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MDCAT Physics

Quick Practice Book

A Companion Book of Nearpeer's Online MDCAT Course

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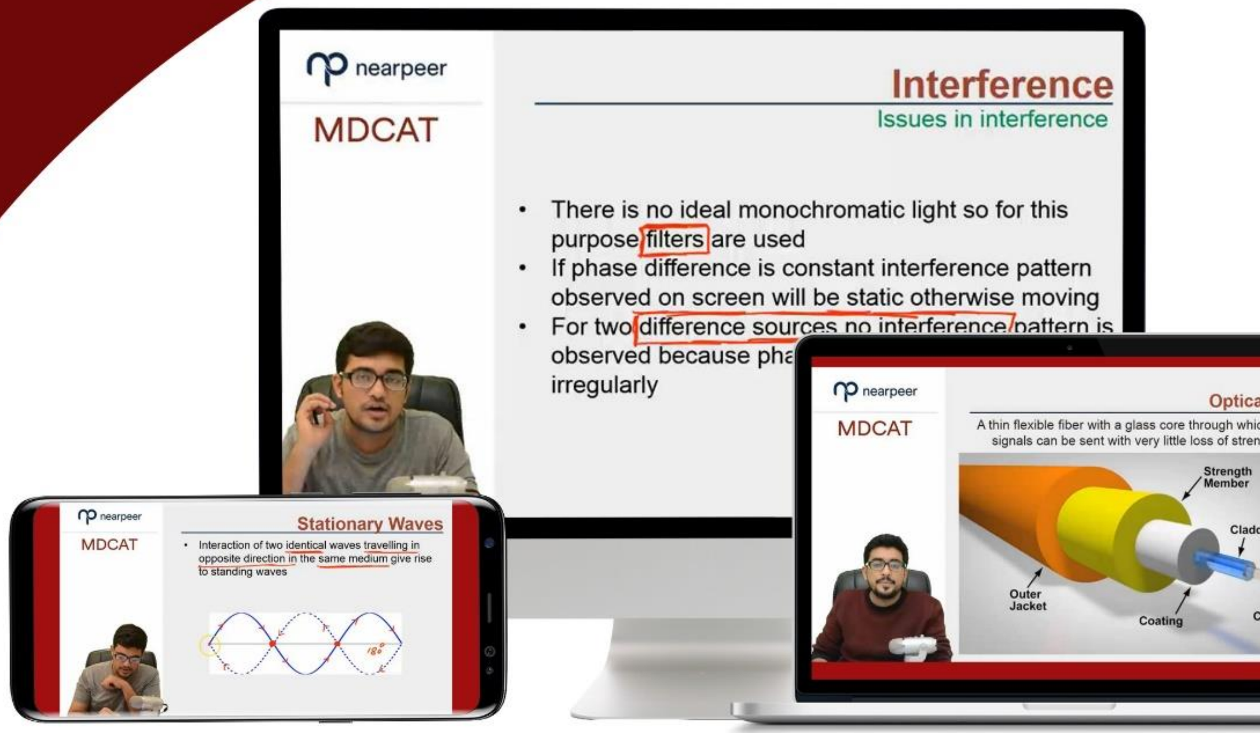
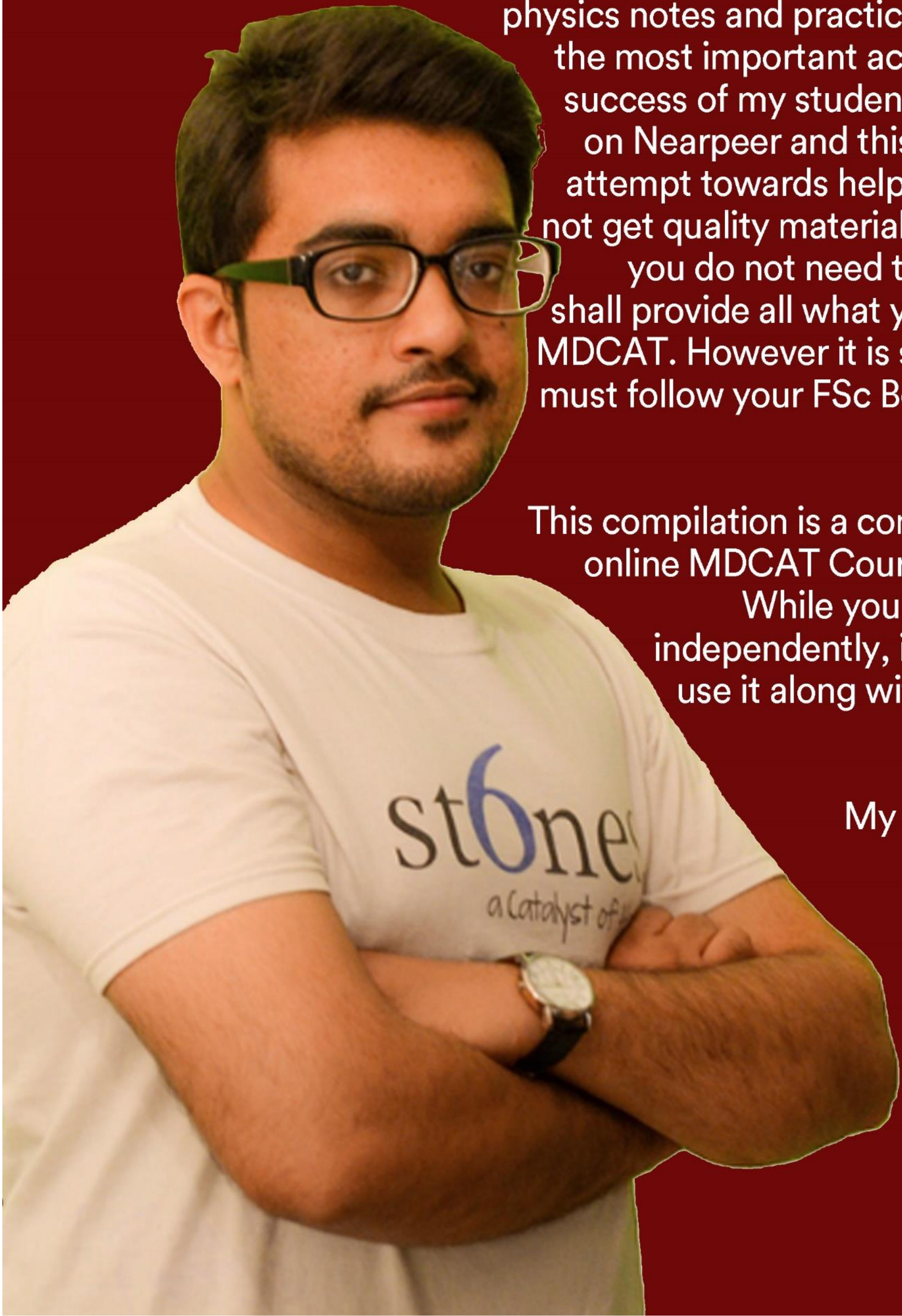


Meet Your Instructor

Prof Zia Ul Haq



It is my pleasure to present our students this compilation of physics notes and practice questions. For me, the most important achievement has been success of my students. My online course on Nearpeer and this book is my humble attempt towards helping all those who do not get quality material to study from. Now you do not need to worry as this book shall provide all what you need to ace your MDCAT. However it is still advised that you must follow your FSc Board book closely as well.

This compilation is a companion book of my online MDCAT Course on Nearpeer.org. While you may use this course independently, it is advised that you use it along with my video lectures and online quizzes.

My prayers with you all.

Prof. Zia.

UNIT 01

Measurements

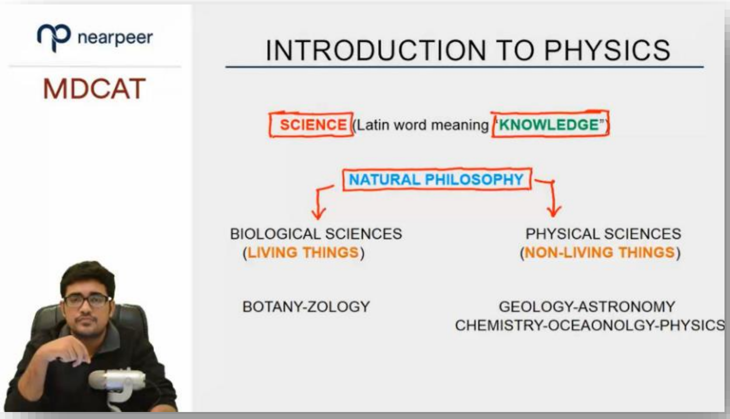
- Natural Philosophy
  - Biological Sciences
    - Botany
    - Zoology
    - Genetics
    - Cell Biology
  - Physical Sciences
    - Chemistry
    - Astronomy
    - Geology
    - Physics
      - Interdisciplinary areas of Physics
        - Astrophysics
        - Biophysics
        - Chemical physics
        - Engineering physics
        - Geophysics
        - Medical physics
        - Physical oceanography
        - Physics of music
      - Main Frontiers of Fundamental Sciences
        - Physics of Cosmology (e.g. Stars, galaxies...)
        - Physics of Middle - Sized Object (From Molecular level to Earth)
        - Physics of Micro - particles (From atomic level to photons)
      - Disciplines of Physics
        - Mechanics
        - Heat and thermodynamics
        - Electromagnetism
        - Optics
        - Sound
        - Hydrodynamics
        - Special relativity
        - General relativity
        - Quantum mechanics
        - Atomic physics
        - Molecular physics
        - Nuclear physics
        - Solid - state physics
        - Particle physics
        - Superconductivity
        - Super fluidity
        - Plasma physics
        - Magneto hydrodynamics
        - Space physics

Physics

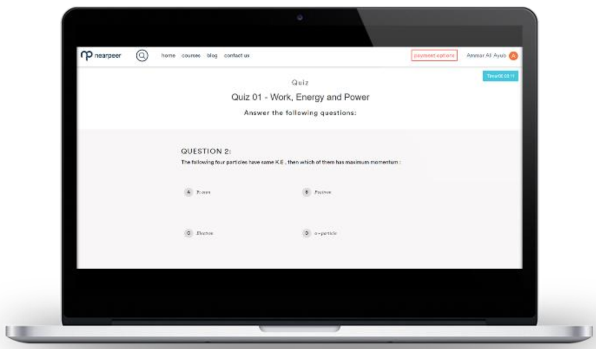
The branch of science which deals with the properties of **matter** and **energy** along with their **mutual relationship**.

The study of physics involves investigating such things as:

- **Laws of motion**
- **The nature and types of forces that hold the materials together.**
- **The interaction between different particles.**
- **The interaction of electromagnetic radiation with matter and so on.**



PRACTICE QUESTIONS



Hundreds of more practice questions in MDCAT Online course on www.nearpeer.org (Click MDCAT)

Q1. Which one of the following is not the interdisciplinary area of physics?

A) Chemical physics B) Engineering physics

C) Geophysics D) Super conductivity

Q2. At present, the numbers of main frontiers of fundamental science are

A) Four B) Two

C) Three D) Five

Q3. Light year is

A) Time B) Year of light

C) Distance D) Reciprocal of time

Q4. Computer chips are made of

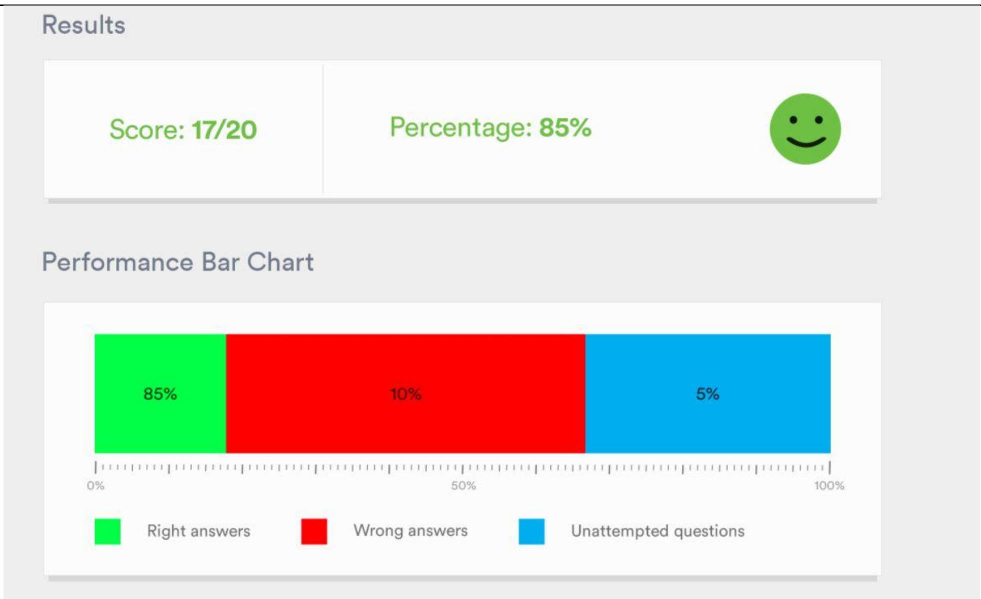
A) Metallic silicon B) Metalloid silicon

C) Super conducting silicon D) All of these

Q5. With the help of which one of the following waves big bang theory was proved?

A) X-rays B) Ultra-violet

C) Radio waves D) γ-rays



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Answers with explanation

Q1. **(D).** Not the interdisciplinary area means discipline (branch) of physics which is super conductivity

Q2. **(C).**

Q3. **(C).** Option (A) and (B) is the time whereas option (D) refers to frequency. And light year is the distance which light travels in one year.

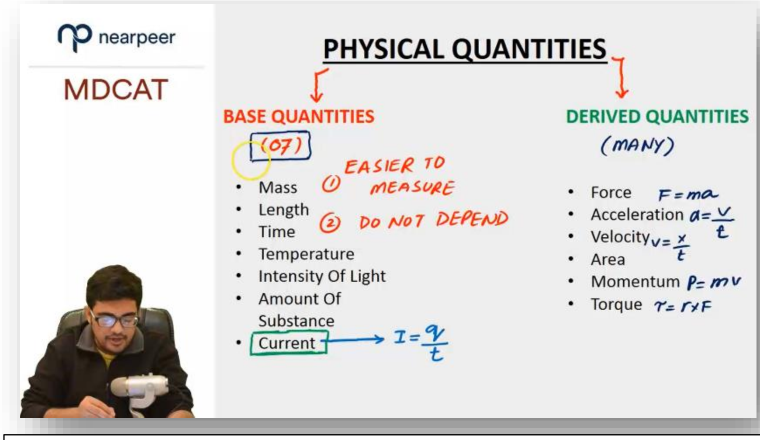
Q4. **(B).**

Q5. **(C).** Radio waves are longest in wavelength than other electromagnetic waves so they can travel longer distances and can reach the earth from the far side of universe.

Computer chips are made from wafers of the metalloid silicon, a semiconductor obtained from sand.

For your information	
Events	Interval (s)
Age of the universe	5×10^{17}
Age of the earth	1.4×10^{17}
One year	3.2×10^{7}
One day	8.6×10^{4}
Time between normal heartbeats	8×10^{-1}
Period of audible sound waves	1×10^{-3}
Period of typical radio waves	1×10^{-6}
Period of vibration of an atom in a solid	1×10^{-13}

Period of visible light waves	2×10^{15}



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Physical Quantities

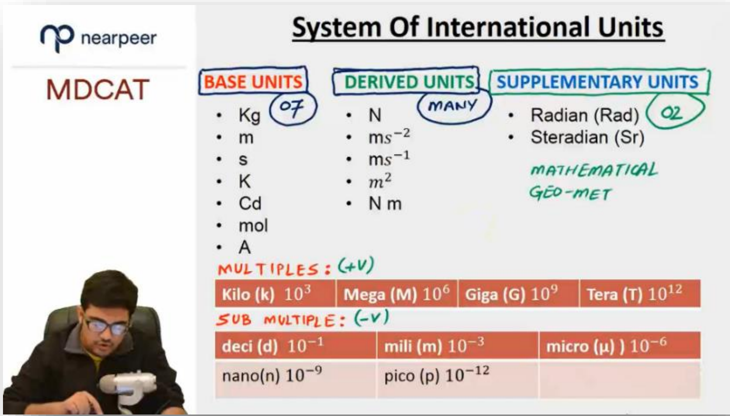
All those quantities in terms of which laws of Physics can be described are called Physical Quantities.

Types of Physical Quantities

Base Quantities
The minimum number of those quantities which do not depend upon any other quantity e.g., length, mass, time etc

Derived Quantities
The quantities that are derived from base quantities e.g., force acceleration, velocity e.t.c

Supplementary Quantities
These are neither base nor derived quantities e.g, plane angle and solid angle.



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System of units

Two systems of units were commonly in use before SI system.

- CGS system

- MKS system

CGS System:

The system of units in which the unit of length is centimeter, mass is gram and time is second.

MKS System:

The system of units in which the unit of length is meter, mass is kilogram and time is second.

SI System:

In 1960 SI system was established. This is an extended version of MKS and is built up of three kinds of units:

- **Base units / Fundamental units**
- **Supplementary units**
- **Derived units**

Base quantities / Fundamental quantities

There are seven base quantities which along with their SI units and dimensions are given below.

No.	Base Quantity	SI Unit	Unit Symbol	Dimensions
1	Length	meter	M	[L]
2	Mass	Kilogram	Kg	[M]
3	Time	Second	S	[T]
4	Temperature	kelvin	K	[K]
5	Electric current	Ampere	A	[A]
6	Luminous intensity	Candela	Cd	[I]
7	Amount of Substance	Mole	Mol	[mol]

Measurement of Base quantities:

The measurement of base quantities involves two steps.

- The choice of standard.
- The establishment of a procedure for comparing the quantity to be measured with the standard so that number and a unit are determined as the measure of that quantity.

An ideal standard has two principal characteristics.

- It is accessible and It is invariable

Some Prefixes		
Value	**Name**	**Symbol**
10^{-18}	atto	A
10^{-15}	femto	F
10^{-12}	pico	P
10^{-9}	nano	N
10^{-6}	micro	μ
10^{-3}	milli	M
10^{-2}	centi	C
10^{-1}	deci	D

Standard definition of base units:

Meter:

The distance traveled by light in vacuum during a time of 1/299,792,458 second.

Kilogram:

The mass of a platinum (90%) and iridium (10%) alloy cylinder, 3.9 cm in diameter and

3.9 cm in height, kept at the International Bureau of Weights and Measures in France.

Second:

One second equal to the duration in which the outer most electron of the cesium-133 atom makes 9,192,631,770 vibrations

Kelvin:

It is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The triple point of water is taken as 273.16 K.

Ampere:

It is that constant current which if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section and placed a meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

Candela:

The luminous intensity in the perpendicular direction of a surface of 1/600000 square meter of a black body radiator at the solidification temperature of platinum under standard atmospheric pressure.

Mole:

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12. One mole on any substance contains 6.0225×10^{23} entities.

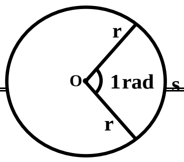
For Your Information	
$1\,\overset{\circ}{A} = 10^{-10}$ m	1″(inch) = 2.54 cm
1X-ray unit (1 XU) = 10^{-13} m	1 astronomical unit (1 AU) = 1.49×10^{11} m
1 yard = 3 foot = 0.9144 m	1 light year (1 *ly*) = 9.46×10^{15}m
1 parsec (1 pc) = 3.08×10^{16} m = 3.26 *ly*	1 foot = 30.48 cm

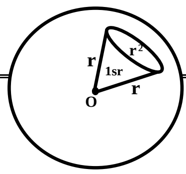
Supplementary Quantities

For the time being this class contains only two units of purely geometrical quantities, which are plane angle and the solid angle.

Sr #	Supplementary Quantity	SI Unit	Unit Symbol	Dimensions
1	Plane angle	radian	rad	$[M^oL^oT^o]$
2	Solid angle	Steradian	sr	$[M^oL^oT^o]$

Radian	Steradian
If arc length = radius, then	If area of surface of sphere = r^2, then





$\theta = \frac{s}{r}$ (rad) $\boldsymbol{\theta = 1}$ **rad**	Solid angle = $\frac{\text{surface area}}{r^2}$ (sr) Solid angle = 1 sr
For the angle subtended by the complete circumference of circle $S = 2\pi r$ $\theta = \frac{2\pi r}{r}$ (rad) $\boxed{\theta = 2\pi \text{ rad}}$	For the angle subtended by the complete surface area of sphere; Surface area = $4\pi r^2$ Solid angle $= \frac{4\pi r^2}{r^2}$ (sr) $\boxed{\text{Solid angle} = 4\pi \text{ sr}}$

Derived Quantities

Those physical quantities whose definitions are based on the other physical quantities are called derived quantities.

Examples:

Velocity, acceleration, force, work, momentum and volume etc.

Conventions for indicating Units

i) Full name should be written with small letters even if it is the name of a scientist. Example: newton, henry

ii) Symbol of unit has initial letter capital if it is the name of scientist otherwise not. Example: N, Pa, W, K, A

> **Caution**
> candela and steradian are not the name of scientists.

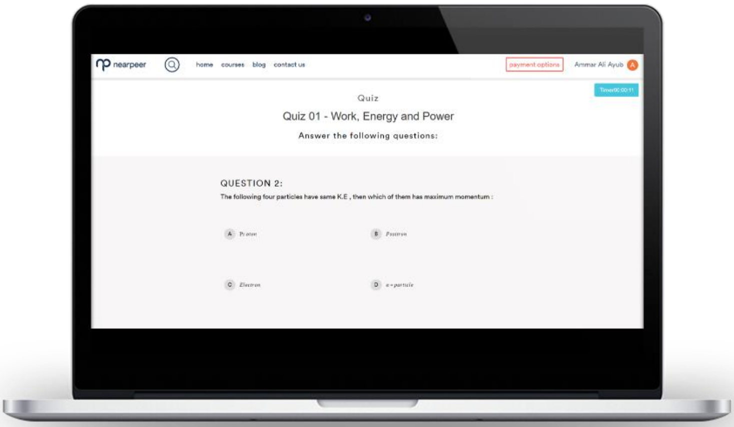
iii) Combination of prefixes are not allowed i.e.,

- 1 μμF (×)
- 1 pF (✓)

iv) When a multiple of a base unit is raised to a power, the power applies to the whole multiple and not the base unit alone. Thus $1\ mm^2 = 1\ (mm)^2 = 1 \times 10^{-6}\ m^2$

v) A combination of base units is written each with one space apart. For example, newton meter is written as N m.

PRACTICE QUESTIONS



Q6. An ideal standard has two principal characteristics. It is

A) Accessible and variable B) Inaccessible and variable
C) Inaccessible invariable D) Accessible and invariable

Q7. Standard kg is an alloy cylinder having

A) 90% Ir, 10% pt B) 20% pt, 80% Ir
C) 10% Ir, 90% Pt D) 20% Ir, 80% pt

Q8. Light travels a distance of ________ meters in one second.

A) 1/299, 792, 458 B) 299, 792, 458
C) 299, 792, 548 D) 1/299, 792, 548

Q9. Unit of power in terms of base units

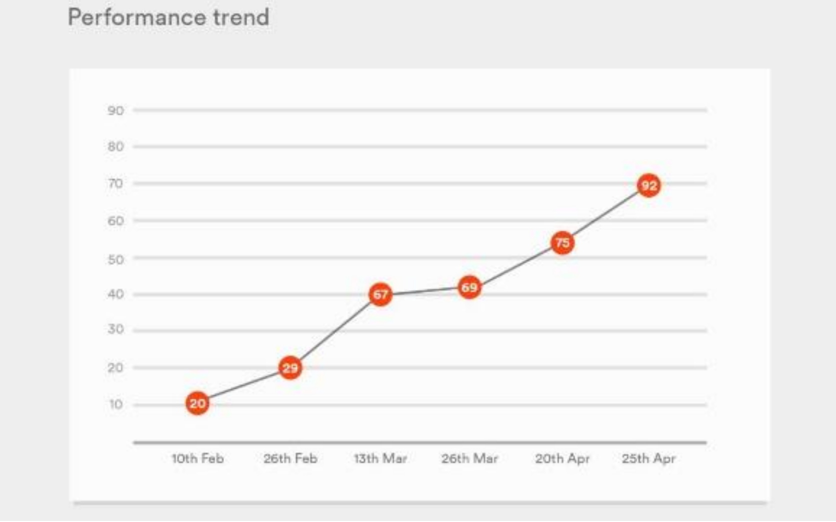
A) watt B) J/s
C) kgm^2s^{-3} D) kgm^2s^{-2}

Q10. The physical quantity which can be written in terms of just two different SI base units

A) Velocity B) Area
C) Angular acceleration D) All

Q11. Which of the following pairs have not the same units?

A) Torque and angular momentum B) Young's modulus and pressure
C) Torque and work D) Work and energy



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Answers with explanation

Q6. **(D).** A standard should be accessible i.e. it is practically available and also it should be invariable i.e. not varying and is a fixed one.

Q7. **(C).**

Q8. **(B).**

Q9. **(C).** $\text{watt} = \frac{J}{s} = \frac{N\,m}{s} = \frac{(kgms^{-2})m}{s} = kgm^2s^{-3}$

Q10. **(A).** "Two different SI base" are keywords. So the option fulfilling all conditions is A

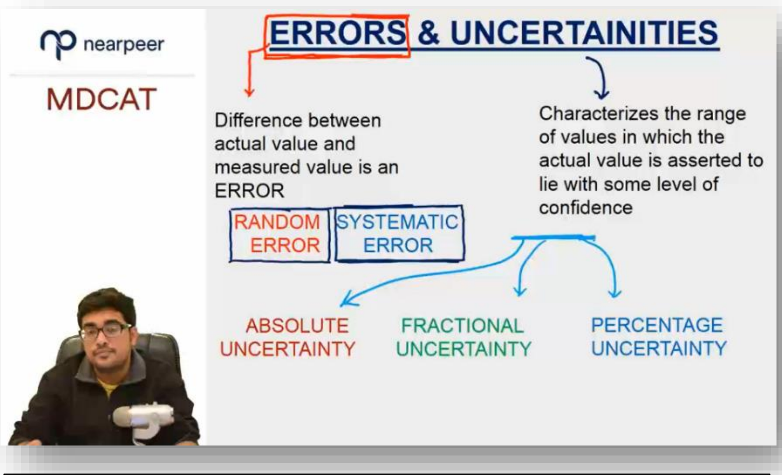
Q11. **(A).**

Q12. **(A).** kilowatt is a unit of power. Where 1 erg = 10^{-7} J and 1 kWh = 3.6×10^6 J.

Errors and Uncertainties

No	Random Error	Systematic Error
1	Repeated measurements of the quantity give different values under the same conditions.	Is the effect that influences all measurements of a physical quantity equally.
2	High fluctuations in reading	Produce consistent difference in reading
3	Its causes are unknown	Causes are known i.e., may be zero error, poor calibration, incorrect marking etc.

4	Repeating the measurements several times and then taking an average can reduce this error.	Can be reduced by comparing the instrument with another instrument which is more accurate or by applying zero correction.



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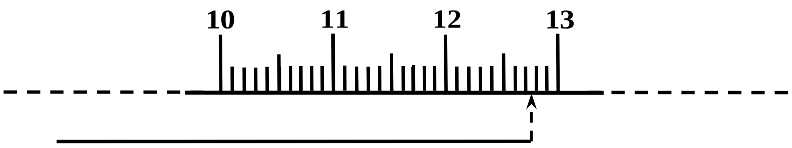
Significant Figures

Length of line measured by students;



12.7 cm (Measured by 50% students)

12. 8 cm (Measured by 50% students)

- In the above measurement, the first two digits are accurately known while the third digit is doubtful digit because there is an uncertainty in it.

Definition:

In any measurement, the accurately known digits and the first doubtful digit are the significant figures (S.F)

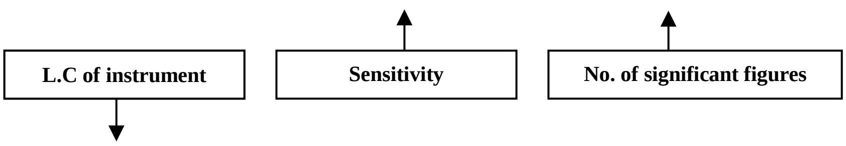
If the same measurement is taken with Vernier calipers, then the results may be

12.75 cm (Measured by 50% students)

12.76 cm (Measured by 50% students)

- In the above measurement, first three digits are accurately known while the fourth digit is doubtful digit so the significant figures have increased up to four.

Conclusion:



Precision and Accuracy

- **Precision** is determined by **least count (L.C)** of instrument or of its **absolute uncertainty.**
- **Accuracy** is concerned with **% age uncertainty** or **fractional uncertainty** in that measurement

Measurement M_1 taken with Meter rod	Measurement M_2 taken with Vernier calipers	Measurement M_3 taken with Screw gauge
$M_1 = 25.0 \text{ cm} \pm 0.1 \text{ cm}$	$M_2 = 0.50 \pm 0.01 \text{ cm}$	$M_3 = 0.500 \pm 0.001 \text{ cm}$
Absolute uncertainty = ± 0.1 cm % age uncertainty = $\frac{0.1\text{ cm}}{25.0\text{ cm}} \times \frac{100}{100}$ % age uncertainty = 0.4 %	Absolute uncertainty = ± 0.01 cm % age uncertainty = $\frac{0.01\text{ cm}}{0.50\text{ cm}} \times \frac{100}{100}$ % age uncertainty = 2 %	Absolute uncertainty = ± 0.001 cm % age uncertainty = $\frac{0.001\text{ cm}}{0.500\text{ cm}} \times \frac{100}{100}$ % age uncertainty = 0.2 %

Results of Above Measurements

Precision: $M_3 > M_2 > M_1$

Accuracy: $M_3 > M_1 > M_2$

M_2 is least accurate because 0.50 cm is a very small measurement and demands more precise instrument i.e., micrometer screw gauge not Vernier calipers.

Conclusion:

A **precise** measurement is one which has **less absolute uncertainty** and an **accurate** measurement is one which has **less % age error** or **fractional uncertainty.**

The **smaller** the **physical quantity**, the more **precise instrument** should be used.

Assessment of total uncertainty in final result

Addition and Subtraction:

Absolute uncertainties are added. For example, we have two measurements X_1 and X_2

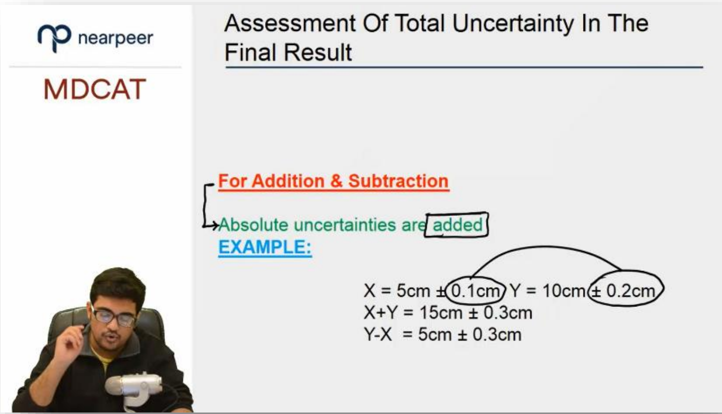
$X_1 = 5.2 \text{ cm} \pm 0.1 \text{ cm}$

$X_2 = 7.2 \text{ cm} \pm 0.2 \text{ cm}$

The final result is obtained by adding the absolute uncertainties

$X = X_2 - X_1 = (7.2 - 5.2) \pm 0.3 \text{ cm}$

$\boxed{X = 2.0 \pm 0.3 \text{ cm}}$



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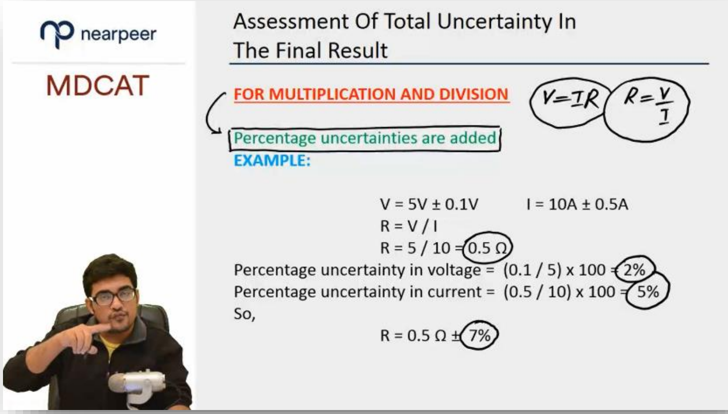
Multiplication and Division:

% age uncertainties are added. For example, from the measurements of voltage and current to find the resistance using the formula R = V/I

$$V = 5.0 \pm 0.1 \text{ V}$$

$$I = 1.00 \pm 0.05 \text{ A}$$

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



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% age uncertainty of $R = \left(\frac{0.1 \text{ V}}{5.0 \text{ V}} \times 100\ \%\right) + \left(\frac{0.05 \text{ A}}{1.00 \text{ A}} \times 100\ \%\right)$

% age uncertainty of R = (2%) + (5%) = 7%

So, $R = \frac{5.0 \text{ V}}{1.00 \text{ A}} = 5.0\ \Omega$ with 7% uncertainty

Absolute uncertainty in resistance $= \pm \frac{5.0\ \Omega \times 7}{100} = 0.35\ \Omega$

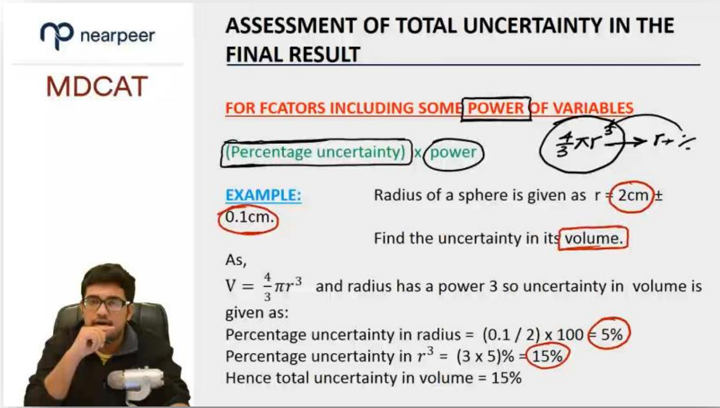
$$\boxed{R = 5.0\ \Omega \pm 0.4\ \Omega}$$

Power Factor:

Multiply the percentage uncertainty by that power. To find the volume of sphere we require the radius measured with the help of Vernier calipers. If r = 2.00 ± 0.01 cm

For volume

$$\text{Vol} = \frac{4}{3}\pi r^3$$



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% age uncertainty in Vol. = 3(% age uncertainty of r)

% age uncertainty in Vol. $= 3\left(\frac{0.01 \text{ cm}}{2.00 \text{ cm}} \times 100\%\right) = 3(\ 0.5\ \%\ ) = 1.5\ \%$

So, $V = \frac{4}{3}\pi\,(2.00 \text{ cm})^3 = \frac{32 \times 3.14}{3} \text{ cm}^3 = 33.49 \text{ cm}^3$ with 1.5% uncertainty

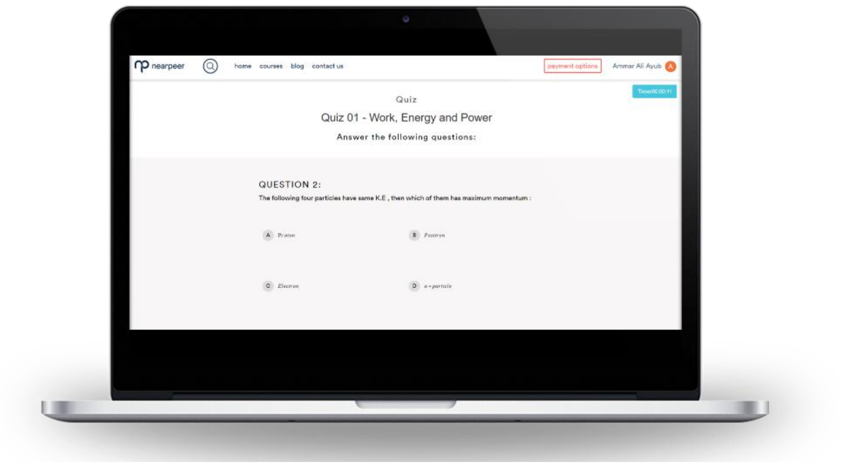
For Uncertainty in the Average Value of Many Measurements:

In the average of many measurements, the uncertainty is equal to **mean of deviations.**

For Timing Experiments:

$$\text{Timing uncertainty} = \frac{\text{Least count of stop watch}}{\text{Number of vibrations}}$$

PRACTICE QUESTIONS



Q13. A precise measurement is one which has

A) High precision   B) Low precision
C) Maximum percentage uncertainty   D) Both B and C

Q14. A student takes 100 observations in an experiment. Second time he takes 500 observations in the same experiment. By doing so the possible error becomes

A) 5 times greater   B) 1/5 times lesser
C) 10 times greater   D) 1/10 times lesser

Q15. Density of a liquid is 13.6 g cm^{-3}. Its value in SI units is

A) 136.0 kg m^{-3} B) 13600 kg m^{-3}
C) 13.6 kg m^{-3} D) 1.36 kg m^{-3}

Q16. The density of a cube is measured by measuring its mass and the length of its side. If the maximum errors in the measurement of mass and length are 3% and 2%, respectively, then maximum error in the measurement of density is

A) 1 %   B) 5 %
C) 7 %   D) 9 %

Q17. **While measuring acceleration due to gravity by a simple pendulum, a student makes a positive error of 1 % in the length of the pendulum and a negative error of 3 % in the value of time period. The percentage error in the measurement of g is**

A) 2 % B) 4 %

C) 7 % D) 10 %

Q18. **If the error in the measurement of radius of a circle is 1 % then the error in the measurement of its area will be**

A) 1.0 % B) 2 %

C) 1.5 % D) 3 %

Q19. **The radius of a wire is 0.24 mm. Then its area of cross-section by taking significant figures into consideration is**

A) 0.19 mm^2 B) 0.190 mm^2

C) 0.18 mm^2 D) 0.180 mm^2

Q20. **The length, breadth and thickness of a block is measured to be 50 cm; 2.0 cm and 1.00 cm. The percentage error in the measurement of volume is**

A) 0.8 % B) 8 %

C) 10 % D) 12.5 %

Q21. **To reduce the timing uncertainty, it is advisable to**

A) Count for smaller number of swing

B) Count for larger number of swing

C) Use a stop watch which is less sensitive

D) Both 'A' and 'C'

Q22. **Which one of the following about systematic error is incorrect?**

A) It influences all the measurement of a physical quantity equally

B) It produces consistent difference in reading

C) It can be reduced by comparing the instrument with standard instrument

D) It always occurs due to incorrect marking

Q23. **In an electrical circuit, the current in a resistor is measured as (2.50 ± 0.05) mA. The resistor is marked as 4.7 Ω ± 2%. What would be the %age uncertainty in power dissipation in resistor?**

A) 2% B) 4%

C) 6% D) 8%

Q24. **Which one of the following measurement is more accurate?**

M_1 = 1.0 cm ± 0.1 cm **M_2 = 0.10 cm ± 0.01 cm** **M_3 = 0.100 cm ± 0.001 cm**

A) M_1 B) M_2

C) M_3 D) All have same accuracy

Q25. **The distance $x = x_2 - x_1$ determined by the difference between two separate position measurements x_1 = 12.2 ± 0.2 cm and x_2 = 16.2 ± 0.1 cm is recorded as**

A) 4.0 ± 0.2 cm B) 4.0 ± 0.1 cm

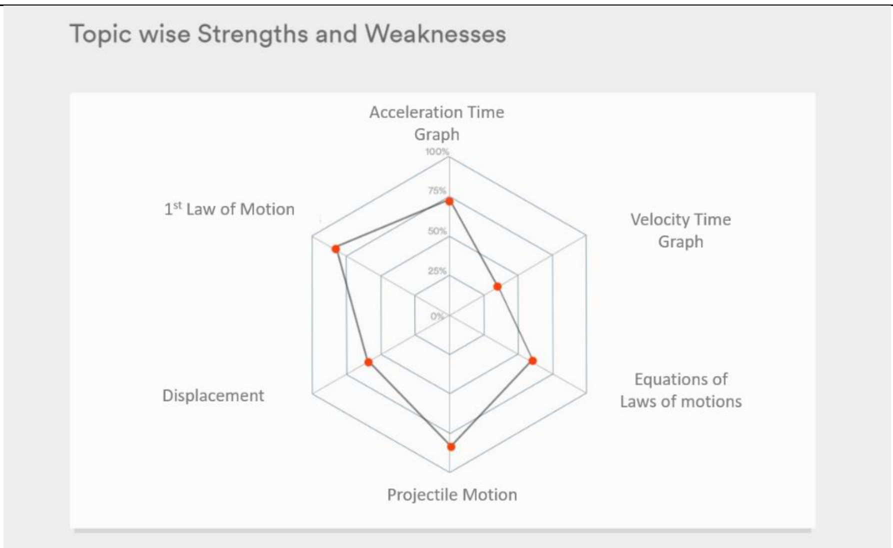
C) 4.0 ± 0.3 cm D) 4.0 ± 0.4 cm

Q26. Three students measured the length of the same needle. Student A measured with micrometer screw gauge, B with Vernier calipers and C with meter rod. Which would have greater experimental accuracy of the result?

A) Student A
B) Student B
C) Student C
D) All have same experimental accuracy

Q27. Instrumental error is

A) Random error
B) Systematic error
C) Both
D) None



Answers with explanation

Q13. (A). More precise measurement is one which is taken with an instrument which has high precision or less least count.

Q14. (B). Possible error has decreased due to the increase in the number of observations.

$$\text{Reduction in the possible error } = \frac{\text{Error in 100 observations}}{\text{Error in 500 observations}} = \frac{1}{5}$$

Q15. (B) $13.6\,\text{g/cm}^3 = 13.6 \times 10^{-3} \times 10^{3} \dfrac{\text{g}}{10^{-6}\,\text{m}^3} = 13.6 \times 10^3\,\text{kg/m}^3$

Q16. (D).

$\rho = \frac{m}{l^3}$; % age unc. of ρ =(% unc. of mass) +3(% unc. of l) =(3%) +3(2%) =9%

Second method; $\frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} + \frac{3\Delta l}{l} \Rightarrow \%\text{unc.} = \frac{\Delta\rho}{\rho} \times 100 = 3 + 3(2) = 9\%$

Q17. (C). $g = \frac{4\pi^2 l}{T^2}$; %unc. in g = (%unc. of l) + 2(% unc. of T) = (1%) + 2(3%) = 7%

Second method; $\%\ \text{error} = \left(\frac{\Delta g}{g}\right) \times 100 = 1 - 2(-3) = 7\%$

Q18. (B). $A = \pi r^2$; %unc. in A = 2(%unc. of r) = 2(1%) = 2%

Q19. (C). Area of cross-section = $\frac{22}{7} \times 0.24 \times 0.24\,\text{mm}^2 = 0.18\,\text{mm}^2$

Q20. (B). % age error = (% age error in *l*) + (% age error in b) + (% age error in t)

% error in Vol = $(\frac{1}{50} \times 100\%) + (\frac{0.1}{2.0} \times 100\%) + (\frac{0.01}{1.00} \times 100\%) = 2\% + 5\% + 1\% = 8\%$

Q21. (B). Timing unc. $= \frac{\text{L.C of stop watch}}{\text{No. of swings}}$; for smaller timing unc. number of swing should be greater

Q22. (D). Systematic error may occur due to poor calibration, incorrect marking or limitation of instrument

Q23. (C). As $P = I^2 R$; so,

%unc. of P = 2(%unc. of I) + (% unc. of R) = $2(\frac{0.05}{2.50} \times 100\%)$ + (2%) = 2(2%) + 2% = 6%

Q24. (C). % age unc. of $M_1 = \frac{0.1}{1.0} \times 100\% = 10\%$

% age unc. of $M_2 = \frac{0.01}{0.10} \times 100\% = 10\%$

% age unc. of $M_3 = \frac{0.001}{0.100} \times 100\% = 1\%$; So, M_3 is most accurate

Q25. (C). $x = x_2 - x_1$ = (16.2 – 12.2) ± 0.3 cm = 4.0 ± 0.3 cm

Q26. (A). Smaller is the least count of instrument greater would be the experimental accuracy.

Q27. (B). Instrumental error is the systematic error.

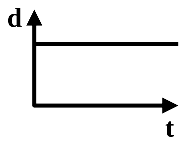
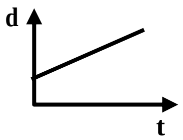
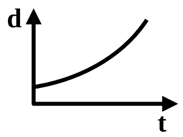
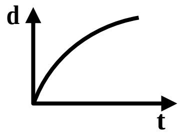
UNIT 02

Motion and Force

Displacement – Time Graph

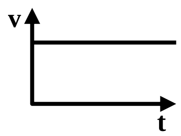
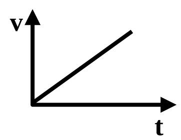
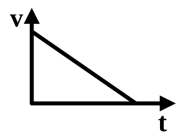
Some Typical Displacement-time Graphs:

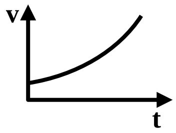
The **slope of the displacement-time graph** at any instant gives the **velocity** of the particle at that instant.

Displacement-time Graph	Velocity of Body	Slope of Graph
	The graph is a straight line parallel to the time axis, i.e., displacement does not change with time. Hence the body is at rest and velocity is zero.	Slope is zero so velocity is zero.
	The graph is a straight line inclined to the time axis. Thus $\Delta d/\Delta t$ is constant and hence the particle moves with a constant velocity and acceleration is zero.	Slope is constant so velocity is uniform and acceleration is zero.
	$\Delta d/\Delta t$ and hence the velocity increases with time so acceleration is positive.	Slope is increasing so velocity is increasing and acceleration is positive.
	$\Delta d/\Delta t$ and hence the velocity decreases with time and acceleration is negative.	Slope is decreasing so velocity is decreasing and acceleration is negative.

Some Typical Velocity-Time Graphs:

The slope of the velocity-time graph at any instant gives the acceleration of the particle at that instant.

Velocity-time Graph	Acceleration of Body	Slope of Graph
	The graph is a straight line parallel to the time axis, i.e., velocity does not change with time. Hence acceleration is zero.	Slope is zero so acceleration is zero.
	The graph is a straight line inclined to the time axis. Thus $\Delta v/\Delta t$ is constant and hence the body moves with a constant acceleration.	Slope is constant so acceleration is uniform.
	Velocity deceases linearly with time hence acceleration is negative and uniform.	Slope is negative so acceleration is negative.

	Δv/Δt and hence the acceleration is increasing and is variable	Slope of graph is increasing so acceleration is increasing

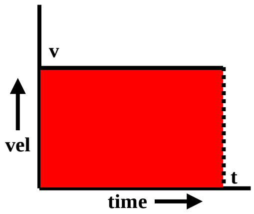
Distance as Area under Velocity -Time Graph:

The area between the velocity-time graph and the time axis is numerically equal to the distance covered by the object.

Example 1

Figure shows that the area of the graph is

$$\text{Area} = v \times t \quad \rightarrow \quad \text{(i)}$$



And distance covered is

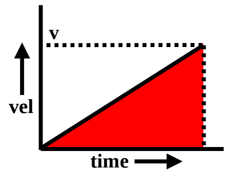
$$S = v_{av} \times t = \frac{v+v}{2} \times t = \frac{2v}{2} \times t = v \times t \rightarrow \text{(ii)}$$

From (i) and (ii) it is clear that area under v-t graph is numerically is equal to the distance covered by the moving body.

Example 2

Figure shows that the area of the graph is

$$\text{Area} = \frac{1}{2}(\text{base})(\text{height}) = \frac{1}{2}(t)(v) = \frac{1}{2}vt \rightarrow \text{(i)}$$



And distance covered is

$$S = v_{av} \times t = \frac{0+v}{2} \times t = \frac{v}{2} \times t = \frac{1}{2}vt \rightarrow \text{(ii)}$$

From (i) and (ii) it is clear that area under v-t graph is numerically is equal to the distance covered by the moving body.

Equations of Uniformly Accelerated Motion:

$$v_f = v_i + at \rightarrow \text{(i)}$$

$$S = \left(\frac{v_i + v_f}{2}\right) \times t \rightarrow \text{(ii)}$$

$$S = v_i t + \frac{1}{2}at^2 \rightarrow \text{(ii)}$$

$$2aS = v_f^2 - v_i^2 \rightarrow \text{(iii)}$$

Caution

- If the acceleration is constant both in magnitude and direction, only then the above equations are applicable.
- The above equations are not applicable to simple harmonic motion or circular motion.

Vertical Motion Undre Gravity

If a body is moving vertically downwards or upwards, it experiences a downward acceleration due to the gravitational force of the earth. This is called acceleration due to gravity and is denoted by the symbol **g**. Strictly speaking g is not a constant, but varies from place to place on the surface of the earth and also with height. However, the variation of **g** is so small that it can be neglected and **g** can be considered a constant unless very large heights are involved.

Its value near the surface of earth is 9.8 ms^{-2} which means that if a body is falling freely under the action of gravity, the change in its velocity after each second will be 9.8 ms^{-1}.
Mathematically;

$$g = \frac{\Delta v}{\Delta t} = \frac{9.8\,ms^{-1}}{1\,s} = 9.8\,ms^{-2}$$

For downward motion **g** is taken positive and vice versa.

When body is thrown vertically upwards:

If a body is thrown upwards with a velocity v_i, then neglecting the effect of air friction, the following results can be obtained using the equations of motion,

Maximum Height Attained $\quad h = \frac{v_i^2}{2g}$

Time to reach the Highest Point $\quad t_1 = \frac{v_i}{g}$

Total Time of Flight $\quad t = \frac{2v_i}{g}$

Speed with which the body hits the ground $\quad v_f = v_i$

When body is dropped from certain height:

When body is dropped from certain height h, $v_i = 0$

Time taken to reach the ground $\quad t = \sqrt{\frac{2h}{g}}$

Velocity with which the body reaches the ground $v = \sqrt{2gh}$

Newton Laws of Motion

1st Law of Motion	2nd Law of Motion	3rd Law of Motion
In the absence of unbalanced external force no acceleration is produced.	When a force is applied on a body acceleration is produced which is directly proportional to the force an inversely proportional to the mass of body and is also directed towards the unbalanced external force.	When bodies interact, they exert equal and opposite impulses
Mathematically; If $\vec{F} = 0$ then $\vec{a} = 0$	Mathematically, $\vec{a} \propto \frac{\vec{F}}{m} \Rightarrow \vec{a} = (1)\frac{\vec{F}}{m}$ $\vec{F} = m\vec{a}$	Mathematically, $\vec{F}_{12} = -\vec{F}_{21}$ $\vec{F}_{12} \times t = -\vec{F}_{21} \times t$ $\vec{I}_{12} = -\vec{I}_{21}$
It is also called law of inertia and it gives qualitative definition of force.	It provides quantitative measure of force.	It implies that forces always occur in pairs
• Mass is the quantitative measure of inertia.		

Momentum

The product of mass (m) and velocity $(\vec{v})$ of the body is called linear momentum. i.e., $\vec{p} = m\vec{v}$

The momentum is a vector quantity and it has the same direction as that of velocity. If two bodies have equal speeds but different directions, then they will have different momenta.

The SI units of momentum are kg ms^{-1} or N s.

(i) $p \propto v$ if m is constant, i.e., for bodies of equal mass, momentum will be maximum for a body having largest velocity.

(ii) (ii) $p \propto m$ if v is kept same, i.e., the heaviest body will have maximum momentum if the bodies have same velocity.

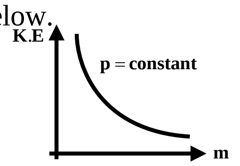
(iii) If p = constant then $v \propto \frac{1}{m}$., i.e., for bodies having same momentum the lightest body will have maximum velocity and hence maximum K.E.

Relation between Momentum (p) and Kinetic Energy (K.E):

$$K.E = \frac{1}{2}mv^2 \quad \Rightarrow \quad 2K.E = mv^2 \quad \Rightarrow \quad 2m\,K.E = m^2v^2$$

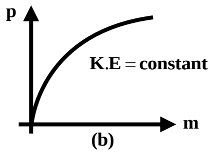
$$\boxed{p = \sqrt{2m\,K.E}} \quad \text{and} \quad \boxed{K.E = \frac{p^2}{2m}}$$

(i) If p = constant then $K.E \propto \frac{1}{m}$ i.e., lightest body will have maximum K.E if the bodies have equal momentum. See fig. (a) below.



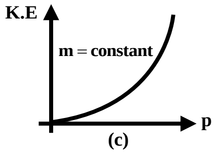
(a)

(ii) If K.E of some bodies is equal then the heaviest one will have maximum momentum i.e., $p \propto \sqrt{m}$. See fig. (b) below.



(b)

(iii) If m is constant then $p \propto \sqrt{K.E}$. See fig. (c) below.



(c)

Note

- $p = \frac{h}{\lambda}$ for a particle wave and $p = \frac{E}{c}$ for photons

Newton's 2nd Law in terms of Momentum:

The time rate of change of linear momentum of a body is equal to the applied force.

Mathematically; $\boxed{\vec{F} = \frac{\Delta \vec{p}}{t}}$

Impulse:

When a large force acts on the body for a very short interval of time then the product of average of the force and the time duration for which this force acts on a body is called impulse.

Mathematically;
$$\vec{F} = \frac{\Delta \vec{p}}{t}$$
$$\vec{F} \times t = \Delta \vec{p}$$
$$\vec{I} = \Delta \vec{p}$$

Impulse is a vector quantity and its direction is same as that of force $\vec{F}$ or change in momentum. In SI system, the units of impulse are N s. The impulse and momentum has same dimension i.e. $[MLT^{-1}]$.

Examples:

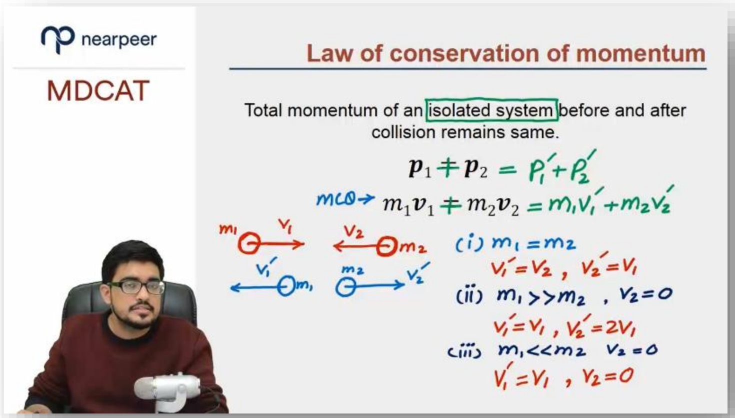
(i) A motorcycle's safety helmet is padded so as to extend the time of any collision to prevent serious injury.

(ii) Your hair acts like a crumple zone on your skull. A force of 5 N might be enough to fracture your naked skull (cranium), but with a covering of skin and hair, a force of 50 N would be needed.

(iii) A wicket keeper moves his hands backwards while catching a ball to increase the time of collision and decrease the force on the hands.

(iv) The thermophore pieces are placed inside the dinner sets to protect the cups and other items from breaking because they increase time of collision thus reducing the force while jerking.

Laws of Conservation of Momentum



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 1.01)

The total linear momentum of an isolated system remains constant.

or

Total initial momentum of the system before collision is equal to the total final momentum of the system after collision.

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$$

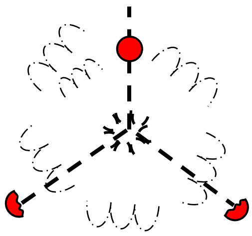
or

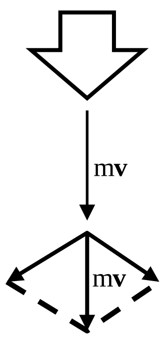
If $\vec{F}_{ext} = 0$ then $\Sigma \vec{p}_i =$ constant, i.e. linear momentum of various particles may change but their vector sum remains unchanged.

Momentum and Explosive Forces:

(i) The explosive force changes the momentum within an isolated system but total momentum of the system remains constant. When a bomb explodes in mid-air, its fragments fly off in different directions but the total momentum of all its fragments is equal to the initial momentum of the bomb.

(ii) When a bullet is fired from a gun, then the momentum of the





gun is equal and opposite to that of bullet. Since, mass of gun is much greater than the bullet, therefore the gun moves back or recoils only a fraction of the velocity of the bullet. Mathematically; $M\mathbf{v}' = -m\mathbf{v}$ $\mathbf{v}' = \frac{-m\mathbf{v}}{M}$

Caution

When the bullet is fired from a gun then the momenta of bullet and gun are equal but their velocities and K.Es are not equal.

$p_{(bullet)} = p_{(gun)}$ but $K.E_{(bullet)} > K.E_{(gun)}$ and $v_{(bullet)} > v_{(gun)}$

Motion of two Masses Connected to a Spring:

Assume spring is massless with two masses m_1 and m_2 attached to its ends. The spring is compressed so that $F_{ext} = 0$

$\therefore \vec{p}_1 + \vec{p}_2 = 0$ or $\mathbf{p_2} = \mathbf{p_1}$

$|\vec{p}_1| = |\vec{p}_2| \therefore \frac{K.E_1}{K.E_2} = \frac{m_2}{m_1}$, i.e., lighter block moves faster or has more K.E when released.

Formula for Common Velocity when two Masses Collide:

A body of mass M moving with velocity v_1 collides with another body of mass m moving with velocity v_2. The two bodies move together after the collision. Their common velocity will be,

$$Mv_1 + mv_2 = Mv + mv$$
$$Mv_1 + mv_2 = Mv + mv$$
$$(M+m)v = Mv_1 + mv_2$$
$$v = \frac{Mv_1 + mv_2}{(M+m)} \Rightarrow \boxed{\text{Common Velocity} = \frac{\text{Total momentum}}{\text{Total mass}}}$$

Force due to Water Flow:

When water from a horizontal pipe strikes a wall normally, a force is exerted on the wall. The force exerted by water on wall is given by

$$F = \left(\frac{m}{t}\right) v = \text{Mass of water flowing per second} \times \text{change in velocity}$$

Example

A hose pipe ejects water at a speed of 0.3 ms^{-1} through a hole of area 50 cm^2. If the water strikes a wall normally, calculate the force on the wall, assuming the velocity of the water normal to the wall is zero after striking.

Solution

The shortcut formula used is

$$F = \rho A v^2$$
$$F = (1000)\,(50\times10^{-4})\,(0.3)^2 = 0.45\ \text{N}$$

Rocket Propulsion:

The rocket moves according to law of conservation of linear momentum. The rocket gains momentum equal to the momentum of the gases expelled from the engine but in opposite direction. A rocket carries its own fuel in the form of a liquid or solid and oxygen. A typical rocket consumes about 10,000 kgs^{-1} of fuel and ejects the burnt gases at speeds of over 4000 ms^{-1}. In fact, more than 80% of the launch mass of a rocket consists of fuel only.

If m is the mass of the gases ejected per second with velocity **v** relative to the rocket, the force (thrust) acting on the rocket will be

$$\mathbf{F} = \frac{\Delta p}{t}$$

As $\Delta p = mv$ and $t = 1$ second so,

$$\mathbf{F} = m\mathbf{v}$$

This force (thrust) is acting on the rocket of mass M and produces acceleration a, i.e.,

$$M\mathbf{a} = m\mathbf{v}$$

$$\boxed{\mathbf{a} = \frac{m\mathbf{v}}{M}}$$

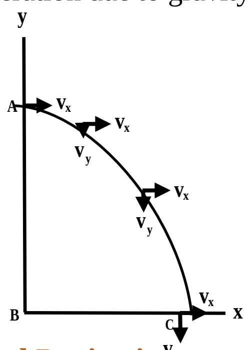
When the fuel in the rocket is burned and ejected, the **mass M decreases** and hence the **acceleration of the rocket increases**.

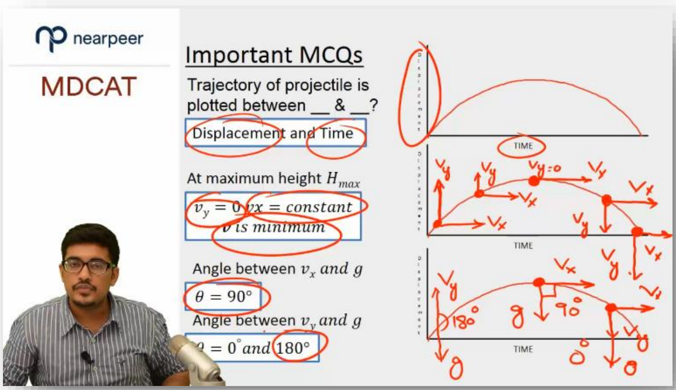
Projectile Motion

Projectile motion is two dimensional motion under constant acceleration due to gravity.

Trajectory of Projectile:

The path followed by the projectile is known as trajectory of projectile. The trajectory of projectile is parabolic when aerodynamic forces and air friction are negligible.





Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 2.03)

Horizontal Projection:

If the projectile is thrown horizontally with velocity v_x,

then its horizontal distance will be

$$\boxed{x = v_x \times t}$$

The vertical distance y of the projectile in time t is

$$\boxed{y = \frac{1}{2} g t^2}$$

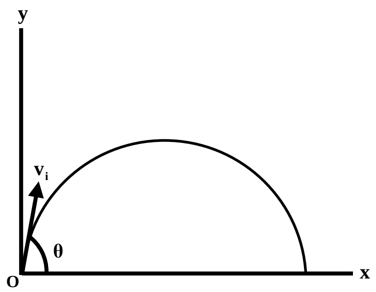
<u>Points to Remember</u>

1. In projectile motion the horizontal component of velocity remains constant throughout the motion hence $\mathbf{a_x = 0}$.
2. In horizontal projectile the **vertical component** of velocity increases throughout the motion hence $a_y = g$.
3. The vertical motion of projectile is same as for freely falling body.

Oblique Projection:

If the projectile is projected with initial velocity v_i at an angle θ with horizontal, then the horizontal component of velocity of projectile at any instant time t will be

$$v_{fx} = v_{ix} = v_i \cos\theta$$



The vertical component of velocity of projectile at any instant time t will be

$$v_{fy} = v_i \sin\theta - gt$$

The magnitude of velocity at any instant is

$$v = \sqrt{v_{fx}^2 + v_{fy}^2}$$

The angle ϕ which the resultant velocity makes with the horizontal at any instant can be found from

$$\phi = \tan^{-1}\left(\frac{v_{fy}}{v_{fy}}\right)$$

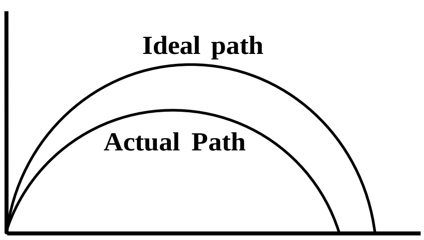
The horizontal displacement of the projectile after time t

$$x = v_i \cos\theta \times t$$

The vertical displacement of the projectile after time t

$$y = (v_i \sin\theta)t - gt$$

For your information



In the presence of air friction the trajectory of a high speed projectile fall short of a parabolic path.

Height of the Projectile:

The maximum height of the projectile is

$$h = \frac{v_i^2 \sin^2\theta}{2g}$$

Time to reach the Maximum Height:

The time to reach maximum height of a projectile is

$$t' = \frac{v_i \sin\theta}{g}$$

Time of Flight:

The time of flight of a projectile is

$$t = \frac{2v_i \sin\theta}{g}$$

Range of Projectile:

The range of the projectile is

$$R = \frac{v_i^2}{g}(2\sin\theta\cos\theta) \Rightarrow R = \frac{v_i^2}{g}\sin 2\theta$$

Maximum Range of Projectile:

The range of the projectile is maximum at 45° so,

$$R_{max} = \frac{v_i^2}{g}\sin 2(45°) \Rightarrow R_{max} = \frac{v_i^2}{g}$$

Relation between Range and Maximum Range:

The relation between range and maximum range of projectile is

$$R = R_{max}(\sin 2\theta)$$

$$R_{max} = \frac{R}{\sin 2\theta}$$

Points to Remember

1. In oblique projectile the vertical component of velocity decreases with time upto the heighest point of trajectory and then begins to increase with time.
2. Projectile attains maximum range when angle of projection is $\theta = 45°$.
3. The horizontal range remains same for any two angles with the horizontal whose sum is 90° i.e, $\theta_1 + \theta_2 = 90°$
4. At the heighest point in oblique projectile the velocity and acceleration are at right angle to each other.
5. At the heighest point $v = v_x$ and $v_y = 0$ i.e., only horizontal component of a velocity exists at the heighest point.
6. The angle of projection of a projectile for which its maximum height and horizontal range are equal is 76°.
7. The relation between range and height of the projectile is $R \tan\theta = 4h$.
8. When a body is projected so that its horizontal range R is maximum then the maximum height attained by the projectile is $h = R/4$
9. For an angle less than 45°, the height reached by the projectile and the range both will be less. When the angle of projectile is large than 45°, the height attained will be more but the range is again less.

Ballistic Missile:

An un-powered and un-guided missile is called a ballistic missile. The path followed by the ballistic missile is called ballistic trajectory. The motion of ballistic missile is the superposition of two independent motions;

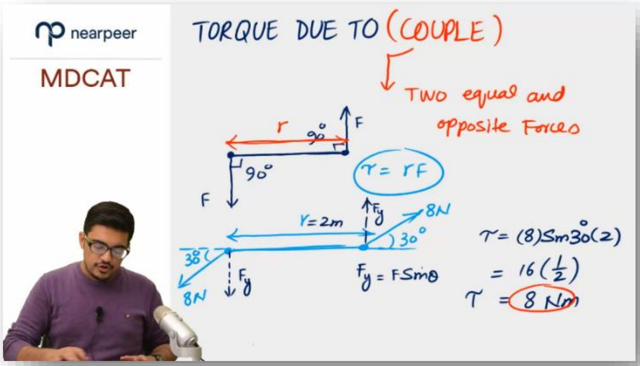
- **A straight line inertial motion along in the direction of launch.**
- **Vertical motion under the action of gravity**.

For short ranges and flat earth approximation, the trajectory is parabolic but the drag less ballistic trajectory for spherical earth should actually be elliptical. At high speed and for long trajectories, the air friction not negligible and sometimes the force of air friction is more than gravity. It affects both horizontal as well as vertical motions. Therefore, it is completely unrealistic to neglect the aerodynamic forces.

Application of Ballistic missiles:

The ballistic missiles are useful only for short ranges. For long ranges and greater precision, powered and remote control guided missiles are used.

Torque / Moment of Force



Turning effect of force is called torque.

Torque depends upon two factors

(i) Force

(ii) Moment arm

$\tau = l\,F$

Torque on a Rigid Body:

Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 2.6)

Force $\vec{F}$ acts on rigid body at point P whose position vector relative to pivot O is $\vec{r}$.

The component of force F sinθ is ⊥ to $\vec{r}$ and F cosθ is along the direction of $\vec{r}$. So, torque due to F cosθ about pivot O is zero. Magnitude of torque,

$$\tau = (F\sin\theta)(r) = r\,F\sin\theta$$

Alternative Way:

We can also resolve $\vec{r}$ into its rectangular components. In this case moment arm l = r sinθ, the magnitude of component of $\vec{r}$ perpendicular to the line of action of force. So,

$$\tau = (r\sin\theta)(F) = r\,F\sin\theta$$

Direction of Torque:

Direction of torque is ⊥ to the plane containing $\vec{r}$ and $\vec{F}$.

Torue as a counterpart of force in rotational motion

Force	Torque
Determines the linear acceleration produced in a body.	Determines the angular acceleration produced in a body.
The formula for force is $\vec{F} = m\vec{a}$ or $\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$	The formula for force is $\vec{\tau} = I\vec{\alpha}$ or $\vec{\tau} = \frac{\Delta \vec{L}}{\Delta t}$
If $\sum \vec{F} = 0$ then $\vec{a} = 0$	If $\sum \vec{\tau} = 0$ then $\vec{\alpha} = 0$
If $\sum \vec{F} = 0$ then $\vec{a} = 0$ → Rest → Uniform velocity ($\vec{v}$)	If $\sum \vec{\tau} = 0$ then $\vec{\alpha} = 0$ → Rest → Rotating with uniform angular velocity $\vec{\omega}$
If $\sum \vec{F} = 0$ then it is called translational equilibrium → Static → Dynamic	If $\sum \vec{\tau} = 0$ then it called rotational equilibrium → Static → Dynamic

Complete Equilibrium

$\sum \vec{F} = 0$ (**First condition** of equilibrium) and $\sum \vec{\tau} = 0$ (**Second condition** of equilibrium)

Centre of Mass (COM):

COM of a system is such a point where an applied force causes the system to move without rotation.

A force applied at COM moves the system without rotation. The system moves as well as rotates when the force is applied away from COM.

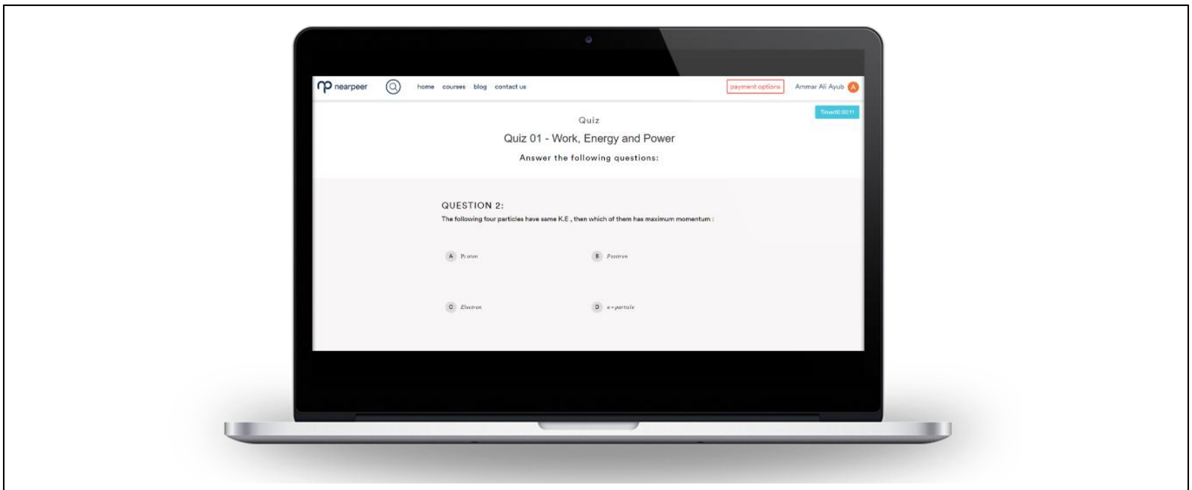
States of Equilibrium:

- **Stable equilibrium**
  - COM rises on slight displacement
  - P.E is minimum
- **Unstable equilibrium**
  - COM goes down on slight displacement
  - P.E is maximum
- **Neutral equilibrium**
  - COM does not change
  - P.E is constant or zero

Trignometric Ratios

Angles	0°	30°	45°	60°	90°
sin	$\frac{\sqrt{0}}{2}$	$\frac{\sqrt{1}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{4}}{2}$
	0	0.5	0.707	0.866	1
cos	$\frac{\sqrt{4}}{2}$	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{1}}{2}$	$\frac{\sqrt{0}}{2}$
	1	0.866	0.707	0.5	0
tan	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞

PRACTICE QUESTIONS



Q.1 A body is moving with uniform velocity. Its

A) Speed changes B) Acceleration changes

C) Direction of motion changes D) Displacement from origin changes

Q.2 Which law of motion is also called law of inertia?

A) 1^{st} law B) 2^{nd} law

C) 3^{rd} law D) All 1^{st}, 2^{nd} and 3^{rd} law

Q.3 Momentum depends upon

A) Force acts on the body
B) Mass of the body
C) Velocity of the body
D) Both mass and velocity of the body

Q.4 Motorcycle safety helmet extends the time of collision hence decreasing the

A) Change of collision
B) Force acting
C) Velocity
D) Impulse

Q.5 At maximum height on trajectory which of projectile becomes zero

A) Acceleration
B) Velocity
C) Vertical velocity
D) Horizontal velocity

Q.6 When car takes turn around a curve road, the passengers feel a force acting on them in a direction away from the center of the curve. It is due to

A) Centripetal force
B) Gravitational force
C) Their inertia
D) Centrifugal force

Q.7 Which of the following is not an example of projectile motion

A) A gas filled balloon
B) Bullet fired from gun
C) A football kicked
D) A baseball shot

Q.8 What is the angle of projection for which the range and maximum height become equal?

A) $\tan^{-1} 1/4$
B) $\tan^{-1} 4$
C) $\tan^{-1} 1/2$
D) $\tan^{-1} 2$

Q.9 Time rate of change of momentum is equal to

A) Force
B) Impulse
C) Velocity
D) Both A and C

Q.10 The angle of projection, at which the range of projectile would become half of its maximum value.

A) 45^o
B) 30^o
C) 15^o
D) 60^o

Q.11 Swimming is possible on account of

A) 1st law of motion
B) 2nd law of motion
C) 3rd law of motion
D) Newton's law of Gravitation

Q.12 If the momentum of a body changes from 100 N s to 200 N s in 10 s then the unbalance external force responsible to change the momentum is

A) 5 N
B) 2.5 N
C) 2 N
D) 10 N

Q.13 An object is projected with 10 ms^{-1} at angle of 60^o with the horizontal its range will be (Take g = 10 ms^{-2})

A) $5\sqrt{3}$ m
B) $10\sqrt{3}$ m
C) $\frac{\sqrt{3}}{5}$ m
D) None

Q.14 Velocity and acceleration are in the same direction when

A) Velocity of a car is increasing on a straight road

B) Velocity of a car is decreasing on a straight road

C) Car is turning round a corner

D) None of these

Q.15 When the average velocity of a moving body is equal to its instantaneous velocity then it is moving with

A) Uniform velocity
B) Variable velocity
C) Uniform acceleration
D) Variable acceleration

Q.16 To a person going east in a car with a velocity of $10ms^{-1}$, a train appears to move towards north with a velocity of $10\sqrt{3}$ ms^{-1}. The actual velocity of the train is

A) $10\ ms^{-1}$ northeast
B) $10\ ms^{-1}$ Northwest
C) $20\ ms^{-1}$ Northeast
D) $20\ ms^{-1}$ northwest

Q.17 A ball is projected at 45° and its horizontal range is 10 m. Velocity of projection is

A) $7\sqrt{3}\ ms^{-1}$
B) $15\ ms^{-1}$
C) $9.6\ ms^{-1}$
D) 7 $7\sqrt{2}\ ms^{-1}$

Q.18 The ratio of distance to magnitude of displacement along a semi-circle of radius r is

A) 2π
B) π
C) $\frac{\pi}{2}$
D) 3π

Q.19 The ratio of range to height at 45° is

A) 1 : 4
B) 1 : 2
C) 4 : 1
D) 2 : 1

Q.20 If h = R then angle of projection is

A) 45º
B) 76º
C) 60º
D) 90º

Q.21 Speedometer of an automobile measures

A) Average velocity
B) Instantaneous velocity
C) Acceleration
D) Instantaneous speed

Q.22 Two bodies are projected at angles θ and (90°–θ) with the horizontal at the same speed. The ratio of their maximum heights is

A) 1 : 1
B) 1 : tan θ
C) 1 : tan θ
D) tan^2 : 1

Q.23 An athlete completes one round of a circular track of radius R in 40 s. What will be displacement at the end of two minutes

A) 0
B) 2 R
C) R
D) $3\pi R$

Q.24 When the mass and speed of a body are doubled K.E of body would

A) Become 4 times B) Become 8 times

C) Become 6 time D) Remain unchanged

Q.25 When a fighter plane chasing another plane opens fire, its speed

A) Increases B) Remains same

C) Decreases D) First decreases then increases

Q.26 If two forces inclined at 120° with each other are acting on a body of mass m, then the acceleration produced in the body will be

A) $\frac{F}{m}$ B) $\frac{\sqrt{3}F}{m}$

C) $\frac{\sqrt{2}F}{m}$ D) $\frac{F^2}{m}$

Q.27 At the highest point on the trajectory of a projectile, its

A) Potential energy is minimum B) Kinetic energy is maximum

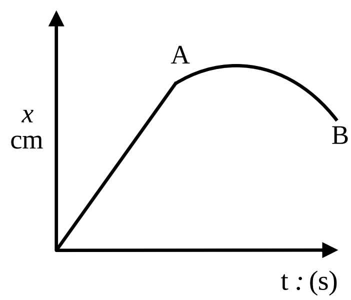
C) Total energy is maximum D) Kinetic energy is minimum

Q.28 If air is considered, then the maximum height achieved by the projectile

A) Decreases B) Increases

C) Remains same D) Very difficult to answer as no data provided

Q.29 Motion along A B is



A) Accelerated B) Retarded

C) Uniform velocity D) Circular

Q.30 If velocity time graph is a straight line parallel to time axis then body is

A) Moving with zero acceleration

B) Moving with constant velocity

C) Covering equal displacement in equal intervals of time

D) All of these

Q.31 Two masses of 1 g and 4 g are moving with equal kinetic energies. The ration of the magnitudes of their linear momenta is

A) 4 : 1 B) $\sqrt{2}:1$

C) 1 : 2 D) 1 : 16

Q.32 The momentum of particle is numerically equal to its kinetic energy. What is the velocity of the particle?

A) 9 ms^{-1} B) 3 ms^{-1}

C) 2 ms^{-1} D) 1 ms^{-1}

Q.33 The range of a projectile when launched at an angle of 15° with the horizontal is 1.5 m. its range, when launched at 45° with the same speed is

A) 3.0 m B) 1.5 m

C) 6.0 km D) 0.75 km

Q.34 A bomb of mass 12 kg, initially at rest, explodes into two pieces of masses 4 kg and 9 kg. Speed of the 8 kg mass is 6 ms^{-1} the kinetic energy of the 4 kg mass is

A) 32 J B) 48 J

C) 114 J D) 288 J

Q.35 A stone is thrown vertically upwards with a velocity of 30 ms^{-1}. If the acceleration due to gravity is 10 ms^{-2}. What is the distance traveled by the particle during the first second of its motion? Take g = 10 ms^{-2}

A) 30 m B) 25 m

C) 10 m D) None of these

Q.36 A body starting from rest covers a distance of 0.45 km and acquires a velocity o 300 km/hr. Its acceleration will be

A) 0.092 ms^{-2} B) 0.5 ms^{-2}

C) 7.71 ms^{-2} D) 0.15 ms^{-2}

Q.37 A force of 100 N acts in a body for 4 seconds, what will be the change in momentum

A) 20 N – s B) 500 N – s

C) 400 N – s D) 1000 N – s

Q.38 The speed of projectile at its highest point if it is projected with initial velocity v_i and at an angle of 45° with the horizontal.

A) $\frac{v_i}{2}$ B) $\frac{v_i}{4}$

C) $\frac{v_i}{\sqrt{2}}$ D) $\frac{v_i}{\sqrt{3}}$

Q.39 The distance covered by a body in time t starting from rest is

A) $at^2/2$ B) vt

C) $a^2t/2$ D) at^2

Q.40 A train of 150 m length is going toward north direction at a speed of 10 ms^{-1} and a parrot is flying towards south direction parallel to the railway track with a speed of 5 ms^{-1}. The time taken by the parrot to cross the train is equal to

A) 12 s B) 8 s

C) 15 s D) 10 s

Q.41 The speed of projectile at its highest point if it is projected with initial velocity v_i and at an angle of 45° with the horizontal.

A) $\frac{v_i}{2}$ B) $\frac{v_i}{4}$

C) $\frac{v_i}{\sqrt{2}}$ D) $\frac{v_i}{\sqrt{3}}$

Q.42 The weight of objects in a rocket when its engine is operating

A) Is constant B) Is decreasing

C) Is Increasing D) Is zero

Q.43 The ratio of height and range of projectile when projected at angle θ is

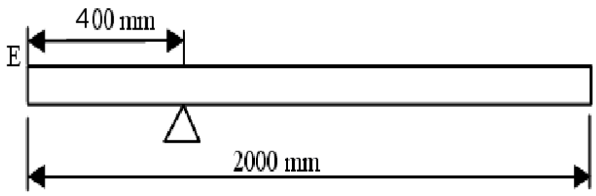
A) $\frac{4}{\tan\theta}$ B) $\frac{\tan\theta}{4}$

C) $4\tan\theta$ D) $\tan\theta + 4$

Q.44 When line of action of applied force passes through the pivot then torque will be

A) Maximum B) Constant C) Negative D) Zero

Q.45 A uniform plank of weight 100 N is 2000 mm long and rests on a support that is 400 mm from end E. At what distance from E must a 160 N weight be placed in order to balance the plank?

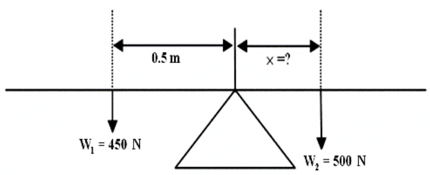


A) 150 mm

B) 125 mm

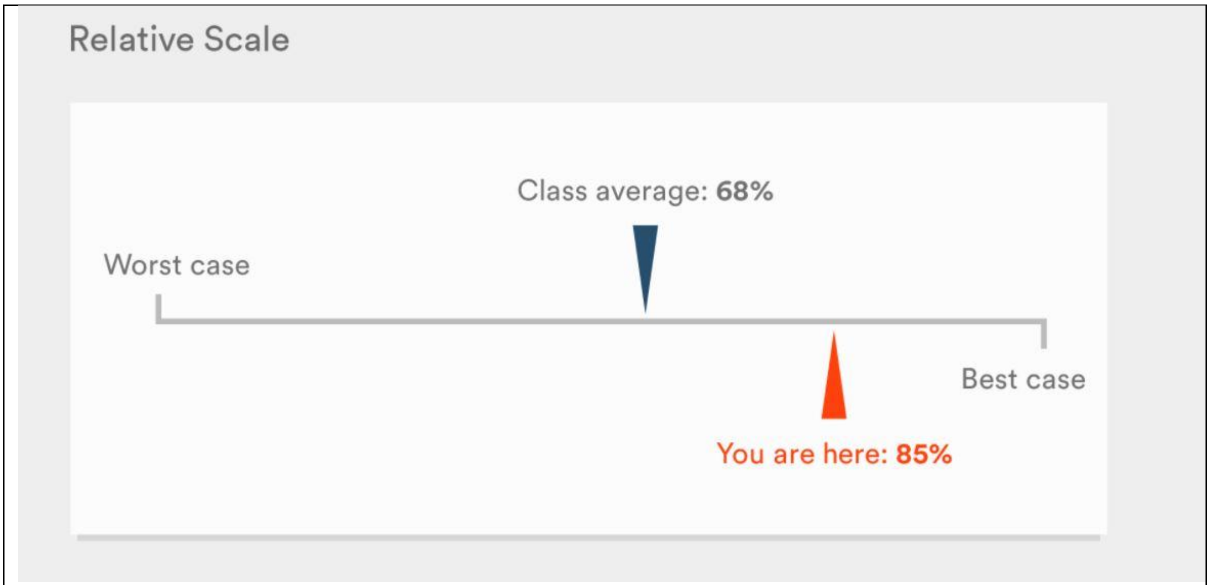
C) 25 mm D) None of these

Q.46 A 450 N child is sitting on a seesaw 0.5 meter from the balance point, as shown below. How far, on the other side, should a 500 N child sit so that the seesaw will remain in balance?



A) Less than 50 cm B) Less than 45 cm

C) Greater than 45 cm D) Greater than 50 cm



When you solve a quiz on www.nearpeer.org, you see much detailed analysis of your results. The above picture shows relatively to whole class, how are you performing. Understanding of this can prepare you better for scoring 1000+ marks in MDCAT.

Answers with Explanation

Q.1 **(D)** **Q.2** **(A)** **Q.3** **(D)** **Q.4** **(B)** **Q.5** **(C)** **Q.6** **(C)**

Q.7 **(A)** **Q.8** **(B)** $\frac{v_i^2 \sin^2\theta}{2g} = \frac{v_1^2 \sin 2\theta}{g}$

Q.9 **(A)** $F = \frac{\Delta P}{\Delta t}$

Q.10 **(C)** $\frac{1}{2}R_{max} = R_{max}\sin 2\theta$

Q.11 **(C)**

Q.12 **(D)** $F = \frac{\Delta P}{\Delta t}$

Q.13 **(A)** $R = \frac{v_i^2 \sin 2\theta}{g}$

Q.14 **(A)** **Q.15** **(A)** **Q.16** **(C)** **Q.17** **(C)** $R = \frac{v_i^2 \sin 2\theta}{g}$

Q.18 **(C)** $\frac{s}{d} = \frac{\pi r}{2r} = \frac{\pi}{2}$

Q.19 **(A)** $\frac{R}{h} = \frac{\frac{v_1^2 \sin 2\theta}{g}}{\frac{v_1^2 \sin 2\theta}{2g}}$

Q.20 **(A)** $\frac{v_1^2 \sin 2\theta}{2g} = \frac{v_1^2 \sin 2\theta}{g} \Rightarrow \tan\theta = 4$ **Q.21** **(D)**

Q.22 **(D)** $\frac{h_1}{h_2} = \frac{\frac{v_i^2 \sin^2\theta}{2g}}{\frac{v_i^2 \sin^2(90-\theta)}{2g}} \rightarrow \frac{h_1}{h_2} = \frac{\sin^2\theta}{\cos^2\theta}$ **Q.23** **(A)**

Q.24 **(B)** $K.E = \frac{1}{2}mv^2$ **Q.25** **(C)** **Q.26** **(A)** **Q.27** **(D)** **Q.28** **(A)**

Q.29 **(B)** **Q.30** **(D)** **Q.31** **(C)** $\frac{P_1}{P_2} = \sqrt{\frac{m_1}{m_2}}$ **Q.32** **(C)** $K.E = |\vec{P}|$

Q.33 **(A)** $R = \frac{v_i^2 \sin 2\theta}{g} \rightarrow 1.5 = \frac{v_i^2 \sin 2(15)}{9.8} \Rightarrow v_i = 5.5\,ms^{-1}$

Therefore

$$R' = \frac{(5.5)^2 \sin 2(45)}{9.8} = 3\,m$$

Q.34 **(D)**

m	=	12 kg
v	=	0
m_1	=	4 kg
m_2	=	8 kg
v_2	=	6 ms^{-1}
v_1	=	?

Using the relation:

$$mv = m_1v_1 + m_2v_2$$

$$0 = 4v_1 + 48$$

$$\boxed{vi = -12\,ms^{-1}}$$

To find K.E using the relation

$$K.E. = \frac{1}{2}m_1v_1^2$$

$$= \frac{1}{2}(4)(12)^2$$

$$= 2\,(144) = 288\text{ J}$$

Q.35 **(B)** $S = v_it - \frac{1}{2}gt^2$

Q.36 **(C)** $v_i = 0$, $v_i = 300\ kmh^{-1} = 83.3\ ms^{-1}$

$S = 0.45\text{ km} = 450\text{ m}$

Using the relation

$$v_f^2 - v_i^2 = 2aS$$

$$(83.3)^2 - 0 = 2a(450)$$

$$\boxed{a = 7.71\ ms^{-2}}$$

Q.37 **(C)** $F = \frac{\Delta P}{\Delta t}$ **Q.38** **(C)**

Q.39 **(C)** $S = v_it + \frac{1}{2}at^2$ Here $\mathbf{V}_i$ = 0 → $S = \frac{at^2}{2}$

Q.40 **(D)** v = 10 + 5 **7** → $s = vt$ or $\frac{s}{v} \Rightarrow \frac{150}{15} = 10\,\text{sec}$

Q.41 **(C)** v_i sin45 **Q42** **(B)** **Q43** **(B)**

Q.44 (D) If line of action of force passes through the pivot then moment arm is zero so,
$\tau = lF = (0)F = 0$

Q.45 (C) x × 160 N = 100 N × 600 mm ⇒ $x = \frac{100\text{ N} \times 600\text{ mm}}{160\text{ N}} = 375\,\text{mm}$

d = 400 mm – 375 mm = 25 mm

Q.46 (A) $x \times 500 = 450 \times 0.5 \Rightarrow x = 0.45\text{ m} = 45\text{ cm}$, so the correct option is less than 50 cm

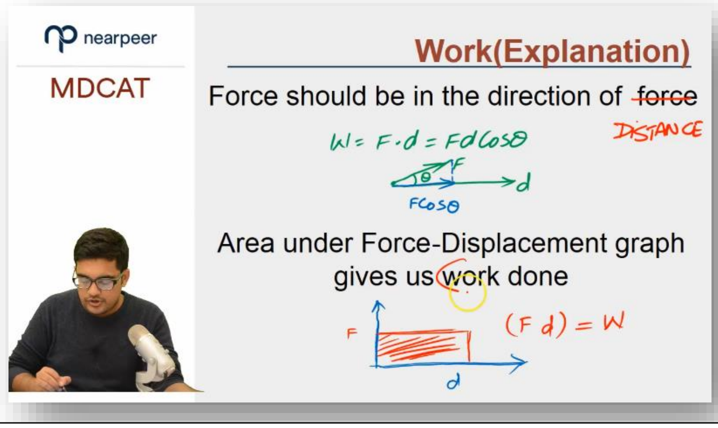
UNIT 03

Work Power and Energy

Work

The work done on a body by a constant force is the product of the magnitudes of the displacement and the component of the force in the direction of the displacement. Mathematically;

$$W = \vec{F}.\vec{d} = Fd\cos\theta$$



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video3.01)

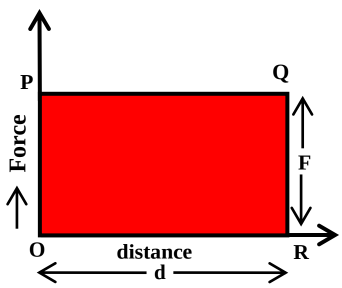
Angle	Work	Example
θ = 0°	W = Fd cos0° = Fd Work is maximum.	Work done by the horizontal force in pushing a body along a horizontal straight path.
θ = 90°	W = Fd cos90° = 0 Work is minimum	When a body moves in circular path work done by the centripetal force is always zero.
θ = 180°	W = Fd cos180° = 0 Work is negative and maximum	When a body is raised in the gravitational field the work done by the gravitational force is negative.

From the definition of work, we find that

- Work is a scalar quantity.
- If $\theta < 90°$, work is done and it is said to be positive work.
- If $\theta = 90°$, no work is done.
- If $\theta > 90°$, the work done is said to be negative.
- No work will be done if the body is in static or dynamic equilibrium i.e., $W = 0$ if $\Sigma F = 0$.
- SI unit of work is N m known as joule (J).

Force Displacement Graph

If the constant force **F** (newton) and the displacement **d** (meter) are in the same direction then the work done is Fd (joule). Clearly shaded area in fig. is also Fd so; work done by force is equal to the area under the force displacement graph.



$$\boxed{W = Fd = \text{Area of Rectangle}}$$

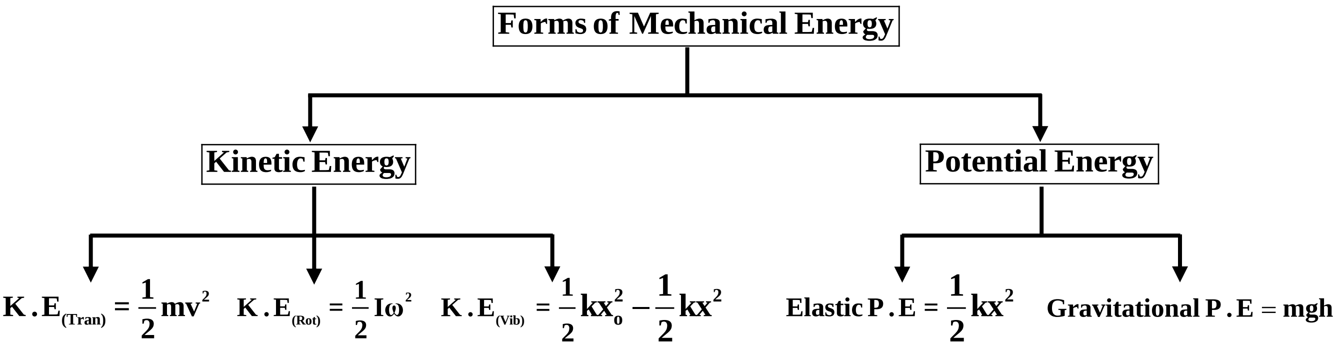
If the force **F** is not in the direction of displacement, the graph is plotted between Fcosθ and d.

Relations of Work done:

Relations	Type of Work Done
$W = Fd\cos\theta$	Work done by constant force
$W = \sum_{i=1}^{n} F_i \cos\theta_i \ \Delta d_i$	Work done by variable force
$W = \Delta K.E$	Work energy theorem
$W = \Delta P.E$	Work done by conservative force
$W = P\Delta V$	Work done by a gas at constant pressure
$W = \frac{1}{2}kx^2$	Work done on a spring
$W = \frac{1}{2}\text{stress} \times \text{strain} \times \text{volume}$	Work done in elastic bodies to store elastic potential energy
$W = \frac{1}{2}CV^2$	Work done to store charge in a capacitor
$W = \frac{1}{2}LI^2$	Work done to store magnetic energy in an inductor

Energy

Energy of a body is its capacity to do work. There are two basic form of energy.



Gravitational P. E:

It is the energy possessed by a body due to its position or height from the surface of the earth. Mathematically;

$$P.E = mgh$$

G.P.E is always determined relative to some arbitrary position which is assigned the value of zero P.E. Zero reference level of G.P.E is surface of earth or point of infinity.

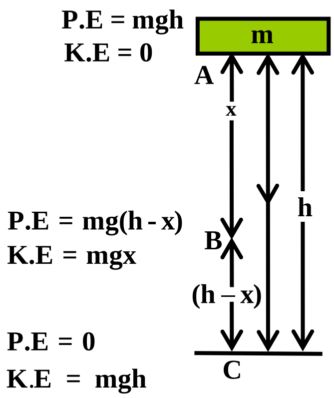
Work – Energy Principle

The work done on a body is equal to change in its kinetic energy.
Mathematically;

$$W = Fd = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

- Work a body is raised up from the Earth's surface; the work done is equal to the change in gravitational potential energy.
- When a spring is compressed; the work done on it equals the increase in its elastic P.E

Interconversion of P.E and K.E



Total energy at point A

$$T.E_A = P.E_A + K.E_A$$

$$= mgh + 0$$

$$\boxed{T.E_A = mgh}$$

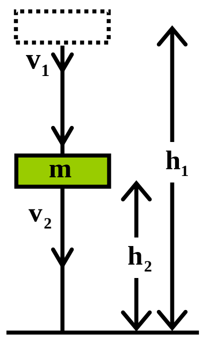
Total energy at point B

$$T.E_B = P.E_B + K.E_B$$

$$= mg(h - x) + \frac{1}{2}mv_B{}^2 = mg(h - x) + \frac{1}{2}m(2gx)$$

$$= mgh - mgx + mgx$$

$$\boxed{T.E_B = mgh}$$



Total energy at point C

$$T.E_C = P.E_C + K.E_C$$

$$= mg(0) + \frac{1}{2}mv_C{}^2 = \frac{1}{2}m(2gh)$$

$$\boxed{T.E_C = mgh}$$

If a body falls from height h_1 to height h_2, then we can write

Loss in P.E = Grain in K.E

$$mg(h_1 - h_2) = \frac{1}{2}m\left(v_2^2 - v_1^2\right)$$

If we assume that a frictional force f is present during the downward motion, then

Loss in P.E = Grain in K.E + Work done against friction

$$\boxed{mgh = \frac{1}{2}mv^2 + fh}$$

Formula for the velocity of freely falling body (When f = 0)

For a body which is dropped from height h_1. Its velocity at height h_2,

$$mg(h_1 - h_2) = \frac{1}{2}m\left(v_2^2 - v_1^2\right)$$

$$2g(h_1 - h_2) = v_2^2 \qquad \boxed{v_2 = \sqrt{2g(h_1 - h_2)}}$$

Formula for the velocity of freely falling body (When f ≠ 0)

For a body which is dropped from height h. Its velocity just before hitting the ground,

$$mgh = \frac{1}{2}mv^2 + fh \quad \Rightarrow \quad \frac{1}{2}mv^2 = mgh - fh$$

$$\boxed{v = \sqrt{\frac{2h(mg - f)}{m}}}$$

Power

Power is the measure of the rate at which work is being done.

If work ΔW is done in a time interval Δt, then the average power is;

$$\boxed{P_{av} = \frac{\Delta W}{\Delta t}}$$

If work is expressed as a function of time, the instantaneous power P is;

$$\boxed{P = \underset{\Delta t \to 0}{\text{Limit}} \frac{\Delta W}{\Delta t}}$$

Now if a constant force $\vec{F}$ gives a particle a displacement $\Delta\vec{d}$ and moves it with a constant velocity $\vec{v}$ then

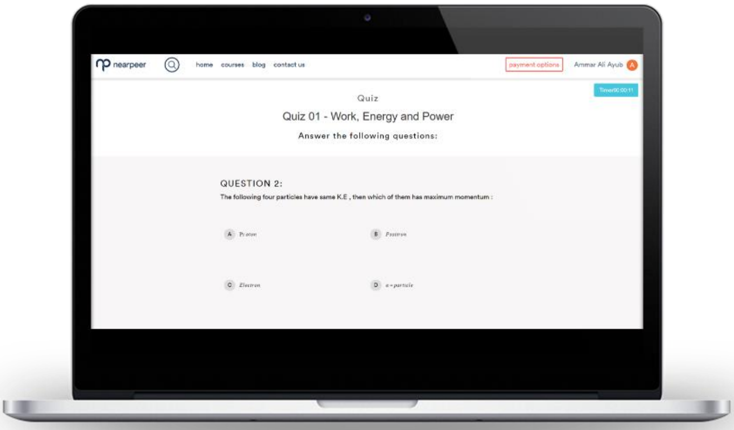
$$P = \underset{\Delta t \to 0}{\text{Limit}} \frac{\vec{F}.\Delta\vec{d}}{\Delta t}$$

$$P = \vec{F}.\left(\underset{\Delta t \to 0}{\text{Limit}} \frac{\Delta\vec{d}}{\Delta t}\right) \qquad \Rightarrow \qquad \boxed{P = \vec{F}.\vec{v}}$$

Units of Energy and Power:

Units of Energy	Units of Power
$\text{watt} \times s = J$	$\text{watt} = J s^{-1}$
$kWh = 3.6 \times 10^6\ J = 3.6\ MJ$	$kW = 1000\ \text{watt} = 1000\ J s^{-1}$
$MWh = 3.6 \times 10^9\ J = 3.6\ GJ$	$MW = 10^6 \text{watt} = 10^6\ J s^{-1}$
$MW\ day = 8.64 \times 10^{10}\ J = 86.4\ GJ$	**1 hp = 746 W**
$1\ erg = 10^{-7}\ J$	
$1\ cal = 4.1865\ J$	

PRACTICE QUESTIONS



Hundreds of more practice questions in MDCAT Online course on www.nearpeer.org (Click MDCAT)

Q.1 If both mass and velocity is doubled then K.E would be

A) Quadrupled B) Doubled
C) Eight times D) Sixteen times

Q2 A child on a swing 1m above the ground at the lowest point and 6m above the ground at the highest point. The horizontal speed of the child at the lowest point of the swing is approximately.

A) $8\ ms^{-1}$ B) $10\ ms^{-1}$
C) $12\ ms^{-1}$ D) $14\ ms^{-1}$

Q.3 When the velocity of a body is doubled

A) Its K.E. is doubled B) Its P.E. is doubled
C) Its momentum is doubled D) Its acceleration is doubled

Q.4 The gravity does no work, when the body moves

A) Horizontally B) Vertically upward
C) Vertically down ward D) At an angle of 45° with horizontal

Q.5 Commercial unit of electrical energy is

A) erg-second B) J/s
C) kWh D) J-s

Q.6 One horse power is equal to

A) 746 watts B) 745 watt
C) 750 watts D) 775 watt

Q.7 If mass and speed of a body are halved then its K.E would

A) Reduce by $\frac{1}{4}$ times

B) Reduce by $\frac{1}{8}$ times

C) Reduce by $\frac{1}{16}$ times

D) Reduce by $\frac{1}{2}$ times

Q8 How much water a pump of 2 kW can raise in one minute to a height of 10 m (Take g = 10 ms^{-2})

A) 1000 liters

B) 1200 liters

C) 100 liters

D) 2000 liters

Q.9 A body moves a distance of 10 m along a straight line under the action of a force of 5 N. If the work done is 25 J, the angle which the force makes with is the direction of motion of body is

A) 0°

B) 30°

C) 60°

D) 90°

Q.10 A constant force F acting through a distance of 10 m changes the kinetic of a body from 30 J to 45 J. The magnitude of force is

A) 15 N

B) 4.5 J

C) 1.5 N

D) 45 N

Q.11 The work done on a body is 49 J in raising it through 2.5 m, the mass of the body is

A) 20 kg

B) 4 kg

C) 2 kg

D) 40 kg

Q.12 A man pushes a lawn mower with 75 N force directed at an angle of 30° from the vertical. The work done by the man as he cuts a strip of grass 20 m long.

A) $750\sqrt{3}$ J

B) $\frac{750}{\sqrt{3}}$ J

C) 750 J

D) 1500 J

Q.13 A body of mass 1000 kg traveling at 36 kmh^{-1} is brought to rest in 50 s. The average retarding force on the body will be

A) 500 N

B) 200 N

C) 250 N

D) 1000 N

Q.14 Two bodies have same kinetic energy. They are stopped by applying same retarding force. Which body will stop earlier?

A) Lighter one

B) Both will stop simultaneously

C) Heavier one

D) It cannot be predicted

Q.15 The engine of a car exerts force 2000 N and moves it with a constant velocity of 10 ms^{-1}. The power develop by the engine is

A) 2 kW

B) 2000 kW

C) 20 kW

D) 200 kW

Q.16 One watt-hour equals

A) 3.6×10^3 J B) 3.6×10^3 cal
C) 3.6×10^6 J D) 3.6×10^6 cal

Q.17 The work done is said to be negative if
A) $\theta = 0$ B) $\theta = \infty$
C) $\theta < 90°$ D) $\theta > 90$

Q.18 The kinetic energy of a body of mass 2 kg and momentum 2 Ns is
A) 1 J B) 2 J
C) 3 J D) 4 J

Q.19 A body is dropped from height h. On reaching the height (h – x) its velocity will be
A) $\sqrt{2g(h-x)}$ B) $\sqrt{2mg(h-x)}$
C) $\sqrt{2gx}$ D) $\sqrt{2mgx}$

Q.20 Which one of the following is not the unit of work?
A) Electron volt B) Joule
C) Megawatt day D) Horse power

Q.21 A 4 kg body is thrown vertically upward from the ground with a velocity of 5 ms^{-1}. Its kinetic energy just before hitting the ground is
A) 25 J B) 50 J
C) 75 J D) 100 J

Q.22 The average power and instantaneous power become equal if work is done at
A) Any rate B) Variable rate
C) Uniform rate D) High rate

Q.23 Proton, electron, neutron, and α particles have same momentum. Which of them have highest K.E?
A) Proton B) Electron
C) Neutron D) α-particle

Q.24 Work done on the body equals to the
A) Change in its K.E always B) Change in its P.E always
C) Change in its K.E or change in its P.E D) Neither change in K.E nor change in its P.E

Q.25 Work done by a force of friction is
A) Always positive B) Always negative
C) Positive only for small frictional force D) Positive only for large frictional force

Q.26 The consumption of energy by a 60-watt bulb in 2 secs is
A) 120 J B) 60 J
C) 30 J D) 0.02 J

Q.27 When two protons are brought close, then
A) Kinetic energy increases B) P.E increases
C) P.E decreases D) P.E does not change

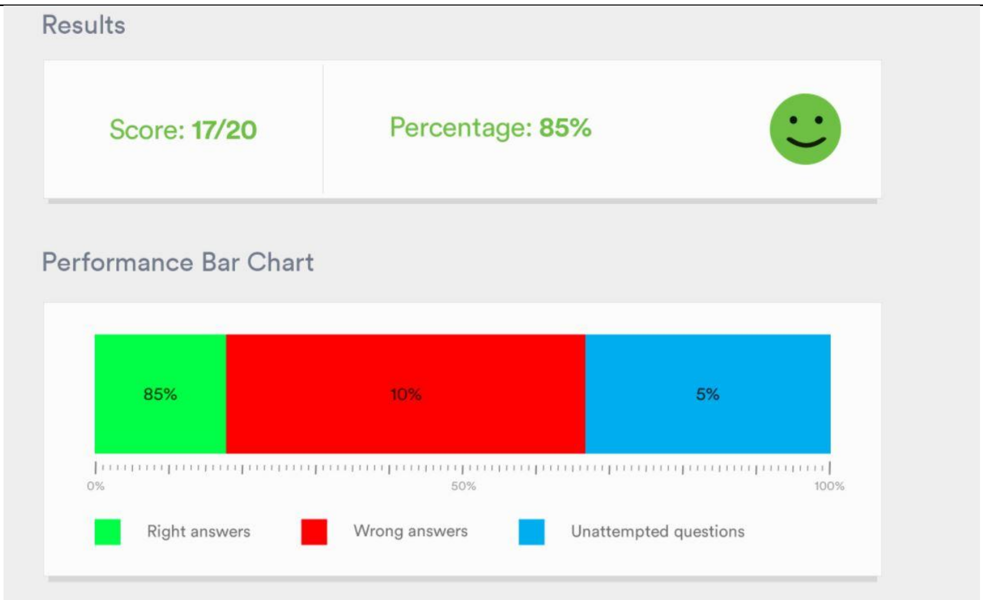
Q.28 The area under the force displacement graph represents
A) Area B) Work done

C) Power D) None of these

Q.29 Gravitational P.E of a body has

A) $\frac{1}{2}kx^2$ B) mgh

C) $q \Delta V$ D) All of these



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Answers with Explanation

Q.1 **(C)** **K.E=** $\frac{1}{2}mv^2$ **Q.2** **(B)** $V=\sqrt{(2)(10)(5)} \rightarrow V=\sqrt{100}=10\,ms^{-1}$

Q.3 **(C)** **P = mv** **Q.4** **(A)** **Q.5** **(C)** **W = P × t** **Q.6** **(A)**

Q.7 **(B)** **K .E =** $\frac{1}{2}$ **mv**^{2} **Q.8** **(B)** $P=\frac{W}{t}$ **Q.9** **(C)** W = Fd cos θ

Q.10 **(C)** F.d = Δ K.E **Q.11** **(C)** W = mgh **Q.12** **(C)** W = F d cos θ

Q.13 **(B)** $a=\frac{F}{m}$ **Q.14** **(B)** **Q.15** **(C)** $P=\vec{F}.\vec{v}$ **Q.16** **(A)**

Q.17 **(D)** **Q.18** **(A)** $K.E=\frac{P^2}{2m}$ **Q.19** **(C)** **Q.20** **(D)**

Q.21 **(B)** K.E = $\frac{1}{2}$ mv^2 **Q.22** **(C)** **Q.23** **(B)** $K.E=\frac{p^2}{2m}$ **Q.24** **(C)**

Q.25 **(B)** **Q.26** **(A)** W = P × t **Q.27** **(B)** **Q.28** **(B)** **Q.29** **(B)**

UNIT 04 Circular Motion

Circular motion

- **Particles of rotating body**
- **Under the action of centripetal force**

- **Rotational Motion** is possessed by a body if every particle of the body moves in circular paths, the centers of which lie on a straight line called axis of rotation.
- In many practical situations, rotational motion is somehow related to linear motion. For example, the rotation of a bicycle's wheels results in its translation. The faster the rotation, the faster the translation, obviously there must be some relation between two motions.

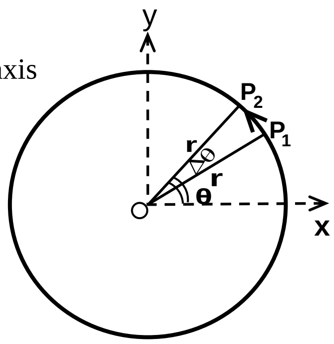
Did You Know?

- Translational motion may be one, two or three dimensional motion
- Rotational motion of a rigid body can be either two or three dimensional. It is because to describe the rotation of body, at least two dimensions are required.

Angular Displacement:

The angle subtended at the center of a circle by a rotating radius during the circular motion of the particle during a particular time is called angular displacement

- A particle p is attached to the end of the massless rigid rod of length r whose other end is pivoted at the center 'O' of the circular path.
- Motion of particle P = circular, Motion of rod OP = Rotatory
- Here plane of rotation is xy plane so axis of rotation is along z-axis
- For small values of $\Delta\theta$, angular displacement is a vector quantity.
- The direction of $\Delta\theta$ is along the axis of rotation and is given by right hand rule.



- Definition of radian gives following useful relation

$$S = r\theta$$

- Units of angular displacement are radian, revolution and degree. But radian is SI unit.
- As

$360° = 2\pi$ rad $\qquad$ 1 rad $= \dfrac{360°}{2\pi} = 57.3°$

Relation between different units of Angular Displacement

θ (rad)	θ (rev)	θ (deg)
2π	1 rev	360°
π	$\frac{1}{2}$ rev	180°
$\frac{\pi}{2}$	$\frac{1}{4}$ rev	90°
$\frac{\pi}{4}$	$\frac{1}{8}$ rev	45°
$\frac{\pi}{6}$	$\frac{1}{12}$ rev	30°

Angular Velocity:

Rate of change of angular displacement is called angular velocity

$$\omega_{av} = \frac{\Delta\theta}{\Delta t}$$

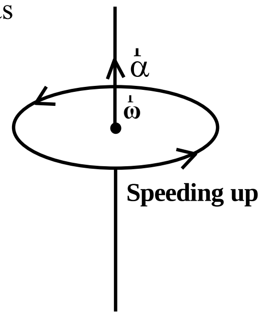
- For instantaneous values,

$$\omega_{in} = \lim_{\Delta t \to o} \frac{\Delta\theta}{\Delta t}$$

- Its unit is rad/sec.
- Direction is along axis of rotation determined by right hand rule.
- Commercial unit is rpm.
- Linear or tangential velocity v and angular velocity 'ω' are related as

$$v = r\omega \quad \text{or} \quad \boxed{\vec{v} = \vec{\omega} \times \vec{r}}$$

- The direction of $\vec{\omega}$ is perpendicular to $\vec{v}$.



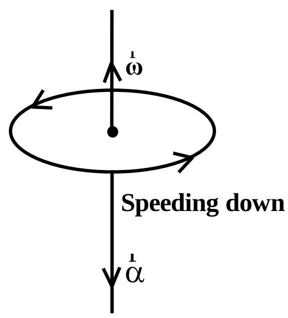
ANGULAR ACCELERATION:

Rate of change of angular velocity is called angular acceleration

$$\alpha_{av} = \frac{\Delta\omega}{\Delta t}$$

- For instantaneous values, $\alpha = \lim_{\Delta t \to o} \frac{\Delta\omega}{\Delta t}$
- Its unit is rad/sec^2.
- $\vec{\alpha}$ and $\vec{\omega}$ are parallel if $\vec{\omega}$ is increasing.
- $\vec{\alpha}$ and $\vec{\omega}$ are antiparallel if $\vec{\omega}$ is decreasing.

  $\vec{\alpha}$ has arbitrary if $\vec{\omega}$ is constant.

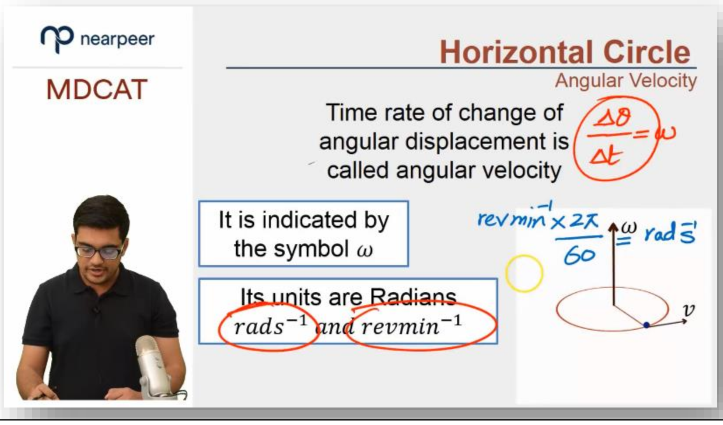


Relation b/w Linear and Rotational Variables

B/w $\vec{s}$ and $\vec{\theta}$	**$S = r\,\theta \Rightarrow \vec{s} = \vec{\theta} \times \vec{r}$**
B/w $\vec{v}$ and $\vec{\omega}$	**$v = r\,w \Rightarrow \vec{v} = \vec{\omega} \times \vec{r}$**
B/w $\vec{a}$ and $\vec{\alpha}$	**$a = r\,\alpha \Rightarrow \vec{a} = \vec{\alpha} \times \vec{r}$**
B/w $\vec{L}$ and $\vec{p}$	$\vec{L} = \vec{r} \times \vec{p}$
B/w F and $\vec{\tau}$	$\vec{\tau} = \vec{r} \times \vec{F}$

Equations of Angular Motion:

Linear	Angular
$v_f = v_i + at$	$\omega_f = \omega_i + \alpha t$
$2aS = v_f^2 - v_i^2$	$2\alpha\theta = \omega_f^2 - \omega_i^2$
$S = v_i t + \frac{1}{2}at^2$	$\theta = \omega_i t + \frac{1}{2}\alpha t^2$



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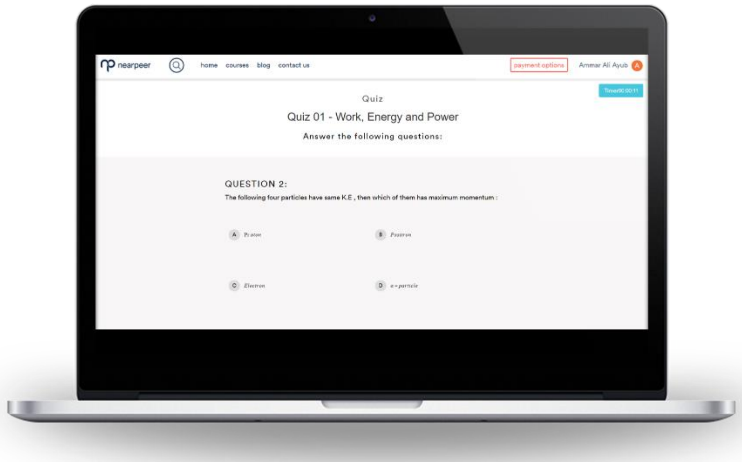
PRACTICE QUESTIONS



Q.1 The point on the rim of a wheel moves 0.3 m when wheel turns through an angle of 30°. The radius of wheel is

A) $\frac{1.8}{\pi}$ m
C) 0.01 m
B) $\frac{\pi}{1.8}$ m
D) 0.1 m

Q.2 Speed of second's hand of a watch in rad s^{-1}.

A) $\frac{\pi}{30}$ rads^{-1}
C) $\frac{\pi}{43200}$ rads^{-1}
B) $\frac{\pi}{1800}$ rads^{-1}
D) $\frac{\pi}{3}$ rads^{-1}

Q.3 Angular speed of earth about its axis

A) $\frac{\pi}{432} \times 10^{-2}$ rads^{-1}
C) 7.3×10^{-5} rads^{-1}
B) $\frac{\pi}{18} \times 10^{-2}$ rads^{-1}
D) Both A and C

Q.4 Three particles of a rigid body rotating about a fixed axis are located at 5 cm, 10 cm and 15 cm from axis of rotation. Which particle has greater tangential velocity?

A) 5 cm
C) 15 cm
B) 10 cm
D) All have same tangential speed

Q.5 The linear velocity of a person standing at the equator of the earth.

A) 465.4 ms^{-1}
B) 4.654 ms^{-1}
C) 46.54 ms^{-1}
D) Zero

Q.6 The ratio of angular speed of minutes' hand and hours hand of a watch is

A) 1 : 12
B) 12 : 1
C) 60 : 1
D) 1 : 60

Q.7 A rotating wheel of radius 0.5 m has an angular velocity of 5 rad s^{-1} at some instant and 10 $rads^{-1}$ after 5s. Its angular acceleration is

A) 2 $rads^{-2}$
B) 1 $rads^{-2}$
C) 0.5 $rads^{-2}$
D) 4 $rads^{-2}$

Q.8 A ball of radius 5 cm rolls down an inclined plane from rest. After 4.0 s, its angular velocity is 8 $rads^{-1}$. Its angular acceleration and linear acceleration would be respectively

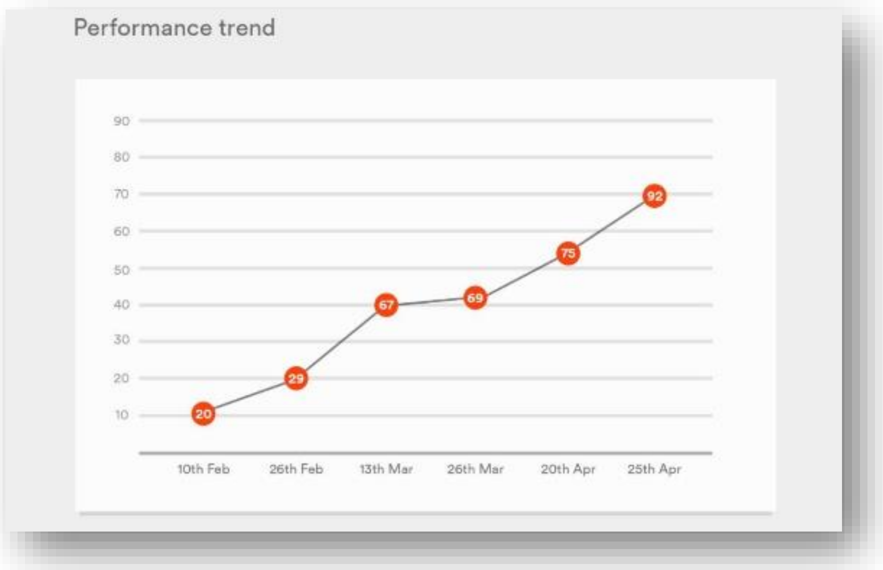
A) 2$rads^{-2}$, 1 ms^{-2}
B) 0.2 $rads^{-2}$, 0.1 ms^{-2}
C) Zero, 0.1 ms^{-2}
D) 2$rads^{-2}$, 0.1 ms^{-2}

Q.9 The direction of angular velocity is along

A) Tangent to the circle
B) Inward radius
C) Outward radius
D) The axis of rotation

Q. 10 If $\vec{r} = 4\hat{i}$ and $\vec{\omega} = 4\hat{j}$ then $\vec{v}$ is along

A) + x – axis
B) + z – axis
C) –z – axis
D) –y – axis



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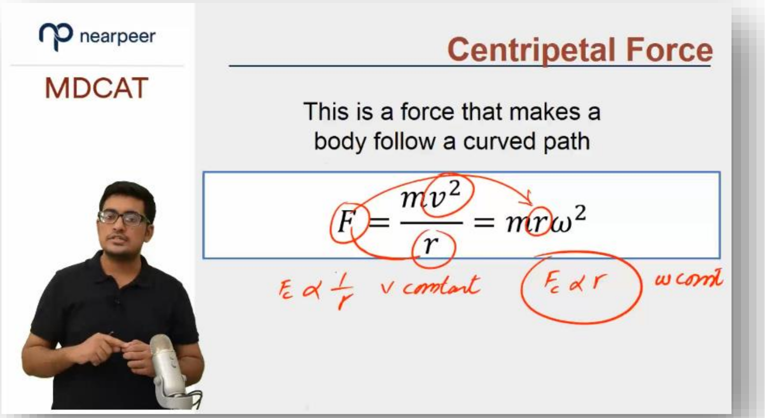

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Centripetal Force

A force which is required to bend the normally straight path of a body into a circular path is called centripetal force.

- The acceleration produced by centripetal force F_c is called centripetal acceleration a_c. Centripetal force in terms of tangential velocity of particle $\vec{F}_C = \frac{mv^2}{r}$
- Angular velocity $\vec{F}_C = mr\omega^2$
- Time period $\vec{F}_C = \frac{4\pi^2 mr}{T^2}$
- Linear momentum $\vec{F}_C = \frac{p^2}{mr}$
- Kinetic energy $\vec{F}_C = \frac{2K.E}{r}$

Centripetal force
- **Is $\perp$ to the velocity**
- **Cannot change speed**
- **Cannot change K.E**
- **Cannot do any work**
- **Is along the radius towards centre**
- **Is an instantaneous force**
- **Is not the basic force of nature**

Knowledge plus

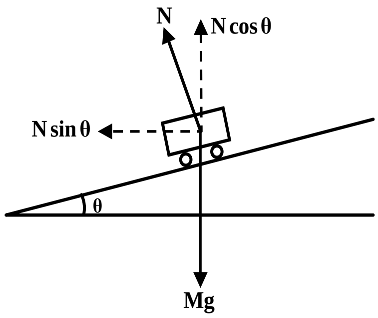
Banking of Roads

- If friction alone cannot provide required centripetal force, then banking of roads is done.
- If outer edge of the road is raised over the inner edge at turns, then it is called banking of roads.
- The angle θ through which the outer edge is raised over the inner edge of the road, is called angle of banking.

From figure, $N \cos \theta = mg$

$$N \sin \theta = \frac{mv^2}{r}$$

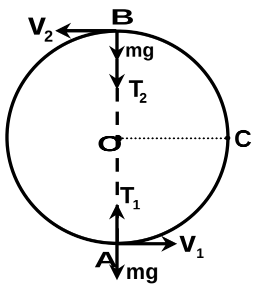
$$\tan \theta = \frac{v^2}{rg}$$



Motion in a vertical circle (Non-Uniform Circular Motion):

- **In a horizontal circle**, gravity does not change the speed at every point of the motion. But still centripetal acceleration acts at every point even when speed is uniform
- **In a vertical circle**, gravity changes the speed at every point of the motion.
- In non- uniform circular motion, the acceleration of body has two components, a radial or centripetal (a_c) and a tangential component (a_t). The magnitude of resultant acceleration is

$$a = \sqrt{a_c^2 + a_t^2}$$



- If a body of mass m, tied at the end of a starting whirled in a vertical circle of a radius r is shown in the figure.
- The motion is circular but not uniform since the speed of the body is different at the different points on the circular path.
- Speed of body is minimum at the highest point B and tension in string is minimum. Critical speed with which body should reach B is

$$v = \sqrt{g\,r}$$

- Speed of body is maximum at the lowest point A and tension in string is maximum. Minimum speed at A should be

$$v = \sqrt{5g\,r}$$

Examples

- If a bucket containing water is rotated in a vertical circular such that its velocity at the lowest point of motion is equal to or greater than $\sqrt{5g\ r}$, the water will not fall out even if the bucket is at highest point with its open top pointing downward. It is because in this case the weight mg of the water is less than the required centripetal force mv^2/r towards the center. So the water stays in the bucket. When an aero plane loops a vertical circle such that its velocity at the lower point is equal to or greater than $\sqrt{5g\ r}$, the pilot does not fall down even when he is not tied down to his seat in the cockpit.

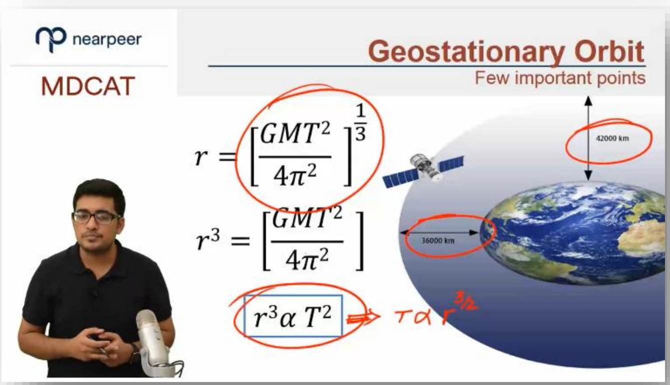
Orbital velocity

- Orbital velocity **v** = $\sqrt{\frac{GM}{r}}$
- Any velocity less than this will bring the satellite trembling back to the Earth.
- It is to be noted that mass of object is not important in determining orbit of satellite.

Knowledge plus

Kepler's laws of planetary Motion

- All planets move around the sun in **elliptical orbits** with the sun located at one of its foci.
- The position vector from the sun to the planet sweeps out equal areas in equal intervals of time i.e., areal velocity of a planet around the sun always remains constant. This means that **angular momentum remains constant** i.e.,
  $$Mvr = \text{constant or } m_1v_1r_1 = m_2v_2r_2$$
- The squares of the periods of the planets are proportional to the cube of the planet's average distance from the sun i.e., for a planet $\mathbf{T^2 \propto r^3}$, $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$



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Geostationary Sattelite

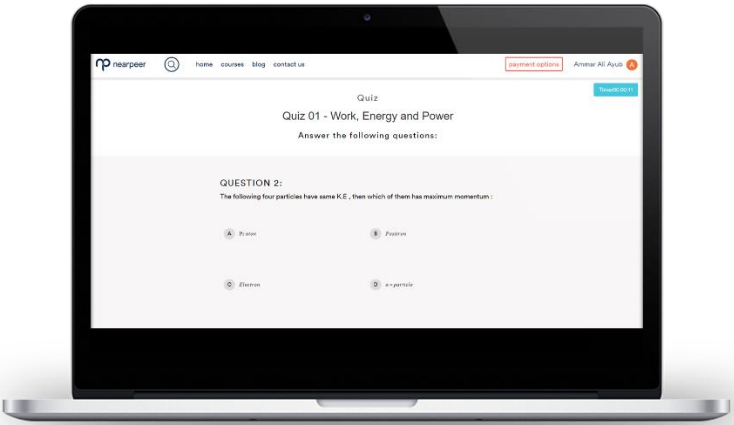
A satellite whose position does not change w.r.t a certain point on earth is called geostationary satellite

- These satellites have time periods equal to that of Earth (24 hours) and their orbital motions are synchronized with the spinning motion of Earth around its own axis.
- These satellites are used for weather report, spying and for communication.

$$r = \left(\frac{GMT^2}{4\pi^2}\right)^{1/3}$$

- Radius of geostationary satellite is given by
- Orbital radius = r = 42400 km
- Height above Earth's surface = h = 36000 km
- The largest satellite system is managed by 126 countries and is named as International Telecommunication Satellite Organization(INTELSAT)
- Minimum three geo-stationary satellites at an angle of 120° each are required to cover whole earth.
- Microwaves having high penetrating powers are used for communication.

PRACTICE QUESTIONS



Q.11 A car is traveling on a circular road of radius 500 m. at some instant its speed is 50 ms^{-1} and increasing at the rate of 2ms^{-2}. Its acceleration will be

A) 0.1 ms^{-2}
C) $\frac{1}{3}ms^{-2}$
B) 3 ms^{-2}
D) 9 ms^{-2}

Q.12 Maximum tension in the string of length 1 m when tied to a mass of 100 g and making 2 revolutions per second is

A) $1.6\pi^2$ N
C) $160\pi^2$ N
B) $16\pi^2$ N
D) $0.16\pi^2$ N

Q.13 A stone tied to the end of a circle is whirled in a vertical circle of radius r(Choose correct)

A) The tension at the lowest point is maximum
B) The speed at the lowest point is maximum
C) The speed at the highest point is minimum
D) All of these

Q.14 If a wheel of diameter 1 m is rotating at 2 $rads^{-1}$ then its linear rim velocity is

A) 1 ms^{-1}
B) 2 ms^{-1}
C) 0.5 ms^{-1}
D) 0.75 ms^{-1}

Q.15 If a disc is rotating anticlockwise in xy plane, then $\vec{\omega}$ is along

A) x-axis
B) y-axis
C) z-axis
D) – ve y – axis

Q.16 The angular speed of minute's hand of clock in rad/sec is

A) $\frac{\pi}{60}$ rad/s
B) $\frac{\pi}{1800}$ rad/s
C) $\frac{\pi}{86400}$ rad/s
D) $\frac{\pi}{43200}$ rad/s

Q.17 A toy car is rotating in circle with angular speed of 60 rev/min. If a circle is 1 m, then linear speed of car in m/s is

A) 2π
B) π
C) 9π
D) 3π

Q.18 If the angular velocity of a body increases from zero to 60 rev/min in 1 sec angular acceleration in rad/sec^2 is

A) π
B) 2π
C) 3π
D) 4π

Q.19 A couple produces

A) Purely linear motion
B) Purely rotational motion
C) Linear and rotational motion
D) No motion

Q.20 A body of mass 5 kg is moving in a circle of radius 1 m with angular speed of 2 rad/s, the centripetal force is

A) 40 N
B) 30 N
C) 10 N
D) 20 N

Q.21 A stone attached to a string is being whirled in a vertical circle. The string is likely to break (as tension is maximum) when the stone is at

A) Lowest position
B) Highest position
C) Any point
D) At middle

Q.22 Work done by centripetal force in half revolution is

A) $2\frac{mv^2}{r}$
B) $\frac{mv^2}{2r}$
C) Zero
D) $\frac{2mv^2}{3r}$

Q.23 A cyclist bends while taking a turn to

A) Reduce reaction
B) Reduce speed
C) Provide centripetal force
D) Reduce friction

Q.24 In uniform circular motion, which of the following does not remain constant?

A) Speed
B) Angular momentum
C) K.E
D) Momentum

Q.25 If a fan is switched ON, then its angular acceleration and angular velocity are

A) Parallel
B) Antiparallel
C) Perpendicular
D) Inclined at an angle less than 90°

Q.26 A motorcyclist doubles its velocity while taking a turn. The force exerted outwardly will be

A) Doubled
B) Increased by 4 times
C) Halved
D) Decreased by 4 times

Q.27 Linear velocity $\vec{v}$ and centripetal force $\vec{F}_c$ are _________ to each other.

A) Perpendicular
B) Parallel
C) Antiparallel
D) Inclined at 45° to each other

Q.28 The point at which an applied force produces a linear acceleration but no rotation is called

A) Centre of gravity
B) Origin
C) Geometric center
D) Centre of mass

Q.29 Which of the following quantities remain constant in a planetary motion?

A) Speed
B) K.E
C) Angular momentum
D) Angular speed

Q.30 If by some process, angular velocity of Earth around its own axis is doubled which statement is correct?

A) $K.E_{rot}$ = doubled, T = halved
B) $K.E_{rot}$ = fourfold, T = halved
C) $K.E_{rot}$ = constant
D) T = constant

Q. 31 The acceleration of a body undergoing uniform circular motion is constant in

A) Magnitude only
B) Direction only
C) Both magnitude and direction
D) Neither magnitude nor direction

Q.32 A pendulum on Earth has a time period 1 sec. Its time period in a box orbiting Earth is

A) 1 s
B) 5 s
C) 0
D) ∞

Q.33 Angular speed of a satellite around Earth is

A) $\sqrt{\frac{GM}{r^3}}$
B) $\sqrt{\frac{GM}{r}}$
C) $\frac{\sqrt{GM^2}}{r^3}$
D) $\frac{\sqrt{GM}}{r}$

Q.34 Trackers in cars use global positioning system which consists of how many satellites?

A) 12
B) 24
C) 6
D) 18

Q.35 Minimum number of geostationary satellites required to cover the whole earth 3. The angular displacement between them will be

A) 60°
B) 120°
C) 180°
D) 240°

Q.36 If a satellite is orbiting around earth then ____________ cannot be used to mean time

A) Pendulum clock
B) Elastic spring watch
C) Atomic clock
D) Electric oscillation clock

Q.37 If value of g is 10 m/s^2, then critical velocity of satellite close to earth is

A) 8 m/s
B) 8 km/s

C) 80 m/s D) 80 km/s

Q.38 A satellite moving round the earth constitutes

A) An inertial frame of reference B) non inertial frame

C) neither inertial nor non inertial D) both inertial and non-inertial

Q.39 When a body moves in a circle, the angle between its linear velocity and angular velocity is always

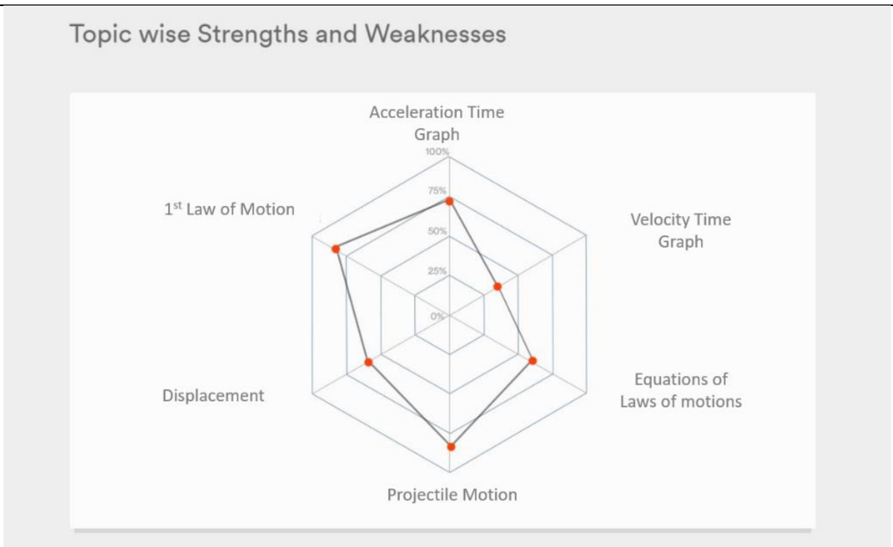
A) 180° B) 0°

C) 90° D) 45°

Q.40 If a car moves with a uniform speed of 2 ms^{-1} in a circle of radius 0.4. Its angular speed is

A) 4 rad. s^{-1} B) 5 rad. s^{-1}

C) 1.6 rad. s^{-1} D) 2.8 rad. s^{-1}



Answers with Explanation

Q. 1 **(A)** $r = \frac{s}{\theta} = \frac{0.3}{\frac{\pi}{6}} = \frac{1.8}{\pi}$ m **(θ should be in radians)**

Q. 2 **(A)** $1\text{rpm} = \frac{1\text{rev}}{1\text{min}} = \frac{\not{2}\pi\,\text{rad}}{60\,\text{s}} = \frac{\pi\,\text{rad}}{30\,\text{s}}$

Q. 3 **(D)** $\omega = \frac{2\pi\,\text{rad}}{1\text{day}} = \frac{\not{2}\pi\,\text{rad}}{\not{24}\times 60\times 60\text{s}} = \frac{\pi}{432}\times 10^{-2}\ \text{rads}^{-1} = 7.3\times 10^{-5}\ \text{rads}^{-1}$

Q. 4 **(C)** $v = r\omega$

Q. 5 **(D)** $v = r\omega$

Q. 6 **(B)** $\frac{\omega_m}{\omega_h} = \frac{12\text{h}}{1\text{h}} = 12:1$

Q. 7 **(B)** $\alpha = \frac{\Delta\omega}{\Delta t} = \frac{(10-5)\text{rads}^{-1}}{5\text{s}} = 1\text{rads}^{-2}$

Q. 8 **(D)** Use $\alpha = \frac{\Delta\omega}{\Delta t} =$ $a_t = r\,\alpha$

Q. 9 **(D)**

Q.10 **(C)** $\vec{v} = \vec{\omega}\times\vec{r}$

Q.11 **(C)** $a = \sqrt{a_t{}^2 + a_c{}^2}$

Q.12 **(A)** $T = mr\omega^2$

Q.13 **(D)**

Q.14 **(A)** $v = r\,\omega$

Q.15 **(C)** Apply right hand rule

Q.16 **(B)** $\omega = \frac{\theta}{t}$

Q.17 **(A)** $v = r\,\omega$

Q.18 **(B)** $\alpha = \frac{\omega_f - \omega_i}{\Delta t} = \frac{2\pi}{1}$

Q.19 **(B)**

Q.20 **(D)** $F_C = mr\omega^2$

Q.21 **(A)**

Q.22 **(C)** $W = Fd\cos 90°$

Q.23 **(C)**

Q.24 **(D)**

Q.25 **(A)**

Q.26 **(B)** $F_C = \frac{mv^2}{r}$

Q.27 **(A)**

Q.28 **(D)**

Q.29 **(C)** Kepler's 2nd law

Q.30 **(B)** $K.E = \frac{1}{2} I\omega^2, \ \omega = \frac{2\pi}{T}$

Q.31 **(A)**

Q.32 **(D)** $T = 2\pi\sqrt{\frac{l}{o}}$

Q.33 **(A)** $v = \sqrt{\frac{GM}{r}}, \ v = r\omega$

Q.34 **(B)**

Q.35 **(B)**

Q.36 **(B)** Value of 'g' will affect its time period

Q.37 **(B)** $v = \sqrt{gR}$

Q.38 **(B)**

Q.39 **(C)** $\vec{v} = \vec{\omega} \times \vec{r}$

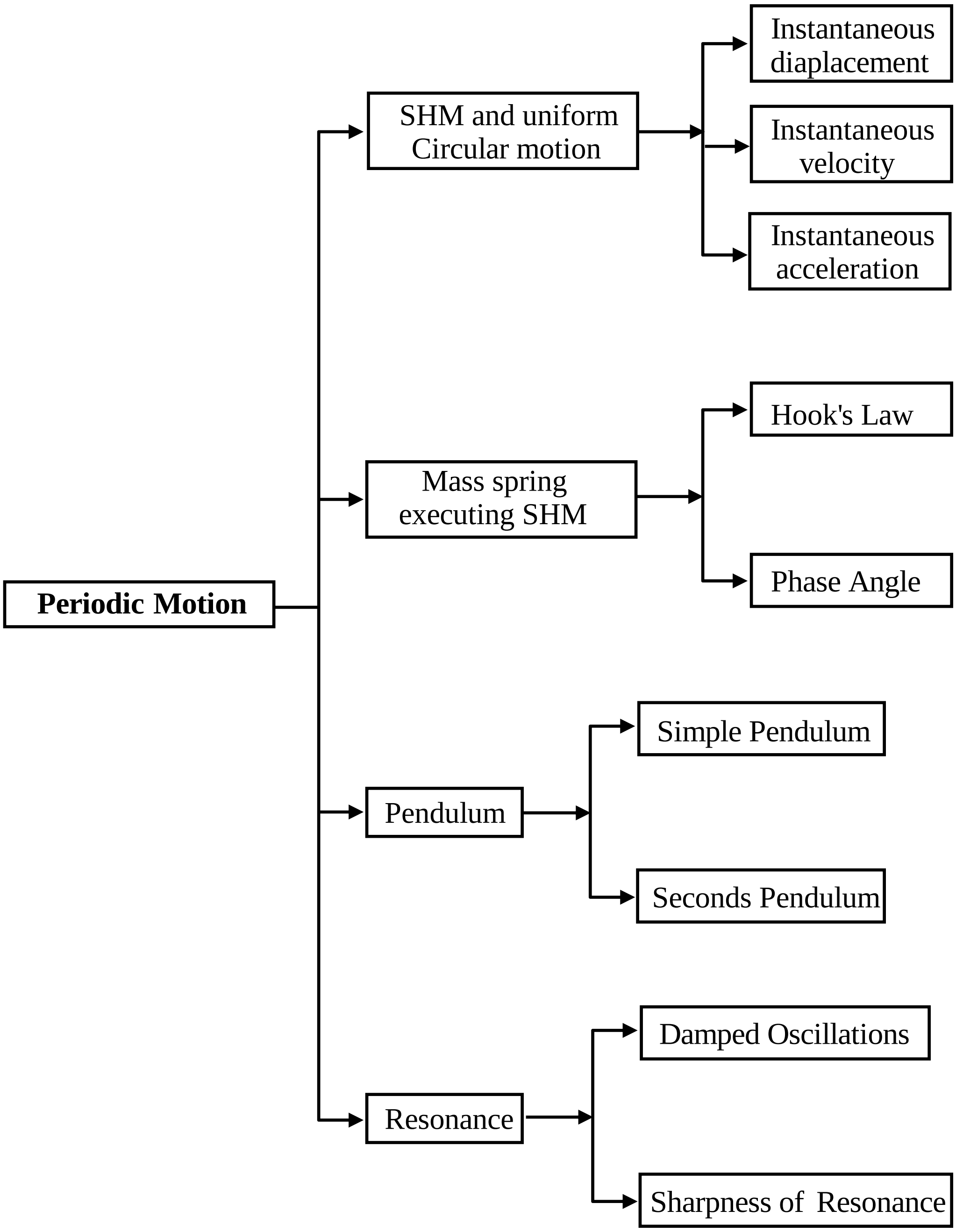
Q.40 **(B)** $\omega = \frac{v}{r}$

UNIT
05

Oscillations

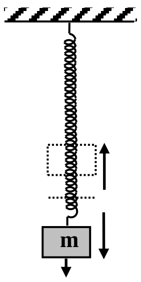
Periodic Motion

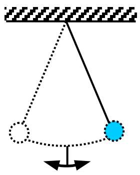
To and fro motion of a body about a fixed position along same path is known as Vibratory motion

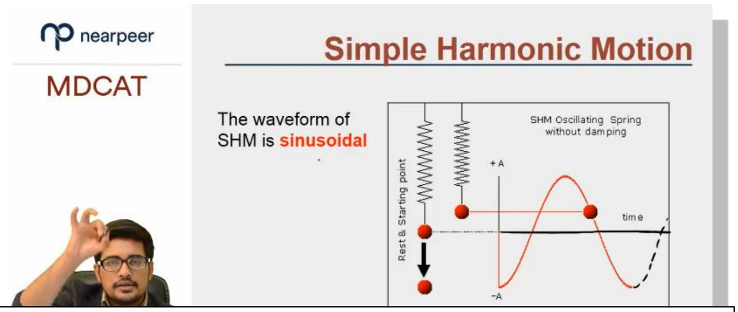


Simple Harmonic Motion

- Vibratory motion is that in which a body moves to and fro about a fixed position along same path. e.g.
  (i) Motion of simple pendulum. (ii) Motion of molecules of a solid.
- Simple harmonic motion (SHM) is a special type of vibratory motion in which
  (i) $\vec{a} \propto -\vec{x}$ (ii) $\vec{a}$ is directed towards mean position.
- Restoring force is always directed towards mean position hence it is assigned negative sign.
- Periodic motion is that which repeats itself after equal time intervals.
- Vibration is defined as one complete round trip of a body about its mean position.
- Time period is defined as time taken by vibrating body to complete its one vibration and denoted by T.
- Frequency is number of vibrations per second and denoted by f so $f = \frac{1}{T}$





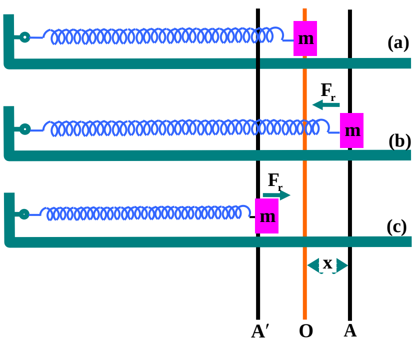


- Amplitude is maximum distance from mean position.

Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 5.01)

- Angular frequency is $\omega = 2\pi/T \rightarrow \omega = 2\pi f$.
- Phase is the angle which specifies the displacement and direction of motion of the point executing SHM i.e. phase = $\theta = \omega t$.
- Initial angle at t = 0 is called phase constant and denoted by ϕ
- If phase constant $\phi = 90°$, then displacement $x = x_o \sin(\omega t + 90°) = x_o \cos \omega t$, and simple harmonic oscillator starts its SHM from positive extreme position.

Horizontal Mass Spring System



- For spring, Hook's law states that:

  stress $\propto$ Strain (within elastic limits)

  $F = k\,x$

  Where $k = \frac{F}{x}$ is called spring constant or force constant
- If a spring is cut into two equal parts then spring constant of each half is doubled.
- Mass attached to spring has SHM. $a = -\frac{k}{m}x$

  For spring mass system doing SHM $\omega = \sqrt{\frac{k}{m}}$

$\vec{a} \propto -\vec{x}$

- Mass-spring system has S.H.M and we can trace its waveform by following relation;

$$x = x_o \sin\left[\frac{2\pi}{T}\right]t$$

- For series combination of springs of spring constants K_1 and K_2, effective spring constant K is

$$\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \ldots\ldots\ldots\ldots$$

- For parallel combination of springs of spring constant K_1 and K_2, … effective spring constant K is

$$K = K_1 + K_2 + K_3 + \ldots\ldots\ldots\ldots$$

- Note that the behaviour of springs resembles with capacitances in series and in parallel combinations

- Time period of single mass attached to spring is given as; $T = 2\pi\sqrt{\frac{m}{k}}$

$$T \propto \sqrt{m} \qquad T \propto \frac{1}{\sqrt{k}}$$

Its displacement is given as; $x = x_o \sin \omega t$

- Instantaneous velocity of mass 'm' attached to a spring is given as;

$$= \sqrt{\frac{k}{m}(x_0^2 - x^2)} = x_o\sqrt{\frac{k}{m}}\sqrt{1 - \frac{x^2}{x_0^2}}$$

$$v_{ins} = v_o\sqrt{1 - \frac{x^2}{x_0^2}}$$

- Maximum speed of mass attached to spring is given as

$$v_{max} = v_o = x_o\sqrt{\frac{k}{m}}$$

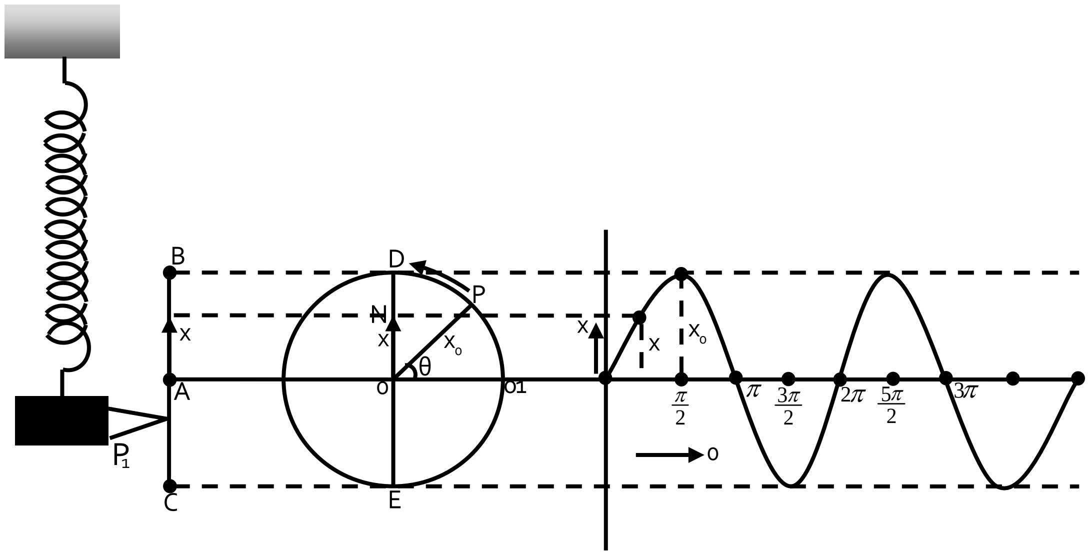
Quantity	Mean position	Extreme position
Displacement	0	Maximum
Acceleration	0	Maximum
P.E	0	Maximum
Velocity	Max	0
K.E	Max	0
Restoring force	0	Maximum

Motion of projection of a body moving in circle

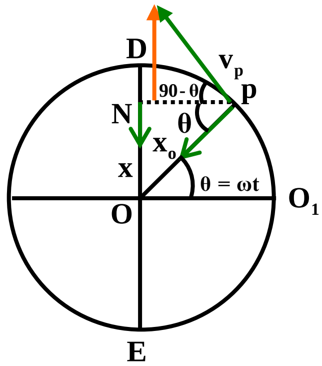
- Motion of projection of a body moving in a circle, on the diameter with constant speed is S.H.M

- Its acceleration is given as; $a = -\omega^2 x$

- Time period of projection is given as; $T = \frac{2\pi}{\omega}$



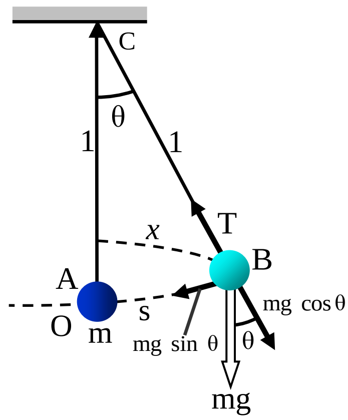
- Instantaneous velocity $v = \omega\sqrt{x_o^2 - x^2}$
- Instantaneous acceleration $a = -\omega^2 x$
- Projection speeds up when moving towards the centre of circle.
- Projection slows down when moving away from the centre of circle.
- If speed ω of body in circular motion is not constant then projection does not have S.H.M but has vibratory motion, which is non-S.H.M.



Simple Pendulum

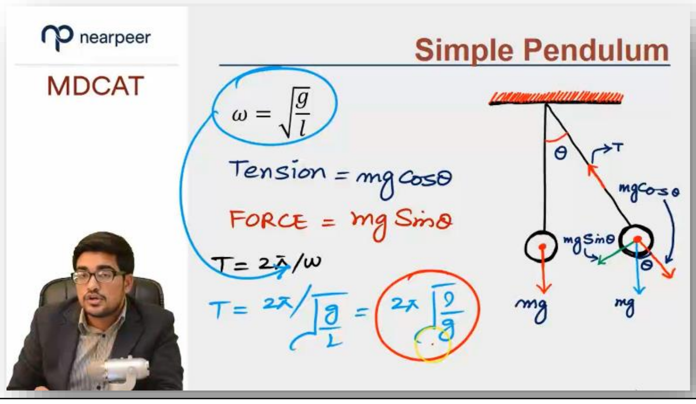
A heavy point mass suspended from a rigid support by means of almost weightless and inextensible string is named as simple pendulum

- Galileo invented simple pendulum.
- Motion of simple pendulum is S.H.M if there is no damping.
- Damping force reduces the amplitude of simple pendulum continuously and finally its motion is stopped.
- T =mg cos θ is tension in the string
- mg sin θ is responsible for motion of simple pendulum.
- Acceleration $a = -\frac{g}{l}x$
- Angular frequency of simple pendulum $\omega = \sqrt{\frac{g}{l}}$
- Maximum velocity of simple pendulum $v_o = x_o\sqrt{\frac{g}{l}}$
- Motion of simple pendulum is SHM.
- $T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow T \propto \sqrt{l} \propto \frac{1}{\sqrt{g}}$



- Time period of second's pendulum is 2 seconds and its frequency is 0.5 HZ.
- A second's pendulum has following characteristics

- In absence of damping force, restoring force on simple pendulum is given as;
  $F_r = -mg \sin\theta$, and for small amplitude oscillations $F_r = -mg\theta$.



Time period	2 seconds
Frequency	0.5 Hz
Length	0.99 or 1 meter

Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 5.02)

Equation of acceleration of simple pendulum for small amplitude is

$$a = -\left(\frac{g}{l}\right)x$$

Thus $\omega = \sqrt{\frac{g}{l}}$ for simple pendulum and does not depend on mass like the mass spring system does.

- Time period and frequency of simple pendulum are given as;

$$T = 2\pi\sqrt{\frac{l}{g}} \text{ and } f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$$

“g” in a simple pendulum:

- As time period of simple pendulum is $T = 2\pi\sqrt{\frac{l}{g}}$

  From above equation, $g = \frac{4\pi^2 l}{T^2}$

  So value of g can be determined from above formula if we know the length and time period of simple pendulum.

Variation of Time Period “T” of a Simple Pendulum in an Elevator Hanging from the Ceiling of Elevator:

- If elevator is at rest or moving with uniform velocity, then T remains unchanged.
- If elevator is accelerating upwards, then T decreases as apparent weight increases.
- If elevator is accelerating downwards then increases as apparent weight decreases.
- If elevator is falling freely under the action of gravity, then It becomes undefined.

COMPARISON OF DIFFERENT SYSTEMS IN HARMONIC MOTION

Quantity	Projection	Mass – spring system	Simple pendulum
Maximum velocity	$v_o = x_o\omega$	$v_o = x_o\sqrt{k/m}$	$v_o = x_o\sqrt{g/l}$
Acceleration	$a = -\omega^2 x$	$a = -\frac{k}{m}x$	$a = -\frac{g}{l}x$
Angular frequency	$\omega = \frac{2\pi}{T}$	$\omega = \sqrt{\frac{k}{m}}$	$\omega = \sqrt{\frac{g}{l}}$
Time period	$T = \frac{2\pi}{\omega}$	$T = 2\pi\sqrt{m/k}$	$T = 2\pi\sqrt{\frac{l}{g}}$

Energy Conservation in SHM:

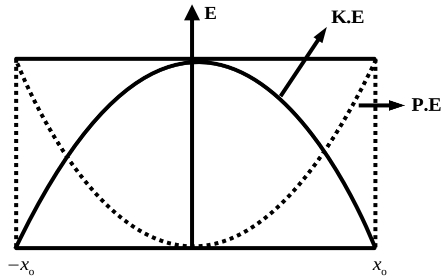
For horizontal mass springs system.

- Its K.E is given as;

  $K.E_{inst} = \frac{1}{2}k x_0^2\left(1-\frac{x^2}{x_0^2}\right)$

  $(K.E)_{max} = \frac{1}{2}kx_0^2$ At mean position

  $(K.E)_{min} = 0$ At extreme position.



- Its P.E is given as

  $P.E_{ins} = \frac{1}{2}kx^2$

  $(P.E)_{max} = \frac{1}{2}kx_0^2$ At extreme position

  $(P.E)_{min} = 0$ at mean position.

- Total energy of system $= \frac{1}{2}kx_0^2$ energy remains conserved in S.H.M.
- In one vibration K.E. attains its maximum value twice. So its frequency is 2f.

- The periodic exchange of energy between K.E and P.E is a basic property of all oscillatory systems.

TYPES OF OSCILLATIONS

Free Oscillations or Natural Oscillations

A body is said to be executing free vibrations when it oscillates without the interference of external force and its frequency is called natural frequency e.g., vibrating atoms in a solid.

Forced or Driven Oscillations

The oscillations under the influence of external force, e.g the vibrations produced by wooden board Instruments

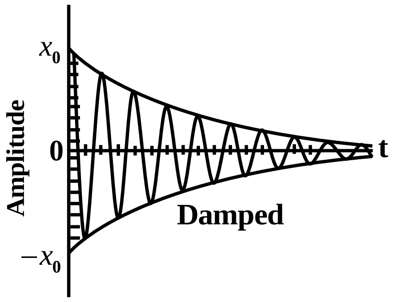
Free and Forced Oscillations:

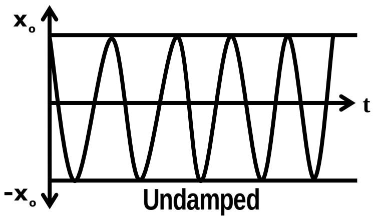
- Oscillation of a system is called free vibration if it oscillates without the interference of an external force.
- Frequency of free oscillation is called natural frequency of the system.
- When a system performs oscillation in the presence of external periodic force, its vibration is called forced oscillation.
- A physical system under going forced vibration is known as driven harmonic oscillator.

Damped Oscillation:

The oscillations in which the amplitude decreases steadily with time are called as damped oscillations.

- In shock absorber of a car critical damping is applied.





Resonance:

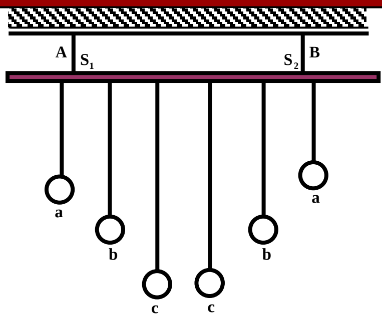
Remarkable increase in the amplitude of a vibrating body under the action of a periodic force whose time period is equal to natural time period of body

OR

Specific response of a system to external periodic force whose time period is equal to natural time period of a body

Did You Know?

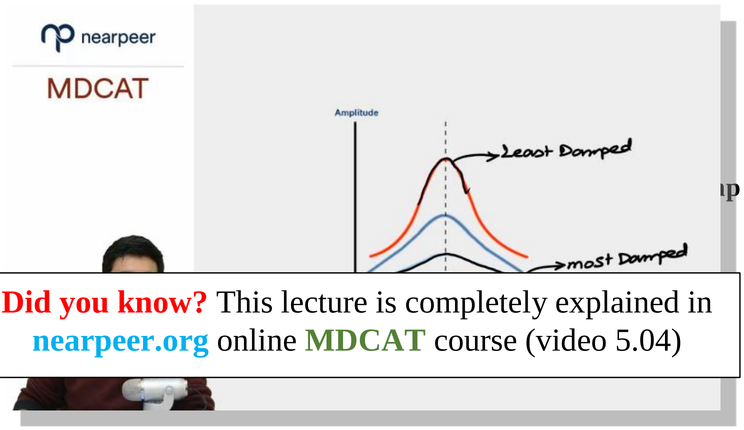
Damping is a process whereby energy is dissipated from the oscillating system.



- Suspension bridge may break down due to vibration with increased amplitude caused by resonance.
- Loose parts of car produce noise at specific speed due to resonance.

Sharpness of Resonance:

- Amplitude of vibration decreases with damping force.
- Amplitude of vibration remains constant with un damped force.
- Smaller the damped force, sharper is the resonance and vice versa.
-



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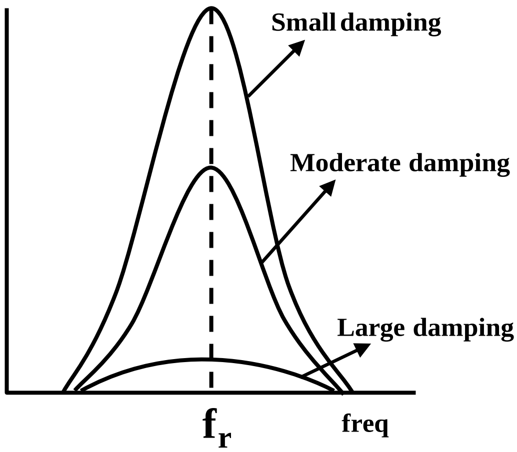


Did You Know?

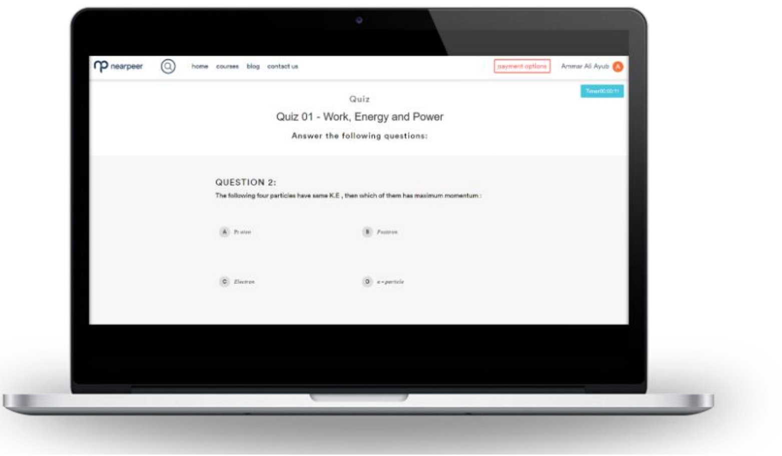
A microwave oven generates high frequency waves, which heat up water and fat molecules by large energy absorption, and hence food is cooked.

Did You Know?

For turning of radio, electrical resonance frequency is $f = \dfrac{1}{2\pi\sqrt{LC}}$

The waves produced in microwave oven have a wavelength of 12 cm and a frequency of 2450 MHz.

PRACTICE QUESTIONS



Q.1 In vibratory motion

A) P.E. remains constant
B) K.E. remain constant
C) Total energy remains constant
D) All of these

Q.2 If a spring is halved then the spring constant of each half will be

A) 3 k
B) 2 k
C) 4 k
D) k/2

Q.3 Total energy of a body executing S.H.M, is directly proportional to

A) Square root of amplitude
B) The amplitude
C) Reciprocal of amplitude
D) Square of amplitude

Q.4 The time period of a second's pendulum is

A) 4 seconds
B) 3 seconds
C) 2 seconds
D) 6 seconds

Q.5 If length of a pendulum becomes four times, then its time period will become
A) Four times
B) Six times
C) Eight time
D) Two times

Q.6 The force responsible for the vibratory motion of the simple pendulum is
A) mg cosθ
B) mg sinθ
C) mg tanθ
D) mg

Q.7 The tension in the string of simple pendulum is
A) Constant
B) Maximum at the extreme position
C) Maximum at the mean position
D) Zero at the mean position

Q.8 The SI unit of force constant is identical with that of
A) Force
B) Pressure
C) Surface tension
D) Loudness

Q.9 When the amplitude of a wave become double, its energy become
A) Double
B) Four time
C) One half
D) None time

Q.10 The total energy of SHM is maximum at
A) Mean position
B) Extreme position
C) In between mean and extreme
D) All positions have same maximum energy during SHM

Q.11 If a hollow bob of a simple pendulum be filled with mercury that drains out slowly, its time period
A) Increases continuously
B) Decreases continuously
C) Remain same
D) First increases then decreases

Q.12 For what displacement the P.E becomes 1/4 of its maximum value?
A) $x = x_o$
B) $x = x_o/2$
C) $x = x_o/4$
D) $x = x_o^2/2$

Q.13 Sharpness of resonance is
A) Directly proportional to damping force
B) Inversely proportional to damping force
C) Equal to square of damping force
D) Equal to square of damping force

Q.14 Which one does not work according to resonance?
A) T. V
B) Radio
C) Microwave oven
D) Bulb

Q.15 At Murree Hills (Assume value of g changes). If we use a simple pendulum as time standard, then one second duration will
A) Increase
B) Decrease
C) Remains same
D) Is zero

Q.16 Displacement of the body in S.H.M is equal to amplitude when body is at
A) Mean position
B) Else where
C) Extreme position
D) None

Q.17 For a simple pendulum the restoring force is caused by
A) Gravity
B) Spring
C) Hand
D) All of these

Q.18 The distance covered by a body in one complete vibration is 20 cm. What is the amplitude of body?
A) 10 cm
C) 15 cm

B) 5 cm D) 7.5 cm

Q.19 If the mass of the spring oscillator becomes half, its frequency will be

A) Quadruple C) $\sqrt{2}$ times
B) Half D) Remain same

Q.20 When a body moving in a circle completes a quarter of its cycle then the time for this part of vibration is

A) T C) T/3
B) T/2 D) T/4

Q.21 If angular velocity of a body moving in a circle is π rad/sec then frequency projection is

A) 2 Hz C) 0.5 Hz
B) 1 Hz D) 1.5 Hz

Q. 22 At which place, simple pendulum will vibrate the slowest?

A) Murree C) Centre of Earth
B) Mount Everest D) Karachi

Q. 23 At which place, the motion of simple pendulum becomes fastest?

A) Murree C) Lahore
B) Mount Everest D) Same at all places

Q. 24 The component of weight of bob of simple pendulum which is responsible to motion is

A) 2 cos θ C) zero
B) w sin θ D) w tan θ

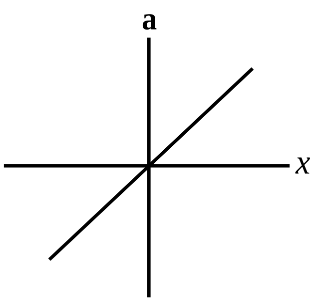
Q. 25 θ is small for simple pendulum so that

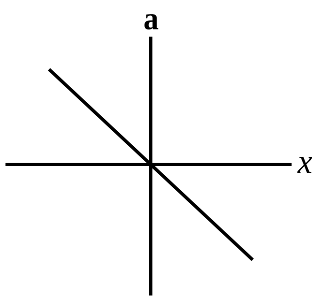
A) θ ≈ sin θ C) Friction is negligible
B) Its motion is linear D) All of these

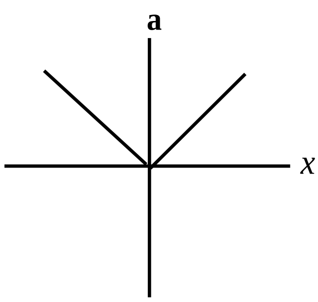
Q. 26 If a lift is falling freely then time period of a pendulum inside it is

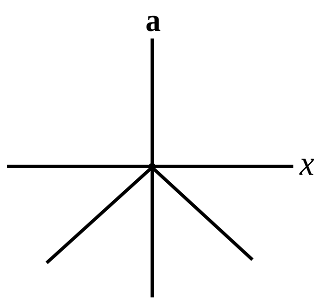
A) 0 C) Undefined
B) Minimum D) Variable

Q.27 Which one is the correct graph between acceleration 'a' and displacement 'x' for SHM?

A) 

B) 

C) 

D) 

Q. 28 Damping is used in (Damping is a process by which energy is dissipated)

A) Rotor of helicopter C) Shock absorber of car
B) Tuning of radio D) All of these

Q. 29 Natural frequency of a pendulum of length 9.8 m is

A) 2π Hz
C) 4π Hz
B) $\frac{1}{2\pi}$ Hz
D) $\frac{1}{4\pi}$ Hz

Q. 30 If for SHM, $x = \frac{1}{2} x_o$ then $\frac{\text{P.E}}{\text{Total energy}}$

A) $\frac{1}{2}$
C) $\frac{1}{4}$
B) 1
D) $\frac{1}{8}$

Q. 31 Two springs of spring constant K_1 and K_2 are joined in series. There is spring constant is

A) $\frac{K_1 + K_2}{2}$
C) $\frac{K_1 K_2}{K_1 + K_2}$
B) $K_1 + K_2$
D) $\sqrt{K_1 K_2}$

Q. 32 A spring block system is oscillating vertically with period T. if this system is taken to moon then its time period will be

A) $\frac{T}{3}$
C) $\frac{T}{6}$
B) $\frac{T}{\sqrt{6}}$
D) $T\sqrt{6}$

Q. 33 Which of the following are characteristics of SHM?

A) Acceleration is proportional to displacement
C) Frequency is independent of amplitude
B) Restoring force is proportional to displacement
D) All of above

Q. 34 A girl is swinging on a swing in the sitting position. How will the period of swing be affected if she stands up?

A) It will decrease
B) It will increase
C) It will remain same
D) It may increase or decrease depending on the height of girl

Q. 35 The resultant of two SHMs is also SHM if the two vibrating bodies have same

A) Time period
C) Phase
B) Frequency
D) All of these

Q. 36 Frequency of second's pendulum is

A) 0.5 Hz
C) 2 Hz
B) 1 Hz
D) 0.25 Hz

Q.37 Frequency of vibrating pendulum is independent of

A) Its amplitude
C) Value of g
B) Its length
D) All of these

Q.38 A particle executing S.H.M with time period of 2 sec and amplitude 5 cm. The maximum magnitude of the velocity is

A) 10π cm sec^{-1}
C) 2.5π cm sec^{-1}
B) 20π cm sec^{-1}
D) 5π cm sec^{-1}

Q.39 Ratio of P.E to total energy of a vibrating body at $x = \frac{x_o}{4}$

A) $\frac{15}{16}$
C) $\frac{7}{8}$
B) $\frac{1}{16}$
D) $\frac{1}{4}$

Q.40 At what distance from the mean position K.E becomes half of its maximum value in horizontal mass spring system

A) $\frac{x_o}{2}$ C) $\frac{x_o}{4}$

B) $\frac{x_o}{\sqrt{2}}$ D) $\frac{x_o}{2\sqrt{2}}$

Q.41 A body performs simple harmonic motion with a period of 6.3 s. The maximum speed of the body is 10 ms^{-1}. What are the values of the amplitude x_o and the angular frequency ω?

	x_o (m)	ω (rad s^{-1})
A)	0.030	100
B)	1.0	10
C)	10	1.0
D)	1.0	100

Q.42 The total energy of a particle executing SHM is

A) $\frac{1}{2}kx_o$ C) $\frac{1}{2}mx_o^2$

B) $\frac{1}{2}m\omega^2x_o^2$ D) $\frac{1}{2}m\omega x_o^2$

Q43 A spring of constant k is cut into two equal parts which are then joined parallel to each other. Then same load is hung from combination, spring constant of combination will be

A) k C) $\frac{k}{2}$

B) 2k D) 4k

Q.44 For a vibrating mass-spring system if $\frac{m}{k} = \frac{1}{4}$ kg m N^{-1} then its frequency is

A) $\frac{1}{\pi}$ Hz C) 2π Hz

B) $\frac{1}{4\pi}$ Hz D) $\frac{1}{2\pi}$ Hz

Q.45 Choose incorrect for a vibrating mass spring-system if its mass is halved

A) Time period would decrease by $\frac{1}{\sqrt{2}}$ times

B) Angular frequency would decrease by $\sqrt{2}$ times

C) Maximum velocity would increase by $\sqrt{2}$ times

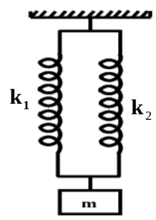
D) Acceleration would increase by 2 times

Q.46 At what displacement from mean position K.E would become $\frac{3}{4}$ of its maximum value

A) $\frac{x_o}{3}$ C) $\frac{1}{2}x_o$

B) $\frac{x_o}{\sqrt{3}}$ D) $\sqrt{\frac{2}{3}}x_o$

Q.47 The frequency of oscillation of the springs of same spring constants as shown in fig. will be



A) $\frac{1}{2\pi}\sqrt{\frac{k_1}{m}}$ C) $\frac{1}{2\pi}\sqrt{\frac{2k}{m}}$

B) $\frac{1}{2\pi}\sqrt{\frac{k}{2m}}$ D) $\frac{1}{2\pi}\sqrt{\frac{k_1 k_2}{(k_1+k_2)m}}$

Q.48 With the decrease of damping, the amplitude at resonance

A) Increases C) Remains same

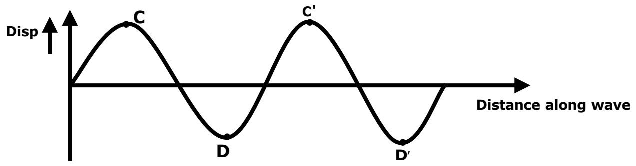
B) Decreases D) May increase and decreases

Q.49 When the length of a simple pendulum is doubled, find the ratio of the old frequency to the new frequency?

A) 2 C) $\sqrt{2}$

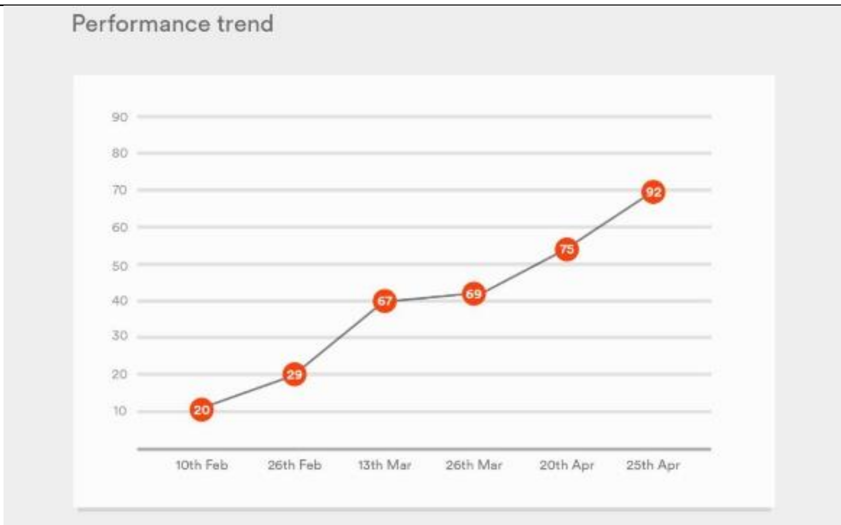
B) $\frac{1}{2}$ D) $\frac{1}{\sqrt{2}}$

Q.50 What is the distance between the points C and D′ in the transverse periodic wave shown in the figure



A) $\frac{\lambda}{2}$ C) $\frac{5\lambda}{2}$

B) $\frac{2\lambda}{3}$ D) 1.5 λ



ANSWERS WITH EXPLANATION

Q.1 **(C)** **Q.2** **(B)** **Q.3** **(D)** $E=\frac{1}{2}kx_o^2$ **Q.4** **(C)**

Q.5 **(D)** $T = 2\pi\sqrt{\frac{l}{g}}$; $T' = 2\pi\sqrt{\frac{4l}{g}}$; $T' = 2\left(2\pi\sqrt{\frac{l}{g}}\right)$; $T' = 2T$ **Q.6** **(B)**

Q.7 **(C)** Tension is maximum at mean position and minimum at extreme position

Q.8 **(C)** $K = \frac{F}{x}$ have same units as surface tension $= \frac{F}{l}$

Q.9 **(B)** $E = \frac{1}{2}kx_0^2$; $E' = \frac{1}{2}k(2x_0)^2$; $E' = 4(\frac{1}{2}kx_0^2)$; $E' = 4E$

Q.10 **(D)** Total Energy remains constant.

Q.11 **(D)** First C.G goes downward. After draining out it moves up ward.

Q.12 **(B)** $P.E = \frac{1}{2}kx^2$

$$\frac{1}{4}(P.E)_{max} = \frac{1}{2}kx^2$$

$$\frac{1}{4}\times\frac{1}{2}kx_0^2 = \frac{1}{2}kx^2$$

$$x = \frac{x_0}{2}$$

Q.13 **(B)** **Q.14** **(D)** **Q.15** **(A)** $T = 2\pi\sqrt{\frac{l}{g}}$ **Q.16** **(C)** **Q.17** **(A)**

Q.18 **(B)** $\frac{20}{4} = 5$ **Q.19** **(C)** **Q.20** **(D)** $t = \frac{T}{4}$

Q.21 **(C)** $\omega = \pi$

$2\pi f = \pi$

$f = \frac{1}{2}Hz$

Q.22 **(C)**

Q.23 **(C)** $T = 2\pi\sqrt{\frac{l}{g}}$ .Faster means less time period and it will be there where g is Maximum and it is in Lahore

Q.24 **(B)** **Q.25** **(A)** $\theta \approx \sin\theta$ when θ is very small

Q.26 **(C)** $T = 2\pi\sqrt{\frac{l}{g}}$

$T = 2\pi\sqrt{\frac{l}{0}} = \infty$

Q.27 **(B)** **Q.28** **(C)** **Q.29** **(B)** $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$

Q.30 **(C)** $\frac{P.E}{T.E} = \frac{1/2kx^2}{1/2kx_0^2} = \frac{\left(\frac{x_0}{2}\right)^2}{x_0^2} = \frac{1}{4}$

Q.31 **(C)** $K = \frac{Product}{Sum} = \frac{k_1k_2}{k_1 + k_2}$

Q.32 **(D)** $T = 2\pi\sqrt{\frac{l}{g}}$ $\frac{T}{T'} = \sqrt{\frac{g'}{g}}$ $\frac{T}{T'} = \sqrt{\frac{\frac{g}{6}}{g}}$ $T' = T\sqrt{6}$

Q.33 **(D)**

Q.34 **(A)** It C.G will move upward so length of pendulum will decrease and Time period will decrease

Q.35 **(D)** **Q.36** **(A)** $T = 2s \;\; f = 0.5\,Hz$ **Q.37** **(A)** $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$

Q.38 **(D)** $v_o = x_o\omega = 5\pi$ **Q.39** **(B)** $\frac{P.E}{T.E} = \frac{\frac{1}{2}kx^2}{\frac{1}{2}Kx_0^2} = \frac{1}{16}$

Q.40 **(B)** $K.E = \frac{1}{2}(K.E_{max}) = \frac{x_o}{\sqrt{2}}$ **Q.41** **(C)** **Q.42** **(B)** **Q.43** **(B)**

Q.44 **(A)** $f = \frac{1}{2\pi}\sqrt{k/m}$ **Q.45** **(C)** **Q.46** **(C)** **Q.47** **(C)** **Q.48** **(A)**

Q.49 **(C)** **Q.50** **(D)**

UNIT 06

Waves

WAVES

- **Wave is a disturbance produced in a medium by which energy is transferred from one point to another point by the vibration of particles of medium.**
- Waves transport energy and momentum without transporting matter.

Type of Waves

Mechanical Waves

Which require medium for their propagation and they propagate by the vibrating particles e.g.,waves in a string and sound waves etc.

Electromagnetic Waves

Which do not require any medium for their propagation and they propagate by the oscillating electric and magnetic fields e.g., light, radio waves etc.

Matter waves

Wave properties associated with the micro particles traveling with speeds comparable to that of light (Discussed in detail) in chapter 19)

Did You Know?

Ultrasonic waves are used for under sea communication because their frequency is greater than 20,000 Hz and their penetrating power in water is very large.

PROGRESSIVE WAVES:

- Progressive wave transfers energy in moving away from the source disturbance.

Types of progressive Waves

Mechanical Waves

Transverse waves are those in which Particles of the medium are displaced in a direction perpendicular to the direction of propagation of waves. e.g., waves in a string, water waves etc.

Matter waves

Longitudinal waves are those in which particles of the medium are displaced along the direction of propagation of waves. e.g. sound waves etc.

- A wave pulse is one of a series of periodic waves

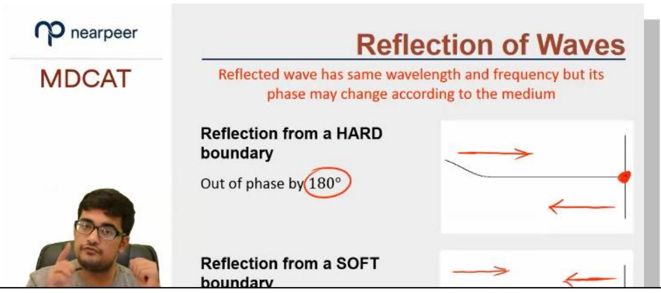
Did You Know?

Both types of progressive waves can be set up in solids. In fluids, transverse waves die out quickly

PERIODIC WAVES:

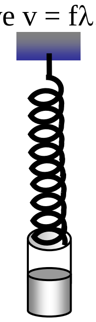
- The source of periodic waves is a periodically oscillating body.
- Distance between two consecutive crests or troughs is wavelength λ.
- Distance between a crest and neighboring trough is $\frac{\lambda}{2}$.
- Number of waves passing through a point per second is called frequency f.
- Time taken by crest to cover a distance λ is called time period T or time taken by one wave to pass through a certain point is called time period T.

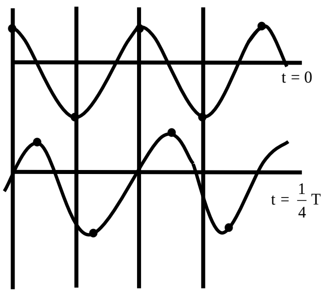
$$\boxed{f = \frac{1}{T}}$$



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 6.01)

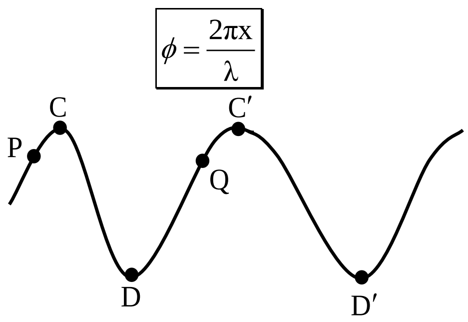
- Velocity o ... ve v = fλ.
- Transverse waves cannot propagate in a gas or a liquid because there is no mechanism for driving motion perpendicular to the propagation of the wave. In longitudinal waves the displacement of the medium is parallel to the propagation of the wave. Sound waves in air are longitudinal waves.
- In fluids, transverse waves die out very quickly and usually cannot be produced at all.
- Velocity of wave v = fλ.





Phase of wave:

- Any two points separated through distances of λ, 2λ, 3λ .... are all in phase.
- Any two points separated from one another by $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$,............ are out of (opposite phase).
- The particles in the wave separated by a distance which is integral multiple of λ i.e. n λ are in phase motion with each other.
  Phase angle ϕ between any two points on a wave x meters apart is



The particles separated by a distance which is odd multiple of λ i.e.: $\left(n+\frac{1}{2}\right)\lambda$ are out phase to each other

Did You Know?

The waves transport both energy and momentum in a medium.

SOUND

- Sound is a form of energy
- Sound is produced by a vibrating body (λ≈ 1 m).
- Three things are essential for the detection of sound.
  - (i) Vibrating body for production of sound.
  - (ii) Medium for propagation of sound.
  - (iii) Listener (ear) for the detection of sound.
- Sound waves are longitudinal waves having three dimensional propagation in air.
- Longitudinal sound waves consist of compressions and rarefactions.
- Compression is a region where crowding of particles of medium is maximum.

Wave	Speed (m/s)
EM waves	300 000 000
Sound in air	332
Sound in water	1483
Sound in steel	5000

- Rarefaction is region where crowding of particles of medium is minimum.
- Sound waves produce Reflection, Refraction, Diffraction, interference but not polarization because sound waves are longitudinal.

Audible frequency Range:

- An average human ear can hear a sound in the frequency range 20 Hz to 20,000 Hz.
- The sound waves with frequencies higher than 20,000 Hz are called ultrasonic and sound waves having frequencies lower than 20 Hz are called infrasonic.

- Both ultrasonic and infrasonic are not heard by human ears. The ear is most sensitive for the sound of frequencies ranging between 2000 to 4000 Hz.

Acoustics:

- The application of the scientific study about the sound in designing a building, halls, concert rooms etc is called acoustics.

- If the buildings are not acoustically well-designed, one hears loud sound at some spots and very feeble at other sports. Such spots are respectively known as loud spots and dead spots. The factors which badly affect the acoustics of big halls are:
  (i) Resounding's or Echoes (ii) Reverberation of sound. (iii) Focusing of sound
  In a well-acoustically designed building, we should take the following steps:

- The distance between the walls should be less than 17m to avoid echo.

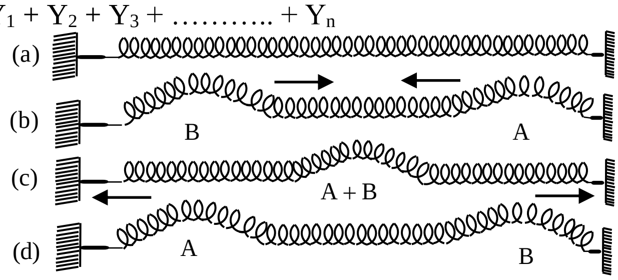
- Cover walls and the ceilings with sound absorbing materials.

- Avoid continuous flat and smooth walls.
- Avoid in designing curved walls and spherical surface on the ceilings.

Principle of superposition:

- When two or more waves reach a point of the medium simultaneously then the resultant displacement of that point of the medium is equal to sum of the individual displacements produced by each wave. This is called principle of superposition.

$$Y_{total} = Y_1 + Y_2 + Y_3 + \ldots\ldots\ldots + Y_n$$



Stationary waves:

Super position of two identical, waves traveling opposite to each other in the same medium simultaneously, gives rise to stationary or standing waves.

- Both constructive, and destructive interference takes place in the formation of stationary waves.

- Points of constructive interference are called antinodes while points of destructive interference are called nodes.

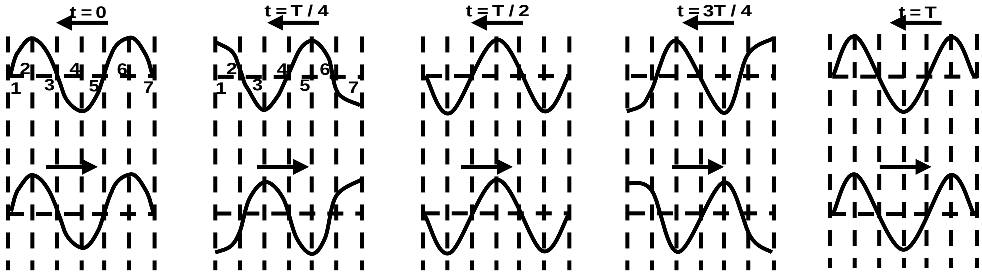
- Amplitude is maximum at antinodes and minimum (zero) at nodes.

- Nodes are stationary points whereas antinodes are points that vibrate with maximum amplitude.

- Two consecutive nodes or antinodes are separated by distance equal to $\lambda/2$ and an antinodes and its consecutive node by $\lambda/4$.

Did You Know?

Energy in a wave moves because of the particles of the medium. The nodes in stationary wave always remain at rest so energy does not flow past these points. The energy stored in antinodes at their extreme point is potential while at mean position, energy stored is wholly kinetic but total energy remains same.

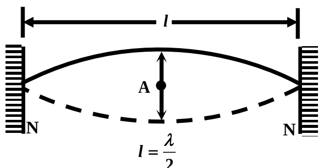


Stationary waves in stretched string:

- At fixed end of string always node is formed while at free end of string always antinode is formed.
- If string is fixed at both ends, then number of nodes is one greater than number of antinodes. N = A + 1.
- If string is free at one to end, then number of antinodes is equal to that of nodes. A = N

$$V = \sqrt{\frac{T}{m}} = \sqrt{\frac{F}{m}}$$

m is called linear mass density.



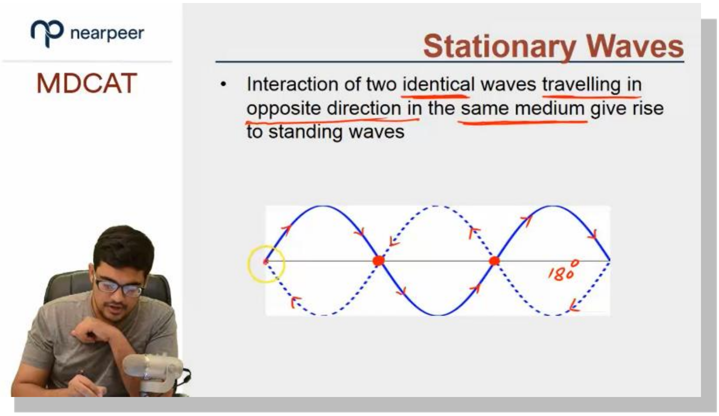
- Only the following quantized frequencies of transverse stationary waves on stretched string can be produced

$$f_n = n f_1, n = 1, 2, 3, ...$$

Where

$$f_1 = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

f_1 is the lowest frequency (fundamental or basic frequency) at which first stationary wave is formed.



The wavelength of stationary waves in stretched string are given by $\lambda n = \frac{2l}{n}$

Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 6.02)

- All other frequencies (f_2, f_3, ……
called overtones

Longitudinal Stationary Waves In air column

Open Pipe:

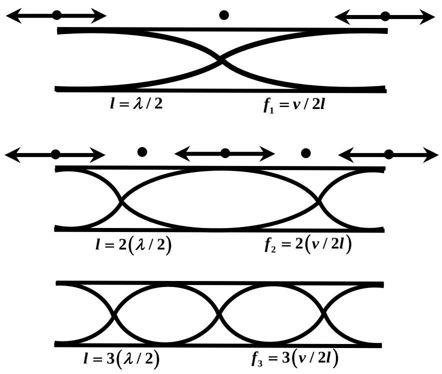
In fundamental mode of vibration, an antinode will be formed at either end with a node between them.

The fundamental frequency and wavelength or first harmonic of an open air column is given by

$$f_1 = \frac{v}{2l} \text{ and } \lambda_1 = \frac{2l}{1}$$

Where v = velocity of sound

l = length of pipe or air column



- All harmonics are present in open organ pipe, so

$f_2 = \frac{2v}{2l}$ (2nd harmonic or 1st overtone)

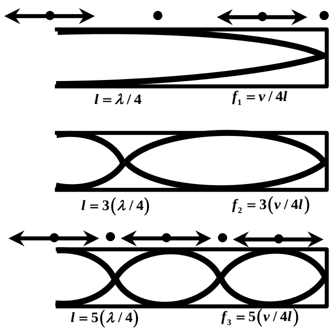
$f_3 = \frac{3v}{2l}$ (3rd harmonic or 2nd overtone)

$f_n = \frac{nv}{2l}$ and $\lambda n = \frac{2l}{n}$

n = mode = harmonic = 1,2,3, …………………

Closed Pipe:

- In closed pipe, at the closed end there is always node while at open always an antinode.
- The fundamental frequency and wavelength of 1st harmonic is



$f_1 = \frac{v}{4l}$ (1st harmonic)

$f_5 = \frac{5v}{4l}$ (5th harmonic or 2nd overtone)

$f_n = \frac{nv}{4l}$ and $\lambda_n = \frac{4l}{n}$

Did You Know?

In stretched string, if n are the number of loops of stationary waves in a stretched string

plucking point = $\frac{1}{2n}$ (the length of string).

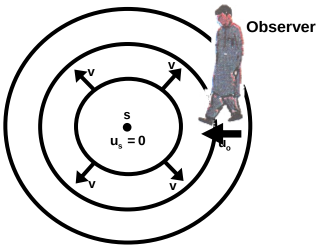
The frequency of vibrating string in a musical instrument can be changed either by varying the tension or by changing the length of vibrating string e.g., guitar is tuned by tightening the pegs. Once the instrument is tuned, the musicians vary the frequency by moving their fingers along the neck and hence changing the length of vibrating portion of string.

Doppler's Effect:

Apparent change in the frequency of wave due to relative motion between source and observer is called Doppler's Effect

- If source (star) is approaching the earth; there is a blue shift, i.e. wavelength decrease and frequency increase.
- source (star) moving away from the earth show a red shift; i.e. wavelength increases and frequency decreases.
- Doppler's effect is applicable to both sound and light.

Cases:



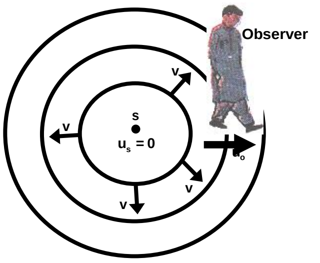
- If observe moves towards stationary source with velocity u_o, then

Apparent frequency $f_A = \left(\frac{v+u_o}{v}\right)f$

v = velocity of wave
f = source frequency

$$f_A > f$$

If observer moves away from stationary source with velocity u_o then



$$f_B = \left(\frac{v-u_o}{v}\right)f$$

$$f_B < f$$

- If source moves towards stationary observer with velocity u_s, then

$$f_C = \left(\frac{v}{v-u_s}\right)f$$

$f_C > f$ and $\lambda' < \lambda$

- If source moves away from stationary observe with velocity u_s. then

$$f_D = \left(\frac{v}{v+u_s}\right)f$$

$f_D < f$ and $\lambda' > \lambda$

- If both source and observe are approaching towards each other then

$$f' = \left(\frac{v+u_o}{v-u_s}\right)f$$

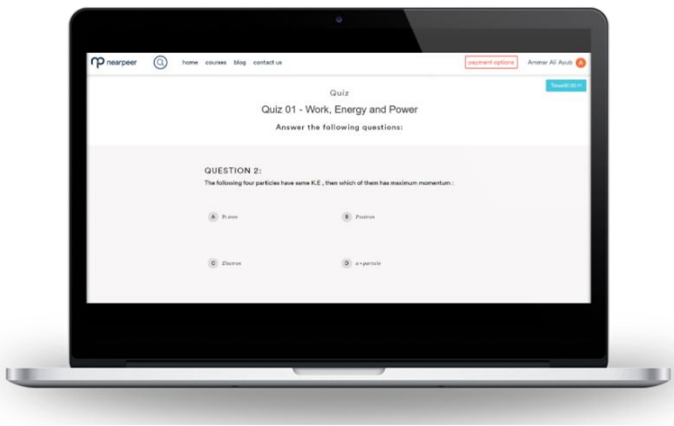
- If both source and observer are moving away from each other then

$$f' = \left(\frac{v - u_o}{v + u_s}\right) f$$

Applications of Doppler's Effect:

- If the frequency of the reflected electromagnetic wave from aeroplane, increases, then it is approaching radar system and vice versa.
- Sonar $\rightarrow$ Sound navigation and ranging
- Uses ultrasonic waves to determine position and speed of submariner it.
- Stars galaxies moving towards the earth show a blue shift in spectrum (wavelength shorter) and stars moving away show red shift in spectrum (wavelength longer)
- Speed trap and bat use Doppler's effect.

PRACTICE QUESTIONS



Q. 1 Star, moving towards earth show a

A) Red shift
B) Blue shift
C) No shift
D) Yellow shift

Q. 2 If the star is moving away from the earth; the wavelength of the waves emitted from the star have a

A) Longer wavelength
B) Smaller wavelength
C) No shift
D) Yellow shift

Q. 3 The pitch of the sound of an approaching locomotive appears to be

A) High
B) Low
C) Same as at rest
D) All of these are possible

Q. 4 Doppler's effect is applicable to

A) Sound waves
B) Electro magnetic waves
C) Radio waves
D) All of these

Q. 5 **An observer is moving towards stationary source with velocity $\frac{v}{3}$. The apparent frequency would be if v is the speed of sound and f is the original frequency**

A) $\left(\frac{4}{3}\right)f$

B) $\left(\frac{2}{3}\right)f$

C) $\left(\frac{3}{4}\right)f$

D) $\left(\frac{3}{2}\right)f$

Q. 6 **The linear distance between any two nearest points of a medium vibrating in phase is**

A) $\frac{\lambda}{2}$

B) $\frac{\lambda}{4}$

C) λ

D) 2λ

Q. 7 **A stationary wave has frequency 165 Hz (speed of sound in air = 330) distance between two consecutive nodes is**

A) 2 m

B) 1 m

C) 0.5 m

D) 4 m

Q. 8 **The energy transmitted per second per unit area held perpendicular direction of propagation of waves is called ____________ of sound.**

A) Loudness

B) Quality

C) Pitch

D) Intensity

Q. 9 **The principle of superposition states that the total displacement due to waves is equal to ____________ of the displacement is due to those waves individually.**

A) Vector sum

B) Scalar product

C) Vector product

D) Scalar product

Q. 10 **Ratio of third mode frequencies for closed pipe to open pipe is**

A) 3: 5

B) 5: 3

C) 1: 3

D) 1: 1

Q.11 **If the radar waves are reflected by an Aeroplane and wavelength of reflected waves decreases then Aeroplane is**

A) Stationary

B) Moving towards Radar

C) Moving away from Radar

D) Either A nor B

Q.12 **The 4th mode frequency of a stationary wave in a string fixed at two ends of open pipe is (where f_1 is fundamental frequency)**

A) $4 f_1$

B) $5 f_1$

C) $6 f_1$

D) $7 f_1$

Q.13 **A stretched string of length 1 m vibrates with a fundamental frequency of 1 Hz. The velocity of wave is**

A) 2 m/s

B) 1 m/s

C) 3 m/s

D) 4 m/s

Q.14 **A stretched string of length 1 m vibrates in five segments. The wavelength of the wave in the string is**

A) 0.2 m

B) 0.4 m

C) 0.6 m

D) 0.8 m

Q.15 **If the wavelength of light coming from a galaxy shifts towards the red end of spectrum, then galaxy is**

A) Stationary

B) Approaching Earth

C) Receding the Earth

D) Approaching Earth or is stationary

Q.16 **Only odd harmonics are present in**

A) Open pipe only
B) Closed pipe only
C) Both open and closed pipes
D) Stretched string

Q.17 If λ_1 is the wavelength of sound wave in air column in the first wavelength in the 3rd mode for closed pipe of length / will be

A) $\frac{4l}{3}$
B) $\frac{4l}{5}$
C) $\frac{4l}{7}$
D) $\frac{2l}{3}$

Q.18 If tension in the vibrating string is increased by four times, then velocity in it

A) Increases by two times
B) Increases by four times
C) Decreases by two times
D) Decreases by four times

Q.19 If an observer moves towards a source and source moves away from the with the same velocity then apparent frequency of light waves

A) Increases
B) Decreases
C) Remains unchanged
D) May increase or decrease

Q.20 If a person moves away from stationary source of sound with speed half of the speed of sound, then frequency of sound waves heard by person will be

A) Doubled
B) Unchanged
C) Halved
D) Increased by 1.5 times

Q.21 A certain stretched string produces a frequency 'f.' if the same produce of frequency twice as high, the tension of string should be

A) Doubled
B) Quadrupled
C) Increased by a factor $\sqrt{2}$
D) Decreased by a factor of $\sqrt{2}$

Q.22 If two waves of amplitude "a" produce a resultant wave of amplitude" a", then the phase difference between them will be

A) 60°
B) 90°
C) 180°
D) 120°

Q.23 A source of sound is moving towards a stationary observer with $\frac{1}{10}$ of the speed of sound. The ratio of apparent to actual frequency of sound is

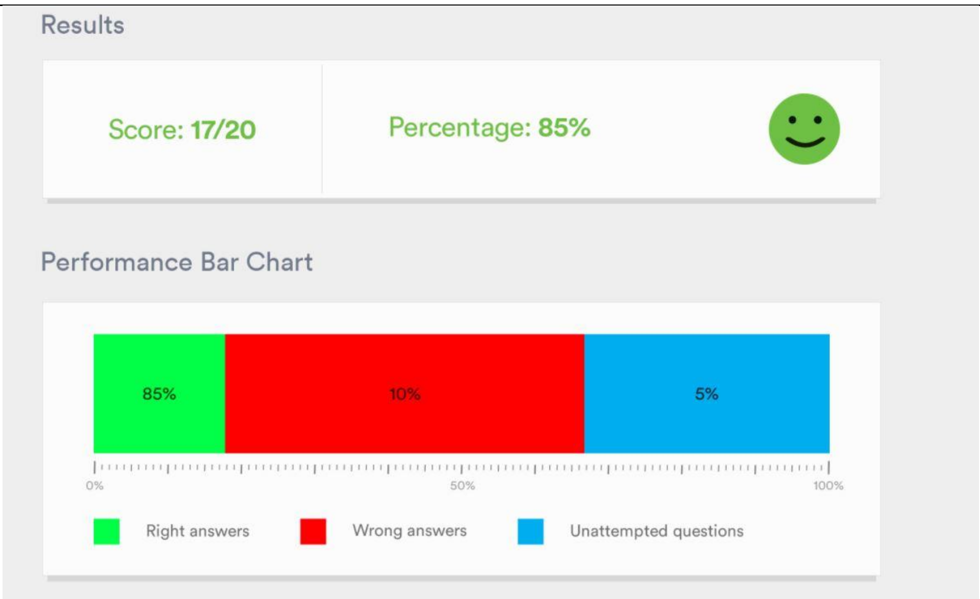
A) $\frac{10}{9}$
B) $\frac{11}{10}$
C) $\frac{11}{9}$
D) $\frac{9}{11}$

Q.24 The sonometer wire is vibrating in the second overtone. There are

A) Two nodes and two antinodes
B) One node and two antinodes
C) Four nodes and three antinodes
D) Three nodes and three antinodes

Q.25 A tuning fork produces waves in a medium. If the temperature of the medium changes, then which of the following will change

A) Amplitude
B) Frequency
C) wavelength
D) time period



When you solve a quiz on www.nearpeer.org, you see much detailed analysis of your results. The above picture shows performance chart. Understanding of this can prepare you better for scoring 1000+ marks in MDCAT.

ANSWERS WITH EXPLANATION

Q.1 **(B)** **Q.2** **(A)** **Q.3** **(A)** **Q.4** **(D)**

Q.5 **(A)** $f_A = \left(\frac{v+\frac{v}{3}}{v}\right) f = \left(\frac{4v}{3v}\right) f$ $\boxed{f_A = \left(\frac{4}{3}\right) f}$

Q.6 **(C)** **Q.7** **(B)** $v = f\lambda$ **Q.8** **(D)** **Q.9** **(A)** **Q.10** **(B)** **Q.11** **(B)**

Q.12 **(A)** **Q.13** **(A)** **Q.14** **(B)** $\lambda_n = \frac{2l}{n}$ **Q.15** **(C)** **Q.16** **(B)**

Q.17 **(B)** $l_n = \frac{4l}{n}$ **Q.18** **(A)** **Q.19** **(C)** **Q.20** **(C)** $f_B = \left(\frac{v-u_o}{v}\right) f$

Q.21 **(B)** $f = \frac{1}{2l}\sqrt{F/m}$ **Q.22** **(D)** **Q.23** **(A)** $f_C = \left(\frac{v}{v-u_o}\right) f$

Q.24 **(C)** $n = 3$ **Q.25** **(C)** $v = f\lambda$

UNIT 07

Light

Light

Wave front is locus of all points which have same of vibration

Wavefront

- **Spherical Wavefront**: **Set of points determining surface of a sphere**
- **Cylinderical Wavefront**: **Set of points determining surface of a sphere**
- **Plane Wavefront**: **A small part of spherical or cylinderical wavefront at large distances**

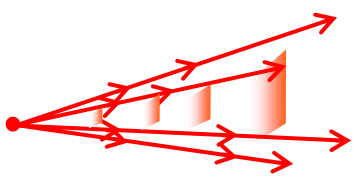
- Point light source produces spherical wave fronts.
- When a point source is placed at focus of converging lens, plane wave fronts are obtained in laboratory.
- Plane wave fronts reach from the Sun to the Earth, as the earth is far off from the sun.
- The distance between two consecutive wave fronts is one wavelength.
- A line normal to the wave front including the direction of motion is called a ray of light

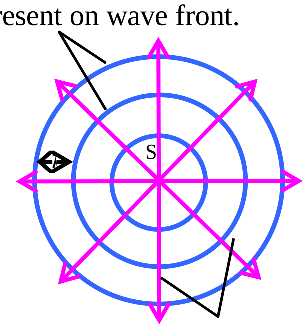
Did You Know?

When a point source is placed at focus of converging lens, plane wave fronts are obtained.

Huygens's Principle:

- Every point on wave front acts as a source of secondary spherical wavelets, which propagate in forward direction with speed of light
- Position of new wave front is tangent envelope to all of secondary wavelets.
- Radius of hemisphere = c Δ t
- There is an infinite number of secondary wavelets present on wave front.

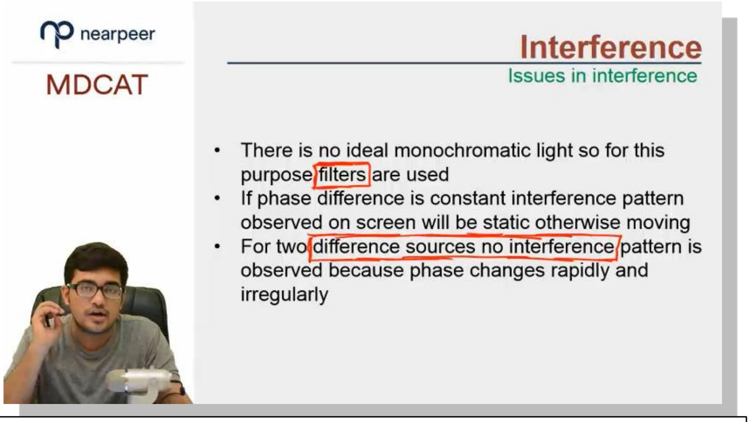




Interference of light:

Interference is a superposition of two light waves of same frequency and same amplitude propagating in same medium along same direction very close to each other.

- For constructive interference, light waves reach a point in phase and their path difference = $n\lambda$
- For destructive interference, light waves reach a point in out of phase and their path difference $= (2n+1)\frac{\lambda}{2}$



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 7.01)

Conditions for interference of light:

(i) Monochromatic (Having single wave length)
(ii) Coherence (Having constant phase difference)
(iii) Same direction
(iv) Same medium
(v) Very close to each other.

- There is no perfect monochromatic source, but by using filters it is possible to produce a source that gives light whose wavelength differ by $\pm 5 \times 10^{-10}$ m.
- If phase difference between two waves remains constant, then interference pattern will be stationary on screen otherwise it will change continuously.

Young's Double Slit Experiment:

- First experimental proof in favor of wave nature of light was provided by Mr. Thomas young in 1801.
- Path difference = $d \sin\theta$
- For bright fringes;
  $d \sin\theta = m\lambda$ 1st bright fringe at m = 1
- For dark fringes $d \sin\theta = (2m+1)\frac{\lambda}{2}$ 1st dark fringe at m = 0
- Vertical distance of bright fringe from central maxima

  $$\mathbf{y_m = \frac{m\lambda L}{d}}$$ (Position of mth bright fringe)
- Vertical distance of dark fringe from central maxima

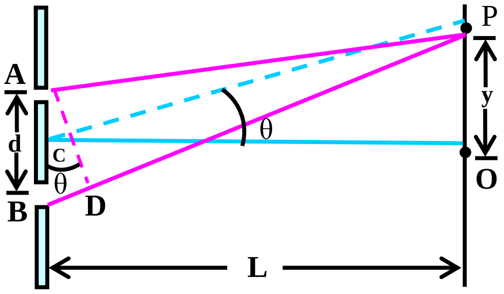
$$Y_m = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} \qquad \text{(position of mth dark fringe)}$$

Where L = perpendicular distance between slits and screen

- Distance between centres of two consecutive dark fringes or bright fringes is called fringe width or fringe spacing

$$\Delta y = \frac{\lambda L}{d}$$

(Applicable both for bright or dark fringes)



- Fringe width can be increased by

$\Delta y \propto \lambda$ (increasing λ)

$\Delta y \propto L$ (increasing L)

$\Delta y \propto 1/d$ (decreasing d)

Did You Know?

At centre of screen, we get zeroth order maximum and there is no order minimum.

Knowledge plus

- **Incandescent objects** are the objects which emit light when they are heated e.g. filament electric bulb.
- **Luminous objects** are the objects which emit their own light e.g fireflies, sun and stars etc.
- **Non-Luminous objects** are the objects which are visible due to light reflected by them e.g. book paper and moon etc.

DIFFRACTION OF LIGHT:

The bending of light near the edges of an obstacle or slit and spreading of light in the shadow region to form interference fringes is called diffraction.

- For diffraction, size of slit or obstacle should be very small and it should be comparable to the wavelength of light.
- The smaller is the size of diffracting object (obstacle), the higher the degree of diffraction is observed.
- Diffraction is a special type of interference of large number of secondary wavelets.

> **Did You Know?**
> Interference fringes width is uniform whereas diffraction fringes are wider near the obstacle and they become small as we move away from it.

Differences between interference and diffraction:

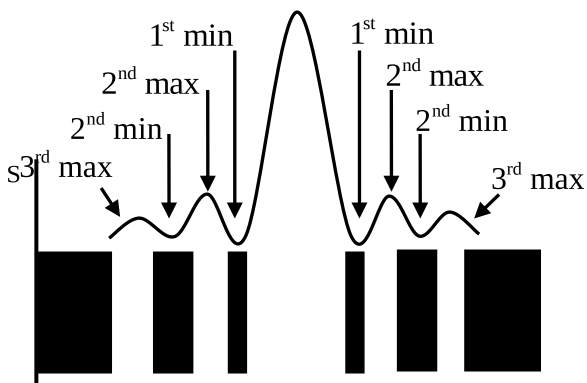
	Interference		Diffraction
(i)	Superposition of few secondary wavelets is involved	(i)	Superposition of large number of secondary wavelets is involved
(ii)	Interference fringes are equal in size	(ii)	Diffraction fringes wide near diffracting object and become small as one move away from it.
(iii)	Interference fringes are equally spaced	(iii)	Diffraction fringes become narrow as distance from diffracting object increases.
(iv)	Points of destructive interference are perfectly dark.	(iv)	Points of minimum intensity are not perfectly dark.

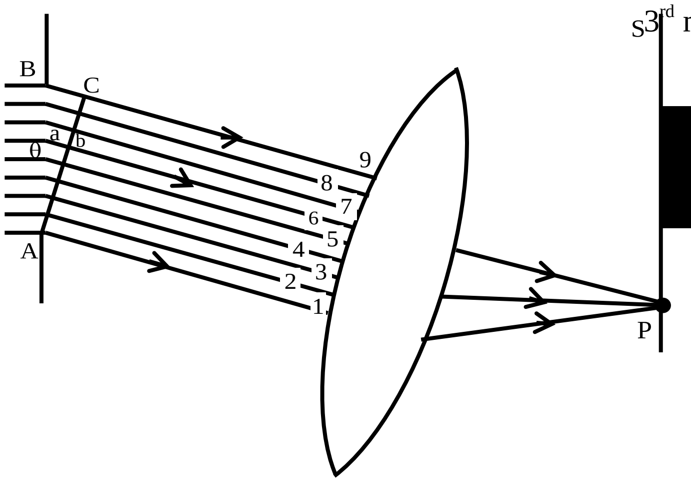
DIFFERACTION DUE TO A NARROW SLIT:

- Diffraction due to a narrow slit has central maximum and alternating secondary minima and maxima on its both sides.
  For the mth order minimum on either side of central maximum

$$d \sin\theta = n\lambda$$

Where d = width of slit
θ = **Angle** of diffraction





DIFFRACTION GRATTING:

A diffraction grating is a glass plate having a large number of closed parallel equidistant slits mechanically ruled on it.

- The transparent spacing between the scratches on the glass plate act as slits.
- A typical diffraction grating has about 400 to 5000 lines per centimeter.

$$d = \frac{1}{N}$$

d = grating element = distance between two adjacent lines
N = 0, 1, 2, 3,……….

- Suppose monochromatic light is directed at the grating parallel to its axis as shown.
- The diffraction pattern on the screen is the result of the combined effects of diffraction and interference.
- Each slit causes diffraction, and the diffracted beams in turn interfere with one another to produce the pattern.
- If the path difference equals one wavelength of some integral multiple of a wavelength, waves from all slits will be in phase and a bright line will be observed. Therefore, the condition for maxima in the interference pattern at the angle θ is

$$d \sin \theta = m \lambda \text{ where } n = 0, 1, 2, 3 \ldots.$$

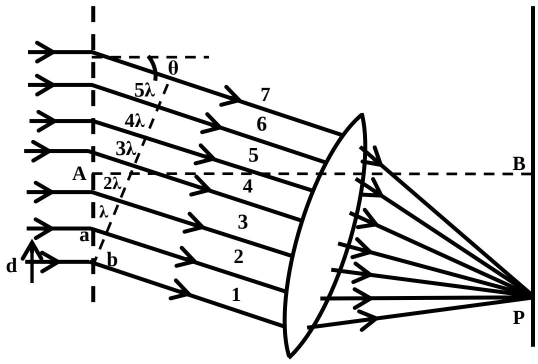
- Because d is very small for diffraction grating, a beam of monochromatic light passing through a diffraction grating splits into very narrow maxima (bright fringes) at large angles θ.

Did You Know?

Practically a diffraction grating is a piece of glass with 400 → 5000 lines per cm.

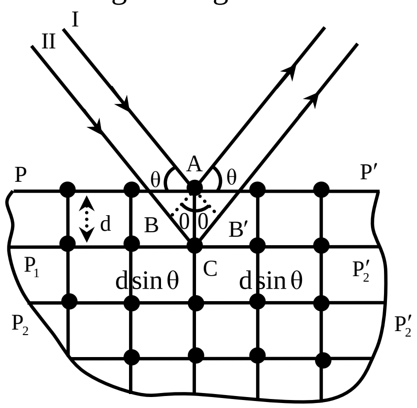
Interesting information

The fine rulings, each 0.5 μm wide, on a compact disc function as a diffraction grating. When a small source of white light illuminates a disc, the diffracted light forms colored "lanes" that are composite of the diffraction patterns from the rulings.



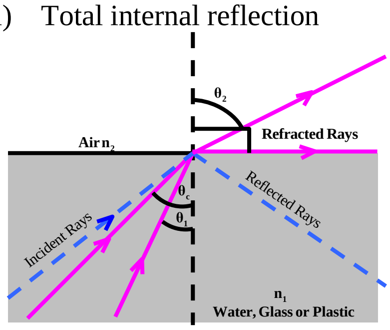
Diffraction of X-rays by Crystals:

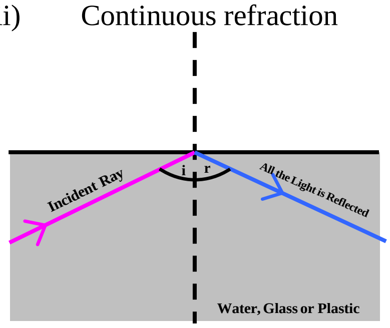
- A usual diffraction grating can not diffract X-Rays because wavelength of X-Rays is smaller than visible light.
- Solid crystals behave as very good natural diffraction gratings and incident ultraviolet light is diffracted from layers of atoms.
- Bragg's law is given as $\mathbf{2d\ sin\theta = n\lambda}$
  Where 'd' is called lattice spacing and θ is called angle of diffraction.
- Hemoglobin structure and double helix structure of DNA is determined by X–rays diffraction.
- Diffraction proves that wavelength of light is smaller than that of sound

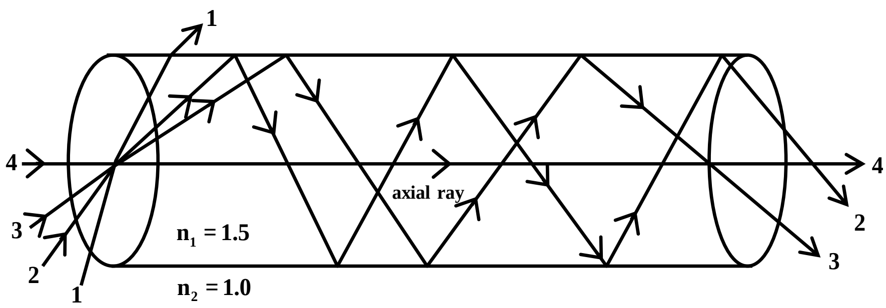


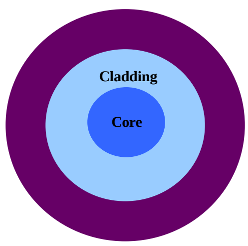
FIBRE OPTICS

- Optical fibre has much higher bandwidth capacity and has immunity from electromagnetic interference as compared with radio waves. Fiber optic system has much thinner and light weight cables.
- Graham Bell invented **photo phone** to transmit voice massage via beam of light.
- In optical fiber, light is used as a **transmission carrier wave.**
- The principle of transmitting signals through optical fibre is
  (i) Total internal reflection (ii) Continuous refraction





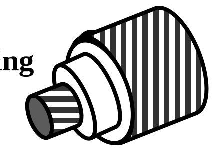




CLASIFICATION OF OPTICAL FIBRES:

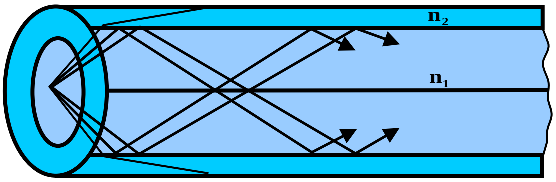
Single mode step index fiber:

It is also called mono mode fibre & has very narrow core of diameter about 5 μm.



Multimode step index fiber:

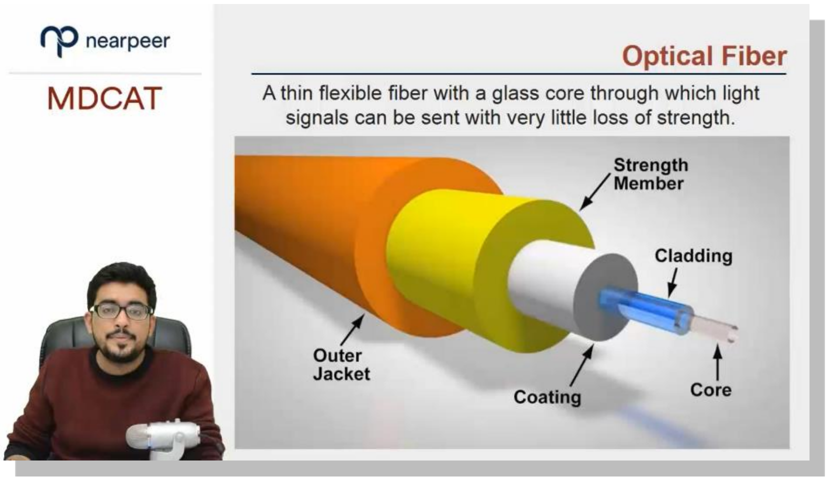
It has larger core (50μm) of constant refractive index. Refractive index changes at the boundary of core and cladding. It is useful for a short distance only. The mode of transmission in it is total internal reflection.



Multimode graded index fiber:

In it, core has diameter from 50 to 1000 μm. There is no noticeable boundary between core and cladding. The mode of transmission of light in it is continuous refraction. It is suitable for long distance transmission to which light is used.

- Critical angle is minimum for violet light.
- In case of total internal reflection Refractive index = $\frac{1}{\sin c}$



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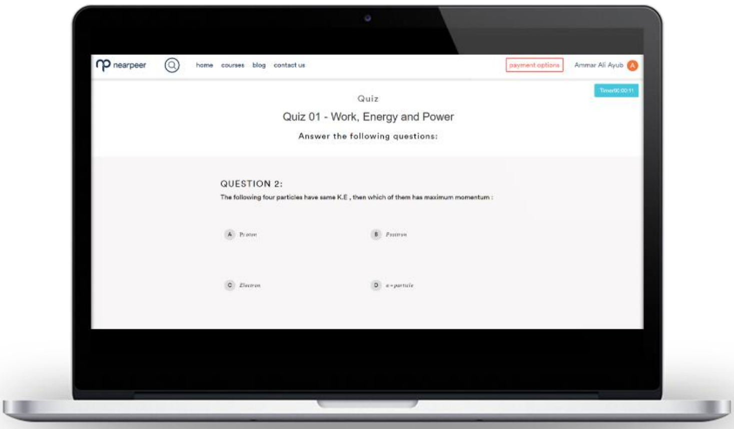
PRACTICE QUESTIONS



Q.1 The ray of light and wave front

A) Parallel
B) Antiparallel
C) Perpendicular
D) At 60° with each other

Q.2 Wavelength of x-rays falling at an angle of 30° on a crystal with inter planar atomic spacing 1×10^{-10} m for first order reflection is (by using Bragg's law)

A) 2×10^{-10}
B) 0.5×10^{-10} m
C) 1×10^{-10} m
D) 0.2×10^{-10} m

Q.3 If whole apparatus of YDSE is placed in water, fringe spacing will

A) Increase
B) Decrease
C) Remain same
D) Increase or decrease depending upon shape of apparatus

Q.4 Twinkling of stars is due to

A) Non-continuous emission of light by stars
B) Fluctuation of refractive index of Earth's atmosphere
C) Intermittent absorption of star light by Earth's atmosphere
D) All of above

Q.5 Interference and diffraction show

A) Wave nature of light
B) Particle nature of light
C) Dual nature of light
D) Longitudinal wave nature of light

Q.6 If slit spacing in Young's experiment is 0.001 mm an second order bright fringed is observed at an angle of 90° then wavelength of light is

A) 5 nm
B) 50 nm
C) 500 nm
D) 5000 nm

Q.7 If slit spacing in Young's experiment is 0.001 mm and second order maxima is observed at vertical distance of one tenth of the distance between slits and screed then wavelength of light is

A) 5 nm
B) 50 nm
C) 500 nm
D) 5000 nm

Q.8 Sky is blue to

A) Scattering of light
B) Interference of light
C) Diffraction of light
D) Refraction of light

Q.9 Colored fringes in soap bubble, colors in peacock feathers and colors in on a wet footpath are due to

A) Interference in thin film
B) Diffraction
C) Polarization
D) Refraction

Q.10 The monochromatic radiations A and B are incident on a diffraction grating second order maxima for A coincides with the third order maxima for B. What is the ratio $\frac{\lambda_A}{\lambda_B} = ?$

A) $\frac{1}{2}$
B) $\frac{2}{3}$
C) $\frac{3}{2}$
D) $\frac{2}{1}$

Q.11 If grating element is 10^{-2} cm and $\theta = 90°$ for 2^{nd} order maxima fringe then wavelength of light is

A) 10^{-2} cm
B) 1×10^{-2} cm
C) 0.5×10^{-2} cm
D) 2×10^{-2} cm

Q.12 If grating element in a diffraction grating is 0.01 mm the number of lines per meter are

A) 10^3
B) 10^4
C) 10^5
D) 10^6

Q.13 The transverse nature of light is confirmed by

A) Interference
B) Reflection
C) Polarization
D) Diffraction

B) $\frac{\lambda}{2}$
D) $2\,\lambda$

Q.14 T.V remote emits a signal traveling with the speed of

A) Light
B) X-rays
C) γ-rays
D) All of these

Q.15 When light incident normally on thin film, the path difference depends upon

A) Thickness of the film only
B) Nature of the film only
C) Angle of incidence only
D) All thickness, nature and angle of incidence

Q.16 In Young's double slit experiment, he separation between the slit is halved and distance the between the slit and screen is doubled. The fringe width is

A) Remain same
B) Double
C) Half
D) Quadrupled

Q.17 Wavelength of X-rays falling at glancing angle of 30° on a crystal with atomic spacing 2×10^{-10} for the first order diffraction is

A) 4×10^{-10} m
B) 2×10^{-10} m
C) 0.02×10^{-10} m
D) 2×10^{-3} mm

Q.18 A diffraction grating has 500 lines per mm. Its slit spacing or grating element will be equal to

A) 500 mm
B) 5×10^{-3} mm
C) 2×10^{-5} mm
D) 2×10^{-3} mm

Q.19 Diffraction fringes are

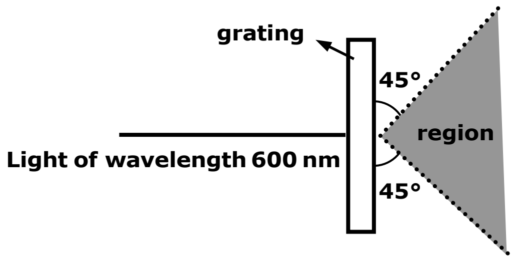
A) Equally spaced
B) Width of bright fringes increase
C) Width of dark fringes increase
D) Bright fringes are adjacent with no space in between

Q.20 In the shadow of a ball the central portion appears bright that happens due to

A) Interference
B) Diffraction
C) Polarization
D) Refraction

Q.21 Crystals of a material can behave as
A) Convex lens
B) Interferometer
C) Diffraction grating
D) Concave

Q.22 A parallel beam of light of wavelength 600 nm is incident normally on a diffraction grating. The grating has 500 lines per millimeter.

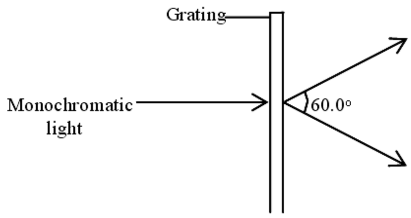


How many beams of coherent light emerge from the grating within the shaded 90° region shown in the diagram?
A) 2
B) 3
C) 4
D) 5

Q.23 The fringe spacing for red color light is
A) Smallest
B) Less than that of blue light
C) Highest
D) Less than that of yellow light

Q.24 Ratio of wavelength of x-rays to that of visible light with least wavelength is
A) 2.5×10^{-3}
B) 2.5×10^{-4}
C) 5.2×10^{-4}
D) 0.13×10^{-3}

Q.25 A diffraction grating is used to measure the wavelength of mono-chromatic light, as shown in the diagram.



The spacing of the slits in the grating is 1.00×10^{-6} m. The angle between the first order diffraction maxima is 60.0°. What is the wavelength of the light?
A) 400 nm
B) 500 nm
C) 450 nm
D) 550 nm

Q.26 Monochromatic light can not be
A) Reflected
B) Refracted
C) Dispersed
D) Diffracted

Q.27 A point source of light situated in a homogenous medium gives rise to
A) A spherical wave front
B) A cylindrical wave front
C) A plane wave front
D) An elliptical wave front

Q.28 In going form a denser to rarer medium a ray of light is
A) Undedicated
B) Bent away form the normal
C) Bent towards the normal
D) Polarized

Q.29 The diamond shines due to

A) Interference
B) Diffraction
C) Scattering
D) Total internal reflection

Q.30 A material having high refractive index has

A) Low density
B) High density
C) Zero density
D) Vero low density

Q.31 Which one type of fibre is more suitable for transmission of signals in which white light is used?

A) Mono mode step index fibre
B) Multi mode step index fibre
C) Multi mode graded index fibre
D) Single mode step index fibre

Q.32 The refractive index of a glass is 1.5, the velocity of light is

A) 3×10^{10} cms^{-1}
B) 2×10^{10} cms^{-1}
C) 4.5×10^{10} cms^{-1}
D) 1.5×10^{10} cms^{-1}

Q.33 A red cloth will primarily

A) Reflect red light
B) Absorb red light
C) Refract red light
D) All of these

Q.34 We see sun set even through it is below horizon due to

A) Reflection
B) Interference
C) Diffraction
D) Refraction

Q.35 The difference of refractive indices of core and cladding in multimode step index fibre is

A) 0.4
B) 0.6
C) 0.04
D) 0.06

Q.36 Velocity of light in a medium whose refractive index is double than that of vacuum, is (where c = velocity of light in vacuum)

A) $\frac{1}{2c}$
B) 2 c
C) c
D) $\frac{1}{3}c$

Q.37 When light moves from denser to rare medium

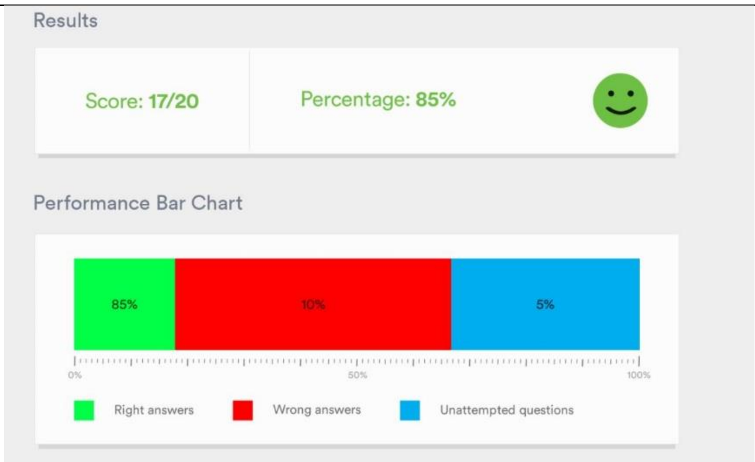
A) Its speed increases
B) Its wavelength increases
C) It bends away from the normal
D) All of these

Q.38 The ratio of core diameter of single mode step index fiber to the core diameter of multimode step index fiber

A) 5: 1
B) 1: 5
C) 1: 10
D) 10: 1

Q.39 Time taken by light to travel a distance of 4 mm in a material of refractive index 3 is

A) 16×10^{-11} s
B) 2×10^{-11} s
C) 4×10^{-11} s
D) 8×10^{-10} s



ANSWERS WITH EXPLANATION

Q.1 **(C)** **Q.2** **(C)** $n\lambda = 2d\sin\theta$

Q.3 **(B)** Wavelength decreases due to increase in refractive index **Q.4** **(B)**

Q.5 **(A)** **Q.6** **(C)** $n\lambda = d\sin\theta$ **Q.7** **(B)** $y = \frac{n\lambda L}{d}$ **Q.8** **(A)**

Q.9 **(A)** **Q.10** **(C)** $2\lambda = d\sin\theta$ **Q.11** **(C)** $n\lambda = d\sin\theta$

Q.12 **(C)** $d = \frac{1}{N}$ **Q.13** **(C)**

Q.14 **(D)** Electromagnetic waves have same speed **Q.15** **(D)**

Q.16 **(D)** $\Delta y = \frac{\lambda L}{d}$ **Q.17** **(B)** $n\lambda = 2d\sin\theta$ **Q.18** **(D)** $d = \frac{1}{N}$

Q.19 **(C)** Width of bright fringes decreases while of dark fringes increases

Q.20 **(B)** It is due to bending of light

Q.21 **(C)** Crystals of a material can behave as diffraction grating.

Q.22 **(C)** $d\sin\theta = n\lambda$ **Q.23** **(C)** $\Delta y = \frac{\lambda L}{d}$ **Q.24** **(B)** $\frac{10^{-10}}{4\times10^{-7}} = 2.5\times10^{-4}$

Q.25 **(B)** $d\sin\theta = n\lambda$

Q.26 **(C)**

Q.27 **(A)** A point source has spherical wave front

Q.28 **(C)** Speed of light decreases and it bends towards normal

Q.29 **(D)** Light is trapped in it, so it glitters

Q.30 **(B)**

Q.31 **(C)** It is useful for long distance

Q.32 **(B)** $n = \frac{c}{v}$

Q.33 **(A)**

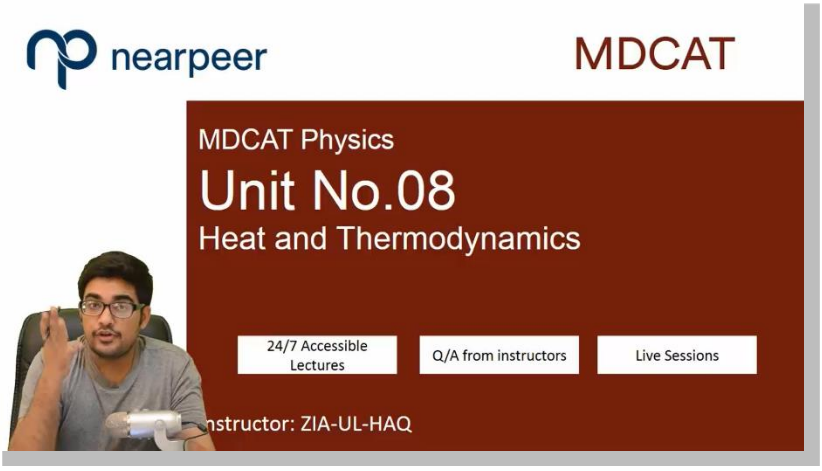
Q.34 **(C)** It is due to bending

Q.35 **(C)**

Q.36 **(A)**

UNIT 08

Heat and Thermodynamics



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HEAT AND THERMODYNAMICS

Thermodynamics is the study of the relationship between heat and other forms of energy. Heat is a form of energy which is in transition from a hot body to a cold body.
Temperature is a measure of degree of hotness or coldness of a body.
Change of temperature affects the physical state of matter.

Major types of thermometer:

(i) Mercury glass thermometer **(ii)** Bimetallic thermometer.

- Any substance that changes uniformly with temperature can be used as thermometric substance in thermometer.
- Mercury is preferred as thermometric substance because
  (1) It is non-wetting
  (2) Its expansion is quite linear
  (3) Boiling point is quite linear

Temperature scales:

- Temperature scale depends upon two fixed points whose values are always same over similar conditions.
- There are three different temperature scales which are generally used.

Fahrenheit scale:

- Lower fixed point = melting point of ice = 32 °F
- High fixed point = boiling point of water = 212 °F
- Scale is divided into 180 divisions.

Centigrade scale:

- Melting point of ice = 0 °C
- Boiling point of water = 100 °C
- Scale is divided into 100 divisions.

Kelvin or Absolute scale (SI Scale):

- Melting point of ice = 273 K
- Boiling point of water = 373 K
- Scale is divided into 100 divisions.

Relation between different temperature scales:

$$\frac{C-0}{100}=\frac{F-32}{180}=\frac{K-273}{100}$$

Conversion formulas of temperature scales:

- $T_c=\frac{5}{9}(T_F-32)$
- $T_F=\frac{9}{5}T_c+32$
- $T_K=273+T_c$
- $T_k=273+\frac{5}{9}(T_F-32)$
- $T_c=T_k-273$

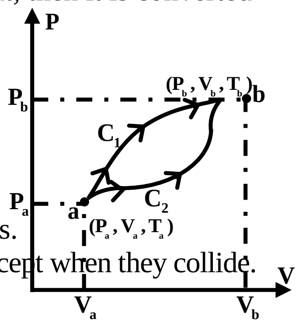
Did you know?

The centigrade and Fahrenheit scale shows the same reading at a temperature of -40°

Important Temperature Conversions:

Description	K	C°	F°
Boiling point of water	373	100	212
Freezing point of water	273	0	32
Normal body temperature	310	37	98.6
Absolute zero	0	– 273	– 460

- Absolute zero is a temperature at which if gases remain in gaseous form, exert zero pressure and have zero volume.
- Heat flows from one body to another due to temperature difference.
- Temperature determines the direction of natural flow of heat.
- Internal energy or thermal energy is the sum of K.E and PE of all molecules of a body.
- When excess of thermal energy flows from one body to another, as heat, then it is converted into internal energy.
- Internal energy is state function.



Postulates of kinetic theory of gases:

Main points of K.M.T of gases are given as:

(i) A finite volume of gas consists of very large number of molecules.

(ii). Molecules move randomly and do not exert force on one another except when they collide.

(iii). Molecules collide with each other elastically.

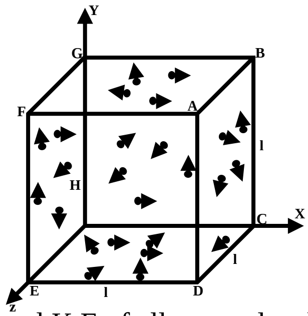
(iv). The collisions with 'walls' give rise to gas pressure.

(v) Gravity does not affect the molecular motion.

(vi). Volume of gas molecules is negligible as compared to the actual volume of the gas.

Gas Pressure from Kinetic Theory:

Under the assumptions of kinetic theory, the average force on container walls is to be determined.



- Average velocity of molecules in a container < v> = 0
- Average square velocity $<v^2> \neq 0$ because $(-v^2)^2 = +v^2$
  And hence the pressure is

$$P = \frac{2}{3} N_o < \frac{1}{2} mv^2 >$$

- Absolute temperature of a gas is measure of its average translational K.E of all gas molecules.

$$P = \frac{2}{3}\frac{N}{V}(K.E) \quad P \alpha (K.E) \quad \text{or} \quad P \alpha (v^2)$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

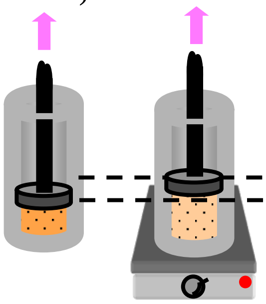
$$V_{rms} = \sqrt{(v^2)} = \sqrt{\frac{3KT}{m}}$$

Did you know?

Average speed of oxygen molecules in air at STP is 461 ms^{-1} and that for nitrogen is 493 ms^{-1}

Work and Heat:

- Work and heat are interconvertible.
- Heat supplied to system is taken positive and heat rejected by the system is taken as negative. Work done by the system is taken positive and on the system is taken as negative.
- At constant pressure (isobaric process)



$$W = P\Delta V = P(V_2 - V_1)$$

- Area under PV diagram = work done

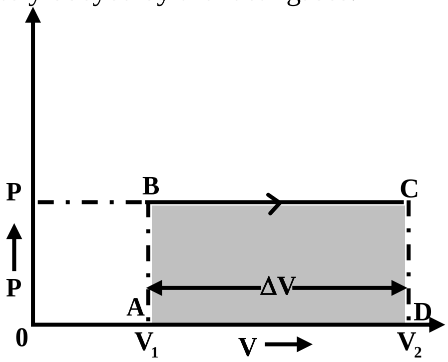
Ideal gas law (Ideal gas equation or general gas equation):

- By combining Boyle's law, Charles's law and Avogadro's law, we get equation which is given below.

$$PV = nRT$$

Where P = pressure of gas, v = volume of gas, n = number of molecule
R = Molar ideal gas constant, T = Temperature of gas.

- This equation is completely obeyed by the ideal gases.



LAWS OF THERMODYNAMICS

Thermal Equilibrium:

It is observed that a higher temperature object which is in contact with a lower temperature object will transfer heat to the lower temperature object. The objects will approach the same temperature, and in the absence of loss to other objects, they will then maintain a constant temperature. They are then said to be in thermal equilibrium. Thermal equilibrium is the subject of the Zeroth law thermodynamics.

Zeroth Law of Thermodynamics:

The "Zeroth law" states that if two systems are at the same time in thermal equilibrium with a third system, they are in thermal equilibrium with each other.

If A and C are in thermal equilibrium with B, then A is in thermal equilibrium with B. practically this means that all three are at the same temperature, and it forms the First and second Laws of Thermodynamic.

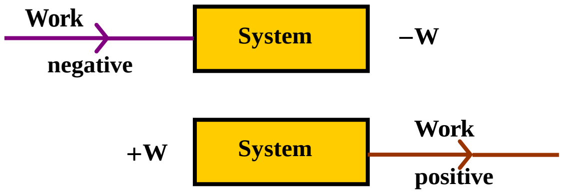
First Law:

When heat is transformed into other forms of energy total heat remains constant.

$\Delta Q = \Delta U + \Delta W$

Where ΔQ is + ve when heat is added and vice versa.

ΔW is + ve when work is done by system and vice versa.



Inferences from 1st Law of thermodynamics:

$\Delta U = \Delta Q - \Delta W$

$$\begin{pmatrix}\text{Change in internal}\\ \text{energy}\end{pmatrix} = (\text{Heat energy flowing in}) - \begin{pmatrix}\text{Heat energy flowing out}\\ \text{as mechanical work}\end{pmatrix}$$

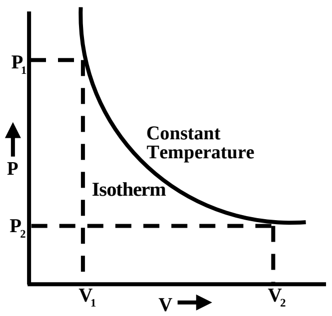
Internal energy is a state function i.e. depends on initial and final states

For a cyclic process, we have-

$\Delta U = O$, $U_l = U_f$, $\Delta Q = \Delta W$

Applications of 1st law of thermodynamics:

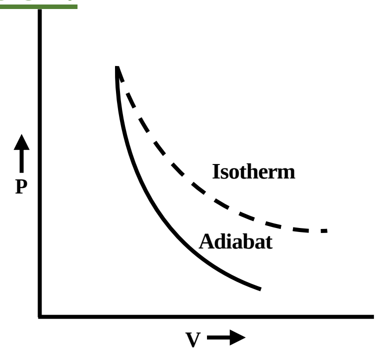
- **Isothermal process** in that in which temperature remains constant.
- Here Boyle's law is applicable.
- As T = constant So U = constant and $\Delta U = 0$.
- In isothermal expansion, +Q = +W
  i.e, heat supplied to the system is equal to the work done by the system.
- In isothermal compression, - Q = -W i.e., work done on the system is equal to the heat rejected by the system.
- Examples are slow processes.
- Isothermal process should be slow for transfer of heat.



- **Isochoric process** is that in which volume remains constant.
  $\Delta Q = \Delta U$ as $\Delta W = 0$
- **Isobaric process** is that in which pressure remains constant.
  $\Delta Q = \Delta U + P\Delta V$
- **Adiabatic process** is that in which no heat enters or leaves the system such that temperature remain constant. $-\Delta U = W$

- Examples are rapid escape of air from burst tire and cloud formation etc.
- Adiabatic process should be rapid to stop transfer of heat and system should have an heat insulator boundary
- Cooling is produced when adiabatic expansion takes place and heating is produced during adiabatic compression.
- Adiabatic process is also termed as isentropic process i.e. a process in which the entropy of the system remains constant.
- Rapid escape of air from automobile tire is a example of adiabatic expansion.

Graphical Representation:



Did you know?
During adiabatic expansion work is done at the expense of drop in internal energy.

Thermodynamic processes:

Process	Definition	Equation	Form of First 1st law of thermodynamics
Isothermal	Constant Temperature	PV = constant	$\Delta U = 0, \Delta Q = \Delta W$
Isobaric	Constant pressure	V/T = constant	$\Delta W = P\Delta V$ $\Delta Q = \Delta U + P\Delta V$
Isochoric	Constant volume	P/T =constant	$V = 0$ $\Delta Q = \Delta U$
Adiabatic	Q=0	PV^{γ} = constant	$\Delta Q = 0$ $\Delta U = -\Delta W$

Specific Heats:

- Amount of heat required to raise the temperature of a substance through 1 K is called heat capacity, denoted by C.

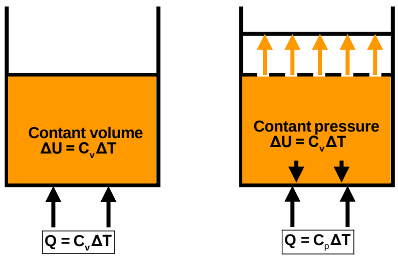
  $$Q = C\,m\,\Delta T$$

  Specific heat is the amount of heat required to raise the temperature of unit mass

  $$Q = C_{sp}\,\Delta T$$

Did you know?

Molar specific heat of diatomic gas is greater than that of monatomic gas.



C_P is greater in value than C_V:

$\Delta Q_v = n\,C_v\,\Delta T$ (Heat supplied at constant volume).

- $\Delta Q_p = n\,C_p\,\Delta T$ (Heat supplied at constant pressure).
- $C_p - C_v = R$.
- $\dfrac{C_p}{C_v} = \gamma$
- $C_p > C_v$ because at constant pressure, heat supplied not only increases internal energy (Temp). But also some work is done, while at constant volume (Isochoric process), no work is done.

Latent Heat:

It is the amount of heat required to change the state of unit mass of substance from liquid to vapor or solid to liquid without changing the temperature.

- It is of two types
- latent heat of fusion $\rightarrow$ solid to liquid

latent heat of fusion of ice = 80 cal / g

- Latent heat of vaporization → liquid to vapor.
  Latent heat of vaporization of water = 540 cal / g

Heat of sublimation:

It is the amount of heat required to convert a solid of unit mass directly to vapor or gas.

Reversible and Irreversible Processes:

- Sequence of processes carried out in such a manner that the values of thermodynamic variables are retrieved at the end of processes then this process is called reversible process. Otherwise called irreversible.
- Liquefaction, evaporation and compression performed slowly are reversible processes.
- All changes that occur suddenly or involve friction or dissipation of energy through conduction, convection or radiation are irreversible processes.

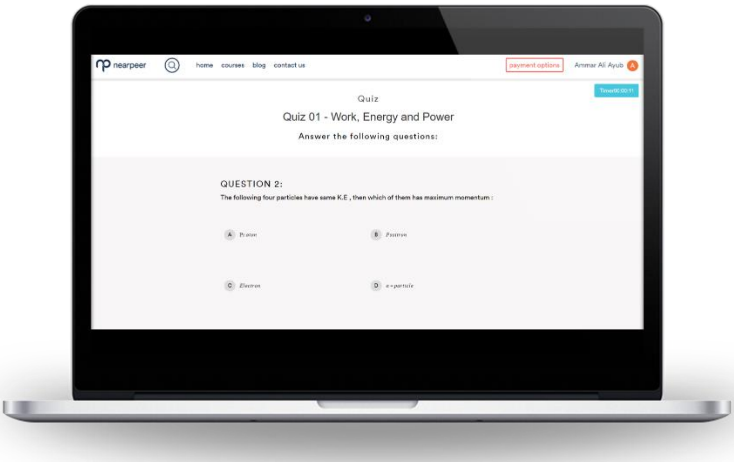
Thermodynamics scale of temperature:

- Thermodynamics scale of temperature is Kelvin Scale.
- It is independent of thermometric property (Volume) of working substance.
- $1K = \frac{1}{273.16}$ (Triple point of water).
- It is the temperature (273.16 K = 0°C) at which the three states of water (Solid ice, liquid water and vapors) co-exist in equilibrium.
- Unknown source temperature = T = $\frac{Q_1}{Q_2} \times 273.16$

  Where Q_1 to Q_2 are heat supplied and heat rejected during carnot cycle.
  This scale is independent of property of working substance. So it can be applied at low temperature.

Did you know?

On a cold morning, a metal surface will feel colder to touch than a wooden surface because metal has high thermal conductivity.



PRACTICE QUESTIONS

Q.1 At absolute temperature, the K.E of the molecules
- A) Become minimum
- B) Become maximum
- C) Become zero
- D) None of these

Q.2 The scales of temperature are based on two fixed points, which are
- A) The temperatures of water at 0°C and 100°C
- B) The temperature of melting ice and boiling water at atmospheric pressure
- C) The temperatures of ice cold and boiling water
- D) The temperatures of frozen and boiling mercury

Q.3 Heating of water under atmospheric pressure is an
- A) Adiabatic process
- B) Isothermal process
- C) Isochoric process
- D) Isobaric process

Q.4 We can produce heat by
- A) Frictional process
- B) Chemical processes
- C) Electrical processes
- D) All of the above

Q.5 Which one is true for internal energy?
- A) It is sum of all forms of molecular energies of a system
- B) It is a state function of a system
- C) It is proportional to transnational K.E of the molecules
- D) All are correct

Q.6 If the volume of a gas is held constant and we increase its temperature then
- A) Its pressure is constant
- B) Its pressure raises
- C) Its pressure falls
- D) Any of above

Q.7 Boyle's law holds for ideal gases in
- A) Isochoric processes
- B) Isobaric processes
- C) Isothermal processes
- D) Adiabatic process

Q.8 For a gas obeying Boyle's law, if the pressure is doubled, the volume becomes
- A) Double
- B) One half
- C) Four times
- D) One fourth

Q.9 Which of the following properties of molecules of a gas is same for all gases at particular temperature

A) Momentum
B) Mass
C) Velocity
D) Kinetic energy

Q.10 Which quantity is not a thermodynamic state function

A) Internal energy
B) Heat energy
C) Pressure
D) Volume

Q.11 1st law of thermodynamics is consequence of conservation of

A) Work
B) Energy
C) Heat
D) All of these

Q.12 If we double the velocity of gas molecules in a closed container then pressure gas is increased by

A) 8 times
B) 2 times
C) 4 times
D) 9 times

Q.13 Heat is transferred through the walls of a steel radiator by

A) Convection
B) Radiation
C) Conduction
D) Convection and radiation

Q.14 Which quantity increases the most when a sphere is heated

A) Radius
B) Circumference
C) Volume
D) Surface

Q.15 A mono-atomic gas has

A) Translational K.E only
B) Vibrational K.E only
C) Rotational K.E
D) All of these

Q.16 Land and sea breeze is due to

A) Conduction
B) Convection
C) Radiation
D) All of these

Q.17 The average K.E of a gas molecule at T Kelvin is

A) $\frac{1}{3}$ kT
B) $\frac{2}{3}$kT
C) $\frac{1}{2}$ kT
D) $\frac{3}{2}$kT

Q.18 Internal energy of a gas is directly proportional to its

A) Pressure
B) Volume
C) Temperature
D) All of these

Q.19 Intermolecular force b/w the molecules of an ideal gas are

A) Very weak
B) Weak
C) Very strong
D) Zero

Q.20 The unit of molar specific heat is same as that of

A) Molar ideal gas constant
B) Temperature
C) Pressure
D) Heat

Q.21 In isothermal expansions, heat Q =

A) Δu
B) – W
C) W
D) $-\Delta u$

Q.22 If average K.E of gas molecules are increased by a factor of 4, then pressure of gas for a fixed volume

A) Increase by a factor of 2
B) Increase by a factor of 8
C) Decreases by a factor of 4
D) Increases by a factor of 4

Q.23 An ideal gas at 27°C is heated at constant pressure so as to double its volume

A) 54°C
B) 327°C
C) 150 K
D) 327 K

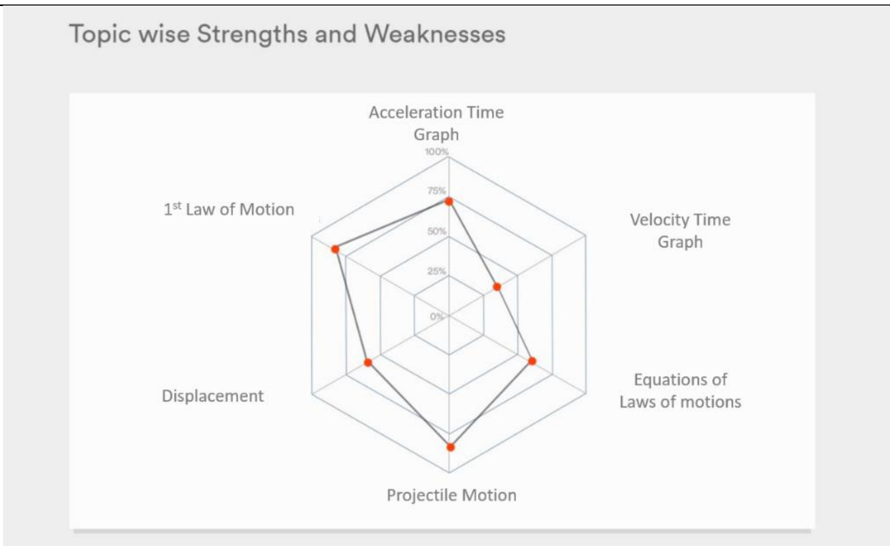
Q.24 Four molecules have speeds of 1 km/s, 2 km/s, 3 km/s and 4 km/s. Root mean square velocity of these molecules in km/s is

A) $\sqrt{15}$

B) $\frac{\sqrt{30}}{2}$

C) $\frac{\sqrt{30}}{4}$

D) $\frac{\sqrt{15}}{2}$



When you solve a quiz on www.nearpeer.org, you see much detailed analysis of your results. The above picture shows analysis of your strengths and weaknesses. Understanding of this can prepare you better for scoring 1000+ marks in MDCAT.

ANSWERS WITH EXPLANATION

Q.1 (C) **Q.2 (B)** **Q.3 (D)** Atmospheric pressure is constant **Q.4 (D)**

Q.5 (D) **Q.6 (B)** The pressure of the gas molecules increases with temperature

Q.7 (C) PV = constant at T = constant

Q.8 (B) PV = constant **Q.9 (B)** **Q.10 (B)** **Q.11 (B)**

Q.12 (C) $P \propto <\frac{1}{2}mv^2>$ **Q.13 (C)** **Q.14 (C)** **Q.15 (A)** **Q.16 (B)**

Q.17 (D) $E = \frac{1}{2}kT + \frac{1}{2}kT + \frac{1}{2}kT = \frac{3}{2}kT$ **Q.18 (C)**

Q.19 (D) Ideal gas has no intermolecular forces

Q.20 (C) $C_p - C_v = R$ Only quantities having same dimensions be added

Q.21 (C) $Q = \Delta U + (W)$; $Q = 0 + (W)$; $Q = W$ **Q.22 (D)** $P \propto <K.E>$

Q.23 (B) $\frac{V_1}{V_2} = \frac{T_1}{T_2}$; $\frac{V_1}{2V_1} = \frac{300}{T_2}$; $\frac{1}{2} = \frac{300}{T_2}$ $T_2 = 600$ k $\boxed{T_2 = 327°C}$

Q.24 (B)

$$V_{rms} = \sqrt{\frac{v_1^2 + v_2^2 + v_3^2 + v_4^2}{v}} = \sqrt{\frac{1+4+9+16}{4}} = \frac{\sqrt{30}}{2}$$

UNIT 09

Electrostatics

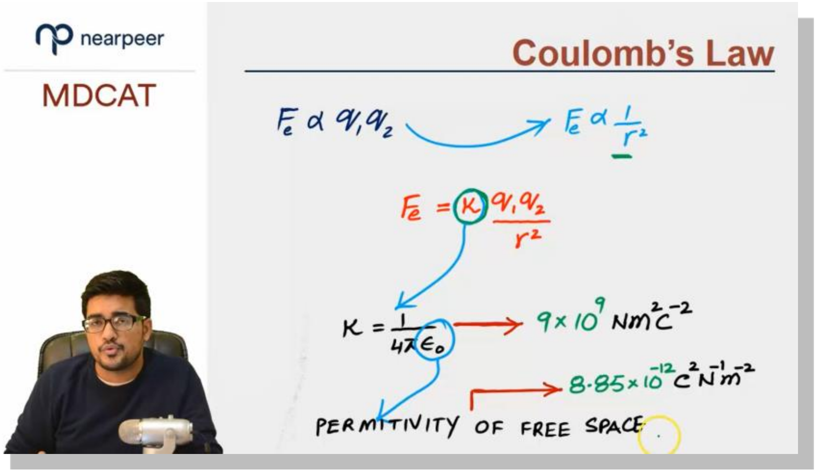
ELECTROSTATICS

The study of electric charges at rest under the action of electric force is known as electrostatics.

Properties of Electric Charges

Charge

- **Conservation** → In an isolated system, charge remains conserved i.e. it can not be created nor destroyed.
- **Quantization** → Charge on any body always exists in the form of integral multiple of fundamental quantity equal to charge on an electron i.e., $Q = \pm ne$. Milikan's oil droplet experiment proved the quantization of charge
- **Charging** → A body can be charged by means of friction, conduction and induction. However charging a body by means of induction is preferable since the same charged body can be used to charge any number of bodies without loss of charge.
- **Existence** → Charge can not exist without mass although mass can exist without charge.
- **Invariance** → The charge on a body is independent of the speed of the body. However, at relativistic speeds charge density and mass of body depends upon the speed of the body.
- **Nature of force** → Charges are of two kinds, positive and negative. Unlike charges attract each other and like charges repel each other.
- **Addition** → Total charge on an isolated system is equal to the algebric sum of all the charges.
- **Surface charge density** → It is charge per unit area of conductor. Surface charge density on a charged conductor decreases with increase of radius of curvature of surface and vice versa. Surface charge density is highest at the sharpest point of a charged conductor.



Did you know? This lecture is completely explained in nearpeer.org online MDCAT course (video 9.01)

Coulomb's Law

"The electrostatic force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them."

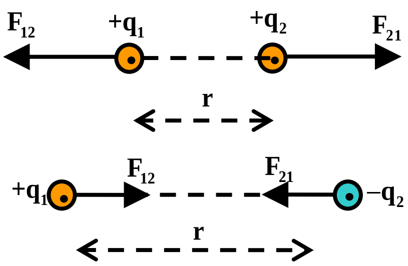
or

$$F = \frac{kq_1q_2}{r^2}$$

or

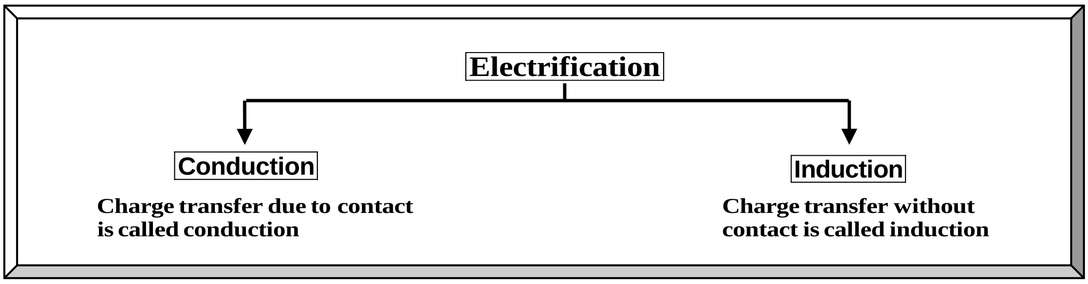
$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r^2}$$

When a body has an excess or deficiency of charge, the process is named as electrification or charging.



- Value of **k depends** upon the **medium** and the **system of units**. Here $k = 9 \times 10^9$ Nm^2/C^2 .k is also called electrostatic force constant and ε_o = permittivity of free space = 8.85×10^{-12} C^2/Nm^2
- Coulombs' force is mutual force i.e both charges exert same force on each other.
- **Coulomb's force depends** upon not only the magnitude of charges but on the **product of charges.**

- **When** a **dielectric** (insulator) is placed between two point charges then coulomb's **force decreases** by a factor $\in_r$ i.e. $F_{med} = \frac{F_{vac}}{\varepsilon_r}$ Where ε_r is relative permittivity of that dielectric
- Coulomb's law is only **applicable** to point **charges** which are at **rest** not in motion.
- Point charges or localized charges are those charges whose sizes are very small as compared to the distance between them.
- If **many charges** are present, the **total force** on a given charge is equal to the **vector sum** of the individual force exerted on it by all other charges taken one at a time.



Relative Permittivity or Dielectric Constant

Permittivity is property of a medium and affects the magnitude of electric force between two point charges. Air or vacuum has maximum value of the permittivity air vacuum is 8.85× 10 $^{-12}$ $C^2N^{-1}m^{-2}$. The absolute permittivity ε of all other insulating materials is grater than ε_0. The ratio $\varepsilon/\varepsilon_0$ is called relative permittivity of the material and is denoted by

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$

So Relative permittivity of a medium is defined as "*the ratio of the permittivity of the medium to permittivity of vacuum*"

Relative permittivity (or dialectic constant) of a medium may also be defined as

"The ratio of force between two charges separated by a certain distance in air to the force between the same charges separated by the same distance in the medium"

$$\varepsilon_r = \frac{F_{vac}}{F_{med}}$$

Material	ε_r
Vacuum	1
Air (1 atm)	1.0006
Ammonia (liquid)	22-25
Bakelite	5-18
Benzene	2.284
Germanium	16
Glass	4.8-10
Mica	3-7.5
Parafined paper	2
Plexiglass	3.40
Rubber	2.94
Teflon	2.1
Transformer oil	2.1
Water (distilled)	78.5

Fields of Force and Electric Field

Fields of Force:

The origin of gravitational and electric forces is unknown. To describe the mechanism by which electric force is transmitted, there are two theories.

i) Action at a distance theory

ii) Field theory, Michael Faraday introduced the concept of an electric field.

Electric Field:

The region around a charge within which it can influence other charges is called electric field. Mathematically.

$$\vec{E} = \frac{\vec{F}}{q_o}$$

Its unit is NC^{-1} or $V\ m^{-1}$.

Electric field due to a point charge q at distance r from it

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$$

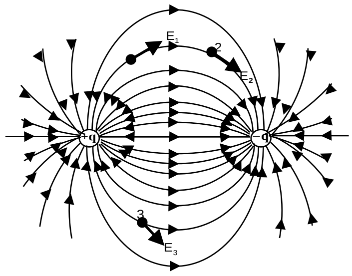
Electrostatic experiments cannot be conducted successfully on humid days. The humid air becomes conducting. Therefore, the static charge on the apparatus leaks off to the air. For this reason, electrostatic experiments do not work well on humid days.

Greater the **charge**, **stronger** will be its **electric field** and vice versa. It obeys inverse square law.

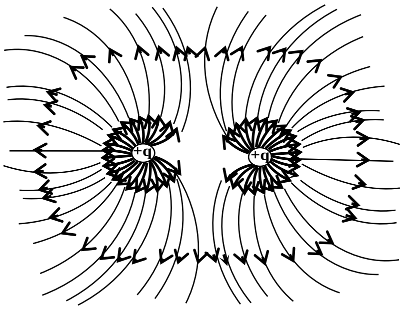
Electric Lines of Force

- The **concept** was introduced by Michael **Faraday.**
- Electric field lines show the **path** followed by a **positive** test **charge** in an electric field.
- Electric field lines **emerge** from the charges in **three dimensions** and infinite lines can be drawn.
- Field lines are **radially outward** or **inward** for a **single** charge.
- The **point** between two **similar** charges where field is zero is called **neutral** point.
- The field between two **oppositely** charged parallel plates in the **middle** region is uniform. (Electric lines are parallel and evenly spaced) and it is non uniform near the edges of plates.
- Field lines **originate** from **positive** charges and **end** on **negative** charges.
- The **tangent** to a field line at any point gives the **direction** of electric field at that point.
- The lines are **closer** where field is **stronger** and are **farther** apart where the field is **weak**.
- **No two** field **lines** can **cross** each other because if they cross then there will be two directions of vector $\vec{E}$ at the point of intersection.

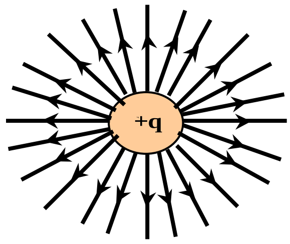
Note: Electric lines of force never form a closed loop. But magnetic lines of force form a closed loop.

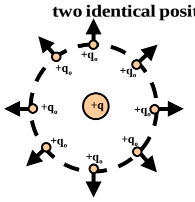


Attractive forces between unlike charges



The electric field lines for two identical positive charges





PRACTICE QUESTIONS

Q.1 **Two point charges are separated by a distance 'd'. If one of the charge is doubled and the separation is reduced to one – third of original distance then the force between charges will become**

A) $\frac{1}{16}$ times

C) 18 times

B) 8 times

D) $\frac{1}{4}$ times

Q.2 **The units of permittivity of free space are**

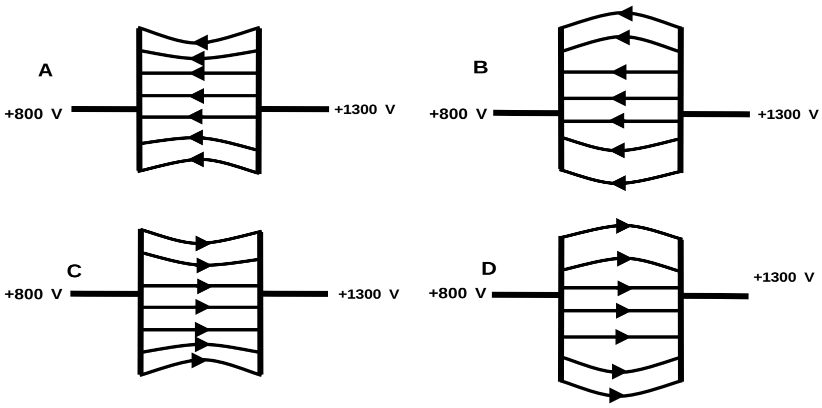
A) $\frac{F}{m}$

C) $\frac{Nm^2}{C^2}$

B) $\frac{C^2}{Nm}$

D) None of these

Q.3 **Two parallel plates are at potentials of +800 V and +1300 V; which diagram best shows the electric field between the metal plates.**



Q.4 **Three point charges each + q are placed at corners of an equilateral triangle of side 'r'. The electric field at center will be**

A) $\frac{3kq}{r^2}$

C) $\frac{3kq}{2r}$

B) $\frac{kq}{r^2}$ D) Zero

Q.5 Two point charges 4 μC and 9 μC are placed 20 cm apart. The electric field between them will be zero on the line joining them at a distance of

A) 8 cm from q_1 C) $\frac{80}{13}$ cm from q_1

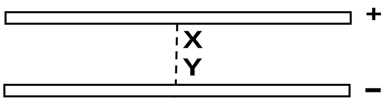
B) 8 cm from q_2 D) $\frac{80}{13}$ cm from q_2

Q.6 The charge on the uranium nucleus is 1.5×10^{-17} C and the charge on the α-particle is 3.2×10^{-19}C. What is the electrostatic force between a uranium and an α-particle separated by 1.0×10^{-13} m?

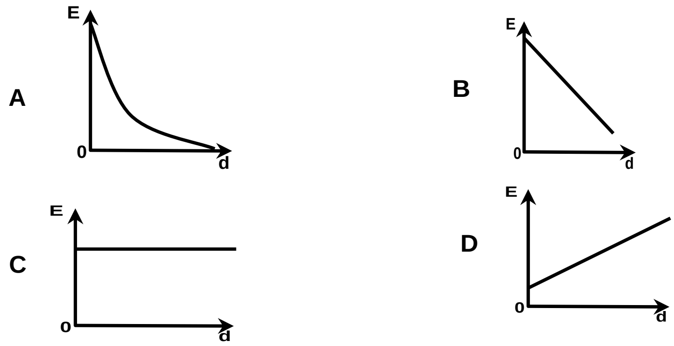
A) 4.3×10^{-33} N C) 4.3×10^{-13} N

B) 4.3×10^{-20} N D) 4.3 N

Q.7 An electric field exists in the space between two charged metal plates.

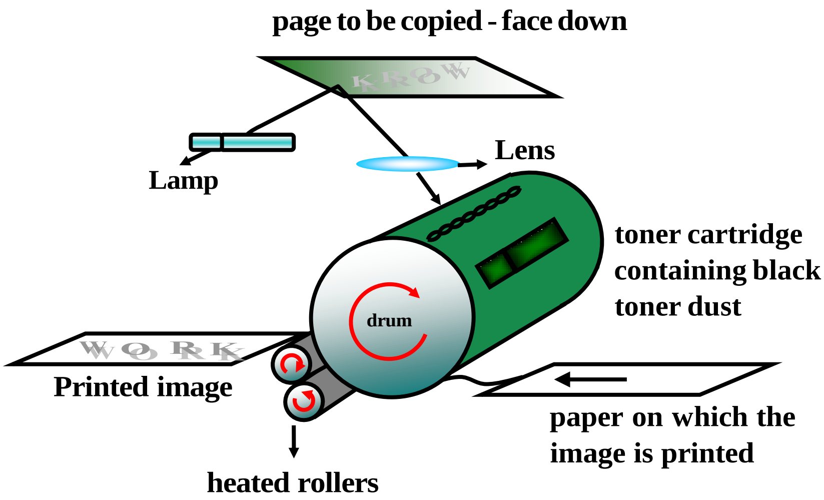


Which of the following graphs show the variation of electric field strength E with distance d from X along the line XY.



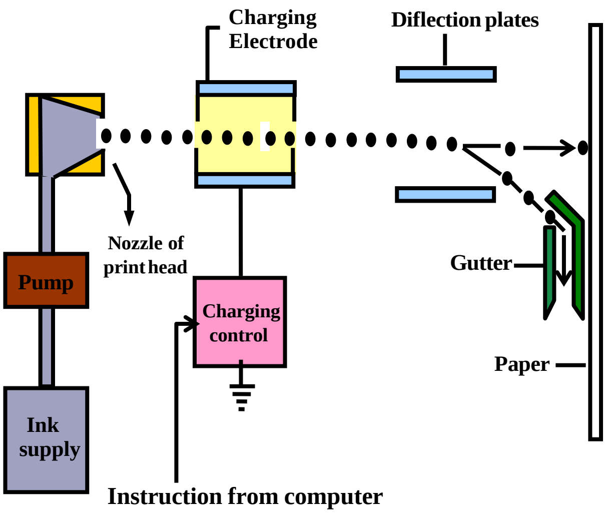
Xerography; Photocopier

- Xeros means dry and graphos means writing.
- Aluminium cylinder coated with selenium is used as a drum.
- Aluminium is an excellent conductor and selenium is a photoconductor.
- Image of document is dark and dark areas on drum retain positive charge.
- Negatively charged toner is spread over the drum which sticks to the positively charged areas.
- Toner from the drum is transferred on to a paper which is given excess positive charge to produce the permanent impression of the document.



Inkjet Printers

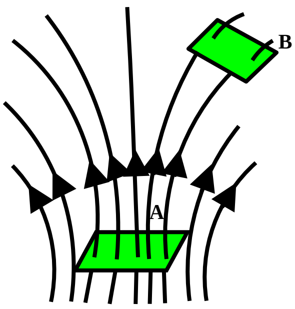
- Charging control makes the charging electrodes neutral when printing is required and droplets fall on the paper.
- Deflection plates are parallel plate capacitors which deflect the droplets to gutter when no printing is required.
- Charging electrodes are used to charge the droplets that are not needed on the paper.
- Charged droplets are deflected into a gutter by the deflection plates, while uncharged droplets fly straight onto the paper.



To eliminate stray electric fields interference, circuits of sensitive electronic devices such as TV and computers are enclosed within metal boxes

Electric Flux:

"Number of electric field lines passing perpendicularly through a surface area"



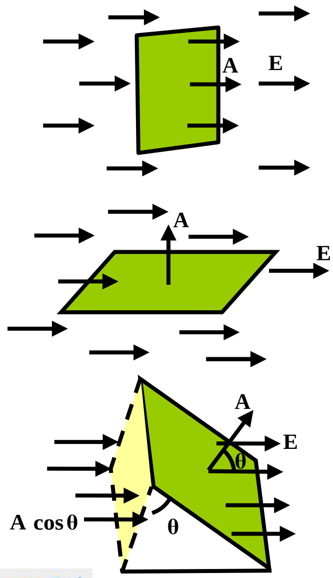
$$\boxed{\phi_e = \vec{E}\cdot\vec{A}}$$

or ϕ_e = EA Cosθ

Where $\vec{A}$ = vector area

θ = angle between $\vec{E}$ and $\vec{A}$

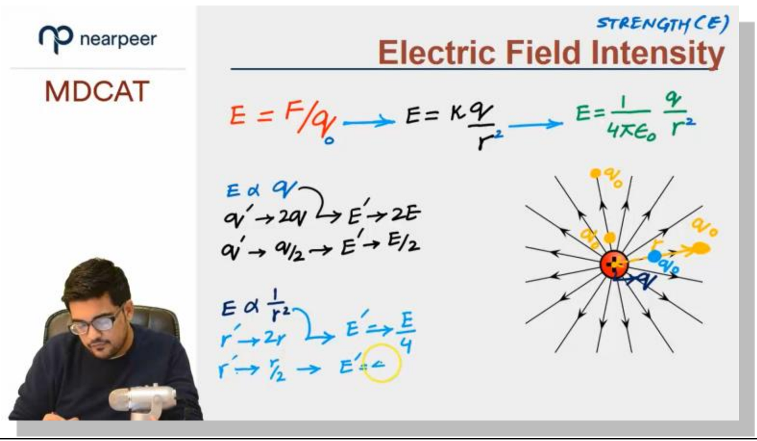
SI unit of electric flux is Nm^2C^{-1} or V m



- $\phi_e = 0$ if θ = 90º (surface is parallel to $\vec{E}$)

- ϕ_e = maximum if θ = 0º (surface is perpendicular to $\vec{E}$)

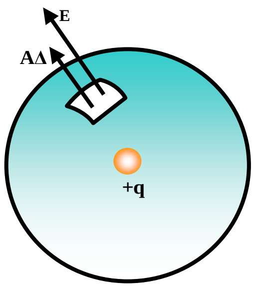
ϕ_e = EA Cosθ (surface is held inclined to $\vec{E}$)

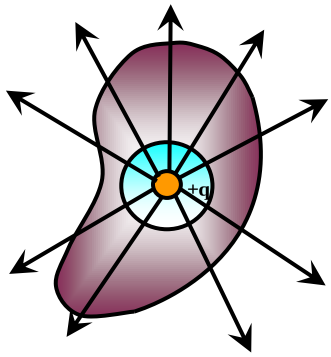


Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 9.02)

Electric flux through a closed surface enclosing a charge

- We divide the close surface into infinitesimally plane patches so that $\vec{E}\cdot\vec{A}$ is applicable to each path.
- The result comes out to be $\phi_e = q/\varepsilon_0$
  Where q = charge enclosed by surface
  ε_0 = permittivity of vacuum
- **Electric flux** through a closed surface **does not depend** upon **shape** or **geometry** of the closed surface. It **depends upon** the **medium** and the **charge** enclosed.



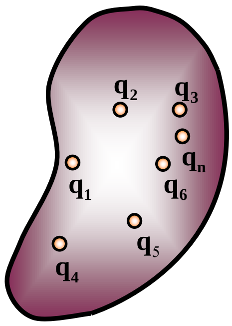


Gauss's Law

- Gauss's law gives relation between total flux passing through a surface and net charge enclosed within it. **It states that Electric flux through a closed surface = ϕ_e = $\frac{1}{\varepsilon_0}$ times (total charge enclosed by the closed surface**)

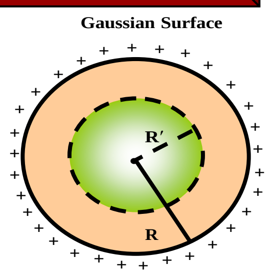
$$f_e = \frac{q}{\varepsilon_o}$$

- Gaussian surface is a hypothetical surface chosen to calculate the electric intensity at any point. It can be of any shape i.e a sphere or cylinder. The selection is made according to the shape of body. Gaussian surface should be symmetric around the body under consideration.



- If electric field lines are leaving a closed surface, then electric flux is positive (there is a source) and if electric lines are entering a closed surface then flux is negative (there is a sink).
- Gauss's law is only applicable to closed surface.
- Coulomb's law can be derived from Gauss's law.

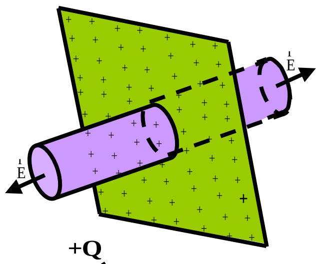
Applications or Gauss's Law



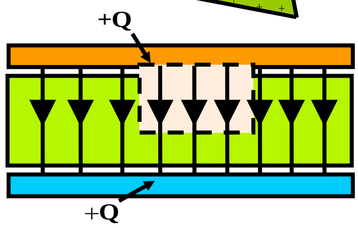
It is used to find electric intensity due to a charged body.

- Electric field inside a hollow charged sphere is zero

- Electric intensity due to an infinite sheet of charge = E = $\dfrac{\sigma}{2\varepsilon_0}$



- Electric field between two oppositely charges plates is E = $\dfrac{\sigma}{\varepsilon_0}$



> To eliminate stray electric fields interference, circuits of sensitive electronic devices such as. TV and computers are enclosed within metal boxes

Electric Potential

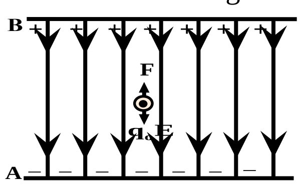
Electric potential is property which determines the direction of flow of charge.

- Positive charge goes from higher potential to a lower potential and negative charge goes from a lower potential to a higher potential.
- Potential difference 'ΔV' is defined as the work done against electric field in moving positive charge keeping the charge in electrostatic equilibrium (charge with uniform velocity)

$$\boxed{\Delta V = \frac{W_{AB}}{q_o}}$$

$W_{AB} = \Delta U$ (change in electric P.E) = $U_B - U_A$

- Electric potential V at a point is defined as the work done against electric field on unit positive charge in moving it from infinity to that point.
- Potential is still a potential difference between infinity and that point whose potential is to be determined.
- SI unit of potential difference is volt = JC^{-1}
- V and ΔV are both scalars because work and charge are both scalars.



Points to Remember

- An ECG (electrocardiography) records the voltage between points on human skin generated by electrical process in the heart. It is done in running condition to provide information about performance under stress.
- In EEG (Electroencephalography), the potential differences created by the electrical activity of the brain are used for diagnosing abnormal behavior

- In ERG (Electroretinography), we check the potential differences created by electrical activity of retina of the eye.

Electric field as potential gradient

$$\vec{E} = -\frac{\Delta V}{\Delta r}$$

Or $\vec{E}$ = -potential gradient

Negative sign shows that electric potential decreases in the direction of $\vec{E}$

Potential gradient is defined as the maximum rate of change of potential with respect to minimum distance between two oppositely charge plates.

Note that potential on right side is a scalar quantity but left side that is electric field is vector. The reason is that gradient of a scalar is always a vector.

Electric potential V at a point due to a point charge q:

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ where r is the distance of the point from point charge

Electric potential V at a point due to two or more point charges:

Notice that the potential due to a positive charge (q > 0) is positive and it is negative in the neighborhood of an isolated negative charge (q < 0). To find the electric potential at a point in the electric field due to two or more charges, we first calculate the potential due to each charge, assuming that all other charges are absent, and then simply add these individual contributions, since unlike electric field, electric potential is a scalar so the addition here is the ordinary sum, not a vector sum.

The potential at any point due to two point charges q_1 and q_2 is, therefore, simply given by

$$V = \frac{1}{4\pi\epsilon_o}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2}\right)$$

Electric potential due to many point charges the potential at any point due to a system of N point charges is given by $V = V_1 + V_2 + ... + V_n$

In electric circuits, potential is equivalent to pressure and electrical pump is a cell or a generator.

Electron Volt

- The conventional unit of energy is joule. But this unit is very large for computing atomic and nuclear physics problems. Therefore, a smaller unit called electron volt is used. The convenience of unit can be understood from simple example. The ionization energies of atoms (energies required to remove an electron from a neutral atom) have range between 1 to 20 eV.

- **The amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.**
- 1 eV = 1.6×10^{-19} J
- 1 joule=6.25×10^{18} eV

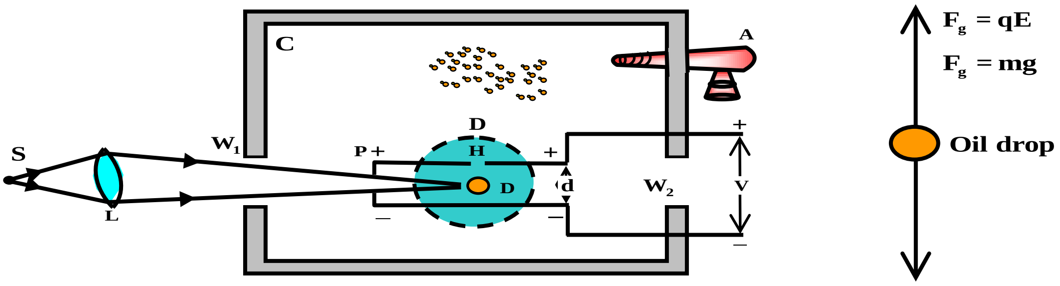
Electron volt is a unit of energy and not the unit of potential difference or voltage.

Comparison of Electric and Gravitational Force

Similarities	Differences
Both are conservative forces	Gravitational force is only attractive while electric force may be attractive or repulsive.
Both obey inverse square law i.e., $F \propto \frac{1}{r^2}$	Electric force is stronger than gravitational force but it has less range as compared to gravitational force.
	Electric force is medium dependent while gravitational force is independent of medium.
	Shielding can be done against electric field but not against gravitational field.

Millikan's Experiment

- Oil droplets are negatively charged by friction.
- Terminal velocity of oil droplet is very small as its mass is small.
- Oil droplet is suspended if $F_e = F_g$
- Electric force is varied by varying the potential difference. so electric field varies according to the relation $E = \frac{-\Delta V}{\Delta r}$
- Minimum charge = charge on electron = 1.6×10^{-19} C



Points to remember:

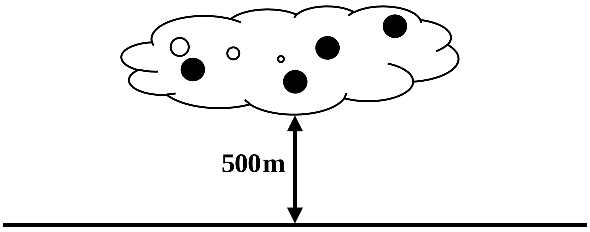
1. Potential difference at a point is a relative term and has meaning only with respect to the assigned value of some reference point.
2. The earth is considered to be a conductor with an electric potential arbitrarily assigned the value of

zero. Since the earth is so large, it acts as a limitless source of electrons so electrons can be added to or removed from the earth without changing its potential. If a conductor is connected to the earth, electrons will move between the conductor and the earth until the potential between them is equal.

3. In other words, any conductor electrically connected to the earth must be at zero potential. Such a conductor is said to be grounded.

PRACTICE QUESTIONS

Q.8 The Diagram shows a thunder-cloud whose base is 500 m above the ground



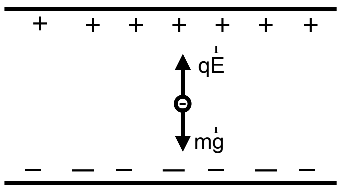
The potential difference between the base of the cloud and the ground is 200 MV. A rain drop q with a change of 4.0×10^{-12} C is in the region between the cloud and the ground. What is the electric force on the drop?

A) 1.6×10^{-6} N
B) 8.0×10^{-4} N
C) 1.6×10^{-3} N
D) 0.40 N

Q.9 In ink jet printer the droplets that are needed on the paper

A) Are charged by charging electrode
B) Are charged by deflecting plates
C) Are charged by friction while passing through the nozzle of print head
D) None of these

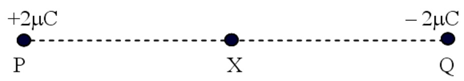
Q.10 What is the magnitude of charge on the droplet if it is balanced and held stationary by the gravitational force and coulomb's force as shown in the fig?



Where m = 4.8×10^{-15} kg and E = 9.8×10^{4} Vm^{-1}

A) 3.2×10^{-19} C
B) 4.8×10^{-18} C
C) 3.2×10^{-18} C
D) 3e

Q.11 Charges of +2 μC and -2 μC are situated at points P and Q respectively, as shown in fig given below. X is midway between P and Q. Which of the following correctly describes the electric field and the electric potential at point X?



	Electric field	Electric potential
A)	Towards **Q**	Zero
B)	Towards **Q**	Negative
C)	Towards **P**	Zero
D)	Towards **P**	Positive

Q.12 If $\vec{E} = (4\hat{j})$ N/C then electric flux through an area of 6 m^2 held in the xy plane is

A) $24\frac{Nm^2}{C}$

B) $0\ \frac{Nm^2}{C}$

C) $10\ \frac{Nm^2}{C}$

D) $-24\frac{Nm^2}{C}$

Q.13 A surface encloses an electric dipole. The electric flux through this surface is

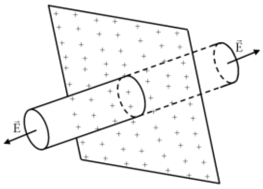
A) Positive

B) Negative

C) Zero

D) Either positive or negative

Q.14 The flux passing through a closed surface in the form of a cylinder whose surface area of flat face is A as shown in the fig is



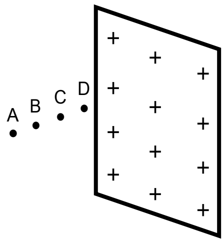
A) Zero

B) EA

C) $\frac{1}{2}$ EA

D) 2 EA

Q.15 At which one of the following point close to an infinite sheet, whose finite part is shown in the fig, the electric field is strong if charge is uniformly distributed on the sheet.



A) At A

B) At B

C) At C

D) None of these

Q.16 If the electric potential at a distance d from a point charge is V, the value of electric potential at $\frac{d}{3}$ will be

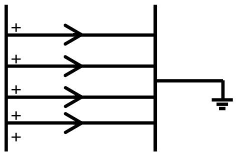
A) $\frac{V}{3}$

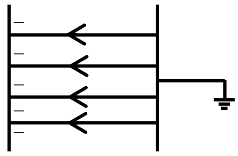
B) $\frac{V}{9}$

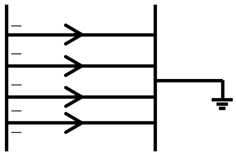
C) 9V

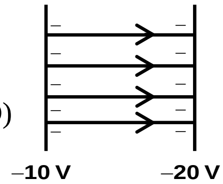
D) 3V

Q.17 Choose the incorrect option for electric field lines

A) 

C) 

B) 

D) 

Q.18 Which one of the following is correct for a hollow charged sphere at its centre?

A) $E = 0, V = 0$ C) $E = 0$, V = constant

B) $E \neq 0, V = 0$ D) E = constant, $V = 0$

Q.19 If an alpha particle is accelerated through a potential difference of 10 V then energy acquired by it will be

A) 10 eV C) 30 eV

B) 20 eV D) 40 eV

Q.20 The voltage across capacitor in RC series circuit (Vc) during charging process

A) Remains same C) Increases exponentially

B) Increases linearly D) Decreases rapidly

Knowledge plus

Electrostatic force is a conservative force

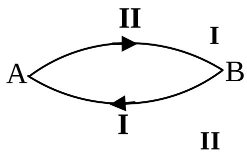
Like gravitational force, electrostatic force is also conservative in nature i.e., work done in moving a unit positive charge over a close path in an electrostatic field is zero.

To prove that electrostatic force is conservative, consider close path from to B.

Work done in carrying unit positive charge from A to B along path **I** is

$$\frac{W_{AB}}{q_0} = V_B - V_A$$

Work done in carrying unit positive charge from B to A along path **II** is



$$\frac{W_{BA}}{q_0} = V_A - V_B$$

Adding equation (i) and (ii) we get

$$\frac{W_{AB}}{q_0} + \frac{W_{BA}}{q_0} = (V_B - V_A) + (V_A - V_B) = 0$$

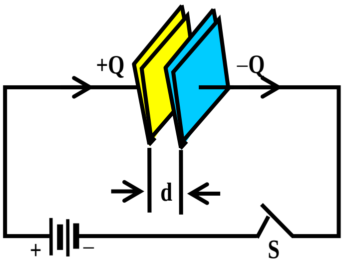
Therefore, no work is done in moving a unit charge over a close path in an electric field. Hence electrostatic force is conservation in nature. Since electrostatics force is conservative in nature. The work done in carrying test charge q_0 from point A to B (assuming $V_B > V_A$) in the electric field is path independent. In order words whatever path you may follow in carrying q_0 from point A to point B, the work done is the same.

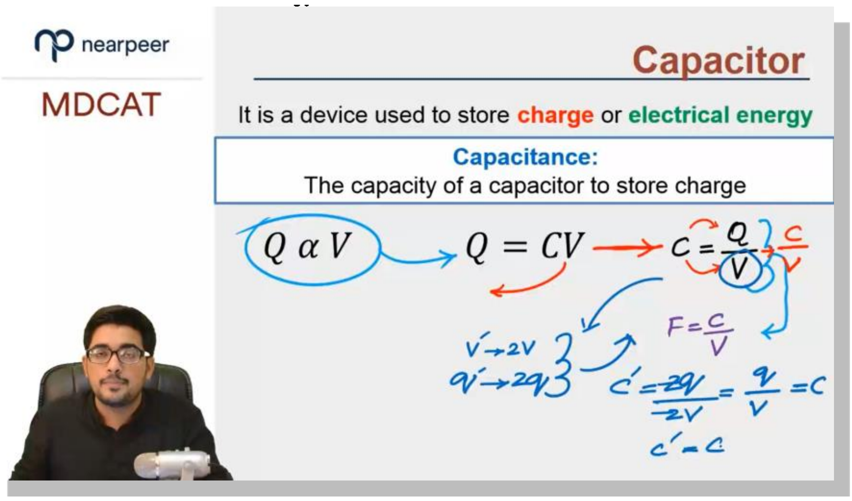
The same in true for gravitational force (conservative force); whatever path you may Follow in carrying a mass m through height h, the work done is the sane i.e. mgh.

CAPACITOR

A capacitor is a device which is used to store charge and hence energy in electric field.

- It consists of parallel metallic plates separated by an insulating medium called dielectric.
- Space between two plates means that circuit is open at that point and when capacitor is connected to a potential difference, the opposite static charges will develop on the two plates.
- A capacitor is named after the dielectric used e.g., air capacitor, mica capacitor and paper capacitor etc.
- Unless stated otherwise, capacitor means an air capacitor.





Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 9.03)

Capacitance:

The ability of a capacitor to store the charge is called capacitance

- It has been found experimentally that charge stored on the plates is directly proportional to the potential difference applied across the plates

$$Q \propto V$$

$$\boxed{Q = CV}$$

or $$C = \frac{Q}{V}$$

If V=1 then Q=C

Therefore, capacitance of a capacitor is the amount of charge required to raise its potential by one volt.

- The capacitance of a capacitor is constant quantity. If **potential difference** is **doubled**(2V),**charge** also becomes **twice**(2Q) so that $C = \frac{2Q}{2V} = C$
- capacitance of a capacitor depends on(i)shape of its plates(ii)Separation between plates and (iii)nature of insulating material(dielectric) between plates.($C = \frac{A\mathcal{E}_o}{d}$)
- Unit of capacitance is farad. 1 farad = $\frac{\text{1 coulomb}}{\text{1 volt}}$

For your Information

- One farad is an enormous amount of capacitance. For practical purposes its sub multiple units are used which are given below,

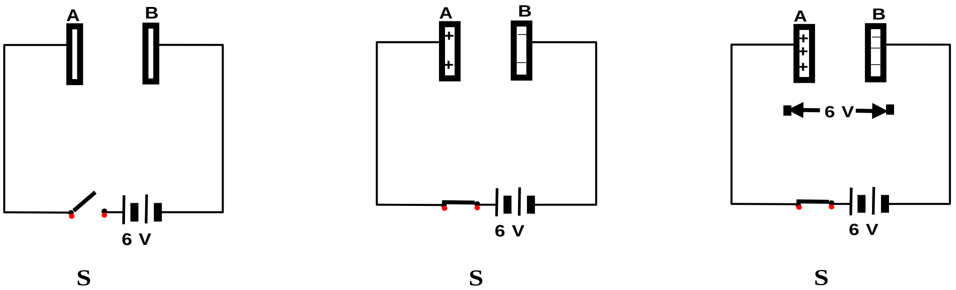
1 micro farad = 1 μF = 10-6 farad

1 pico farad = 1 pF = 10-12 farad

How does capacitor store charge?

Figure below shows how capacitor (parallel plates) store charge when connected to a d.c. supply. The parallel plate capacitor having plat A and B is connected across 6V battery. When the switch S is open as shown in the fig. (i) the capacitor plates are natural i.e there is no charge on the plates. When switch is closed as shown in the fig, (ii) the electrons from plate A are attracted by the battery and these electrons start accumulating on plate B.(Electrons can not flow from plate B to A as there is insulating medium between the plates so detached electrons start piling on plate B.) This action is referred to as charging of a capacitor because capacitor plates are being charged.

After very short time, potential difference between A and B becomes equal to the 6 V (i.e battery voltage) but is oppositely directed .The capacitor is said to be fully charged and the charging current ceases to flow. Due to charging process, Plates A and B get equal amount of charge of opposite sign. The capacitor plates which were natural at start now have charge on them. This shows that a capacitor stores charge.



(i) (ii) (iii)

Discussion. Following points are note worthy:

(i) The charging current will flow until the capacitor is fully charged. Once the capacitor is fully charged, charging current stops. Thus, a capacitor once charged prevents the flow of direct current.

(ii) The charging current does not flow through the capacitor i.e., between the plates. There is only transfer of electrons from one plate to the other.

(iii) When a capacitor is charged, the plates carry equal and opposite charges (say +q and –q). This is expected because one plate loses as many electrons as the other plate gains thus charge on a capacitor means charge on either plate.

(iv) The energy required to charge the capacitor (i.e., transfer electrons from one plate to the other) is supplied by the battery.

Capacitance of parallel plate capacitor

If there is vacuum between two plates, then

$$\boxed{C_{vac} = \frac{A\varepsilon_o}{d}}$$

where A = Area of each plate of capacitor.

d = distance between plates of capacitor.

If dielectric is inserted between the plates then

$$C_{med} = \frac{A\varepsilon_o\varepsilon_r}{d} \quad \text{or}$$

$$\boxed{\varepsilon_r = \frac{C_{med}}{C_{vac}}}$$

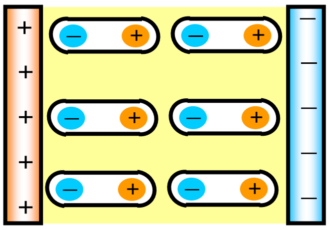
Where ε_r = relative permittivity of medium, dielectric constant or dielectric co-efficient (For most dielectrics ε_r = 1-10)

Relative permittivity is defined with reference to capacitance as **"The ratio of capacitance of parallel plate capacitor with an insulating substance as medium between the plates to its capacitance with vacuum (or air) as medium between them"**

Electric Polarization of Dielectrics

- It is the formation (arrangement) of positive and negative charge (dipoles) on the two opposite faces of a dielectric due to an external field.
- Two equal and opposite charges separated by a very small distance are said to constitute a dipole.
- Due to electric polarization, electric field and potential difference between two plates decreases but capacitance increases.

If a dielectric medium is inserted between the two plates of a parallel capacitor then both electric field and potential difference decrease and capacitance increases.



Knowledge plus

Electron volt is a unit of energy and not the unit of potential difference or voltage.

Dielectric Strength

The degree of polarization of dielectric depends upon the intensity of electric field applied to the dielectric material. As electric field intensity increases, polarization of dielectric also increases till a stage reaches when electron breakup from the molecules of dielectric. At this stage of the insulation of dielectric breaks down i.e. the nature of dielectric changes from insulator to conductor. As result to this electric break up down a spark passes through the dielectric.

The maximum value of electric field intensity that can be applied to a dielectric without its electric breakdown is called dielectric strength of the dielectric

The directed strength is generally measured in kV/cm. For example, air has a dielectric strength of 30 kV/cm. It means that maximum p.d that 1 cm, thickness of air can with stand across it without electric breakdown is 30 kV.

For your Information

$$F_{med} = \frac{F_{vac}}{\varepsilon_r} \qquad E_{med} = \frac{E}{\varepsilon_r} \qquad C_{med} = \varepsilon_r C_{vac} \qquad V = \frac{V_{med}}{\varepsilon_r}$$

Energy Stored in a Capacitor

- Energy is stored in the electric field between the two plates of a capacitor.

$$E = \frac{1}{2}qV$$

or $$E = \frac{1}{2}CV^2$$

Here V = potential difference between the plates of capacitor

- Energy stored $= \frac{1}{2}\varepsilon_0\varepsilon_r E^2 (Ad)$
- Energy stored $= \frac{1}{2}\varepsilon_0\varepsilon_r E^2 (\text{volume})$

- $\frac{\text{Energy}}{\text{Volume}} = \text{energy density} = \frac{1}{2}\varepsilon_0\varepsilon_r E^2$

Effect of Introducing a Dielectric in a Parallel Plate Capacitor:

Let C be the capacitance of the capacitor, charged to potential V, by connecting it to a battery. Let q be the charge on it, E the electric field between the plates and E is energy stored. After introduction of dielectric, the new quantities will be indicated by primes $(')$. It is assumed that the dielectric slab completely fills in the space between the plates. Two cases arise.

The Battery remains Connected:

(i) $V' = V$; **Potential** remains **unchanged.**

(ii) $E' = E$; **Electric field** is **unchanged.**

(iii) $q' > q$; **Charge** is **increased** by factor K. The additional charge is moved from the negative to the positive plate by the battery, as the dielectric slab is inserted.

(iv) $C' > C$; **Capacitance** is **increased** by a factor K.

(v) $U' = \frac{1}{2}q'V'$ $U' > U$ Energy is increased

The Battery is disconnected:

(i) $V' < V$; **Potential** is **decreased**

(ii) $E' < E$; **Electric field** is **decreased**

(iii) $q' = q$; **Charge** remains **unchanged** as there is no path for charge transfer.

(iv) $C' > C$; Capacitance is increased as $c = \frac{q}{V}$; q=constant but V decreases

(v) $U' = \frac{1}{2}q'V'$; $U' < U$

Thus, the new **energy** is **lowered** as q = constant but V decreases

Effect of Increasing the Plate Separation:

Two cases arise

The Battery Remains Connected:

(i) $V' = V$; **Potential** remains **unchanged.**

(ii) $E' < E$; The **electric field** is **decreased** since E = V/d, and V is constant.

(iii) $C' < C$; **Capacitance** is **reduced** since $C \propto 1/d$.

(iv) $q' < q$; The **charge** is **reduced** since q = CV, C decreasing and V remaining constant. Some charge is transferred from the capacitor to charging battery.

(v) $U' < U$, The **energy** is **decreased** since $U = \frac{1}{2}qV$ (and q decreased, V remaining constant).

Battery is Disconnected:

(i) $q' = q$; The **charge** remains **constant.**

(ii) $C' < C$; The **capacitance** is **decreased** since $C \propto 1/d$.

(iii) $V' < V$; The **potential** is **increased** because $q = CV$, and C decreases.

(iv) $E' = E$; The **electric field** is **constant** because $q = CV = \frac{\varepsilon_o AV}{d} = \varepsilon_o AE$, and q is constant.

(v) $U' > U$; **Energy increases**, $U = \frac{1}{2}qV$ and V increases, q remaining constant.

Charging and discharging of capacitor:

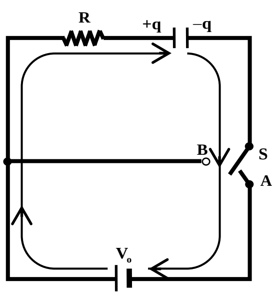
- Initially speed of charging is high but then it decreases and charging stops when charge on plates equals the charge on the terminals of supply.
- Speed of charging and discharging $\propto \dfrac{1}{\text{time constant RC}}$
- Car indicators use charging and discharging of capacitor.
- Windshield wipers operate by charging and discharging of capacitor. Their time of the on-off cycle is controlled by time constant RC.
- For **larger** values of **time constant**, a **capacitor** charges or discharges **slowly**. For smaller values of time constant, a capacitor charges or discharges rapidly.

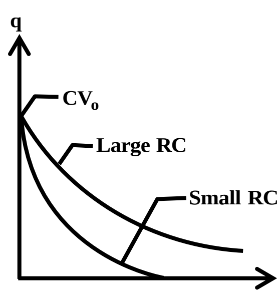
Time constant:

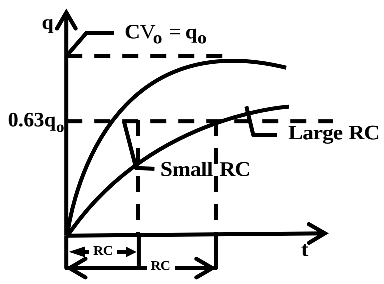
Time constant for charging process is the **time** during which **63 % of charge** is stored on the capacitor or **37 % is left** to be stored on the capacitor. Time constant for discharging process is the time during with 63 % of total charge has discharged or 37 % of total charge remains on the capacitor. A capacitor has total five time constants.

It is determined by the product of Resistance and capacitance of the circuit

i.e $\boxed{t = RC}$







Combination of Capacitors:

Series combination:

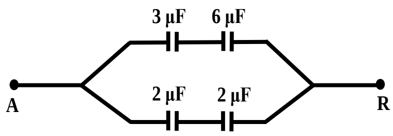
- If capacitors are connected end to end, then it is series combination.
- In series combination**, charge** stored on each capacitor has **same** value 'q'
- In series combination, **P.D** across different capacitors have **different** value and $V = V_1 + V_2 + V_3$
- In series combination, **reciprocal** of the equivalent capacitance $\mathbf{C_e}$ is equal to the **sum** of the **reciprocals** of **individual capacitance** used in series combination i.e., $\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$

Parallel combination:

- In parallel combination, **charge** stored on different capacitors have **different** value i.e., $q = q_1 + q_2 + q_3$
- In parallel combination, **P.D** across each capacitor has **same** value.
- In parallel combination, equivalent capacitance $\mathbf{C_e}$ is equal to the **sum** of the **individual capacitances.** i.e,. $C_e = C_1 + C_2 + C_3 + ...$

PRACTICE QUESTIONS

Q.21 The equivalent capacitance in the adjoining diagram will be



A) 13 μ F
B) 36/13 μF
C) 7 mF
D) 3 μF

Q.22 If time constant is 3 sec and resistance in RC series circuit is 6 m Ω the capacitance of capacitor used is

A) 0.0005 F
B) 0.005 F
C) 500 F
D) 5 F

Q.23 If plates of a charged capacitor are still attached with a battery and a dielectric is inserted then

A) Capacitance increases
B) Potential difference decreases
C) Charge on plates increases
D) Both 'A' and 'C'

Q.24 If (n – 1) capacitors each of capacitance 'C' are connected in series then their equivalent capacitance will be

A) $C_1 + C_2 + C_3 + ... + C_{n-1}$
B) $(n - 1) C$
C) $\frac{C}{n-1}$
D) $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_{n-1}}$

Q.25 The equivalent capacitance of capacitors of 1 μF, 2 μF and 3 μF in series is

A) $\frac{11}{6}$ μF

B) 6 μF

C) $\frac{6}{11}$ μF

D) $\frac{1}{6}$ μF

Time Saving Tips

1. For Series combination of two capacitor, use $C_e = \frac{\text{Product}}{\text{Sum}}$
2. The equivalent capacitance of more than one capacitors of same capacitance in parallel $C_e = nC$
3. The equivalent capacitance of more than one capacitors of same capacitance in series $C_e = \frac{C}{n}$
4. Electric field is from higher potential towards lower potential; not necessarily from positive to negative potential.

Some Brain teasers for your practice

(1) What is sure test of electrification; attraction or repulsion?

(2) If you are given a solid metal and hollow metal sphere. This will hold more charge if both spheres are of same radius?

(3) The safest way to protect your self from lighting is to be inside a car rather than under a tree or somewhere else. Why?

(4) What is the net charge on a charged capacitor?

(5) What is the capacitance of earth; High or low?

(6) When a dielectric slab is introduced between the plates of a capacitor, energy stored decreases. Why?

(7) How will you obtain a capacitance of 3 μ F from three capacitors, each of capacitance 2 μ F?

(8) What should be the capacitance of a capacitor capable of storing 1 joule energy when used with a 100 V d.c supply.

(9) How much work is done to charge 24 μF capacitor when potential difference between plates is 500V.

(10) Why the dielectric constant of a metal is infinity?

PRACTICE QUESTIONS

Q.26 In RC series circuit, for the rapid charging of a capacitor of constant capacitance, resistance attached should be

A) Larger

B) Smaller

C) Either larger or smaller

D) It is impossible to control charging time with resistance

Q.27 If magnitude of electric field at a point is equal to electric potential at that point, then distance of point from charge is

A) 1 meter

B) 2 meter

C) 3 meter

D) 4 meter

Q.28 If distance between two point charges is doubled keeping the charges same then electrostatic force is

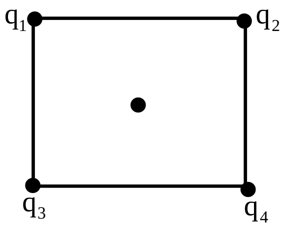
A) Halved

B) Doubled

C) Increased by four time

D) Decreased by four times

Q.29 Four charges; $q_1 = 4\mu C, q_2 = 3\mu C$, $q_3 = -5\mu C$ and $q_4 = -1\mu C$ **are located at the corners of a square of length** $\sqrt{2}$ **m of each side as shown. The potential at the center will be**



A) 4000V

B) 5000V

C) 9000V

D) 0 V

Q.30 If 5 N is the force between two charges in free space then force between the same two charges having same distance between them in a dielectric medium of relative permittivity 5 is

A) 1 N

B) 5 N

C) 4 N

D) 25 N

Q.31 Selenium is

A) Conductor in the dark

B) Insulator in light

C) Conductor in the dark and insulator in light

D) Conductor in light and insulator in the dark

Q.32 An electron of mass m and charge e can be suspended in an electric field of value

A) e/mg

B) mge

C) mg/e

D) 1/mge

Q.33 If the distance from charged particles is doubled, how do the new values of filed strength and potential due to charge change compared to the original values.

	Field Strength	Potential
A	$\frac{1}{4}$	$\frac{1}{4}$
B	$\frac{1}{4}$	$\frac{1}{2}$
C	$\frac{1}{2}$	$\frac{1}{4}$
D	$\frac{1}{2}$	$\frac{1}{2}$

Q.34 Electrostatic force between two charges is minimum in

A) Water
B) Glass
C) Vacuum
D) Rubber

Q.35 Choose incorrect regarding properties of charge

A) A body can have charge less than 1.6×10^{-19} C
B) A body can have charge equal to $\frac{15}{2}e$
C) A body can have a charge equal to 0.8×10^{-19} C
D) All of these

Q.36 The paper used in photocopier is

A) Positively charged
B) Negatively charged
C) Neutral
D) Given either negative or positive charge

Q.37 An alpha particle is accelerated through a P.D of 10^3 volt. Its K.E will be

A) 1 Kev
B) 2 Kev
C) 3 Kev
D) 4 Kev

Q.38 If a charge is placed at the centre of cube, the flux emitted through its one of the face

A) $\frac{q}{\varepsilon_o}$
B) $\frac{q}{2\varepsilon_o}$
C) $\frac{q}{6\varepsilon_o}$
D) $\frac{q}{12\varepsilon_o}$

Q.39 The force between two charges 1 m apart is 5 N. If each is moved by .25 towards the other, then force between them will become

A) 10 N
B) 5 N
C) 15 N
D) 20 N

Q.40 How three capacitors of 2 μ F each have to be connected to have an equivalent capacitance of 3 μF?

A) All the capacitors should be connected in series
B) All the capacitors should be connected in parallel

C) Two capacitors in series and one in parallel

D) Two capacitors in parallel and one in series

Q.41 Electric field due to point charge depends upon

A) Magnitude of charge
C) Medium in which charge is placed
B) Distance from charge
D) All of these

Q.42 Electric flux through a closed surface does not depend upon

A) Charge enclosed by surface
C) Shape or geometry of closed surface
B) Medium enclosed by surface
D) All of these

Q.43 If E_1 is the electric field near an infinite charged sheet and E_2 is the electric field between two oppositely charged plates of same surface charge density then which statement is correct?

A) $E_1 = E_2$
C) $E_1 = 2 E_2$
B) $E_1 = \frac{1}{2} E_2$
D) $E_1 = \frac{1}{4} E_2$

Q.44 Equal charges are given to two spheres of different radii. The potential will

A) Depend upon the material of sphere
C) Be more on large sphere
B) Be more on smaller sphere
D) Be equal on both sphere

Q.45 The potential at point A in an electric field is 10 V higher than at point B. If a negative charge Q = –2 C, is moved from point A to point B, then potential energy of this charge will

A) Decrease by 20 J
C) Increase by 5 J
B) Decreases by 5 J
D) Increases by 20 J

Q.46 ECG is related to

A) Brain
C) Heart
B) Eye
D) Stomach

Q.47 Electric flux through due to an atom is

A) Positive
C) Zero
B) Negative
D) Maximum

Q.48 A charge of +2Q is transferred to a solid metal sphere of radius r. where does this excess charge reside?

A) +2Q on the outer surface
C) +Q on the outer surface
B) +2Q at the centre
D) +Q/2 on the outer surface

Q.49 If 1 C charge is moved through a P.D of 10 V then K.E gained by charge is

A) 1 J
C) 0.1 J
B) 10 J
D) 100 J

Q.50 If electric field between two oppositely charged plates is 100 N/C then potential gradient is

A) 1 V/m
C) 100 V/ m
B) 1 N/C
D) 10 V/ m

Q.51 Electric potential is zero at

A) Surface of earth
B) Centre of earth
C) Infinity
D) All of these

Q.52 Which of the following is incorrect?

A) $1eV = 1.6 \times 10^{-12}$ erg
B) $1eV = 1.6 \times 10^{-19}$ J
C) $1 J = 6.25 \times 10^{9}$ GeV
D) None of these

Q.53 If electric field between the two plates of a capacitor is doubled then energy stored is

A) Constant
B) Doubled
C) Halved
D) Increased by four times

Q.54 A bullet of mass 2 g is having a charge 2 μC. Through what potential difference must it be accelerated , from rest to acquire a speed of 10 m/s?

A) 50 Kv
B) 5 KV
C) 50 V
D) 5 KV

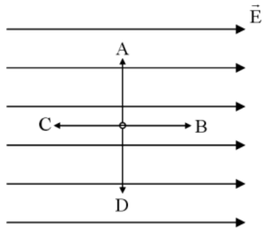
Q.55 In series combination of capacitors, equivalent capacitance is

A) Less than the largest individual capacitance
B) Less than the smallest individual capacitance
C) Equal to average capacitance
D) Greater than the largest individual capacitance

Q.56 In electric polarization, induced and external field are

A) Parallel
B) Antiparallel
C) Perpendicular
D) At 60° with each other

Q.57 An electron is in an uniform electric field, as shown in figure below. In which one of the following direction must the electron be moved in order to gain electric potential energy?



Q.58 If 2 ohm resistance is connected to a capacitor of 1 μF, then time constant is

A) 1 μs
B) 2 μs
C) 3 μs
D) $\frac{1}{2}$ μs

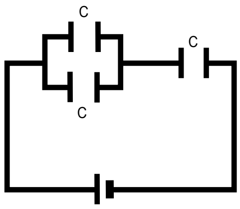
Q.59 Due to electric polarization, potential difference and electric field between the plates of capacitor_______ and capacitance_______

A) Decreases, increases
B) Increases, decreases
C) Remains unchanged , increases
D) Increases then deceases, decreases

Q.60 Which of the following is the principle of capacitor?

A) Charging by polarization
B) Charging by conduction
C) Charging by electrostatic induction
D) Charging by radiation

Q.61 Three capacitors each of capacitance C are connected as shown in the fig. Their equivalent capacitance will be.

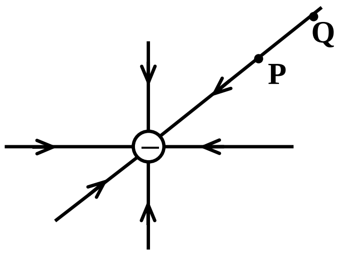


A) $\frac{2}{3}C$
B) $\frac{3}{2}C$
C) $\frac{1}{3}C$
D) 3C

Q.62 A parallel plate condenser (capacitor) with oil between the plates (dielectric constant = 2) has a capacitance C. If oil is removed then capacitance of capacitor becomes

A) $\sqrt{2}\,C$
B) 2 C
C) $\frac{C}{\sqrt{2}}$
D) $\frac{C}{2}$

Q.63 Figure shows the electric field lines due to a negative point charge. If P and Q are two points in electric field of point charge then



A) $V_Q = V_P$
B) $V_Q > V_P$
C) $V_Q < V_P$
D) $V_Q = V_P = 0$

Q.64 A parallel plate capacitor (condenser) is charged and then disconnected form battery and a dielectric is inserted. What happens to potential difference and the stored electrical P.E

A) P.D decreases and P.E decreases
B) Both decreases
C) P.D decreases and P.E increases
D) Both increases

Q.65 The units of electric flux are

A) $\frac{Nm}{C^2}$
B) Vm
C) $\frac{Nm^2}{C}$
D) Vm^{-1}

Q.66 Which one the following force lacks the property of shielding

A) Electrostatic force
B) Gravitational force
C) Magnetic force
D) Both A and C

Q.67 The negative of gradient of electric potential energy is equal to

A) Electric force

B) Electric field intensity

C) Electric charge density

D) Electric potential

Q.68 A positron in a uniform electric field moves

A) Along electric field

B) Opposite to electric field

C) Perpendicular to electric field

D) None of these

Q.69 An oil droplet of mass m, carrying a charge q, is in the region between two horizontal plates. When the potential difference between the upper and lower plates is V, the droplet is held stationary. The potential difference is then increased to 3V.What is the initial upward acceleration of the droplet?

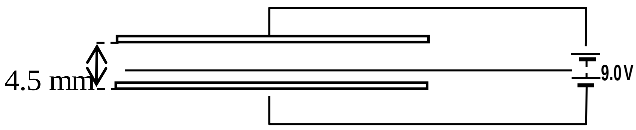
A) g

B) 2g

C) $\frac{2qV}{m} - g$

D) None of these

Q.70 The diagram shows a metal plate 4.5 mm apart connected a 9.0 V battery. What is the electric field between the plates?



A) 4.4×10^{-4} NC^{-1}

B) 3.6×10^{-2} NC^{-1}

C) $36 NC^{-1}$

D) 2×10^{3} NC^{-1}

ANSWERS WITH EXPLANATION

Q1. **(C).** $\frac{F'}{F} = \frac{K\frac{2q_1q_2}{\left(\frac{1}{3}d^2\right)}}{K\frac{q_1q_2}{d^2}}$ or $F' = 18\,F$

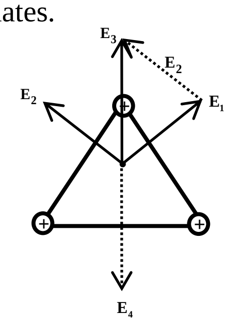
Q2. **(A).** The units of permittivity of free space are $C^2\,m^{-2}\,N^{-1}$ or $\frac{C^2\,m^{-1}N^{-1}}{m}$

but $C^2\,m^{-1}\,N^{-1} = F$ as $\left[\begin{aligned} c &= \frac{q}{V} \\ &= \frac{C}{J/C} \\ &= C^2J^{-1} \\ F &= C^2\,N^{-1}\,m^{-1} \end{aligned}\right]$

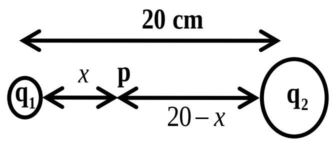
so units of $\varepsilon = \frac{F}{m}$

Q3. **(B)** Electric lines of force travel from high potential to low potential. Near the ends of the parallel plates, there is some outward bending of the parallel plates.

Q4. **(D)** From diagram it is clear that E_4 will cancel E_3, so resultant field is zero. As there is no resultant field, so there is no force.



Q5. **(A)** In case of same charges, zero field lies between the charges (near the small charge) so From Fig.



$|\vec{E}_1| = |\vec{E}_2|$

$\frac{kq_1}{x^2} = \frac{kq_2}{(20-x)^2}$

8 cm = x

Q.6 **(D)**

Q7. **(C)** $E = \frac{\Delta V}{\Delta r}$, Electric field is constant between two plates.

Q8. **(A)** $F = qE \;\; = q(V/d) = 1.6 \times 10^{-6}$ N

Q9. **(D)** In ink jet printer the droplets that are needed on the paper are not charged .so None of these is the right option.

Q10. **(D)** $q = \frac{mg}{E} = \frac{4.8 \times 10^{-5} \times 9.8}{9.8 \times 10^{4}} = 3\,(1.6 \times 10^{-19}) = 3e$

Q11. **(A)** $V = V_{+} + V_{-} = \frac{kq}{PX} - \frac{kq}{QX}$

As (PX = Q X)

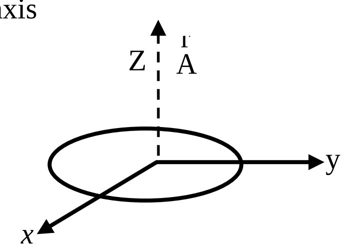
So $V = (k - k)\frac{q}{PX}$

$V = 0$

And electric field is towards decreasing potential so towards Q.

Q12. **(B)**

Area lies in xy–plane so vector area is directed along z-axis



$\varphi_e = \vec{E} \cdot \vec{A}$

$= (4\hat{j}) \cdot (\hat{k})$

$\varphi_e = 0$

Q13. **(C)**

Q.14 **(D)** Flux is only passing through faces and through not curved surfaces.

Q.15 **(D)** Close to the sheet, electric field is independent of distance;

$E = \frac{\sigma}{2\varepsilon_o}$ But at a very long distance, sheet behaves as a point charge, so

$E = \frac{kq}{r^2}$ Now it obeys inverse square law.

Q16. **(D)** $V = \frac{kq}{d}$

$V' = \frac{kq}{d/3}$

$V' = 3V$

Q17. **(B)** Direction of electric field is not only from + ve plate to –ve plate, but from higher to lower potential

Q18. **(C)** Electric filed is a region where potential is changing uniformly

so if

$E = 0$

$E = \frac{\Delta V}{\Delta r}$

$O = \Delta V$

Constant $= V$

Q19. **(B)** K.E $= q\Delta V$

$= (2e)\,(10v)$

$= 20eV$

Q20. **(C)**

Q21. **(D)** 6μF and 3μF are in series

$C'_e = \frac{3 \times 6}{3 + 6} = \frac{18}{9}$

$C'_e = 2$

Both 2μF are also in series

$C''_e = \frac{2 \times 2}{2 + 2} = 1$

Now finally

$C'''_e = 2 + 1 = 3\ \mu F$

Q22. **(C)** $t = RC$

$c = t/R = \frac{3}{6\times10^{-3}}$

$c = 500\ F$

Q23. **(D)** In the presence of battery, potential difference should remain constant. So when dielectric is inserted then potential difference decreases but battery sends next increment of charge to maintain potential difference

Q24. **(C)** General formula for equivalent capacitance of 'n' capacitors is

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

For n – 1 capacitors $Ce = \frac{C}{n-1}$

Q25. **(C)**

Q26. **(B)** t = RC

Q27. **(A)**

$|E| = V$

$\frac{kq}{r^2} = \frac{kq}{r}$

$r = 1$

Q28. **(D)**

Q29. **(C)** From Diagram r = 1

$v = v_1 + v_2 + v_3 + v_4 = \frac{k}{r}(q_1 + q_2 + q_3 + q_4) = (4 + 3 - 5 - 1) = 9000\ V$

Q30. **(A)** $\varepsilon_r = \frac{F_{vac}}{F_{med}}$

Q31. **(D)**

Q32. **(C)** mg = eE

Q33. **(B)** $E \propto \frac{1}{r^2}, \ V \propto \frac{1}{r}$

Q34. **(A)** $F = \frac{q_1 q_2}{4\pi\varepsilon_o \varepsilon_r}$ So, $\varepsilon_r^{\uparrow}$ $F_{\downarrow}$

Q35. **(D)**

Q36. **(A)**

Q37. **(B)** $K.E = qV$

Q38. **(C)** Flux through 6 faces = $\frac{q}{\varepsilon_o}$

Flux through 1 face = $\frac{q}{6\varepsilon_o}$

Q39. **(D)** Distance is halved**;** So, F′ = 4 F

Q40. **(C)**

Q41. **(D)** $E = \frac{q}{4\pi\varepsilon_o r^2}$

Q42. **(C)** $\varphi_e = \frac{q}{\varepsilon_o}$

Q43. **(B)** Electric field between parallel plates is stronger than due to an infinite sheet of charge.

Q44. **(B)** $V = \frac{kq}{r}$

Q45. **(D)** K.E = qV

Q46. **(C)**

Q47. **(C)**

Q48. **(A)**

Q49. **(B)**

Q50. **(C)**

Q51. **(D)**

Q52. **(D)** All relations are correct

For option (A) leV = 1.6×10^{-19} J

= $1.6 \times 10^{-19} \times 10^{7}$ erg

leV = 1.6×10^{-12} erg

For option (C) 1J = 6.25×10^{18} eV = $6.25 \times 10^{9} \times 10^{9}$ eV

1J = 6.25×10^{9} GeV

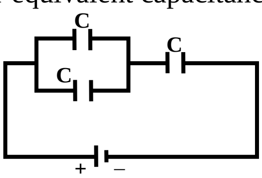
Q53. **(D)** Energy **=** $\frac{1}{2}\varepsilon_r \varepsilon_o E^2 (Ad)$ **Q54.** **(A)** **Q55.** **(B)** **Q56.** **(B)**

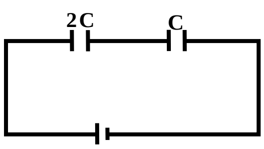
Q57. **(B)** **Q58.** **(B)** **Q59.** **(A)** **Q60.** **(C)**

Q61. **(A)** First two capacitors are in parallel so their equivalent capacitance will be

C_e = 2 c

Now the new combination will become





$$C_e = \frac{\text{Product}}{\text{sum}}$$

$$= \frac{2C \times C}{2C + C}$$

$$\boxed{C_e = \frac{2}{3} C}$$

Q62. **(D)** $C_{vac} = \frac{C_{med}}{\varepsilon_r}$ **Q63.** **(B)** **Q64.** **(A)** $q = CV,\ E = \frac{1}{2} qV$

Q65. **(B)** **Q66.** **(B)**

Q67. **(A)** $E = -\frac{\Delta V}{\Delta r}$

or $qE = -\frac{q\Delta V}{\Delta r}$

$F = -\frac{W}{\Delta r}$ which is potential energy gradient.

Q68. **(A)**

Q69. **(B)** When droplet is stationary

$$0 = qE - mg = \frac{V}{d}q - mg\ ,\ mg = \frac{qV}{d}$$

Now when potential difference is increased to 3V

$$ma = \frac{qV'}{d} - mg = \frac{q(3v)}{d} - mg = 3\left(\frac{qV}{d}\right) - mg = 3\ mg - mg,\ ma = 2\ mg,\ \ a = 2\ g$$

Q70. **(D)** $E = -\frac{\Delta V}{\Delta r}$

UNIT 10

Current Electricity

CURRENT ELECTRICITY

The branch of physics which deals with charges in motion is called current electricity or electrodynamics.

Electric Current:

"The rate of flow of charge through a cross section of some region of a conductor say a metallic wire is called current through that region"

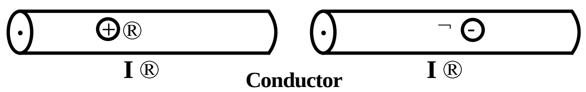
$$I = \frac{\Delta Q}{\Delta t}$$

- SI unit of electric current is 1 A = 1 C/s
- In case of metals, charge carriers are electrons.
- The charge carriers in electrolytes are positive and negative ions.
- The charge carriers in semiconductors are electron and positive holes.

Metals have high electron density e.g there are 10^{29}electrons in each cubic metre of copper.

Conventional Current:

- That current which Passes from a point at higher potential to a point at lower potential as if it represents movement of positive charge
- Positive charge moving in one direction is equivalent in all external effects to a negative charge moving in the opposite direction.
- For motion of electrons, we use the term electronic current
- In metallic conductors, the charge is carried by free electrons. In electrolytes, the charge is carried by positive and negative ions. The direction of current is taken to be the direction in which the positive charge moves.
- A positive charge moving in one direction is equivalent to negative charge moving in the opposite direction



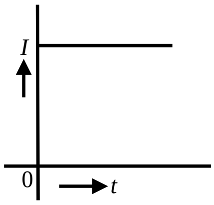
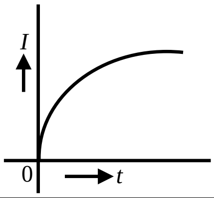
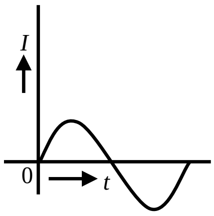
TYPES OF ELECTRIC CURRENT

The electric current may be classified into three main classes:

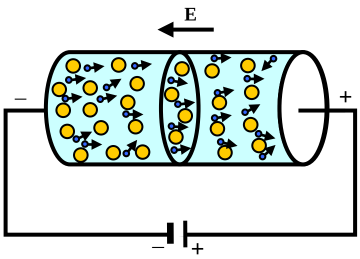
(i) Steady current or Direct current

(ii) Varying current

(iii) Alternating current

Steady Current	When the magnitude of current does not change with time, it is called a steady current or direct current. Fig. (i) shows the graph between steady current and time. Note that value of current remains the same as the time changes. The current provided by a battery is almost a steady current. 
Varying Current	When the magnitude of current changes with time, it is called a varying current .Fig.(ii) shows the graph between varying current and time. Note that value of current varies with time. 
Alternating Current	An alternating current is one whose magnitude changes continuously with time and direction changes periodically. Due to technical and economical reasons, we produce alternating currents that have sine wave form (or cosine waveform) as shown in fig.(iii). It is called alternating current because current flows in alternate directions in the circuit, i.e., from 0 to T/2 second (T is the time period of the wave) in one direction and from T/2 to T second in the opposite direction. 

Current Through a Metallic Conductor:



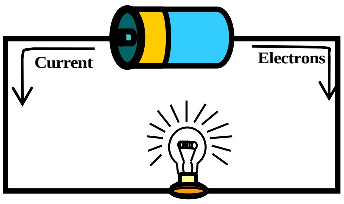
- The direction of electronic current is antiparallel to electric field $\vec{E}$ and direction of conventional current is parallel to $\vec{E}$.
- The uniform velocity acquired by free electrons in a conductor when an electric field is applied across it, is called drift velocity v_d

Drift Velocity:

- Metallic conductor has large number of electrons and in the absence of electric field, they move in all directions randomly and therefore their average velocity is zero.
- At room temperature due to their thermal motion their velocity is several hundred kilometers per second.

- When an electric field is applied, they are accelerated opposite to the electric field and therefore they have a net drift in that direction. That velocity is called drift velocity

"The average velocity with which the free electrons move under the action of applied electric field is called drift velocity".



The drift velocity is of the order of 10^{-3} m/s,
Relation between drift velocity v_d and electric current is

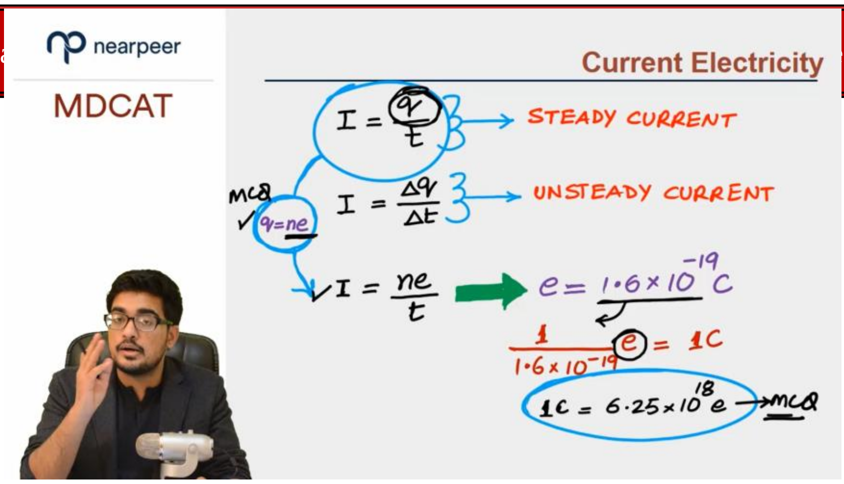
$$\mathbf{v_d} = \frac{I}{nAq}$$

Where n = number of charge carriers per unit volume = Charge density
A = cross – sectional area of conductor

Sources of current

- **Cells** ⇓ Chemical energy to Electrical energy
- **Generators** ⇓ Mechanical energy to Electrical energy
- **Thermocouples** ⇓ Heat energy to Electrical energy
- **Solar cells** ⇓ Light energy to Electrical energy

Ratio of ma … d mobility.



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 10.01)

PRACTICE QUESTIONS

Q.1 If 1.6 A of current flows through a copper wire of cross sectional area 1 mm^2 and if the free electron density in copper is 8×10^{28} per m^3 then the drift velocity of electrons in ms^{-1}

A) 12.5×10^{-4}
B) 1.25×10^{-4}
C) 2.5×10^{-5}
D) 12.5×10^{-5}

Q.2 All of the following statements are incorrect except

A) Silver is the best conductor followed by aluminum and then copper
B) Copper is the best conductor followed by silver and then aluminum
C) Copper is the best conductor followed by aluminum and then silver
D) Silver is the best conductor followed by copper and then aluminum

Q.3 The working of electric iron is based upon;

A) Ohm's Law
B) Joule's Law
C) Faraday's Law
D) Ampere's Law

Q.4 The current flowing through a wire is 3.2 μA. What is the time taken by 20,000 electrons to pass through any cross sectional area of that conductor?

A) 1 ns
B) 1 μs
C) 1.5 ps
D) 1.2 ms

Q.5 In a discharge tube, the number of hydrogen ions (i.e. protons) drifting across a cross section per second is 1.2×10^{18} while the number of electrons drifting in opposite direction is 2.8×10^{18} per second. The current through the tube will be

A) 0.64 A
B) 64 A
C) 0.19 A
D) 0.44 A

Ohm's law

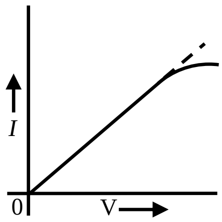
The current flowing through a conductor is directly proportional to the potential difference applied across the ends of a conductor provided the physical state of the conductor remains constant.

$$\boxed{V = IR}$$

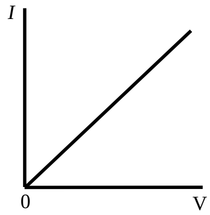
- Resistance R of a conductor is due to collision of free electrons with the atoms of conductor. It depends upon dimensions and material of conductor.
- 1 ohm = 1 volt / 1 ampere
- A conductor which strictly obeys ohm's law is called ohmic device (linear device). Some examples of ohmic conductors are eureka wires and carbon resistors
- The devices which do not body Ohm's law are non-ohmic devices (non linear devices). The examples of non ohmic devices are filament bulbs and semiconductor diode.

For Your Information

Ohm's law is applicable to both Ohmic and non-Ohmic but Ohmic substances strictly obey Ohm's law.



I-V characteristics of tungsten filament



I-V characteristics of eureka wire

- Ohm's law is an electrical form of Newton's 2nd law
- Resistance is analogous to mass

Series and Parallel Combination of Resistors:

Series Combination:

- Re = $R_1 + R_2 + \dots\dots\dots$
- In series, equivalent resistance is greater than the greatest individual resistance.
- In series, current in each resistor remains same but potential difference varies
- The total resistance is equal to the sum of the individual resistances.
- The voltage drop across any resistance is directly proportional to its resistance

Note. The main disadvantage of series is that if one component (device) fails then current in the whole circuit stops.

Series Circuit

- A series circuit has only one conducting path available for flow of current.
- Devices in a series circuit should be rated to operate at the same current.

Parallel Combination:

- $\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \dots\dots\dots$
- In parallel combination, equivalent resistance is less than the smallest individual resistance.
- In parallel combination, potential difference across each resistor remains same but current through each resistor changes.
- The current through any resistance is inversely proportional to its resistance
- The reciprocal of the total resistance is equal to the sum of reciprocals of the individual resistances

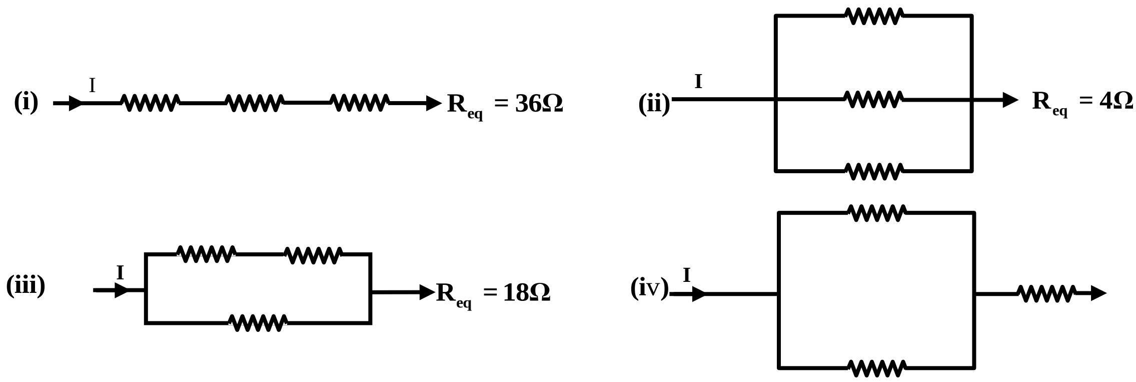
Note. The household circuit is connected in parallel so that if any device is switched off, the rest of devices remain on.

Parallel Circuit

- A parallel circuit provides more than one conducting paths. The circuit has two or more components connected across two common points in the circuit.
- Devices in a parallel circuit should be rated to operate at same voltage.

Possible Combinations of Resistors:

If we have three resistances, each of 12 Ω then the different equivalent resistances that can be obtained by combining all of them in various ways is



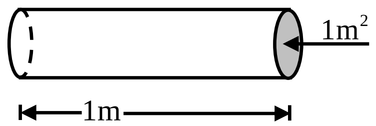
Calculation of Electricity Units

The electricity consumed units can be calculated by using the formula $\text{units consumed} = \frac{\text{power in watts} \times \text{time in hours}}{1000}$

In above combination, order of power dissipation is ii < iii < iv < i

RESISTIVITY OR SPECIFIC RESISTANCE

- Resistance R of a conductor of length L and area A is given by R = ρL/A
  Where ρ = resistivity of material
- Specific resistance is the resistance of unit cube volume of a substance and its unit is Ohm-m.
- Specific resistance of a material can also be defined as the resistance offered by a wire of length 1 metre and area of cross section 1 m^2.



- Conductance $= \frac{1}{R} = \frac{1}{\text{ohm}} = \Omega^{-1}$=mho=siemens
- $\rho = \frac{\mathbf{RA}}{\mathbf{L}} = \Omega\ \text{m}$
- Conductivity $= \sigma = \frac{1}{\rho} = \Omega^{-1}\ \text{m}^{-1} = \text{mho m}^{-1} = \text{siemen m}^{-1}$

Caution

- Resistance is a characteristic of a wire and depends upon the resistivity, dimensions and temperature.
- Resistivity is a characteristic of the material and depends upon temperature and not upon dimensions.

Temperature Coefficient of Resistance

- Fractional change in resistance per unit change in temperature.
- $\alpha = \frac{R_t - R_o}{R_o t}$ where R_t = resistance at t °C R_o = Resistance at 0 °C
- With increase in temperature, resistance of conductor increases as the probability of collision of free electrons with the vibrating lattice atoms increases.
- For conductors ,α is positive i.e., resistance increases with increase in temperature
- For carbon, rubber, mica, electrolytes, semiconductors and insulators, α is negative i.e. resistance decreases with increase in temperature.

For Your Information

Large value of 'α' (Temperature coefficient of resistance) for a material means there will be enormous change in resistivity of material even for small charge in temperature.

Resistivities and Conductivities for Different Materials

Substance	ρ(Ω m)	α(k^{-1})
Silver	1.52×10^{-8}	0.00380
Copper	1.54×10^{-8}	0.00390
Gold	2.27×10^{-8}	0.00340
Aluminium	2.63×10^{-8}	0.00390
Tungsten	5.00×10^{-8}	0.00460
Iron	11.00×10^{-8}	0.00520
Platinum	11.00×10^{-8}	0.00520
Constantan	49.00×10^{-8}	0.00001
Mercury	94.00×10^{-8}	0.00091
Nichrome	100.0×10^{-8}	0.00020
Carbon	3.5×10^{-5}	-0.0005
Germanium	0.5	-0.05

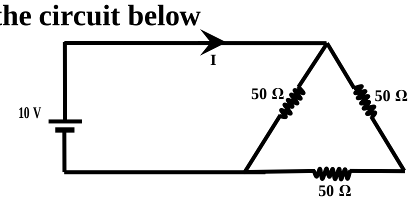
Silicon	20-2300	-0.07

Points to remember:

- Nichrome (Heating wire) has high resistivity
- Copper (Best conductor) has low resistivity
- Manganin (Standard resistor) has high resistivity and low temperature coefficient of resistance.

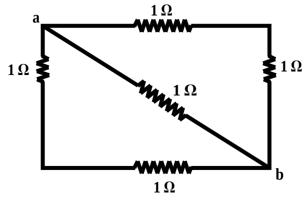
PRACTICE QUESTIONS

Q.6 What is the current in the circuit below



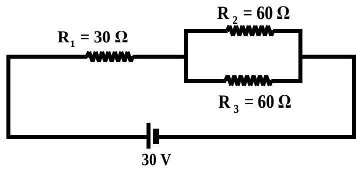
A) 0.3 A
B) 0.2 A
C) 0.1 A
D) None of these

Q.7 Equivalent resistance across the points 'a' and 'b' is



A) 2 Ω
B) $\frac{3}{5}$ Ω
C) 5 Ω
D) $\frac{1}{2}$ Ω

Q.8 The potential difference across R_1 is



A) 30 V
B) 10 V
C) 15 V
D) 20 V

Q.9 A piece of a certain material has resistance of 100 Ω at 0 °C and 10 Ω at 18 °C. The material is of

A) Carbon
B) Germanium
C) Silicon
D) None of these

Q.10 Siemen m^{-1} are the units of

A) $\frac{1}{\text{Conductivity}}$
B) $\frac{1}{\text{Resistivity}}$
C) Conductance
D) Resistance

Q.11 The relationship between electric field and conductivity across the terminals of a conductor of length l and area of cross – section A.

A) $\sigma = \frac{I}{AE}$
B) $E = AI\sigma$
C) $\sigma A^2 = E$
D) None of these

Q.12 When the length as well as diameter of a wire is doubled, its resistance will become

A) Double
B) Four times
C) One fourth
D) One half

Q.13 Resistivity of platinum in Ω cm is

A) 1.1×10^{-8}
B) 1.1×10^{-5}
C) 1.1×10^{-7}
D) 1.1×10^{-6}

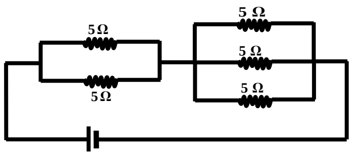
Q.14 A uniform wire of resistance 16 Ω is stretched uniformly to twice of its length. The resistance of stretched wire is now.

A) 32 Ω
B) 8 Ω
C) 16 Ω
D) 64 Ω

Q.15 The resistance of a metallic wire becomes 8 times when:

A) Length is doubled
B) Length is tripled
C) Length is doubled and radius is halved
D) Length is halved and radius is doubled

Q.16 What is the equivalent resistance of the circuit?



A) $\frac{6}{25}\ \Omega$
B) $\frac{25}{6}\ \Omega$
C) $\frac{25}{3}\ \Omega$
D) $\frac{3}{25}\ \Omega$

Q.17 In case of tungsten filament, the deviation of I-V graph from straight line is due to

A) Increase in potential difference
B) Increase in current
C) Increase in resistance
D) All of these

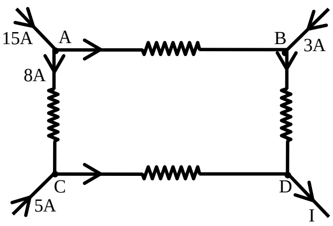
Q.18 Slope of I-V graph for an ohmic substance gives

A) Conductance
B) Resistance
C) Conductivity
D) Temperature co-efficient of resistance

Q.19 One million electrons are passing through a cross section of a conductor in one millisecond. The current through the conductor is

A) 0.16 nA
B) 1.6×10^{-11} A
C) 1.6 μA
D) 16×10^{-12} A

Q.20 Figure shows a net work carrying currents. The current I in the circuit will be



A) –3 A
B) 3 A
C) 13 A
D) 23 A

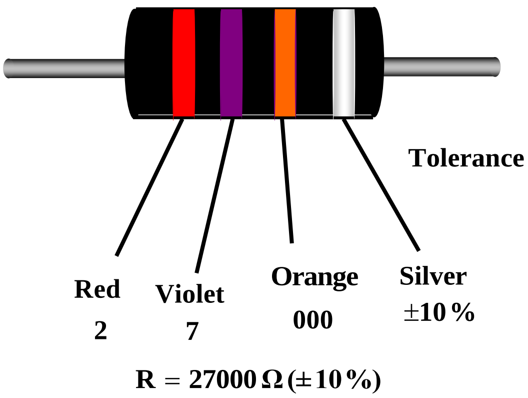
CARBON RESISTORS

A component whose function in a circuit is to provide a specified value of resistance is called a resistor.

- Most commonly used resistors in electrical and electronic circuits are the carbon resistors.
- Are made from powdered carbon mixed with a binding material and baked into a small tube with a wire attached to each end.
- Are manufactured in values from a fraction of an ohm to several million ohms.

Colour Code for Carbon Resistors:

- Since a carbon resistor is physically quite small, it is more convenient to use a colour code indicating the resistance value than to imprint the numerical value on the case.
- Four colour bands are printed on the body of the resistor as shown in Fig.
- First three colour bands give the value of the resistance while the fourth band tells about the tolerance in percentage
- **Possible variation of resistance from the marked value is called as tolerance**



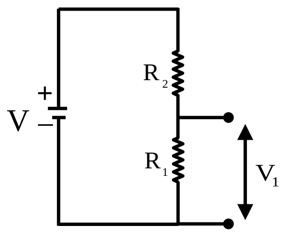
Colour Code	Tolerance
Gold	± 5 %
Silver	± 10 %
No colour	± 20 %

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Gray	White
0	1	2	3	4	5	6	7	8	9

POTENTIAL DIVIDER

A potential divider is an arrangement of resistors which is used to obtain a fraction of the potential difference provided by a voltage supply.

- When resistances are connected in series; they divide the potential in the circuit. .Figure shows a simple divider which consists of two known resistors of resistances R_1 and R_2 connected in series to a voltage supply V.
- The potential difference V is then connected to a load, such as a lamp



The current I flowing is given by

$$I = \frac{V}{R_1 + R_2}$$

Therefore, the potential difference across R_1

$$V_1 = IR_1 = \left(\frac{R_1}{R_1 + R_2}\right)V = \frac{\text{(resistance)}}{\text{(total resistance)}} \times \text{(main voltage)}$$

Knowledge plus

Current Divider:

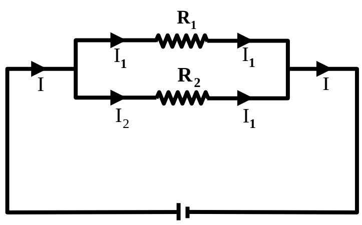
When resistances are connected in parallel; they divide the current in the circuit.
The equivalent resistance R of two resistors with resistances R_1 and R_2 connected in parallel is

$$\mathbf{R = \frac{R_1R_2}{R_1 + R_2}}$$

The potential difference across R_1 = potential difference across equivalent resistance R

$$\mathbf{= I\left(\frac{R_1R_2}{R_2 + R_1}\right)}$$

Current through the resistance R_1 is



$$\mathbf{I_1 = \left(\frac{R_2}{R_1 + R_2}\right)I}$$

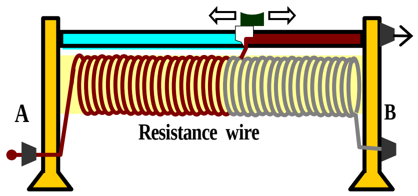
$$= \frac{\text{(the other resistance)}}{\text{(total resistance)}} \times \text{(main current)}$$

RHEOSTAT

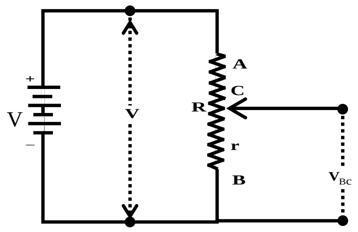
It is a wire wound variable resistor of manganin wire wound on insulating cylinder.

Uses

Variable resistor



Potential divider



For rheostat as potential divider

$$\mathbf{V_{BC} = \frac{r}{R} \times V}$$

Thermistors:

"A heat sensitive device usually made of semiconductor materials whose resistance changes rapidly with the change of temperature"

- Temperature coefficient of a thermistor is very high and it can be both positive and negative.
- Thermistors are made by heating under high pressure semiconductor ceramic made from mixtures of metallic oxides of manganese, nickel, cobalt, copper, iron etc.

- It is a temperature sensor i.e., it converts changes of temperature into electrical voltage.

Electromotive force EMF and potential difference:

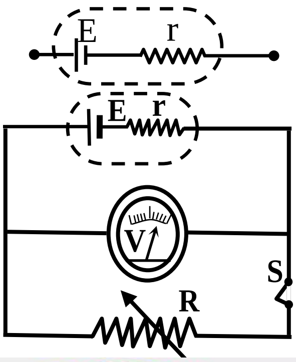
E.M.F (E)	Potential Difference
It is the potential difference across the terminal of the cell when it is delivering no current i.e. when cell is in the open circuit.	It is the potential difference across the terminals of the cell when it is delivering current i.e. the cell circuit is closed.
It is independent of circuit resistance and depends upon the nature of the electrodes and the electrolyte.	It depends upon circuit resistance and circuit current.
It maintains potential difference.	It cause to current flow in circuit.
It is greater than V.	It is less than E.
The tern e.m.f is used for a source of voltage.	The p.d (V) is voltage between two points in closed circuit.

Internal Resistance:

The resistance offered by a cell due to its electrolyte to the current flow is called internal resistance

- The internal resistance (r) of a fresh cell is generally low and as the cell is used, its internal resistance goes on increasing.
- The internal resistance of a cell depends upon the distance between the plates, nature of the electrolyte, concentration of the electrolyte, nature of the electrode and area of the plates.

Terminal Potential Difference:

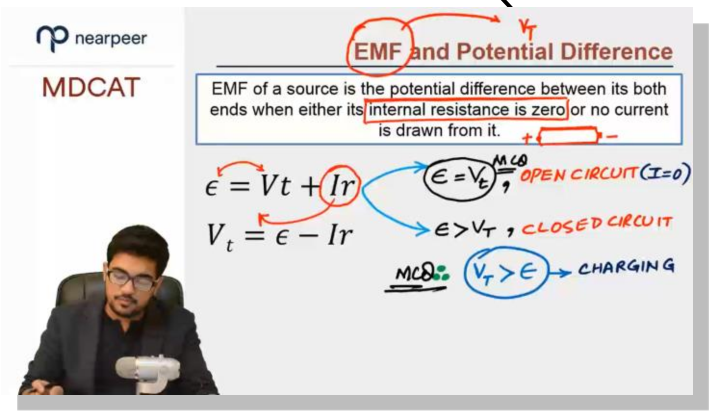


- The terminal potential difference of a cell is the potential difference between the electrodes of the cell when the cell is delivering current (i.e., cell circuit is closed). It is denoted by the symbol V.
- For open circuit ($R = \infty$ and $I = 0$),

  $V_t = E - I r$; $E = V_t$
- For closed circuit (finite current), It is when battery is discharging

  $V_t = E - I r$; $V_t < E$
- If a cell is being charged then

  $V_t = E + I r$; $V > E$



For Your Information

A cell is charged by connecting +ve terminal of charging D.C source to the +ve terminal of the cell and –ve terminal with that of –ve terminal.

ELECTRICAL POWER

The rate at which work is done by voltage source (e.g a battery) for the flow of current in circuit is called electrical power

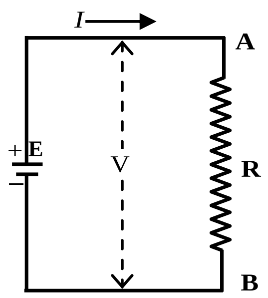
Electrical Power and Power Dissipation in Resistors:

- The time rate at which energy is supplied by the battery is called electrical power P_e and it is equal to power dissipated P_d in resistor according to law of conservation of energy.

$$P = VI = I^2R = \frac{V^2}{R}$$

If two bulbs of power P_1 and P_2 are connected in series then total power consumed

$P = P_1 + P_2$



- If two bulbs are connected in parallel with the same voltage source, then the both with the higher power rating have lower resistance. In parallel , $\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2}$

Maximum Power Transfer Theorem:

When load is connected across a D.C voltage source, power is transferred from the source to the load. The amount of power transferred will depend upon the resistance. This can be stated as follows:

Maximum power is transferred from a D.C source to a load when the load resistance is made equal to the internal resistance of the source.

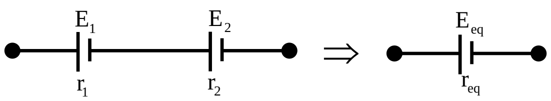
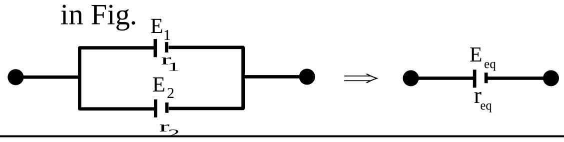
So If R = r then $P_{max} = \frac{E^2}{4r}$

Points to remember

Rating of Electrical Appliances:

1. On every electrical appliance its rating is specified as (P watts. V volts). This indicates that this appliance is designed for V volts and when connected to these voltages, it consumes a power of P watts. From the rating, we can find the resistance as $\mathbf{R} = \frac{\mathbf{V^2}}{\mathbf{P}}$
2. And the maximum current that can be passed without the appliance getting fused as $\mathbf{I} = \frac{\mathbf{P}}{\mathbf{V}}$

GROUPING OF CELLS

Cells connected in series	Cells connected in parallel
If the cells are connected in series as shown in Fig. 	If the cells are connected in parallel as shown in Fig. 
The equivalent emf and equivalent internal resistance of the combination is given by $E_{eq} = E_1 + E_2$ where $r_{eq} = r_1 + r_2$	The equivalent emf and equivalent internal resistance of the combination is given by $\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$ Where $\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$
For n cells in series $E_{eq} = E_1 + E_2 + \ldots + E_n$ and $r_{eq} = r_1 + r_2 + \ldots + r_n$	**For n cells in parallel** $\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2} + \ldots + \frac{E_n}{r_n}$ and $\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \ldots + \frac{1}{r_n}$

PRACTICE QUESTIONS

Q.21 If we have five resistors each of 1/5 Ω, then minimum resistance we can obtain by combining them is

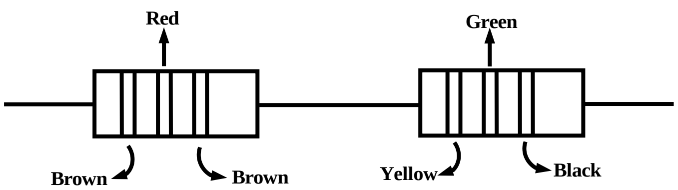
A) $\frac{1}{25}\Omega$

C) $\frac{1}{100}\Omega$

B) $\frac{1}{5}\Omega$

D) $\frac{1}{75}\Omega$

Q.22 The combined resistance of the two resistors connected as in figure below is about



A) 120 Ω C) 165 Ω

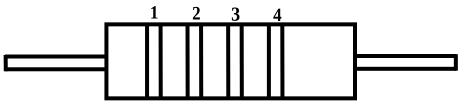
B) 145 Ω D) 155 Ω

Q.23 Lengths of two wires of same material are in ratio 2:3 and their radii have the ratio 1:2. Then ratio of their resistances is

A) 1:3 C) 1:6

B) 4:3 D) 8:3

Q.24 The colour codes of the carbon resistor shown in the figure is



A) Red, orange, red, gold C) Orange, orange, orange, gold

B) Orange, orange, red, gold D) Red, red, violet, silver

Q.25 When maximum power is dissipated in the external circuit then terminal potential difference would be

A) Half than emf C) Equal to internal potential drop

B) Double than emf D) Both A and C

Q.26 The potential difference between the terminal of a battery in open circuit is 2.2 V when it is connected across a resistance of 6 Ω, the potential falls to 1.8 V. The internal resistance of the battery is

A) 1.33 Ω C) 1 Ω

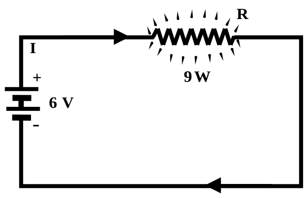
B) 1.11 Ω D) 1.2 Ω

Q.27 1000 W, 500 W, 200 W and 100 W filament bulbs are connected in parallel with 220 V DC supply. Which one of these has the least resistance?

A) 1000 W C) 200 W

B) 500 W D) 100 W

Q.28 The value of resistance 'R' of the resistor shown in the figure is



A) 3 Ω C) 2 Ω

B) 9 Ω D) 4 Ω

Q.29 Electromotive force can be _________ terminal potential difference

A) Less than C) Equal to

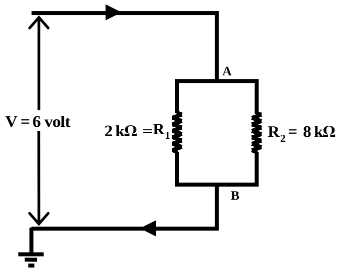
B) Greater than D) All is possible

Q.30 A cell having pure emf of 2.0 V with an internal resistance 0.5 Ω. When short circuited its current would be

A) 2 A C) 8 A

B) 4 A D) Infinite

Q.31 The circuit shown in the figure has two resistors having resistances R_1 and R_2. The current I_2 through resistor R_2 is

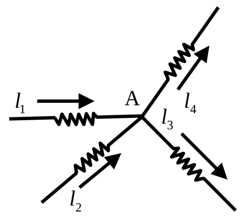


A) 0.75 mA C) 1.2 mA
B) 1.5 mA D) 2 mA

Q.32 The change in potential is positive when resistor is traversed

A) In the direction of current C) In the direction of decreasing potential
B) Opposite to the direction of current D) Both B and C

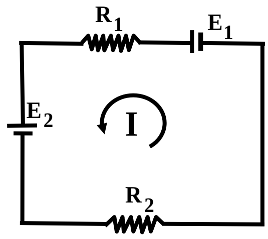
KIRCHHOFF'S RULES



- These rules are very suitable for complex circuits.

Kirchhoff's First Rule (point or node rule):

- Sum of all currents meeting at a point in a circuit (loop) is zero. It is according to law of conservation of energy.



Kirchhoff's Second Rule:

- The algebraic sum of potential changes for a complete circuit (loop) is zero. It is according to law of conservation of energy.
- If a source of emf is traversed from negative to positive terminal, the potential change is positive and vice versa

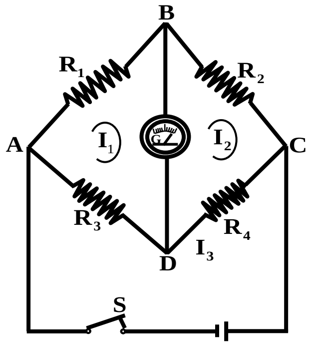
For Your Information

- **Junction;** The point of a circuit where three or more wire segments are joined together is called or node.
- **Branch**; The path that connects two junctions of a circuit is called branch.
- **Loop;** The path that starts from a node and proceeds along the circuit and finally meets the same node is called loop.

WHEATSTONE BRIDGE

The Wheatstone bridge is a circuit which is used to measure an unknown resistance accurately

Properties and Uses:



- It consists of two fixed (unknown), one variable (unknown), and another variable unknown) resistance
- It is an electrical circuit used to measure unknown resistance.
- For no current in galvanometer (balanced bridge)
- (Wheatstone bridge principle) $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
- Wheatstone bridge is most sensitive when current in all four arms (Branches) of the bridge is of the same order (to avoid heating)
- When no current flows through the galvanometer, bridge is said to be balanced.

Wheatstone Bridge Principle:

This principle states that when bridge is balanced, the products of the resistance of opposite arms are equal. i.e $R_1R_4=R_3R_2$

- Practical application of Wheatstone bridge is slide wire bridge
- It is called a bridge because it bridges the opposite junction B and D

POTENTIOMETER

It is an electrical instrument which is used to measure the emf of a source potential difference between two points accurately.

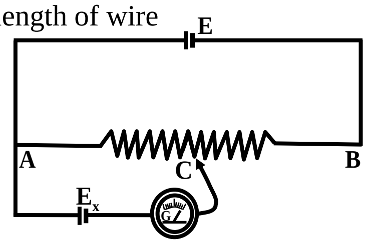
- Potentiometer is accurate because it does not draw any current from main circuit.
- The working principle of potentiometer is that potential difference across any length of wire of uniform area of cross section is directly proportional to the length of wire.
- Used to determine unknown emf of cell.
- Used to determine internal resistance of cell.

Unknown emf:

$E_x = \frac{E}{L} l$ E = Emf of source or driver cell l = balancing length

E_x = unknown emf of cell L = length of wire

Comparison of emfs:

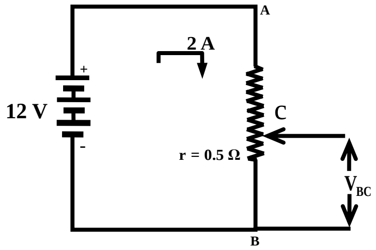


For comparison of emfs of two cells $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

If $\frac{E_1}{E_2} = 1$ then $E_1 = E_2$, If $\frac{E_1}{E_2} > \mathbf{1}$ then $E_1 > E_2$, If $\frac{E_1}{E_2} < 1$ then $E_1 > E_2$

PRACTICE QUESTIONS

Q.33 In the figure given below if r = 0.5 Ω then voltage across portion BC of the circuit is

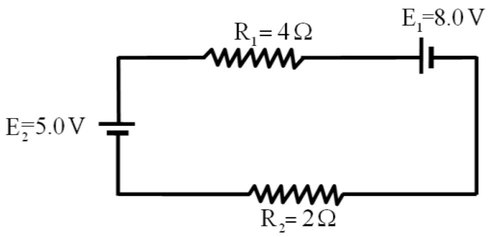


A) 1 V C) 1.5 V
B) 0.5 V D) 3 V

Q.34 Potential difference across 150 cm long wire of a potentiometer is volts if 10 V battery is connected across it

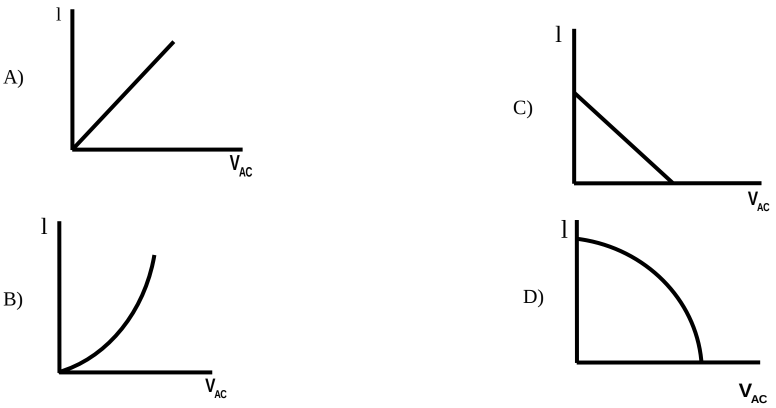
A) 3.75 V C) 7.5 V
B) 2.5 V D) None

Q.35 The current in the following circuit is

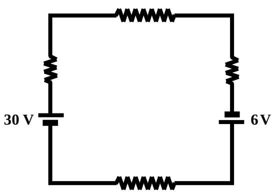


A) 0.5 A clockwise C) 0.2 A clockwise
B) 0.5 A anticlockwise D) 0.2 A anticlockwise

Q.36 If V_{AC} is the potential which changes with 'l' when a battery of emf E is connected across the potentiometer wire of length L then according to the principle of potentiometer the graph between V_{AC} and l will be

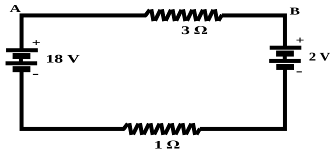


Q.37 The net emf in the circuit is



A) 36 V | C) 24 V
B) 18 V | D) 30 V

Q.38 What is the magnitude and direction of flow of current in the figure shown below



A) 4 A from A to B | C) 4 A from B to A
B) 5 A from A to B | D) 5 A from A to B

Q.39 If a wire is cut into two equal halves then resistivity of each half

A) In doubled | C) Remains same
B) Is halved | D) In increased by 4 times

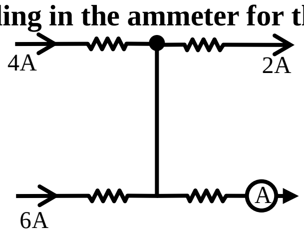
Q.40 If balancing length is one-sixth of the length of potentiometer and cell of emf 1.5 V is connected across it then voltage of accumulator (driver cell) is

A) 6 V | C) 3 V
B) 9 V | D) 4 V

Q.41 In short circuit, resistance is _______ and in open circuit, resistance is ______.

A) Zero,∞ | C) 1, zero
B) ∞, zero | D) Variable, zero

Q.42 What must be the reading in the ammeter for the circuit shown?



A) 10 A | C) 8 A
B) 6 A | D) 12 A

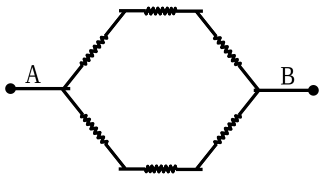
Q.43 Electric field and direction of flow of electronic current in a conductor are

A) Parallel | C) Perpendicular
B) Antiparallel | D) Inclined to each other

Q.44 Resistance of a conductors depends upon

A) Length | C) Nature of Material
B) Area | D) All of these

Q.45 Six identical resistors, each of 1 ohm, are connected as shown. The equivalent resistance between A and B is



A) 1 Ω | C) 2.5 Ω
B) 1.5 Ω | D) 3 Ω

Q.46 The cost of operating two 100 watt fans for 10 hours If cost of electricity per unit (per KWh) is 2 Rs,

A) Rs. 4
C) Rs. 6
B) Rs. 2
D) Rs. 1

Q.47 Which material has negative temperature coefficient of resistivity?

A) Steel
C) Tungsten
B) Iron
D) Silicon

Q.48 A wire has resistance 12 Ω. It is bent in the form of circle. The effective resistance between two points across a diameter is

A) 3Ω
C) 6 Ω
B) 12Ω
D) 254Ω

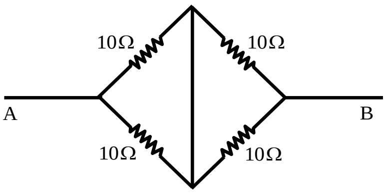
Q.49 Chose incorrect regarding properties of thermistors

A) The resistance of a thermistor changes rapidly with temperature
B) The temperature coefficient of a thermistor is always negative
C) The temperature coefficient of thermistors is very high
D) None of these

Q.50 Choose correct regarding characteristics of a parallel circuit

A) The voltage across each resistor is the same
B) The total current in the circuit is equal to the sum of currents in parallel branches
C) The reciprocal of equivalent resistance is equal to the sum of reciprocals of the individual resistances
D) All of these

Q.51 In the circuit shown in the figure, the equivalent resistance between points A and B



A) 25 Ω
C) 20 Ω
B) 10 Ω
D) 30 Ω

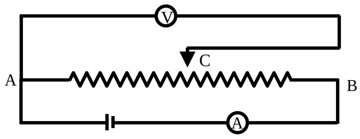
Q.52 Rheostat connected in parallel with a battery acts as a

A) Variable resistor
C) Both A and B
B) Potential divider
D) Bridge

Q.53 Which of these can be used as a potential divider?

A) Rheostat
C) Potentiometer and rheostat
B) Wheatstone bridge
D) Thermistor

Q.54 In the given circuit, as the sliding contact C is moved from A to B.



A) The reading of both the ammeter and the voltmeter remain constant.
B) The reading of the both ammeter and the voltmeter increase.

C) The reading of the ammeter remains constant but the voltmeter decreases.

D) The reading of the ammeter remains constant but that of the voltmeter increases.

Q.55 If source of emf is traversed from its negative terminal to positive terminal then potential change is

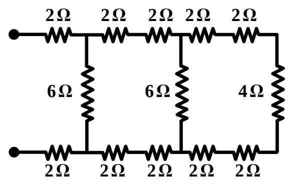
A) Zero

B) Positive

C) Negative

D) Undefined

Q.56 The equivalent resistance between the terminals A and B in the given network is



A) 30 Ω

B) 40 Ω

C) 16 Ω

D) 8 Ω

Q.57 A person has five resistances each of value $\frac{1}{5}$ ohm. The minimum resistance he can obtain by combining them is

A) $\frac{1}{50}$ Ω

B) $\frac{1}{25}$ Ω

C) $\frac{1}{10}$ Ω \

D) $\frac{1}{5}$ Ω

Q.58 If resistances in the successive arms of a balanced Wheatstone bridge are 3 ohms respectively, then unknown resistance in the fourth arm is

A) 6 ohm

B) 3 ohm

C) 2 ohm

D) 4 ohm

Q.59 If a potentiometer of length 4 metre is connected to a supply of 3 V and balancing length is 2.0 metre then unknown emf of cell is

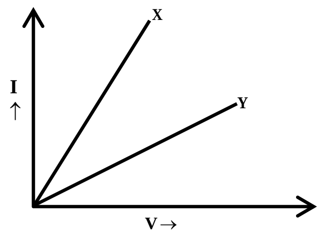
A) 1.0 V

B) 1.5 V

C) 2.0 V

D) 2.5 V

Q.60 The voltage current graph for two metallic wires X and Y at constant temperature is shown in fig. Assuming that the two wires have same length and same diameter, the resistivity of



A) Wire X is greater than wire Y

B) Wire Y is greater than wire X

C) Both wires is same

D) Resistivity can't be predicted from the given data

<u>Some Brain teasers for your practice</u>

(1) Is the formula V=IR only applicable to Ohm's law?

(2) As drift velocity of free electrons is very small then why does room light turn on at once when switch is closed?

(3) A carbon resistor of 74 kΩ is to be marked with rings of different colors for identification. What will be sequence of colors?

(4) A wire of 1 Ω is stretched to double of its length. What will be its new resistance?

(5) A wire is carrying. Is it charged?

(6) Name the charge carriers in a platinum wire, a cell, germanium crystal and in a superconductor.

(7) In how many parts, a wire having resistance of 100 Ω be cut so that we may obtain a resistance of 1 Ω by connecting them in parallel?

(8) The resistance of a coil is 4.2 Ω at 100^0C and temperature coefficient of resistance is $0.004/^0$C.what is its resistance at 0 ^{0}C. energy decreases .Why?

(9) A wire has resistance of 2.0 Ω at 25°C and 2.5 Ω at 100°C. Find the temperature coefficient of resistance of the wire.

(10) Two wires, when connected in series, have an equivalent resistance of 18Ω, and an equivalent resistance of 4 Ω when connected in parallel, Find their resistance.

ANSWERS WITH EXPLANATION

Q.1 **(B)** $v_d = \frac{I}{nAq} = 1.25 \times 10^{-4}\ ms^{-1}$

Q.2 **(D)** Silver has less resistivity than copper and copper has less than that of aluminum.

Q.3 **(D)** Joule's law $H = I^2Rt$

Q.4 **(A)** $I = \frac{ne}{t} \Rightarrow t = \frac{ne}{I}$

Q.5 **(A)** $I = \frac{q}{t} = \frac{e}{t}(n_p + n_e),\ I = 0.64A$

Q.6 **(A)** $I = \frac{V}{Re}$ Form figure, two resistors are in series ;

So, equivalent resistance is 100 Ω ; So $Re = \frac{(100)(50)}{100+50}$; $Re = 33.33\Omega$

Q.7 **(D)** After solving, So $\frac{1}{R_e} = \frac{1}{2} + \frac{1}{1} + \frac{1}{2}$; $R_e = \frac{1}{2}\Omega$

Q.8 **(C)** After 60 Ω resistor, equivalent resistance is 30 Ω so according to v = I R, across both 30 Ω resistors, potential drop will be half i.e 15 V

Q.9 **(B)** $\alpha = \frac{R_t - Ro}{R_o t}$ After solving $\alpha = -0.05\ k^{-1}$ which is germanium.

Q.10 **(B)** It is unit of conductivity

Q11. **(A)** $\rho = \frac{RA}{L}$, $\sigma = \frac{L}{RA} = \frac{L}{V} \times \frac{I}{A}$, $\sigma = \frac{I}{EA}$

Q.12 **(D)** $R = \frac{4\rho L}{\pi d^2}$, $R' = \frac{4\rho(2L)}{\pi(2d)^2}$, $R' = \frac{1}{2}R$

Q.13 **(B)** See the table in book

Q.14 **(D)** $R = \frac{\rho L}{A}$, $R' = \rho\left(\frac{2L}{A/2}\right)$, $R' = 4R = 4(16) = 64\,\Omega$

Q.15 **(C)** $R = \frac{\rho L}{A}$

Q.16 **(B)** $R_{eq} = 5/2 + 5/3 = \frac{25}{6}\Omega$

Q.17 **(C)** It is due to increase in resistance.

Q.18 **(A)** $R = \frac{V}{I}$, If 'V' is along x-axis and 'I' along y-axis

Q.19 **(A)** $I = \frac{q}{t}$

Q.20 **(D)** By Kirchoff's first rule

Q.21 **(A)** $Re = \frac{R}{n}$

Q.22 **(C)** These resistors are in series; So, $R_{eq} = 120 + 45 = 165\,\Omega$

Q.23 **(D)** $R = \frac{\rho L}{A}$

Q.24 **(C)** It is also symbol for resistor

Q.25 **(A)** $P_{out} = \frac{E^2}{4r}$; as, $r = R$; $\frac{V^2}{R} = \frac{E}{4r}$; $V = E/2$

Q.26 **(A)** $r = \frac{E - IR}{I} = 1.33\,\Omega$

Q.27 **(A)** $p = \frac{V^2}{R}$; The bulb with maximum power will have least resistance.

Q.28 **(D)** $p = \frac{V^2}{R}$, $R = 4$

Q.29 **(D)** All are possible

Q.30 **(B)** Short circuit means that resistance is zero (R = 0) $I = \frac{E}{R + r}$

Q.31 **(A)** $R_{eq} = \frac{8}{5}$; **and** $I_2 = \frac{V}{R_2} = 0.75$ mA

Q.32 **(B)** If we traverse a resistor opposite to the direction of current, the change in potential is positive

Q.33 **(A)** $V_{BC} = Ir = 2\left(\frac{1}{2}\right)$, $V_{BC} = 1$ V

Q.34 **(A)** $V_{AC} = \frac{l}{L} \times E = \frac{150}{400} \times 10$, $V_{AC} = 3.75$ V; (Standard length of potentiometer is 400 cm)

Q.35 **(B)** If same terminals of batteries are connected then net e.m.f is found by subtraction

i.e $E = 8 - 5 = 3$; end $I = \frac{E}{R} = \frac{3}{6} = 0.5$ A

Q.36 **(A)** $V_{AC} = \frac{l}{L}E$, Here $\frac{E}{L}$ is constant; So, $V_{AC} \propto l$; So, graph giving this sense is (A)

Q.37 **(A)** $\varepsilon_{net} = \varepsilon_1 + \varepsilon_2 = 30 + 6 = 36$ V

Q.38 **(A)** $I = \frac{\varepsilon_{net}}{R_{tot}} = \frac{16}{4} = 4$ A

Q.39 **(C)** Resistivity is characteristic of material.

Q.40 **(B)** $E_x = \frac{l}{L}E$, $\frac{E_x L}{l} = E$, $1.5 \times \frac{l}{1/6} = E$; E = 9 V

Q.41 **(A)** In short circuit, circuit is closed

Q.42 **(C)** Apply Kirchoof's first rule.

Q.43 **(B)** Electrons always move opposite to electric field

Q.44 **(D)** $R = \rho\frac{L}{A}$

Q.45 **(B)** Upper three resistors are in series

Q.46 **(A)** $\text{Units consumed} = \frac{\text{Power in watts} \times \text{time in hours}}{1000}$

Q.47 **(D)** Semiconductors and insulators have negative temperature coefficient of resistance

Q.48 **(A)** It becomes two resistors each of 6 Ω connected in parallel.

Q.49 **(B)** It is temperature dependent resistor

Q.50 **(D)**

Q.51 **(B)** In balanced wheatstone bridge, centre wire has zero resistance

Q.52 **(B)** Resistors in series divide the potential

Q.53 **(C)** Both can be used as potential divider because in both there is a long wire used

Q.54 **(D)** Current is circuit remains same.

Q.55 **(B)** For example one end at –10 V and other is at + 10 V then change in potential is + ve.

Q.56 **(D)** Start from closed end of the circuit and go on solving using series and parallel formulae

Q.57 **(B)** $R_e = \frac{R}{n}$

Q.58 **(B)** $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

Q.59 **(B)** $E_x = \frac{l}{L}E$

Q.60 **(B)** Resistivity does not depend upon length and area

UNIT 11 Electromagnetism

ELECTROMAGNETISM

The branch of physics which deals with magnetic fields produced by moving charges (electric current) is called electromagnetism.

Magnetic effects of current:

- Oersted in 1820 discovered the magnetic effect of current. It was accidentally when at the end of his lecture, he placed a current carrying wire near a compass needle which was deflected.
- Applications of all electrical machinery are due to magnetic effects of current in one way or other.

Magnetic field due to current in a long straight Conductor:

- A circular magnetic field is set up in the region surrounding a current carrying wire.
- The direction of magnetic field is determined by right hand rule as shown in the figure.
- The magnetic field lasts only as long as the current is flowing through the wire.
- The magnetic field will be anticlockwise when current flows from bottom to top and vice versa

Did You Know?

- A charge at rest has only electric field and no magnetic field.
- Magnetic field lines have similar properties as electric field lines.

Force on a current carrying conductor in a uniform magnetic field

$$\boxed{F_m = ILB\sin\alpha}$$

Where I = current

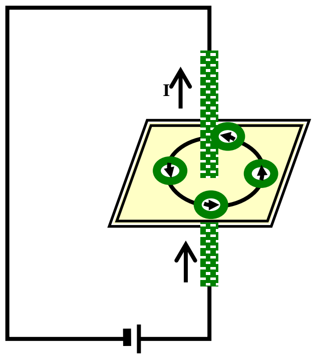
L = length of conductor

B = magnetic field induction

α = angle between I and B

$F_m = 0$ if $\alpha = 0$ F_m = maximum if $\alpha = 90^o$

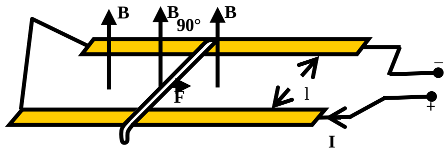
Vector from $\vec{F}_m = I\vec{L} \times \vec{B}$



- The direction of $\vec{L}$ (displacement vector) is same as that of I.
- To determine direction of $\vec{F}_m$, we rotate $\vec{L}$ towards $\vec{B}$ (through the smallest of the two possible angles) by right hand rule and the thumb shows the direction of $\vec{F}_m$.

$$B = \frac{F_m}{IL}$$

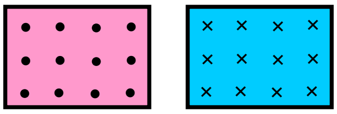
- Magnetic force on a current carrying conductor is produced due to interaction of field of current and external magnetic field.



- Magnetic force according to extension of right hand rule is from strong region of field to a weaker region of field.

Direction of Magnetic force

- **Right hand cross product rule**
- **Right hand palm rule**



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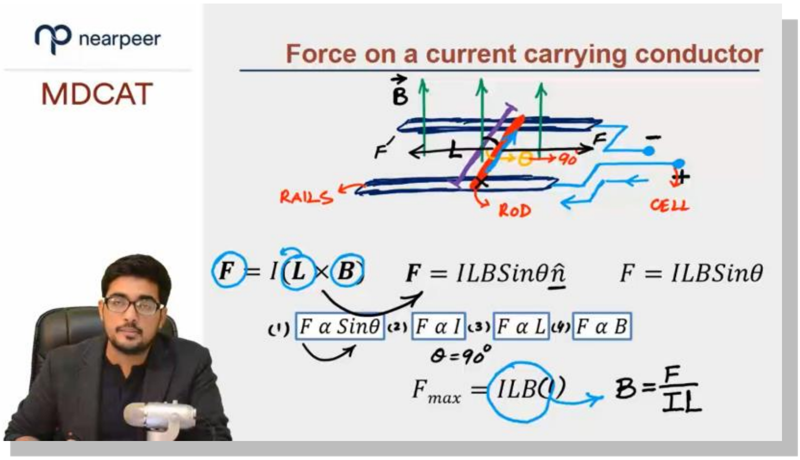
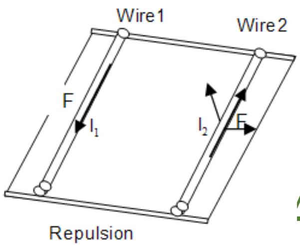
- **Fleming's left hand rule**
- **Stronger to weaker field (Extension of right hand rule)**

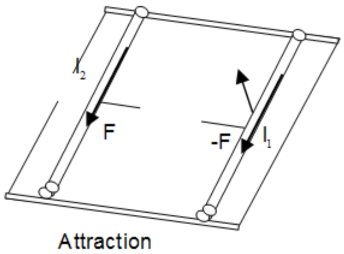


Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 11.02)

Two long parallel wires carrying current I_1 and I_2 in opposite directions repel each other

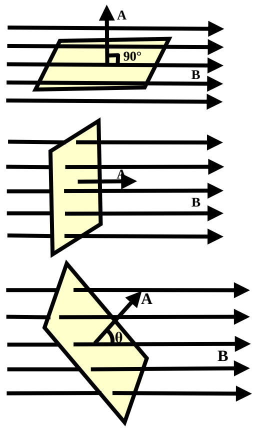
Two wires attract each other when the currents are in the same direction.





Magnetic flux

Number of magnetic field lines passing perpendicularly through a surface is called magnetic flux.



$$\boxed{\phi_B = \vec{B}\cdot\vec{A}}$$ □□□□□□cosθ

- $\vec{A}$ = vector area and θ = angle between $\vec{B}$ and $\vec{A}$
- $\phi_B = 0$ if θ = 90° (surface is parallel to $\vec{B}$)
- ϕ_B = maximum if θ = 0° (surface is perpendicular to $\vec{B}$)
- $\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta$ (surface is held inclined to $\vec{B}$)
- 1 weber = 1 Tesla × 1 m^2 = 1 Nm/A

Magnetic Induction:

- It is defined as "**the force acting on one meter length of conductor placed at right angles to the magnetic field carrying a current of 1 A"**

$$\boxed{B = \frac{F_m}{IL}}$$

- It is also called as flux density and can be defined **as**
  "Magnetic flux passing perpendicularly through a surface per unit area"

$$\boxed{B = \frac{\phi_B}{A}}$$

- Another way to define magnetic induction is from the concept of force on a charged particle in magnetic field
  "The force acting on a charged particle of 1C moving with a speed if 1 ms^{-1} at right angles in the magnetic field"

$$\boxed{B = \frac{F_m}{qv}}$$

Unit of magnetic induction is T = Wb m^{-2}

DIFFERENCE BETWEEN ELECTRIC AND MAGNETIC FORCES

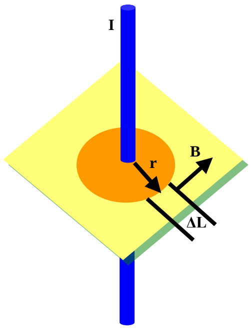
- Electric force on the charged particle is parallel to the electric field whereas the magnetic force is always perpendicular to the magnetic field.
- Electric force acts on the particle whether at rest or in motion. However, the magnetic force acts on a charged particle only when it is moving
- Electric force does work in displacing the charged particle in an electric field, whereas the magnetic force does no work while displacing the charged particle in uniform magnetic field.
- Electric force changes the speed and hence K.E. of the charged particle. However, magnetic force does not change the speed and hence K.E. of the charged particle.
- Electric force is much larger than the magnetic force.

Ampere's law

"Magnetic field due to a straight conductor is proportional to the magnetic field produced and inversely proportional to the distance from the axis"

$$B = \frac{\mu_o I}{2\pi r}$$

- It also states that **"the sum of the quantities $\vec{B}.\Delta\vec{L}$ for all the path elements into which whole loop is divided, is equal to μ_o times the current enclosed by the path"**

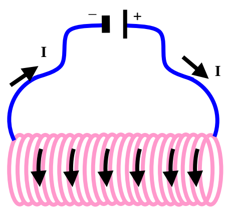


$$\sum_{r=1}^{n}\left(\vec{B}.\Delta\vec{L}\right)_r = \mu_0 I$$

Where μ_o = permeability of free space = $4\ \pi \times 10^{-7}$ Wb/ A m

and I = current enclosed by path

Field due to a current carrying solenoid:



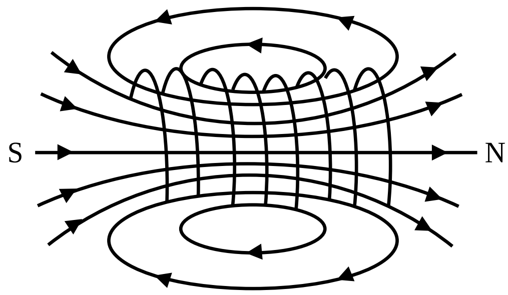
A long, tightly wound, cylindrical coil of wire is called solenoid.

- The direction of field due to a current carrying solenoid is along the axis of solenoid and is according to inverse right hand rule

- For solenoid, $\boxed{B = \mu_0 nI}$

Where $n = \frac{N}{L}$ = number of turns per unit length of solenoid

or $B = \mu_o \frac{N}{L} I$



Solenoid

- If a soft iron piece is inserted into the solenoid, the magnetic field within solenoid is given by expression

$$\boxed{B = \mu_0 \mu_r nI}$$

Where μ_r is a constant known as relative permeability of soft iron.

Right hand Palm rule

- Fingers ⇒ direction of magnetic field
- Thumb ⇒direction of current.
- Push on Palm⇒direction of force on the conductor.

Magnetic permeability:

The magnetic permeability of a material is a measure of its conductivity for magnetic field lines.

- The greater the permeability of a material, the greater is its conductivity for magnetic field lines and vice-versa. Since magnetic flux density (B) is the magnetic field lines passing per unit area of the material, it is a measure of magnetic permeability of the material.
- Suppose magnetic flux density in vacuum/air is B_0. If air is replaced by a material and magnetic flux density in the material becomes B. Then ratio B/B_0 is called the relative permeability (μ_r) of the material.
- **Relative permeability of a material is the ratio of magnetic flux density (B) in that material to the flux density (B_0) that would be if the material were replaced by vacuum/ air i.e.,**

Relative permeability, $\mu_r = \frac{B}{B_0}$

Clearly, μ_r is a pure number and its value of vacuum/ air is 1 ($\because B_0/B_0 = 1$)

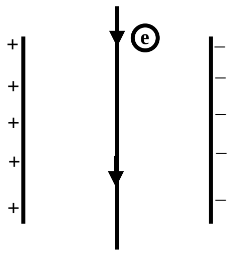
- The absolute (or actual) permeability μ_0 of vacuum/ air is $4\pi \times 10^{-7}$ H/m. The absolute (or actual) permeability of other materials is denoted by μ. The ratio μ/μ_0 is called relative permeability μ_r of the material. i.e.,
- Hence relative permeability (μ_r) of a material may also be defined as "**the ratio of absolute permeability (μ) of the material to absolute permeability (μ_0) of vacuum/air".**

PRACTICE QUESTIONS

Q.1 A charged particle is moving in a uniform magnetic field

A) Its momentum changes but K.E remains same
B) Both momentum and K.E remain same
C) Both momentum and K.E change
D) K.E changes but momentum remains same

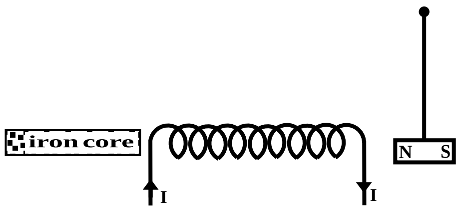
Q.2 A potential difference of 600 V is applied across the plates of a parallel plate capacitor. The separation between the plates is 3 mm. A magnetic field also exists between the plates. An electron



Projected parallel to the plates as shown with a speed of 2×10^6 m/s, moves undeflected between the plates. The magnitude and direction of the magnetic field is

A) 0.2 T, into the paper
C) 0.1 T, into the paper
B) 0.2 T, out of the paper
D) 0.1 T, out of the paper

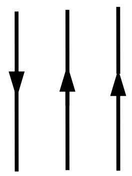
Q.3 The diagram shows a small magnet hanging on a thread near the end of solenoid carrying a steady current I.



What happens to the magnet as the iron core is inserted into the solenoid?

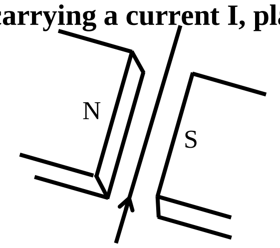
A) It moves towards the solenoid
B) It moves towards the solenoid and rotates
C) It moves away from the solenoid
D) it moves away from the solenoid and rotates through 180°

Q.4 Diagram shows three parallel wires carry equal currents. The resultant force on the middle wire is



A) Zero
B) Downward
C) To the left
D) To the right

Q.5 The diagram shows a wire, carrying a current I, placed between the poles of a magnet.



In which direction does the force on the wire act?

A) Downwards
B) Upwards
C) Towards the N pole of the magnet
D) Towards the S pole of the magnet

For Your information

- The current loop can be imagined to be a phantom bar magnet with a north pole and a south pole.
- In CGS system, unit of B is gauss.
- 1 gauss = 10^{-4} tesla
- Magnetic forces are much weaker than electrostatic forces.
- Magnetic field of earth is 0.4 G
- Electric field in atmosphere of earth is 100V/m

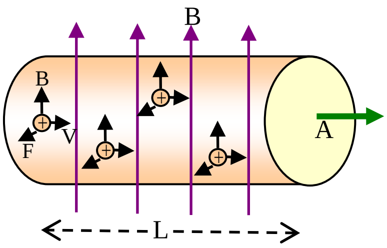
Force on a moving charge in a magnetic field

Magnetic force F_m on a charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by

$$\boxed{\vec{F}_m = q\vec{v} \times \vec{B}}$$

or $F = qvB\sin\theta$

Where θ = angle between $\vec{v}$ and $\vec{B}$



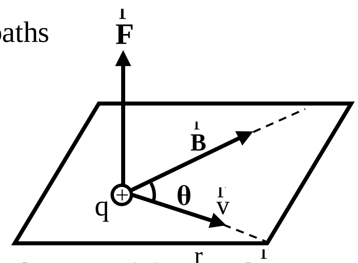
Note that
$\vec{F} \perp \vec{v}$
$\vec{F} \perp \vec{B}$
$\vec{F} \perp$ plane containing $\vec{v}$ and $\vec{B}$

- At different angles between $\vec{v}$ and ,particles follow different paths

If

$\theta = 0^o$ (Straight path)

$\theta = 90^o$ (Circular path)

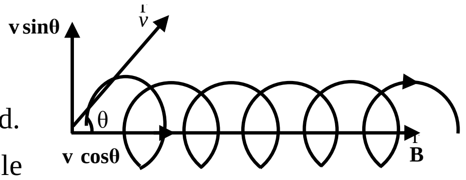


$\theta \neq 0^o$ nor 90^o (Helical path)

- For electron $\vec{F}_m = -e\vec{v} \times \vec{B}$ and for proton, $\vec{F}_m = +e\vec{v} \times \vec{B}$
- If force is at 90^o to velocity, then it only changes direction not the speed.
- If charged particle moves in a straight line through some region of space then either field in that region is zero or change is moving parallel or antiparallel to field.

Helical path of charged particle in magnetic field:

Suppose the charged particle moving with velocity $\vec{v}$ enters a uniform magnetic field $\vec{B}$ making angle θ to the direction of the field as shown in Fig. 9.5. The velocity $\vec{v}$ can be resolved into two rectangular components viz.



(a) $v_x = v\cos\theta$ acting in the direction of the field.

(b) $v_y = v\sin\theta$ acting perpendicular to the direction of the field.

The perpendicular component v sinθ moves the charged particle in a circular path while the horizontal component v cosθ moves it in the direction of the magnetic field. In other words, the charged particle covers circular path as well as linear path. Consequently, the charged particle will follow a helical path as shown in figure.

Motion of charged particle in electric and magnetic field:

Electric field can perform work

$\vec{F}_e = q\vec{E}$ and $\vec{F}_e$ is parallel to $\vec{E}$

$$\vec{a} = \frac{\vec{F}e}{m} = \frac{q\vec{E}}{m}$$

Equations of motion are applicable if $\vec{a}$ is uniform due to a uniform electric field $\vec{E}$.

- In magnetic field $\vec{F}_B = q\vec{v} \times \vec{B}$

When both fields are applied then Lorentz force $\vec{F} = \vec{F}_e + \vec{F}_B = q\vec{E} + q\vec{v} \times \vec{B}$

For Your information

- Work done by magnetic force is zero because magnetic force $\vec{F}m$ is perpendicular to velocity $\vec{v}$ of charged particle
- Magnetic force can not change speed and K.E of charged particle.
- Magnetic force changes velocity and momentum of charged particle continually.

Velocity Selector:

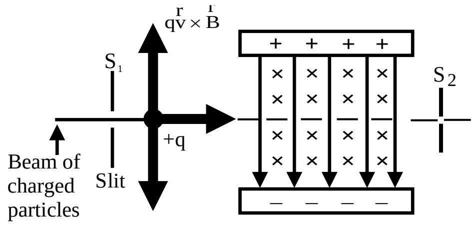
Velocity selector is a device used to select the charged particles of a particular velocity out of a beam of charged particles having different velocities.

- It consists of two slits S_1 and S_2 held parallel to each other some distance apart. Between the slits, there is a region of uniform electric and magnetic field perpendicular to each other.
- Directions of the two fields are such that they produce deflections on the charged particles in the opposite directions.

- A beam of positively charged particles having different velocities enters the region of cross fields after passing through the slit S_1. Since the charged particles are positive, we see that magnetic force F_m (= qvB) is upward and electric force F_e (= qE) is downward.
- If for a particle having speed v, $F_e = F_m$, then that particle will pass through the cross fields straight i.e. without any deflection. The value of v is given by

$$F_e = F_m$$

or $$qE = qvB$$



$$\boxed{v = \frac{E}{B}}$$

- Only those charged particles whose speed is v = E/B will pass through the cross fields undeflected and emerge through slit S_2. Particles with velocity other than v (= E/B) will either be deflected upward or downward.
- Thus velocity selector is able to select charged particles of particular velocity out of a beam of charged particles having different velocities.
- The velocity selector is also called velocity filter because it filters out particles of particular velocity.

For Your information

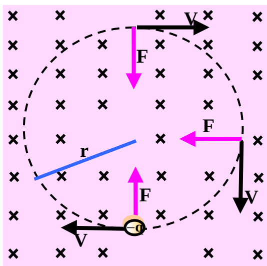
- Two magnetic lines of force can not intersect each other.
- The direction of $\vec{B}$ at a point is found by drawing a tangent at that point.
- We can not have a magnetic monopole.

Determination of e/m of an electron

- Magnetic force can move a charge particle in a circular path.
- If a charged particle q is moving with speed v in a circular path of radius r in a magnetic field B then

$$\boxed{r = \frac{mv}{qB}}$$

For electron, $$\boxed{\frac{e}{m} = \frac{v}{Br}}$$



$$= 1.7588 \times 10^{11} \text{ C/kg}$$

- Magnetic field can be used to separate isotopes by the Principle $r \propto m$ where r = radius of charged isotopes and m = mass of isotope.

- For determination of radius of circular path followed by an electron in a magnet field, we use a tube placed in a field with gas at low pressure.
- e/m of a proton is less than that of an electron.
- If an electron is accelerated by a P.D V then velocity v gained by electron will be

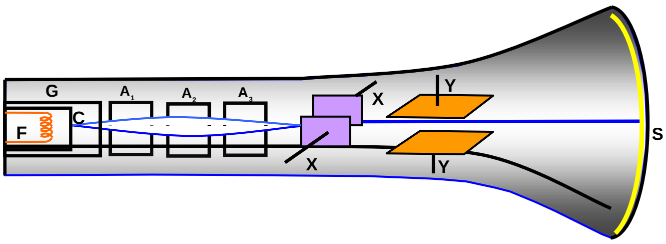
$$v = \frac{\sqrt{2eV}}{m}$$

Parameters of motion of charged particle in magnetic field

- **Radius of path** of particle moving in magnetic field in circular path is $r = \frac{mv}{qB}$
- **Time period** of revolution of charged particle in magnetic field is $T = \frac{2\pi m}{qB}$
- **Frequency** of revolution of charged particle in magnetic field is $f = \frac{qB}{2\pi m}$

Cathode ray oscilloscope:

It is a high speed graph plotting device.



Parts of CRO

- **Electron Gun**
  - **Filament** Thin wire is used to heat cathode
  - **Cathode** emits electrons
  - **Anodes** used to accelerate and focuss electrons
  - **Grid** it is given negative potential and controls number of electrons and hence brightness of spot on screen
- Evacuated glass tube
- Deflection plates
- Time base generator θI Sweep generator
- **Fluorescent Screen**

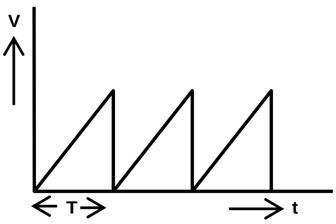
F = filament $\quad$ A_1, A_2, A_3 = anodes

C = cathode $\quad$ XX = horizontal deflection plates

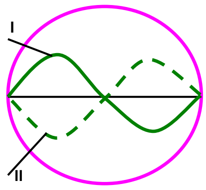
G = Grid $\quad$ YY = vertical deflection plates

S = fluorescent screen

- Time base generator generates saw tooth voltage.

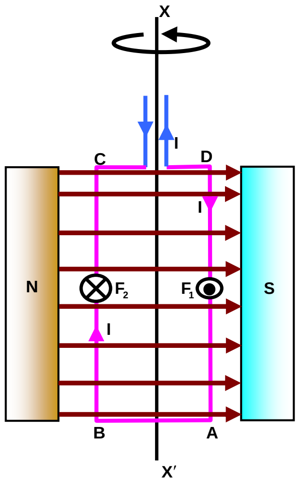


- Saw tooth voltage rises slowly and falls to zero quickly.
- Saw tooth voltage is applied to horizontal deflection plates.
- Input voltage is applied to vertical deflection plates.
- The patterns on the screen will appear stationary if the time period T of saw tooth voltage is equal to or is some multiple of the time period of voltage on Y plates (Frequency synchronization)



- Time period, frequency, voltage and phase can be determined from CRO

Torque on a current carrying coil placed in a uniform field:



Torque on a current carrying coil is given by

$$\boxed{\tau = \text{NIAB} \cos\alpha}$$

Where, N = number of turns of coil,

I = current in the coil

A = area of coil,

B = magnetic field induction

α = angle between plane of coil and field

Net force on coil is zero but torque is not zero (as deflecting couple acts).

- When current coil is placed in magnetic field, a torque acts on it. This effect is also called **motor effect.**

For Your information

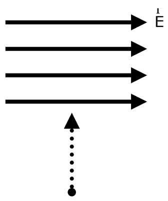
Torque on a current carrying coil placed in a uniform magnetic field is also determined by the formula

$$\boxed{\tau = \text{NIAB} \sin\theta}$$

Where θ is the angle between vector area $\vec{A}$ of plane of coil and magnetic field $\vec{B}$.

PRACTICE QUESTIONS

Q.6 An electron is projected at right angles to a uniform electric field $\vec{E}$

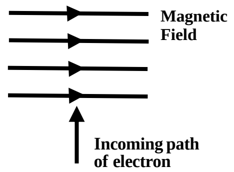


In the absence of other fields, in which direction is the electron deflected?

A) Into the plane of the paper C) To the left

B) Out of the plane of the paper D) To the right

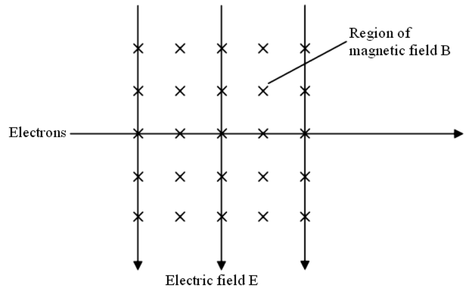
Q.7 The diagram shows an electron as it enters a magnetic field. The path of the electron and the magnetic field are in the plane of the paper. In which direction is the electron initially deflected?



A) Into the plane of the paper C) To the left of its incoming path

B) Out of the plane of the paper D) To the right of its incoming path

Q.8 A beam of electrons enters a region in which there are magnetic and electric fields directed at right angles. It passes straight through without deviation.



A second beam of electrons traveling twice as fast as the first is then directed along the same line; how is this second beam deviated?

A) Downwards in the plane of the paper C) Out of the plane of the paper

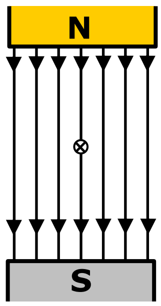
B) Upwards in the plane of the paper D) Into the plane of the paper

Q. 9 At distance r perpendicular from a straight conductor carrying a current I has a magnetic field B. The magnetic field of the conductor at distance 2r from the conductor carrying the same current I will be

A) $\frac{B}{4}$ C) 2B

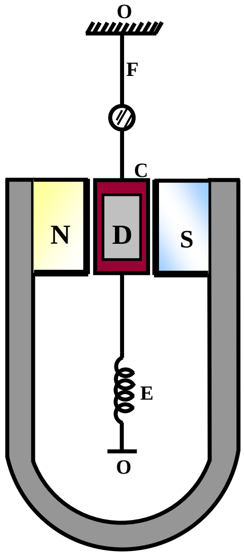
B) $\frac{B}{2}$ D) $\frac{B}{\sqrt{2}}$

Q.10 The direction of magnetic force on a straight conductor carrying a current into the plane of paper as shown in the figure is



A) To the right C) Upward

B) To the left D) Downward



Galvanometer

"A sensitive instrument used to detect small amount of current"

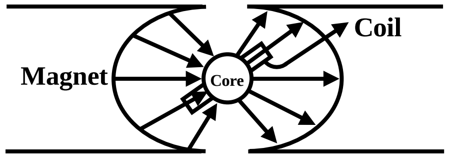
- Its working principle is torque on a current carrying coil placed in a magnetic field.
- Suspension wire of coil is used as one current lead to the coil.
- Loosely wound spiral E provides restoring torque and also acts as second current lead.

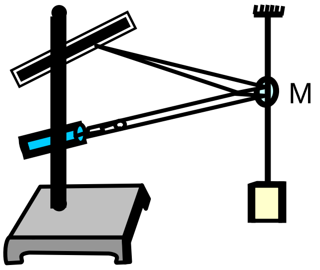
$$I = \frac{C}{BAN}\theta$$

or $$I \propto \theta$$

Where c = torsional constant or fiber constant depending upon the properties of fiber

- Lamp and scale arrangement (Separated by one meter) is used to determine angle of deflection θ (provided θ is small)
- For pivoted type galvanometers, lamp and scale are replaced by an aluminum pointer.



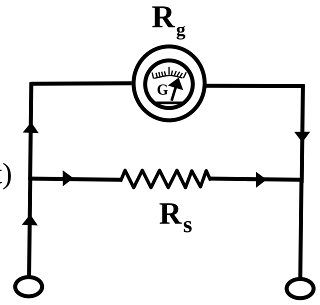


- A galvanometer is said to be sensitive if it gives a large deflection θ for a small value of current I.
- For sensitivity, C/NAB is made small.
- A sensitive galvanometer can not be stable and vice versa.
- Current sensitivity of galvanometer is defined as the current in micro amperes required to produce one millimeter deflection on a scale placed one meter away from the mirror of the galvanometer.
- Such galvanometer in which the coil comes to rest quickly after the current is passed through it or the current is stopped from flowing through it, is called stable or a dead beat galvanometer.

Note. A radial magnetic field is the field in which magnetic lines of force point along the radii of the circle.
It is produced by placing a soft iron cylinder between concave shaped pole pieces.

Ammeter:

"An instrument used to measure higher currents in amperes"



- Galvanometer is converted into ammeter by connecting a small resistance (shunt) R_s in parallel with coil (meter movement) of galvanometer. This is done so that current is divided and majority of current flows through shunt.
- The shunt R_s required is

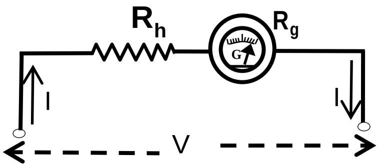
For Your information

A shunted galvanometer is called an ammeter

$$\boxed{R_s = \frac{I_g R_g}{I - I_g}}$$

Where I is range of ammeter

- The resistance of ammeter should be very small so that it does not alter circuit current and ammeter should always be connected in series (as current in series remains the same).
- The resistance of ammeter is $R_A = \frac{R_g R_s}{R_g + R_s}$



Voltmeter:

"An instrument used to measure higher voltages in volts"

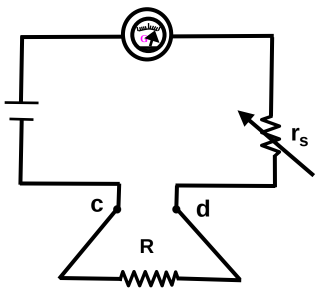
- Galvanometer is converted into voltmeter by connecting a high resistance R_h in series with coil (meter movement) of galvanometer. The resistance connected should be high.
- The high resistance R_h required is

$$\boxed{R_h = \frac{V}{I_g} - R_g}$$

> **For Your information**
>
> A galvanometer in series with a high resistance is called voltmeter

Where V is range of voltmeter

- The resistance of voltmeter is $R_V = R_g + R_h$



Ohmmeter:

"An instrument used to measure resistance in ohms directly"

- The series resistance r_s is so adjusted that when terminals c and d are short circuited i.e., when R = 0, the galvanometer gives full scale deflection. So extreme graduation is marked zero.
- When c and d are not joined here R = ∞ (open circuit). So zero of the scale is marked as infinity.
- Ohmmeter should be zeroed before using

> **For Your information**
>
> All meters actually measure currents but their scales are different e.g., a voltmeter actually measures current but displays it on the scale of volts.

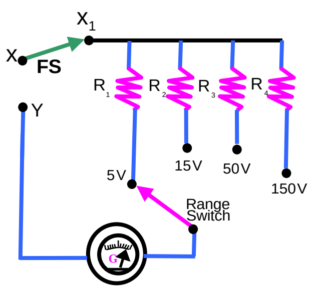
AVOMETER (Multimeter)

"An instrument used to measure current in amperes, potential difference in volts and resistance in ohms"

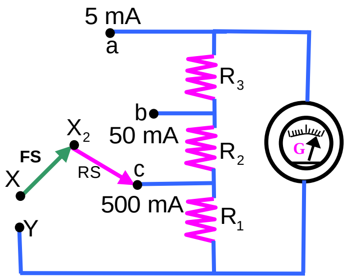
Function switch FS controls the function of AVO Meter i.e., whether it acts as voltmeter, ammeter or ohmmeter.

Voltage measure part of AVO Meter:

- It is a multi range voltmeter.
- The high resistance connected in series controls the range of voltmeter with the help of a range switch RS.



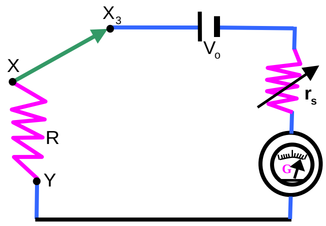
- Greater is the resistance in series with galvanometer, greater will be the range.



Current measuring part of AVO Meter:

- It is multi range ammeter.
- The low resistances connected in parallel controls the range of ammeter.
- Smaller is the resistance in parallel with galvanometer, greater will be the range of ammeter.

Resistance measuring part of avo-meter:



- Before measuring an unknown resistance by an ohmmeter it is first zeroed which means that we short circuit the terminals X,Y and r_s to produce full scale deflection.

Digital multimeter (DMM):

- It is an electronic instrument.
- It displays the digital values with decimal point, polarity and the unit i.e., V,A and Ω.

Some Brain teasers for your practice

(1) The net charge in a current carrying conductor is zero, even then it experiences a force in a magnetic field. Why?

(2) A voltmeter, an ammeter and a cell are connected in series. It is observed that ammeter practically shows no deflection. Why?

(3) Will (i) a stationary charge and (ii) a moving charge experience a force in an electric field?

(4) The north pole of a magnet is brought near a stationary negatively charged conductor. Will the pole experience any force?

(5) What is a shunt? State its SI unit?

(6) What happens when an ammeter is connected in parallel with a circuit?

(7) The path executed by a charged particle whose motion is perpendicular to a uniform magnetic field is.

A) A straight line B) An ellipse
C) A helix D) A circle

(8) A power line lies along the east-west direction and carries a current of 10 A. The force per meter due to earth's magnetic field of 10^{-4} is

A) 10^{-5} N B) 10^{-4} N
C) 10^{-3} N D) 10^{-2} N

(9) A proton of energy 1 meV describes a circular path in a plane at right angles to a uniform magnetic field of 6.28×10^{-4} T. The mass of the proton is 1.7×10^{-27} kg. The cyclotron frequency of the proton is very nearly equal to

A) 10^7 Hz B) 10^6 Hz
C) 10^5 Hz D) 10^4 Hz

PRACTICE QUESTIONS

Q.11 A positively charged particle enters in a region where both electric and magnetic fields are parallel to its motion then the force on the charged particle will be

A) $\vec{F} = q\vec{E} + q(\vec{v}\times\vec{B})$ C) $\vec{F} = q\vec{E}$

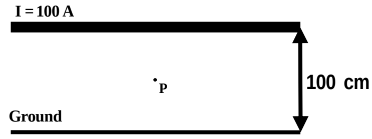
B) $\vec{F} = q(\vec{v}\times\vec{B})$ D) Zero

Q.12 In a current carrying solenoid, the magnetic field produced does not depend upon

A) Current flowing through the solenoid C) Radius of the solenoid

B) Number of turns per unit length D) Core material

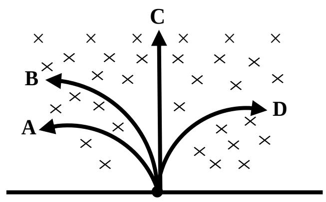
Q.13 In the figure given below; the flux density at point P which is at the mid of current carrying wire and ground



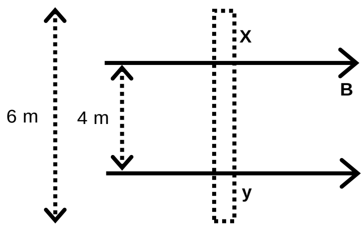
A) 0.5 G C) 0.4 G

B) 4 G D) 0.2 G

Q.14 A neutron, a proton, an electron and an α-particle enter a region of uniform magnetic field with equal velocities. The magnetic field is perpendicular and directed into the paper. The tracks of the particles are labeled in figure. The electron follows the track



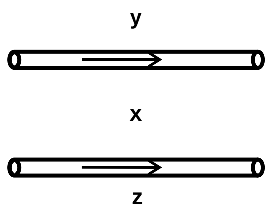
Q.15 A current carrying conductor xy is placed in magnetic field of 1T. It experiences a force of 4.0 N perpendicularly upward to the plane of paper then current through conductor will be



A) 1 A from x to y C) 0.1 A from x to y

B) 1 A from y to x D) 0.1 A from y to x

Q.16 Two long parallel wires carrying current in the same direction are shown in the figure. At which one of the following points magnetic field is weaker?



A) z
B) y
C) x
D) Both y and z

Q.17 The magnetic field due to a solenoid is given by B = μ_on I. Units of 'n' in the formula are

A) kgm^{-1}
B) m
C) m^{-1}
D) kg m

Q18. If a wire of length 20 cm carrying a current of 1 A is placed in a magnetic field of 1 T making in angle of 30^o with field then magnitude of force on the wire is

A) 0.1 N
B) 0.2 N
C) 0.3 N
D) 0.4 N

Q19. An electron is projected along the axis of a circular conductor carrying some current. Electron will experience

A) Force along the axis
B) Force perpendicular to the axis
C) Force at an angle of 60^o with axis
D) No force

Q20. Ampere's law is only applicable to

A) Closed surface
B) Open surface
C) Closed path
D) Open path

Q21. If direction of velocity of charge is along +x-axis and direction of magnetic force on it is along –y-axis , then direction of magnetic field is along

A) +z-axis
B) +y-axis
C) –y-axis
D) –z-axis

Q22. if an electron enters a magnetic field directed into the plane of paper, from left to right perpendicularly, then it is deflected

A) Towards right
B) Upwards
C) Downwards
D) Towards left

Q23. A straight wire of length 2 m carries a 10 A current. How much weaker is the magnetic field at a distance of 4 cm from the wire than it is at 2 cm from wire?

A) $2\sqrt{2}$ times
B) 2 times
C) 4 times
D) $4\sqrt{2}$ times

Q24. A charge is moving parallel to magnetic field. The magnetic force on the charge is

A) Maximum
B) Minimum
C) Variable
D) Zero

Q25. Two parallel wires carrying current in same direction

A) Attract each other
B) repel each other
C) Do not affect each other
D) First repel then attract each other

Q26. Magnetic flux through a surface is maximum if surface is

A) Parallel to $\vec{B}$ C) Perpendicular to $\vec{B}$

B) Inclined at 60° with $\vec{B}$ $\vec{B}$ D) Inclined at 30° with $\vec{B}$

Q27. Magnetic force on a charge in a magnetic field is zero if

A) Charge is at rest C) $\vec{v}$ is antiparallel to $\vec{B}$

B) $\vec{v}$ is parallel to $\vec{B}$ D) All of these

Q28. The force is which simply a deflecting force is

A) Magnetic force C) Lorentz force

B) Electric force D) All of these

Q29. If an electron is accelerated by a P.D of V then velocity gained by electron

A) $\sqrt{2}$ V C) $\sqrt{\frac{2Ve}{m}}$

B) 2Ve D) $\frac{2Vm}{e}$

Q30. The electron gun in CRO consists of

A) Cathode C) Anode

B) Grid D) All of these

Q31. The grid in CRO is given __________ to control_______

A) Negative potential, speed of electrons C) Zero potential, number of electrons

B) Positive potential, speed of electrons D) Negative potential, number of electrons

Q32. Saw tooth voltage in CRO is given to

A) Gird C) Vertical deflection plates

B) Horizontal deflection plates D) Anodes

Q33. A charged particle q is projected perpendicular to a field B. If it moves in circular path of radius r, then its momentum will be

A) qB/r C) qBr

B) q/Br D) r/qB

Q34. When a charged particle enters perpendicularly in a uniform magnetic field its kinetic energy

A) Remains constant C) Decreases

B) Increases D) Becomes zero

Q35. A proton and an α particle are projected perpendicular to field with same velocity the ratio of radius of proton to radius of α-particle is

A) 1 : 2 C) 4 : 1

B) 2 : 1 D) 1 : 4

Q36. The direction of field around a wire carrying current towards you is

A) Upwards C) Towards right

B) Downwards D) Anticlockwise

Q37. In particle velocity selector method, magnetic field and electric field are ________ and velocity of particle is ______

A) Parallel , EB
B) Antiparallel, E/B
C) Perpendicular, E/B
D) At 45° with each other, E/B

Q38. If number of turns of solenoid are doubled and its length is halved then magnetic field is (keeping current constant)

A) Doubled
B) Halved
C) Constant
D) Increased by 4 times

Q39. For ammeter, shunt should be connected in ___________ and in voltmeter resistance should be connected in

A) Parallel, series
B) Series , parallel
C) Series , series conductor
D) Inclined to axis

Q40. 1 gauss =

A) 10^4 tesla
B) 10^{-4} tesla
C) 10^3 tesla
D) 10^{-3} tesla

Q41. Sensitivity of a galvanometer can be increased by increasing

A) Number of turns of coil
B) Area of coil
C) Magnetic field
D) All of these

Q42. Which of the following statement is correct for CRO synchronization

A) Frequency of sawtooth voltage = integral multiple of frequency of input
B) Sawtooth voltage frequency > frequency of input
C) Sawtooth voltage should be applied to vertical plates
D) Sawtooth voltage frequency is equal to frequency of step wave

Q43. If a current carrying wire carries current towards east and is placed in a field directed towards west, then force on the wire is directed towards

A) North
B) South
C) East
D) Has arbitrary direction

Q.44 The magnetic field in a certain region is given by $\vec{B} = (3\hat{i} + 7\hat{k})$ Wbm^{-2}. The flux that passes through 600 cm^2 area of loop in this region if the loop lies flat in yz plane

A) 1.8 NmA^{-1}
B) 18 NmA^{-1}
C) 0.18 NmA^{-1}
D) None of these

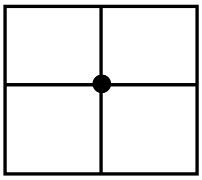
Q45. Which electrical measuring instrument has the highest resistance?

A) Ammeter
B) Voltmeter
C) Galvanometer
D) All have same resistance

Q46. Which instrument has the lowest resistance?

A) Ammeter
B) Voltmeter
C) Galvanometer
D) Both A and B

Q47. How can we obtain following spot on screen of CRO when potential of



A) X plates is OFF
B) Both x and y plates is off
C) Y plates is OFF
D) Both x and y plates is ON

Q48. DMM shows values with

A) Decimal
B) Polarity
C) Unit
D) All of these

Q49. If current is passed through a copper spring then spring will

A) Be compressed
B) Expand
C) Remain unaffected
D) May expand or remain unaffected

Q50. Dimensions of magnetic flux are

A) $[ML^2T^2A^{-2}]$
B) $[ML^2T^{-2}A^{-1}]$
C) $[ML^2T^1A^{-1}]$
D) $[ML^2T^2A^{-2}]$

ANSWERS WITH EXPLANATION

Q.1 **(A)** **Q.2** **(D)** **Q.3** **(C)** **Q.4** **(A)** Both outer wires repel the middle

Q.5 **(A)** **Q.6** **(C)** **Q.7** **(B)**

Q.8 **(A)** Magnetic force is speed dependent but electric force is not speed dependent

Q.9 **(B)** $B \propto \frac{1}{r}$ **Q.10** **(B)** **Q.11** **(C)** Magnetic force does not act in parallel

Q.12 **(C)** $B = \mu_o nI$ **Q.13** **(C)** $B = \frac{\mu_o I}{2\pi r}$, also 1T =$10^4$ **Q.14** **(D)**

Q.15 **(A)** F = I L B

Q.16 **(C)** As wires are attracting each other so magnetic field is weaker in the centre.

Q.17 **(C)** **Q.18** **(A)** $F = I L B \sin\theta$ **Q.19** **(D)** **Q.20** **(C)** **Q.21** **(A)**

Q.22 **(C)** **Q.23** **(B)** $\frac{B_1}{B_2} = \frac{r_2}{r_1}$, $B_2 = \frac{1}{2}B_1$ So two times weaker **Q.24** **(D)**

Q.25 **(A)** **Q.26** **(C)** **Q.27** **(D)** **Q.28** **(A)** **Q.29** **(C)** **Q.30** **(D)**

Q.31 **(D)** **Q.32** **(B)** **Q.33** **(C)** $r = \frac{mv}{qB}$ **Q.34** **(A)**

Q.35 **(A)** $r = \frac{mv}{qB}$; $\frac{r_p}{r_\alpha} = \frac{(m_p)(2q_p)}{(q_p)(4m_p)}$ **Q.36** **(D)** **Q.37** **(C)**

Q.38 **(D)** $B = \frac{\mu_o NI}{L}$ **Q.39** **(A)** **Q.40** **(B)** **Q.41** **(D)** $I = \frac{C}{BAN}\theta$

Q.42 **(A)** **Q.43** **(D)** **Q.44** **(C)** **Q.45** **(B)** $R_v = R_h + R_g$

Q.46 **(A)** $R_A = \frac{R_s R_g}{R_g + R_S}$ **Q.47** **(C)** **Q.48** **(D)**

Q.49 **(A)** Two loops carrying current in same direction attract each other. **Q.50** **(B)**

UNIT 12

Electromagnetic Induction

ELECTROMAGNETIC INDUCTION

It is the phenomenon of inducing an emf in a conductor by varying magnetic flux

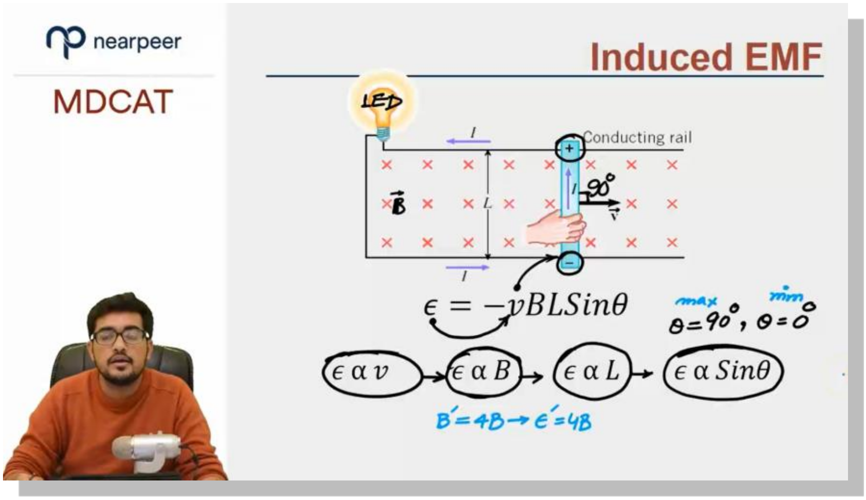
Induced EMF and induced current

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

The induced emf leads to an induced current when the circuit is closed. The current can be increased by

- Using a stronger magnetic field
- Moving the loop faster.
- Replacing the loop by a coil of many turns.

Did You Know?
Induced current is inversely proportional to resistance of circuit.



Did you know? This lecture is completely explained in nearpeer.org online MDCAT course (video 12.01)

Methods of inducing EMF

- When a bar magnet is pushed towards a coil then current is induced in the coil
- When a bar magnet is pulled away from a coil then current is induced in the coil but in opposite direction.
- Current can also be induced in the coil by changing area of the coil.
- An induced current can also be generated when a coil of constant area is rotted in a uniform magnetic field.

Motional EMF

The emf induced in a conductor due to its motion in a magnetic field.

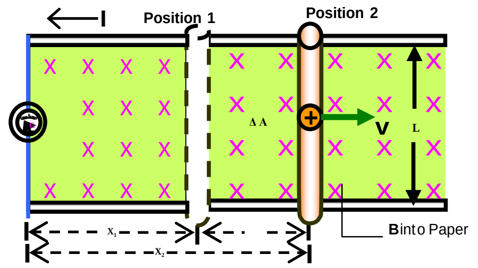
Motional current will be uniform if

$F_m = F_e$

$qvB = qE$

or $E = vB$

$$\boxed{\varepsilon = vBL\sin\theta}$$



Where v = velocity of conductor,

B = magnetic field induction.

Faraday's law

It is states that "**The average emf induced in a conductor coil of N loops is equal to the negative of the rate at which the magnetic flux through the coil is changing with time** "

$$\boxed{\mathcal{E} = \frac{-N\Delta\phi}{\Delta t}}$$

Where negative sign shows Lenz's law

An equivalent statement is **when a conductor cuts magnetic field lines; an e.m.f is induced in it.**

Lenz's law

Lenz's law states that "**The direction of induced current is always such as to oppose the change which causes the current**"

In the figure, according to Lenz's law, the direction of induced current is anticlockwise. If the magnet is pulled away, then the direction will be clockwise.

Did You Know?

Flux Linkage is the product of number of turns (N) of the coil and the magnetic flux (ϕ) linking the coil i.e.

flux linkages = $N\phi$

Did You Know?

- Lenz's law refers to induced current and not to induced emf.
- Lenz's law is in accordance with law of conservation of energy.

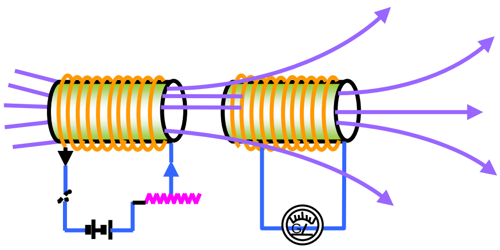
Mutual induction

"**A phenomenon in which a changing current in one coil (primary coil) induces and emf in another coil (secondary coil)**"

Mutual inductance $M = N_s\, \phi_s / I_p$

Where N_s = number of turns of secondary coil

and ϕ_s = flux through secondary coil.



- Value of M depends upon number of turns of coils, their area of cross section, the distance between the coil and the core material of the two coils.

or $$\varepsilon_s = -M\frac{\Delta I_p}{\Delta t}$$

or $$M = \frac{\varepsilon_s}{\Delta I_p / \Delta t}$$

Did You Know?

Mutual induction is the working principle of transformer.

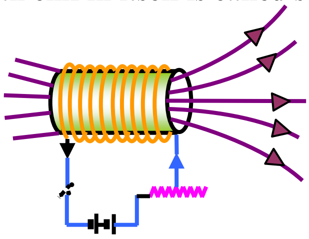
- If an emf of one volt is induced in the secondary coil due to one and second rate of change of current in the primary coil, then mutual inductance coils is said to be one henry.

Mutual Inductance:

Hence Coefficient of mutual induction of two coils is numerically equal to the mutually induced e.m.f. in one coil when the rate of change of current in the other coil is unity.

Self-induction

"The phenomenon in which a changing current in a coil induces an emf in itself is called self induction"



Self inductance L = N ϕ/ I

Where I = current in one turn of coil

ϕ = flux through one turn of coil

- Self inductance depends upon number of turns of coil,
- Area of cross section and core material.

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

or $$L = \frac{\varepsilon_L}{\Delta I / \Delta t}$$

or 1 henry = 1 volt / 1 ampere. sec

- Self induced emf is also called back emf because if we increased current coil, the back emf will oppose by inducing a current opposite to original and if we decrease current, induce current will be in the same direction as current (to keep the current steady).
- Coils are also called inductors and they behave as resistors in alternating current circuits.

Self inductance:

The property of a coil (or circuit) by virtue of which it opposes any change in the amount of current flowing through it is called self inductance of the coil.

$$L = \frac{N\phi}{I}$$

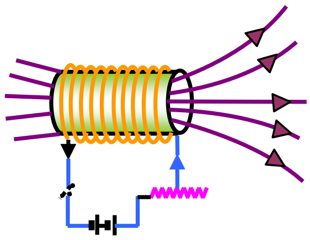
Hence coefficient of self induction ir self inductance of a coil is numerically equal to the self induced e.m.f. in the coil when the rate of change of current in the coil is unity.
Self inductance is also known as electrical inertia of a circuit as it opposes any change in current

Did You Know?

Flux Linkage is the product of number of turns (N) of the coil and the magnetic flux (ϕ) linking the coil i.e.

flux linkages = N ϕ

Energy stores in an inductor



- The energy is stored in the magnetic field of an inductor.

$$U_m = \frac{1}{2} LI^2$$

or $$\text{Energy} = \frac{1}{2}\frac{B^2}{\mu_o}(Al)$$

$$\text{Energy} = \frac{1}{2}\frac{B^2}{\mu_o}(\text{Volume})$$

$$\frac{\text{Energy}}{(\text{Volume})} = \frac{1}{2}\frac{B^2}{\mu_o}$$

$$\text{Energy density} = \frac{1}{2}\frac{B^2}{\mu_o}$$

For Your information

- **Inductor** or Choke is a coil with large inductance and negligible resistance
- Energy is stored in a coil in its magnetic field and is supplied by the source of emf

Did You Know?

Inductance of a coil is given by formula

$L = \mu_o n^2 lA$ Where $n = \frac{N}{l}$

Inductors in Series

Suppose two inductors L_1 and L_2 are connected in series across a source. The mutual inductance of the system is M.

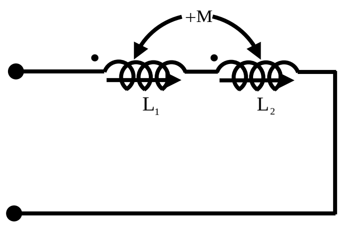
Let ε_1 and ε_2 be the emfs induced in L_1 and L_2, respectively. Since the coils are in series the total emf is

$$\varepsilon = \varepsilon_1 + \varepsilon_2 \quad \dots\dots\dots \quad (1)$$

Now $$\varepsilon_1 = -L_1\frac{dI}{dt} - M\frac{dI}{dt} \quad \dots\dots\dots \quad (2)$$

and $$\varepsilon_2 = -L_2\frac{dI}{dt} - M\frac{dI}{dt} \quad \dots\dots\dots \quad (3)$$

If L_{eq} is the equivalent inductance, then



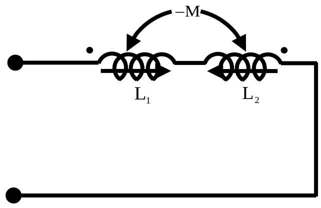
$$\varepsilon = -L_{eq}\frac{dl}{dt}(1)$$

Using Eqs. (1), (2), (3), we get

$$\boxed{L_{eq} = L_1 + L_2 + 2M}$$

Here we have assumed that the currents flow in the same sense in the two coils. If the currents flow in opposite senses, then

$$\boxed{L_{eq} = L_1 + L_2 - 2M}$$



If the inductor are separated by a large distance then M = 0.
In that case

$$\boxed{L_{eq} = L_1 + L_2}$$

Inductors in Parallel

Suppose two inductors L_1 and L_2 are connected in parallel across a source. They are so far apart that their mutual inductance is negligible.
Let ε be the emf across the combination and let l_1 and l_2 be the currents through L_1 and L_2 respectively. Then,

$$\varepsilon = -L_1\frac{dl_1}{dt} = -L_2\frac{dI_2}{dt} \qquad \text{..........(1)}$$

The total current is

$$I = I_1 + I_2$$

or

$$\frac{dI}{dt} = \frac{dI_1}{dt} + \frac{dI_2}{dt} \qquad \text{..........(2)}$$

If L_{eq} is the equivalent inductance, then

$$\varepsilon = -L_{eq}\frac{dI}{dt} \qquad \text{..........(3)}$$

Eqs. (1), (2) and (3), give

$$\boxed{\frac{I}{L_{eq}} = \frac{I}{L_1} + \frac{I}{L_2}}$$

$$\boxed{Leq = \frac{L_1 L_2}{L_1 + L_2}}$$

M in terms of L1 and L2:

Suppose two inductors L_1 and L_2 are placed so close together that the same flux is linked with both. If M is the mutual inductance of the pair, then it can be shown that

$$\boxed{M = \sqrt{L_1 L_2}}$$

The coefficient of coupling (k) between two coils is defined as the fraction of magnetic flux produced by the current in one coil that links the other coil.

Interesting Information

Resemblance between resistance, capacitance and inductance

$$R = \rho\frac{L}{A}\ ;\quad C = \varepsilon\frac{A}{d}\ ;\quad L = \frac{N^2\mu A}{l}$$

- In each case, there is involvement of physical property of medium viz resistivity ρ for resistance, permittivity ε for capacitance and permeability μ for inductance
- In each case, there appears a ratio between length and area

PRACTICE QUESTIONS

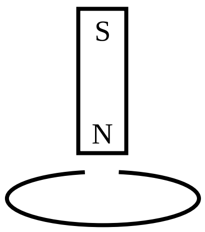
Q.1 A coil has an inductance of 1 H. If current is changing at the rate of 2 A/s its back emf will be

A) Greater than 1 volt
C) Less than 1 volt
B) Greater than 2 volt
D) Less than 2 volt

Q.2 To induce an emf in a coil, the linking magnetic flux

A) Must increase
C) Must remain constant
B) Muse decrease
D) Can either increase or decrease

Q.3 A bar magnet falls towards a metal ring and there is a cut in the ring. The magnet will fall with acceleration

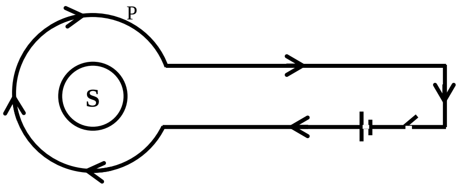


A) Equal to 'g'
C) Greater than 'g'
B) Less than 'g'
D) Zero

Q.4 If two identical loops, one of copper and other of iron are rotated with the same speed in same magnetic field, then

A) emf induced in both coils is equal
B) Current induced in both coils is equal
C) Current induced in copper coil is more than iron coil
D) Both A and C

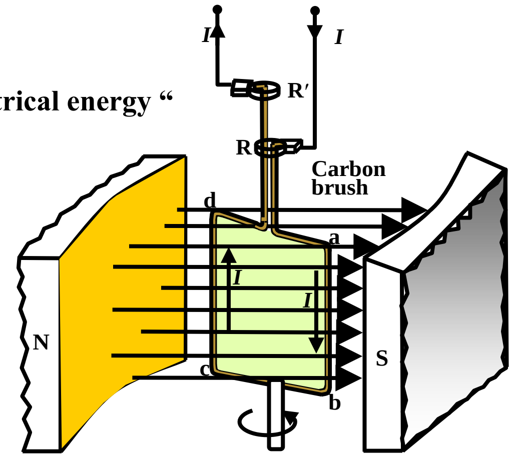
Q.5 Two coils P and S are arranged as shown in Fig. The direction of induced current in S when the switch is closed is



A) Clockwise
B) Anticlockwise
C) Zero
D) None of these

Alternating current generator

"It is a device which converts mechanical energy into electrical energy "



- Its working principle is Faraday's law.
- Emf induced in a coil is

$$\varepsilon = N\omega AB \sin\theta$$

Where,

N = number of turns of coil,

ω = angular velocity of coil

A = Area of coil

B = magnetic field induction

θ = angle between $\vec{v}$ and $\vec{B}$

Maximum emf is given by

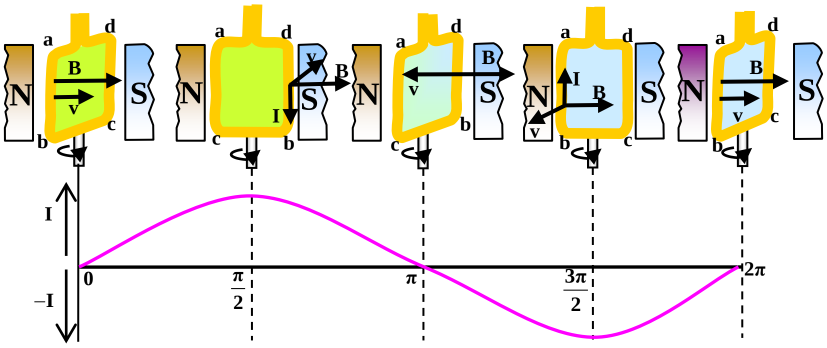
$$\varepsilon = N\omega AB$$

Did You Know?
If a plane flies due north in a region where earth's field is vertically down then west wing of plane is positively charged.

- Split rings and carbon brushes are arrangement to transfer current produced in the rotating coil to external static circuit.
- Current induced in a coil is

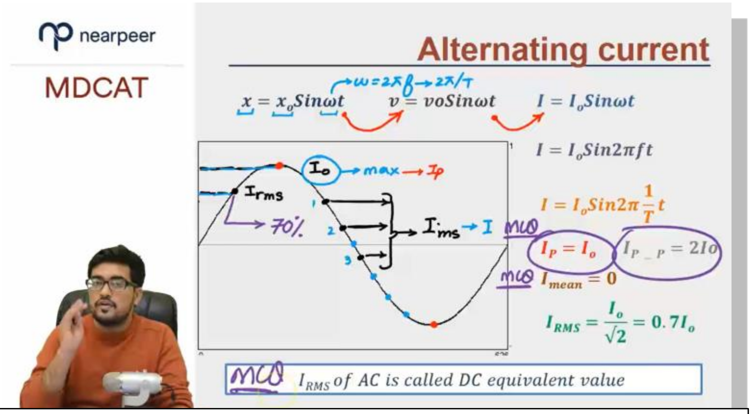
$$I = I_o \sin\theta$$

- An assembly of number of coils wound around a cylinder is called armature which is rotated by a fuel engine of a turbine run by a water wall.



DC Generator

"It is a device which converts mechanical energy into electrical energy "



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 12.03)

- Its construction and principle are same as that of an A.C generator with the only difference that slip rings are replaced by split rings or commutator.
- Commutator converts AC to DC in this generator
- Output of DC generator is pulsating D.C.
- More than one coil with a commutator each is used to produce constant emf.

> **Did You Know?**
> D.C. generator is more expensive than A.C. generator

Applications of alternating and direct current

- Direct currents are less easy to generate than alternating currents, and alternating emfs are more convenient to step up and step down, and to distribute over a wide area.
- Alternating current is just as suitable for heating as direct current, because the heating effect or a current is independent of its direction. It is equally suitable for lighting, because filament lamps depend on the heating effect, and gas discharge lamps neon, sodium, mercury run as well on alternating current as on direct.
- Small motors, of the size used in vacuum cleaners and common machine tools, run satisfactorily on alternating current, but large ones, as a general rule, do not. Direct current is therefore used on most electric railway systems. These systems either have their own generating stations, or convert alternating current from the grid into direct current.

Back motor effect in generator

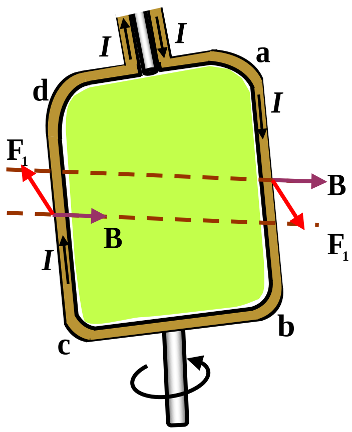
> **Did You Know?**
> Generators and motors have same constructions. Only input and output are reversed

Back motor effect is given by

$$\tau = \text{NIAB} \cos\alpha$$

Where, N = number of turns of coil,
I = current in the coil
A = area of coil,
B = magnetic field induction
α = angle between plane of coil and field

- Loads are those devices which consume electricity.
- Back torque at no load is zero.
- Back torque increases with increase in load.



D.C Motor

"It is a device which converts electrical energy into mechanical energy"

- Its working principle is torque on a current carrying coil placed in a uniform magnetic field (motor effect)
- For smooth running of coil (without jerks), we use more than one coil.
- In motors, field coils may be in series or in parallel to the armature coils.

Back Emf (Generator) effect in motors

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

- When motors is just started, back emf $\varepsilon = 0$ and starting current is large.
- As the motors speeds up, the back emf $(\varepsilon = N\omega AB\sin\theta)$ increase and the current becomes smaller and smaller.
- If the motor is overloaded, it slows down and hence back emf decreases which allows the motor to draw more current. If the motor is overloaded beyond limits, the current could be so high that it may burn the motor out. $(H = I^2Rt)$

Did You Know?
Commutator is only used in DC generator and DC motor and not in AC motor or AC generator.

PRACTICE QUESTIONS

Q.6 A circular coil has N turns. If current I produces a magnetic flux φ across the core's cross section then the energy stored in magnetic field of coil is

A) $N\varphi I^2$ C) $\frac{1}{2\mu_o}B(Al)$

B) $\frac{1}{2}NI\varphi$ D) Both B and C

Q.7 WbA^{-1} is the unit of

A) Flux density C) Self inductance

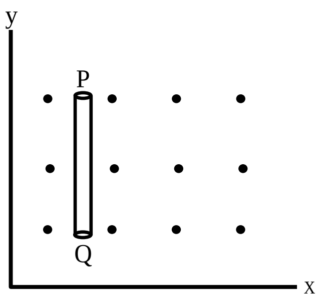
B) Mutual inductance D) Permeability of free space

Q.8 Transformer is used to increase or decrease emf .The quantity that remains unchanged in transformer is

A) Voltage C) Frequency of voltage

B) Current D) None of these

Q.9 A conducting rod PQ moves parallel to positive x-axis in a uniform magnetic field pointing in positive z-direction then



A) The end Q of the rod becomes positively charged
B) The end P becomes positively charged
C) Both ends will remain neutral
D) None of these

Q.10 A glass rod of length L moves with velocity $\vec{v}$ perpendicular to a uniform magnetic field B, the emf induced in rod is

A) vBLSin θ
C) Zero
B) vBL
D) NωABsin θ

Q.11 The emf induced in a coil of wire which is rotating in a magnetic field does not depend upon

A) The angular speed of rotation
C) Area of the coil
B) The number of turns of coil
D) Resistance of the coil

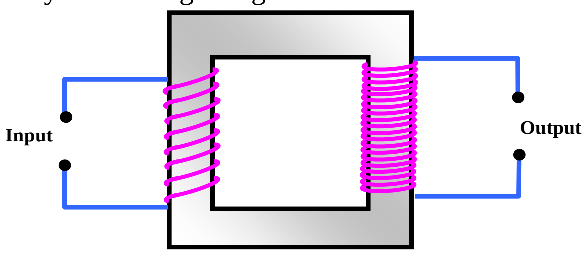
Transformer

"A transformer is an electrical device used either to increase or decrease alternating emf with corresponding increase or decrease in current"

- Its principle is mutual induction. Its consists of two insulated copper wires wound on an iron core.
- Power from primary coil is transferred to secondary coil through magnetic flux.

In transformer, turns ratio is given as

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

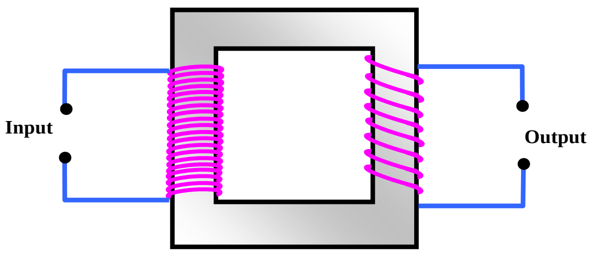


Step up tranformeer

Where V_p = primary voltage, V_s = secondary voltage
N_p = number of primary turns, N_s = number of secondary turns
If $N_s > N_p$ then $V_s > V_p$ (step up transformer)
If $N_s < N_p$ then $V_s < V_p$ (step down transformer)

In terms of currents

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



Step down transformer

- For ideal transformer

Input power = output power
$V_pI_p = V_sI_s$

- At generating stations, A.C generator produces moderate voltage(say 11 kV) and step up transformer is used which steps up voltage(say 220 kV) .Current is stepped down resulting in less line losses (I^2R) so that power is transmitted over long distances.
- At consumer's end , voltage is stepped down(say 11 kV) and current is stepped up for use.
- Transformers with several secondaries are used in televisions and radio receivers where several voltages of different levels are required.

Power Losses

- **Copper Losses**
  - Windings consist of copper conductors and have winding resistance, so there will be power loss. As core is usually wound with copper so it is termed as copper losses
- **Core Losses**
  - **Eddy Current Loss**: It is due to current induced in the core and it is reduced by taking laminated iron sheets core
  - **Hysteresis Loss**: It is due to friction between the domains of iron core during magnetization and de-magnetization. It is reduced by taking soft iron core having small hysteresis loop area (less hysteresis loss)

Knowledge plus

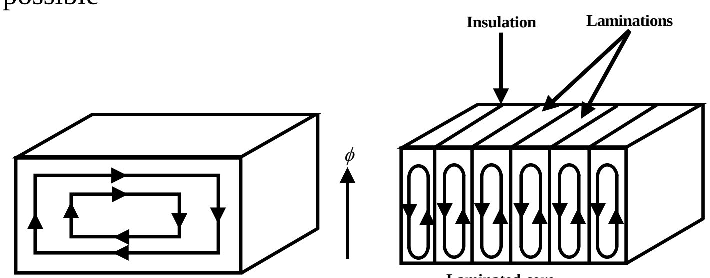
Eddy currents are the currents induced in metallic masses when the magnetic flux linking them changes.

- Whenever a block of metal (e.g. iron) is located in a changing magnetic field, the induced currents circulate throughout the volume of the metal. Because of their general circulating nature, these are called eddy currents.
- Since the resistance of metallic parts is low, the amount of eddy currents may be large even though the induced emfs are small. Therefore, eddy currents can produce considerable heating and magnetic effects.

Eddy current is given as $I = \frac{\varepsilon}{R}$

Obviously, the magnitude of eddy currents can be reduced if ε is reduced and R is increased.

- To reduce the eddy currents, the cores are not taken as a single piece of iron but are split into thin sheets (called laminations) in planes parallel to magnetic field as shown in Fig. Each lamination is insulated from the other by a layer of varnish. This arrangement reduces the area of each section and hence the induced e.m.f. (ε). It also increases the resistance (R) of eddy current paths since the area through which the currents can pass is smaller.
- Both these effects combine to reduce the magnitude of eddy currents. In electrical machines (motors, generators, transformers etc.), eddy currents are undesirable and must be kept to as low value as possible



Solid core (i) Laminated core (ii)

Use of Eddy Currents:

If the core of a moving coil is non-metal, the oscillations take a long time out. If the non-metallic core is replaced by a metallic core then due to currents produced in the metallic core, oscillations die out quickly.

Some Brain teasers for your practice

- A conductor is moved in a direction parallel to a uniform magnetic field. Will an induced current develop in the conductor?
- A soon as current is switched on in a high-voltage wire, the bird sitting on it files away. Why?
- A bar magnet falls through a metal ring [See Fig. 12.29]. Will the acceleration of the magnet be less than g, equal to g or more than g?
- Two identical loops, one of copper and another of iron, are rotated with the same speed in the same magnetic field. In which case (i) e.m.f. (ii) current will be more and why?
- Why are the inductance coils made of copper?
- Are eddy currents useful or harmful?
- If the number of turns and the length of the solenoid are double keeping the area of cross-section same, how is inductance affected?
- The inductance of a coil is directly proportional to

  (A) Its length (B) The number of turns

  (C) The resistance of the coil (D) The square of the number of turns
- A coil of wire of radius r has 600 turns and a self inductance of 108 mH. The self inductance of a similar coil of 500 turns will be

  (A) 108 mH (B) 90 mH

  (C) 75 mH (D) None of these
- The north pole of a long horizontal bar magnet is being brought closer to vertical conducting plane along the perpendicular direction. The induced current in the conducting plane is

  (A) Anti clock wise (B) Clockwise

  (C) Horizontal (D) Vertical

PRACTICE QUESTIONS

Q.12 The number of turns in a secondary coil is twice the number of turns in primary coil. An a.c source of 200 V is connected across the primary. The voltage across secondary is

A) 440 V
C) 200 V
B) 100 V
D) 400 V

Q.13 A bar magnet is passed through a wire loop. The induced current will be greatest when

A) North pole of magnet enters the coil first
C) The magnet moves fast
B) South pole of magnet enters the coil first
D) The magnet moves slowly

Q.14 The rate at which a single conductor should cut the flux in order that a current of 1.2 mA is induced in a conductor when 10 Ω resistor is connected across its ends is

A) 1.2×10^{-3} Wb/s
C) 1.2×10^{-4} Wb/s
B) 1.2×10^{-2} Wb/s
D) 12×10^{-2} Wb/s

Q.15 Keeping all other factors same, the number of turns of a coil is doubled, the magnetic flux linking with the coil is

A) Halved
C) Trebled
B) Doubled
D) Quadrupled

Q.16 If the rate of change of change current is 1A/sec in the coil, the induced emf is equal to

A) Thickness of coil
C) Number of turns in the coil
B) Magnetic flux
D) Self inductance

Q.17 A coil is rotated in a uniform magnetic field about an axis perpendicular to the field. The emf induced in the coil would be maximum when plane of the coil is

A) Parallel to the field
C) Perpendicular to the field
B) At 45° to the field
D) none of the above positions

Q.18 The mutual inductance of a pair of coils is 3H. If the current changes from 10 A to zero in 0.1 S, the emf induced in the other coil is

A) 3 V
C) 0.2 V
B) 300 V
D) 200 V

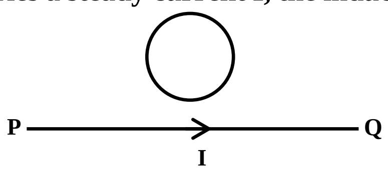
Q.19 Which one of the following is also referred as electrical inertia?

A) Magnetic flux
C) Flux density
B) Mutual inductance
D) Self inductance

Q.20 Choose correct about the commutator

A) Keeps the direction of current same in D.C Generator
B) Reverses the current in the D.C motor after each half revolution
C) Reverses the torque after each half revolution in D.C motor
D) Both A and B

Q.21 A straight wire PQ carries a steady current I, the induced current in circular loop will be



A) Clock wise
C) Zero

B) Anticlockwise

D) None of these

Q.22 In a certain region, the earth's magnetic field point vertically downward. When a plane flies due west, which wing tip is negatively charged

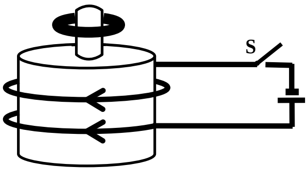
A) East

C) South

B) West

D) North

Q.24 In the figure given below, the upper end of the ring will behave as ………… when the switch is closed.



A) North pole

C) A Non magnetic ring

B) South pole

D) Both A and B are possible

Q.25 As the D.C motor slows down, the current drawn by it

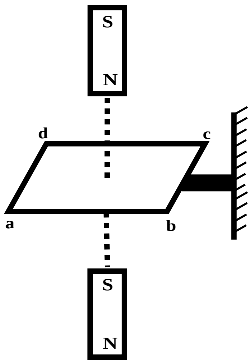
A) Becomes larger and larger

B) Becomes smaller and smaller

C) Remains constant

D) All of these are possible depending on the shape of armature

Q.26 A rectangular loop is held horizontal with the help of some non-conducting support as shown in fig. If a bar magnet is dropped from upper side then the direction of induced current viewed from above in the loop will be when bar magnet is in upper region



A) Abcda

C) Zero

B) Adcba

D) None of these

Q.27 Volt-second are the units of

A) Potential gradient

C) Rate of change of flux

B) Magnetic field strength

D) Magnetic flux

Q.28 A metal rod of length 25 cm is moving at a speed of 0.5 m/s in a direction making an angle 60° with vertical. The magnetic field is horizontal in this region. The emf induced in the rod is

A) Half of maximum induced emf

C) One-third of maximum induced emf

B) Maximum induced emf | D) $\frac{1}{4}$ th of maximum induced emf

Q.29 During the rotation of coil of A.C generator in a uniform magnetic field, when the plane of coil is perpendicular to the magnetic field then at this instant

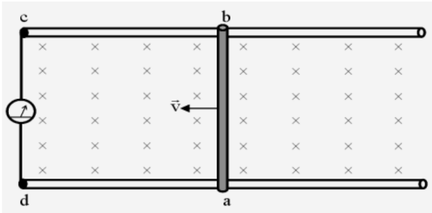
A) Induced current is zero but flux passing through coil and motor effect are maximum

B) Induced current is maximum but flux passing through the coil and motor effect are zero

C) Induced current and motor effect are zero but flux passing through the coil is maximum

D) Induced current and motor effect are maximum but flux passing through the coil is zero

Q.30 In the figure, a conducting straight rod is placed on two parallel metal rails separated by a distance L in a uniform magnetic field $\vec{B}$ directed into the page. If the conducting rod is moving towards left then



A) A charge carrier within the rod is experiencing a magnetic force $(q\vec{v} \times \vec{B})$ from b to a

B) A charge carrier within the rod is experiencing an electric force $(\vec{E}q)$ from a to b

C) All A, B and D

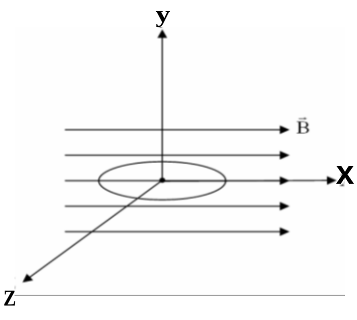
D) The conducting rod is experiencing magnetic force $(I\vec{L} \times \vec{B})$ towards right

Q.31 Step down transformer

A) Increases current | C) Increases power

B) Decreases current | D) Decreases power

Q.32 Around which of three coordinate axes should the coil be rotated in order to generate an emf and a current in the coil?



A) X-axis

B) Y-axis

C) Z-axis

D) No emf will induce at any rotation because magnetic field is uniform

Q.33 The inductance of a coil of 400 turns is 4 mH. The magnetic flux through each turn of the coil when the current flowing through it is 5 mA

A) 0.1 μWb | C) 0.6 μWb

B) 0.05 μWb | D) 0.5 μWb

Q.34 The average emf induced in a coil of N loops is equal to the negative of the rate at which the magnetic flux through the coil is changing with time

A) Lenz's law | C) Ampere's law

B) Faraday's law D) Gauss's law

Q.35 Mutual inductance of the pair of coils does not depend upon

A) Number of turns of coils

B) Core material upon which two coils are wound

C) Current in the primary

D) All of these

Q.36 Energy stored by an inductor of inductance 8 H when current through it rises from zero to maximum value of 3 A.

A) 6 J C) 36 J

B) 12 J D) None of these

Q.37 In a D.C motor; if the back emf is half of the applied battery voltage then the current at that instant is

A) Maximum C) Minimum

B) Half of the maximum value D) Half of the minimum value

Q.38 Which of the following is generated first?

A) Induced emf C) Both at the same time

B) Induced current D) Depends upon conditions

Q.39 If the current passing through a coil of inductance 5 H decreases at the rate of 2 A/s, the induced emf in the coil is

A) 2.5 V C) 4.5 V

B) 10 V D) 6.5 V

Q.40 If rate of change of flux linking with a coil is doubled then emf induced in the coil is

A) Halved C) Constant

B) Doubled D) Increased by four times

Q.41 If a current of 2 A is passing through a solenoid of inductance 2 H, then energy stores in it is

A) 2 J C) 3 J

B) 4J D) 8 J

Q.42 The energy stored in an inductor is

A) Electrostatic C) Magnetic

B) Electromagnetic D) Mechanical

Q.43 If current in a solenoid is doubled then energy stored in its magnetic field is

A) Doubled C) Increased by four times

B) Halved D) Decreases by four times

Q.44 In AC generator, if both number of turns and angular velocity of coil are doubled then induced emf is

A) Doubled C) Unchanged

B) Halved D) Increased by four times

Q.45 When overloaded, back emf in DC motor

A) Increases
B) Decreases
C) Remain unchanged
D) Increases then decreases

Q.46 The primary winding of transformer has 500 turns whereas its secondary ahs 5000 turns. The primary is connected to an AC supply of 20 V, 50 Hz. The secondary winding output will be

A) 200 V, 50 Hz
B) 2 V, 50 Hz
C) 200 V, 500 Hz
D) 2 V, 5 Hz

Q.47 An air core solenoid has 1000 turns and is one meter long. Its cross sectional area is 10 cm². Its self inductance is

A) $4\pi \times 10^{-3}$ Henry
B) $4\pi \times 10^{-4}$ Henry
C) $4\pi \times 10^{-2}$ Henry
D) $4\pi \times 10^{-5}$ Henry

Q.48 For transformer, if $\frac{N_s}{N_p} = 2 : 1$ then $\frac{I_p}{I_s} =$

A) 1 : 2
B) 2 : 1
C) 4 : 1
D) 1: 1

Q.49 The starting current for motor is

A) Zero
B) Small
C) Medium
D) Large

Q.50 Line losses are reduced by using

A) Step down transformer
B) Step up transformer
C) Motor
D) Generator

ANSWERS WITH EXPLANATION

Q.1 (A) $\varepsilon = L\frac{\Delta I}{\Delta t}$ **Q.2 (D)** $\varepsilon = -N\frac{\Delta\varphi}{\Delta t}$

Q.3 (A) e.m.f will be induced in the cut ring but no current will flow to oppose the magnet as it is open loop

Q.4 (D) emf does not depend upon resistance but current depends upon resistance copper has less resistivity than iron.

Q.5 (B) Q.6 (B) $U = \frac{1}{2}LI^2 = \frac{1}{2}L\left(\frac{N\varphi}{I}\right)I^2 = \frac{1}{2}N\varphi I$;

Q.7 (C) $N\varphi = LI$; $\frac{N\varphi}{I} = L$ **Q.8 (C) Q.9 (A)** $\vec{F} = q(\vec{v} \times \vec{B})$

Q.10 (C) Glass is not a metal **Q.11 (D) Q.12 (D)** $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Q.13 (C) $\varepsilon = N\frac{\Delta\varphi}{\Delta t}$, smaller the time, more will be induced emf.

Q.14 **(B)** $\frac{\Delta\varphi}{\Delta t} = \frac{\varepsilon}{N}$ **Q.15** **(B)** $\varphi = NBA$ **Q.16** **(D)** $\varepsilon = L\frac{\Delta I}{\Delta t}$

Q.17 **(A)** **Q.18** **(B)** $\varepsilon = M\frac{\Delta I}{\Delta t}$

Q.19 **(D)** $\varepsilon = L\frac{\Delta I}{\Delta t}$, It opposes rate of change of current. **Q.20** **(D)**

Q.21 **(C)** As it is D.C, so no emf will be induced **Q.22** **(D)** **Q.23** **(C)**

Q.24 **(A)** **Q.25** **(A)** **Q.26** **(A)** **Q.27** **(D)** $\Delta\varphi = \varepsilon \Delta t$

Q.28 **(A)** $\varepsilon = V\beta L \sin 30°$ **Q.29** **(C)** **Q.30** **(C)** **Q.31** **(A)** **Q.32** **(C)**

Q.33 **(B)** $N\varphi = LI$ **Q.34** **(B)** **Q.35** **(C)** **Q.36** **(C)** $E = \frac{1}{2}LI^2$

Q.37 **(B)** $I = \frac{v-\varepsilon}{R}$ **Q.38** **(C)** **Q.39** **(B)** $\varepsilon = L\frac{\Delta I}{\Delta t}$ **Q.40** **(B)**

Q.41 **(B)** **Q.42** **(C)** **Q.43** **(C)** **Q.44** **(D)** $\varepsilon = N\omega A B\sin\theta$

Q.45 **(B)** **Q.46** **(A)** **Q.47** **(B)** $L = \mu_o n^2 lA$ **Q.48** **(A)** $\frac{N_s}{N_p} = \frac{I_p}{I_s}$

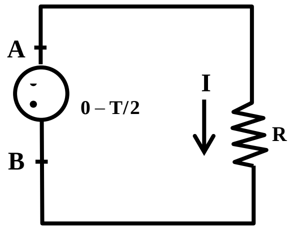
Q.49 **(D)** **Q.50** **(B**

ALTERNATING CURRENT

"The current which changes its magnitude continuously and reserves its direction periodically is called Alternating current"

A.C can be transferred to long distances but not D.C be because transformer works on the principle of mutual induction.

- The time interval during which the alternating current reverses its direction only once is called the time period T.
- Output of A.C generator is



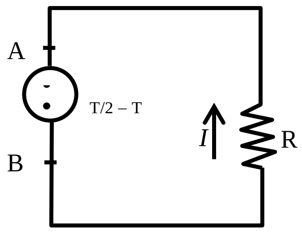
$$V = V_o \sin 2\pi f t$$

Peak value:

- It is the highest value reached by the voltage or current in one cycle of AC waveform.

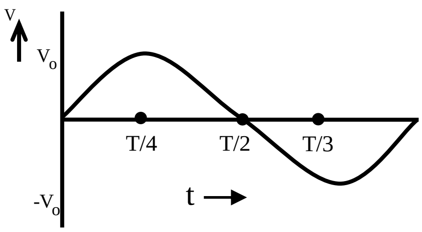
Peak to Peak Value:

- Peak to peak 2 V_o value is the sum of the positive and negative peak value usually written as p-p value

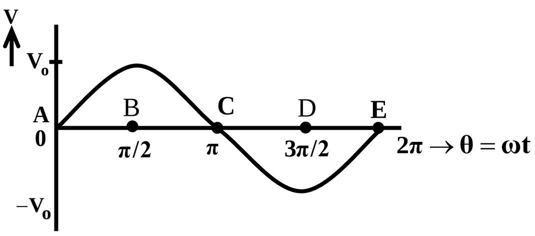


Root mean square (rms) value

The effective or r.m.s. value of alternating current is that steady current (d.c) which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current when flowing through the same resistance for the same time. It is also called virtual value of A.C. and is represented by $1_{r.m.s}$ or I_{eff}. or I_v.

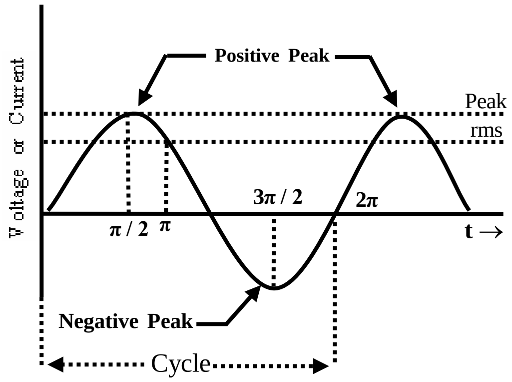


- Average value of AC over a cycle = 0 but $P = I^2 R \neq 0$
- Average (mean) square value of AC $\neq 0$ because $(-I)^2 = +I^2$



- When we say that alternating current in a circuit is 5 A, we are specifying the r.m.s. value. It means that the alternating current flowing in the circuit has the same heating effect as 5 A d.c. under similar conditions.

- A.C. ammeters and voltmeter record r.m.s. values of current and voltage respectively.



$V_{rms} = 0.7V_o$
$1_{rms} = 0.71_o$
A.C. Waveform

Phase of A.C:

- Output of A.C generator is

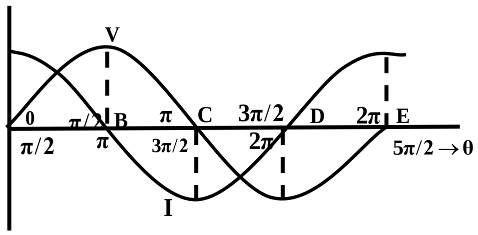
$$\boxed{V = V_o \sin 2\pi ft}$$

$$= V_o \sin \theta$$

- Phase θ shows the instantaneous value and direction of AC. At phase angle of 0, π and 2π, instantaneous value is zero. At phase angle of $\frac{\pi}{2}$, value is $+V_o$.At phase angle of $\frac{3\pi}{2}$, value is $-V_o$.

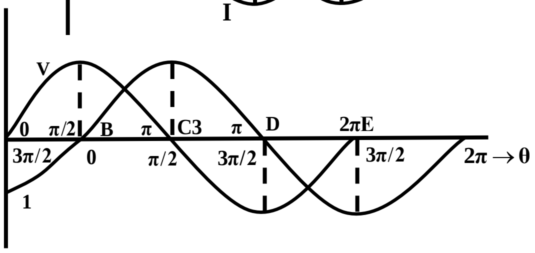
Phase lead:

- I leads V by a phase angle of $\frac{\pi}{2}$ rad



Phase lag:

- I lags V by a phase angle of $\frac{\pi}{2}$ rad



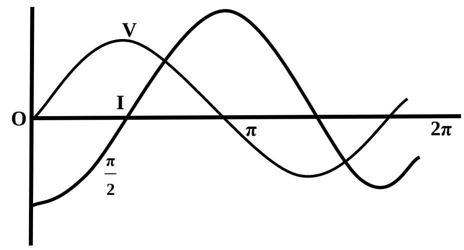
Vector representation of an alternating quantity (Phasors)

Alternating current or voltage is graphically represented by an anticlockwise rotation vector such that

i. Its length on a scale represents the peak or rms value of the alternating quantity.

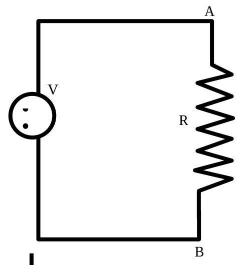
ii. As the wave starts from zero and goes forward, the vector (phase) starts from 0 rad and rotates anticlockwise.

iii. The angular frequency of vector is same as that of alternating quantity.

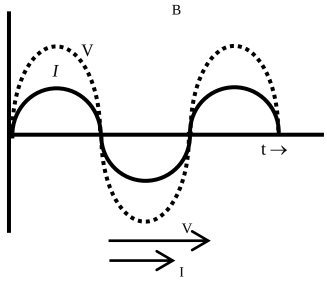


> The elements which control the current in the circuit
> - For DC Resistor
> - For AC Resistor, inductor and capacitor

A.C through a resistor

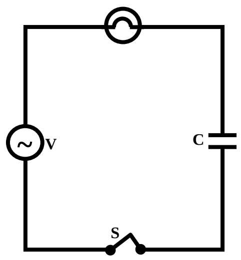


- $V = V_0 \sin \omega t$
- $I = I_0 \sin \omega t$, $R = \dfrac{V}{I}$
- $P = I^2R = VI = \dfrac{V^2}{R}$
- Here current and voltage are in phase
- A resistance opposes current but does not oppose a change in current. Hence, current is in phase with voltage.

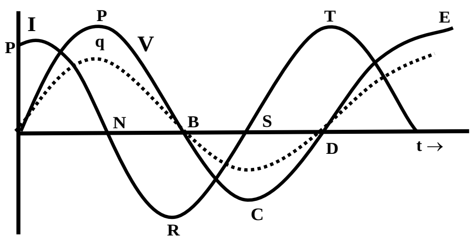


A.C through a capacitor

- Capacitor blocks DC but not AC (Due to charging and discharging of capacitor)
- $q = CV_0 \sin \omega t$
- $I = \dfrac{\Delta q}{\Delta t}$ = slope of q-t graph
- When q = 0 , I = maximum and when q = maximum , I = 0
- Alternating current leads alternating voltage in pure capacitive circuit by a phase angle of $\dfrac{\pi}{2}$.



- A capacitor has infinite resistance for a DC source. With an AC source, voltage changes, hence charge on the plates of the capacitor changes with time, i.e., there is a current. The current leads the voltage by $\pi/2$.

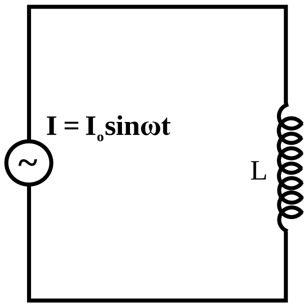


- **Reactance of a Capacitor** is defined as

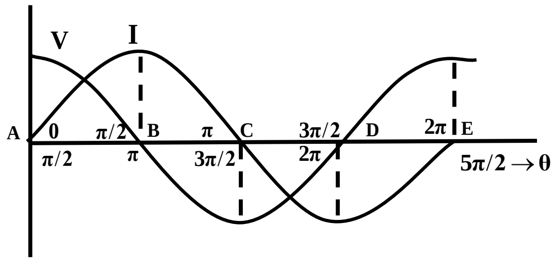
$$\boxed{X_C = \frac{1}{\omega C}}$$

or $$\boxed{X_C = \frac{1}{2\pi f C}}$$

A.C through an inductor



- $I = I_o \sin \omega t$
- $V = L\frac{\Delta I}{\Delta t} = L$ (Slop of I-t graph)
- Alternating current lags alternating voltage by a phase angle of $\frac{\pi}{2}$ in a pure inductive circuit



- **Reactance of an inductor is** defined as

$$\boxed{X_L = \omega L}$$

or $$\boxed{X_L = 2\pi f L}$$

Impedance:

The combined (total) opposition offered by circuit consisting of resistance and reactance to the flow of AC

$$\boxed{Z = \frac{V_{rms}}{I_{rms}}}$$

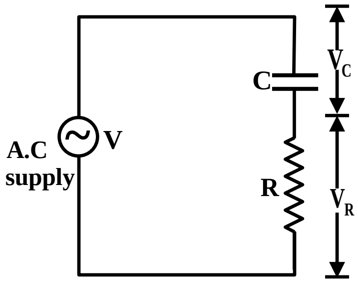
R-C series circuit

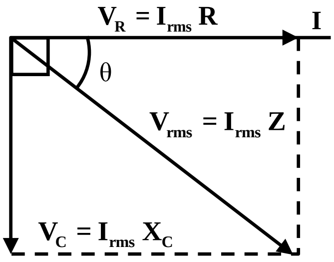
- Impedance is give by

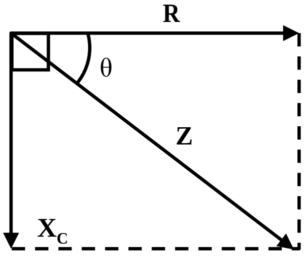
$$Z = \sqrt{R^2 + \frac{1}{(\omega C)^2}}$$

- I leads the applied voltage by an angle θ such that:

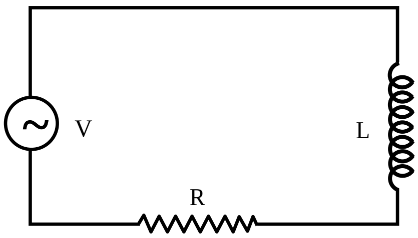
$$\tan\theta = \frac{1}{\omega CR} \qquad \theta = \tan^{-1}\frac{1}{\omega CR}$$







R- L series circuit

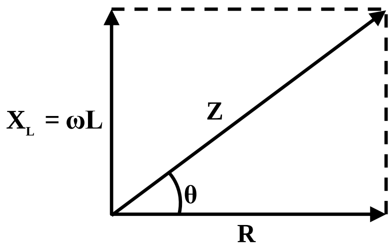


- Impedance is give as $\mathbf{Z} = \sqrt{R^2 + (\omega L)^2}$
- V leads I by

$$\theta = \tan^{-1}\frac{\omega L}{R}$$

- If a coil of resistance R and inductance L are connected in series across a battery of voltage V, then current in coil is $\mathbf{I} = \frac{\mathbf{V}}{\sqrt{\mathbf{R}^2 + (\boldsymbol{\omega}\mathbf{L})^2}}$

Power in A.C Circuits



- When V and I are not in phase then:

$$P = VI\cos\theta$$

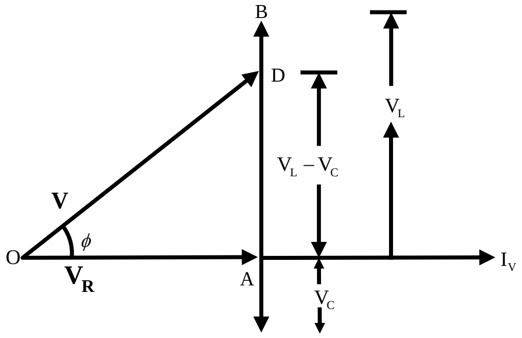
  i.e., I and V cosθ are in phase.
- cos θ is known as power factor
- When A.C pass through R then V and I are in phase i.e. θ = 0°
  Power factor = cos 0° = 1, Power dissipation is maximum
- When A.C pass through C and L then phase difference between V and I is 90°
  Power factor = cos 90° = 0, No power is dissipated

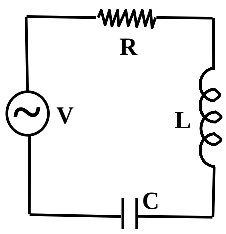
Series resonance circuit: (RLC series circuit)

- Supply a voltage V of variable frequency f.
- At low f, $X_c > X_L$ and this circuit behaves as RC series circuit.
  ($X_L = \omega L$ and $X_c = \frac{1}{\omega C}$ where X_L and X_c are directed opposite to each other)
- At high f, $X_L > X_C$ and this circuit behaves as RL series circuit.
  At a certain intermediate frequency f_r, $X_L = X_c$ and they cancel each other because they are oppositely directed.
- Here impedance Z = R is minimum and circuit behaves as a resistive circuit.
- Current is same in series, so phasor diagram is drawn taking current as the reference phasor.

- In the phasor diagram, VL is in phase opposition to V_C. It follows that the circuit can be effectively inductive or capacitive depending on which voltage drop (V_L or V_C) is predominant. For the case considered $V_L > V_C$ so that net voltage drop across L – C combination is $V_L – V_C$ and is represented by AD.

Therefore, the applied voltage V is the phasor sum of V_R and $V_L – V_C$ and is represented by OD





$$\mathbf{V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{(I\ R)^2 + (I\ X_L - I\ X_C)^2}} = \sqrt{R^2 + (X_L - X_C)^2}$$

The quantity $\sqrt{R^2 + (X_L - X_C)^2}$ offers opposition to the current flow and is called impedance Z of the circuit.

Circuit power factor, $\cos\theta = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$

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

Since X_L, X_C and R are known, the phase angle θ can be determined.

Resonance in R-L-C Series Circuit:

"The R-L-C series A.C circuit is said to be in electrical resonance if $X_L = X_C$**, this is called series resonance"**

- The frequency at which resonance occurs is called the resonance frequency f_r. The resonance in R-L-C series circuit (i.e. $X_L = X_C$) can be achieved by changing the supply frequency because X_L and X_C are frequency dependent. At a certain frequency, called the resonant frequency f_r, X_L becomes equal to X_C and resonance occurs.

At resonance, $X_L = X_C$

For R-L-C series circuit, $Z = \sqrt{R^2 + (X_L - X_C)^2}$. For the circuit, power factor to be unity X_L should be equal to X_C $X_L = X_C$

or $2\pi f_r L = \frac{1}{2\pi f_r c}$

or $f_r^2 = \frac{1}{4\pi^2 LC}$

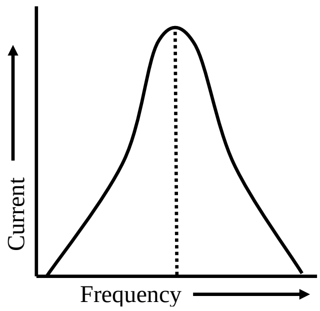
or $\boxed{\mathbf{f_r} = \frac{1}{2\pi\sqrt{LC}}}$

Properties of the series resonance Circuit:

- Resonance frequency $f_r = \frac{1}{2\pi\sqrt{LC}}$
- As circuit is resistive at f_r, so voltage and current are in phase i.e., $\theta = 0^o$ and power factor $\cos\theta = 1$
- At f_r, impedance is minimum and $Z = R$
- When series resonance occurs, the effect on the circuit is the same as though neither inductance nor capacitance is present. The current under this condition is dependent solely on the resistance of the circuit and voltage across it.
- Since at resonance, the current flowing in the circuit is very large, the voltage drops across L and C are also very large. In fact, these drops are much greater than the applied voltage . However, voltage drop across L-C combination as a whole will be zero because these drops are equal in magnitude but 180° out of phase with each other.

Resonance Curve:

The curve between the circuit current and the supply frequency is known as resonance curve. Note that current reaches the maximum value at the resonant frequency (f_r), falling off rapidly on either side at that point.



- It is because if the frequency is below f_r, $X_C > X_L$ and the net reactance is no longer zero. If the frequency is above f_r, $XL > X_C$ and the net reactance is again not zero.

Parallel Resonance Circuit

- The circuit will be in resonance when the circuit power factor is unity. In this case $IL = I_c$
- The frequency at which resonance occurs is called the resonant frequency f_r.
- The resonance in a parallel a.c. circuit (i.e. $I_L = I_C$) can be achieved by changing the supply frequency because X_L and X_C are frequency dependent. At a certain frequency, called resonant frequency f_r, I_C becomes equal to I_L and resonance occurs.

At resonance,

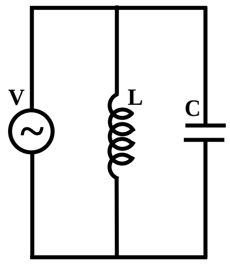
$$I_L = I_C$$

or $$\frac{V}{X_L} = \frac{V}{X_C}$$

or $$X_L = X_C$$

or $$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$



- The capacitor draws a leading current I_C and the coil draws a lagging current I_L.
- At f_r, I_L and I_C are equal and opposite. A minimum source current I_r is drawn is due to resistance of coil. And At f_r, $X_L = X_C$ and $z = max = R$ and I_r is minimum.

Properties of the series resonance Circuit:

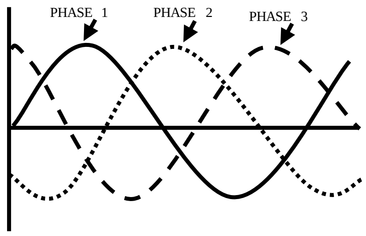
- $$f_r = \frac{1}{2\pi\sqrt{LC}}$$
- At f_r, Z = maximum = R
- At f_r,, circuit is resistive, hence V and I are in phase are θ = 0°. Power factor cos θ = I
- At resonance, the branch current I_L and I_C many be larger than the source current I_r.

Knowledge plus

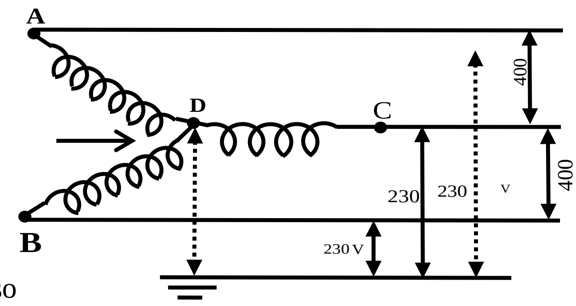
- Series resonance circuit is also called acceptor circuit because at resonance, the impedance of circuit is at its minimum, so it easily accepts the current whose frequency is equal to resonant frequency.
- Parallel RLC circuit is called ejector circuit because at resonance, the impedance of circuit is its maximum therefore rejecting or suppressing the current whose frequency is equal to resonant frequency.

Three phase AC supply

- In three phase supply, combination of three coils rotate in the magnetic field, each connected to its own pair of slip rings. Thus, three alternating voltages having phase difference of 120° between them, are generated as shown in figure.
- During rotation, if one coil is making an angle 0° with the field, other will be making 120°and third one will be making 240°.



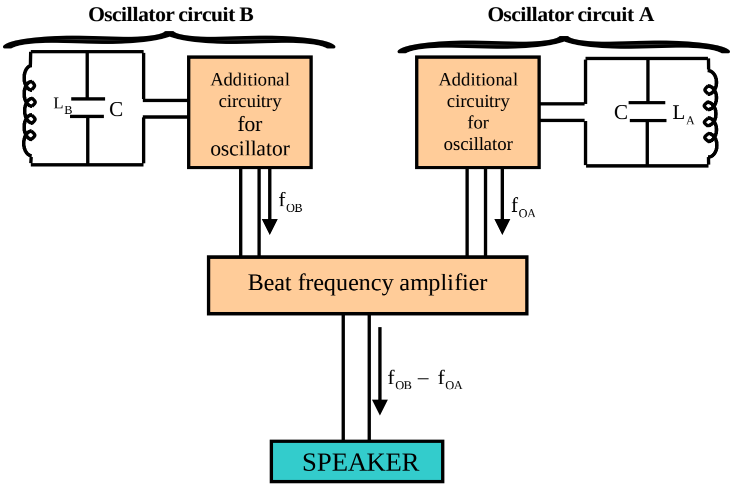
- There are four terminals because the starting points of all the coils have the common junction which is often earthed to the shaft of generator and the other three ends are connected to the three separate terminals A,B and C on the machine.
- The main advantage of three phase supply is that the total load is divided in three parts, so that none of the line is over loaded. If overloaded, terminal voltage drops.



- Three phase supply also provides 400 V which can operate certain appliances.

Principle of metal detectors

- An L-C electrical oscillator behaves just like an oscillating mass spring system in this case energy oscillates between a capacitor and an inductor.
- In the absence of nearby metal, $L_A = L_B$ and hence f_r of two L-C circuits is also same.
- When search coil B comes near a metal object, L_B decreases and f_{OB} (resonance frequency of oscillator circuit B) increases. Hence beat not is heard in the speaker.



Choke

- It is an ideal inductor whose resistance is negligible and inductance is very large because it consists of a thick copper wire wound closely in a large number of turns over a soft iron laminated cores.
- It consumes extremely small power to limit the current.
- This is used in fluorescent tubes to control the current.
- Hence, the use of resistance is avoided in AC circuits.

Analogy Between Mechanical and Electrical Quantities:

- The LC oscillations are similar to the oscillations of a mass-spring system.
- In the LC oscillations, the energy alternates between electrostatic and magnetic forms while in mechanical oscillations, it alternates between potential and kinetic forms.
- In case of mechanical system F = m a
- In case of electrical system $\varepsilon = -L\dfrac{\Delta I}{\Delta t}$

S. No	Mechanical System	Electrical System
1	Mass m	Inductance L
2	Force constant k	Reciprocal of capacitance 1/C
3	Displacement x	Charge q
4	Velocity $v = \dfrac{\Delta x}{\Delta t}$	Current, $\mathbf{I} = \dfrac{\Delta q}{\Delta t}$
5	Mechanical Energy, $E = \dfrac{1}{2}kx^2 + \dfrac{1}{2}mv^2$	Electromagnetic energy,

		$E = \frac{1}{2}\frac{q^2}{C} + \frac{1}{2}LI^2$

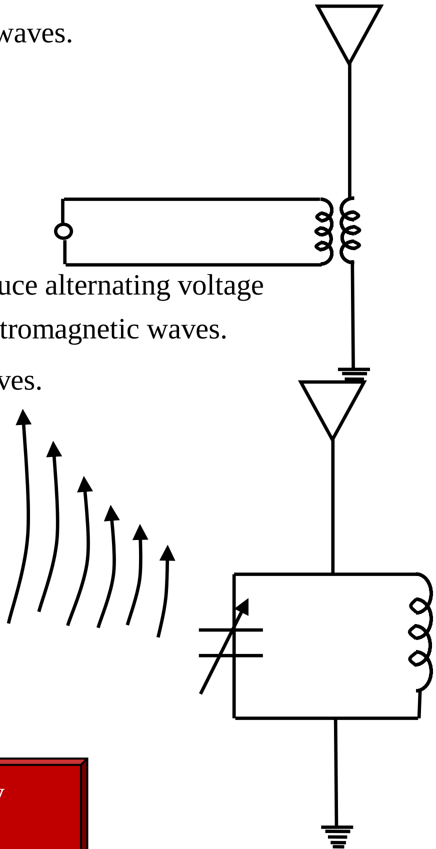
ELECTROMAGNETIC WAVES

These waves are periodic, require no medium for their propagation and travel with speed of light.

- In 1864 Maxwell formulated a set of equation known as Maxwell equations. Maxwell proved that light waves are electromagnetic.
- To generate electromagnetic wave electrical charges must accelerate.
- A changing magnetic flux develops an electric field in the surrounding region and a changing electric flux develops a magnetic field in the surrounding region.
- In electromagnetic waves electric and magnetic fields oscillate at right angle to each and to the direction of propagation of wave.

When electrons in the transmitting antenna vibrate 94000 times each second, they produce radio waves having frequency 94 KHz i.e., frequency of source voltage is equal to the frequency of generated electromagnetic waves.

PRINCIPLE OF GENERATION, TRANSMISSION AND RECEPTION OF ELECTROMAGNETIC WAVES



- We require ac or oscillating charge to generate electromagnetic waves.
- A transmitting antenna is shown in the figure.
- In free space, speed of electromagnetic wave = speed of light = $c = \frac{E}{B} = \sqrt{\frac{1}{\mu_o \varepsilon_o}}$
- When electromagnetic waves reach a reception antenna they induce alternating voltage in the antenna whose frequency is equal to the frequency of electromagnetic waves.
- To receive a single wave out of a number of electromagnetic waves. We use LC tuning circuit with variable capacitance
- When a number of electromagnetic waves reach a tuning LC circuit, the circuit resonance frequency is changed by changing C until it becomes equal to the frequency of one of the electromagnetic waves which is to be picked up by the resonating LC circuit.

For AC mains of 220 volt, the peak value of the voltage is given by

$V_0 = \sqrt{2}V_{rms} = \sqrt{2} \times 220 = 311$ **volt**

MODULATION

Modulation is the process of combining the low frequency signal with a high frequency radio wave called carrier wave.

- A high frequency carrier wave is used to carry the audio signal
- The question arises how the audio signal should be "added" to the carrier wave. The solution lies in changing some characteristic of carrier wave in accordance with the signal. Under such conditions, the audio signal will be contained in the resultant wave.
- Modulation means "to change". In modulation, some characteristic of carrier wave is changed in accordance with the intensity (i.e. amplitude) of the signal. The resultant wave is called modulated wave or radio wave and contains the audio signal. Therefore, modulation permits the transmission to occur at high frequency while it simultaneously allows the carrying of the audio signal.
- ***Need for modulation*** is there because audio signals have a frequency range from 20 Hz to 20 kHz. These low frequency signals cannot be transmitted directly (i.e. without modulation) into space without modulation

Types of modulation:

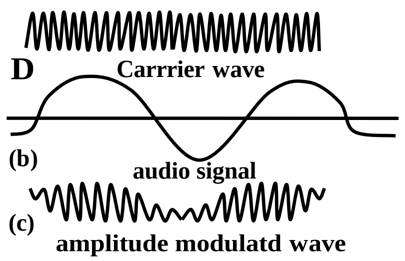
- **Amplitude modulation (A.M)**
- **Frequency modulation (F.M)**

Amplitude Modulation:

- **When the amplitude of high frequency carrier wave is changed in accordance with the amplitude of audio signal, then this is called amplitude modulation**
- **The A.M transmission frequency range from 540 kHz to 1600 kHz.**

Limitations of A.M:

- **Noisy reception** is one problem with A.M. In an AM wave, the signal is in the amplitude variations of the carrier. Practically all the natural and man-made noises consist of electrical amplitude disturbances. As a radio receiver cannot distinguish between amplitude variations that represent noise and those that contain the desired signal, therefore, reception is generally noisy.
- **Small operating range** is another problem with A.M Due to low efficiency of amplitude modulation, transmitters employing this method have a small operating range i.e. messages cannot be transmitted over larger distances



Frequency modulation:

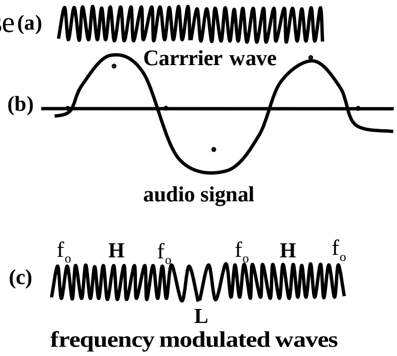
When the frequency of high frequency carrier wave is changed in accordance with the amplitude of audio signal, then this is called frequency modulation

F.M transmission frequencies are much higher and ranges between 88 MHz to 108 MHz.

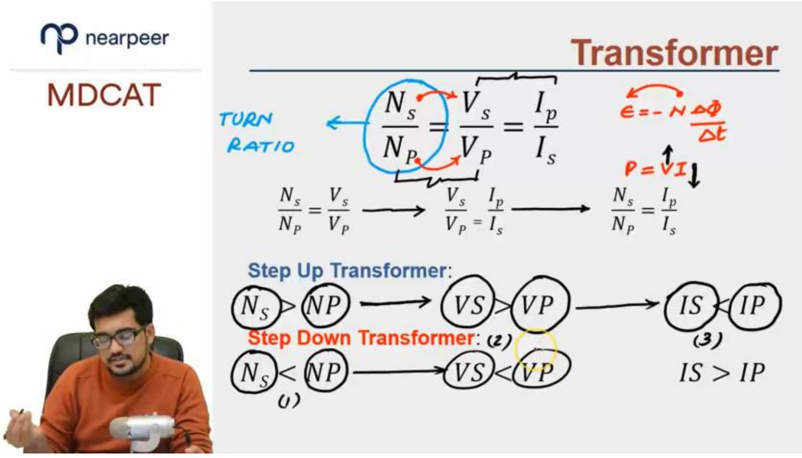
- Frequency variations of carrier wave depend upon the instantaneous amplitude of the signal as shown in Fig. When the signal voltage is zero the carrier frequency is unchanged. When the signal approaches its positive peaks, the carrier frequency is increased to maximum as shown by the closely spaced cycles. However, during the negative peaks of signal, the carrier frequency is reduced to carrier frequency is increased to maximum as shown by the closely spaced cycles. However, during the negative peaks of signal, the carrier frequency is reduced to minimum as shown by the widely spaced cycles. The following points may be noted:
- From figure, the frequency of the modulated carries wave is highest (point H), when the audio signal amplitude is at its maximum positive value and is at its lowest frequency (Point L) when signal amplitude has maximum negative value. When signal amplitude is zero the carrier frequency is at its normal frequency f_o.

Advantages and Disadvantages of FM:

- **Advantages** of F.M are that it gives noiseless reception. As noise is a form of amplitude variations and an FM receiver will reject such signals. Moreover, its operating range is quite large.
- **Disadvantages** are that FM transmitting and receiving equipments are complex, particularly for modulation and demodulation. Therefore, FM is more expensive.



frequency modulated waves



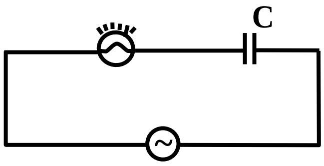
Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 12.04)

<u>Practice Questions</u>

Q.1 Time required by 50 Hz A.C to reach peak starting from zero is

A) 20 s
C) $\frac{1}{50}$ s
B) $\frac{1}{200}$ s
D) 50 s

Q.2 A bulb and a capacitor are connected to an A.C source as shown in fig. If the frequency of A.C is increased, then brightness of bulb will



A) Increase
C) Remain same
B) Decrease
D) Data incomplete

Q.3 The resonance frequency of circuit is f. If the capacitance is made four times of the initial value, the resonance frequency will become

A) f/4
C) f
B) 2 f
D) f/2

Q.4 In RCL Series Circuit, the capacitance is made one-forth when in resonance. What should be the change in inductance so that the circuit remains in resonance?

A) 4 times
C) 8 times
B) ¼ times
D) 2 times

Q.5 In an A.C circuit, the current

A) Is in the phase with the voltage
B) Leads the voltage
C) Lags the voltage
D) Ay one of the above depending upon circumstances

Q.6 In an A.C circuit, the resistance R is connected in series with an inductance L. If phase difference between voltage and current is 45^0, the value of inductive reactance will be

A) R/4
C) R
B) R/2
D) None of these

Q.7 An inductor is connected to a 220v, 50 Hz A.C source and then to a 220, 100 Hz source (choose correct)

A) Current flowing is same in two cases
C) Current will be more in second case
B) Current will be more in first case
D) None of these

Q.8 Electromagnetic waves are

A) Transverse
B) Longitudinal
C) Produced by charges moving with constant velocity
D) None of these

Q.9 **If a television station transmits electromagnetic waves of frequency 100 Hz, then the wavelength of electromagnetic waves transmitted from the source will be**

A) 0.3×10^{5} m
C) 3×10^{6} m
B) 1.67×10^{-6} m
D) None of these

Q.10 **If the time period of alternating current is 10 milliseconds, the current reverses its direction after every**

A) 10 ms
C) 5 ms
B) 15 ms
D) 20 ms

Q.11 **If an inductor of inductance $\frac{1}{\pi}$ henry is connected to an A.C supply of 50 Hz, then its reactance will be**

A) 10 Ω
C) 1000 Ω
B) 100 Ω
D) 50 Ω

Q.12 **The inductor opposes the flow of**

A) A.C
C) Both A.C and D.C
B) D.C
D) Neither A.C nor D.C

Q.13 **Power factor is 1 for**

A) Pure capacitive Circuit
C) Pure resistive Circuit
B) Pure inductive Circuit
D) RC Circuit

Q.14 **Which one is more dangerous?**

A) 220 V A.C
C) Both are equally dangerous
B) 220 V D.C
D) Data is insufficient to predict danger

Q.15 **Reactance of an inductor for direct current is**

A) 0
C) 1
B) ∞
D) None of these

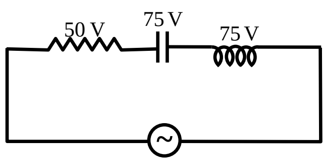
Q.16 **If the frequency of A.C source in RLC series circuit is increased, the current in the circuit**

A) Will increase
C) First increase then decreases
B) Will decrease
D) First decrease then increases

Q.17 **In non resonant series circuit, the nature of circuit for frequencies higher than that of resonance frequency is**

A) Resistive
C) Capacitive
B) Inductive
D) None of These

Q.18 **The circuit shows the potential difference across various elements. The power factor of the circuit will be**



A) 1
C) 0
B) 0
D) Insufficient data

Q.19 If I_{rms} and V_{rms} are the rms values of alternating current and voltage whereas I_o and V_o are their peak values then mean power dissipated in a pure resistive circuit will be

A) $I_{rms} \times V_{rms}$

B) $\frac{I_o}{\sqrt{2}} \times \frac{V_o}{\sqrt{2}}$

C) $I_{rms} \times V_{rms} \sin\theta$

D) Both A and B

Q.20 The phase at which the sinusoidal instantaneous voltage has the same value as that of rms voltage over a cycle

A) $\frac{\pi}{3}$ radian

B) $\frac{\pi}{4}$ radian

C) $\frac{\pi}{6}$ radian

D) $\frac{\pi}{12}$ radian

Q.21 A 0.1 μF capacitor will have a reactance of 1000 Ω at a frequency of

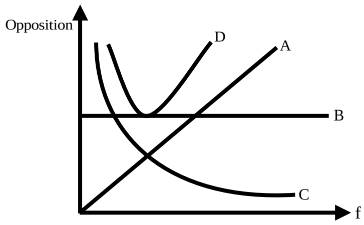
A) $\frac{5}{\pi} \times 10^3$ Hz

B) $\frac{\pi}{5} \times 10^{-3}$ Hz

C) $\frac{5}{\pi} \times 10^{-3}$ Hz

D) None of these

Q.22 Which one of the following curve is the variation of capacitive reactance with frequency?



A) A

B) B

C) C

D) D

Q.23 Which of the following is the incorrect relation?

A) $I_o = \frac{I_{rms}}{\sqrt{2}}$

B) $I_{PP} = \sqrt{3}\, I_{rms}$

C) $I_{rms} = \frac{I_{pp}}{2\sqrt{2}}$

D) Both A and B

Q.24 When A.C flows through a pure capacitive circuit the phase difference b/w voltage V and charge q on the capacitor at any instant

A) π

B) π/2

C) 3π/2

D) 0

Q.25 The voltage across any two lines in three phase A.C supply in volts is about

A) 120

B) 220

C) 230

D) 400

Q.26 In FM, when the signal amplitude is minimum, the frequency of carrier wave is at its

A) Highest frequency

B) Lowest frequency

C) Normal frequency

D) All of these are possible

Q.27 Series Resonance circuit is also known as

A) Acceptor circuit

B) Rejector circuit

C) Capacitive circuit

D) Inductive circuit

Q.28 The speed of electromagnetic waves in free space is

A) $\frac{1}{\sqrt{\varepsilon_o\mu_o}}$ C) $\frac{1}{\pi\sqrt{\varepsilon_o\mu_o}}$

B) $\sqrt{\varepsilon_o\mu_o}$ D) $\frac{1}{2\pi\sqrt{\varepsilon_o\mu_o}}$

Q.29 In RLC series circuit angle between X_L and X_c is

A) $\tan^{-1}(\omega L/R)$ C) $\tan^{-1}(Z/R)$

B) $\tan^{-1}(R/\omega L)$ D) π

Q.30 If we oscillate a charged body then we generate

A) Electric field only C) Electromagnetic field

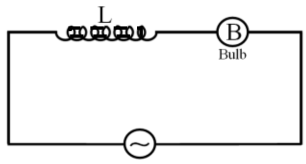
B) Magnetic field D) None of these

Q.31 In an RLC series circuit, if the inductive reactance is one-third of the capacitive reactance then impedance of the circuit is

A) $\frac{1}{3}\sqrt{9R^2+4x_C^2}$ C) Both 'A' and 'B'

B) $\sqrt{R^2+4x_L^2}$ D) $\sqrt{R^2+\frac{1}{3}x_C^2}$

Q.32 If an iron rod is inserted in inductor shown in fig. then bulb



A) Will get dimmer C) Keep same brightness

B) Will get brighter D) Will first become dimmer then brighter

Q.33 In a metal detector, the inductance of a search coil in the presence of a metal object usually

A) Increases C) May increase or decrease

B) Decreases D) Remains same

Q.34 An alternating voltage of 13 V and 50 Hz is applied across R-L series circuit. If the potential difference across inductor is 12 V, then the potential difference across resistor will be

A) 5 V C) 1 V

B) None of A, C and D D) 8 V

Q.35 The wavelength of 500 m corresponds to the region of electromagnetic spectrum

A) FM C) UV

B) AM D) IR

Q.36 In inductive circuit V leads I by

A) π C) 2π

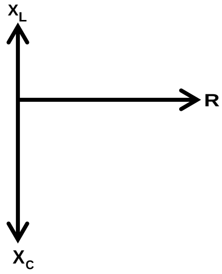
B) $\pi/2$ D) $\pi/4$

Q.37 Unit of capacitive reactance is

A) ohm C) henry

B) farad D) weber

Q.38 At which one of the following frequency, RLC series circuit will have the behavior shown in the figure



A) High frequencies C) Resonance frequency
B) Low frequency D) All of these are possible

Q.39 A sinusoidal wave has a frequency of 50 Hz. Its angular velocity would be

A) $50/\pi\ s^{-1}$ C) $50\pi\ s^{-1}$
B) $25/\pi\ s^{-1}$ D) $100\pi\ s^{-1}$

Q.40 The A.M frequency ranges between

A) 540 Hz to 1600 Hz C) 540 Hz to 1600 kHz
B) 5.4×10^5 Hz to 1.6×10^5 Hz D) 540 MHz to 1600 MHz

Q.41 The frequency of domestic AC supply in Pakistan is

A) 50 Hz C) 150 Hz
B) 100 Hz D) 75 Hz

Q.42 If peak alternating current is $\sqrt{2}$ A , then rms value of current is

A) $\sqrt{2}$ A C) 1 A
B) $\frac{1}{\sqrt{2}}$ A D) $\sqrt{3}$ A

Q.43 The basic circuit element in a DC circuit is

A) resistor C) inductor
B) capacitor D) all of these

Q.44 If time period of alternating current is 10 ms (millisecond) then current reveres its direction after every

A) 10 ms C) 5 ms
B) 15 ms D) 20 ms

Q.45 At high frequency of AC supply , the reactance of capacitor will be

A) Low C) Large
B) Variable D) Zero

Q.46 Which circuit element is short circuit (R=0) for AC

A) Resistor C) Capacitor
B) Inductor D) None of these zero

Q.47 If an inductor of inductance $\frac{1}{\pi}$ henry is connected to an AC supply of 50 Hz then its reactance is

A) 10 Ω
C) 1000 Ω
B) 100Ω
D) 10.1 Ω

Q.48 The impedance of RC series circuit connected to an AC supply is

A) $R^2 + (\omega c)^2$
C) $R^2 + \frac{1}{(wc)^2}$
B) $\sqrt{R^2 + (wc)^2}$
D)

Q.49 In which AC circuit, the current leads the voltage by an angle θ < 90º?

A) RL series circuit
C) LC series circuit
B) RC series circuit
D) Resistive circuit

Q. 50 An AC voltage is applied across the inductor. When the frequency of the voltage is increased, the current

A) Decreases
C) Does not change
B) Increases
D) Becomes Zero

Q.51 If both frequency of AC supply and inductance of an inductor are double the inductive reactance is

A) Double
C) Increased by four times
B) Halved
D) Decreased four times

Q.52 Mostly load is

A) resistive
C) Inductive
B) Capacitance
D) Resistive

Q.53 if a glass plate is placed between the plates of a capacitor which is placed in series with a glowing bulb, then brightness of bulb

A) Increases
C) Remain constant
B) Decreases
D) May resistive circuit

Q.54 Power factor is 0 for

A) Pure inductive circuit
C) Both A and B
B) Pure capacitive circuit
D) Pure resistive circuit

Q.55 If rms value of AC current and voltage are 1A and 2 volt respectively, then power dissipated in pure inductive circuit is

A) 2 watt
C) 1.6 watt
B) 1 watt
D) 2.6 watt

Q.56 Power dissipate in pure inductive circuit is

A) 0
C) large
B) 1
D) small

Q.57 If current lags the voltage by $\frac{\pi}{2}$,then power factor is

A) 0 C) -1

B) 1 D) 0.5

Q.58 phase angle for RL series circuit is

A) $\tan^{-1}\frac{1}{X_L R}$ C) $\tan^{-1}\frac{X_L}{R}$

B) $\tan^{-1}(X_L R)$ D) $\tan^{-1}\frac{R}{X_L}$

Q.59 A coil and an electric bulb are connected in series with an AC source .If a soft iron bar is placed inside the coil the brightness of bulb

A) increases C) remains

B) decreases D) may increases or decreases

Q.60 Which of these waves has the highest frequency?

A) Infra-red radiation C) Ultra –violet radiation

B) X-rays D) Gamma rays

ANSWERS WITH EXPLANATION

Q.1 (B) $t=\frac{T}{4}$ **Q.2 (A)** $1=\frac{V}{\sqrt{\sqrt{R^2_+ y_C^2}}}$ and $X_C=\frac{1}{2\pi fc}$ **Q.3 (D)**

Q.4 (A) Q.5 (D) Q.6 (A) $\theta=\tan^{-1}\frac{X_L}{R}$ **Q.7 (B)**

Q.8 (A) Q.9 (C) Q.10 (C) Q.11 (B) $X_L = 2\pi fL$

Q.12 (A) Q.13 (C) Q.14 (A)

Q.15 (A) $X_L = 2\pi fL$ (frequency of D.C is zero) **Q.16 (C)** See the resonance curve

Q.17 (B) Q.18 (B) Q.19 (A) $P = V_{rms} I_{rms}$ **Q.20 (B)** $V = V_{rms}$

Q.21 (A) $X_C=\frac{1}{2\pi fC}$ **Q.22 (C) Q.23 (D) Q.24 (D) Q.25 (D)**

Q.26 (C) Q.27 (A) Q.28 (A) $c=\frac{1}{\sqrt{\mu_o\,\varepsilon_o}}$ **Q.29 (D) Q.30 (C)**

Q.31 (C) $Z=\sqrt{R^2+(X_L-X_C)^2}$ **Q.32 (A)** $I=\frac{V}{2\pi fL}$ **Q.33 (B)**

Q.34 (A) $v2=v_R^2+v_L^2$ **Q.35 (B)** $c = f\,\lambda$, $f = 600$ kHz **Q.36 (B)**

Q.37 (A) Q.38 (B) Q.39 (D) Q.40 (B) Q.41 (A)

Q.42 (C) $V_{rms}=\frac{V_o}{\sqrt{2}}$ **Q.43 (A) Q.44 (C) Q.45 (A)** $X_c=\frac{1}{2\pi fc}$

Q.46 (D) Q.47 (B) $X_L=2\pi fL$ **Q.48 (B) Q.49 (B) Q.50 (A)**

UNIT 13

Physics of Solids

Crystalline Solids:

Solids whose constituent particles (atoms, ions or molecules) are arranged in an orderly manner throughout in three dimensional patterns are called crystalline solids

- There is regular arrangement of molecules in crystalline solids.
- Examples are copper, iron and zinc Ionic compounds such as sodium chloride ceramics such as zirconia are crystalline.
- Crystalline structure can be determined by X-rays diffraction.
- Vibrational K.E of particles depends upon temperature.
- Every crystalline solid has a definite (sharp) melting point.

Did You Know?

- Solids tend to keep their volume and shape
- Liquids tend to keep their volume but not their shape
- Gases tend to keep neither their volume nor their shape

Amorphous or Glassy Solids:

Solids whose constituent particles (atoms, ions or molecules) are not arranged in an orderly manner are called crystalline solids

- There is no regular arrangement of molecules.
- Glass is an example.
- These solids have no definite melting point.

Polymeric Solids:

Solids whose constituent particles (atoms, ions or molecules) have structure that is intermediate between order and disorder manner are called polymeric solids

- These are partially arrangement of molecules.
- These solids have three dimensional ling chain molecules which are obtained by polymerization.
- These materials have low specific gravity compared with even the lightest of metals and they exhibit good (high) strength –to-weight ratio.
- These solids consist of carbon with oxygen, hydrogen, nitrogen and other metallic or non metallic elements.
- Examples are Plastic, polythene, nylon etc.

> **Did You Know?**
> Glass is also known as solid liquid it molecules are irregularly arranged as in a liquid but fixed in their relative positions.

Crystal Lattice:

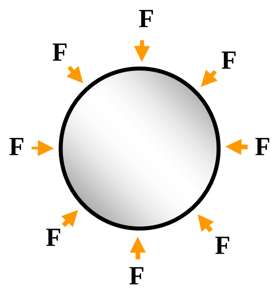
The smallest three dimensional basic structures is called unit cell and the whole structure obtained by the repetition of unit cell is known as crystal lattice.

MECHANICAL PROPERTIES OF SOLIDS

Properties of materials in response to applied stress are termed as mechanical properties

Deformation in solids:

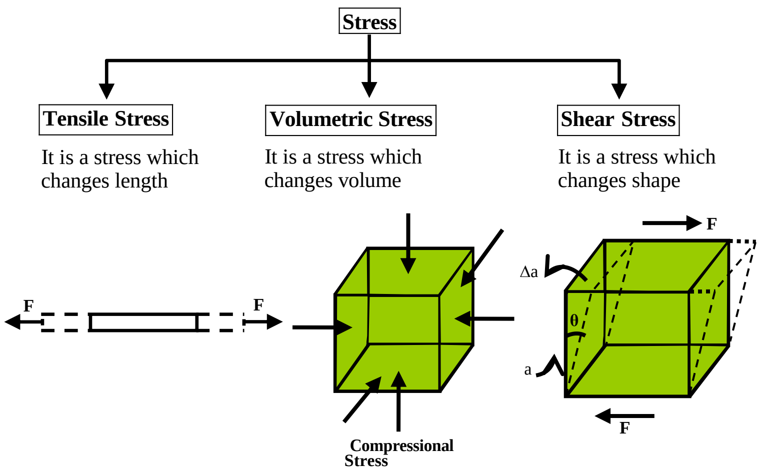
- Deformation is the change in length, volume or shape of a solid dye to an external force.



- ***Elasticity*** is the property of a solid to return to its original length, volume or shape after the removal of an external force is called

Stress:

It is defined as the force applied on unit area to produce any change in the length, shape or volume of a body $\sigma = \frac{F}{A}$



Tensile stress is the stress set up in a body if there is increase in length of the body in the direction of the applied force.

Compressive stress is the stress set up in a body if there is decrease in length of the body due to applied force.

Tangential stress or shear stress is the force per unit area if the deforming force is applied parallel to the surface over the body.

Strain:

"It is the measure of deformation in a solid"

Strain

- Tensile stress $= \frac{\Delta l}{l}$
- Volumetric Strain $= \frac{\Delta V}{V}$
- Shear Stress $\frac{\Delta a}{a} = \tan\theta$

Where θ = measure of deformation of a face of crystal,

Δa = Shift in area of a face of crystal,

a = Original area of a face,

- Strain is dimensionless

Did You Know?

- All types of stress have same formula but different types of strains have different formulae.
- Stress is the measure of deforming force and strain is the measure of deformation.

Modulus of Elasticity:

- Modules of elasticity $= \frac{Stress}{Strain}$ provided external applied

Force is not too great i.e, it obeys Hooke's law

Modulus of Elasticity

- Young's Modulus: $\mathbf{Y} = \frac{F/A}{\frac{\Delta l}{l}}$
- Bulk Modulus: $K = \frac{F/A}{\Delta V/V}$
- Shear Modulus: $G = \frac{F/A}{\tan\theta}$

Did You Know?

SI unit of modulus of elasticity is same as that of stress.

Did You Know?

Shear modulus is also called modulus of rigidity.

Modulus of elasticity

- It depends upon the material of object.
- If it has large value for some material, it means a large stress will produce only a small strain.
- Greater the modulus of elasticity of a material body, the harder it is to change its size or shape and vice-versa.
- It is property of material and remains same even though a material may be fashioned in different shapes

Compressibility:

The compressibility of a material is a measure of how easily the material is compressed

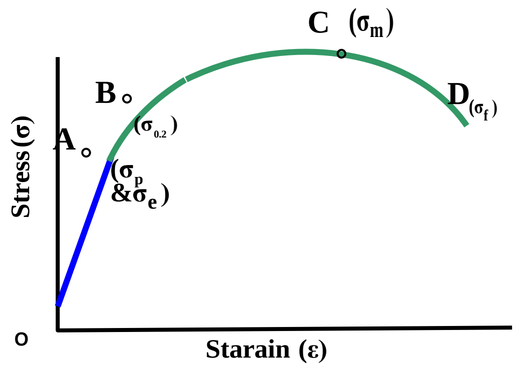
- In other words, compressibility is just the reciprocal of bulk modulus i.e.,

$$\text{Compressibility, } c = \frac{1}{K}$$

- The bulk moduli of solids and liquids are very large indicating the fact that large forces are needed to produce even minute change in volume.
- Gases are more easily compressed and have corresponding smaller bulk moduli. Thus greater the bulk modulus (K) of a material, the harder it is to changes its volume
- The SI unit of compressibility is $N^{-1}\,m^2$ or Pa^{-1} (i.e., the reciprocal of unit of K) Solids and liquids are relatively incompressible i.e., they have small values of compressibility (c) or large values of bulk modulus (K) and these values are almost independent of temperature and pressure.
- Gases are easily compressed (small c and large k) and the value of c and k strongly depend on the pressure or temperature.
- A liquid or gas flows under the influence of a shear stress and cannot permanently support such a stress.
- The shear modulus is roughly one-third the value of Young's modulus for the same solid material. For example, Young's modulus for steel is 20×10^{10} N/m², whereas shear modulus for steel is 8×10^{10} N/m².

STRESS-STRAIN CURVE

- To study the mechanical properties of solids and their appropriate use a machine called UTM and check the response of materials.



- From O to A stress ∝ strain (Hooke's Law is obeyed).
- At point A, we have proportional limit is σ_e .It is the greatest stress that a material can endure without losing straight line proportionality.
- For all practical purposes, elastic limit σ_e or yield stress and proportional limit σ_p are identical . σ_e is the greatest stress that a material can endure without any permanent change in shape or dimensions. Temporary or elastic deformation is from O to B , B is the yield point.
- After σ_e ,the specimen undergoes permanent or plastic deformation .
- At point C, σ_m or UTS is the ultimate tensile stress .It is the maximum stress that a material can withstand and is also called the nominal strength of material.
- The material breaks at point D and stress at this point is fracture stress σ_f.
- Elastic limit differs widely for different solid materials. It is high for a material like steel and low for a material like lead.

Did You Know?

Elastic limit differs for different materials. It is high for substances like steel and low for substances like lead.

Toughness and stiffness

- The toughness (plastic or flexible) of a material is a measure of its ability to resist crack growth. This is not to be confused with strength. Plasticine, for example, is a tough material but not strong. Glass is much stronger than plasticine but not as tough.
- The **stiffness** (brittle or non flexible) of a material is a measure of its resistance to plastic deformation.

Types on basis of mechanical properties

Ductile Substances

These substances undergo plastic deformation until they break e.g., lead, copper and wrought iron

Brittle Substances

These substances break just after the elastic limit e.g., glass and high carbon steel

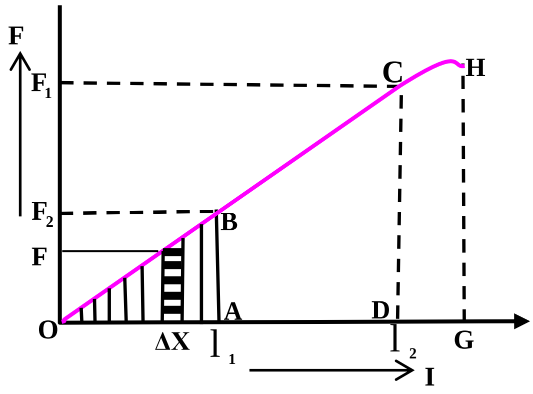
STRAIN ENERGY IN DEFORMED MATERIALS

"It is the P.E stored in the molecules of a deformed solid and it is equal to the work done by deforming force"

Strain energy is given as

$$\mathbf{W = \frac{1}{2}\frac{EA\times l^2}{L}}$$

Force extension graph



Where E = Modulus of elasticity

A = Cross sectional area if wire

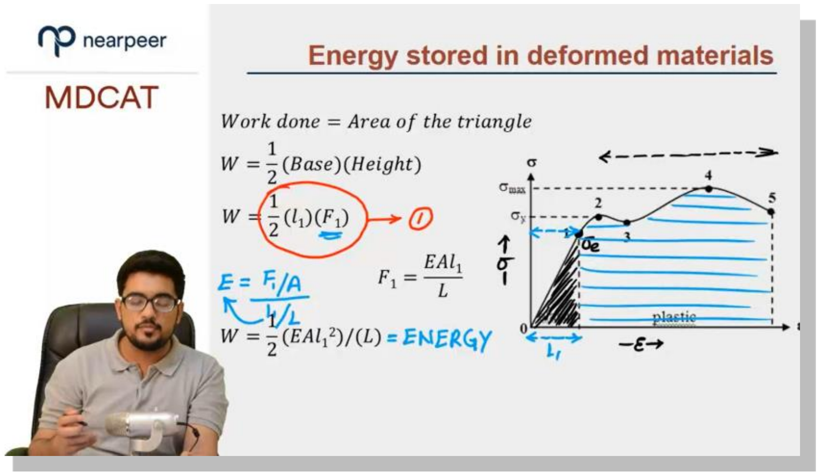
l = Change in length

L = Original length

Strain energy density is given as

$$\textbf{Strain energy density} = \frac{1}{2}\,\textbf{stress}\times\textbf{srain}$$

- The above formula is applicable in both elastic and non-elastic regions.



Did you know? This lecture is completely explained in **nearpeer.org** online **MDCAT** course (video 13.03)

Did You Know?

When external deforming forces are removed, the stored elastic energy gets released usually in the form of vibrational K.E or heat.

Electrical Classification of Solids

Conductors

High conductivities e.g.,metals with conductivities of the order of $10^7\ (\Omega m)^{-1}$

Insulators

Very low conductivities ranging between 10^{-10} and $10^{-20}\ (\Omega m)^{-1}$ e.g., wood, diamond etc.

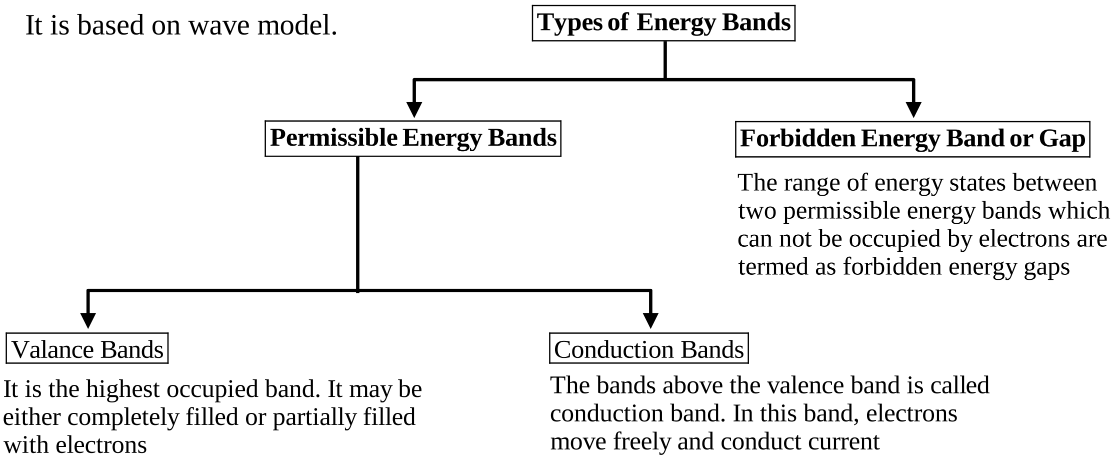
Semiconductor

Intermediate conductivities from 10^{-6} to $10^{-4}\ (\Omega m)^{-1}$ e.g., silicon, germanium etc.

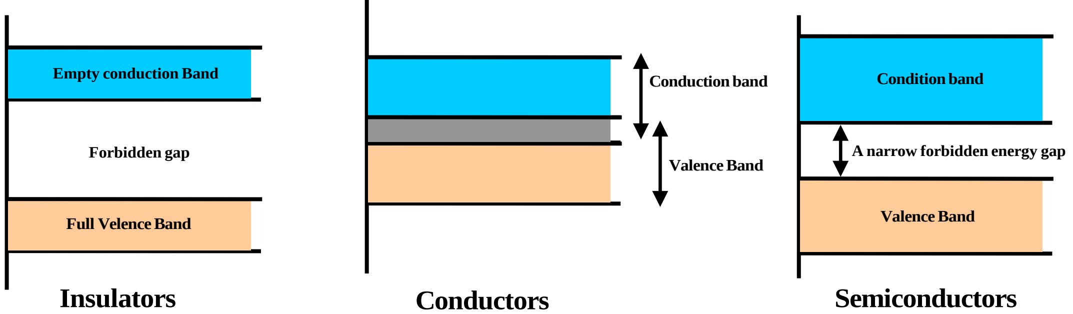
ENARGY BAND THEORY:

“The range of energies possessed by an electron in a solid is known as energy band”

- It is based on wave model.



Material	Conduction Band	Valence Band	Energy Gap between Valence and conduction Band
Insulator	Empty(No Free electron)	Full	A large energy gap of several eV
Conductor	Partially filled	Partially filled	No energy gap
Semiconductor	Partially filled	Partially filled	Narrow energy Gap



Insulators **Conductors** **Semiconductors**

- A solid can be treated as a densely packed system obtained by bringing together isolated single atoms. An isolated single atom possesses a number of discrete energy levels that can be occupied by electrons of the atom. Ordinary, the electrons exist in the ground state, and excited electrons can shift to higher energy levels.
- Usually only the valence electrons can participate in these excitations. When two atoms interact, each previous single energy level is split into two levels. For N atoms, the splitting is N-times. In case of solids N is very large; the number of splitting is very large.
- Since the value of energy for different level splitting remains approximately the same, the overall effect of bringing a large number of atoms is to form bands of continuous energy levels, separated by gaps where no electron states exist. The gap is called forbidden energy gap.

Extrinsic Semiconductors

n – type substances

Obtained by mixing tetravalent Si or Ge with pentavalent impurity (donor) e.g., Phosphorus

Majority charge carries are electrons.

Minority charge carries are holes

p – type substances

Obtained by mixing tetravalent Si with trivalent impurity (acceptor) e.g., Aluminum

Majority charge carries are holes.

Minority charge carries are electrons

Electrical Conduction in Semiconductors

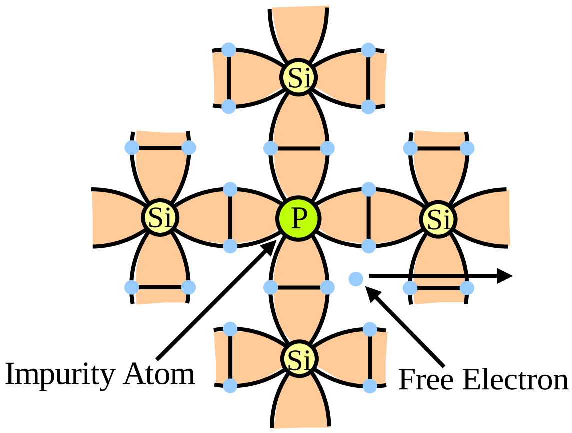
Intrinsic Semiconductors

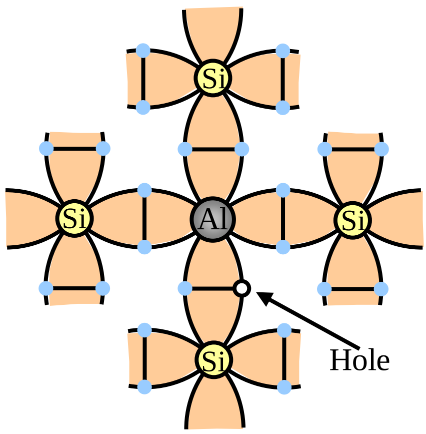
Conduction is due to electron-hole pair

$I_{(total)} = I_{(electrons)} + I_{(holes)}$

Extrinsic Semiconductors

Conduction depends upon doping level

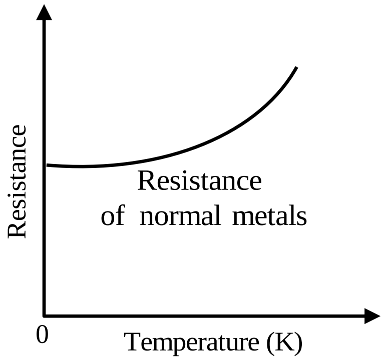




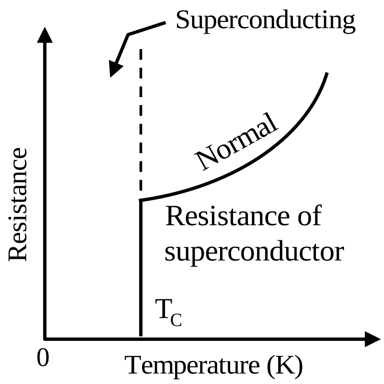
SUPERCONDUCTORS

The metals and compounds whose resistivity goes to zero below a certain temperature T_C called critical temperature (or transition temperature) are known as superconductors.

- This phenomenon of zero resistance of some metals and compounds when cooled to critical temperature is called superconductivity.
- At present, the problem with using the materials listed in the table for practical applications is that we must use liquid helium to cool them into the superconducting state. Liquid helium is expensive and supplies are limited.
- Fig.(i) shows resistance-temperature graph for normal metals whereas Fig (ii) shows resistance-temperature graph for a superconductor. Note that resistance-temperature graph for a superconductor follows that for a normal metal at temperature above T_C (critical temperature). When the temperature is at or below T_C, the resistance drops suddenly to zero.



i



ii

- Recent measurements have shown that resistivities of superconductors below are less than 4×10^{-25} Ω m which is around 10^{17} times smaller than the resistivity of copper?
- One of the remarkable features of superconductors is that once a current is set up in the material, the current will persist without any applied voltage (since R = 0).
- The critical temperature is sensitive to chemical composition, pressure and crystalline structure.

Applications of superconductors:

The scientists are making continuous efforts to produce room-temperature superconductors. Once this goal is achieved, the superconductivity will offer the following uses.

- It will offer the possibility of loss-free transmission of electric power. It is because superconducting transmission lines would have zero resistance.
- It will help for the construction of superconducting magnets in which the magnetic field intensities would be about 10 times greater than those of the best normal electromagnets.
- A superconducting computer would be smaller and faster than today's computers.
- Superconductors are used in magnetic resonance imaging (MRI) which makes use of the property of Nuclear magnetic resonance (NMRI) to image nuclei of atoms inside the body.

Types of Superconductors

Low Temperature

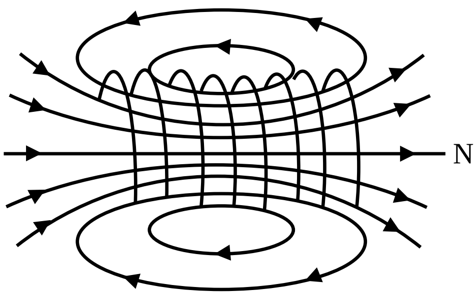
$T_C < 77$ K
e.g., aluminum ($T_C = 1.18$ K)
Tin ($T_C = 3.72$ K)

High Temperature

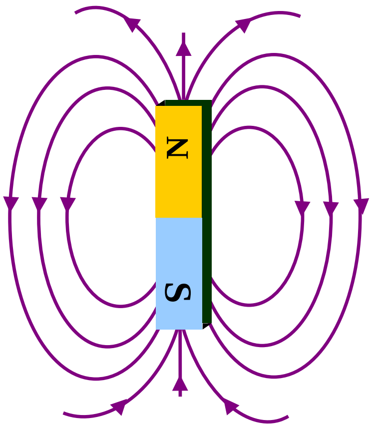
$T_C > 77$ K
Some ceramic materials have
$T_C = 125$ K
YBa_2Cu_3O have $T_C = 163$ K

MAGNETIC PROPERTIES OF SOLIDS

- The origin of magnetism is moving charge (current) i.e., spin and orbital motion of electrons.
- Charged nucleus itself spins giving rise to a magnetic field.
  However, it is much weaker than that of orbital electrons.
- An insolated north pole is impossible. The north-pole is merely one side current loop. The other side will always be present as a south pole and these not be separated.



Solenoid



Long bar magnet

Magnetic Classification of Solids

- **Diamagnetic Substance** → These are substances in which atoms do no behave like magnetic dipoles e.g., water,copper and bismuth etc.
- **Paramagnetic Substance** → These are substance in whcih fields of orbital and spin motion of electrons add up so that atoms behave as magnetic dipoles e.g., platium, ozone etc.
- **Ferromagnetic Substance** → These are substances in which atoms co-operate to exhibit strong magnetic effect e.g., iron, steel, nickel etc

- **Diamagnetic substances** are substances which when placed in an external magnetic field are weakly magnetized in a direction opposite to that of the applied external magnetic field e.g. bismuth, copper, zinc, silver, gold, air, water, hydrogen etc.

- It may be noted that a diamagnetic substance loses its magnetism as soon as the external magnetic field is removed
- Cause of diamagnetism is that each electron in an atom is revolving in an orbit around the nucleus. This revolving electron is equivalent to a tiny current loop
- **Paramagnetic substances** are substances which when placed in an external magnetic field are weakly magnetized in the direction of applied external magnetic field e.g., aluminum, antimony, chromium, lithium, oxygen, copper chloride, sodium, tungsten etc.
- A paramagnetic substance is feebly attracted by a strong magnet. It is a because paramagnetic substance develops weak magnetization in the direction of the applied external magnetic field.
- In a paramagnetic substance, the individual atom/ molecule/ ion has circulating current that is not zero.
- **Ferromagnetic substances** are substances which when placed in an external magnetic field are strongly magnetized in the direction of the applied external magnetic field e.g. iron, nickel, cobalt etc.
- Since the strong induced magnetic field is in the direction of the applied magnetic field, the resultant magnetic field inside the ferromagnetic substance is very large; often thousands times greater than the external field.
- When external magnetic field is removed, some ferromagnetic substances retain magnetism. Ferromagnetic substances show all the properties of paramagnetic substances but to a much greater degree.
- A ferromagnetic substance is strongly attracted by a magnet.
- Ferromagnetic substances have small regions called domains. The domains size is of the order of millimeters or less but large enough to contain 10^{12} to 10^{16} atoms. Each domain behaves as a small magnet.
- Ferromagnetic materials preserve the orderliness at ordinary temperature. When heated, they begin to lose their orderliness due to the increased thermal motion.
- This process begins to occur at a particular temperature called Curie temperature (Different for different materials).
- Above the Curie temperature, iron is paramagnetic but not ferromagnetic. The curve temperature for iron is about 750^0C.

Ferromagnetic Material

Soft Material

Its domains are easily oriented on applying an external field and also readily return to random positions when the field is removed i.e., they can be magnetized and demagnetized easily e.g., soft iron

Hard Material

Its domains are not easily oriented on applying an external field and do not return to their random positions when the field is removed i.e., they can not be magnetized and demagnetized easily e.g., steel, Alinico-V etc.

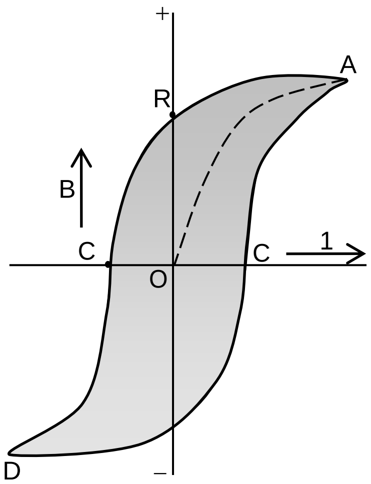
HYSTERESIS LOOP

The phenomenon of lagging of magnetism behind the magnetizing current in ferromagnetic materials when subjected to cycles of magnetization is called hysteresis.

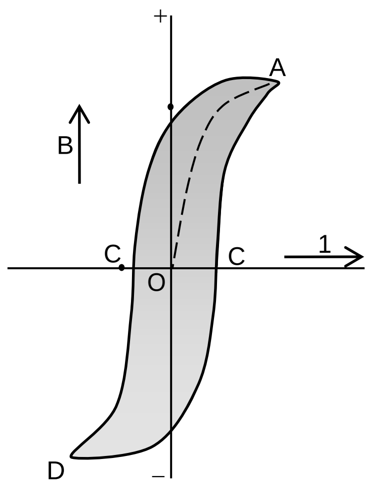
- Hysteresis loop is a graph between magnetizing current I and magnetic field B (flux density) due to orientation (alignment and de-alignment) of domains.
- It shows the magnetic properties of ferromagnetic materials.
- Saturation property of ferromagnetic material (points A) is due to maximum alignment of domains.
- Property of domains to retain their alignment even thought the magnetizing current become zero, is called retentivity or remenance.
- Reverse current OC which is required to demagnetize the material i.e, to make the field of domain equal to zero is called the coercive current and this property is called coercivity.
- Lagging of B behind I (when both are going towards their zero value) is called hysteresis. Reverse is the case when B and I are increasing.

HYSTERESIS LOSS:

- When a ferromagnetic material is subjected to cycles of magnetization, the domains of the material resist being turned first in one direction and then in the other direction. Energy is thus expended in the material to overcome this opposition. This loss is in the form of heat and is called hysteresis loss.
- Hysteresis loss is present in all those electrical machines whose iron parts are subjected to cycles of magnetization. The obvious effect of hysteresis loss is the rise of temperature of the machine.



Hysteresis loop of steel



Hysteresis loop of soft iron

IMPORTANCE OF HYSTERESIS LOOP:

- The shape and size of hysteresis loop largely depends upon the nature of the material. The choice of a ferromagnetic material for a particular application often depends upon the shape and size of the hysteresis loop Figures show the hysteresis loops of soft iron and steel. We can draw the following conclusions about the magnetic properties of the substances from the shape and size of the loops:
- The area of hysteresis loop for soft iron is much smaller than that for steel. Therefore, the hysteresis loss in soft iron is smaller than that in steel. For this reason, soft iron is used for making transformer cores.

- The retentivity of soft iron (OB′) is greater than the retentivity of steel (OB). Therefore, soft iron is more strongly magnetized than steel.
- The coercitivity of soft iron (OC′) is less than the coercivity of steel (OC). Therefore, residual magnetism in steel cannot be destroyed that easily an in case of soft iron.
- Area of Hysteresis Loop $\Rightarrow$ Work done against friction of domains for magnetizing current or by external field.
- Soft iron has less retentivity, coercivity and hysteresis loss. So it is used as cores of transformer to reduce hysteresis loss.
- Steel has greater hysteresis loss it is used as core of an electromagnetic it has large retentivity and coercivity.

Did You Know?

- Squids (or super-conducting quantum interference devices) are used to detect very weak magnetic fields such as produced by brain.
- Magnetic materials made out of organic materials could be used in optical disks and components in computers, mobile phone, TVs, motors, generators and data storage devices. Circuit can make use of ceramic magnets that do not conduct electricity

Magnetic Levitation Train

Magnetic levitation or magnetic suspension is a method by which an object is suspended with no support other than magnetic fields. Magnetic pressure is to counteract the effects of the gravitational and any magnetic levitation trains which travel with very high velocity as compared to conventional trains. This is due to the fact that these trains only have to overcome the air drag forces.

PRACTICE QUESTIONS

Q.1 A large modulus of elasticity for a material means

A) A larger stress will produce a larger strain in it
B) A larger stress will produce only a smaller strain in it
C) A smaller stress will produce a smaller strain in it
D) It will be easy to change its shape

Q.2 Measure of deforming force on a material is called

A) Stress
B) Strain
C) Young's modulus
D) None of these

Q.3 The tendency of domains to stay partly in line, once they have been aligned is

A) Saturation
B) Coercivity
C) Hysteresis
D) Remanence

Q.4 The product of dimensions of Young's modulus and strain are

A) $[ML^2T^{-1}]$
B) $[ML^{-1}T^2]$
C) $[ML^{-1}T^{-2}]$
D) $[ML^2T^{-3}]$

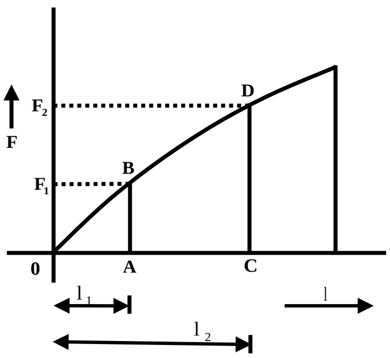
Q.5 Radii and lengths of two different wires of the same material are both in ratio 1:3. If the extension in both wires is same then the ratio of stretching forces on the two wires is

A) 1:3
B) 3:1
C) 2:1
D) 1:2

Q.6 The process of doping causes resistivity of semiconductors to

A) Decrease
B) Remain same
C) Increase
D) Become zero

Q.7 Force extension graph is shown in the figure if l_1 = 4.0 cm, l_2 = 8.0 cm, F_1 = 20 N, F_2 = 45 N then the work done to produce extension from l_1 to l_2 is



A) 1.03 J
B) 1.3 J
C) 1.125 J
D) None of these

Q.8 **A wire 1.0 mm in radius is fastened to a log and then pulled by tractor. The length of the wire between the log and the tractor is 50 m. If a force of $\pi \times 10^3$ N is required to pull the log then stress in the wire would be**

A) 1.0×10^6 kPa
C) 1.5×10^2 MPa
B) 5×10^6 Pa
D) None of these

Q.9 **It is revealed from experiments that young's modulus of a wire is equal to stress necessary to make the length of wire**

A) 2 times
C) 3 times
B) $\frac{1}{2}$ times
D) 4 times

Q.10 **Compressibility of a material (choose incorrect)**

A) Is the measure how easily a material can be compressed
B) Has the units of Pa^{-1}
C) Is the reciprocal of young's modulus
D) None of these

Q.11 **Solids having resistivities 10^{5} Ω m should be**

A) Conductors
C) Insulators
B) Semiconductors
D) Superconductors

Q.12 **If Y_g and Y_r are young's moduli of glass and rubber respectively and it is said that glass is more elastic than rubber, then it follows**

A) $Y_g = Y_r$
C) $Y_g > Y_r$
B) $Y_g < Y_r$
D) None of these

Q.13 **The work done in increasing the length of 1m long wire of cross sectional area 1 mm^2 through 1 mm will be (if Y = 2×10^{11} Nm^{-2}**

A) 10.1 J
C) 10 J
B) 0.1 J
D) 250 J

Q.14 **Two steel wires of lengths 1 m and 2 m have radii 1 mm and 2 mm respectively. If they are stretched by forces of 40 N and 80 N respectively, then the ratio of their elongations is**

A) 1 : 2
C) 2 : 1
B) 1 : 4
D) 1 : 1

Q.15 **In intrinsic semiconductor at 0ºC**

A) Number of free electrons is greater than number of holes
B) Number of holes is greater than number of free electrons
C) Number of free electrons is equal to number of holes
D) No free electrons and holes are available

Q.16 **The force required to stretch a steel wire 2 cm^2 in cross–section to double of its length if (Y= 2×10^{11} N/m^2)**

A) 4×10^7 N
C) 2×10^7 N
B) 1×10^7 N
D) 8×10^7 N

Q.17 A 30 m long wire is subjected to stretching force and its length increases by 15 cm. The % age elongation which the wire undergoes

A) 0.5 % C) 2.5 %

B) 0.25 % D) 5.0 %

Q.18 In semiconductors the movement of holes takes place in

A) Valence band only C) Both valence and conduction band

B) Conduction band only D) None of these

Q.19 The Young's modulus of a perfectly rigid body is

A) One C) Infinite

B) Zero D) None of these

Q.20 Which one of the following is suitable for making the core of transformer?

A) Copper C) Steel

B) Iron D) All of these

Q.21 Young's modulus of a wire with increase in temperature

A) Decreases C) Remains constant

B) Increases D) first increases then decreases

Q.22 The semiconductor in which current flows only due to the breakage of covalent bonds

A) Intrinsic C) p-type

B) n-type D) All of these

Q.23 A wire is stretched to double of its length, strain in wire will be

A) 1 C) $\frac{1}{2}$

B) 2 D) 3

Q.24 Which one of the following can not show plastic deformation?

A) Lead C) Wrought iron

B) Glass D) Both A and C

Q.25 Bonding in Germanium crystal is

A) Metallic C) Covalent

B) Ionic D) Coordinate covalent bond

Q.26 Gases can not have

A) Bulk modulus C) young's modulus

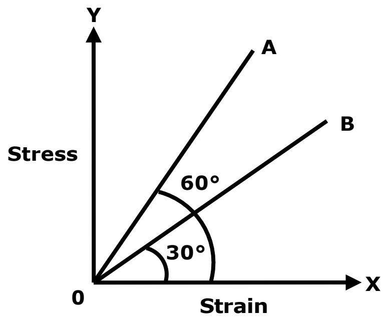
B) Shear modulus D) Both B and C

Q.27 Which one of the following has ratio of young's modulus and bulk modulus equal to 5:4?

A) Diamond C) Copper

B) Steel D) Ice

Q.28 The stress versus strain graphs for wires of two materials A and B are as shown in the figure. If Y_A and Y_B are the Young's modulii of the materials, then



A) $Y_B = 2Y_A$ C) $Y_B = 3Y_A$

B) $Y_A = Y_B$ D) $Y_A = 3Y_B$

Q.29 Rubber has less elastic modulus than steel because for a given load the strain produced in rubber as compared to that produced in steel is

A) Less C) Equal

B) More D) Nothing can be said

Q.30 If length of wire increases by 1 % on stretching then its tensile strain is

A) 0.01 C) 0.1

B) 1.0 D) 10

Q.31 The source of magnetism in an atom is

A) Spin of nucleus C) Orbital motion of electrons

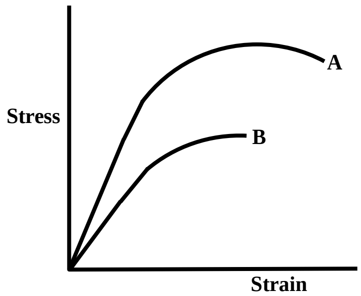
B) Spin motion of electrons D) Both B and C

Q.32 The ratio of young's modulus of concrete to that of bone is

A) 3: 5 C) 2: 5

B) 5: 3 D) 5: 2

Q.33 Stress strain curve for two materials is shown in Fig. Which one is more brittle?



A) A C) Both have equal brittleness

B) B D) Data is insufficient

Q.34 $\frac{1}{2}\varepsilon\sigma =$ **…………… where ε = strain, σ = stress**

A) Strain energy C) Stress strain energy

B) Strain energy density D) Modulus of elasticity

Q.35 According to Hook's law, within the elastic region if stress is increased, then the ratio of stress to strain

A) Increases C) Decreases

B) Becomes zero D) Remains constant

Q.36 Substances in which the orbits and the spin axes of the electrons in an atom are so oriented that their magnetic fields cancel each other

A) Ferromagnetic substances C) Diamagnetic substances

B) Paramagnetic substances D) Magnetic substances

Q.37 A body of weight 'mg' is hanging on a string, which extends its length by l **. The work done in extending the string is**

A) mgl C) 2mgl

B) $\frac{1}{2}mgl$ D) $\frac{1}{2}mgl^2$

Q.38 The materials in which neighboring atoms react on one another so that all their magnetic axes are lined up in the same direction even when there is no external magnetizing field

A) Paramagnetic C) Ferromagnetic

B) Diamagnetic D) Soft ferromagnetic

Q.39 Which one of the following is a solid which is known as liquid solid?

A) Copper C) Steel

B) Glass D) Rubber

Q.40 Units of stress are same as that of the units of

A) Elastic constants C) $\frac{\text{Stress}}{\text{Strain}}$

B) Reciprocal of compressibility D) All of these

Q.41 If regular displacement of any face of a cube is 45^0, then shear strain is

A) 0.5 C) 1.5

B) 1 D) 0.866

Q.42 Permanent deformation produced in a solid is also called

A) Rubber deformation C) Plastic deformation

B) Nylon deformation D) Elastic deformation

Q.43 If a wire of length 1 m and cross-sectional area 1 m^2 is elongated such that its change in length is 0.1 m and its Young's modules is $2\times10^6 Nm^{-2}$,then strain energy stored in It is

A) 1×10^2 J C) 1×10^4 J

B) 1×10^3 J D) None of these

Q.44 Which of these solids is also known as liquid solid?

A) Copper C) Glass

B) Steel D) Rubber

Q.45 Insulator is

A) A full valence band

B) An empty valence band

C) An empty valence or partially filled valence band

D) Partially filled valence band

Q.46 Which of these is an acceptor impurity?

A) Indium C) Aluminum

B) Gallium D) All of these

Q.47 The minority change carries in p-type substance are

A) Electrons C) Positives charges

B) Holes D) All of these

Q.48 MRI means

A) Maximum resonance imaging C) Maximum resonance imaging

B) Magnetic resonance imaging D) Magnetic resonance imaging

Q.49 For permanent magnets, which material is used?

A) Steel C) Copper

B) Soft iron D) Bismuth

Q.50 The curie temperature for iron is

A) 450^0C C) 650^0C

B) 550^0C D) 750^0C

Q.51 The lagging of B behind I (when both are going to zero) is called

A) Saturation C) Hysteresis

B) Resonance D) Coercivity

Q.52 Reverse current which demagnetizes the ferromagnetic material is called ----------current

A) Retentive C) Coercive

B) Coercivity D) Hysteresis

Q.53 The atoms is a solid are held together by

A) Adhesive C) Solid forces

B) Cohesive D) Resistive forces

Q.54 A cable that suppose a load W cut into two equal parts. The maximum load that can be supported by either part is

A) W C) 2W

B) W/2 D) W/4

Q.55 Materials that undergo plastic deformation before breaking are called

A) Polymeric C) Ductile

B) Brittle D) Amorphous

Q.56 The Young's modules of wire of length L and radius r is Y . If the length is reduced to L /2 and radius to r/2 , its Young's modules will be

A) Y C) 2Y

B) Y/2 D) 4Y

Q.57 Substance whose atoms do not form magnetic dipole are

A) Ferromagnetic C) Diamagnetic

B) Paramagnetic — D) All of these

Q.58 In an extrinsic semiconductor, the ratio of impurity atoms to that of Si/Ge atoms is called

A) $1:10^7$ — C) $1:10^6$

B) $1:10^8$ — D) $1:10^9$

Q.59 MRI is preferred over CT because, it

A) Differentiate between soft and hard tissue — C) Does not involve any ionizing radiation

B) Is useful for heart and brain scanning — D) All of above

Q.60 Which of these solids have no definite melting point?

A) Crystalline — C) Polymeric solids

B) Amorphous — D) Long chain molecules solids

ANSWERS WITH EXPLANATION

Q.1	**(B)**	**Q.2**	**(A)**	**Q.3**	**(A)**	**Q.4**	**(C)**	**Q.5**	**(A)**	$\frac{F_1}{F_2}=\frac{r_1^2}{r_2^2}\times\frac{l_2}{l_1}$	
Q.6	**(A)**	**Q.7**	**(B)**	Area under the curve				**Q.8**	**(A)**	$q=\frac{F}{A}$	
Q.9	**(A)**	$y=\frac{\sigma}{\varepsilon}$		**Q.10**	**(C)**	**Q.11**	**(B)**	**Q.12**	**(C)**		
Q.13	**(B)**	$E=\frac{1}{2}\frac{EAl_1^2}{L}$		**Q.14**	**(D)**	**Q.15**	**(C)**	**Q.16**	**(A)**	**Q.17**	**(A)**
Q.18	**(A)**	**Q.19**	**(C)**	**Q.20**	**(B)**	**Q.21**	**(A)**	**Q.22**	**(A)**	**Q.23**	**(A)**
Q.24	**(B)**	**Q.25**	**(C)**	**Q.26**	**(D)**	**Q.27**	**(B)**	**Q.28**	**(D)**	$\frac{Y_A}{Y_B}=\frac{\tan 60°}{\tan 30°}$	
Q.29	**(B)**	**Q.30**	**(A)**	**Q.31**	**(B)**	**Q.32**	**(B)**	**Q.33**	**(B)**	**Q.34**	**(B)**
Q.35	**(D)**	**Q.36**	**(C)**	**Q.37**	**(B)**	$w=\frac{1}{2}Fl$		**Q.38**	**(C)**	**Q.39**	**(B)**
Q.40	**(A)**	**Q.41**	**(B)**	**Q.42**	**(C)**	**Q.43**	**(C)**	**Q.44**	**(C)**	**Q.45**	**(A)**
Q.46	**(D)**	**Q.47**	**(B)**	**Q.48**	**(B)**	**Q.49**	**(A)**	**Q.50**	**(D)**	**Q.51**	**(C)**
Q.52	**(B)**	**Q.53**	**(B)**	**Q.54**	**(A)**	**Q.55**	**(C)**	**Q.56**	**(A)**	**Q.57**	**(C)**
Q.58	**(C)**	**Q.59**	**(D)**	**Q.60**	**(B)**						

UNIT 14 Electronics

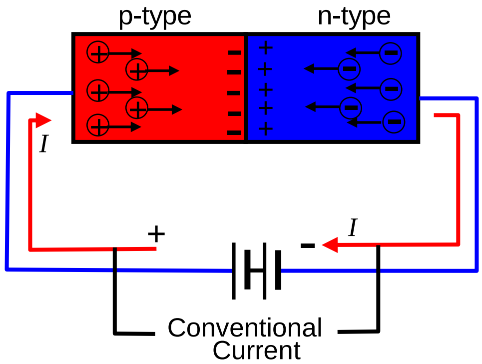
The branch of Physics which deals with the conduction of electricity thorough a gas, vacuum or a semiconductor is called electronics

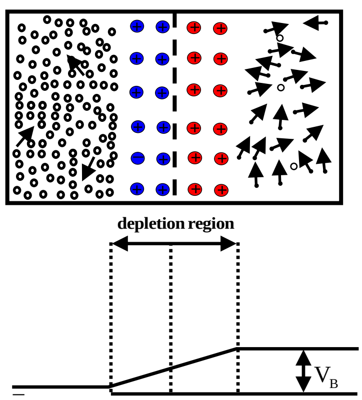
Did You Know?

- P and n type substances are neutral because we dop neutral atoms in them
- P and n type names are because of their majority carriers

P-N JUNCTION:

- The p-type or n-type semiconductor as such has little practical utility. However, when a semiconductor crystal (germanium or silicon) is so prepared that one half is p-type and the other n-type, a usual phenomenon occurs.
- The boundary dividing the two halves in called the p-n junction. Many electronic devices have one or more than one p-n junctions. For example, a semiconductor diode has one pn junction while a transistor has two p-n junctions. The p-n junction is of great importance because it is, in effect, the control element for semiconductor devices.
- If one half of a crystal of germanium or silicon is doped with a trivalent or acceptor impurity like Al, Ga etc. and the other half with a pentavalent or donor impurity like phosphorous, arsenic etc., then a p-n junction is formed.





- Note that a p-n junction cannot be formed just by placing a p-type semiconductor in contact with n-type semiconductor. In fact, p-n junction is formed by special methods. One common method of making p-n junction is called alloying

Formation of Depletion Region and Potential barrier:

- Just after the formation of the junction, majority free electrons in the n-region diffuse into the p-region. A charge less region is formed around the junction in which charge carriers are not present (due to $\vec{E}$ and complete structure) This region is called depletion region.

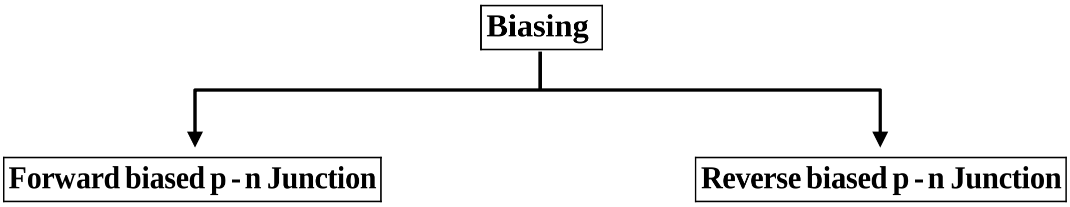
- The ions around the junction develop a potential difference across the depletion region which stops further diffusion. The potential difference is called potential barrier. Its value is 0.7 V for silicon and 0.3 V for germanium.
- Width of the depletion layer is about 10^{-6} m.
- This means that barrier electric field (E) set up by V across the junction is very high

$$E = \frac{V}{d} = \frac{0.7}{10^{-6}} = 7 \times 10^{5}\ \text{Vm}^{-1}$$

- The barrier potential of a p-n junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature.

BIASING A PN JUNCTION:

In electronics, the term bias refers to the use of DC voltage to establish certain operating conditions for an electronic device

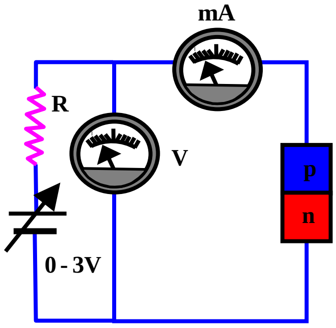


Forward Biased p-n Junction:

When external D.C voltage applied to the p-n junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing.

- P-side terminal is connected to positive terminal and n-side is connected to negative of supply.
- If external voltage is greater than potential barrier, then current flows in the order of mA due to majority charge carriers.
- Forward resistance is given as

$$r_f = \frac{\Delta V_f}{\Delta I_f}$$



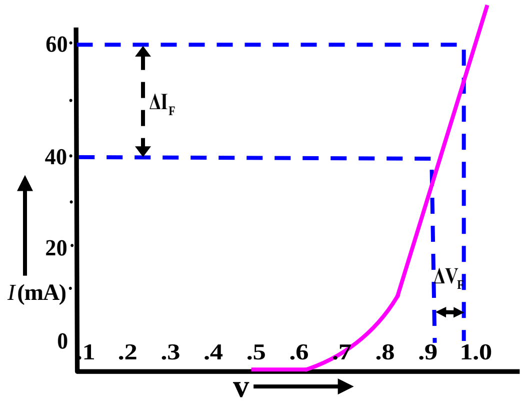
The forward voltage at which the current through the diode starts to increase rapidly with increase in forward voltage is called knee voltage.

- Its value is 0.7 V for silicon and 0.3 V for germanium.

I-V Characteristics during Forward biasing:

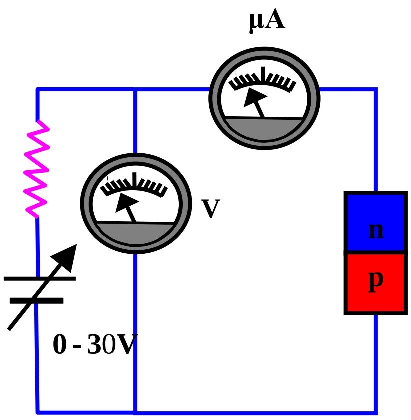
I -V characteristic curve of a. p-n junction is the curve between voltage across the diode and current through the diode

- Below the knee voltage, the curve is non-linear. But once the forward voltage exceeds the knee voltage, the diode behaves like an ordinary Conductor. Therefore, forward current rises sharply with increase in forward voltage). The curve is now almost linear.
- Forward resistance is found from linear portion



Reverse Basic p-n Junction:

When external D.C voltage applied to the p-n junction is in such a direction that potential barrier is increased, it is called reverse biasing.



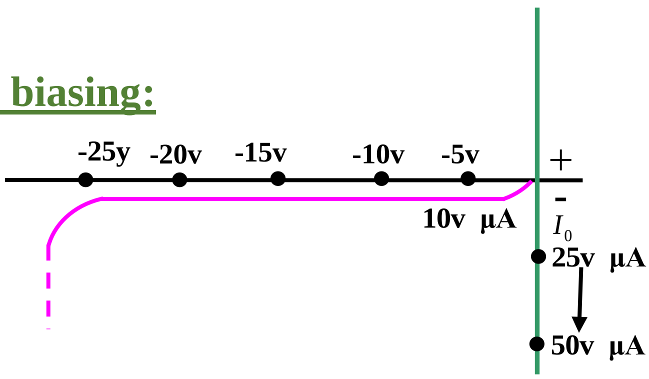
p- side is connected to negative terminal of supply. In this situation, a very small current called reverse leakage current I_0 of the order of a few μA , flows due to minority charge carriers begin to multiply resulting in the break down of junction.

- Now current rises sharply and it damages of junction. This voltage V_0 is called reverse breakdown voltage.

I-V Characteristics during Reverse biasing:

- Reverse resistance is given as

$$r_r = \frac{\Delta V_r}{\Delta I_r}$$

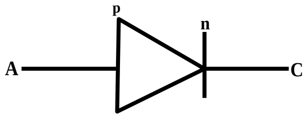


- **p-n junction** behaves as a switch. When the p-n junction is forward biased, it corresponds to closure of switch and current flows in the circuit.
- When the p-n junction is reverse biased, it corresponds to opening of switch and no current flows in the circuit.
- This switching action of diode permits it to be used as a rectifier
- A p-n junction is commonly called a semiconductor diode or crystal diode.
- p-n junction is grown out of a crystal diode instead of p-n junction.

P-N Junction Diode:

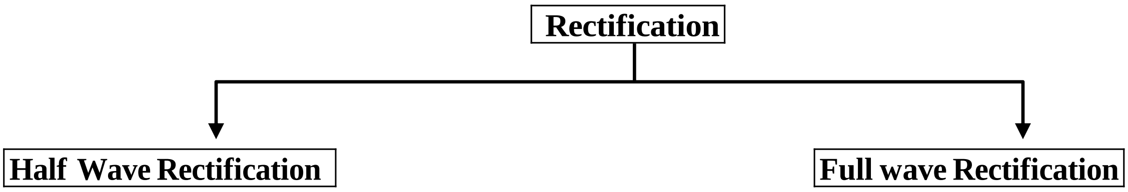
A two terminal unidirectional semiconductor device is called a diode

- **Its shown below**



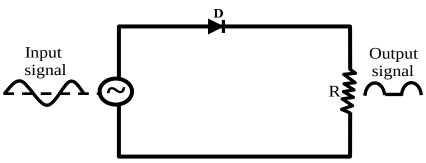
RECTIFICATION

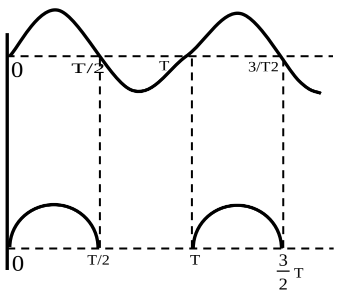
Conversion of A.C into D.C is called rectification, and device (diode) used for this purpose is called Rectifier.



Half- Wave Rectification:

- It uses a single diode, an ac supply and a load resistor R.
- Output appears across R only during positive half cycle of input $\left(0 - \frac{T}{2}\right)$
- Output is zero during negative half cycle $\left(\frac{T}{2} - T\right)$ reverse biased.
- Drawbacks are that average value of DC output drops and pulsation in output waveform appears.

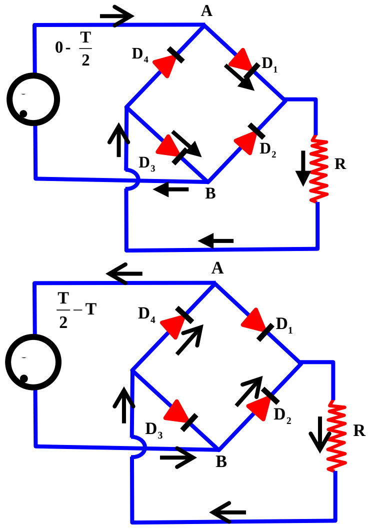




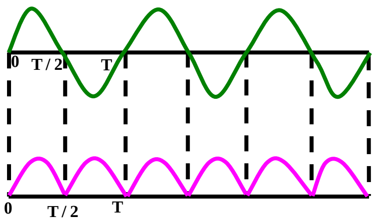
Full Wave Rectification:

Full wave rectifier using four diodes is Bridge rectifier.

Bridge Rectifier:



- Here both halves of the alternating input voltage send a unidirectional current load R.
- During positive half cycle of input, only diodes D_1 and D_3 of the bridge conduct (forward biased).
- During negative half cycle of input, only diodes D_1 and D_2 conduct.
- Output voltage is pulsating and is made smooth by using a circuit known as filter.
- Advantages are that average value of DC does not drop significantly and there are less pulsations as compared to half wave rectification.

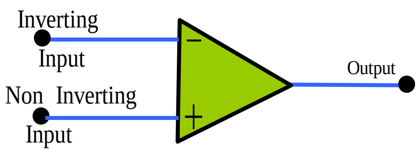


entirely flows in the collector circuit. Therefore, a transistor transfers the input signal current from low-resistance circuit to a high-resistance circuit. This is the key factor responsible for the amplifying capability of the transistor.

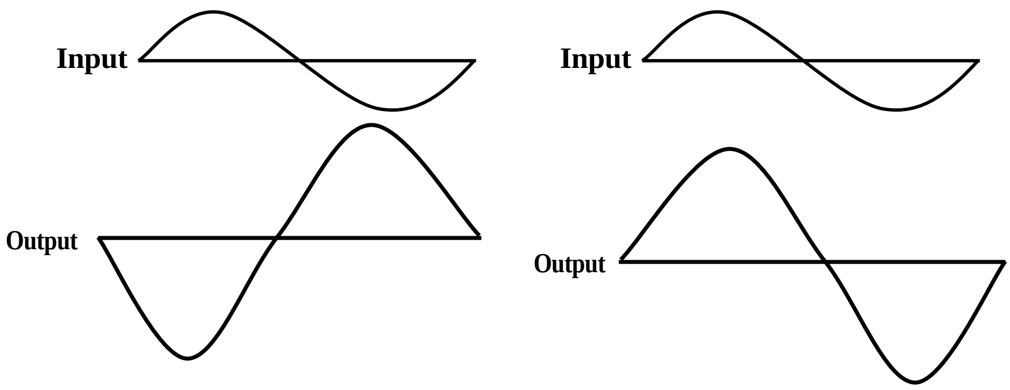
AMPLIFIER

An amplifier is an electronic device that raises the strength of a weak signal

OPETATIONAL AMPLIFIER:

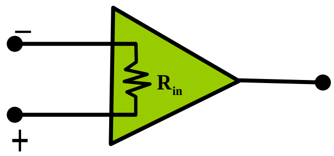


- The whole amplifier circuit integrated o a small silicon and enclosed in a capsule is called an op-amplifier.
- The pins of this amplifier are connected to inputs,
- outputs and power supplies etc
- Such an integrated amplifier is known as operational amplifier (op-amp), is it is sometimes used to perform mathematical operations electronically.
- V_- is inverting input and V_+ is non-inverting input.



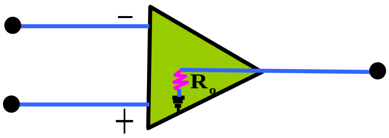
Characteristics of Op-amp:

Input Resistance:



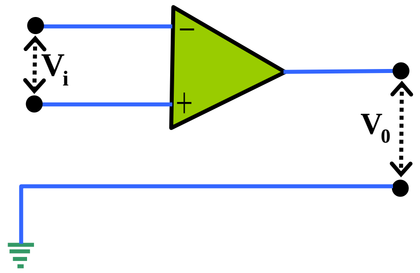
- It is resistance between two inputs of amplifier.
- Its value is of the order of several mega ohms.
- Due to high value of R_{in}, practically no current flows between the two input terminals.

Output Resistance:



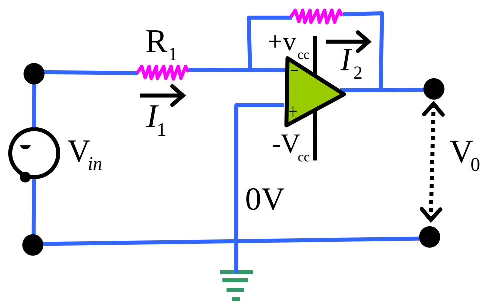
- It is the resistance between the output terminal and ground.
- Its value is only a few ohms.

Open Loop Gain:



- It is the ratio of output V_0 to the voltage difference between non-inverting input V_+ and inverting input V_- when there is no external connection between the output and the inputs.
- It is given by $A_{OL} = \dfrac{V_{OUT}}{V_+ - V_-} = \dfrac{V_0}{V_i}$
- It is very high of the order of 10^5

OP-AMP AS INVERTING AMPLIFIER:



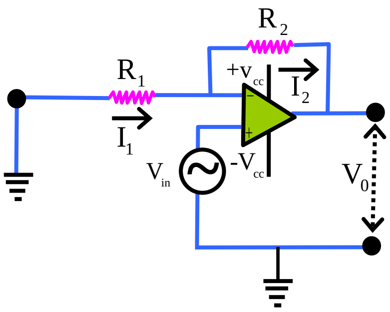
- As open loop gain $= \dfrac{V_0}{V_+ - V_-}$ is Very high so

  $V_+ - V_- \approx 0$ and $V_+ = V_-$
- From figure,
  as $V_+ = 0$ volt (ground) so
  $V_- = 0$ volt (ground)
- As R_{in} is very so $I_1 = I_2$

- Gain is given by $G = \frac{-R_2}{R_1}$

  Negative sign shows that output signal is inverted.
- Closed loop gain G depends upon R_1 and R_2 and is independent of internal structure of op-amp.

OP-AMP AS Non inverting AMPLIFIER:



- In this case $V_+ = V_-$(input)
- Gain is given by $G = 1 + \frac{R_2}{R_1}$

  Positive sign shows that input and output are in phase

PRACTICE QUESTIONS

Q.1 The base of a transistor is

A) P-type
B) n-type
C) Either p-type or n-type
D) Intrinsic semiconductor

Q.2 What is the current in the circuit shown in Fig?

A) 0.1 A
B) 10^{-2} A
C) 1 A
D) 0 A

Q3 When n-type semiconductor is heated, the

A) Number of electrons increases while that of holes' decreases
B) Number of holes increases while that of electrons decreases
C) Number of electrons and holes remains the same
D) Number of electrons and holes increases equally

Q.4 Slope of I – V characteristic curve for a reverse biased diode is

A) 0
B) Infinity
C) 1
D) None of these

Q.5 In a full-wave rectifier, the frequency of the input AC. voltage is 50 Hz. The frequency of the output voltage is

A) 25 Hz
B) 50 Hz
C) 100 Hz
D) None of these

Q.6 The least doped region in transistor is

A) Emitter
B) Base
C) Collector
D) Either emitter or base

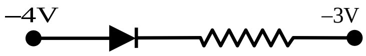
Q.7 On increasing the reverse bias to a large value in a p-n junction, the diode current

A) Remains fixed
B) Increases slowly
C) Decreases slowly
D) Suddenly increases

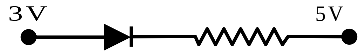
Q.8 For a full-wave rectifier, the minimum number of diodes required is

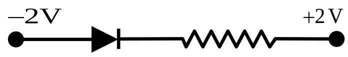
A) 2
C) 4
B) 3
D) 1

Q.9 In Figure shown, the diode which is forward biased

A) 

C) 

B) 

D) 

Q.10 When transistor is used as a switch and the resistance between collector and emitter becomes zero, the transistor switch is

A) Opened
C) Neither open nor closed
B) Closed
D) Can't be decided

Q.11 When NPN transistor is used as an amplifier, then

A) Electrons move from base to collector
C) Electrons move from collector to base
B) Holes move from emitter to base
D) Holes move from base to emitter

Q.12 The non-inverting amplifier has R_2 = 30 kΩ. To obtain a gain of 5 we have a connect R_1 of

A) 6.4 kΩ
C) 0.125 kΩ
B) 7.5 kΩ
D) 8 kΩ

Q.13 In a transistor, if I_B = base current, I_E= emitter current and I_C = collector current then (choose correct)

A) $I_E > I_C$
C) $I_E = I_B + I_E$
B) $I_E > I_B$
D) All of these

Q.14 The width of the depletion region of an unbiased P-N junction is about

A) μm
C) cm
B) mm
D) nm

Q.15 Application of forward bias to a PN junction (Choose incorrect)

A) Widens the depletion zone
B) Increases the potential difference across the depletion zone
C) Increases the electric field in the depletion zone
D) All of these

Q.16 In a p-n junction having depletion layer of thickness 10^{-6} m, the potential across it is 0.1 V. The electric field over there in Vm^{-1} is

A) 10^5
C) 10^{-5}
B) 10^6
D) 10^{-6}

Q.17 With increase in junction temperature, the barrier potential

A) Decreases
C) Remains same
B) Increases
D) First increases then decreases

Q.18 The output of operational amplifier (comparator) switches to + V_{cc} used as night switch

A) When R_L becomes smaller
C) When the intensity of light is greater
B) When R_L becomes larger
D) Both A and C

Q.19 The gain of a transistor used as an amplifier in which collector resistance R_c is 5 kΩ, the input resistance between base and emitter 2.5 kΩ and the value of its β is 100

A) –100
B) –200
C) –400
D) None of these

Q.20 Saturation of operational amplifier means its outputs

A) Becomes less than + V_{cc} or -V_{cc}
B) Becomes greater than + V_{cc} or -V_{cc}
C) Becomes equal to + V_{cc} or -V_{cc}
D) Both B and C

Q.21 Open loop gain of an OP – AMP is

A) Infinite
B) Zero
C) 10^5
D) 10^4

Q.22 The gain of non inverting amplifier for which $R_1 = \infty$ and $R_2 = 0$ is

A) 0
B) Infinite
C) 1
D) – 1

Q.23 The band gap in ZnO is 3.2 eV. If an electron from conduction band combines with a hole in valence band then wavelength of photon emitted is

A) 387.5 nm
B) 297.5 nm
C) 437.5 nm
D) 367.5 nm

Q.24 In a common base transistor the collector current is 5.488 mA for an emitter current of 5.70 mA, the value of base current

A) 0.212 mA
B) 0.112 mA
C) 51 mA
D) 48 mA

Q. 25 When a p-n junction is forward biased then width of depletion region

A) Increase s
B) Decreases
C) Remains unchanged
D) Is variable

Q. 26 Potential barrier for Ge p-n junction is

A) 0.5 V
B) 0.7 V
C) 0.3 V
D) 0.1 V

Q. 27 The current through p-n junction in reverse biasing condition is due to

A) Majority charge carries
B) Minority charge carries
C) Both A and B
D) None of these

Q.28 In half wave rectification, diode conducts for

A) Only positive half cycle of AC
B) Only negative half cycle of AC
C) Complete cycle of AC
D) quarter cycle of AC

Q.29 In full wave rectification bridge circuit

A) All diodes conduct simultaneously
B) Three diodes conduct
C) Two pairs of diodes conduct alternately
D) All diodes conduct one by one

Q.30 Circuit used to convert pulsating dc into constant dc is called

A) Rectifier
B) Inverter
C) Filter
D) Converter

Q.31 A transistor consists of

A) One p-n junction
B) Two p-n junction
C) Three p-n junction
D) Four p-n junction

Q.32 $\beta = \frac{I_C}{I_B}$ **is called**

A) Voltage gain
B) Resistance gain
C) Current gain
D) Power gain

Q.33 In inverting op- amplifier, if R_1 is the external resistance between input and inverting output and R_2 is external resistance between input and output, then its closed loop gain is

A) $\frac{R_2}{R_1}$
B) $\frac{R_1}{R_2}$
C) $-\frac{R_2}{R_1}$
D) $-\frac{R_1}{R_2}$

Q.34 A diodes characteristics curve is a plot between

A) Voltage and time
B) Current and time
C) Voltage and current
D) All of these

Q.35 When a diode is forward biased then its resistance is in

A) Few ohms
B) Kilo ohms
C) Mega ohms
D) Milliohms

Q.36 Transistor was discovered by

A) Edison
B) Curie
C) Bardeen
D) Newton

Q.37 If on increase temperature, the resistance decreases then it is

A) Super conductor
B) Insulator
C) Semiconductor
D) Conductor

Q.38 The depletion region of a junction is formed

A) During the manufacture process
B) When forward bias is applied to it
C) When reverse bias is applied to it
D) When its temperature is reduced

ANSWERS WITH EXPLANATION

Q.1	**(C)**	**Q.2**	**(D)**	Reverse biased		**Q.3**	**(D)**	**Q.4**	**(A)**	**Q.5**	**(C)**
Q.6	**(B)**	**Q.7**	**(D)**	**Q.8**	**(A)**	**Q.9**	**(C)**	‘o’ is high potential than – 2 V			
Q.10	**(B)**	**Q.11**	**(A)**	**Q.12**	**(B)**	$G = 1+\frac{R_2}{R_1}$		**Q.13**	**(D)**	**Q.14**	**(A)**
Q.15	**(D)**	**Q.16**	**(A)**	**Q.17**	**(A)**	**Q.18**	**(B)**	**Q.19**	**(B)**	**Q.20**	**(C)**
Q.21	**(C)**	**Q.22**	**(C)**	**Q.23**	**(A)**	**Q.24**	**(A)**	$I_B = I_E - I_C$		**Q.25**	**(B)**
Q.26	**(C)**	**Q.27**	**(B)**	**Q.28**	**(A)**	**Q.29**	**(C)**	**Q.30**	**(C)**	**Q.31**	**(B)**
Q.32	**(C)**	**Q.33**	**(C)**	**Q.34**	**(D)**	**Q.35**	**(A)**	**Q.36**	**(B)**	**Q.37**	**(C)**
Q.38	**(A)**										

UNIT 15

Modern Physics

- **Modern physics** is based on the theory of relativity and quantum mechanics.
- **Theory of relativity** is concerned with the relation between the observations of same phenomenon or quantity taken by two observers from two different frames of reference.
- **Quantum mechanics** considers electromagnetic radiations as discrete packets of energy and it tells us that subatomic particles can show wave properties.
- **Classical physics** is based on Newton's law of motion, laws of thermodynamics, kinetic theory of gases and Maxwell's theory of electromagnetic waves etc.

Did You Know?

- Classical physics is the physics upto the end of 19^{th} century
- Modern physics is the physics from the start of 20^{th} century

BLACK BODY RADIATION

A black body is an ideal absorber and an ideal radiator

- It is a good absorber and bad reflector.
- The emissive or absorptive power is 1

INTENSITY DISTRIBUTION CURVE:

- This is a curve which shows the characteristics of blackbody at different temperatures.
- At a given temperature T of black body, the energy is not uniformly distributed in the radiation spectrum of the body.

$$\boxed{\lambda_{max} T = \text{constant}}$$

$$\lambda_{max} \propto \frac{1}{T} \text{ or } = 2.9 \times 10^{-3} \text{ mk}$$

- This is known as **Wein's displacement law** and holds good for shorter wavelengths in the explanation of black body curve
- The radiation intensity at a particular temperature of black body increases with increase in wavelengths and at λ_{max}, intensity has maximum value. After λ_{max} intensity decreases with further increase in wavelength.(λ_{max} is the wavelength with maximum intensity)
- Area under curve = Total energy E radiated per second over all wavelengths at a particular temperature T to unit area of surroundings. (area gives emissive power)

$$E \propto T^4 \text{ or } \quad \boxed{E = \sigma T^4}$$

Where σ = Stephen's constant = 5.67×10^{-8} Watt m^{-2} k^{-4}

This is known as **Stefan's Boltzmann law**

- **Rayleigh Jean's Law** holds good for longer wavelengths in the explanation of black body curve.

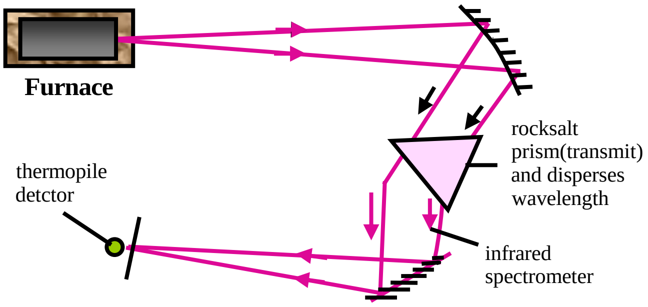
Planck's Assumption:

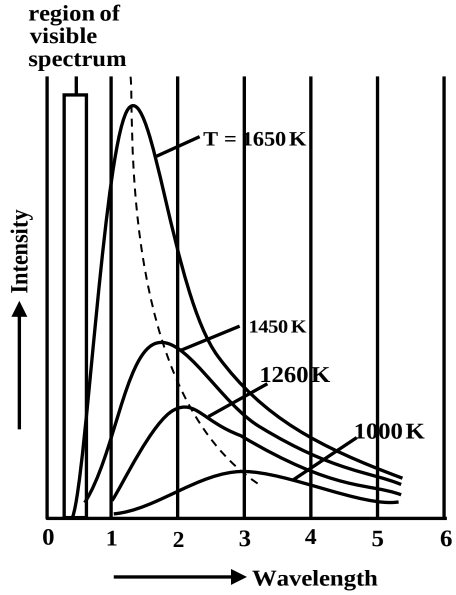
- Energy is radiated or absorbed in the form of packets, called quanta and not in the form of continuous wave. (Energy of each quant)

$$E \propto f \quad \text{or} \quad \boxed{E = hf}$$

where h = Plank's constant = 6.63×10^{-34} J × s.

- Planck's assumption successfully explains the whole intensity distribution curve of black body.
- Max Planck received noble prize in Physics in 1918 for his discovery of energy quanta.





For Your information

Human body emits electromagnetic waves in infra red region at 310 K

The Photon:

Packets of electromagnetic radiations are known as photons

- Einstein presented the idea of light energy consisting of electromagnetic energy
- .Momentum of photon $\boxed{P = \frac{h}{\lambda}}$ or $P = \frac{hf}{C}$
- γ-ray photons are detected by counters because their energies are of the range of 1 MeV where as radio waves are detected as continuous waves because their quanta are of low energy (10^{-10} eV).

INTERACTION OF ELECTROMAGNETIC RADIATION WITH MATTER

It is of three types depending upon energy of photons

- Photoelectric effect
- Compton effect
- Pair production

Photoelectric Effect:

The phenomenon of electron ejection from a metal surface by a light of suitable frequency is called photoelectric effect

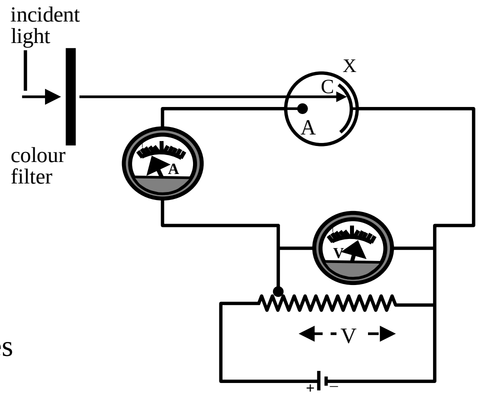
- Hertz discovered photoelectric effect in 1887.
- The minimum frequency of incident light at which photoelectric effect takes place is called threshold frequency (f_o)

$$f_o = \frac{\phi}{h} \quad \text{Or} \quad \phi = hf_o$$

Where ϕ is work function.

- Threshold frequency is different for different metals
- Certain alkali metals (e.g. sodium, potassium, calcium etc) show photoelectric effect when visible light falls on them. However, metals like zinc, cadmium, magnesium etc, show photoelectric effect to ultraviolet light.
- Two points are noteworthy about photoelectric effect
- If the frequency of incident radiation is equal to or greater than the threshold frequency for the metal, electrons will be emitted from the metal, no matter how low is the intensity of radiation.
- If the frequency of incident radiation is less than the threshold frequency for the metal, no photoelectrons will be emitted from the metal surface, no matter how great is the intensity of radiation.

Experimental Study of Photoelectric Current:



- To study the effect of intensity and frequency of incident light on photoelectric current, we apply a negative (retarding) potential to anode A w.r.t cathode C.
- As the retarding potential is increased,
the photoelectric current further decreases. At some retarding potential, the photoelectric current becomes zero and no photoelectron reach the anode A.

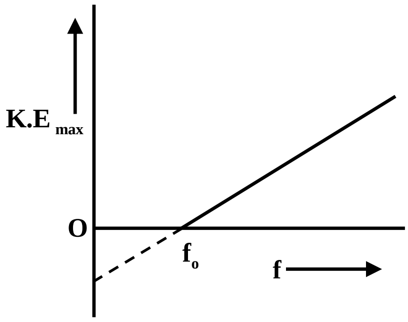
The minimum retarding potential (i.e. anode negative w.r.t. cathode) at which photo electric current becomes zero is called stopping potential or cut-off potential. It is denoted by V_o

- At V_0, even the photoelectrons having maximum kinetic energy $K.E_{max}$ (i.e. fastest photoelectrons) does not reach the anode A. Therefore, the stopping potential V_0 is a measure of the maximum kinetic energy of the photoelectrons.
- If m is the mass of emitted photoelectrons and v_{max} its maximum velocity, then,

$$K.E_{max} = \frac{1}{2} mv_{max}^2 = V_o e$$

Note that eV_o is the work done by the retarding force to stop the photoelectron with maximum kinetic energy and is, therefore, equal to K_{max}.

- At V_o, it is found that the photoelectric current cannot be obtained even if we increase the intensity of radiation.
- Millikan determined the value of h by the slope of the graph between frequency f of incident light and maximum K.E of photoelectron



- **Frequency of incident radiation** is directly proportional Stopping potential. The greater the frequency of incident radiation, the higher is the stopping potential and vice – versa.
- **Intensity of incident radiation** is directly proportional to photoelectric current.

Results of Photoelectric Effect

- Maximum kinetic energy of photoelectron depends on the nature of metal surface and the frequency of incident light.
- There is minimum frequency of incident light below which no photoelectrons are emitted. This is called threshold frequency (f_o)
- Electrons are emitted instantaneously.

Failure of Wave Theory to Explain Photoelectric Effect

(i) According to wave theory of radiation, the greater the intensity of a wave, the greater is the energy of the wave. But it fails to explain the experimentally observed fact that the velocity or kinetic energy of the emitted photoelectrons is independent of the intensity of incident radiation. According to wave theory, an increase in the intensity of radiation should increase the kinetic energy of the emitted photoelectrons but it is contrary to the experimentally observed fact.

(ii) According to wave theory, intensity of radiation is independent of its frequency. Therefore, an increase in the frequency of radiation should not affect the velocity of kinetic energy of the emitted electrons. But it is observed experimentally that if the frequency of the incident radiation is increased, the kinetic energy of the emitted electrons also increases.

(iii) According to wave theory, electrons should always be emitted from a metal by radiation of any frequency if the incident beam is strong enough. However, experiments show that no matter how great is the intensity of the incident radiation, no electrons are emitted from the metallic surface if the frequency of radiation is less than a particular value (i.e. threshold frequency).

(iv) According to wave theory, the energy of radiation is spread continuously over the wave fronts of the radiation. Therefore, a single electron in the metal will intercept only a small fraction of the wave's energy. Consequently, considerable time would be needed for an electron to absorb enough energy from the wave to escape the metal's surface. But experiments show that electrons are emitted as soon as radiation of suitable frequency falls on the metallic surface. In other words, photoelectric emission is instantaneous; there is no delay.

Einstein's Explanation

- Photon energy = Work function + $K.E_{max}$
- Work function ϕ is the minimum energy of photon required to overcome the binding energy of photoelectron. It corresponds to threshold frequency.

$$hf = \phi + K.E_{max}$$

$$\boxed{\frac{1}{2}mv_{max}^2 = hf - \phi} \rightarrow \text{Einstein's photoelectric equation}$$

- If $hf = \phi$ then $K.E_{max} = 0$ and $f = f_o$

  $\phi = hf_o$

  $V_oe = h(f - f_o)$ Modified Einstein's equation
- All the photoelectron does not have maximum K.E because some lose energy in the atomic collisions before coming out of metal surface.
- Einstein was awarded Nobel Prize in Physics in 1921 for explanation of this effect.
- Photoelectric effect shows particle nature of light

Photocell:

- A photocell is based on photoelectric effect.
- It consists of an evacuated glass bulb with a thin anode rod and a metallic cathode.
- Material of cathode is according to the frequency range of incident light over which cell is to be operated e.g. sodium cathode emits electrons for visible light.
- Applications of photo cells are security systems, counting systems, automatic street lighting, and exposure meter of photography and sound track of movies.

PRACTICE QUESTIONS

Q.1 In photo electric cell, the photo electric current

A) Decreases with increase in frequency of light

B) Depends on intensity and frequency of light

C) Does not depend upon the frequency of light and but depends upon intensity of light

D) Increases with increase in frequency of light.

Q.2 Wavelength of a photon having energy of 124 eV is

A) 124 nm C) 10 nm

B) 0.1 nm D) 10 Å

Q.3 Choose incorrect about properties of photon

A) Rest mass of photon is zero

B) A photon is never at rest

C) Photon is deflected by electric field but not by magnetic field

D) The velocity of photon is different in different media

Q.4 Work function of all metals varies from 2 eV to 4eV. It is 4.2 eV for Aluminum and 2eV for Sodium. If these two metals are illuminated by same light, the threshold frequency of Aluminum is

A) Less than Sodium C) Equal to that of Sodium

B) Grater than Sodium D) Can't be decided

Q.5 A photo cell receives light from a source at 50 cm away and produces 40mA current in the circuit. When the same source at is at distance 1 m from photo cell, current in the circuit will be

A) 20 mA C) 80mA

B) 60 mA D) 10 mA

Q.6 Temperature of black body radiating at 27^{0}c is increased to 327^{o}c, then emitted energy will increase by

A) 2 times C) 12 times

B) 16 times D) 4 times

Q.7 In an electron microscope, resolution upto 1 nm is possible when electrons are accelerated through

A) 4 kV C) 50 kV

B) 20 kV D) This high resolution is not possible

Q.8 de-Broglie wavelength associated with an electron moving at a speed of $1x10^{6}$ ms^{-1} is

A) $4x10^{-10}$ ms^{-1} C) $5x10^{-10}$ m

B) $6x10^{-10}$ m D) $7x10^{-10}$ m

Q.9 Momentum of an electron if wavelength associated with it is 2Å

A) $2.31\times10^{-24}\,kgms^{-1}$ (Approx) C) $\frac{1}{3.31}\times10^{-24}\,kgms^{-1}$

B) $3.31\times10^{-24}\,kgms^{-1}$ (Approx) D) $3.31\times10^{24}\,kgms^{-1}$

WAVE NATURE OF PARTICLES (de-Broglie's hypothesis)

According to de-Broglie's hypothesis if a wave can behave like a particle then particles should also possess wave like properties.

- The wave associated with a moving particle is called matter wave or de-Broglie wave
- de-Broglie wavelength is give by $\boxed{\lambda = \frac{h}{mv}}$

- We can not observe wave nature of macro particles because their wavelength is too short under ordinary observations (speeds).

Davison and Germer Experiment:

- Davisson and Germer gave experimental proof of ***de-Broglie's hypothesis.*** They showed experimentally that electrons are diffracted from metals in the same manner as X-Rays or any other wave.
- If electron is accelerated through a P.D V = 54 volt and is diffracted by a crystal as shown in figure, then

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mVe}} = \frac{h}{\sqrt{2mKE}} = 1.66 \times 10^{-10}\ m$$

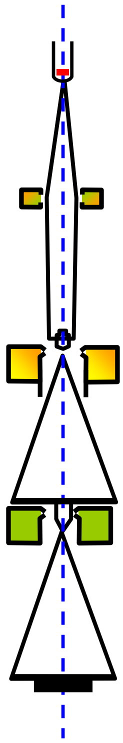
- This wavelength is equal to wavelength observed for X-rays diffraction (Using Bragg Equation)
- This confirms wave nature of particles.
- Prince louis de Broglie was awarded Noble Prize in 1929. Davion and Germer shared Noble Prize in 1937.

Wave-Particle Duality:

- Particles can behave like waves e.g., electron in Davisson-Germer experiment and waves can behave like particles e.g., light in photoelectric effect, Compton effect etc. This is called wave-particle duality.
- Niel Bohr's principle of complementary states that both wave and particle aspects are required for the complete description of both radiation and matter.
- Both wave and particle nature is not revealed in a single experiment.
- Light propagates as a wave and interacts with matter as a particle.
- Similarly, all micro particles e.g., electrons, protons etc propagate as waves and exchange energy as particles.

Uses of Wave Nature of Particles:

Electron Microscope



- It uses wave nature of electrons i.e., electron diffraction.
- In an electron microscope, electric and magnetic fields rather than optical lenses are used to focus electrons accelerated through potential difference from 30kV to several mega volts.
- Electron microscopes have a greater resolving power than a light-powered optical microscope because electrons have wavelengths about 100,000 times shorter than visible light and can achieve better than 0.2 mm resolution and magnifications up

to 2,000,000 X, where as ordinary light microscopes are limited by diffraction to about 200 mm and useful magnifications below 2000 X.

- The transmitted electron beam has spatial differences in density corresponding to features of specimen.
- The final image is seen on a fluorescent screen or a special film called electron micrograph.

ATOMIC SPECTRA

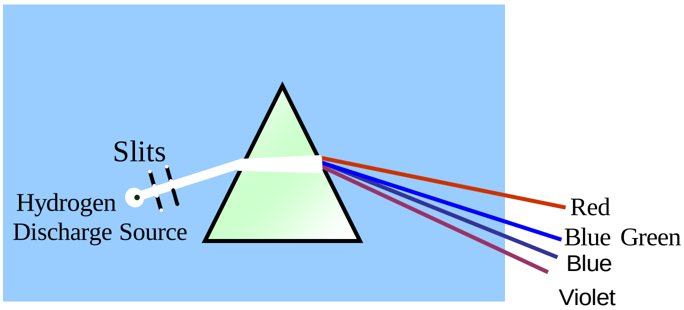
A set of rays (wavelengths) obtained by passing light through a prism is called a spectrum e.g., spectrum of white light, rainbow etc.

Spectroscopy:

The branch of physics which deals which the investigation of wavelengths and intensities of EM radiation emitted or absorbed by atoms is called spectroscopy

Atomic spectra:

- When an electric current is passed through a gas (or vaporized solid) at low pressure, the gas/ vapor emits light whose colour is characterized by the properties of gas/ vapor.
- If the emitted light is analyzed with a spectroscope, a series of discrete lines is observed, each line corresponding to a different wavelength of colour. We call such a series of lines as line emission spectrum.



> Atomic spectrum is line spectrum.
> Molecular spectrum is band spectrum
> Blackbody spectrum is continuous spectrum

Types of Sepctra

Atomic Spectrum
It is emitted by atoms of an element e.g., spectrum of H atoms. Spectral lines are not diffused into each other and every two bright lines are separated by dark lines.

Continuous Spectrum
It is emitted by condensed matter (solid or liquid) e.g., a black body spectrum

Band Spectrum
Molecular spectrum is band spectrum e.g., spectrum of H_2

Rutherford's Model of an Atom

1. The positive charge is concentrated in a small region of the order of 10^{-15} m, called the nucleus.
2. Electrons revolve around the nucleus in circular orbits.
3. There is large empty space around the nucleus (consequence of his α-particle scattering experiment).
4. Atom is electrically neutral.

Bohr's model of the Hydrogen atom

- In order to remove the defects of Rutherford's model of atom, Niels Bohr in 1913 suggested that laws of classical mechanics and electromagnetism which are applicable to big bodies cannot be applied blindly to the sub-atomic particles like electrons.

  This semi-classical and semi-modern model successfully explains the empirical results obtained from hydrogen atom spectrum.

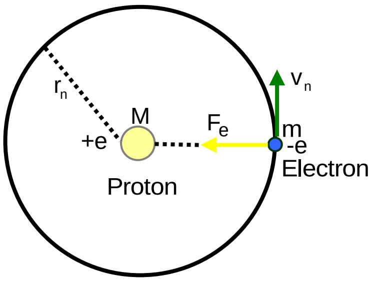
  Postulate I: Electrons revolve around the nucleus in certain circular orbits or discrete stationary states without radiating.

  Postulate II: Angular momentum is given by $\boxed{mvr = \frac{nh}{2\pi}}$

  i.e., angular momentum is quantized where n = principal quantum number = 1,2,3, …. showing number of orbit. Note that according to this postulate, the angular momentum of the electron does not have continuous range i.e. the angular momentum of the revolving electron is quantized.

  Postulate III: Whenever electron jumps from high energy state E_n to a lower energy state E_p then a photon of energy hf is emitted so that $hf = E_n - E_p$ (according to law of conservation of energy)

QUANTIZED RADII



- Centripetal force is provided to electron by the coulomb's force between nucleus and electron.
- Velocity of electron in nth orbit is $v_n = \frac{2\pi k e^2}{nh}$
- Expression for radii is $\boxed{r_n = n^2 \times r_1}$

where $r_1 = 0.053$ nm

So according to Bohr's theory, the radii of different stationary orbits of the electrons in the hydrogen atom are given by

$$r_n = r_1, 4r_1, 9r_1, 16r_1, \ldots\ldots\ldots$$

QUANTIZED ENERGIES

Energy of an electron in the nth orbit = $E_n = K.E + P.E = \frac{Ke^2}{2r_n} - \frac{Ke^2}{r_n} = -\frac{Ke^2}{2r_n}$

- Total energy is given as $\boxed{E_n = -\frac{E_o}{n^2}}$

$$= -\frac{13.6}{n^2}\text{eV}$$

where n = 1, 2, 3, ………

$$E_n = -E_o, -\frac{E_o}{4}, -\frac{E_o}{9}, -\frac{E_o}{16}, \ldots\ldots\ldots\ldots 0$$

Total energy of electron in a Bohr's orbit is negative which implies that its P.E is greater than its K.E and so it is bound to the nucleus.

Excitation Potential and Ionization Potential:

- The atom/ electron may be excited by collision with externally accelerated electron.
- The potential through which an electron should be accelerated so that on collision it can lift the electron in the atom from its ground state to some higher state, is known as excitation potential e.g., if we lift electron from 1st orbit to 2nd orbit then

  $$E_{ex} = E_2 - E_1 = (-3.4) - (-13.6) = 10.2\,\text{eV}\,; \quad V_{ex} = 10.2 \text{ volt}$$

- The potential through which electron should be accelerated so that on collision it can lift the electron in the atom from its ground state to an infinite orbit (out of the atom), is known as ionization potential.

  $$E_{ion} = E_{\infty} - E_1 = 0 - (-13.6) = 13.6\,\text{eV}\,; \quad V_{ion} = 13.6 \text{ volt}$$

Ionization Energy of hydrogen like atoms in nth state $= \frac{13.6Z^2}{n^2}$ eV e.g. ionization energy of helium atom is 54.4 eV.

Did You Know?
Photon must have energy exactly equal to the energy difference between the two shells for excitation of an atom but an electron with K.E. greater that the required difference can excite the gas atoms.

Three ways of ionization / Excitation

Thermal Excitation
Heat is supplied

Optical Pumping
Photon of specific energy is incident

Electrical Discharge
Charged particle e.g., electron is bombarded towards atom.

Types of Sepctra

Absorption Spectrum
It is a set of wavelengths absorbed by atoms of a substance.

It is caused by up transition of electrons of atoms

Emission Spectrum
It is a set of wavelengths emitted by atoms of a substance.

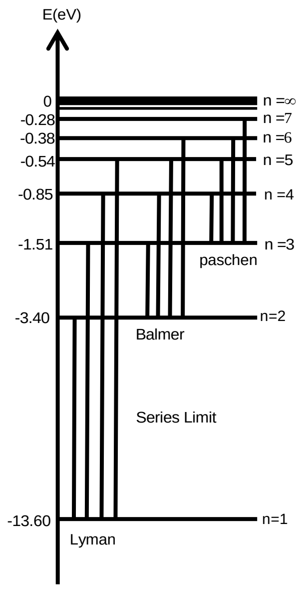
It is caused by de-excitation of electrons of atoms.

Hydrogen Emission Spectrum

- Although hydrogen contains one electron but its spectrum contains many spectral lines due to different electronic transitions between different energy levels.

- A glowing gas like hydrogen gives only certain wavelengths (energies) of light and is capable of absorbing the same wavelengths (energies) due to the presence of certain (discrete) energy levels inside the atom. It also means that gas atoms are transparent to other wavelengths.
- When an electron of an atom is excited to higher energy levels then we say that atom is excited.

Energy Level Diagram:



- It is a diagram in which the total energies of electron in different stationary orbits of an atom are represented by parallel horizontal lines, drawn according to some suitable energy scale.
- In order to draw energy level diagram of an atom, we must know the total energy of electron in different stationary orbits.
  The total energy of an electron in the nth orbit of hydrogen atom is

$$E_n = -\frac{13.6}{n^2} eV$$

By putting value of n = 1, 2, 3…... we can find the total energy of electron in various stationary orbits of hydrogen atom as:

$$E_1 = -\frac{13.6}{(1)^2} = -13.6eV \quad \text{…. First orbit (n = 1)}$$

$$E_2 = -\frac{13.6}{(2)^2} = -3.4eV \quad \text{…. second orbit (n = 2)}$$

$$E_3 = -\frac{13.6}{(3)^2} = -1.51eV \quad \text{…. third orbit (n = 3)}$$

- Hydrogen emission spectrum consists of 5 spectral series

Name of Series	Formula	Region	Transition
Lyman	$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right); n > 1$	Ultraviolet	From n > 1 to n = 1
Balmer	$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right); n > 2$	Visible	From n > 2 to n = 2
Paschen	$\frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n^2}\right); n > 3$	Infrared	From n > 3 to n = 3
Bracket	$\frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n^2}\right); n > 4$	Infrared	From n > 4 to n = 4
Pfund	$\frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n^2}\right); n > 5$	Infrared	From n > 5 to n = 5

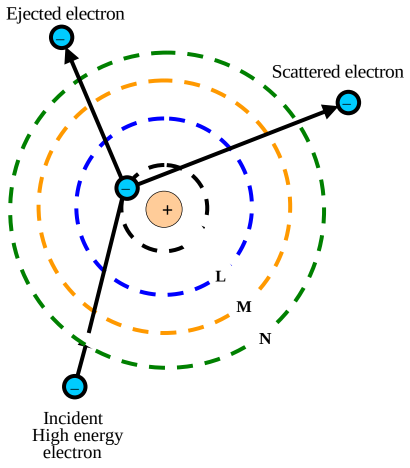
X-RAYS

"High energy photons emitted from heavy elements when bombarded with high energy electrons are called X Rays"

Discovered by Roentgen in 1895.

X-rays are electromagnetic waves of very small wavelength ranging from $100A^0$ to $0.1A^0$.

Inner Shell Transitions and Characteristic X-Rays:



- The transitions which take place when vacancies are created in the inner shells due to ejection of electrons from inner shells (K, L, M etc) of heavy atoms when very fast moving electrons collide with these inner shell electrons, are called inner shell transitions and the radiations emitted due to these transitions are of specific wavelengths (energies) corresponding to certain energy orbits. These radiations are called characteristic X-rays.
- Let a vacancy is created in the K-shell as shown in fig.
- The photons emitted when electrons transit from higher shells to k-shell are called K-series of X-rays.
- If electron comes back from L-shell to K-shell then photon emitted is called k_α X-rays

$$\boxed{hf_{k\alpha} = E_L - E_K}$$

And the wavelength of emitted photon is

$$\boxed{\lambda_{k\alpha} = \frac{hc}{E_L - E_k}}$$

And if electron comes from M-shell then photon emitted is called k_βX-rays and so on.

$$\boxed{hf_{k\beta} = E_M - E_K}$$

And the wavelength of emitted photon is

$$\boxed{\lambda_{k\beta} = \frac{hc}{E_M - E_k}}$$

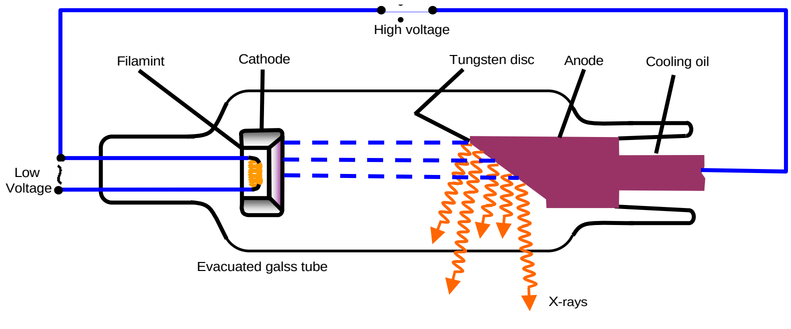
- Similarly, if a vacancy is created in the L-shell then series of photons emitted, are called L-series X- rays. Also there is M, N series and so on.
- K-series of X-rays is the most energetic series.

Production of X-rays:

- The apparatus used for the production of X-rays consist of a source of electron, a filament surrounded by a cathode C. The filament is heated by a low A.C voltage source.
- An evacuated metal or glass tube to accelerate the electrons.
- A system with high AC voltage source V to accelerate the electrons emitted by filament.

$$\boxed{K.E = eV}$$

- A target T, usually of tungsten (high atomic number elements) to serve as anode with which the electrons strike to produce X-rays.



- The high energy electrons strike a target embedded in a copper anode, Most X-ray tubes use tungsten for the target because this metal has the highest efficiency for the production of X-rays. Other heavy metals may also be used as targets.
- Although only about 0.2 % of the total energy from the electrons that strike the target is converted into X-rays. Most of the energy from the electrons is converted into heat at the anode. Hence the target must also be a metal of high melting point.

Properties of Cathode:

The cathode should have these properties:

(i) A **low** value for its **work function** so that electrons can escape from its surface easily.

(ii) A **low heat capacity** so that less heat is required to raise its temperature.

Properties of Anode:

The target should have these properties:

(i) A **high melting point** to withstand the large amount of heat produced when electrons bombard it.

(ii) A **high atomic number** so that it is more efficient in the production of X-rays

(iii) A **good conductor** of heat so that heat can be removed from it easily.

The X-ray Spectrum:

The X-rays emitted from an X-ray tube which has a constant potential difference between the cathode and anode consist of various wavelengths and form a spectrum. The X-ray spectrum consists of the continuous spectrum and the line or characteristic X-ray spectrum.

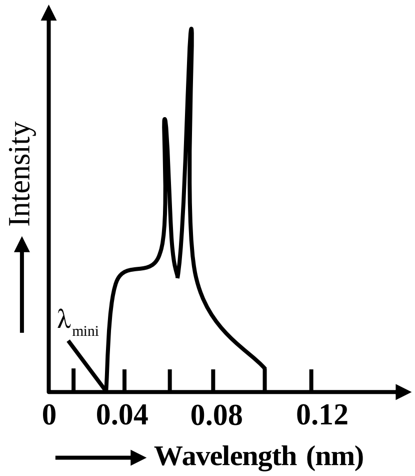
Characteristic X-Rays:

- These X-rays are emitted when high-energy electrons from the cathode strike the atoms in the target and knock out electrons from the inner levels of the atoms. When an electron from a higher level falls into a vacancy in the inner level, a photon of X-ray is emitted.
- When a bombarding electron from the cathode knocks out one of the electrons in the K-shell and the vacancy in the K-shell is filled by an electron from the L-shell, a photon of X-ray, the K-line, is emitted. When this happens, a photon of X-ray which forms the K_α-line is emitted. The K_α - and K_β - line form a series known as the K-series characteristic X-rays

$$\boxed{\lambda_{k\alpha} = \frac{hc}{E_L - E_k}}$$

- Figure shows that the K_α-line has a higher intensity than the K_β-line. This is because electrons in the L-shell are nearer to the K-shell and there is a greater probability that the vacancy in the K-shell is filled by an electron from the L-shell than from the M-shell.
- The wavelength of the K_α-line is longer than that of the K_β-line. This means that a photon of K_α-line X-ray has less energy than a photon of K_β-line X-ray because the energy difference between the L-shell and K-shell is smaller than that between the M-shell and the K-shell.
- The line X-ray spectrum is a characteristic of the metal used as the target.
- Even when the accelerating potential difference of the X-ray tube is increased from 20 kV to 50 kV,

the wavelengths of the K-lines remain unchanged.



- For a low accelerating potential difference no characteristic X-rays are produced, and only X-rays in the continuous spectrum are obtained.
- These X-rays have discrete energy or particular wavelength.
- These particular wavelengths are characteristic nature of the target
- A line spectrum is obtained for characteristic X rays.
- The heaviest elements such as uranium and thorium emit a complete spectrum where all the series K, L, M and N are present.

Continuous X-Rays

- X-rays in the
- continuous part of the spectrum are emitted from a target where the bombarding electrons from the cathode are slowed down upon hitting the target. These X-rays are referred to as *bremsstrahlung* or braking radiation.
- Fast moving electrons which are bombarded on the target are suddenly slowed on impact with the target. As accelerating charge emits electromagnetic radiation so x rays are produced.
- In the case when electrons lose all their K.E in first impact entire energy appears as x-ray photon then energy is given as $\boxed{K.E = hf_{max}}$ or $\boxed{\lambda_{min} = \frac{hc}{eV}}$
- X-rays have high penetration power: the shorter the wavelength, the higher the penetration power. Shorter wavelength X-rays can be produced by increasing the accelerating potential between the cathode and the target.
- Most of the bombarding electrons are stopped after a number of impacts. At the various points of impact, X-rays of different wavelengths are emitted. Since there is an infinite number of ways in which the bombarding electrons are decelerated, the energy converted into X-rays varies widely from one impact to another. Hence these X-rays form a spectrum known as the continuous X-ray spectrum.
- A continuous spectrum is obtained for continuous rays.

> - **Intensity** (Number of x-ray photons) depends upon filament current (number of electrons striking the metal)
> - **Penetration power** (hardness) depends upon P.D between cathode and anode

Time Saving Tips

1. **To find energy of photon in eV directly when wavelength is given in meters,**

   Use directly $E = \frac{1240\ nm}{\lambda}$ **instead of using** $E = \frac{hc}{\lambda}$

2. **To find no. of photons emitted during different transitions, use formula**

   $\text{No. of spectral lines} = \frac{n(n-1)}{2}$

3. **Memorize energies in different states of H-atom to solve MCQs quickly**

Properties of X-rays:

- X-rays are electromagnetic radiation (no medium is required) of short wavelengths. They are not charged and hence not deflected by a magnetic or electric field.
- X-rays affect photographic films. Photographic films are darkened by X-rays. And darkening of photographic film is proportional to X-ray Exposure
- X-rays can penetrate through several centimeters of a solid material.
- X-rays cause ionization in the material that they pass through. The ejected then disperse the energy throughout the material through collisions.
- X-rays have high penetration power: the shorter the wavelength, the higher the penetration power. Shorter wavelength X-rays can be produced by increasing the accelerating potential between the cathode and the target.
- These rays travel in straight line with the speed of light.
- X-rays can produce damage in living tissues.
- Fluorescent materials glow when X-rays are incident on them. The X-ray photons cause excitation of the atoms in the fluorescent materials. The electrons in the atoms of these materials jump from lower energy to higher energy levels when each electron absorbs an X-ray photon. The electrons return to the lower energy levels in steps and emit visible light instead of X-rays.

Soft and hard X-rays Depending upon the penetration power, X-Rays are of two types

Soft X-rays Are **X-**rays having wavelength $4A^0$ or above are called soft

X-rays due to their low penetration power. They are used for medical purposes

Hard X-rays Are X-rays having low wavelength of the order of $1A^0$ have high frequency and are called hard X-rays due to their high penetration power.

They are used for industry purposes.

Uses of X-rays:

- These rays are used to locate bone fractures. Shadow of bones appears lighter than the surrounding flesh. It is because bones contain elements with high atomic number and flesh contains elements with low atomic number.

- To take the X-ray photograph of soft organs such as the stomach and the intestinal tract, the patient is given a 'barium meal' consisting of barium sulphate and water. Those parts will then show up clearly in an X-ray photograph.
- Cancer cells can be destroyed within the body by focusing a beam of X-rays on the affected area.
- These rays are widely used in the industry e.g., non-destructive testing of materials (defects etc.)
- The diffraction property of X-rays is used to obtain information about the crystalline structure of the material.
- In engineering, X-rays are used to locate cracks in metals. Cracks show up on a photographic film placed behind the metal.

CAT scanner:

- Computerized axial tomography (CAT) uses an instrument called CAT scanner.
- In this type of scanning the X-ray source produces a thin fan-shaped beam that is detected on the opposite side of the object by detectors in all directions. The changing reactions of the detectors are recorded digitally (in the form of zeroes and ones)
- A computer processes over an entire cross-section of the subject.
- Density differences of the order of one percent can be detected with CAT scanner.
- Tumors and other anomalies much too small to be seen with older techniques can be detected.

Advantages of CAT Scanner Over traditional radiography:

- CT scan completely eliminates the superimposition of images of structures outside the area of interest.
- High contrast resolution of CT scan helps us to differentiate between tissues that differ in physical density by less than 1 %.
- Computer software in CT builds up a three dimensional image of patients

Biological Effects of X-rays:

- X-rays cause damage to living tissues. As X-rays photons are absorbed in tissues, they break molecular bonds and create highly reactive free radicals (such as H^+ and OH^-) which can disturb the molecular structure of the proteins and especially the genetic material.
- As young and rapidly growing cells are particularly affected by X-rays, so X-rays are useful for selective destruction of cancer cells. Because cell may be damaged by radiation and may continue to live and also continue dividing to produce generation of defective cells. Thus X-rays can cause cancer.

> The thick piece of glass on the front of a television set is used to absorb the X-rays. As a precaution, children should be discouraged from sitting too close to the television screen. Though the radiation dosage received by them is small but it builds up over a long period.

ENARGY BAND THEORY

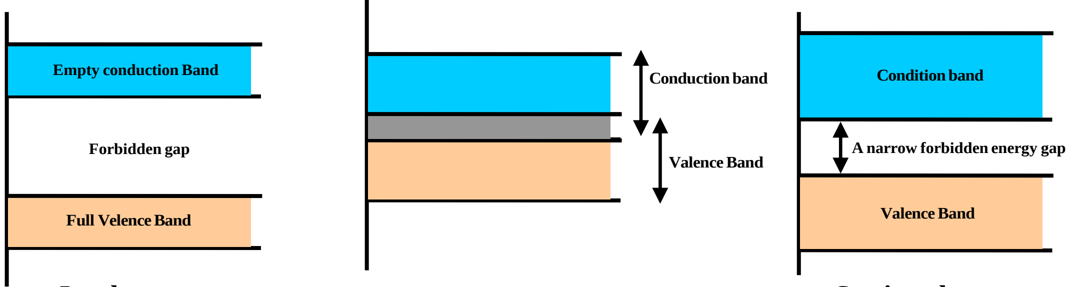
"The range of energies possessed by an electron in a solid is known as energy band"

- It is based on wave model.

Types of Energy Bands

- **Permissible Energy Bands**
  - Valance Bands
    It is the highest occupied band. It may be either completely filled or partially filled with electrons
  - Conduction Bands
    The bands above the valence band is called conduction band. In this band, electrons move freely and conduct current
- **Forbidden Energy Band or Gap**
  The range of energy states between two permissible energy bands which can not be occupied by electrons are termed as forbidden energy gaps

Material	Conduction Band	Valence Band	Energy Gap between Valence and conduction Band
Insulator	Empty(No Free electron)	Full	A large energy gap of several eV
Conductor	Partially filled	Partially filled	No energy gap
Semiconductor	Partially filled	Partially filled	Narrow energy Gap



Insulators **Conductors** **Semiconductors**

- A solid can be treated as a densely packed system obtained by bringing together isolated single atoms. An isolated single atom possesses a number of discrete energy levels that can be occupied by electrons of the atom. Ordinary, the electrons exist in the ground state, and excited electrons can shift to higher energy levels.
- Usually only the valence electrons can participate in these excitations. When two atoms interact, each previous single energy level is split into two levels. For N atoms, the splitting is N-times. In case of solids N is very large; the number of splitting is very large.
- Since the value of energy for different level splitting remains approximately the same, the overall effect of bringing a large number of atoms is to form bands of continuous energy levels, separated by gaps where no electron states exist. The gap is called forbidden energy gap.

- No material can have a full conduction band or an empty valance band.
- No. of electrons in a conduction band is equal to number of holes in valence band.
- At absolute zero temperature, conduction band is completely empty and semiconductor behaves as an insulator.

PRACTICE QUESTIONS

Q.10 If an α-particle and a proton have same kinetic energy then the de-Broglie wavelength will be least for

A) Proton
B) α particle
C) Both have same de-Broglie wavelength
D) Can't be decided

Q.11 In photoelectric effect experiment, stopping potential depend upon

A) Intensity of light
B) Frequency of light
C) Photoelectric current
D) Both A and B

Q.12 In electron microscope, we use high speed electrons because them

A) Penetration power is higher
B) Wavelength is smaller
C) Frequency is smaller
D) K.E is smaller

Q.13 Light of frequency 2 times the threshold frequency is incident on the metal surface. If the frequency is by quartered and intensity is doubled, the photo electric becomes

A) Quadrupled
B) Doubled
C) Zero
D) Halved

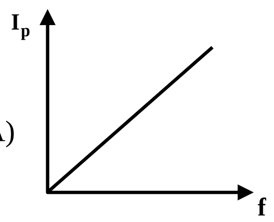
Q.14 The threshold frequency of a metal is f_0. When light of frequency $4f_0$ is incident on the metal, the maximum K.E of photo electrons is

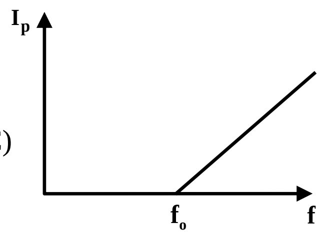
A) $4 hf_0$
B) $\frac{hf_o}{2}$
C) $2hf_0$
D) $3hf_0$

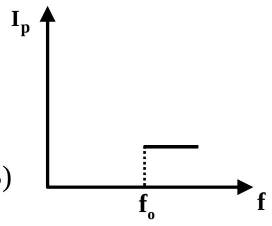
Q.15 Of the following particles moving with the same momentum, wavelength is largest for

A) α-Particle
B) A Proton
C) An electron
D) All have same de-Broglie wavelength

Q.16 In photoelectric if f_o = threshold frequency of metal I_p = photoelectric current, then the graph which is best representing the relation between frequency of light and photoelectric current is

A)


C)


B)


D) All of these

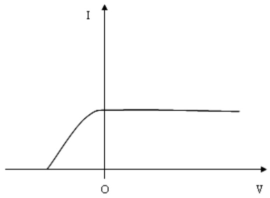
Q.17 When green light is incident on a certain metal surface; electrons are emitted but no electrons are emitted by yellow light. If now red light is incident on the same metal surface

A) More electrons will be emitted
B) Less energetic electros will be emitted
C) Emission of electrons will depend or the intensity of light
D) No electrons will be emitted

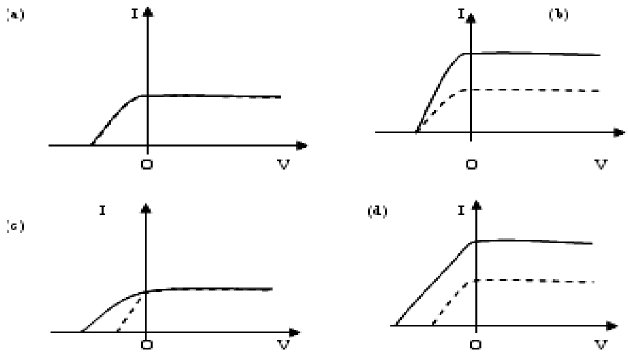
Q.18 A beam of red, yellow and blue light have exactly the same energy. Which beam contains lesser number of photons?

A) Red
B) Yellow
C) Blue
D) All contains equal number of photons

Q.19 For a given intensity of light, the way in which the photocurrent I depends on the potential difference V between the electrodes is as shown in the diagram below.



If the experiment were repeated with light of twice the intensity but the same wavelength, which of the graphs below would best represent the new relation between I and V? (In these graphs, the result of the original experiment is indicated by a broken line.)



Q.20 A photon of energy 6.2 eV is allowed to strike a metal surface of work function 3.7 eV. The K.E of electrons at the time of ejection will be

A) 1.5 eV
B) 2.5 eV
C) 3.7 eV
D) 3.5 eV

Q.21 A proton accelerated through a potential V has de- Broglie wavelength λ. The de-Broglie wavelength of an α-particle, when accelerated through the same potential difference V is

A) $\frac{\lambda}{2}$
B) $\frac{\lambda}{\sqrt{2}}$
C) $\frac{\lambda}{2\sqrt{2}}$
D) $\frac{\lambda}{8}$

Q.22 If an electron is accelerated such that its K.E is 4 times of its rest mass energy then the total relativistic energy of electrons is about

A) 5×10^{-12} J
B) 3×10^{-13} J
C) 4×10^{-13} J
D) 6×10^{-12} J

Q.23 When a proton is accelerated with 1-volt potential difference then its kinetic energy is

A) 1/1840 eV
B) 1840 eV
C) 1 eV
D) None of these

Q.24 If different metals were illuminated with light from various monochromatic sources of different frequencies and variable intensities. It was found that, for a given metal, frequency and intensity, electrons were emitted with a spread of kinetic energies up to a maximum value. On what does this maximum kinetic energy depend?

	Metal	Frequency of light	Intensity of light
A	×	✓	✓
B	✓	×	×
C	✓	✓	×
D	✓	✓	✓

Q.25 Discrete nature of radiation was introduced by

A) Hertz
B) Einstein
C) Max Planck
D) Stephan Boltzmann

Q.26 Wavelength of a particle of mass 9.11×10^{-10} kg at rest is

A) Zero
B) Infinite
C) In between zero and infinity
D) Maximum

Q.27 Photon A has half the energy of photon B. The ratio of momentum of B to that of A is

A) 1:2
B) 2:1
C) 4:1
D) 1:4

Q.28 Concept of matter waves was given by

A) Bohr
B) Einstein
C) Planck
D) de-Broglie

Q.29 Photoelectric threshold frequency depends upon

A) Intensity of light
B) Frequency of light
C) Energy of photons
D) Nature of metal surface

Q.30 When a body is heated, it first appears

A) Violet
B) Red
C) Green
D) Blue

Q.31 As a body is heated and its temperature is increased, the radiation becomes richer in

A) Shorter frequencies
B) Shorter wavelengths
C) Longer wavelengths
D) Very long wavelengths

Q.32 With respect to an observer at the surface of Earth, pulse rate of astronauts in a moving space station

A) Increases
B) Decreases
C) Remains unchanged
D) First increases then decreases

Q.33 Which of the following light has highest momentum?

A) Blue
B) Violet
C) Yellow
D) Red

Q.34 If energy of photon A = 2 (energy of photon B) then ratio of their momentums $\frac{P_A}{P_B} =$

A) 2 C) 4

B) $\frac{1}{2}$ D) $\frac{1}{4}$

Q.35 U.V radiation of 6.2 eV falls on an aluminium surface, K.E of fastest electron emitted is (work function = 4.2 eV)

A) 3.2×10^{-21} J C) 9×10^{-32} J

B) 7×10^{-25} J D) 3.2×10^{-19} J

Q.36 If stopping potential is 3 volts, then maximum K.E of photoelectron is

A) 1.6×10^{-19} J C) 4.8×10^{-19} J

B) 3.2×10^{-19} J D) 6.4×10^{-19} J

Q.37 $K.E_{max}$ of photoelectrons depends upon

A) Intensity of light C) Energy of light

B) Frequency of light D) Both B and C

Q.38 Photoelectric effect shows

A) Particle nature of light C) Dual nature of light

B) Wave nature of light D) None of these

Q.39 If work function for a surface is $\frac{h}{2}$ then photoelectric threshold frequency is (where h is plank's constant)

A) 1 HZ C) 1.5 Hz

B) 0.5 Hz D) 2 Hz

Q.40 Which cathode material emits photoelectrons for white light?

A) Potassium cathode C) Both A and B

B) Cesium cathode oxidized silver cathode D) Aluminium cathode

Q.41 Which photon out of red, green or blue lights carries the most energy and momentum?

A) Red C) Blue

B) Green D) All have same values

Q.42 A brighter light as compared to a dimmer light of same colour will eject

A) More number of electrons C) Electrons of greater K.E

B) Less number of electrons D) Electrons of lesser K.E

Q.43 The name of the photon for quantum of light was proposed by

A) Ampere C) Thomson

B) Planck D) Einstein

Q.44 The rest mass of photon is

A) Zero C) Finite

B) Infinite D) Constant

Q.45 When a ball is thrown upwards, then its de-Broglie's wavelength will be minimum

A) At the point of projection

B) At maximum height

C) At a point mid way between the initial and final points

D) Both A and B

Q.46 If an electron, neutron and a proton have the same de-Broglie wavelength then which particle will have the greatest speed

A) Electron
C) Proton
B) Neutron
D) All have same speed

Q.47 If electron, alpha particle, neutron and proton have the same K.E then which particle has the longest wavelength?

A) Electron
C) Neutron
B) Alpha particle
D) Proton

Q.48 Which of the following shows the wave nature of light?

A) Photoelectric effect
C) Pair production
B) Compton effect
D) Polarization

Q.49 If the temperature of black body is raised, the wavelength corresponding to maximum intensity

A) Remains the same
C) Shifts towards longer wavelengths
B) Shifts towards shorter wavelength
D) Either A or C

Q.50 On increasing the frequency of incident light in photoelectric effect

A) Photoelectric current decreases
C) Stopping potential increases
B) Photoelectric current increases
D) Stopping potential decreases

Q.51 The slope of the graph between $K.E_{max}$ of photoelectrons and frequency of incident light is equal to

A) h
C) e/h
B) h/e
D) he

Q.52 In electron microscope, we use high speed electrons because their

A) Penetrating power is high
C) Frequency is small
B) Wavelength is small
D) K.E is small

Q.53 The dimensions of Planck's constant are equal to that of

A) Work
C) Linear momentum
B) P.E
D) Angular momentum

Q.54 The idea of matter wave was given by

A) Planck
C) de-Broglie
B) Heisenberg
D) Einstein

Q.55 If the wavelength of incident radiation in a photoelectric experiment is decreased then

A) The photoelectric current will decrease
C) The stopping potential will decrease
B) The photoelectric current will increase
D) The stopping potential will increase

Q.56 A direct X-ray photograph of the intestines is not generally taken by the radiologists because

A) Intestines would burst on exposure to X-rays

B) X-rays would not pass through intestines

C) X-rays would pass through the intestines without casting a good shadow for any useful diagnosis

D) A very small exposure of x-rays causes cancer in intestines

Q.57 In X-ray tube, the intensity of the emitted x-rays is increased by

A) Increasing the filament current

C) Increasing the target potential

B) Decreasing the filament current

D) None of these

Q.58 Highest frequency of Balmer series of hydrogen atom in terms of Rydberg constant R_H and velocity of light c is

A) $R_H C$

C) $\frac{4}{R_H C}$

B) $4R_H C$

D) $\frac{R_H C}{4}$

Q.59 The potential difference applied to an X-ray tube in 5k V and the current through it is 3.2 mA. The number of electrons striking the target per second is

A) 2×10^{16}

C) 0.2×10^{16}

B) 0.5×10^{-16}

D) 2×10^{18}

Q.60 The wavelength in air associated with a photon of energy E is (where symbols have their usual meanings)

A) $\frac{hc}{E}$

C) $\frac{c}{hE}$

B) $\frac{h}{cE}$

D) $hc\,E$

Q.61 The minimum wavelength of x-rays produced in x-rays tube is λ_{min} when operating voltage is V. If operating voltage is changed to $\frac{V}{2}$, then the minimum wavelength will become

A) $\frac{\lambda_{min}}{2}$

C) $2\,\lambda_{min}$

B) λ_{min}

D) $4\,\lambda_{min}$

Q.62 Planck's constant has same dimensions as that of

A) Power

C) Angular momentum

B) Linear momentum

D) Stephan's constant

Q.63 $\frac{E_o}{hc}$ has same dimensions as that of (where E_o = Energy of photon, h = Planck's constant, c = speed of light)

A) Length

C) Decay constant

B) Energy

D) None of these

Q.64 If potential difference applied to X-ray tube is V, then maximum frequency of X-rays produced is proportional to

A) V^2

C) $\frac{1}{V^2}$

B) V

D) $\frac{1}{V}$

Q.65 For production of X-rays in X-ray tube, the target used should have

A) High atomic number and low melting point

B) Low atomic number and low melting point

C) Low atomic number and high melting point D) High atomic number and high melting point

Q.66 Lyman series of hydrogen atom lies in

A) Visible region C) Infrared

B) U.V region D) None of these

Q.67 K-series characteristics X-rays are emitted when electron makes transition from

A) L to K shell C) M to K shell

B) M to L shell D) Both A and C

Q.68 K_α-line of characteristic x-rays has______ intensity than the K_β-lines

A) Higher C) Lower

B) Equal D) Sometimes higher and sometimes lower

Q.69 When the accelerating potential difference of the X-rays tube is increased then the wavelength of K-lines

A) Increase C) Decrease

B) Remain unchanged D) None of these

Q.70 If V is the potential difference between cathode and target in x-rays tube, then the velocity with which electrons strike the target is given by

A) $\sqrt{\frac{2V}{me}}$ C) $\sqrt{\frac{m}{2Ve}}$

B) $\sqrt{\frac{Ve}{m}}$ D) $\sqrt{\frac{2Ve}{m}}$

Q.71 In X-ray tube if the electron of the M shell jump to occupy the vacancy in the K shell then the wavelength of emitted photon will be

A) $\lambda_{k\beta} = \frac{E_M - E_k}{hc}$ C) $\lambda_{k\beta} = \frac{E_M - E_L}{hc}$

B) $\lambda_{k\beta} = \frac{hc}{E_M - E_k}$ D) $\lambda_{k\beta} = \frac{hc}{E_M - E_L}$

Q.72 The penetration power of the X-rays can be increased by

A) Increasing the number of electrons hitting the target

B) Increasing the filament current

C) Increasing the potential difference between cathode and anode

D) All of these

Q.73 A tungsten target is struck by electrons that have been accelerated from rest through 124 kV potential difference. The shortest wavelength of bremsstrahlung radiation emitted will be

A) 1×10^{-9} m C) 1×10^{-10} m

B) 1×10^{-11} m D) None of these

Q.74 The minimum wavelength of X-rays is 2 A°. The applied potential difference between cathode and anticathode will be

A) 25.8 kV C) 2.48 kV

B) 62 kV D) 6.2 kV

Q.75 The ratio of energies of first two excited states of hydrogen atom is

A) 4 C) $\frac{4}{9}$

B) $\frac{1}{4}$ D) $\frac{9}{4}$

Q.76 Ground state energy of hydrogen atom is –13.6 eV. It is excited by absorbing a photon of energy 12.1 eV. The quantum number of orbit to which it is excited is

A) 1 C) 3

B) 2 D) 5

Q.77 Continuous spectrum of X-rays is due to

A) Inner shell transitions C) Filament current

B) target D) Braking radiation

Q.78 Braking radiation are usually of _______ wavelengths

A) Shorter C) Longer

B) Medium D) Maximum

Q.79 Which of these series of hydrogen spectrum lies in the ultra-violet region?

A) Paschen series C) Pfund series

B) Brackett series D) Lyman series

Q.80 The ratio of longest and shortest wavelengths of Lyman series is approximately

A) 4/3 C) 9/5

B) 9/4 D) 16/7

Q.81 With increasing quantum number, the energy difference between adjacent levels in atoms

A) Increases C) Remains constant

B) Decreases D) Increases only for high z

Q.82 Characteristic X-rays spectrum is

A) Line C) Band

B) Continuous D) Either A or C

Q.83 Which of the following statement is correct for X-rays?

A) These are electromagnetic waves C) Their penetrating power is high

B) Their velocity is equal to speed of light D) All of these

Q.84 X-rays are similar in nature to

A) α-rays C) Positive rays

B) Cathode rays D) γ-rays

Q.85 The minimum wavelength of X-rays can be reduced by

A) Increasing the temperature of filament

B) Decreasing the temperature of filament

C) Increasing the accelerating potential difference of electron

D) Using a target of lower atomic number

Q.86 Which of the following is the true for both x-rays and α- particles?

A) They can cause ionization of air when they pass through it

B) They can be deflect in electric and magnetic fields

C) They can be used to detect flaws in metal castings

D) They travel with speed of light

Q.87 Insulator is

A) A full valence band

B) An empty valence band

C) An empty valence or partially filled valence band

D) Partially filled valence band

Answers with explanation

Q.1	**(C)**	**Q.2**	**(C)**	$E=\frac{hc}{\lambda}$	**Q.3**	**(C)**	**Q.4**	**(B)**	**Q.5**	**(D)**		
Q.6	**(B)**	$E \propto T^4$			**Q.7**	**(C)**	**Q.8**	**(D)**	$\lambda=\frac{h}{mv}$			
Q.9	**(B)**	**Q.10**	**(B)**	$\lambda=\frac{h}{\sqrt{2meV}}$			**Q.11**	**(B)**	**Q.12**	**(B)**		

Q.13 **(C)** $f=\frac{1}{4}f_o$ This frequency is less than threshold frequency so no photoelectric effect

Q.14	**(D)**	$hf=\varphi+K.E$			**Q.15**	**(D)**	$\lambda=\frac{h}{P}$		**Q.16**	**(B)**		
Q.17	**(D)**	**Q.18**	**(C)**	E = nhf	**Q.19**	**(B)**	**Q.20**	**(B)**	$K.E=hf-\varphi$			
Q.21	**(C)**	$\lambda=\frac{h}{\sqrt{2meV}}$			**Q.22**	**(C)**	$\Delta K.E = mc^2 - m_oc^2$ **so,** $mc^2 = \Delta k.E + m_oc^2$					
Q.23	**(C)**	K.E= eV			**Q.24**	**(C)**	**Q.25**	**(B)**	**Q.26**	**(B)**		
Q.27	**(B)**	**Q.28**	**(D)**		**Q.29**	**(D)**	**Q.30**	**(B)**	$\lambda_{man}\,\alpha\,\frac{1}{T}$			
Q.31	**(B)**	**Q.32**	**(B)**	$t=\frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$			**Q.33**	**(B)**	**Q.34**	**(B)**	$\frac{\in_A}{\in_B}=\frac{P_A}{P_B}$	
Q.35	**(D)**	$hf=\varphi+K.E$			**Q.36**	**(C)**	K.E = eV.		**Q.37**	**(D)**		
Q.38	**(A)**	**Q.39**	**(B)**	$\varphi=hf$	**Q.40**	**(A)**	**Q.41**	**(C)**	**Q.42**	**(A)**	**Q.43**	**(D)**
Q.44	**(A)**	**Q.45**	**(A)**	$\lambda=\frac{h}{mv}$	**Q.46**	**(A)**	$\lambda=\frac{h}{mv}$					
Q.47	**(A)**	$\lambda=\frac{h}{\sqrt{2m\,K.E}}$			**Q.48**	**(D)**	**Q.49**	**(B)**	**Q.50**	**(C)**	**Q.51**	**(A)**
Q.52	**(B)**	**Q.53**	**(D)**	$mvr=\frac{nh}{2\pi}$			**Q.54**	**(D)**	**Q.55**	**(D)**	$K.E=eV_o$	

Q.56 **(C)** Soft tissue does not absorb X-rays

Q.57 **(A)** Intensity of X-rays is proportional to filament current.

Q.58	**(D)**	$\frac{1}{\lambda}=R_H\left(\frac{1}{4}\right)$	**Q.59**	**(A)**	I =q/t	**Q.60**	**(A)**	
Q.61	**(C)**	$\lambda_{min}=\frac{hc}{eV}$	**Q.62**	**(C)**	$mvr=\frac{nh}{2\pi}$			

Q.63 **(D)** $\frac{1}{\lambda}=R_H=m^{-1}$

Q.64 **(B)** $hf_{max}=eV$

Q.65 **(D)** Target should have high atomic number and high melting point.

Q.66 **(B)** Lyman series lie in ultraviolet

Q.67 **(D)** K- series consist of both k_{α} and k_{β}

Q.68 **(A)** More photons of K_{α} are produced than that of K_{β}

Q.69 **(B)** Wavelength of lines does not depend upon P.D

Q.70 **(D)** $eV = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2Ve}{m}}$

Q.71 **(B)** **Q.72** **(C)** $\lambda_{min} = \frac{hc}{eV}$ **Q.73** **(B)** $\lambda_{min} = \frac{hc}{eV}$

Q.74 **(D)** $V = \frac{hc}{e\lambda_{min}}$ **Q.75** **(D)** $E_n = -\frac{E_o}{n^2}$

Q.76 **(C)** Energy will be added to existing energy $-13.6 + 12.1 = -1.5$; So it is excited to third state

UNIT 16 Nuclear Physics

The branch of physics which deals with the properties of atomic nuclei is called nuclear physics

Atomic Nucleus:

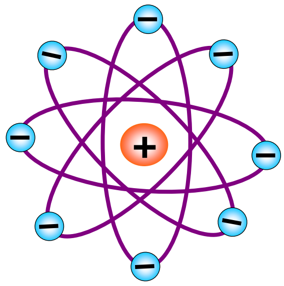
"The central core of the atom which contains all of the atom's positive charge and most of its mass is known as atomic nucleus"

- The size of the nucleus is much smaller than that of atom. In fact, the size of the nucleus is 10,000 times smaller than the size of the atom.
- More than 99.9 % of the whole mass of the atom is concentrated in the nucleus.
- Density of nucleus is 10^{17} kg m^{-3}
- It contains two particles named proton and neutron. They are as *nucleons*

- Electron was discovered by J.J Thomson.
- Proton was discovered by Goldstein.
- Neutron was discovered by James Chadwick.
- Nucleus was discovered by Rutherford.

Nucleons

Protons | Neutrons



- **Proton** is a positively charged particle and has a charge equal to that of an electron. However, the mass of a proton is about 1836 times that of the electron. Charge on proton, e = + 1.6 × 10^{-19} C
- **Neutron** is a neutral particle i.e. it has no charge. Its mass is about 1840 times that of the electron. Charge on neutron = Zero

Atomic Mass Unit:

- The SI unit of mass is kg. However, the atomic and nuclear masses are very small so that we measure them in a smaller unit of mass called atomic mass unit (a.m.u)

  "1 atomic mass unit (a.m.u.) is equal to one-twelfth (1/12) mass of 1 atom of ${}_6C^{12}$"

$$1 \text{ a.m.u.} = \frac{1}{12} \times \text{Mass of 1 atom of } {}_6C^{12}$$

Now Mass of 6.023 × 10^{23} atoms of ${}_6C^{12}$ = 12 g

$$\text{Mass of 1 atom of } {}_6C^{12} = \frac{12}{6.023 \times 10^{23}} \text{ g}$$

$$\therefore \quad 1 \text{ a.m.u.} = \frac{1}{12} \times \frac{12}{6.023 \times 10^{23}} = 1.66 \times 10^{-24} g$$

$$\boxed{1 \text{ a.m.u.} = 1.66 \times 10^{-27} \text{ kg}}$$

- Mass of electron, m_e = 0.00055 a.m.u. = 9.11 × 10^{-31} kg
- Mass of proton, m_p = 1.007276 a.m.u. = 1.673 × 10^{-27} kg
- Mass of neutron, m_n = 1.008665 a.m.u. = 1.675 × 10^{-27} kg

Nuclear notation:

A nucleus of an atom is specified by its atomic number Z and mass number A. A nucleus is represented as: ${}_Z^A X$

Where X = Chemical symbol of the element

Z = Atomic number of the element

A = Mass number of the element

- Nucleus of protium atom is called **proton**
- Nucleus of deuterium atom is called **deuteron**
- Nucleus of tritium atom is called **triton**

- **Atomic Number** or charge number or proton number is defined as the number of protons inside a nucleus
- **Mass number** or nucleon number is defined as the sum of number of protons and neutrons inside a nucleus

$$A = \text{Number of protons} + \text{neutrons}$$
$$A = Z + N$$
or
$$\boxed{N = A - Z}$$

Isotopes

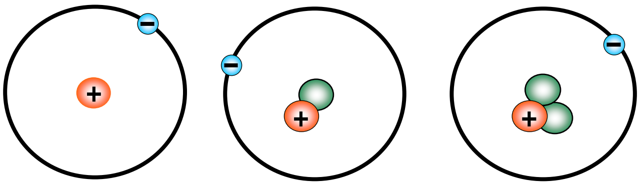
"Nuclei of an element which have same atomic number but different mass number of neutrons are called isotopes"

Isotopes of carbon: ${}_6C^{10}$, ${}_6C^{11}$, ${}_6C^{12}$, ${}_6C^{14}$

Isotopes of Oxygen: ${}_8O^{16}$, ${}_8O^{17}$, ${}_8O^{18}$

Isotopes of Hydrogen: ${}_1H^1$, ${}_1H^2$, ${}_1H^3$

- Isotopes have same chemical properties (same electrons configuration) but different physical properties.
- Isotopes are separated due to their different physical properties.
- Isotopes of an element have the same number of protons and electrons but the number of neutrons is different. Hence the atomic weights of the isotopes of an element are different.
- Both xenon and cesium each have 36 isotopes.



$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Isobars have same 'A' but different 'Z' e.g. $^{14}_{6}C$ and $^{14}_{7}N$

Isotones have same 'N' but different 'Z' e.g. $^{3}_{1}H$ and $^{4}_{2}He$

Stability of Nucleus

- There is no membrane around nucleus and due to repulsion between protons, nucleus should collapse; but it does not happen.
- Strong nuclear force hold nucleus and is stronger than electrostatic force of repulsion.
- Strong nuclear force is short range force and its range is 10^{-15}m.
- Besides strong nuclear force, exchange particles are exchanged between nucleons so make the nucleus stable.
- B.E per nucleon is also responsible for nuclear stability.

Mass Defect And Binding Energy

"The difference between the sum of the masses of nucleons (protons and neutrons) in the nucleus and the actual mass of the nucleus is called mass defect"

$$\Delta m = Zm_p + (A - Z)m_n - m_{nuclues}$$

- Mass is decreased when protons and neutrons are combined to form a nucleus and this decease in mass is converted into energy (binding energy) according to Einstein's equation.
- ***Binding Energy*** is the energy required to liberate all the nucleons from the nucleus i.e., separating the protons and neutrons of the nucleus infinite distance apart.

Binding energy per nucleon of nucleus:

The binding energy per nucleon (B.E/ nucleon) is the average energy required to extract one nucleon from the nucleus to infinite distance. It is given by the total binding energy of a nucleus divided by the mass number of the nucleus i.e. $\text{B.E / nucleon} = \frac{\text{B.E}}{\text{A}}$

Binding Energy Curve:

The curve between binding energy per nucleon and the mass number A for various nuclei is called binding energy curve.

- Except for lighter nuclei (A < 30), the average binding energy per nucleon is about 8 MeV for all nuclei.
- The nuclei with A ; 60 have large binding energy per nucleon and are also very stable.
- The binding energy per nucleon is small for both light nuclei (A < 30) and heavy nuclei (A> 170).
- The binding energy per nucleon is practically constant (i.e. practically independent of mass number) for nuclei of middle mass number (A = Between 30 and 170).

- B.E per nucleon reaches a maximum value of 8.8 MeV at a mass number of 58 and then it decreases gradually to a value of 7.6MeV at a mass number of 238.
- Iron is the most stable element because its binding per nucleon is maximum.

Relation between a.m.u. and MeV

According to Einstein, mass and energy are equivalent so that one can be converted into the other. Therefore, using Einstein equation $E = mc^2$, we can have energy equivalent of mass of 1 a.m.u.

$$E = mc^2$$

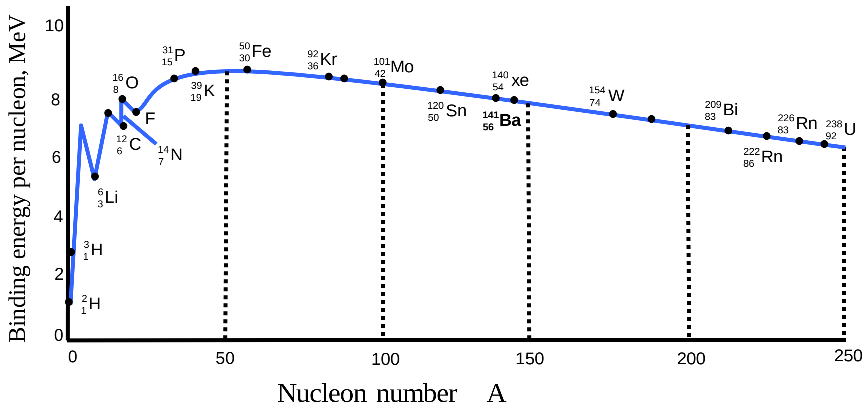
Here $m = 1 \text{ a.m.u} = 1.66 \times 10^{-27}$ kg ; $c = 3 \times 10^8 \text{ ms}^{-1}$

$\therefore$ $E = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 \text{ J} = 1.49 \times 10^{-10}$ J

Now $1 \text{ MeV} = 1.6 \times 10^{-13}$ J

$$E = \frac{1.49 \times 10^{-10}}{1.6 \times 10^{-13}} \text{ MeV} = 931.5 \text{ MeV}$$

or $1 \text{ a.m.u.} = 931.5$ MeV



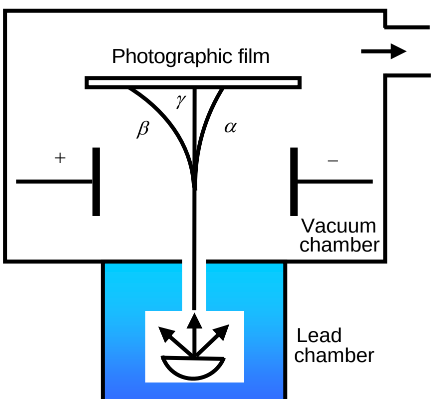
Did You Know?

- Mass defect is zero for ${}^{1}_{1}H$
- Mass defect has largest value for iron

Radioactivity

The process of spontaneous (i.e., without external means by itself) disintegration of the nuclei of heavy elements with the emission of certain types of radiations is called radioactivity.

- Elements with Z>82 emit invisible radiation that affect photographic plates. These elements are called radioactive elements.
- It was discovered (through uranium ore) by Becquerel in 1896.
- Polonium and radium were discovered by Curies.



- There are three types of nuclear radiation.
- α Particles are helium nuclei. Charge= + Ze = + 2e
  and mass + 4u.
  It consists of two protons and two neutrons.
- β-particles are negatively charged electrons coming out of the nucleus of radioactive elements.
- γ-rays are massless and charge less photons.
- The number of radioactive elements known at present is 40.

Note. **It is important to note that α-particles bend towards the negative plate by a small amount showing that they are heavy positively charged particles. On the other hand, β particles bend towards the positive plate by a large amount showing that they are light negatively charged particles.**

Nuclear Transmutation

"The phenomenon of conversion of a nucleus into a new nucleus after radioactivity is called nuclear transmutation or nuclear decay"

- Radioactivity is purely nuclear phenomenon and does not depend upon physical or chemical properties.
- Law of conservation of mass, energy, momentum and charge are applicable during nuclear change.
- Three types of decays are there

Alpha Decay:

The phenomenon of emission of α-particle from a radioactive nucleus is called α-decay

- After emission of an alpha particle from a nucleus, its atomic number decreases by 2 and mass number decreases by 4.
- When a nucleus emits an alpha particle, actually two protons and two neutrons are emitted from it.

$^{A}_{Z}\mathbf{X}$ ® $^{A-4}_{Z-2}\mathbf{Y} + ^{4}_{2}\mathbf{He}$

e.g. $^{226}_{88}\mathbf{Ra} \rightarrow ^{222}_{86}\mathbf{Rn} + ^{4}_{2}\mathbf{He}$

Beta Decay:

The phenomenon of emission of a beta particle from a radioactive nucleus is called β decay.

- After emission of a negative beta particle from a nucleus, its atomic number increases by 1 and mass number remains the same.

$^{A}_{Z}\mathbf{X}$ ® $^{A}_{Z+1}\mathbf{Y} + ^{0}_{-1}\mathbf{e}$

e.g. $^{234}_{90}\mathbf{Th} \rightarrow ^{234}_{91}\mathbf{Pa} + ^{0}_{-1}\mathbf{e}$

- Electron emitted does not reside inside the nucleus but is produced just at the time of emission.
- In β^- decay, a neutron inside the nucleus is converted into an a proton emitting an electron
- In some β^+ decays, a positron instead of an electron is emitted. A positron is similar to an electron in all respects except that it has a charge +e instead of –e.

- In β^+ decay, a proton inside the nucleus is converted into a neutron emitting a positron

$$\boxed{{}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e}$$

e.g. $\quad {}^{17}_{9}F \rightarrow {}^{17}_{8}O + {}^{0}_{1}e$

Gamma Decay:

The phenomenon of emission of gamma ray photon from a radioactive nucleus is called γ *decay*.

- After emission of a γ ray photon from a nucleus, it's atomic and mass numbers remain the same.

$$\boxed{{}^{A}_{Z}X^* \rightarrow {}^{A}_{Z}X + \gamma}$$

- It means that no new nucleus is formed as γ-rays are massless and charge less photon. This emission is similar to the emission when electron returns from excited state to ground state.

  How, you may wonder, does nucleus get into an excited state? The more common cause is the emission of an α or β-particle from the parent nucleus. The daughter nucleus may be created with one of its protons or neutrons in an excited state. As the proton or neutron returns to its ground state, a γ-ray is emitted.

- In any radioactive decay, either an α-particle or β-particle is emitted by the atom. Both the particles are not emitted simultaneously. Moreover, an atom does not emit more than one α-particle or more than one β-particle at a time. On emission of α-particle or β-particle, the new atom formed may emit γ-ray photon in case the nucleus is left in the excited state.

Did You Know?

- An α-particle is a doubly ionized helium atom.
- A β-particle is fast moving electron emitted from nucleus.
- A γ-particle is photon emitted by a nucleus.

Half life

"The time taken by half of the atoms of a radioactivity sample to decays is called half life"

$$\boxed{T_{1/2} = \frac{0.693}{\lambda}}$$

- Radioactivity decay is a random process and it is the nuclear property of the atom. It does not depend upon the physical or chemical properties (condition) of nucleus.

Decay law:

$$\Delta N \propto -N\Delta t$$

Where λ is called decay constant of radioactive element

- Negative sign indicates decrease in number of un decayed atom N.

- Decay constant is given as $\boxed{\lambda = \frac{\Delta N / N}{\Delta t}}$

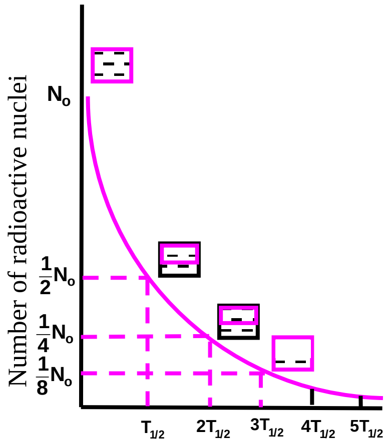
It is defined as "**fraction of atoms decaying per unit time**"

- Unit of decay constant is s^{-1}
- The emission of radiations from a radioactive substance is a matter of chance and there is no way to decide when any particular nucleus will disintegrate. Half life of an element can have any value, two seconds or two years.

2nd law of radioactivity

No radioactive elements can completely decay. An infinite time is required for all the atoms of radioactivity elements to decay.

- Half life of radium -226=1620 years
- Half life of uranium -238=4.5×10^9 years
- Half life of radon gas = 3.8 days



Activity of a radioactive element:

Reconsider the above equation i.e $\boxed{\frac{\Delta N}{\Delta t} = \lambda N}$

Activity is defined as "**Number of atoms decaying per unit time**

It can also be defined as" **rate of disintegration (i.e. number of disintegrations per second) in a radioactive substance is known as its activity**

$\boxed{A = \frac{\Delta N}{\Delta t}}$ or $\boxed{A = \lambda N}$

- Its unit is also being s^{-1}
- It is clear that the activity of a radioactive substance is inversely proportional to its half-life.

Units of Activity (or Radioactivity):

- **Becquerel (Bq)**

  The SI unit of activity is Becquerel (Bq). One Becquerel is equal to an activity of 1disintegration per second.

  1 Bq= dps

- **Curie (Ci)**

  The activity of a radioactive sample is said to be one curie (1Ci) if it undergoes 3.7×10^{10} disintegrations per second i.e.

  1 curie (1Ci) =3.7×10^{10} dps

  In practical, we use smaller unit viz,

  1 millicurie (1 mCi) = 3.7×10^7 dps

1 microcurie (1 μCi) = 3.7×10^4 dps

- **Rutherford (rd)**

  The activity of a radioactive substance is said to be one Rutherford (1 rd) if it undergoes 10^6 disintegrations per second i.e.

  1 rutherford (rd) = 10^6 dps

- After n half lives, numbers of nuclei undecayed are given as

$$\text{Undecayed} = \left(\frac{1}{2}\right)^n N_0$$

and

$$\text{Decayed} = N_0 - \left(\frac{1}{2}\right)^n N_0$$

Did You Know?

All transuranic elements finally decay into lead

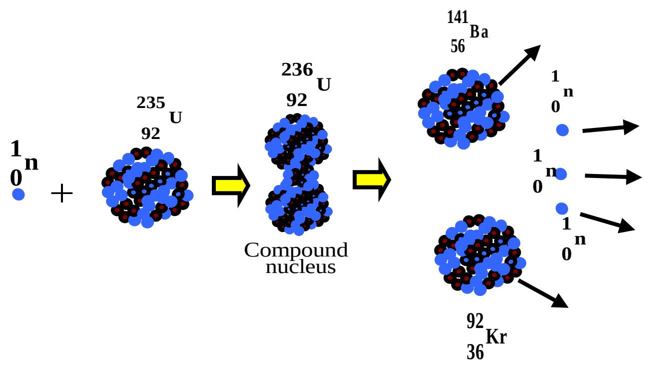
Where N_0= Number of undecayed atoms at t =0

NUCLEAR FISSION

"The process of splitting up of a heavy nucleus into lighter nuclei with the release of tremendous amount of energy"

- A typical nuclear fission reaction performed by Otto Hahn and Fritz Strassman is given below

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^* \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3^{1}_{0}n + Q$$



$^{236}_{92}U^*$ is the compound nucleus which decays to Kr and Ba,

As binding energy per nucleon for uranium is 7.6MeV and average binding energy per nucleon for $^{141}_{56}Ba$ and $^{92}_{36}Kr$ is 8.5MeV , so energy released per nucleon =8.5-7.6=0.9MeV per nucleon.

- Hence total energy released =235×0.9 = 211 MeV
- Fission can also take place with other heavy nuclei e.g plutonium -239.

  Critical Mass is the mass of uranium in which one neutron, out of all the neutrons produced in one fission reaction, produces further fission, is critical mass. The volume of this mass is called *critical volume.*

Fission Chain Reaction

Uncontrolled Fission Chain Reaction

Mass > critical mass
e.g. atomic bomb

Controlled Fission Chain Reaction

Mass < critical mass
e.g. atomic reactor

NUCLAEAR FUSION

Such nuclear reaction in which lighter nuclei combine to forma heavy nucleus with the release of tremendous energy

- Fusion reaction on the surface of earth

  $\mathbf{{}_1^2H + {}_1^2H \rightarrow {}_1^3H + {}_1^1H + 4MeV}$ (B.E Nucleon = 4/4=1MeV/Nucleon)

  $\mathbf{{}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.3MeV}$ (B.E Nucleon = 3.3/4=0.825MeV/Nucleon)

  $\mathbf{{}_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n + 17.6MeV}$ (B.E Nucleon = 17.6/5=3.52MeV/Nucleon)

  The above reaction is more energetic than fission.

- To start fusion, the temperature is increased to a very large value about 10 million degrees Celsius so that speed of smaller nuclei becomes greater and hence the smaller nuclei fuse to form a heavy nucleus.
- Nuclear fusion takes place in hydrogen bomb.

Nuclear Fusion in the Sun:

- The temperature of the core of sun is about 20 million degrees Celsius and its surface temperature is about 5 million degrees Celsius.
- In this reaction two hydrogen nuclei ${}_1^1H$ or protons fuse to form deuteron ${}_1^2H$ as give below

$${}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0e + Energy$$
$${}_1^1H + {}_1^2H \rightarrow {}_2^3He + \gamma - ray + Energy$$

$${}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0e + Energy$$
$${}_1^1H + {}_1^2H \rightarrow {}_2^3He + \gamma - ray + Energy$$

Net reaction is ${}_2^3He + {}_2^3He \rightarrow {}_2^4He + {}_1^1H + {}_1^1H + \gamma - ray + 2{}_1^0e + energy$

- Energy released = 25.7MeV and 6.4 MeV /Nucleon which is much greater than the energy released in fission reaction 1 MeV /Nucleon)

COMPARISON BETWEEN FISSION AND FUSION:

S. #	Particular	Fission	Fusion
1	Process	Heavy nucleus splits into middle-weight nuclei	Light nuclei form heavy nucleus
2	Energy per nucleon	Less	More
3	Materials used	U^{235}, Pu^{239} and some others	Deuterium, tritium, Lithium
4	Availability of materials	Limited, expensive	Unlimited, cheap

5	Radioactive isotopes	Many	Almost none
6	Reaction	Occurs when a slow neutron is absorbed by the nucleus	Occurs at a very high Temperature (2 to 3 million °C)

RADIATION EXPOSURE

- Background radiation is the radiation present around us although no radioactive source is close to us.
- Background radiation is due (i) cosmic radiation consisting of high energy charged particles and (ii) naturally occurring radioactive substance in the Earth's crust.
- The ozone layer around Earth filter ultraviolet rays reaching us. The depletion of ozone layers may result in increased eye and skin diseases.
- Chlorofluorocarbons (CFC) used in refrigeration, aerosol spray and plastic foam industry is the reason of depletion of ozone layer.
- Radon gas level inside the building can be reduced by ventilation.
- The most common radioactive substance in food are potassium -40 and carbon -14 isotopes.
- X-rays exposure is the main cause of radiation exposure due to human activities. The other source of radiation due to human activities include radioactive waste from nuclear facilities, hospitals, research and industries, color television luminous watches and tobacco leaves.

BIOLOGICAL EFFECTS OF RADIATION

Activity:

- It is defined as the number of disintegrations of radioactivity sample per second. It shows the strength of radiation.
- It SI units are Becquerel

1Bq = 1 disintegration per second

A practical unit is curie

$$1\text{ci (curie)} = 3.7\times10^{10}\text{ Bq}$$

$$1\text{ci (curie)} = 3.7\times10^{10}\text{ dps}$$

Absorbed Dose:

Energy of ionizing radiations absorbed per unit mass is called absorbed dose

$$\boxed{D = \frac{E}{m}}$$

- Its units are 1 Gray = 1J kg^{-1} (SI Units)
- 1 rad (radiation absorbed dose) = 0.01 Gy.

Biological Effects of Equal Doses of Different Radiations:

- Equal doses of different radiation do not produce same biological effect. For same absorbed dose , α-rays are 20 times more damaging than X-rays .
- The effects also depend on the part of the body absorbing the radiation. Neutrons are particularly more damaging to eye than any other part of the body.

Equivalent Dose (De):

$$\boxed{D_e = D \times RBE}$$

- Equal equivalent dose means same effect.
- Its units are 1Sv = Gy RBE

1 rem = 0.01 Sv

Relative Biological Effectiveness (RBE)	
Radiations	**RBE**
X-rays , γrays,α-particles of 30 keV or more	1.0
α-particles of less than 30 keV	1.7
Neutrons and protons below 10 MeV	10
α-particles from natural radioactivity	30
Heavy recoil nuclei	10

General information about biological effects of radiation:

- The background radiation, to which we are exposed, on the average, is 2mSv per year.
- Dose of 3 Sv will cause radiation burns to the skin.
- For workers in the nuclear facilities or mines, a weekly dose of 1mSv is normally considered safe.
- The damage of α-particles is small unless the source enters the body.
- α and β particles can cause redness and sores on the skin.
- Some other low level radiation effects are loss of hair, ulceration, stiffening of lungs, and a drop in the white blood cells which is followed by a sickness pattern of diarrhea, vomiting and fever known as radiation sickness.
- High level of radiation may disrupt the blood cells seriously leading to disease such as anemia and leukemia.
- Chromosome abnormalities or mutation may cause delayed genetic effects such as cancer.

BIOLOGICAL AND MEDICAL USES OF RADIATION

Tracer Techniques:

A radioactivity used to indicate or trace to path followed by chemical or biological process.

- In this technique, we substitute radioactive atoms for stable atoms of the same kind in a substance and then we follow the tagged atoms with the help of radiation detector on the process.

Applications:

- It is used in agriculture e. g C-14 has helped to study the process of photosynthesis.
- It was used to identify faults in the underground pipes of the fountain system of the historical Shalimar gardens of Lahore by scientist of Pakistan atomic energy commission.
- It is used in medical diagnostics and therapy.
- Radioactive iodine can be used to check that whether a person's thyroid gland is working properly or not. A diseased or a hyperactive gland absorbs more than twice the amount of normal thyroid gland.
- A similar method is employed to study the circulation of blood using radioactive isotopes sodium -24.
- Radio therapy with γ-rays from cobalt -60 is used in the treatment of cancer.
- Radioactive iodine -131 is used for treatment of thyroid cancer.
- For skin cancer, phosphorous -90 is used for skin cancer.
- Patient undergoing radiation treatment often feels ill, because the radiation also damages the healthy cells.

Radiography:

- It is the process in which images are obtained by passing radioactive rays through a body.
- It is used for determination of the size and location of a tumor. Any sudden increase in count rate of γ-particles indicates activity within the object.

For Your Information

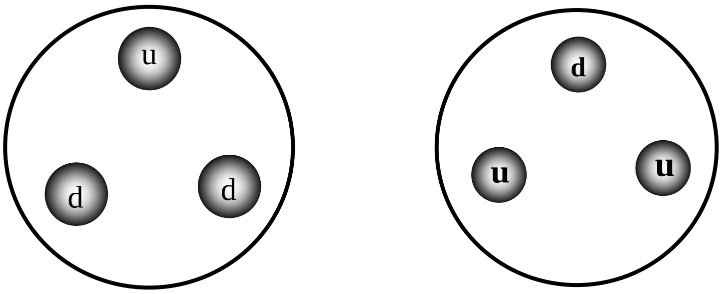
Film badge dosimeters are used to monitor radiation received by works in nuclear facilities.

Building Blocks of Matter					
Quarks				Antiquarks	
Name	Symbol	Charge		Symbol	Charge
Up	u	$+\frac{2}{3}e$		$\bar{u}$	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$		$\bar{d}$	$+\frac{1}{3}e$
Strange	s	$-\frac{1}{3}e$		$\bar{s}$	$+\frac{1}{3}e$
Charm	c	$+\frac{2}{3}e$		$\bar{c}$	$-\frac{2}{3}e$
Top	t	$+\frac{2}{3}e$		$\bar{t}$	$-\frac{2}{3}e$

Bottom	b	$-\frac{1}{3}e$	$\bar{b}$	$+\frac{1}{3}e$

Quarks:

- According to quark theory of M-Gel Mann and G. Zweig, the quarks are proposed as the building blocks of the mesons and Baryons.
- A pair of quark and antiquark makes meson.3 quarks make a baryon.
- It is believed that quarks can not exist on their own; their existence has been indirectly verified.



Proton **Neutron**

Some Brain teasers for your practice

(1) You are given two nuclides ${}_3X^7$ and ${}_3Y^4$.

(i) Are they isotopes of the same element?

(ii) Which one of the two is likely to be more stable?

(2) Can a single nucleus emit α-particle, β-particle and γ-rays together.

(3) A radioactive substance emits either α-particle or β-particle only. Then why is radioactive radiation divided into three parts on applying electric or magnetic field?

(4) When does β-decay occur?

(5) Can radioactivity be controlled?

(6) Plutonium has a half-life of 24,000 years. What fraction of it will remain after 72,000 years?

(7) Suppose there is nuclear mass of size of 0.1 mm. Will you be able to lift it yourself?

(8) How many α and β particles are emitted when ${}_{90}Th^{232}$ changes to ${}_{82}Pb^{208}$?

(9) The half-life of a radioactive substance is 30 days. What is the time taken for 3/4th of its original mass to disintegrate?

(10) If the activity of a radioactive element drops to 1/32th of its initial value in 50 years, find its half-life period.

PRACTICE QUESTIONS

Q.1 α, β and γ radiations come out of a radioactive substance

A) When it is put under pressure
B) When it is put in a reactor
C) When it is heated
D) Spontaneously

Q.2 In alpha decay, the ratio of decrease in proton number to the decrease in neutron number is

A) 2 : 1
B) 1 : 2
C) 1 : 1
D) 4 : 1

Q.3 The mass number of a nucleus is

A) Always less than its atomic number

B) Always more than its atomic number

C) Sometimes equal and sometimes smaller than its atomic number

D) Sometimes equal and sometimes larger than its atomic number

Q.4 A given radioactive sample is reduced from 20 g to 1.25 g in 40 days. Its half life would be

A) 10 days C) 8 days

B) 5 days D) None of these

Q.5 After two hours, one sixteenth of the starting amount of a certain radioactive isotope remains undecayed. The half-life of the isotope is

A) 15 minutes C) 45 minutes

B) 30 minutes D) 1 hour

Q.6 The percentage of the original quantity of a radioactive material left after five half lives is approximately

A) 1 % C) 5 %

B) 3 % D) 20 %

Q.7 Choose the correct

A) Gamma rays are high energy neutrons

B) Protons and neutrons have exactly the same mass

C) Beta rays are similar in nature to cathode rays

D) Alpha particles are singly ionized helium atoms

Q.8 Fusion reaction takes place at high temperature because

A) Atoms are ionized at high temperature

B) Molecules break up at high temperature

C) Nuclei break up at high temperature

D) Kinetic energy is high enough to overcome repulsion at high temperature

Q.9 If the end A of a wire is irradiated with alpha rays and the end B is irradiated with beta rays then

A) A current will flow from B to A

B) A current will flow from A to B

C) A current will flow from each end to the midpoint of the wire

D) There will be no current in the wire

Q.10 Neutron is made of

A) Two up and one down anti quark C) Two up and one down quark

B) Two down and one up anti quark D) Two down and one up quark

Q.11 Electrons, muons and neutrinos belong to the family of

A) Baryons C) Leptons

B) Mesons D) Hadrons

Q.12 Nuclear density is very high. It is order of 10^{17} kg m^{-3} because (choose incorrect)

A) 99.9 % of whole mass of atom is concentrated in nucleus

B) Size of nucleus is 10,000 times larger than that of atom

C) Size of nucleus is 10,000 times smaller than that of atom

D) None of these

Q.13 Number of protons, electrons and neutrons in a nucleus of atomic number 11 and mass number 24 are

A) 11, 13, 0

B) 24, 0, 11

C) 11, 0, 13

D) 0, 13, 11

Q.14 Two nucleons are at a separation of 1×10^{-15} m. The net force between them is F_1 if both are neutrons, F_2 if both are protons and F_3 if one is proton and the other is neutron. In such a case

A) $F_2 > F_1 > F_3$

B) $F_1 = F_2 > F_3$

C) $F_1 = F_3 > F_2$

D) $F_1 = F_2 = F_3$

Q.15 One milligram of matter converted into energy will give

A) 9×10^5 J

B) 9×10^3 J

C) 90 J

D) 9×10^{10} J

Q.16 The particle whose emission does not affect the charge number and nucleon number of nucleus

A) α-particles

B) β-particles

C) γ- particles

D) None of these

Q.17 When thorium ($_{90}Th^{234}$) emits a β-particle, the difference in neutron numbers of parent and daughter nuclei will be

A) 0

B) 1

C) 2

D) Infinite

Q.18 Consider a radioactive material of half-life 1 minute. If one of the nuclei decays now, the next one will decay

A) After one minute

B) After two minutes

C) After any time

D) After $\frac{1}{2}$ minute

Q.19 An 40 kg person receives a whole body radiation dose of 20 mrad delivered by α-particles for which RBE factor is 12. The absorbed energy in joules would be

A) 1 m J

B) 0.1 m J

C) 10 m J

D) 8 m J

Q.20 A nucleus having nucleon number 14 and charge number 7 captures an α - particle and then emits a proton. The resulting nucleus will be

A) $^{16}_{8}O$

B) $^{17}_{8}O$

C) $^{18}_{8}O$

D) $^{17}_{9}F$

Q.21 Most of the cobalt is absorbed by

A) Bones

B) Skin

C) Liver

D) Thyroid gland

Q.22 If $_{92}U^{233}$ decays twice by α-emission, the resulting isotopes will be

A) $^{225}Ra_{88}$

B) $^{225}Rn_{86}$

C) $^{234}Pa_{88}$

D) $^{229}Th_{90}$

Q.23 **α - particles from natural radioactivity has equivalent dose of 20 Sv for a person having mass of 40 kg. The energy that is absorbed by that person due to α - particles**

A) 10 J
B) 100 J
C) 80 J
D) 500 J

Q.24 **What is the ratio of undecayed and decayed nuclei of a radioactive element after 3 half lives have elapsed?**

A) 1/7
B) 7
C) 7/8
D) 8/7

Q.25 **The pressure of suitable mixture of the gas, used in GM tube is**

A) 1 atmosphere
B) 10 atmosphere
C) 0.1 atmosphere
D) None of the option is correct

Q.26 **Which one of the following is incorrect diameter?**

A) Molecule (10^{-9} m)
B) Atom (10^{-10}m)
C) Nucleus (10^{-15} to 10^{-14} m)
D) Quark (equal to 10^{-18} m)

Q.27 **At higher energies (More than 1.02 MeV) the dominant process of electromagnetic radiations with matter is**

A) Photo electric effect
B) Compton's effect
C) Pair production
D) Both B and C

Q.28 **$+\frac{2}{3}$e is the charge on**

A) Down quark
B) Charm quark
C) Bottom quark
D) None of these

Q.29 **The order of penetration power of α and β and γ -rays is**

A) $\alpha > \beta > \gamma$
B) $\alpha > \beta < \gamma$
C) $\alpha < \beta > \gamma$
D) $\alpha < \beta < \gamma$

Q.30 **Two radioactive elements X and Y have half- lives of 30 minutes and 90 minutes respectively. Sample of X and Y initially contain equal numbers of atoms. After 180 minutes what is the value of the following fraction?**

$$\frac{\text{No. of nuclei of X unchanged}}{\text{No. of nuclei of Y unchanged}}$$

A) 1 : 16
B) 16 : 1
C) 1 : 32
D) 32 : 1

Q.31 **If half-life of a substance is 3.5 days and its quantity is 16.0 g. Then the quantity left after 14 days will be**

A) 0.25 g
B) 0.5 g
C) 1.0 g
D) 2.0 g

Q.32 **The SI unit(s) of activity is (are)**

A) Becquerel
B) Curie
C) Rutherford
D) All of these

Q.33 In the uranium radioactive series the initial nucleus is $^{238}_{92}U$ and the final nucleus is $^{206}_{82}Pb$. When the uranium nucleus decays to lead, the number of α-particle and β-particle are

A) $8\alpha, 6\beta$
B) $10\beta, 6\alpha$
C) $8\alpha, 8\beta$
D) $12\alpha, 6\beta$

Q.34 When $_{84}Po^{218}$ emits β- particle then neutron to proton ratio of the resulting isotope would be

A) 85/133
B) 133/85
C) 85/134
D) 134/85

Q.35 Which one of the following pair is of isobars

A) $^{12}_{6}C$ and $^{14}_{6}C$
B) $^{4}_{2}He$ and $^{3}_{1}H$
C) $^{14}_{6}C$ and $^{14}_{7}N$
D) Both A and C

Q.36 If the decay constant of an element is smaller then

A) More of its atoms will decay in a particular interval
B) Less of its atoms will decay in a particular interval
C) Its infinite atoms will decay in a particular interval
D) Both A) and B) are possible depending upon the half life of element

Q.37 Beta rays emitted by a radioactive material are

A) Electromagnetic radiations
B) Electrons orbiting around the nucleus
C) Negatively charged particles emitted by the nucleus
D) All of these

Q.38 The sample of radioactive element decayed after 5 – half lives

A) $\frac{1}{32}N_o$
B) $\frac{31}{32}N_o$
C) $\frac{N_o}{31}-\frac{N_o}{32}$
D) $\frac{N_o}{32}-\frac{N_o}{31}$

Q.39 In negative β emission, atomic number of daughter nucleus?

A) Increases by 1
B) Decreases by 1
C) Remains constant
D) Increases by 2

Q.40 If number of atoms radioactive elements is N_0 ,then number of atoms decayed after four half-lives is ?

A) $\frac{15}{16}N_o$
B) $\frac{31}{32}N_o$
C) $\frac{1}{16}N_o$
D) $\frac{1}{32}N_o$

Q.41 After α-emission from $^{226}_{88}Ra$, the daughter nucleus will be

A) $^{226}_{86}Ra$
C) $^{226}_{86}Ra$

B) $^{226}_{86}Rn$ D) $^{222}_{86}Rn$

Q.42 After β-emission from nucleus, which particle is/are formed?

A) proton C) Electron

B) Neutron D) Proton and electron

Q.43 An α-emission is always accompanied by

A) β-emission C) Both A and B

B) γ-emission D) Neutron

Q.44 If decay constant is doubled, then half life is

A) Reduced to half of its original C) Reduced to one forth of its original value

B) Doubled D) Unchanged

Q.45 Ion pairs per mm produced in air by γ-rays is about

A) 1 C) 3

B) 2 D) 4

Q.46 Range of γ-rays in air obeys

A) Square law C) Linear law

B) Cube law D) Inverse square law

Q.47 Which one is used for treatment of liver cancer?

A) Nal C) Kr

B) Cobalt -60 D) Na -24

Q.48 Strontium-90 is used as a

A) β-source C) γ-source

B) α-source D) Neutron source

Q.49 Which one has the highest penetrating power?

A) Alpha rays C) Gamma rays

B) Bata rays D) Neutron

Q.50 Which one is the most energetic reaction

A) Fission C) Chemical reaction

B) Fusion D) All are equally energetic

Q.51 Which radioactive element is present in air

A) U C) Rn

B) Kr D) Ra

Q.52 Which of these force has the longest range?

A) Gravitational force C) Magnetic force

B) Electromagnetic force D) Strong nuclear force

Q.53 Subatomic particles are divided into how many groups

A) 1 C) 2

B) 4 D) 3

Q.54 The range of weak nuclear force is

A) 10^{-12}m C) 10^{-17}m

B) 10^{-15} m D) 10^{-13}m

Q.55 Photosynthesis may be traced by

A) C-12 C) C-14

B) C-13 D) C-15

Q.56 Neutrons are particularly more damaging to

A) Eyes C) Nose

B) Legs D) Brain

Q.57 1 rem =

A) 1 Sv C) 0.001Sv

B) 0.1Sv D) 0.01 Sv

Q.58 In fast factors, we do not require

A) Fuel C) Moderators

B) Control rods D) Coolant

Q.59 If mass of U-235 is less than the critical mass then

A) No fission chain reaction takes place C) Uncontrolled fission takes place

B) Controlled fission takes place D) None of these

Q.60 The SI unit of decay constant is

A) sec C) $1/sec^2$

B) sec^2 D) 1/sec

Q.61 To have the same biological effect on the human body, the unit of the absorption of a radiation is called a

A) Rem C) curies

B) Rad D) |Gray

Q.62 The capture of a neutron by a nucleus results in the formation of

A) Tritium C) Isotones

B) Isobar D) Radio isotopes

Q.63 A Baryon is made up of _______ quarks

A) 2 C) 3

B) 4 D) 5

Q.64 After 4 hours, $\left[\frac{1}{16}\right]$th of atoms of a radioactive sample remain undecayed, the half life of the radioactive element is

A) 2 hours C) 3 hours

B) 1 hour D) 30 minutes

Q.65 The γ-rays radiographs are used in____ industry

A) Agriculture
B) Sports
C) Medical
D) Entertainment

Q.66 When the number of nucleons in a nucleus increases, the binding energy per nucleon _______ with increases of mass number.

A) Decrease continuously
B) Increases continuously
C) Remain constant
D) First increases and then decreases

Q.67 According to Yukawa; nuclear force are due to the exchange of

A) Leptons
B) π -mesons
C) Muons
D) All of these

Q.68 After how many years, shall the radioactive radium on earth will be completely decayed if its half life is 1590 years ?

A) 104 years
B) 1.59×10^{4} years
C) 1.59×10^{5} years
D) Never

Q.69 γ-rays are used to sterilize surgical equipments because they are

A) Chargless
B) Massless
C) Highly penetrating
D) Less penetrating

Q.70 Which of the fowling will be a better shield against γ-rays?

A) Aluminum
B) Paper
C) Lead
D) All of these

Q.71 The rate of decay of radioactive substance ____ with time?

A) Increases linearly
B) Decreases linearly
C) Increases exponentially
D) Decreases exponentially

Q.72 When a radioactive nucleus emits a beta particle, the proton to neutron ratio

A) Decreases
B) Remain the same
C) Increases
D) Decreases or remain the same

Q.73 Penetrating power of β particles is ________ than that of α-rays

A) 100 times more
B) 100 time less
C) 1000 times more
D) 1000 times less

Q.74 Chadwick discovered neutrons by the study of bombardment of alpha particles on

A) Oxygen
B) Nitrogen
C) Beryllium
D) Carbon

Q.75 Which of the following are suitable for radiation therapy inside the body?

A) α-rays
B) β-rays
C) γ-rays
D) X-rays

Q.76 The maximum safe dose limit for workers in a nuclear power plant is ______ per year

A) 5 rem
B) 4 rem
C) 3 rem
D) 6 rem

Q.77 The tumors are irradiated by

A) α-rays
B) β-rays
C) γ-rays
D) Proton

Q.78 The relative abundance of isotopes of an element is determined by

A) Cloud chamber
B) Mass spectrograph
C) G.M counter
D) Solid state detector

Q.79 Which of the following rays with energrgy 30 keV has the greatest RBE?

A) γ-rays
B) α-rays
C) X-rays
D) All have same RBE

Q.80 Which of the following particles do not experience strong nuclear force?

A) Electrons
B) Baryons
C) Mesons
D) All of these

ANSWERS WITH EXPLANATION

Q.1 (D) Radioactive decay is a spontaneous phenomenon and does not depend upon external factors.

Q.2 (C) **Q.3 (D)** For $^{1}_{1}H$ Z = A, for others A > Z. **Q.4 (A)**

Q.5 (B) Un decayed = $\left(\frac{1}{2}\right)^n N_o$ **Q.6 (B)** **Q.7 (C)** **Q.8 (D)**

Q.9 (B) **Q.10 (D)** **Q.11 (C)**

Q.12 (B) $\rho = \frac{m}{V}$; 99.9 % of mass of atom is in nucleus. Volume of nucleus is 10,000 times smaller than that of atom.

Q.13 (C) Nucleus does not have electrons in it.

Q.14 (D) Strong nuclear force is charge independent. **Q.15 (D)** $E = mc^2$

Q.16 (C) **Q.17 (B)**

Q.18 (C) Radioactive decay is random process. It can't be predicted that which particular atom will decay.

Q.19 (D) $E = D \times m$ **Q.20 (B)** **Q.21 (C)**

Q.22 (A) The mass number is decreased by 8 and atomic number is decreased by 4

Q.23 (C) $D = \frac{De}{RBE}$ **Q.24 (A)** **Q.25 (C)** **Q.26 (D)** **Q.27 (C)**

Q.28 (B) **Q.29 (D)** **Q.30 (A)**

Q.31 (C) Un decayed = $\left(\frac{1}{2}\right)^n N_o$

Q.32 (A) Curie and Rutherford are practical units.

Q.33 (A) $^{238}_{92}U \rightarrow {}^{206}_{82}Pb + 8\,^{4}_{2}He + 6\,^{o}_{-1}e$

By the emission of one α-particle, mass number decreases by 4 so 8 α, particles are emitted. For, β decayed 'Z' increases by 1 and by α-emission 'Z' decreases by 2. So 8 β particles are emitted.

Q.34 **(B)** **Q.35** **(C)** **Q.36** **(B)** **Q.37** **(C)**

Q.38 **(B)** Decayed = $N_O - \left(\frac{1}{2}\right)^n N_O$

Q.39 **(D)** ${}_{Z}^{A}X \rightarrow {}_{z+1}^{A}Y + \underset{-1}{\overset{0}{e}}$

Q.40 **(A)** Un decayed $= N_o - \left(\frac{1}{2}\right)^n N_o$

Q.41 **(D)**

Q.42 **(D)** A neutron in nucleus in converted into a proton in β-emission.

Q.43 **(B)** After α or β-emission, α γ-rays photon is emitted.

Q.44 **(A)** $T_{\frac{1}{2}}\lambda = 0.693$

Q.45 **(A)**

Q.46 **(D)** $I \alpha \frac{1}{r^2}$ **Q.47** **(B)** **Q.48** **(A)** **Q.49** **(D)** **Q.50** **(B)** **Q.51** **(C)**

Q.52 **(A)** **Q.53** **(D)** **Q.54** **(C)** **Q.55** **(C)** **Q.56** **(A)** **Q.57** **(A)**

Q.58 **(C)** **Q.59** **(A)** **Q.60** **(D)** **Q.61** **(A)** **Q.62** **(D)** ${}_{Z}^{A}X + {}_{0}^{1}n \rightarrow {}^{A+1}_{Z}y$

Q.63 **(C)** **Q.64** **(B)** **Q.65** **(C)** **Q.66** **(D)** **Q.67** **(B)** **Q.68** **(D)**

Q.69 **(C)** **Q.70** **(C)** **Q.71** **(D)** **Q.72** **(C)** **Q.73** **(A)** **Q.74** **(C)**

Q.75 **(C)** **Q.76** **(A)** **Q.77** **(A)** **Q.78** **(B)** **Q.79** **(D)** **Q.80** **(A)**