists of atoms covalently bonded. At low temperatures, there are no free electrons. If temperature increases, some bonds are broken, electrons become free, leaving behind holes. Both electrons and holes move randomly.
- The number of broken bonds increases with temperature. It may increase also by an external stimulus, such as light, provided that the photon energy is sufficient to break the bond.
- The number of free electrons and holes increases by adding impurities (doping). Thus, the material becomes n-type or p-type.
- The conductivity of a semiconductor depends on the conduction of free electrons and holes. Thus, a semiconductor has two current carriers: electrons and holes, while in a metal there is only one current carrier (the electron). Electron concentration in a metal is constant and does not depend on temperature.
- Semiconductors are environment-sensitive. They can be used as sensors to light, heat, pressure humidity, chemical pollution, radiation etc.
- A diode (pn junction) consists of a p–type region and an n-type region. If the p-side is connected to the positive terminal of the battery and the n-side to the negative terminal

(forward connection or forward bias) current flows. If the battery is reversed no current flows.

This is why a diode is used in rectification.

- A transistor may be pnp or npn, and can be used as an amplifier, since the ratio of the collector current to the base current β_e is large. Therefore, any small change in the base current leads to an amplified change in the collector current.
- A transistor may also be used as a switch. It is used in logic gates, such as an inverter (NOT), AND, OR gates.
- Digital electronics is superceding analog electronics for its ability to overcome electrical noise . Its basic concept is to code information in binary form (0 , 1).

Questions and Drills

I) Drills:

1) If electron or hole concentration in pure silicon is $1x10^{10}cm^{-3}$, phosphorus is added at a concentration of $10^{12}cm^{3}$, calculate the concentrations of electrons and holes in this case. Is this silicon n-type or p-type? ($n=10^{12}cm^{-3}$ $p=10^{8}cm^{-3}$)

(n - type)

2) Calculate the concentration of aluminum to be added so that silicon returns pure .

($N_A^- = 10^{12}cm^{-3}$)

3) A transistor has $\alpha_e = 0.99$. Calculate β_e. Then calculate the collector current if the base current is 100 µA ($\beta e=99$, $I_C = 99x10^{-4}A$)

4) The electrical signal in the base of a transistor is 200 µA . The collector current is to be 10 mA. Calculate α_e and β_e. ($\alpha_e = 0.98$, $\beta_e = 50$)

5) A diode can be represented by a forward resistance 100Ω ,while it is infinity in the reverse direction. We apply +5 V ,and then reverse it to – 5 V. Calculate the current in both cases. (50 mA, O)

II) Essay questions:

1) Discuss the importance of digital electronics and mention 5 applications.
2) Deduce the truth table for an AND gate followed by an inverter.
3) Deduce the truth table for an OR gate followed by an inverter.

General Revision

1) In electric circuits connected in parallel, thick wires are used at the ends of the battery,but at the ends of each resistor less thick wires are used. Why?

2) What is meant by:

a) the effective value of AC.

b) eddy current.

c) the sensitivity of a galvanometer.

d) the efficiency a transformer.

3) What is the physical concept for the operation of the following devices: galvanometer – transformer – current divider (or shunt)– potential multiplier.

4) Give reason :The step- down transformer increases the current, and the

step - up transformer decreases the current.

5) There are three essential factors that must be considered when designing transformers to decrease the loss of the electric energy. What are these factors and how?

6) Give reason: The eddy current is not generated in the metallic blocks unless a magnetic field of variable intensity exists.

7) Compare between an AC generator and a DC generator.

8) Give reason: To increase the power of a motor ,several coils seperated by small angles are used.

9) The following table shows values of resistance of wire of cross sectional area 0.1 m^2 and different lengths.

Length l m	2	4	6	10	14	16
Resistance R Ω	5	10	15	25	35	40

Plot the relation between the length (l) on the X axis and Resistance (R) on the Y axis. From the plot find:

a) resistance of a part of the wire of length 12 m .

b) the resistivity of the material of the wire.

c) the conductivity of the material of the wire.

10) A wire 30 cm long and 0.3 cm^2 cross sectional area is connected in series with a DC source and an ammeter . The potential difference between the ends of the wire is 0.8 V, when a current of 2A passes through it. Calculate the conductivity of the wire material.

11) A rectangular coil of N turns and surface area A is placed parallel to the lines of a regular magnetic field of flux density B Tesla. If the coil starts rotation from this position with a regular angular velocity ω, until it compelets half a revolution. Clarify with a labeled diagram how the value of the emf changes with the rotational angle during this time, and what is the maximum value of the induced emf generated in this coil.

12) A galvanometer has a resistance 40 Ω and reads up to 20 mA. Calculate the resistance of the shunt required to convert it into an ammeter, reading up to 100 mA. If the coil of the galvanometer is connected to a potential multiplier with resistance 210 Ω.Calculate the maximum potential difference to be read.

13) Compare between each of

a) a step -down transformer and a step- up transformer in terms of function, use, and number of turns of the secondary coil.

b) dynamo and motor in terms of function and use.

14) Why does the transmission of the electric power from a generating station require wires under high voltage?

Choose the correct answer and give account

a) to be able to use the transformers .

b) to insure that the current will flow for a long distance.

c) to minimize the loss in the electric energy .

d) to minimize the resistance of the wires.

15)What is meant by :

a) the coefficient of mutual induction between two coils =2H.

b) the efficiency of a transformer=90%.

c) eddy currents.

d) the effective value of an AC current =2A.

16) A step -down transformer of efficiency 100% is to be used to light a lamp of power 24 W at a potential difference 12 V. If the power source applied to the transformer is 240 V, the number of turns of the secondary coil is 480 turn.

1) calculate the current passing through each of the primary and secondary coils

2) the number of the turns of the primary coil.

17) When an electric current is flowing through a perpendicular wire in a uniform magnetic field, the wire is affected by a force. Which of the following instruments is based on this principle:

(1) electromagnet.

(2) motor.

(3) generator.

(4) transformer.

18) Calculate the emf of a source if the work done to transfer 5C is 100 J.

19)Three resistors 10 Ω , 20 Ω , 30 Ω are connected to a power supply . If the currents are 0.15 A , 0.2 A , 0.05 A, respectively. Calculate the equivalent resistor for this circuit, and illustrate your answer with a labeled diagram.

20) Two resistors 400 Ω and 300 Ω are connected in series to a 130V power supply. Compare between the readings of a voltmeter of resistance 200 Ω when connected across each resistor seperately (neglecting the internal resistance of the power supply).

21) A wire has length 2 m and cross sectional area 0.1 m^2 is connected to a source with emf 10 V. Calculate the resistivity and conductivity of its material if it carries a current of 2A.

22) A wire of a uniform cross section carries a current of 0.1 A when the potential difference between its terminals is 1.2 V. If a square abcd is made of this wire, calculate the equivalent resistance for the wire when the power source is connected one time to the points a and c, and another time to the points a and d.

23) A power station is connected to a factory 2.5 km away be two wires. The potential difference between the terminals of the wires at the station is 240 V, and that for the other terminals at the factory 220 V. Calculate the resistance of one meter of the wire and its radius, if the resistivity of its material is 1.57×10^{-8} Ω, m and the current flowing through it is 80 A.

24) Find the percentage of the potential drop inside a car battery of emf 12V and internal resistance 0.5 Ω when connected to a bulb of resistance 2 Ω.

25) Determine the magnetic flux density at a point in air 0.1 m from a long straight wire that carries a current of 10A, where $\mu = 4x \times 10^{-7}$ Web/Am.

(26) Two parallel straight wires, the first carries a current of 10A, and the second carries a current of 5A. Calculate the total magnetic flux density at a point between the two wires 0.1m from the first wire and 0.2 m from the second, when the current in the wires is, once in the same direction, and another time in the opposite direction.

27) A current- carrying straight wire is formed as a loop, once from one turn, and another time from four turns. Compare between the flux densities in the center of the loop in the two cases?

28) A long solenoid has 300 turns. What current is required to produce a flux density 1.2 x 10^{-3} Web/m^2 in the center of the solenoid, if its length is 0.22m? and what is the value of the total magnetic flux in the interior of the solenoid, if its cross sectional area is 25 x10^{-4} m^2?

29) A straight wire in a magnetic field makes an angle 30° with its direction. If the length of the wire is 10 cm and the current flowing is 20A, calculate the force on the wire if the magnetic flux density is 2 x 10^{-3} Web / m^2.

30) A rectangular coil of length 30 cm and width 20cm consists of 10 turns carrying a current of 3A is placed in a reqular magnetic field of flux density 0.1 Tesla. Calculate the torque acting on the coil when the angle between the plane of the coil and the direction of the field is 50°.

31) A circular coil has 100 turns, and carries a current of 10A. It has a cross sectional area of 0.3 m^2 and is placed in a magnetic field of flux density 0.2 Tesla. Calculate the maximum value of the torque acting on the coil, and determine the position of the coil with respect to the field in this case.

32) If the angle between the face of the coil and the magnetic field in a galvanometer is 60°, when a current of 30 mA passes. Calculate the sensitivity of this galvanometer?

33) A galvanometer has resistance 5 Ω and full scale deflection 20 mA. Calculate the value of the maximum current when a shunt of 0.1 Ω is connected to its coil. Also, calculate the value of the potential multiplier which is to be connected to the galvanometer to make it a voltmeter that reads up to 5V.

34) A shunt of 0.1 Ω decreases the sensitivity of an ammeter by an order of magnitude (10 times). Calculate the shunt resistor which decreases its sensitivity to 1/4 of FSD.

35) Discuss in details the problem which faced classical physics to interpret the curves or radiation versus the wavelength for hot bodies at different termperatures.

36) Explain how Planck was able to clarify the problem of blackbody radiation.

37) What is meant by the photoelectric effect and how did quantum theory explain it?

38) Compton effect is considered a good example for the particle nature of the wave. Discuss.

39) The electron microscope is an applicable example for the wave nature of electrons. Explain the physical concept of this device. Clarify why the electron microscope is superior to the optical microscope?

40) What is the role of the electric field between the cathode and the target in generating X-rays in Coolidge tube.

41) Give reason: The wavelength of the characteristic X- ray spectrum depends on the

Type of material of the target and not on the potential difference between the cathode and the target.

42) The active medium must be in population inversion state for laser sources to operate, but that is not essential for ordinary light sources. Why?

43) Resonant cavity is an essential component in laser to complete the amplification and stimulated emission process. Explain the mechanism of both processes.

44) Clarify the role of He and Ne elements in He-Ne laser?

45) He-Ne laser is considered an example for transforming the electrical energy into optical and thermal energy. Explain the mechanism of this transformation.

46) Compare between ordinary photography and holography from the point of view of the way information in the image is recorded.

47) What is meant by a pure semiconductor? What are its properties as an electrical conducting material?

48) Discuss ways to increase the conductivity of a semiconductor.

49) Discuss the meaning of the following terms In the diade:

- a hole.
- a doping atom.
- p-type semiconductor.
- n-type semiconductor.
- current due to the electric field (drift current)
- diffusion current.

Appendixes

Appendix 1

Symbols and Units of Some Physical Quantities

serial	quantity	symbol	unit
1	displacement	x,y,z,d	m (meter)
2	area	A	m^2
3	volume	V_{ol}	m^3
4	time	t	s (second)
5	periodic time	T	s
6	velocity / speed	v	$m\ s^{-1}$
7	angle	α,θ,ϕ	deg , rad
8	angular velocity	ω	$rad\ s^{-1}$
9	mass	m,M	kg
10	electron mass	m_e	kg
11	density	ρ	$kg\ m^{-3}$
12	acceleration	a	$m\ s^{-2}$
13	acceleration due to gravity	g	$m\ s^{-2}$
14	linear momentum	P_L	$kg\ m\ s^{-1}$
15	force	F	N , $kg\ ms^{-2}$
16	weight	F_g	N(Newton)
17	torque	τ	Nm
18	work	W	J(Joule)
19	energy	E	J
20	kinetic energy	KE	J

serial	quantity	symbol	unit
21	potential energy	PE	J
22	power	P_w	W , Js^{-1} (watt)
23	impulse	I_{imp}	Ns
24	temperature	t°C , t°F , T°K	Celsius, Fahrenheit, Kelvin
25	quantity of matter	n	mole
26	pressure	P	pascal , Nm^{-2}
27	atmospheric pressure	P_a	pascal , Nm^{-2}
28	quantity of heat	Q_{th}	J
29	specific heat	C_{th}	$J\,kg^{-1}\,{}^{\circ}K^{-1}$
30	heat capacity	q_{th}	JK^{-1}
31	latent heat for evaporation	B_{th}	$J\,kg^{-1}$
32	latent heat for fusion	L_{th}	$J\,kg^{-1}$
33	volume expansion coefficient	α_V	per degree rise
34	pressure expansion coefficient	β_P	per degree rise
35	mass rate of flow	Q_m	kg/s
36	volume rate of flow	Q_V	m^3/s
37	viscosity coefficient	η_{vs}	$Ns\,m^{-2}$
38	efficiency	η	——
39	electric charge	Q,q	C (Coulomb)
40	electron charge	e	C
41	potential difference	V	V (Volt)
42	battery voltage	V_B	V

serial	quantity	symbol	unit
43	electromotive force (emf)	emf	V
44	field intensity	ε	Vm^{-1}
45	electric flux	ϕ_e	Gauss
46	electric current	I	A (Ampere)
47	electrical resistor	R	Ω (Ohm)
48	resistivity	ρ_e	Ω m
49	conductivity	σ	Ω^{-1} m^{-1}
50	transistor gain	α_e , β_e	——
51	magnetic field intensity	H	Am^{-1}
52	magnetic flux density	B	Tesla , Wb m^{-2}
53	magnetic flux	ϕ_m	Wb (Weber)
54	self inductance	L	H (Henry)
55	mutual inductance	M	H
56	permeability	μ	Weber A^{-1} m^{-1}
57	magnetic dipole	$\overrightarrow{m_d}$	Nm $Tesla^{-1}$
58	speed of light	c	ms^{-1}
59	frequency of wave	ν	Hertz (Hz)
60	frequency of electric current	f	Hz
61	wave length	λ	m
62	refractive index	n	——
63	dispersive power	ω_α	——

Appendix 2

Fundamental Physical Constants

Physical Constant	symbol	value
1-Universal gravitation constant	G	6.677×10^{-11} N m^2 kg^{-2}
2-Boltzmann constant	k	1.38×10^{-23} JK^{-1}
3-Avogadro's number	N_A	6.02×10^{26} Molecule.kmol^{-1}
4- Universal gas constant	R	8.31×10^{3} J.kmol^{-1} K^{-1}
5-Coulomb's law constant	K	9×10^{9} Nm^{2}C^{-2}
6-Permeability of free space	μ	$4\pi\times10^{-7}$ Weber m^{-1}A^{-1}
7-Speed of light in vacuum	c	3×10^{8} m.s^{-1}
8-Elementary charge	e	1.6×10^{-19} C
9- Electron rest mass	m_e	9.1×10^{-31} kg
10-Specific charge of electron	$\frac{e}{m_e}$	1.79×10^{11} C.kg^{-1}
11-Proton rest mass	m_p	1.673×10^{-27} kg
12-Planck's constant	h	6.63×10^{-34} Js
13-Atomic mass unit	u	1.66×10^{-27} kg
14-Rydberg constant	R_H	1.096×10^{7} m^{-1}
15-Neutron rest mass	m_n	1.675×10^{-27} kg
16-Molar volume of ideal gas at S.T.P		22.4×10^{-3} m^3
17-Standard gravity at the Earth's surface	g	9.8066 ms^{-2}
18-Equatorial radius of the Earth	r_e	6.374×10^{6} m
19- Mass of the Earth	M_e	5.976×10^{24} kg
20-Mass of the Moon	M_m	7.35×10^{22} kg
21- Mean radius of the Moon's orbit around the Earth	r_m	3.844×10^{8} m

Physical Constant	symbol	value
22-Mass of the Sun	M_s	$1.989x10^{30}$ kg
23- Mean radius of the Earth's orbit around the Sun	r_{es}	$1.496x10^{11}$ m
24-Period of the Earth's orbit around the Sun	yr	$3.156x10^{7}$ s
25- Diameter of our galaxy	—	$7.5x10^{20}$ m
26- Mass of our galaxy	—	$2.7x10^{41}$ kg
27- Radius of the Sun	—	$7x10^{8}$ m
28- Sun's radiation intensity at the Earth's surface	—	0.134 J cm^{-2} s^{-1}

Appendix 3

Standard Prefixes

power of 10	name
10^{-24}	Yocto
10^{-21}	Zepto
10^{-18}	Atto
10^{-15}	Femto
10^{-12}	Pico
10^{-9}	Nano
10^{-6}	Micro
10^{-3}	Milli
10^{-2}	Centi
10^{-1}	Deci
10^{0}	—
10^{1}	Deka
10^{2}	Hecto
10^{3}	Kilo
10^{6}	Mega
10^{9}	Giga
10^{12}	Tera
10^{15}	Peta
10^{18}	Exa
10^{21}	Zetta
10^{24}	Yotta

Appendix 4

Greek Alphabet

Α	α	alpha	a	"father"
Β	β	beta	b	
Γ	γ	gamma	g	
Δ	δ	delta	d	
Ε	ε	epsilon	e	"end"
Ζ	ζ	zêta	z	
Η	η	êta	ê	"hey"
Θ	θ	thêta	th	"thick"
Ι	ι	iota	i	"it"
Κ	κ	kappa	k	
Λ	λ	lamda	l	
Μ	μ	mu	m	
Ν	ν	nu	n	
Ξ	ξ	xi	ks	"box"
Ο	ο	omikron	o	"off"
Π	π	pi	p	
Ρ	ρ	rho	r	
Σ	σ, ς	sigma	s	"say"
Τ	τ	tau	t	
Υ	υ	upsilon	u	"put"
Φ	φ	phi	f	
Χ	χ	chi	ch	"Bach"
Ψ	ψ	psi	ps	
Ω	ω	omega	ô	"grow"

Appendix 5

Gallery of Scientists

Ibn Malka (1072 -1152)	A pioneer in medicine and the discoverer of the laws of motion
Ibn Unis (952 -1009)	A pioneer in astronomy and the inventor of the simple pendulum.
Al Baironi (973 – 1048)	A pioneer in geography and astronomy.
Ibn Al-Haytham (965 – 1040)	A pioneer in mathematics, astronomy, medicine and the founder of optics.
Al Kindy (800 – 873)	A pioneer in philosophy, physics , particularly optics.
Edison (Thomas) (1847-1931)	The inventor of the phonograph and the electric lamp, and other inventions "1000".
Arkhimêdês (287 -212 BC)	The discoverer of the ratio of the radius of a circle to its circumference, buoyancy and the reflecting mirror.
Avogadro (Amedeo) (1776 - 1856)	The discoverer of the molcular theory

Ampére (André - Marie) (1775 - 1836)	He performed studies on electricity, telegraph and magnetism.
Oersted (Christian) (1777 - 1851)	The founder of the theory of electromagnetism in 1820
Ohm (George) (1789 - 1854)	The discoverer of Ohm's law
Einstein (Albert) (1879 - 1955)	He was awarded Nobel prize in 1921 for his explanation of the photoelectric effect, the founder of the theory of relativity
Pascal (Blaise) (1623 - 1662)	The discoverer of Pascal's rule.
Al Joazri	A pioneer in fine mechanics and water clocks.
Bragg (William) (1862 - 1942)	The founder of X-ray diffraction.
Bohr (Neils) (1885 - 1962)	He produced a model for the atom.
Boyle (Robert) (1627 - 1691)	The discoverer of Boyle's law.

Torricelli (Evangelista) (1608 - 1647)	The inventor of the barometer
Galileo (Galilei) (1564 - 1642)	The inventor of the telescope and the discoverer of accelration due to gravity.
Galvani (Luigi) (1737 - 1798)	The discoverer of the electric charge in muscles.
Dalton (John) (1766 - 1844)	The discoverer of the law of mixing gases.
Rutherford (Ernest) (1871 - 1937)	The discoverer of radioactivty.
Ruhmkorff (Heinrich) (1803 - 1877)	The discoverer of the induction coil.
Rontgen (Wilhelm) (1845 - 1923)	The discoverer of X-rays.
Schrodinger (Erwin) (1887 - 1961)	The discoverer of Quantum Mechanics.
Al-Khazin	A pioneer in hydrostatics.

Faraday (Michael) (1791 - 1867)	The discoverer of the laws of electromagnetics.
Van Der Waals (Johannes) (1837 - 1923)	The discoverer of Van Der Waals' effect.
Fraunhofer (Joseph Von) (1787 - 1826)	He interpreted the atomic spectra and diffraction
Volta (Alessandro) (1745 - 1827)	The inventor of the battery.
Fermi (Enrico) (1901 - 1954)	He contributed to the atomic bomb.
Kamelingh (Onnes) (1853 - 1926)	The discoverer of liquid helium.
Kepler (Johannes) (1571 - 1630)	The discoverer of the laws of planetary motion.
Copernicus (Nicolas) (1473 - 1543)	He proved that the Earth rotates around the Sun.
Kirchhoff (Gustav) (1824 - 1887)	The discoverer of Kirchhoff's law.

Lenz (Heinrich) (1804 - 1865)	The discoverer of Lenz's rule.
Planck (Max) (1858 - 1947)	The discoverer of the photon and the blackbody radiation.
Maxwell (James)	The discoverer of Maxwell's equations.
Newton (Isaac) (1642 - 1727)	The discoverer of the laws of motion, gravity and colors.
Hertz (Heinrich) (1857 - 1894)	The discoverer of the electromagnetic waves
Huygens (Christian) (1629 - 1695)	He proposed the secondary sources in the from of a wave.
Young (Thomas) (1773 - 1829)	The discoverer of interference.

Appendix 6

Selected Physics Sites on the Internet

http://www.dke-encyc.com

http://imagine.gsfc.nasa.gov

http://csep10.phys.utk.edu

http://www.howstuffworks.com

http://www.colorado.edu/physics/2000/index.pl

http://scienceworld.wolfram.com/physics

http://www.physlink.com

http://www.intuitor.com/moviephysics

http://www.newport.com/spectralanding

http://www.mathpages.com/home/iphysics.htm

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

http://www.smsec.com

المواصفات الفنيـة:

رقـم الكتـــاب:	١٥٥١/١٠/١٥/٣٣/٣/٢٧
مقـــاس الكتـــاب:	$\frac{١}{٨}$ (٥٧ × ٨٢) سم
طبـــع المتـــن:	٤ لون
طبـــع الغـــلاف:	٤ لون
ورق المتـــن:	٨٠ جم أبيض
ورق الغـــلاف:	٢٠٠ جم كوشيه
عدد الصفحات بالغلاف:	٢٢٨ صفحة

http://elearning.moe.gov.eg

الأشــراف برنتنج هاوس