APPLIED PHYSICS-II

(with Lab Manual)

Hussain Jeevakhan

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FOREWORD

Engineering has played a very significant role in the progress and expansion of mankind and society for centuries. Engineering ideas that originated in the Indian subcontinent have had a thoughtful impact on the world.

All India Council for Technical Education (AICTE) had always been at the forefront of assisting Technical students in every possible manner since its inception in 1987. The goal of AICTE has been to promote quality Technical Education and thereby take the industry to a greater heights and ultimately turn our dear motherland India into a Modern Developed Nation. It will not be inept to mention here that Engineers are the backbone of the modern society - better the engineers, better the industry, and better the industry, better the country.

NEP 2020 envisages education in regional languages to all, thereby ensuring that each and every student becomes capable and competent enough and is in a position to contribute towards the national growth and development.

One of the spheres where AICTE had been relentlessly working from last few years was to provide high-quality moderately priced books of International standard prepared in various regional languages to all it's Engineering students. These books are not only prepared keeping in mind it's easy language, real life examples, rich contents and but also the industry needs in this everyday changing world. These books are as per AICTE Model Curriculum of Engineering & Technology – 2018.

Eminent Professors from all over India with great knowledge and experience have written these books for the benefit of academic fraternity. AICTE is confident that these books with their rich contents will help technical students master the subjects with greater ease and quality.

AICTE appreciates the hard work of the original authors, coordinators and the translators for their endeavour in making these Engineering subjects more lucid.

(Anil D. Sahasrabudhe)

Acknowledgement

The author grateful to AICTE for their meticulous planning and execution to publish the technical book for Diploma students.

I sincerely acknowledge the valuable contributions of the reviewer of the book Prof. Kavita Agrawal, for making it students' friendly and giving a better shape in an artistic manner.

This book is an outcome of various suggestions of AICTE members, experts and authors who shared their opinion and thoughts to further develop the engineering education in our country.

It is also with great honour that I state that this book is aligned to the AICTE Model Curriculum and in line with the guidelines of National Education Policy (NEP) -2020. Towards promoting education in regional languages, this book is being translated in scheduled Indian regional languages.

Acknowledgements are due to the contributors and different workers in this field whose published books, review articles, papers, photographs, footnotes, references and other valuable information enriched us at the time of writing the book.

Finally, I like to express my sincere thanks to the publishing house, M/s. Khanna Book Publishing Company Private Limited, New Delhi, whose entire team was always ready to cooperate on all the aspects of publishing to make it a wonderful experience.

Hussain Jeevakhan

Preface

The book titled "Applied Physics II" is an outcome of the experience of my teaching physics courses at UG and PG level and training of technical teachers on content specific areas in physics. The importance of applied physics has been proven in all fields of technology and everyone has experienced that Applied physics is important in the development of future technology. As a result, regardless of their primary discipline, every diploma student must master fundamental knowledge and skills to get an understanding of technology's potential and application.

Focus in writing this book has been on developing outcomes in the students related to applied physics, as expected from diploma engineers and to provide learner a successful learning experience. Method for developing unit outcomes and course outcomes adopted in the book is to connect concepts and principle of physics with day to day life experiences and observations, in line with national education policy (NEP) 2020. Corresponding to concept and principles, some activities and microproject are suggested, to create interest and learning challenges in students and which would benefit their clarification. To harness the ICT tool available for teaching learning, QR codes and *url* for the online resources of simulation and videos are given in each unit covering almost all topics, so that it will develop element of self-learning in the students.

In the end of each units the laboratory instructions for the practical's related to that unit has been provided, which will guide students and to perform the practical in the right way with necessary resources required to achieve desired outcome. The laboratory instructions are designed in a way that it is helpful to both the instructors and the students.

Students can apply the knowledge and skills they've gained via this reading this book and by hands-on learning experiences in laboratory and connected activities to tackle real-world problems in their careers.

Hussain Jeevakhan

Outcome Based Education

Outcome based education (OBE) is based on three pillars outcome- based curriculum (OBC), outcome-based learning teaching (OBLT) and outcome-based assessment (OBA). The learning outcomes can be at program levels (POs), course level (COs), unit level (UOs) and session level outcomes (attained in classroom learning, practical's and using other basic and advanced instructional methods). The mapping between POs and COs & COs and UOs is given in the book so that student can connect learning at any different level directly to the program level outcomes. Assessment is an integral part of learning teaching process. Hence to assess learning outcomes, the difficulty level of solved and unsolved problems given in the book matches with the cognitive level of unit learning outcomes. The course level outcomes can be attained through unit outcome and practical outcomes(PrOs). At the end of the programme running with the aid of outcome based education, a student will be able to arrive at the following outcomes

PO-1. **Basic and Discipline specific knowledge**: Apply knowledge of basic mathematics, science and engineering fundamentals and engineering specialization to solve the engineering problems.

PO-2. **Problem analysis**: Identify and analyse well-defined engineering problems using codified standard methods.

PO-3. **Design/development of solutions**: Design solutions for well-defined technical problems and assist with the design of systems components or processes to meet specified needs.

PO-4. **Engineering Tools, Experimentation and Testing**: Apply modern engineering tools and appropriate technique to conduct standard tests and measurements.

PO-5. **Engineering practices for society, sustainability and environment**: Engineering practices for society, sustainability and environment: Apply appropriate technology in context of society, sustainability, environment and ethical practices.

PO-6. **Project Management**: Use engineering management principles individually, as a team member or a leader to manage projects and effectively communicate about well-defined engineering activities.

PO-7. **Life-long learning**: Ability to analyse individual needs and engage in updating in the context of technological changes.

Course Outcomes

After completion of the course the students will be able to:

CO-1: Apply the concept of waves and sound waves for various acoustics and other engineering applications involving wave dynamics

CO-2: Use optical equipment/ instruments based on ray optics

CO-3: Select relevant capacitors in electrical circuits.

CO-4: Apply Laws of current electricity in engineering problems

CO-5: Select relevant material by analysing its magnetic properties

CO-6: Apply the basic concepts of semiconductor physics, laser and nanotechnology in solving engineering problems

Course Outcome	Expected Mapping with Programme Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)						
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7
CO-1	3	1	1	2	1	-	1
CO-2	3	1	1	2	-	-	1
CO-3	3	2	1	2	-	-	1
CO-4	3	2	1	2	1	-	1
CO-5	3	1	1	2	-	-	1
CO-6	3	1	1	1	1	-	-

Abbreviations and Symbols

List of Abbreviations

General Terms			
Abbreviations	**Full form**	**Abbreviations**	**Full form**
AC	Alternating Current	NDT	Non-Destructive testing
AFM	Atomic Force Microscope	OHP	Over Head Projector
CO	Course Outcome	OCT	Optical Coherence Tomography
CD	Compact Disc	PE	Potential Energy
DC	Direct Current	PO	Programme Outcome
DVD	Digital Video Disc	RF	Radio Frequency
DTH	Direct To Home	RI	Refractive Index
FSD	Full Scale Deflection	RP	Resolving Power
He-Ne	Helium-Neon	SHM	Simple Harmonic Motion
KE	Kinetic Energy	SONAR	Sound Navigation and Ranging
KCL	Kirchhoff's Current Law	SET	Single Electron Transistor
KVL	Kirchhoff's Voltage Law	SI	International System of Units
LASER	Light Amplification by Stimu-lated Emission of Radiation	SEM	Scanning Electron Microscope
LC	Least Count	STM	Scanning Tunneling Microscope
LCD	Liquid Crystal Display	TIR	Total Internal Reflection
LED	Light Emitting Diode	TV	Television
NA	Numerical Aperture	UO	Unit Outcome
Units Used			
Abbreviations	**Full form**	**Abbreviations**	**Full form**
Å	angstrom	eV	electron-volt
C	coloumb	kWh	kilowatt hour
F	farad	mm	millimeter
Hz	hertz	ms	millisecond
W	watt	mW	milliwatt
cm	centimeter	nm	nanometer
dB	decibel	Ω	ohm
esu	electrostatic unit	μF	microfarad

List of Symbols

Symbols	Description	Symbols	Description
Al_2O_3	Aluminum Oxide	h	Planck's Constant
B	Magnetic Field	i_c	Critical Angle
C	Capacitance	k	Wave number
D	Least Distance of Distinct Vision	v	Velocity
E_g	Band Gap Energy	f	Frequency
H	Magnetic Intensity	f_b	Beat Frequency
H_c	Coercive Magnetic field	f_e	Eyepiece focal length
I	Intensity of Magnetization	f_o	Objective focal length
I_R	Retentivity Magnetization	v_d	Drift Velocity
I_s	Saturation Current	ε_r	Relative Permittivity
R	Resistance	κ	Specific Conductance
RT_{60}	Reverberation Time	λ	Wavelength
T	Time period	μ	Refractive Index
T_B	Beat Period	ρ	Specific Resistance
Y	Young's modulus	τ	Torque
C	Velocity of Light	ω	Angular velocity

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UNIT 4

UNIT 5

Guidelines for Teachers

To implement Outcome Based Education (OBE) knowledge level and skill set of the students should be enhanced. Teachers should take a major responsibility for the proper implementation of OBE. Some of the responsibilities (not limited to) for the teachers in OBE system may be as follows:

- Within reasonable constraint, they should manipulate time to the best advantage of all students.
- They should assess the students only upon certain defined criterion without considering any other potential ineligibility to discriminate them.
- They should try to grow the learning abilities of the students to a certain level before they leave the institute.
- They should try to ensure that all the students are equipped with the quality knowledge as well as competence after they finish their education.
- They should always encourage the students to develop their ultimate performance capabilities.
- They should facilitate and encourage group work and team work to consolidate newer approach.
- They should follow Blooms taxonomy in every part of the assessment.

Bloom's Taxonomy

Level	Teacher should Check	Student should be able to	Possible Mode of Assessment
Creating	Students ability to create	Design or Create	Mini project
Evaluating	Students ability to Justify	Argue or Defend	Assignment
Analysing	Students ability to distinguish	Differentiate or Distinguish	Project/Lab Methodology
Applying	Students ability to use information	Operate or Demonstrate	Technical Presentation/ Demonstration
Understanding	Students ability to explain the ideas	Explain or Classify	Presentation/Seminar
Remembering	Students ability to recall (or remember)	Define or Recall	Quiz

Guidelines for Students

Students should take equal responsibility for implementing the OBE. Some of the responsibilities (not limited to) for the students in OBE system are as follows:

- Students should be well aware of each UO before the start of a unit in each and every course.
- Students should be well aware of each CO before the start of the course.
- Students should be well aware of each PO before the start of the programme.
- Students should think critically and reasonably with proper reflection and action.
- Learning of the students should be connected and integrated with practical and real life consequences.
- Students should be well aware of their competency at every level of OBE.

Contents

4. Current Electricity 90-119

5. Electromagnetism 120-143

1 Wave Motion and its Applications

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Wave motion,
- Transverse and longitudinal waves
- Sound and light waves and their properties,
- Wave equation
- Superposition of waves and beat formation.
- Simple Harmonic Motion and Simple harmonic progressive wave
- Free, forced and resonant vibrations.
- Acoustics of buildings : reverberation and reverberation time
- Coefficient of absorption of sound and Sabine formula
- Ultrasonic waves and its applications

Applications of waves in daily life are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. After the related practical, based on the content, there is a suggested micro project activity which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book. Industrial applications and real life applications on variety of aspects, case study and create inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Wave is a very common term which we generally use in our daily life. Some forms of energy which we receive from our surroundings is through wave propagation. When a wave is passed through medium or vacuum we say that energy has been transferred from one point to another. Sound waves, light waves, mobile signals, TV signals etc. are the examples of waves with which we commonly interact. The knowledge of wave motion is required in every discipline of science and engineering. This unit will explain the basics of wave motion, its mathematical expression and different terms required to describe wave motion, which will help to comprehend the engineering applications of wave and apply the principles of wave motion in the relevant engineering discipline.

PRE-REQUISITES

- **Mathematics:** Trigonometric functions, Algebra, logarithms.
- **Physics:** Energy, concept of dB, elasticity.
- **Other's:** Basic technology of computer and use of mobile application.

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U1-O1: Differentiate between longitudinal and transverse waves.
U1-O2: Explain superposition of waves and beat formation with mathematical expressions.
U1-O3: Find the parameters required to analyse a given simple harmonic motion.
U1-O4: Distinguish between forced, free and resonant vibrations.
U1-O5: Explain the factors affecting reverberation time for a given space.
U1-O6: Comprehend the medical and engineering applications of Ultrasonic waves.

Unit-1 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U1-O1	3	-	-	1	-	1
U1-O2	3	-	-	1	-	1
U1-O3	3	-	-	-	-	-
U1-O4	3	-	-	1	-	1
U1-O5	3	-	-	1	-	1
U1-O6	3	-	-	-	-	-

1.1 WAVE MOTION

Interesting Facts

- Velocity of sound in Vacuum: Is it equal to velocity of sound in air?
- Velocity of sound waves in different layers of atmosphere.
- Radio and TV catches the desired signal: how TV/radio channel switches from one to another through remote control?

When a stone is dropped on water surface there is sound of dropping stone and ripples in the water surface. The sound travels through air and we hear that sound through our ears and at the same time circular ripples propagates on water surface from the point of origin to the region all around (Fig. 1.1). A part of kinetic energy of stone is transferred to water molecules and we say that a wave has propagated through water. Similarly, a part of kinetic energy of stone is converted into sound energy and it reaches to ear through air and a sound wave propagates through air. When energy is transferred from one point of medium to another, there is

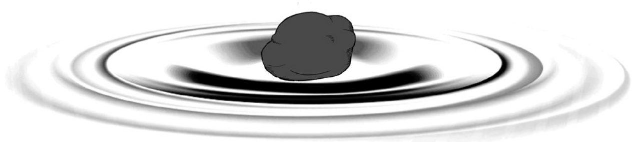


Fig. 1.1 Ripple in water due to energy transfer from stone

a propagation of wave, without changing the average position of particles of the medium. The wave motion describes how a wave propagates though a medium without changing the overall position of the particles in the medium.

Activity

- Take a nylon or cotton string, fix one end of string with rigid wall and hold the other-end with hand. Pull the string tight along its length. Give a disturbance from hand in perpendicular direction to the length of string and observe.
- Repeat the activity with string of different thickness.
- Repeat the activity with a long steel spring (stretched length around 1m) and give disturbance parallel to the length of spring.

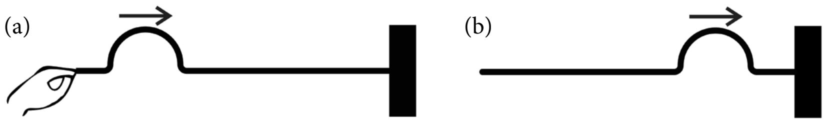
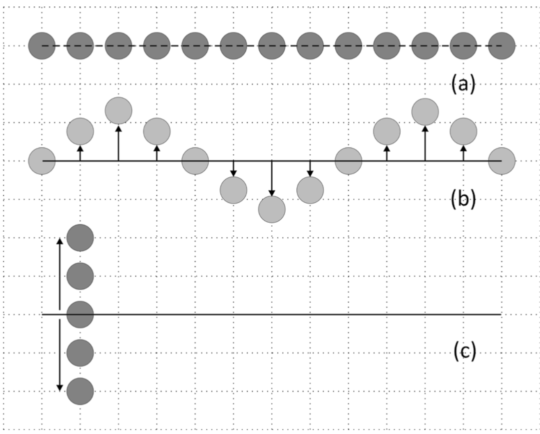


Fig. 1.2 Pulse on string

As shown in Fig. 1.2, the disturbance introduced with hand will travel along the string with certain velocity. In this case the energy from hand transferred to the string (medium in this case) and a bump travels along the string. Similarly, when any disturbance or energy is given in any medium it travels along the medium and we say that a wave has passed through the medium. In actual situations the picture is bit different and displayed in simple form in Fig. 1.3. In this figure a one-dimensional medium has been displayed and the circles represents the particles of medium. When energy is transferred to this medium the energy propagates from one particle to another as in case of string. Each particle vibrates along its mean position and the energy is transferred through the medium. Fig. 1.3 b displays the position of different particle is at instant of time and Fig. 1.3 c displays the vibration of individual particle at same position but at different instant of time. Hence, we conclude that when wave travels through a medium then particles of the medium vibrate from their mean position to transfer energy from one particle to other. In the given example the direction of propagation of wave is along the direction of one dimensional medium.



Introduction to waves

Fig. 1.3 Disturbance in one dimensional medium

1.1.1 Transverse and Longitudinal waves

As briefed in previous section that when a wave passes through any medium, the constituent particles of medium vibrates along their mean position. If the direction of vibration is perpendicular to the travel of the wave than the waves are called **Transverse waves** and if the direction of vibration is along the direction of wave propagation than the waves are called **Longitudinal waves.** As in case of activity related to string where the disturbance is perpendicular to length of string it is like transverse wave and in activity of spring the disturbance is along the length of spring which is like longitudinal wave.

Fig. 1.4 displays the relative position of different constituent particles in transverse and longitudinal waves. In each case the particle reaches to certain maximum position during vibration and return to their mean position and again displaced to maximum position in opposite direction. The maximum position and minimum position are known as **crest** and **trough** respectively in Transverse waves. In transverse waves the distance between the corresponding particles dose not changes as the particles have perpendicular vibrations along the mean position.

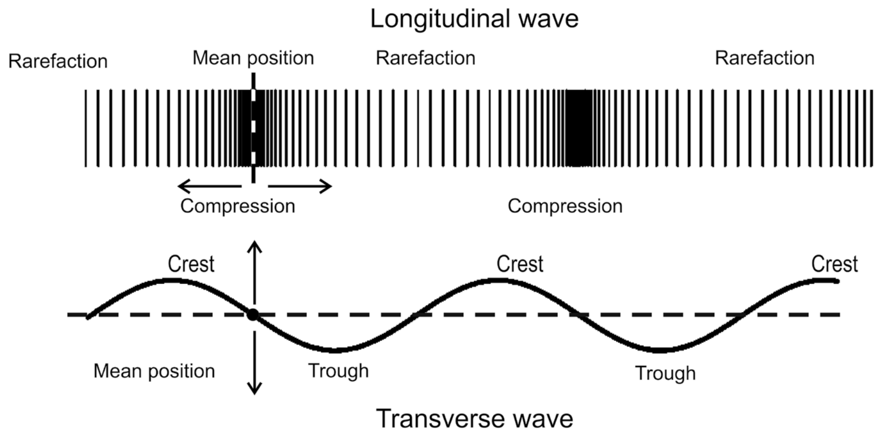


Fig. 1.4 Longitudinal and transverse waves

The crest and trough of a transverse wave correspond respectively to the compression, and the rarefaction of longitudenal wave. As in longitudinal wave the particle vibrates along the direction of wave propagation the distance between the corresponding particle changes. A compression is when the particles in the medium through which the wave is traveling are closer or the distance between particles is less than actual distance, that is, when their density is greatest. A rarefaction is when these particles are further apart, the distance between particles is more than their actual distance or when their density is least.

1.1.1.1 Wave Velocity

In Fig. 1.2, the disturbance given in string moves along the string with certain velocity which depends upon the elastic properties and density of string. If the disturbance is given continuously 'to and fro' than we say that wave propagates with a velocity known as wave velocity and the magnitude of wave velocity depend upon the elastic properties and density of medium. It is represented by 'v' and given by formula

$$v = x/t(m/s) \qquad ...(1.1)$$

where 'x' is the distance in meters travelled in time 't' sec.

1.1.1.2 Frequency

Fig. 1.5 displays oscillatory to and from motion of particle of medium at any point 'x', with respect to time. It goes to maximum displacement from its mean position in one direction come back to mean position and goes to maximum displacement in opposite direction and again come back to mean position and this process continues. The time between Point 'A' and 'C' is the time to complete one oscillation and it is known as Time period 'T'.

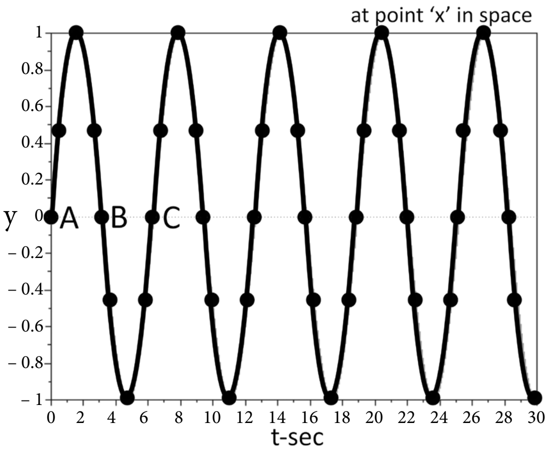


Fig. 1.5 Displacement v/s Time graph

The reciprocal of Time period is known as frequency of oscillation. It is also defined as the number oscillations in one second. Its unit is Hertz (Hz)

$$f = 1/T \quad ...(1.2)$$

Example: If the Time period of one oscillation is 0.5 second, then the frequency is 2 Hz i.e. two oscillations will be completed in one second.

1.1.1.3 Wave length

Fig 1.6 display displacement of different particles of medium at any instant of time 't', with respect to their mean positions. Each particle is at different displacement from mean position. The distance between Point A' and C', which are at mean position and their direction of displacement is same the distance between A' and C' for one oscillation in space is known as wave length 'λ', SI unit of wavelength is meter (m).
Wave length and frequency are related as follows:

$$v = f\lambda \quad ...(1.3)$$

derivation of Eq. 1.3 has been given in section 1.1.4

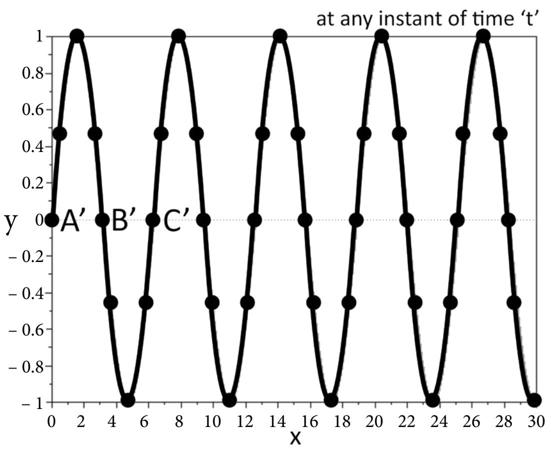


Fig. 1.6 Displacement v/s position graph

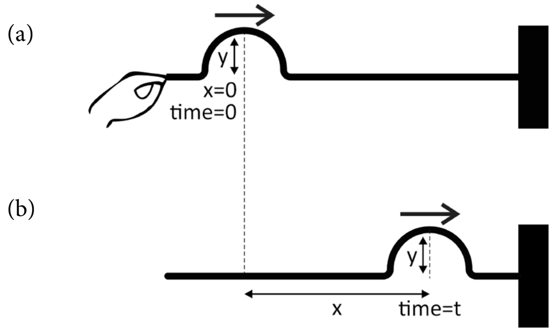
1.1.2 Sound and light waves and their properties

Sound and light waves are very common forms of waves with which there is general interaction in day to day activities. As discussed in previous section the waves have transverse and longitudinal nature. Apart from this classification there is one more difference that waves can be mechanical or electromagnetic wave. The mechanical waves require medium to travel, whereas the electromagnetic waves can travel without medium in vacuum also.

Sound waves as they require medium to travel cannot travel in vacuum. It can travel in air, solids and liquid. The velocity in different medium is different. The sound wave can be longitudinal and transverse both. In air the sound waves are longitudinal. As the sound wave moves in air there will be air density distribution due to longitudinal nature. Hence there will be difference in the air pressure due to compression and rarefaction. The velocity of sound waves in air varies with density of air. The velocity of sound wave is 340 m / s at 20°C in air.

Light wave can propagate in vacuum and in medium also. The light waves are transverse in nature. As the light waves move there is variation of electric and magnetic field vectors. The velocity of light wave is 3×10^8 m / s in air or vacuum.

1.1.3 Wave Equation



Waves on string

Fig. 1.7 Propagation of disturbance

As in the above Fig. 1.7, the disturbance moves in positive x direction, It moves with velocity 'v'. The disturbance at x = 0 reaches to x after time 't' with velocity, *v*.

The displacement 'y', at x = 0 is

$$y = f(t) \qquad ...(1.4)$$

The displacement at distance x at time t, will be same as, at x=0 and at time = t - x / v

At point 'x' displacement will be

$$y = f(t-x/v) \qquad ...(1.5)$$

If we introduce a continuous disturbance at x=0, then this continuous disturbance will propagate along 'x' with velocity 'v'. For an oscillatory displacement 'y', which is defined by following equation

$$y = a\sin(\omega t) = a\sin\{(2\pi/T)t\} \qquad ...(1.6)$$

Where, a is the amplitude of oscillatory displacement, T is periodic time or Time period

and

$$\omega = 2\pi/T$$

Hence, at distance x

$$y = a\sin\{\omega(t-x/v)\} \qquad [\because \omega=2\pi f] \qquad ...(1.7)$$

$$\Rightarrow y = a\sin\{2\pi f(t-x/v)\} \qquad ...(1.8)$$

$$\Rightarrow y = a\sin\{2\pi(t/T-x/\lambda)\} \qquad ...(1.9)$$

$$\Rightarrow y = a\sin(\omega t-kx) \qquad ...(1.10)$$

Eq. 1.9 and Eq. 1.10 are known as general wave equation representing wave motion in medium, where $k = 2\pi / \lambda$ is wavenumber, $\omega = 2\pi f$ is angular frequency. Eq 1.9 and 1.10 represents wave travelling in positive 'x' direction and having displacement in 'y' direction, the displacement can also be represented as displacement vector

$$y \rightarrow \bar{y} \qquad ...(1.11)$$

As, waves moves in medium both x and t changes, if 't' increases 'x' also increases such that the argument of sin function in Eq. 1.10 remains constant

Hence, $\omega t\text{-}kx = constant$

Differentiating w.r.t time

$$\omega\text{-}k(dx/dt) = 0 \qquad ...(1.12)$$

$$\omega = k(dx/dt) \qquad ...(1.13)$$

$$\omega/k = (dx/dt) \qquad ...(1.14)$$

$$v = \omega/k = f\lambda \qquad ...(1.15)$$

Eq. 1.15 gives velocity of wave in terms of frequency and wavelength.

1.1.3.1 Amplitude

In Eq. 1.9 and 1.10, 'a', represents the maximum displacement in either direction of mean position and is known as amplitude of wave traveling in 'x' direction. Intensity of wave is proportional to the square of amplitude of the wave.

1.1.3.2 Phase

Till now, we are stating the disturbance as displacement from mean position, this displacement has amplitude and direction both. This dynamical state (as it changes with time) is known as phase of particle. The phase of particle at any point varies at each instant of time. The different points at any instant of time have different phases. Phase is a dynamical state depends on position and direction of displacement. The wave velocity may also be termed as phase velocity.

1.1.3.3 Phase difference

In the Fig.1.8, the point A, B and C are at mean position, but the point A and C are at same phase. For these two points the position and direction of displacement are same. The point B is at same position, but direction of displacement is opposite. Hence it will have some phase difference with point A. The Point B will change its position and it will take T / 2 time to reach the same phase as A, Hence the time taken for point B to reach the phase which the point A, initially has is known as phase difference between points A and B. The phase difference between two points is the time difference to acquire the same dynamical state. As the wave motion resembles with trigonometric function, it is simpler to express phase difference in terms of angle. In period 'T', the wave completes one oscillation. Similarly, it takes '2π' angle to complete one cycle in trigonometric functions. Therefore 'T' can be expressed as 2π and T / 2 as π and so on. If two waves have phase difference of T / 4 we can say that they have phase difference of π / 2.

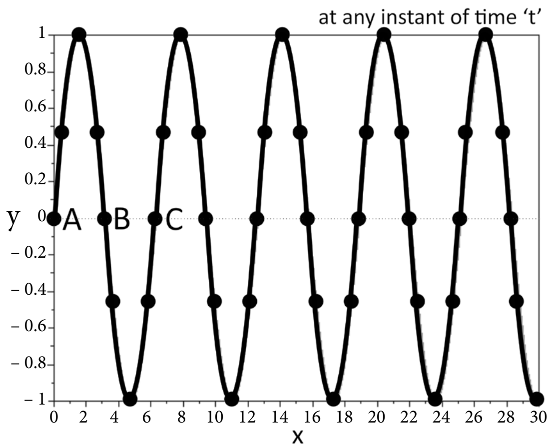


Fig. 1.8 Particles in same and different phases

1.1.4 Principle of superposition of waves

In the previous section, it was described that if a wave passes through medium then the particle performs oscillatory motion. If two waves meet at any point, then the resultant motion of the particle is a resultant of the vector addition of the displacement of two waves at that point and this is known as superposition of waves.

Resultant displacement

$$\vec{y} = \vec{y}_1 + \vec{y}_2 \quad ...(1.16)$$

Let first wave and second wave have same frequency and are represented as

$$y_1 = a_1 sin(\omega t)$$
$$y_2 = a_2 sin(\omega t + \phi)$$

where ϕ is phase difference between two waves

resultant displacement will be

$$y = y_1 + y_2 = a_1 sin(\omega t) + a_2 sin(\omega t + \phi) \quad ...(1.17)$$
$$\Rightarrow y = a_1 sin(\omega t) + a_2 sin(\omega t)cos(\phi) + a_2 cos(\omega t)sin(\phi) \quad ...(1.18)$$
$$\Rightarrow y = sin(\omega t)[a_1 + a_2 cos(\phi)] + a_2 cos(\omega t)sin(\phi) \quad ...(1.19)$$

Let

$$a_1 + a_2 cos(\phi) = a' cos(\alpha) \quad ...(1.20)$$
$$a_2 sin(\phi) = a' sin(\alpha) \quad ...(1.21)$$
$$\Rightarrow y = sin(\omega t)a' cos(\alpha) + cos(\omega t)a' sin(\alpha) \quad ...(1.22)$$
$$\Rightarrow y = a' sin(\omega t + \alpha) \quad ...(1.23)$$

This is the resultant amplitude due to superposition of waves at any point. The amplitude of resultant wave is a' and frequency is same as the combining waves.

1.1.5 Beat Formation

Activity

- Take two tuning forks of nearly equal frequency (say 380 and 384 Hz) and first, sound them separately and then sound them together. Do you observe any difference?

In the previous section, it was considered that the two waves of same frequency superimpose at a point. If the frequency of the two superimposing waves is slightly different or nearly equal than the resultant wave is known as beat wave and this phenomenon is known as beat formation.

Mathematically,

$$y = y_1 + y_2 = a_1 sin(\omega_1 t) + a_2 sin(\omega_2 t + \phi) \quad ...(1.24)$$

Let $\phi=0$ and $a=a_1=a_2$, then

$$y = y_1 + y_2 = a sin(\omega_1 t) + a sin(\omega_2 t) \quad ...(1.25)$$
$$\Rightarrow y = 2a sin(\omega_1 + \omega_2)t/2 \times cos(\omega_1 - \omega_2)t/2 \quad ...(1.26)$$
$$(\omega_1 + \omega_2)t/2 \approx \omega$$ (As the two frequency is slightly different)

Eq. 1.26 can be re written as $y = A sin(\omega)t$ ...(1.27)

Where, $A = 2a cos\{(\omega_1 - \omega_2)t/2\}$

Eq. 1.27 represents beat wave with frequency ω_1 and amplitude A

Fig 1.9 represents beat wave as given by Eq. 1.27, as it is clear from the figure that the resultant amplitude 'A' has maximum and minimum value alternately, after fixed interval of time and the period between two consecutive maximum amplitude is known as beat period. Beat period can be calculated as follows:

As $cos(n\pi) = \pm 1$ for n = 0, 1, 2, 3

For A to be maximum,

$(\omega_1 - \omega_2)t/2 = 2\pi[f_1 - f_2]t/2 = n\pi$

For n = 0, t = 0 (maxima at t = 0)

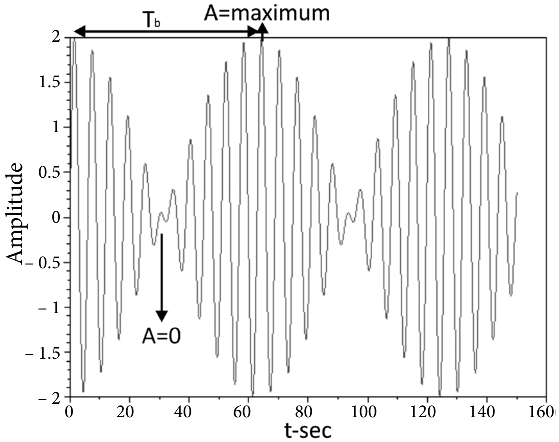


Fig. 1.9 Formation of beats

n = 1, $t = 1 / f_1 - f_2$, (first maxima at $t = T_b$)

n = 2, $t = 2 / f_1 - f_2$, (second maxima at $= 2T_b$)

Hence we define Beat frequency (f_b) as,

$$f_b = [f_1 - f_2] \quad ...(1.28)$$

Such that the time between two maximum amplitude of resultant wave is called as beat period (T_b) and given by following

$$T_b = 1/f_b \quad ...(1.29)$$

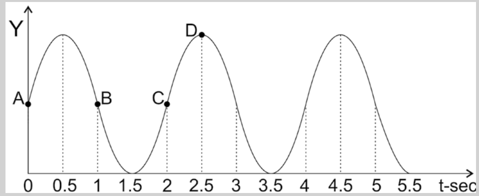
EXAMPLE 1.1

Ques. In the following figure find

(i) Frequency of wave

(ii) Phase difference between point A and B

(iii) Phase difference between point C and D



Solution:

(i) As from the figure, the time for complete one cycle is 2 sec

Time period T = 2 sec

Frequency $f = 1 / T = 1 / 2 = 0.5\ s^{-1}$ 0.5 Hz

(ii) The phase difference between point A and B is 1 sec as it is half of T or π

(iii) The phase difference between point C and D is ½ sec as it is one fourth of T or π / 2

EXAMPLE 1.2

Ques. If a wave has Time period of 20 millisecond, find the frequency of wave.

Solution:

Time period (T) = 20 millisecond = 20×10^{-3} sec

= (20 / 1000) sec

Frequency=1 / T

= 1 / (20 / 1000) = 1000 / 20 = 50 sec^{-1} = 50 Hz

EXAMPLE 1. 3

Ques. Find the wave length of sound wave of 20 Hz signal moving in air with velocity 340 m/s. Does this wavelength sound wave will be same in water?

Solution:

(a) velocity $v = f\lambda$

$v = 340$ m / s

$f = 20$ Hz $= 20\ s^{-1}$

$\lambda = v / f$

$\lambda = 340 / 20 = 17$ m

Wavelength of sound wave in air = 17 m

(b) The wave length of the sound wave of 20 Hz signal will not be 17 m because the velocity of sound wave in water is different.

EXAMPLE 1. 4

Ques. If a wave is represented by equation $y = a\sin 2\pi(t / 0.1 - x / 0.02)$, where t is in second x is in meters, then find

(i) Frequency of wave

(ii) Wave length of wave

(iii) Direction in which wave is moving

Solution:

Comparing the equation with wave equation as $y = a\sin 2\pi(t / T - x / \lambda)$

(i) $T = 0.1$ sec, hence, $f = 1 / T = 1 / 0.1 = 10$ Hz

(ii) $\lambda = 0.02$ meter $= 2$ cm

(iii) The sign of x is negative, the wave is moving in positive x direction.

EXAMPLE 1.5

Ques. Find the resultant amplitude at point 'p', If two waves of same frequency and same amplitude are superimposed at that point with initial phase difference of (i) 0 and (ii) π

Solution:

Resultant amplitude can be derived from Eq.1.20 and Eq.1.21

$a_1 + a_2\cos(\phi) = a'\cos(\alpha)$

$a_2\sin(\phi) = a'\sin(\alpha)$

squaring and adding above Eq's

$[a'\cos(\alpha)]^2 + [a'\sin(\alpha)]^2 = [a_1 + a_2\cos(\phi)]^2 + [a_2\sin(\phi)]^2$

As $\cos^2\alpha + \sin^2\alpha = 1$, $a_1 = a_2$

$a'^2 = [a_1 + a_1\cos(\phi)]^2 + [a_1\sin(\phi)]^2$

$a'^2 = a_1^{\,2} + 2a_1^{\,2}\cos(\phi) + a_1^{\,2}\cos^2(\phi) + a_1^{\,2}\sin^2(\phi) = 2a_1^{\,2} + 2a_1^{\,2}\cos(\phi)$

(i) for $\phi = 0$

$a'^2 = 4a_1^{\,2} \Rightarrow a' = 2a_1$

(ii) for $\phi = \pi$

$a'^2 = 2a_1^{\,2} - 2a_1^{\,2}$ [as $\cos(\pi) = -1$] $\Rightarrow a' = 0$

1.2 SIMPLE HARMONIC MOTION (SHM)

1.2.1 SHM

As wave propagates through medium the motion of particle at any point described in the previous section is doing periodic motion from mean point. The periodic motion is also known as oscillation or vibration of particle. If a particle displaces from its mean position, there is elastic force on the nearby particle due to this displacement. Hence the nearby particle also moves from its mean position and the same process progresses.

Simple Harmonic motion (SHM) is a simplest and special case of oscillatory motion. In SHM the particle oscillates from its mean position in straight line. The restoring force is linear and directed towards center and it tries to bring back the particle in mean position. Restoring force is directly proportional to displacement and opposite from the direction of displacement.

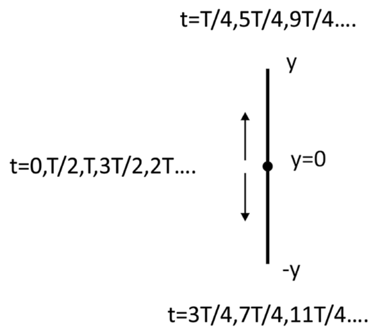


Fig. 1.10 Particle executing SHM

In the above Fig. 1.10 the particle displaced from its mean position, to maximum position in y direction and comes back to mean position and moves in opposite direction (due to inertia) reaches to maximum position and again comes back to mean position. The restoring force act towards center and opposite to displacement. As the restoring force is proportional to displacement it will be maximum when displacement is maximum. We can write this in equation as

$$F \propto -y \qquad \text{...(1.30)}$$

$$F = -ky \qquad \text{...(1.31)}$$

where k is proportionality constant and from Newton's second law of motion

$$F = ma \quad ...(1.32)$$

$$a = F/m \quad ...(1.33)$$

$$a = -(k/m)y \quad ...(1.34)$$

1.2.1.1 Expression for displacement, velocity, acceleration, time period and frequency

As from the previous section if a particle is performing oscillatory motion its displacement can be written as

$$y = A\sin(\omega t) \quad ...(1.35)$$

Displacement: The displacement is defined as shift in distance from mean position and as it is a vector quantity, the direction of displacement is measured with respect to mean position in half oscillation it is positive and in other half oscillation it is negative.

The maximum displacement is called as Amplitude of SHM. It is denoted as 'A' in Eq. 1.35.

Velocity: Rate of change of displacement is velocity and is given by differentiating Eq. 1.35 with time

$$v = dy/dt = A\omega\cos(\omega t) \quad ...(1.36)$$

The velocity of particle doing SHM is represented by 'v' and given by Eq. 1.36.The velocity of particle increases as it moves towards the mean position, become maximum at mean position, where restoring force and acceleration is zero. As the particle moves the velocity will decrease as it moves away from mean position due to restoring force in opposite direction and it becomes zero at maximum displacement.

Acceleration: Rate of change of velocity is acceleration and is given by differentiating

Eq.1.36 with time

$$a = dv/dt = -A\omega^2\sin(\omega t) \quad ...(1.37)$$

$$a = -\omega^2 y \quad ...(1.38)$$

from Eq 1.34 and 1.38

$$\omega^2 = k/m \quad ...(1.39)$$

This is the equation which helps to explain number of parameters related to SHM. The acceleration of particle also varies proportionally as force at every instant of time . At mean position the acceleration is zero. It is maximum at extreme positions and it is given as in equation.

Frequency: The frequency of oscillation will be calculated from angular frequency given in equation 1.39.

As,

$$\omega^2 = k/m$$

$$\omega = \sqrt{(k/m)}$$

$$\omega = 2\pi f \Rightarrow f = \omega/2\pi$$

Hence

$$f = (½\pi)(\sqrt{(k/m)} \quad ...(1.40)$$

Time period: The time period of oscillator is reciprocal of frequency. It is also defined as time taken to complete one oscillation.

Hence

$$T = 2\pi(\sqrt{(m/k)}) \quad ...(1.41)$$

The time period of SHM is given by above equation and helpful in calculating the Time period of system performing SHM, As from above equation the time period of oscillation is independent of amplitude in SHM for small displacement.

The following are the examples of some basic mechanical systems which perform SHM and clarify the physics of oscillating systems of small and large dimensions. Such system performing SHM are also known as simple Harmonic oscillator. Analysis of these systems helps learner to explain the dynamics of wave motion.

a. Simple Pendulum
b. Spring Oscillator
c. Cantilever

1.2.2 Simple harmonic progressive wave

Eq. 1.7 represents wave equation and Eq. 1.35 represents SHM of particle of medium. The particle of medium undergoes SHM and the wave travel continuously in the medium are called as progressive waves or Simple harmonic progressive waves. Eq. 1.7 can be rewritten as,

$$y = a\sin\{\omega(t-x/v)\}$$

$$y = a\sin\{(2\pi/T)(t-x/v)\} \quad ...(1.42)$$

$$y = a\sin\{(2\pi/vT)(vt-x)\} \quad ...(1.43)$$

$$y = a\sin\{(2\pi/\lambda)(vt-x)\} \quad ...(1.44)$$

Eq 1.44 also represents simple harmonic progressive waves. Following are the characteristics of simple harmonic progressive waves.

- All the particles of medium perform SHM, when simple harmonic progres sive wave passes through medium.
- All the particles vibrates with same amplitude and same frequency.
- Energy is transmitted through the medium

1.2.2.1 Energy transfer

As the energy from one particle is transferred to another particle, when simple harmonic waves passes through medium, the particle doing SHM have kinetic energy (KE) and potential energy (PE) and the sum of the KE and PE i.e. total energy is the energy transferred to the other particle. PE is due to the displacement from mean position. The KE is due to the velocity of particle. As, from 1.31, the restoring force is written as

$$F = -ky$$

If dW is work done against the restoring force for displacing the particle through dy, then

$$dW = -kydy \quad ...(1.45)$$

$$dW = Fdy \quad ...(1.46)$$

Total work done in displacing particle from 0 to y is

$$W = \tfrac{1}{2}ky^2 \quad ...(1.47)$$

Where negative sign has been removed as it is only resemblance of direction.

Hence

$$PE = \tfrac{1}{2}ky^2 \quad ...(1.48)$$

from Eq.1.35 and Eq.1.39

$$PE = \tfrac{1}{2}m\omega^2A^2\sin^2(\omega t) \quad ...(1.49)$$

The Eq. 1.49 gives the P E of particle at instant 't'. It will be zero at t = 0, T / 2, T, 3T / 2 …. and maximum at t = T / 4, 3T / 4, 5T / 4….

The KE is due to the velocity of particle. The KE of particle doing SHM can be given by following

$$KE = \tfrac{1}{2}mv^2 = \tfrac{1}{2}mA^2\omega^2\cos^2(\omega t) \quad ...(1.50)$$

[v from Eq.1.36]

The kinetic energy of particle will be zero at t = T/ 4, 3T / 4, 5T / 4…. and maximum t = 0, T / 2, T, 3T / 2...

The total energy of particle at any instant is given by adding Eq. 1.49 and Eq. 1.50

$$\textit{Total energy} = KE + PE = \tfrac{1}{2}mA^2\omega^2 \quad ...(1.51)$$

The energy given by Eq 1.51 is transferred from one particle to another as the simple harmonic waves travels through medium. The total energy of particle will remain same at each instant of time.

1.2.3 Vibration of cantilever

A cantilever is a system, in which one end of beam which is made up of elastic material such as steel is fixed with rigid support and another end is kept free. The length of cantilever is very large as compared to its width. A separate body having certain mass is hanged at free end for applying force for deflection. If the free end is given a little deflection and released, the beam starts vibrating along the fixed end, this vibration is known as cantilever vibration. The Time period of the vibration depends upon the elastic properties of beam material and dimensions of the beam.

In the Fig 1.11 a cantilever has been shown with Length L, width w and thickness t

The Time period of SHM is given by

$$T = 2\pi(\sqrt{(m/k)} \quad ...(1.52)$$

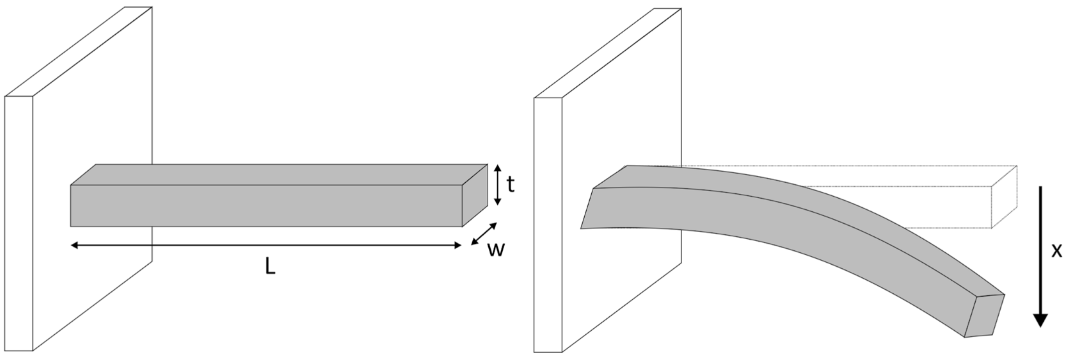


Fig. 1.11 Vibration of cantilever

In case of cantilever, k is the stiffness of the system and m is the mass hanged on free end. k depends on the length (L), area, moment of inertia (I) and Young's Modulus (Y) of the material of the beam and for a cantilever beam is given by:

$$I = wt^3/12$$

In case of rectangular beam

$$k = 3Y\,wt^3/12L^3 = Ywt^3/4L^3$$

Therefore

$$T = 2\pi(\sqrt{(\,m4L^3/\,Y\,wt^3)}$$

Hence the T of cantilever oscillations is given by

$$k = 3YI/L^3 \quad ...(1.53)$$

As from above Eq 1.53. Time period of cantilever oscillations depends on its dimensions and elasticity of material of cantilever.

1.2.4 Free, forced and resonant vibrations with examples

In case of given examples of simple harmonic oscillator and other similar cases three types of vibrations can be generated. They are free, forced and resonant vibrations.

Free vibration

When a simple pendulum or cantilever are given an initial amplitude or deflection and the external force is removed. Then the system oscillates with a frequency known as its natural frequency and such vibration are known as free vibrations. The vibration frequency or natural frequency totally depends upon the system parameters.

Examples:

- Hitting a tuning fork and let it sound.
- Give displacement to a simple pendulum and let it oscillate.

Forced vibration

When an oscillatory system is vibrating in its natural frequency. The overall energy of system given at the time of deflection decreases due the external damping forces, say due to air friction in case of simple pendulum. The amplitude of the vibration decreases continuously due to damping and the vibration stops, and the system again comes to rest.

If an oscillator has given continuous external energy, so that it will over comes damping and vibrate continuously. In such systems an external signal (may be electrical), through proper arrangements continuously provides energy to the oscillator. The frequency of the external oscillator may not be equal to natural frequency of oscillator. Such vibrations are known as forced vibrations. The frequency of forced harmonic oscillator vibration is the frequency of external source.

Examples :

- A swing is provided energy, when it goes down swing.
- Vibration in suspension bridge, due to vehicle movement.

Resonant vibration

In forced vibrations the transfer of energy from the external source to the oscillator is less if the frequency of external source differs with the natural frequency of oscillator. The amount of energy transfer increase if the frequency of external source approaches towards their natural frequency of oscillator. When the frequency of external source is equal to natural frequency of oscillator than such vibrations are known as resonant vibrations

Examples :

- Tuning of radio station.
- Vibration produced in a tuning fork placed near a vibrating tuning fork of same frequency.
- Cooking in microwave oven.

Case study on resonance

EXAMPLE 1. 6

Ques. For a SHM oscillator, find the force constant (k), the mass attached is 0.2 kg and it oscillates with a period of 3s.

Solution:

Time period (T) = $T = 2\pi(\sqrt{(m/k)}$

$T = 3$ sec, $m = 0.2$ Kg

$T^2 = 4 \times \pi^2\ (m/k)$

$9 = 4 \times 3.14 \times 3.14 \times (0.2/k)$

$k = 4 \times 3.14 \times 3.14 \times 0.2/9$

$k = 0.876$ N/m

(ii) for $\phi = \pi$

$a'^2 = 2a_1^2 - 2a_1^2$

$[\text{as } \cos(\pi) = -1] \Rightarrow a' = 0$

1.3 ACOUSTICS OF BUILDINGS

Activity

- In empty classroom, keep the duster on the desk hardly or clap, so that it makes loud sound, observe the sound.
- List out the difference observed between the wall and ceiling of classroom or laboratories with auditorium or multiplex cinema Halls.

1.3.1 Echo and Reverberation

Echo point is very common spot in Hilly tourist area, where reflection of sound from mountains is observed. Direct sound and reflection of direct sound produced from the source that arrives at the listener with an time interval is known as Echo. The time interval between the direct and reflected sound is directly proportional to the distance of the reflecting surface from the source and the listener. Another example of the echo produced by the bottom of a well or Tube well. In Echo time interval is large so that the ear can separate the direct sound and its reflection. The sensation of any sound persists for about 0.1 second in human ear. The two sound can be clearly distinct by ear if it comes in interval of 0.1 sec.

In a room the situation is bit different, as the wall are near to source and listener the reflection of sound takes very less time and reaches to listener in very less time. The direct sound and its multiple reflections with decreasing intensity reaches to listener in very less time interval such that a continuous sound of decreasing intensity arrives at listener. This phenomenon is known as reverberation.

1.3.2 Reverberation time

As Reverberation is due to multiple reflection of sound in closed room or space and as the time passes the sound decays. Although the time for which the sound persists in class room or space is small and can be measured and is called as reverberation time. It is defined as the time it takes for sound to decay by 60dB. If the sound in a room took 5 seconds to decay from 100dB to 40dB, the reverberation time would be 5 seconds. This is also known as RT_{60} time. When the sound decay from 100 dB to 40 dB, the ratio of the intensity of the source sound to the reflected sound decrease from 10^{10} to 10^{4}.

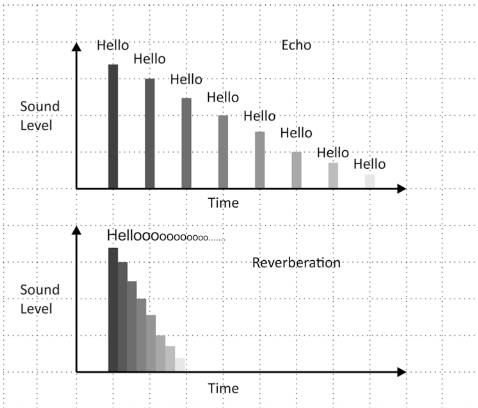


Fig. 1.12 Reverberation and Echo

1.3.3 Coefficient of absorption of sound

Reverberation reduces, when the reflections form surfaces such as ceiling, curtains, chairs and wall absorbs sound and hence reverberation time decreases. Absorption of sound is measure of decrease in energy of sound when it hits the sound absorbing material and it is measured in terms of sound absorbing coefficient (α) which can be mathematically defined as :

$$\alpha = (E_a/E_i) \quad ...(1.54)$$

Where E_i: incident sound energy on the surface and

E_a: absorbed sound energy by the surface

An open window is a perfect absorber, as all the sound waves incident on open window will pass through it. The absorption coefficient of all the material are measured with reference to open window.

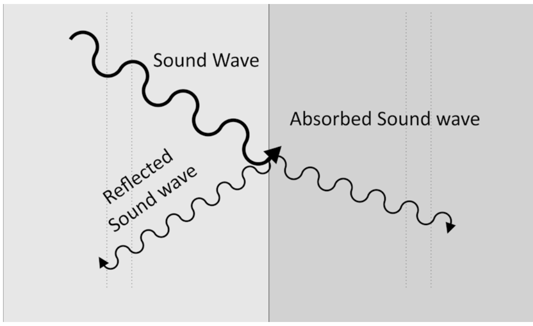


Fig. 1.13 Absorption of sound wave

The absorption coefficient 'α' of any material surface can also be defined as the reciprocal of its area which absorbs same sound energy as absorbed by unit area of open window. The unit of 'α' is sabine.

The sound absorption coefficient is different for different material and it also depend upon the frequency of sound. There are six frequencies: 125 Hz,250 Hz, 500Hz, 1000 Hz,2000Hz and 4000Hz, if the average of sound absorption coefficient of material for these frequencies is bigger than 0.2, than the material is known as good sound absorbing material. Table 1.1 summarizes absorption coefficient of some common materials.

Table 1.1: Absorbtion coefficient (at f = 500 Hz)

Material	α in Sabine
Wooden floor	0.1
Glazed tile	0.01
Concrete (sealed or painted)	0.02
Cushioned seats	0.76

Note: If the 'α' of glazed tile is 0.01, then 100 square meter of glazed tile will absorb the same sound energy which is absorbed by 1 square meter of open window.

1.3.4 Methods to control reverberation time

Reverberation is hurdle for listening the sound clearly and sometimes it is required to increase the effectiveness of sound as in concerts in auditorium. We make choices on the basis of our requirement. The following are the methods that are generally used to decrease the reverberation time.

- Soft furnishing
- Installation of acoustic panels
- Use of sound absorbing material in ceiling and wall
- Proper installation of sound devices.
- Overall architecture of room as per requirements
- Audience in room
- Decorations on wall such as paintings etc.

Applications: Methods of controlling reverberation time are used in Cinema Halls, auditorium, home theaters, multiplex, meeting room as per requirements of acoustics of particular space.

Sabine's formula

The Sabine formula is used to calculate reverberation time of room or space

$$RT_{60} = 0.165V/S\alpha \qquad ...(1.55)$$

where,

RT_{60} is the time in seconds required for a sound to decay by 60 dB,

V is the volume of the room, in m^3

S is the boundary surface area, in m^2

α is the average absorption coefficient of material for at a given frequency

1.3.5 Ultrasonic waves

Any measuring instrument we use in laboratory or in other applications has a certain "range" for inputs (physical quantity) so that we can use that instrument only for that specified range.

Example: The thermometer, we use for clinical purpose has some temperature range , we can use the thermometer only for measuring that specified range of temperature.

Our Eyes and ears are natural instruments, which we use for sensing light and sound waves respectively. The range of sound frequencies for which the human ear is sensitive is 20 Hz to 20,000Hz. The frequency of sound wave below 20 Hz is known as Infrasonic and the sound wave having frequency above 20,000Hz is Ultrasonic waves. Audible sound is between the range of 20 Hz to 20,000Hz. The sound wave below and above this range is not audible to Human ears.

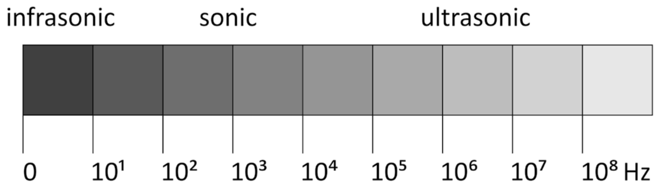


Fig. 1.14 Types of sonic waves

1.3.6 Engineering and medical applications of ultrasonic waves

There are number of medical and engineering applications of ultrasonic waves. As ultrasonic have high frequency and shorter wavelength as compared to sonic waves, it can move larger distance with less attenuation as compared to sonics waves. Ultrasonic waves have number of practical applications. Bats, dolphins and other animals can hear ultrasound and uses for detection of obstacle coming in their path. Some of the applications of ultrasonic waves are as follows:

(a) Ultrasound scanning

This application is generally known as sonography in medical test. It is majorly used for diagnosis of organs and scan of fetuses (unborn babies). It is mainly based on reflection of ultrasonic waves from the hard boundaries of organs or fetuses and reconstruction of images of the reflected ultrasonic waves. The diagnostic sonography machine operates in the frequency range of 2 to 18 megahertz.

(b) Non - Destructive testing

The cracks in metal effects the overall mechanical strength of metal and working of the machine made up of these metals such as engine of plane. The ultrasound scanner is moved around the surface of metal and detects the cracks inside the metal. The ultrasound waves are reflected from the cracks, due to change in the medium at the cracks. This method of detecting cracks is also known as non-destructive testing (NDT).

(c) Sound navigation and ranging (SONAR)

SONAR is an application used by submarines to detect the nearby ships, submarines and other obstacles. As sound is mechanical wave and the sound travels faster in water as compared to air. An ultrasonic signal is sent by submarine when it is beneath the surface and it receives echo of the same signal. The time of flight is the time between sending signal and receiving echo.

Time of flight = 2 × Distance of nearest submarines / (velocity of sound)

Time of flight gives the twice of the distance of the nearby ships or submarine, when it is multiplied with the velocity of ultrasonic sound in water. This method is also used to find the depth of sea.

(d) Position sensor

Such sensors are now easily available in market based on the same principle as SONAR. It consists of one sender and one receiver antenna of ultrasonic wave. The distance is measured by measuring the time of flight of ultrasonic wave. The velocity of sound wave is changed with temperature hence care has to be taken while making calculations for the distance.

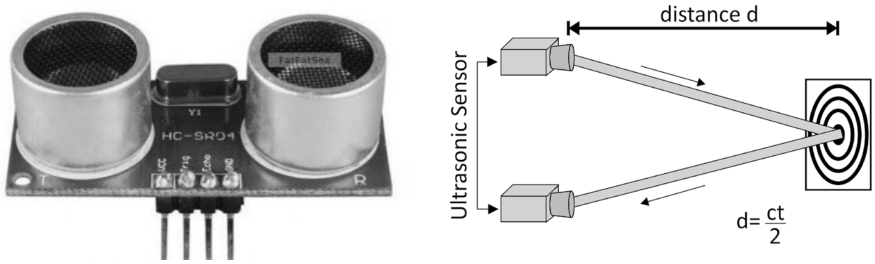


Fig. 1.15 Ultrasonic position sensor

(e) Ultrasonication

Ultrasonication helps in processing of chemical reactions and cleaning of chemical equipment in industries and laboratories. Ultrasonication generates alternating low-pressure and high-pressure waves in liquids, leading to the formation and violent collapse of small vacuum bubbles. This helps in removing air bubbles inside the chemical reaction chamber and makes reaction faster.

EXAMPLE 1.7

Ques. Calculate minimum distance required to clearly hear an echo in air (Velocity of sound is 340m/s).

Solution :

Minimum time interval for echo = 0.1 sec

Velocity of sound = 340 m / s

Distance = velocity × time = 340 × 0.1 = 34 meters

Minimum distance = 34 / 2 = 17 m (as sound goes towards obstacle and return)

EXAMPLE 1.8

Ques. An ultrasonic position sensor sends 40 kHz and detect the reflected signal from obstacle after 40ms. Find the distance of obstacle from sensor. (Velocity of sound is 340m/s)

Solution:

Frequency of ultrasonic signal: 40 kHz

Time taken in sending and receiving signal: 40 ms = 40×10^{-3} sec

Velocity of waves: 340 m/s

Distance = (Time × velocity) / 2

= $(40 \times 10^{-3} \times 340) / 2$

= 6.8 m = 680 cm

Distance of obstacle from sensor is 680 cm

EXAMPLE 1.9

Ques. An Ultrasonic wave of frequency 100 kHz is sent from a ship through water and air to detect distance of distant ship moving towards it. Find the frequency and wavelength of the ultrasonic waves in air and water (The velocity of waves in air and water is 340 m/s and 1500 m/s respectively).

Solution:

a. As frequency is fundamental quantity the frequency of ultrasonic wave in air and water is 100 kHz .

b. Wavelength (λ) = velocity (v) / frequency (ν)

Wavelength in air = 340 ms^{-1} / 100 kHz = 340 / 100 × 10^3 = 0.0034m = 0.34 cm

wavelength in water = 1500 ms^{-1} / 100 kHz = 1500 / 100 × 10^3 = 0.015 m = 1.5 cm

EXAMPLE 1.10

Ques. In a home theatre of volume 3000 $feet^3$, the reverberation time is 0.6 sec. Calculate the total absorption in Hall.

Solution:

Volume of home theater = 3000 $feet^3$

1 m^3 = 35.31 ft^3

Hence volume in cubic meter is = 3000 / 35.31 = 84.96m^3

T = 0.165 V / αS = 0.165 / Total absorption

Total Absorption = 0.165 × 84.96 / 0.6 = 23.36 sabine m^2

UNIT SUMMARY

- Waves motion are transverse and longitudinal in nature.
- Sound waves are mechanical waves and needs medium for travelling.
- Every SHM is Oscillation, but every Oscillation is not SHM.
- Energy transfer is maximum in case of resonant vibrations.
- The frequency range of sonic waves is 20 Hz to 20 kHz.
- The sound wave below 20 Hz and above 20 kHz are called infrasonic and Ultrasonic wave respectively.
- Time of flight = (velocity × distance) / 2, for measurements in SONAR and other applications.
- Ultrasonic sound waves have number of industrial and medical applications.

EXERCISES

Multiple Choice Questions

1.1 The unit of wavelength is

a. hertz (Hz)
b. second (s)
c. meter (m)
d. meter/second (m/s)

1.2 The property of sound wave affected by change in temperature of air is

a. Amplitude

b. Frequency
c. Wavelength
d. Intensity

1.3 Select the incorrect statement
a. Sound travels as waves.
b. Sound is a form of energy.
c. Sound travels faster in water than air.
d. Sound travel faster in vacuum than air.

1.4 The Time period of SHM oscillator is
a. $2\pi(\sqrt{(k/m)}$
b. $2\pi(\sqrt{(m/k)}$
c. $2\pi\,(m/k)$
d. $2\pi\,(k/m)$

1.5 In Sabine formula: $RT_{60} = 0.165\ V / S\alpha$, V and S are calculated in
a. meters
b. centimeters
c. feet
d. inch

1.6 Absorption coefficients of material
a. Depends upon thickness
b. Does not depend upon thickness
c. Changes with frequency
d. Does not depends upon frequency

1.7 Sound of frequency more than 20 kHz and less than 1 GHz is known as
a. Hypersonic
b. Sonic
c. Infrasonic
d. Ultrasonic

1.8 Select the correct statement
a. Ultrasonic sound wave travels with same velocity in every medium.
b. Ultrasonic sound wave travels faster in water as compare to air.
c. Ultrasonic sound wave travels faster in air as compare to water.
d. Ultrasonic sound wave does not require medium to travel.

1.9 A submarine sends an ultrasound that returns from the other submarine and is detected after 4.12 s. If the speed of the ultrasound through seawater is 1400 ms^{-1}, then the distance between the ship would be

a. 2884 m
b. 5768 m
c. 2800 m
d. 1400 m

Answers of Multiple Choice Questions
1.1 (c), 1.2 (c), 1.3 (d), 1.4 (b), 1.5 (a), 1.6 (c), 1.7 (d), 1.8 (b), 1.9 (a)

Short and Long Answer Type Questions

Category-I

1. Give four examples of waves in daily life.
2. Explain transverse waves with labelled diagram.
3. Explain Longitudinal waves with labelled diagram.
4. Differentiate between longitudinal and transverse wave on any four points.
5. Define the following terms: wave velocity, frequency and wavelength.
6. Differentiate between sound and longitudinal waves on any four points.
7. Are sound waves always longitudinal. Give reasons.
8. Derive wave equation and describe the various terms in wave equation.
9. Explain superposition of waves. Derive the equation for resultant displacement due to superposition of waves of same frequency.
10. Find the resultant amplitude due to superposition of two waves of equal amplitude and frequency having initial phase difference of $(\pi / 2)$.
11. Describe beat wave with diagram. Derive mathematical expression for beat wave.
12. Find the beat period, if tuning forks of 380 Hz and 384 Hz are sounded simultaneously.
13. Explain Simple harmonic motion (SHM). Is every oscillation is SHM?
14. Derive the expression for frequency of oscillator performing SHM.
15. Distinguish between the free, force and resonant vibrations with examples.
16. Differentiate between Echo and reverberation with diagram.
17. Explain absorption of sound wave with diagram. Explain absorption coefficient and the factors af fecting absorption coefficient.
18. Explain the criterion for a material to be good sound absorbing material.
19. Write Sabine formula for calculation of reverberation time of room with description of each term in equation.
20. Give the range of infrasonic, sonic and ultrasonic sound waves.
21. Explain the reason for using ultrasonic sound wave in place of sonic waves in ultrasound scanning.
22. Describe the method to find the distance between two submarines using SONAR.

Category-II

1. Two near sounding bodies, producing progressive waves given by
   $y_1 = 4 \sin(400 \pi t)$ and $y_2 = 6 \sin(500 \pi t)$, then

a. Is beat wave will be generated?

b. Does human ear will be able to listen beats?

2. Draw a diagram of a Wave, locate three points with phase difference 3T / 4. Write the phase 3T / 4 in terms of π.
3. Calculate reverberation time of an empty hall of 1200 m3 with following data. Is reverberation time increases or decreases when it will be filled with audience?

Surface	Area in m^2	α in Sabine
Plastered walls	480	0.03
Wooden floor	150	0.06
Plastered ceiling	150	0.08

4. Draw potential energy and kinetic energy curves for a particle doing SHM. Interpret the potential energy and kinetic energy curves.

PRACTICAL

There are two laboratory experiment(s) which are related to this unit and given are in ANNEXURE-I

- To determine and verify the time period of a cantilever.
- To determine velocity of ultrasonic in different liquids using ultrasonic interferometer.

Practical 1 - Cantilever

P1.1 Practical Statement

To determine and verify the Time period of a cantilever.

P1.2 Practical Significance

Cantilever is beam, in which the length is very large as compare to its width. It is common structure in buildings and bridges which has single support. Bending of beam with mass loaded on free end depends on the elasticity of material of beam and moment of inertia of beam. The cantilever also vibrates with natural frequency, if displacement is introduced on free end. This experiment helps to find the Frequency of cantilever and elasticity of material of cantilever.

P1.3 Relevant Theory

Refer: Section 1.2.3 of Unit 1

P1.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

Pr O1: Determine the Time period of a given cantilever.

Pr O2 : Determine the Young's modulus

P1.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

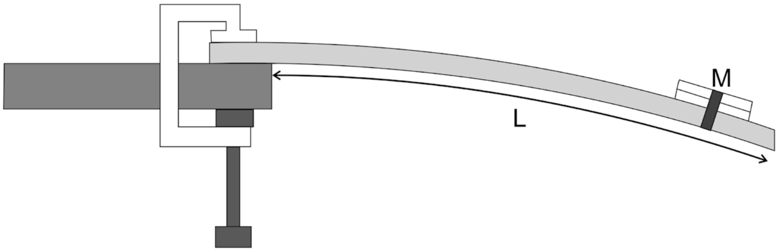


Fig P1.1

P1.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
	Clamp, Stopwatch, Cantilever beam	01			
	Slotted masses	5 no.			

P1.7 Precautions

1. Load mass on a cantilever gradually.
2. Displace cantilever carefully such that oscillations are in one direction.
3. Displace cantilever with small amplitude.
4. Add mass of pan for calculations if any.

P1.8 Suggested Procedure

1. Set the cantilever, fixed one end and add mass hanger on free end
2. Add mass (m_1 = 50) grams on free end.
3. Give little displacement at free end.
4. Start stop watch and measure time for 20 Oscillations to measure time period.
5. Repeat the process two times with same mass.
6. Add 50 grams mass and measure time period.
7. Plot graph between square of time period v/s mass for further calculations.

P1.9 Observations and Calculations

Length of cantilever (L) = ...m

Width of cantilever (w) = ...m

Thickness of cantilever (t) = ...m

Sr. No	Mass on Free end	Time for Twenty Oscillations (sec)			Time period ($T = t_{mean}$ /20)	T^2
		t_1	t_2	$t_{mean} = (t_1 + t_2)/2$		
1						
2						
3						
4						
5						

Plot graph between T^2 v/s mass

Slope of graph:

$$k = 4\pi^2 / slope$$

For rectangular cantilever, $$Y = k\, 4L^3 / w\, t^3$$

P1.10 Results and/or Interpretation

(to be filled by student)

1. ....

2. ....

P1.11Conclusions and/or Validation

(to be filled by student)

1. ....

2. ....

P1.12 Practical related Questions

(Use separate sheet for answer)

Note : Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Predict the change in time period of cantilever oscillator with material?
2. For the given practical setup find the maximum amplitude, so that oscillations will remain SHM?
3. Predict the change in time period if the length of cantilever is halved.
4. Give reasons for measuring the time taken for twenty oscillations, for determination of time period.
5. Give the sources of errors in the present experiment.

P1.13 Suggested Learning Resources

- https://vlab.amrita.edu/?sub=3&brch=175&sim=1078&cnt=1

P1.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Setting up experiment		
2	Taking measurement		
3	Plotting graph and calculations		
4	Individual and team work		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 2 - Ultrasonic Interferometer

P2.1 Practical Statement

To determine velocity of ultrasonic in different liquids using ultrasonic interferometer.

P2.2 Practical Significance

Ultrasonic waves have numbers of medical and engineering applications. As ultrasonic have high frequency and shorter wavelength as compare to sonic waves, it can move larger distance with less attenuation as compared to sonics waves. The velocity of waves is different in different medium. This experiment will help students to measure the velocity of ultrasonic waves in different liquids.

P2.3 Relevant Theory

The velocity (v) of ultrasonic waves in a liquid is given by

$$v = \upsilon\lambda \qquad ...(1)$$

Where, υ is the frequency and

λ is the wavelength and of the ultrasonic waves in the liquid.

P2.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use ultrasonic interferometer to determine the velocity of ultrasonic waves in a given liquid.

P2.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

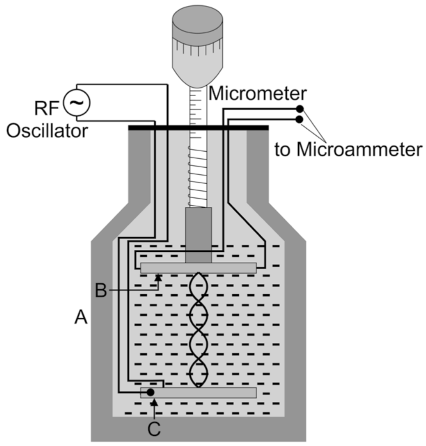


Fig P2.1

Ultrasonic interferometer set up, consist of rf generator, vessel, micrometer and current meter. The liquid (may be distilled water) in which the velocity of ultrasonic waves is to be determined is filled in a vessel (A). Two quartz crystal, (B) and (C) are placed in liquid, C is placed at the bottom of a vessel (A) and (B) is placed above (C) such that B and C are parallel inside the liquid. The crystal (B) is movable. The quartz crystal (C) is given RF oscillation of its natural frequency from external RF Oscillator. Due to piezoelectric effect ultrasonic wave generated by the crystal (C), which moves up in liquid in the vessel. This ultrasonic wave is reflected from crystal B. The position of the crystal B is changed with micrometer screw arrangement, such that stationary waves are formed inside the liquid column due to the superposition of the incident waves from C and the reflected waves from B. Maximum energy is transfer to B when stationary waves are formed. Again, due to piezoelectric effect, maximum voltage is generated along the ends of crystal B which are perpendicular to the vibrations and maximum anode current flows in external circuit, which can be measured by external ammeter. When the position B is again changed, then at some other position, the anode current is again have maximum value. The distance (d) between two consecutive positions of maximum anode current is half of the wavelength.

$$d = \lambda / 2$$

$$v = 2d\upsilon \qquad ...(2)$$

υ *is in Hz and d is in m, v is obtained in m/s.*

P2.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	Ultrasonic interferometer set up consists of rf oscillator, Quarts crystal, ammeter, micrometer screw gauge.				
2	Liquid (Distilled water)				

P2.7 Precautions

1. The length and vessel should be much larger than the wavelength of the ultrasonic waves in the liquid.
2. The temperature of the liquid should remain constant during the experiment.
3. Rotate the micrometer screw always in one direction to avoid the back-lash error.

P2.8 Suggested Procedure

1. Set up the apparatus as shown in Fig. P2.1
2. Keep the position the reflecting crystal B at a convenient height from C inside the liquid.
3. Note the reading of the micrometer.
4. Switch on the RF power oscillator and adjust its frequency to the natural frequency of the crystal C (given as per apparatus specifications). In some apparatus it is already set.
5. Decrease the height of B slowly.
6. Observe the reading of the ac microammeter.
7. Note the micrometer reading when the microammeter shows maximum value (x_1).
8. Repeat the step 5 -7 for five times and note position of maximum current as x_2, x_3 ...
9. The difference between x_1-x_2, x_2-x_3,…..is half of wavelength.
10. Calculate velocity of ultrasonic wave from formula

P2.9 Observations and Calculations

Frequency of rf oscillator = ... Hz least count of micrometer = ... mm

Sr. No	Micrometer reading x (cm)			d (cm)
	Circular scale reading	Main scale reading	Total reading	
1			x_1	$x_1 - x_2 =$
2			x_2	$x_3 - x_2 =$
3			x_3	$x_4 - x_3 =$
4			x_4	...

Mean d = ...

$v = \upsilon \times 2d$

P2.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P2.11Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P2.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give reasons for taking length of vessel more than the wavelength of ultrasonic waves.
2. Can this experiment be performed by using any other liquid also?
3. Give the sources of errors in present experiment.
4. Suggest method to minimize error.

P2.13 Suggested Learning Resources

- https://vlab.amrita.edu/?sub=1&brch=201&sim=803&cnt=4

P2.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Set up of experiment		
2	Tuning at resonance		
3	Measurement of position with micrometer		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course:

- Musical scale frequency
- Speed of sound and Laplace corrections
- Standing waves formation

Applications

- The sound waves of different wavelength have number of applications in real life such as the frequency range (20Hz to 20KHz) of sound waves, which is audible gives sense of hearing.
- Sound waves of high frequency are used in Medical applications.
- The electromagnetic waves have wide range of applications including radio, mobile phones, satellite communications.
- Diving board is a type of cantilever.
- Cantilever beams concept is used in building design

Use of ICT

- The student can visit the following url for simulation of cantilever
- https://mdmv-nitk.vlabs.ac.in/exp1/index.html#
- Use voice recorder app to display the reverberation time

Cantilever

Case study on resonance

Case-Study (Environmental)

Analyze the case study of Tacoma-narrows-bridge given in the following link

- https://theconstructor.org/case-study/tacoma-narrows-bridge-case-study/352365/

Analyze the case study for calculation of reverberation time given in the following link

- https://www.acousticlab.com/en/reverberation-time-and-sabines-formula/

Design innovative Practical /Projects/ Activities

- Prepare model to demonstrate transverse and longitudinal wave on spring and string and measure the velocity of mechanical wave
- Measure reverberation time for different places in institute by using Mobile application.
- Prepare model to measure the velocity of sound.
- Use voice recorder app to demonstrate beats formation with tuning fork.

Inquisitiveness and Curiosity Topics

- Does listening abilities changes with age?
- Waxing and waning of sound.
- Is every periodic motion is SHM?
- Rhythmic marching of soldiers on bridge.
- List the reverberation time of famous concert Halls.
- Find the wave length range of light waves for which human eye is sensible.
- Find two applications of Ultrasonic waves, which has not been listed in section 1.3.6.
- Find the methods with which we can generate and detect Ultrasonic sound.

REFERENCES & SUGGESTED READINGS

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2 Optics

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Optical phenomena of reflection and refraction
- Image formation by mirrors and lenses
- Lens formula
- Defects in lenses
- Light propagation in optical fiber.
- Optical Instruments: microscope and telescope
- Optical projection systems

Applications of optics in daily life are discussed for creating interest and activities are suggested for comprehension of topics. Applications based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. Micro project activity is suggested which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book.

Industrial applications and real life applications on variety of aspects, inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Optical instruments give us the power to see the things around us, whether it is a natural optical instrument that is our eye, or it may be the camera of our mobile phone. Humans are always interested to see things that are either very large or very small to their dimensions. An optical instrument such as microscope and telescope empowered us to observe a small organism and distant planet respectively. Various engineering applications require the knowledge of the optical instrument and optical devices such as lens and mirror. This unit will help the students to apply the basic concepts of ray optics, lens and optical instrument in various engineering situations.

PRE-REQUISITES

- **Mathematics:** Trignometry and Algebra.
- **Physics:** Lens (Convex & concave) and Mirror (convex & concave).
- **Other's:** Basic technology of computer and use of mobile application.

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U2-O1: Explain laws of reflection and refraction of light using ray model.

U2-O2: Predict the details of image formation for concave and convex thin lenses and mirror.

U2-O3: Explain the power of lens, magnification and defects in lenses.

U2-O4: Explain the working of optical fiber by applying the concept of TIR.

U2-O5: Differentiate between simple and compound microscope.

U2-O6: Describe the working of astronomical telescope with resolving power and applications.

Unit-2 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U2-O1	-	3	-	1	-	1
U2-O2	-	3	-	1	-	1
U2-O3	-	3	-	-	-	-
U2-O4	-	3	-	1	-	1
U2-O5	-	3	-	1	-	1
U2-O6	-	3	-	-	-	1

2.1 BASIC OPTICAL LAWS

As per Fig 1.2 in section 1.1 of previous chapter, when a pulse is moving on string and as it reaches to the closed end, the pulse will get reflected. The same phenomenon will be observed in case of water ripples, when they will reach to the boundary. The wave whether it may be sound wave or light wave when they reach to the boundary of the medium in which they are travelling, there will be either reflection or refraction or both the process can take place. An optical phenomenon will be observed, whenever a wave moves from one medium to another.

In the present chapter to explain the phenomena related to light are described by using the ray model. The optical phenomena covered in this chapter can also be described by considering light as a ray without the loss of generality.

As explained above, when there is change in medium there are changes in some physical properties, one of them is the velocity of light ray in the mediums. For any two mediums, say medium I and II, the speed of light is different in both medium. The medium I in which the speed of light less is known as denser medium as compared to medium II and the medium II in which the speed is more is known as rarer medium as compared to medium I. Generally, the medium in which the speed of light is less are considered as denser medium and the medium in which the speed of light is more are known as rarer medium.

Example: a) Water is denser medium for light ray as compared to air.

b) Glass is denser medium as compared to water.

Note: At the boundary of two medium, the line passing perpendicular to interface of two medium is known as normal.

2.1.1 Reflection

Laws of reflection

When a light ray moving in a medium and incident to the interface with other medium, where it makes some angle with the normal, it gets back in the same medium in the other side of normal with the same angle with which it has been incident. This phenomenon is known as reflection of light. Let the incident ray makes 'i' angle (called as angle of incidence) with normal and the ray is reflected with 'r' (called as angle of reflection) angle. The angle of reflection is always equal to the angle of incidence and this law is known as Law of reflection. Also, the incident ray, reflected ray and normal lies in same plane as given in Fig. 2.1

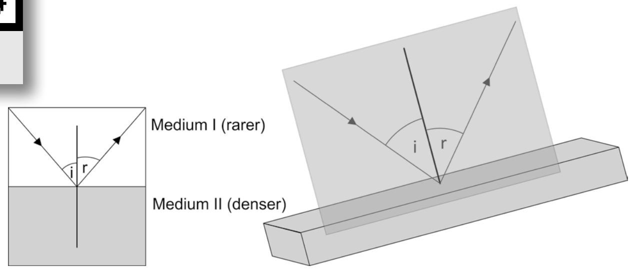


Fig. 2.1 Phenomenon of reflection

$$\angle i = \angle r \quad \text{...(2.1)}$$

2.1.2 Refraction

When a light ray moving in a rarer medium and incident on the interface of a rarer and a denser medium making some angle with the normal, when the light ray enters the denser medium it bends towards the normal. This phenomenon is known as refraction of light and vice versa will happen when light ray moves from a denser to a rarer medium. The light ray moves away from normal when it enters from denser to rarer medium.

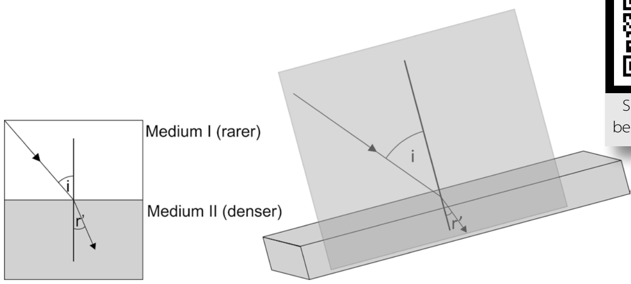


Fig. 2.2 Phenomenon of refraction

Simulation of bending of light

Let the incident ray makes 'i' angle (called as angle of incidence) with normal and the refracted ray makes r' (called as angle of refraction) angle with normal. The ratio of sin of angle of incidence to sin of angle of refraction is equal to the ratio velocity of light in both mediums and this law is known as Snell's Law of refraction.

$$\sin(i) / \sin(r') = v_1 / v_2 \quad \text{...(2.2)}$$

where v_1 is the velocity of light in rarer medium and v_2 is the velocity in denser medium. When a light ray travelling in air is incident on a surface it gets partially reflected and refracted from the surface. The surface which reflects more are shiny or opaque surfaces such as mirror, metal surface etc. and the surfaces which refracts more are transparent surfaces such as glass, water surface etc. No surface is 100 % reflective or 100 % refractive.

2.1.3 Refractive index

The refractive index of any medium is defined as ratio of the velocity of light in vacuum or air to the velocity of light in that medium. It is represented by 'μ' and in some literature as '*n*'. It is a dimensionless physical quantity. The refractive index of any medium with respect to air cannot be less than '1'.

$$\textit{Refractive index of } (\mu) = (\textit{velocity of light in air or vacuum}) / (\textit{velocity of light in medium})$$

Example: The refractive index of glass is 1.5. More the value of refractive index, less the velocity of light in that medium.

As per definition of refractive index the Eq. 2.2 can also be written as

$$sin(i) / sin(r') = {}_1\mu_2$$

Where, ${}_1\mu_2$ is defined as the refractive index of medium 2 with respect to 1 (vacuum or air). Refractive index of air or vacuum is '1'.

2.1.4 Image and image formation by mirrors, lens and thin lenses

Activity

- Take plain paper, keep it in front of the window from where mild sunlight is coming. Place a convex lens in between the window and paper. Try to form an image of a window on paper and measure the distance between paper and lens.

If a ray of light coming from an object (say point 'O') passes through a lens (due to refraction) or falls on mirror and after reflection, converges to one point I or appear to diverge from one point I, then 'I' is called as image of point 'O'.

Real Image and virtual Image

Real image is formed when the light rays meets after refraction or reflection from lens or mirror respectively. It is Inverted and can be taken on screen.

Virtual image is formed when the light rays appears to meet after refraction or reflection from lens or mirror respectively. It is erect and cannot be taken on screen.

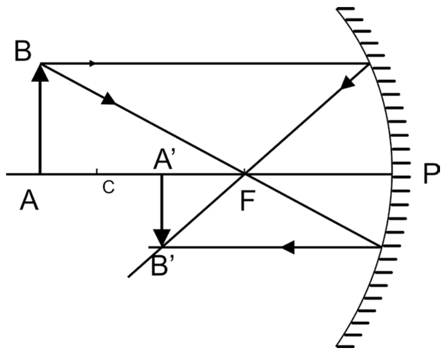
Image formation by mirrors, lens and thin lens

To explain image formation from Lens or mirror following points can be comprehended:

- The light ray passing through parallel to axis after reflection or refraction passes through focus of mirror or lens respectively and vice versa.
- The light ray passing though optical center moves without deviation after reflection or refraction from mirror or lens respectively.

Note: Learners are advised to recapitulate the concept of concave and convex lens and mirror, pole, center of curvature, focal length, radius of curvature, optical center and principal axis.

The following tables summarizes the image formation in mirrors and lens, when object is kept at different position form optical center.

Table 2.1	Image formation by concave mirror
When object is placed beyond C Image is • Formed between F and C • Real • Inverted • Diminished	

<table>
<tr>
<td>When object is placed at C

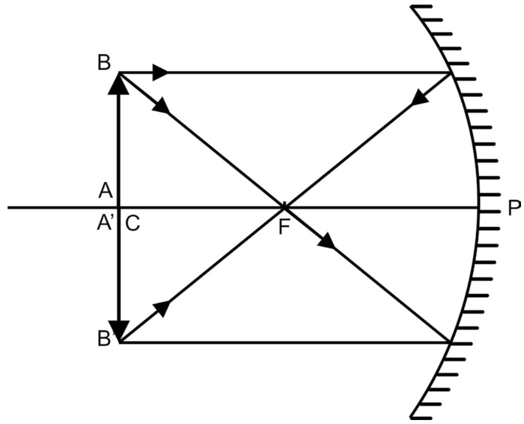
Image is
• Formed at C
• Real
• Inverted
• Same size</td>
<td>
</td>
</tr>
<tr>
<td>When object is placed between C and F

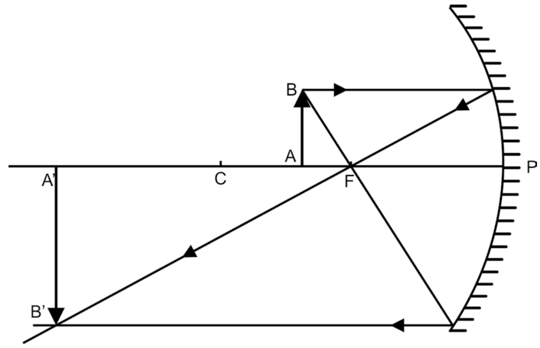
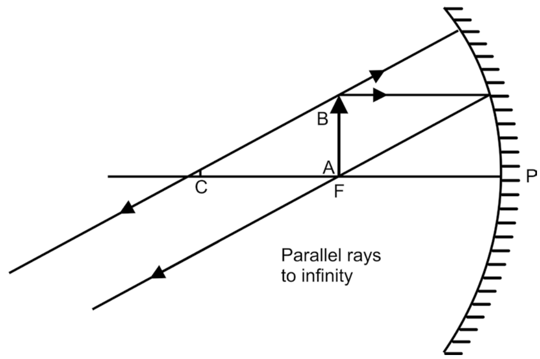
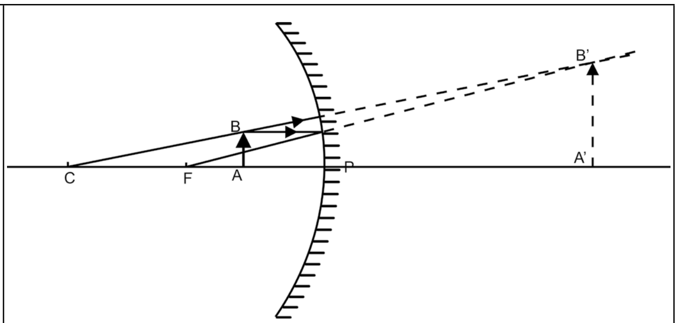
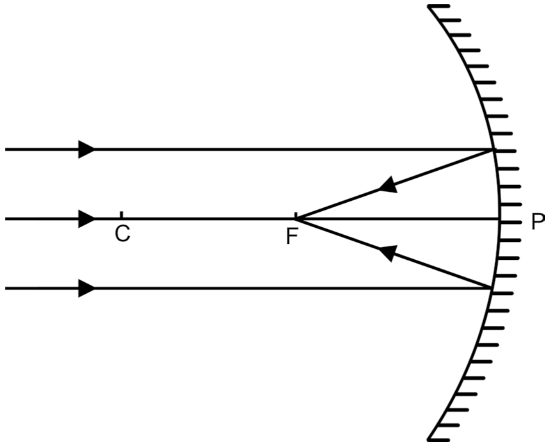
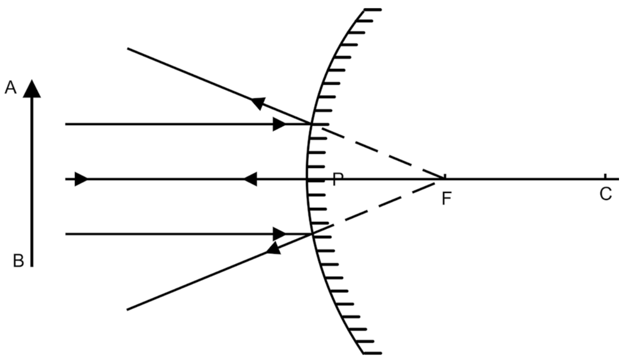
Image is
• Formed beyond C
• Real
• Inverted
• Magnified</td>
<td>
</td>
</tr>
<tr>
<td>When object is placed at F

Image is
• Formed at infinity
• Real
• Inverted
• Magnified</td>
<td>
</td>
</tr>
</table>

Concave mirror ray diagram

When object is placed between F and P Image is • Formed behind the mirror • Virtual • Erect • Magnified	
When object is placed at infinity Image is • Formed at F • Real • Inverted • Highly diminished (point size)	
Table 2.2	**Image formation by convex mirror**
When object is placed at infinity Image is • Formed behind the mirror • Virtual • Erect • Highly diminished (point size)	

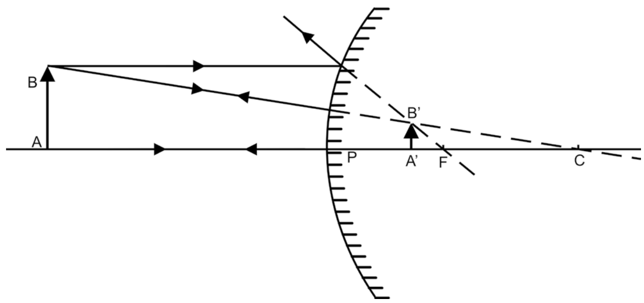
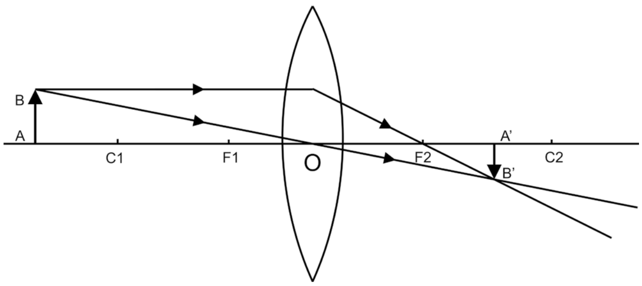
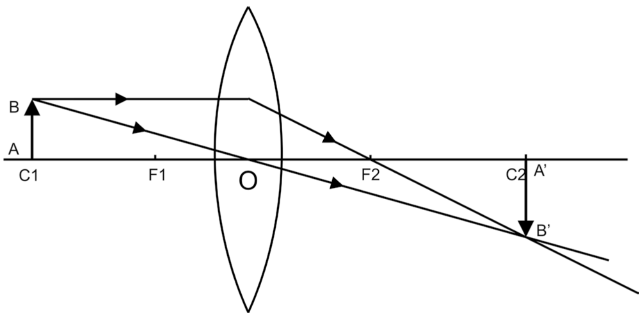
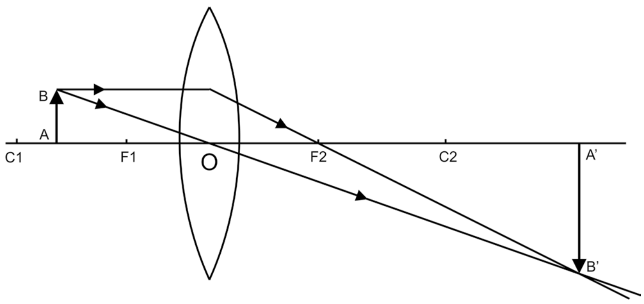
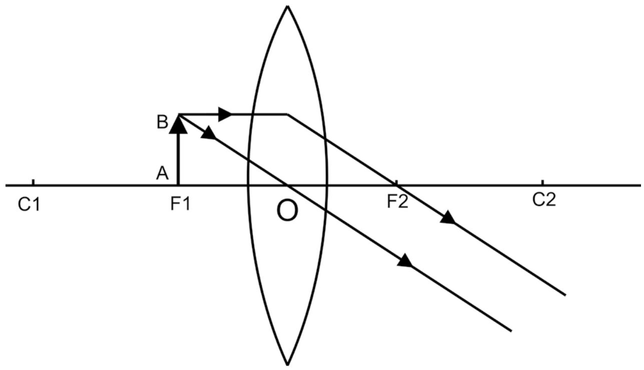
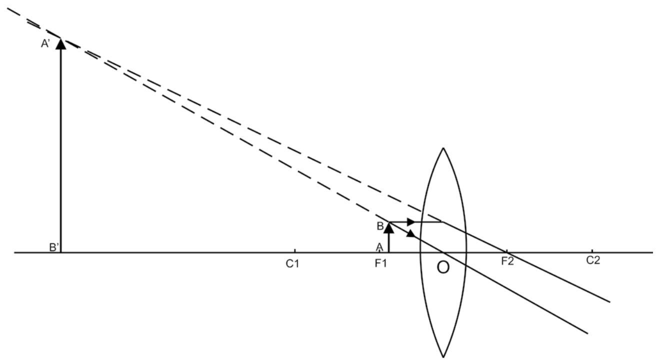
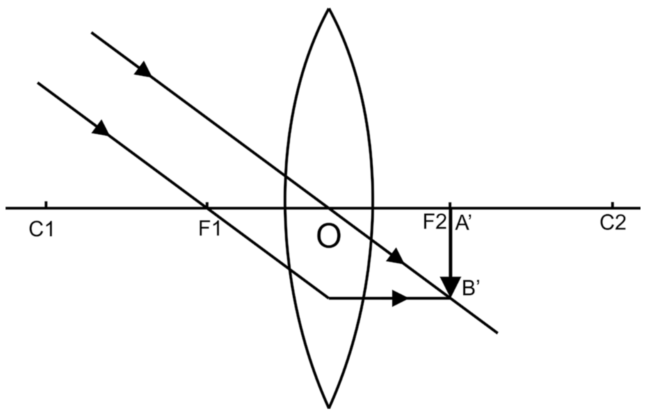
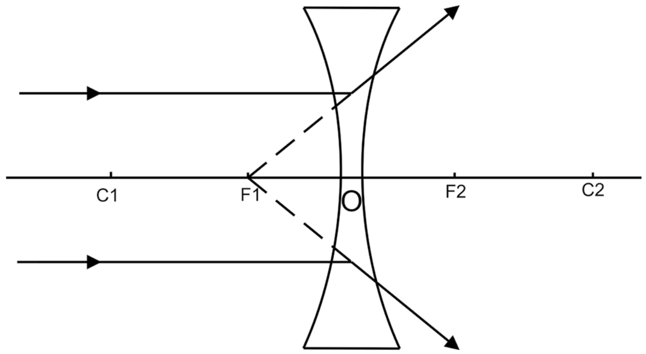
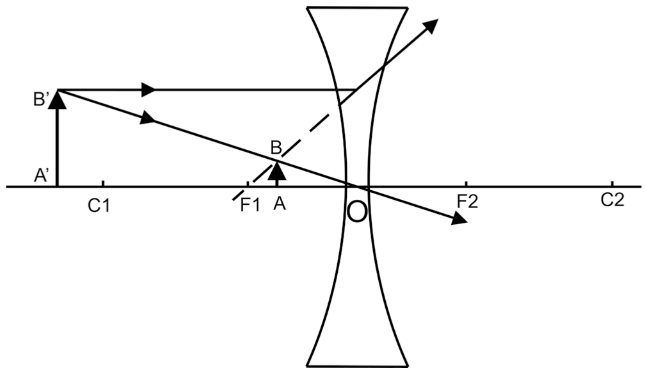
When object is placed between Infinity and P Image is • Formed between P and F behind the mirror • Virtual • Erect • Diminished (point size)	

Table 2.3	Image formation by convex lens
When object is placed beyond C1 Image is • Formed between F2 and C2 • Real • Inverted • Diminished	
When object is placed at C1 Image is • Formed at C2 • Real • Inverted • Same size	

When object is placed between C1 and F1 Image is • Formed beyond C2 • Real • Inverted • Magnified	
When object is placed at F1 Image is • Formed at infinity • Real • Inverted • Magnified	
When object is placed between F1 and O Image is • Formed on same side of objects • Virtual • Erect • Magnified	

When object is placed at infinity Image is • Formed at F2 • Real • Inverted • Highly diminished	
Table 2.4	**Image formation by concave lens**
When object is placed at infinity • Image is • Formed on same side • Virtual • Erect • Highly diminished (point size)	
When object is placed between infinity and O Image is • Formed between O and F1 • Virtual • Erect • Diminished	

Thin Lenses

In the Tables 2.3 and 2.4 we have seen the different cases of image formation in convex and concave lenses. For practical purpose and applications, we are Intrested in the finding the distance of image and objects from lens. A thin lens is a lens which has small thickness, in other words the distance from image or object from lens surface and optical center is almost equal.

2.1.5 Lens formula

Activity

- Draw a convex lens by intersecting two circles of the same radius on graph paper. Make an object on one side of the convex lens and form an image of the object and measure the distance of object and image from the center of the lens.

For a lens 'L' with focal length 'f', let AB is an object and Its image is A'B'. The distance of object and image from optical center is u and v respectively

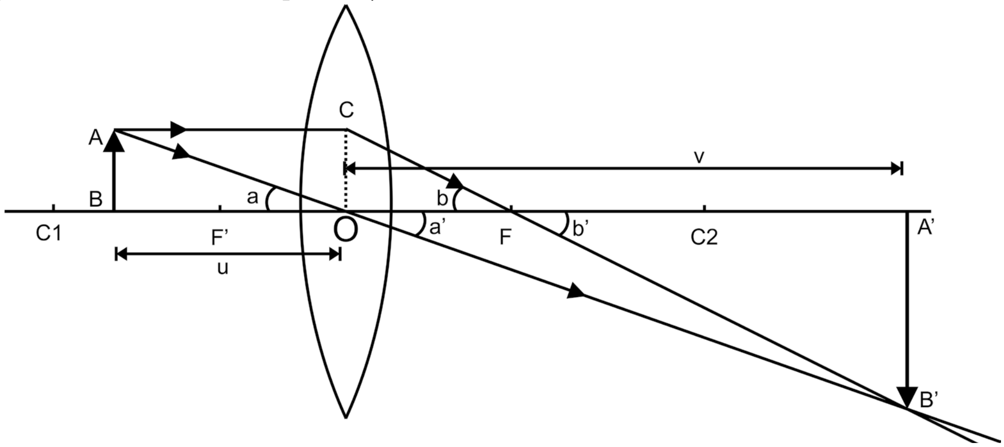


Fig. 2.3 Image formation by lens

Let us find the general relation between f, u and v. The distance is taken from surface of lens. The distance which is in direction of light ray is taken positive and the distance opposite to direction of light ray is negative. In present case v is taken positive and u is taken negative.

In Δ AOB and Δ A'OB'

$$\angle a = \angle a' \quad \text{[vertically opposite angle]}$$
$$\tan(a) = \tan(a')$$
$$AB/OA = A'B'/OA'$$
$$AB/A'B' = -u/v \qquad ...(2.3)$$

Similarly, in Δ COF and Δ A'FB'

$$\angle b = \angle b' \quad \text{[vertically opposite angle]}$$
$$OC/OF = A'B'/FA'$$
$$AB/A'B' = f/v-f \qquad ...(2.4)$$

As $AB = OC$ from figure

Equating Eq. 2.3 and 2.4

$$-u/v = f/v-f$$
$$-u(v-f) = vf$$
$$-uv + uf = vf \qquad ...(2.5)$$

Dividing both sides of Eq . 2.5 with uvf

$$-1/f + 1/v = 1/u \quad \text{or}$$
$$1/v - 1/u = 1/f \qquad ...(2.6)$$

The Eq. 2.6 is known as lens formula, it will also be valid for concave lens.

Activity

- Cross check the image formation distance given in table 2.3 with lens formula.

2.1.6 Power of Lens

The power of any lens is the ability to bend the light ray. The converging of light ray means meeting of all ray to one point and diverging of light rays means coming out of light ray from one point. The power of lens can also be defined as the converging or diverging ability of lens. Mathematically, it is defined as the reciprocal of focal length of lens. The lens which has less focal length has more power and vice versa.

$$\text{Power of lens} = 1/f \text{ (meters)}$$

The unit of power is diopter. The focal length of lens is to be taken in meter to calculate the power of lens. The thick lens has more power as compare to thin lens. The power of lens is different from the term power of machine or motor which we generally use in our daily life. The power of lens in diopter is used by opticians to categories the different lenses. Convex lens has positive power value, whereas concave lens has negative power values.

2.1.7 Magnification and Defects

The ratio of the size of image to the size of object is known as the image magnification. Magnifying is a very common and important application of lens. As from Fig. 2.3

$$\text{Magnification} = \text{size of image / size of object}$$
$$= A'B'/AB$$

From Eq. 2.4

$$m = (v - f)/f \qquad ...(2.7)$$

From lens maker formula

$$1/v - 1/u = 1/f$$
$$1/v - 1/f = 1/u$$
$$(f - v)/vf = 1/u$$
$$(v - f)/f = -v/u \qquad ...(2.8)$$

comparing Eq 2.7 and Eq 2.8

We have $m = -v/u$ ...(2.9)

here – sign indicates inverse image and magnitude of magnification is given by v/u.

Activity

- Find magnification for different cases as given in Table 2.3

Defects

It is also known as aberrations of lens. The image formation of an object from convex lens, kept at different distance from surface of convex lens is given in Table 2.3. and it can also be explained with Eq. 2.4. In actual situations there is deviation in the formation of images, which is explained in Table 2.3, this is due to defects or aberration of lens. It is of two type:

2.1.7.1 Chromatic aberration

In image formation, we have considered a light having single wave length. White light consists of several color wavelength. If we take white light as a source, then different color light forms images at different point. This defect due to color of light is known as chromatic aberration.

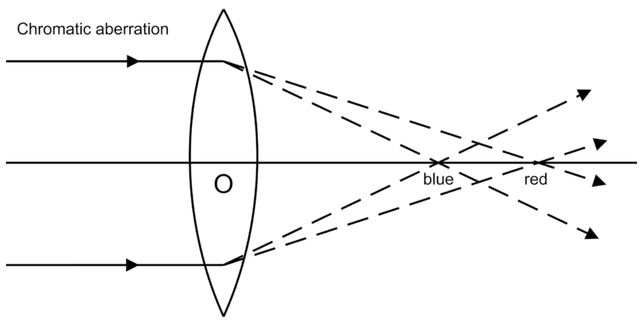


Fig. 2.4 Chromatic aberration

In unit I, in one of the solved examples, it was given that the wavelength of sound wave changes with medium, similarly the component of white color light will have different wavelength and hence different refractive indices in glass. As per Snell's law, different color light will have different angle of refraction and focused at different point.

Effect: series of color images formed when white light is incident on spherical lens

2.1.7.2 Spherical aberration

In convex or concave lens, when objects are placed at infinity, their point images are formed at focus. All the parallel rays of light are supposed to pass through the focus, but in actual case the lines near to principal axis bent little and lines away from principal axis bent more and hence they do not focus on single point. This defect is due to spherical surface of lens and known as spherical aberration.

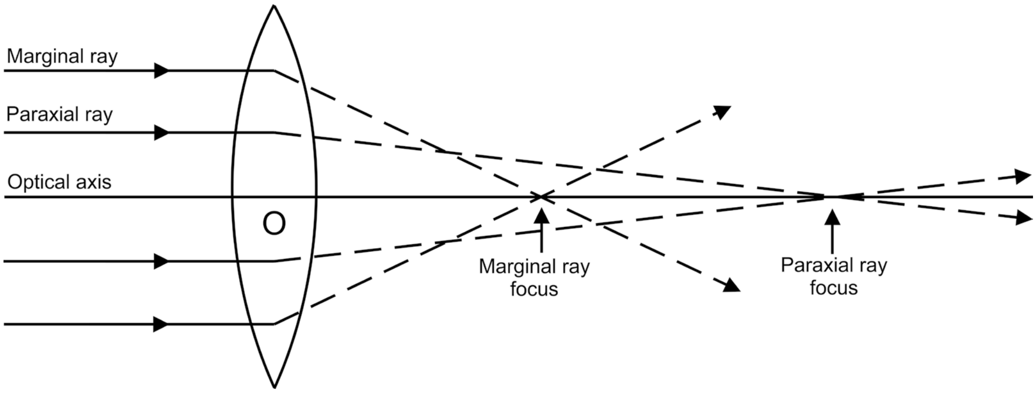


Fig. 2.5 Spherical aberration

Effect: out of focus image, or focus is not sharp point.

2.1.7.3 Coma

In spherical aberration the light rays coming from the object are parallel to principal axis. If the point object is away from principal axis, the light rays coming from the point not parallel to principal axis and spherical aberration applied to such rays results in defects known as Coma. Unequal magnification of the image formed due to different zones of lens. The circular image of point will be formed perpendicular to principal axis.

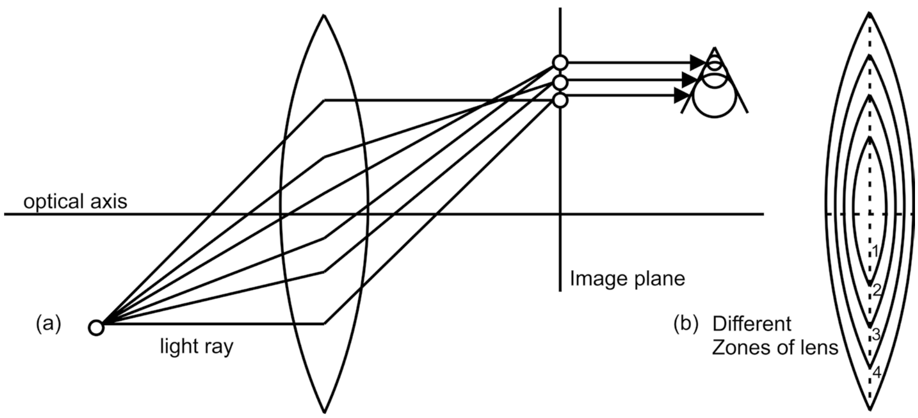


Fig. 2.6 Coma

Effect: Image is sharped in center but blurred towards the edges.

2.1.7.4 Astigmatism

If the light from a point object is passed through lens then for a perfect lens it should form a focused bright spot on the opposite side of the lens. In case the focal length of the lens is different for different planes, there will be no such sharp focus point, where all the light rays incident from the object meet.

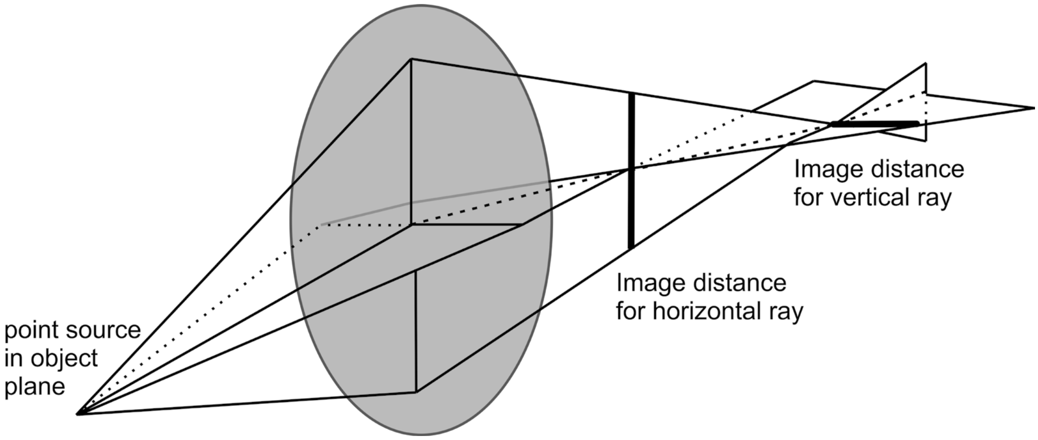


Fig. 2.7 Astigmatism

Effect: The light coming from horizontal and vertical plane will meet at vertical line and horizontal line respectively as a result a blurred image will form. The size of image changes along the principal axis.

2.1.8 Total Internal reflection (TIR)

As from Snell's law of refraction, when a light ray passes from denser to rarer medium, it bends away from the normal. If we increase the angle of incidence the angle of refraction also increases as given in Fig. 2.8 At a angle of incidence, the angle of refraction is 90^0. This angle of incidence is known as critical angle. If we increase the angle of incidence above the critical angle, the angle of refraction is greater than 90^0 and the light ray renters the denser medium or we can say that reflected in the same medium. This phenomenon of reflection is known as total internal reflection.

$$\sin(i)/\sin(r) = {}_2\mu_1$$

$i = i_c$, then $r = 90^0$

$$\sin(i_c) = {}_2\mu_1 = 1/{}_1\mu_2 \qquad ...(2.10)$$

Example of TIR : Shining of diamond
Formation of mirage
Periscope

Applications of Total internal reflection in Optical fiber

Now a day's optical fiber is mostly used as medium of sending signals from telephone instruments to another instrument. Besides this there are numerous applications of optical fiber in medical and engineering applications. Optical fiber is a thin fiber or a wire of micrometer thickness (equal to human hair) made up of glass. It is optically transparent and allows the light ray to propagate through it. The light ray in optical fiber travel due to phenomena of Total Internal reflection. Fig 2.9 gives the schematic of optical fiber. The inner part

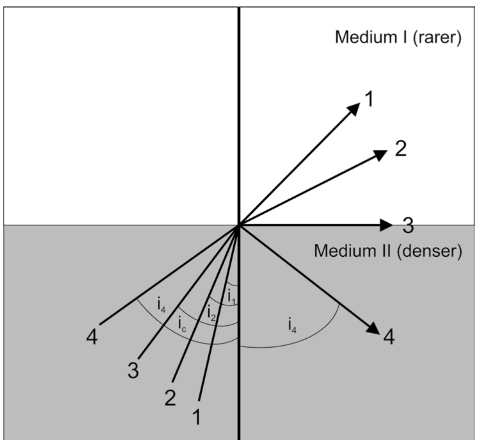


Fig. 2.8 Total internal reflection

of Optical fiber is core and it has more refractive index than out part of fiber i.e. cladding. The audio or video signal or digital signal are first converted into light signal before sending it through optical fiber.

When a light ray enters the optical fiber, making angle i with the core axis, it is refracted, and angle r is smaller than angle i. The refracted ray reaches the core cladding interface and if the angle I' is greater than critical angle the light ray will be totally internally reflected. This light ray will further have successive TIR at each core cladding and until it reaches the end of the fiber. The process of TIR to take place in optical fiber depends upon following factors

- Angle of incidence (i) with optical axis.
- Refractive index of core and cladding.

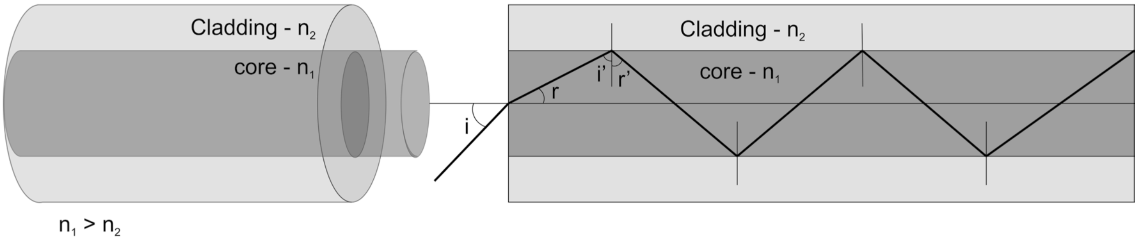


Fig. 2.9 TIR in optical fiber

EXAMPLE 2.1

Ques. Find refractive of glass with respect to water.

(Given $_a\mu_g = 3/2$ *and* $_a\mu_w = 4/3$)

Solution:

Refractive index of glass with respect to water ($_w\mu_g$) =

velocity light in water/(velocity of light in glass)

= (velocity light in air / velocity light in glass) × (velocity light in water / velocity of light in air)

$= {_a\mu_g}/(1/{_a\mu_w})$

= 3/2 × 3/4

= 9/8

EXAMPLE 2.2

Ques. In the following figure find the value of r_2

Solution:

For air and water interface- $\sin(i)/\sin(r_1) = {_a\mu_w} = 4/3$

$\sin(r_1) = 3/4 \sin(i)$

Now

For water and glass interface

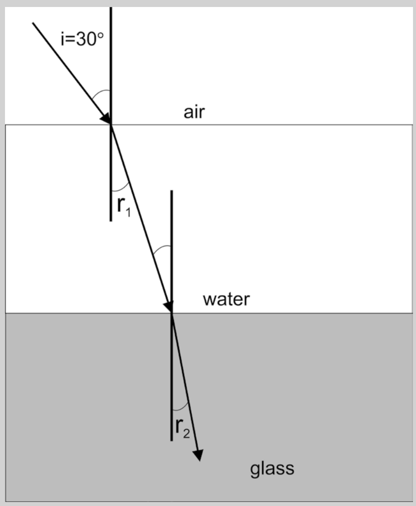
$\sin(r_1) / \sin(r_2) = {_w\mu_g}$

$\sin(r_2) = 8/9 \times \sin(r_1) = 8/9 \times 3/4 \times \sin(30)$

$= 8/9 \times 3/4 \times 1/2$

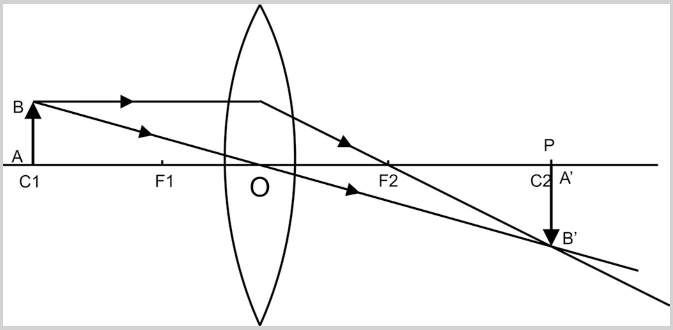
$= 1/3$

$r_2 = \sin^{-1}(1/3)$



Ques. In the following figure find the value of OP, if the object is kept at 2f, where f is the focal length of lens and also find magnification

Solution:



From lens formula

$1/v - 1/u = 1/f$

$v = OP, u = -2f$

Hence

$1/v - 1/(-2f) = 1/f$

$1/v + 1/2f = 1/f$

$1/v = 1/f - 1/2f$

$1/v = 1/2f$

$v = 2f$

The image will formed at the other side of lens at 2f distance from 'O'

Magnification (m) = v/u

$= 2f/2f$

$= 1$

The image will be of same size as object.

EXAMPLE 2.3

Ques. Find the critical angle for TIR for glass air interface. (RI of glass is 1.5)

Solution:

As $\sin(i_c) = {}_2\mu_1$

$\sin(i_c) = {}_g\mu_a = 1/{}_a\mu_g$

$= 1/1.5$

$i_c = \sin^{-1}(0.667)$

$i_c = 42^0$

EXAMPLE 2.4

2.2 OPTICAL INSTRUMENTS

Optical Instruments are the instruments based on the principle of optics and uses optical devices such as lens or mirror to measure the physical quantities or to observe objects. In the present topic, some of the optical instruments based on ray optics are explained in detail with applications. Every instrument needs source of energy to observe the objects, the instruments that uses light source as energy provider are known as optical instrument.

Example: Human eye, spectrometer, periscope, microscope, telescope, projector

2.2.1 Simple and compound microscope

A microscope is an optical instrument used to magnify small objects. It is made up of lens or combination of lenses. The magnifying power of microscope depends upon the parameters of lens used for making microscope and the wavelength of source of light used. The meaning of micro is small, and scope is to see, hence the name suggest that microscope is used to observe small objects. The two basic types of microscope are

- Simple microscope
- Compound microscope

Simple microscope

As from table 2.3, when an object kept between focus and optical center of convex lens its virtual and enlarged image is formed. This property of convex lens is used in designing simple microscope. The following is the ray diagram of simple microscope. It consists of one convex lens. (The details of actual microscope is given in the video link). The object is observed by keeping eye close to convex lens and the image is clearly seen when it forms at distance of distinct vision, which is 25 cm for human eye.

Let 'b' is the angle which eye made with image formed at v = D and 'a 'is the angle which eye (without lens) made with object kept at distance of distinct vision. The magnification is calculated as ratio of the angle 'b' with 'a'.

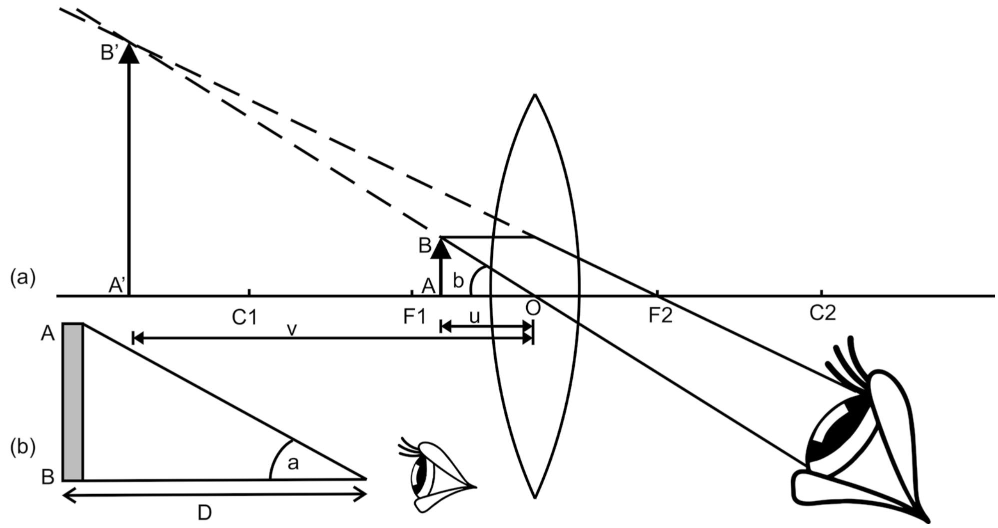


Fig. 2.10 Simple microscope

Magnifying power, $m = b/a$

In ΔA'B'O in Fig. 2.10 a, $tan(b)=A'B'/D$ and ΔABO in Fig. 2.10 b, $tan(a)= AB/D$ if a and b are very small then

$$tan(b)/tan(a) = b/a = A'B'/AB \quad ...(2.11)$$

As from Fig. 2.10 (a) ΔA'B'O and ΔABO are similar triangles then

$$A'B'/AB = -v/-u = D/u \quad ...(2.12)$$

$$m = D/u$$

From Lens Equation

$$1/v - 1/u = 1/f$$

$$(1/-D) - (1/-u) = 1/f$$

$$1/u = 1/D + 1/f$$

Multiply D both sides

$$D/u = 1 + D/f \text{ hence } m = \{1 + D/f\} \quad ...(2.13)$$

This equation gives magnification of simple microscope. If we decrease the focal length of lens the magnification of microscope increases.

Compound microscope

A simple microscope has a limitation of magnification, for larger magnification a combination of two lens microscope or compound microscope is used Fig. 2.11 shows the ray diagram for compound microscope. The lens which is near to object is objective lens and the lens from which, the image is observed is eye piece. The focal length of objective and eyepiece is f_o and f_e respectively.

The object AB is kept at distance slightly greater than f_o such that real and inverted magnified Image A'B' is formed on other side of objective. The A'B' is formed between the focal length and Optical center of Eyepiece. The enlarged virtual erected image A"B" of A'B' is seen through eyepiece.

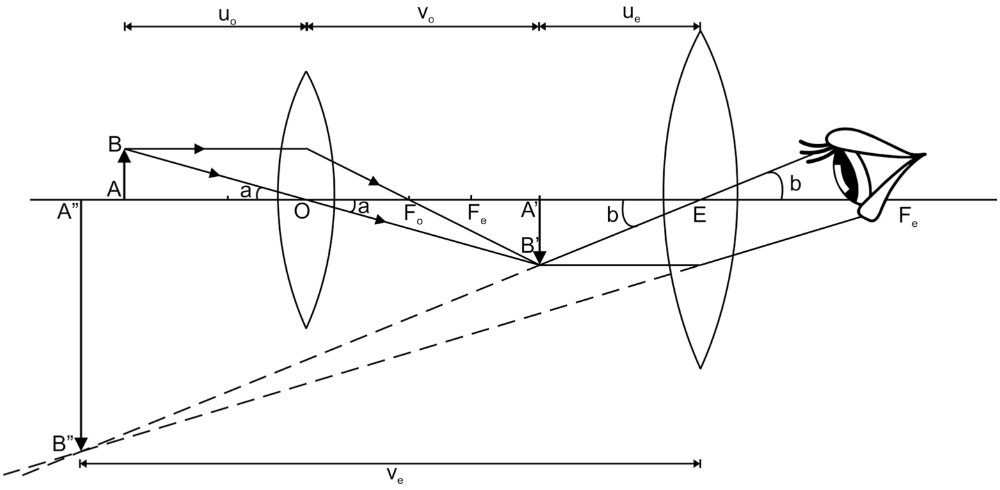


Fig. 2.11 Compound microscope

The magnifying power of compound microscope is product of the magnification by two lenses. Magnifying power of compound microscope is = $m_o \times m_e$

$$= (-v_o/u_o)[1+D/f_e] \quad ...(2.14)$$

2.2.2 Astronomical telescope in normal Adjustment

The meaning of 'tele' is 'distant' or 'far', hence as the name suggest that telescope is used to observe distant objects such as astronomical objects or terrestrial objects. The simple astronomical telescope consists of two lenses as given in ray diagram of astronomical telescope in Fig. 2.10. The objective is a convex lens of long focal length and with large aperture. The real image of the distant object forms at the focus of objective lens. The eyepiece is convex lens of small focal length. The optical system of telescope is like microscope. The objective lens forms real and diminished image AB of the object. The eyepiece enlarges the image AB (which is object for eyepiece) and forms magnified virtual image.

In normal adjustment the image AB is formed at the focus of eyepiece and its magnified and enlarged virtual image is formed at infinity. If the final image formed by the by the eyepiece lies at infinity. The distance between the objective and eyepiece is the sum of their focal length, $f_o + f_e$

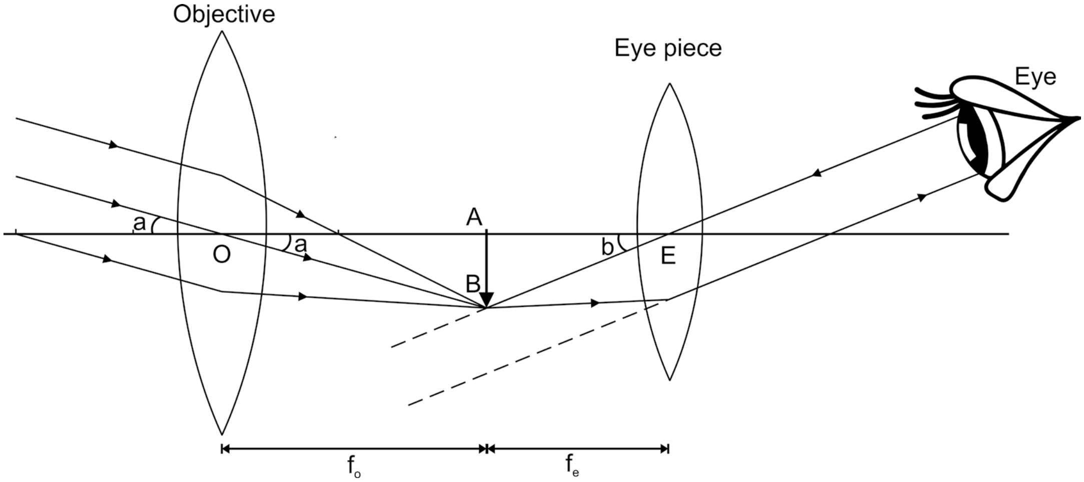


Fig. 2.12 Astronomical telescope

2.2.3 Magnifying power

To find magnifying power it is assumed that the eye is very close to the eyepiece. The distance between the objective and eyepiece is very small as compared to the distance of the objective from the object. The angle 'a' subtended at the unaided eye by the object can be taken as the angle subtended by the object at the objective.

Magnifying power, $|m| = b/a$

In ΔABO and ΔABE of Fig. 2.12

$$\tan(b)/\tan(a) = (AB/BE)/(AB/OB) \quad ...(2.15)$$

$$b/a = OB/BE \quad \text{[if a and b are very small]}$$

$$|m| = f_o/f_e \quad ...(2.16)$$

2.2.4 Resolving power

The resolving power of any optical instrument, whether it's a microscope, telescope or human eye, is the ability of instrument to resolve any two near objects and form separate image of those nearby objects. In case of telescope the resolving power is the ability to form separable images of two distant objects or astronomical object. In case of microscope the two smaller nearby objects are resolved. Our eye is also an optical instrument. It is seen by experiment that if the angle subtended by two objects on eye is less then 1' (1 minute) then the objects will not be separate. This angle is called the 'resolving limit of the eye'.

Similarly, every optical instrument has a limit to form separate images of two objects and is called as the limit of resolution of that optical instrument. Smaller the limit of resolution of an optical instrument, greater is said to be its resolving power.

The resolving power of telescope = $d/1.22\,\lambda$

Where, d is the diameter of objective lens and λ is the wave length of light used.

The resolving power of microscope = $2n\sin(\theta)/\lambda$

Where, n is the refractive index between specimen and lens

θ is the half of the angle subtended by objective lens on object,

λ is the wave length of light used.

2.2.5 Uses of microscope and telescope

Microscope

- Analysis of soil particles
- Find out various skin diseases.
- In microbiology to study samples of algae, fungi.
- To magnify the fine parts of the jewelry.

Telescope

- View astronomical objects such as planets, galaxy, natural satellite of planet.
- Solar and lunar eclipse.
- Observe Moon surface.

2.2.6 Optical Projection system

Optical projection systems are optical devices used to form magnified projected image of an object. Overhead projector (OHP), slide projector and LCD projector are the examples of optical projector systems, generally used in class room and seminars to project the teaching learning material, power point presentations etc. Fig 2.13 display the schematic of optical projection system. It consists of light source, collimator lens, projector lens and screen. The object is kept between the collimator and projector lens. A real magnified image of object is formed on the screen. Arrangement must be made to form erect image of object in case of OHP projector a mirror is used to form erect image.

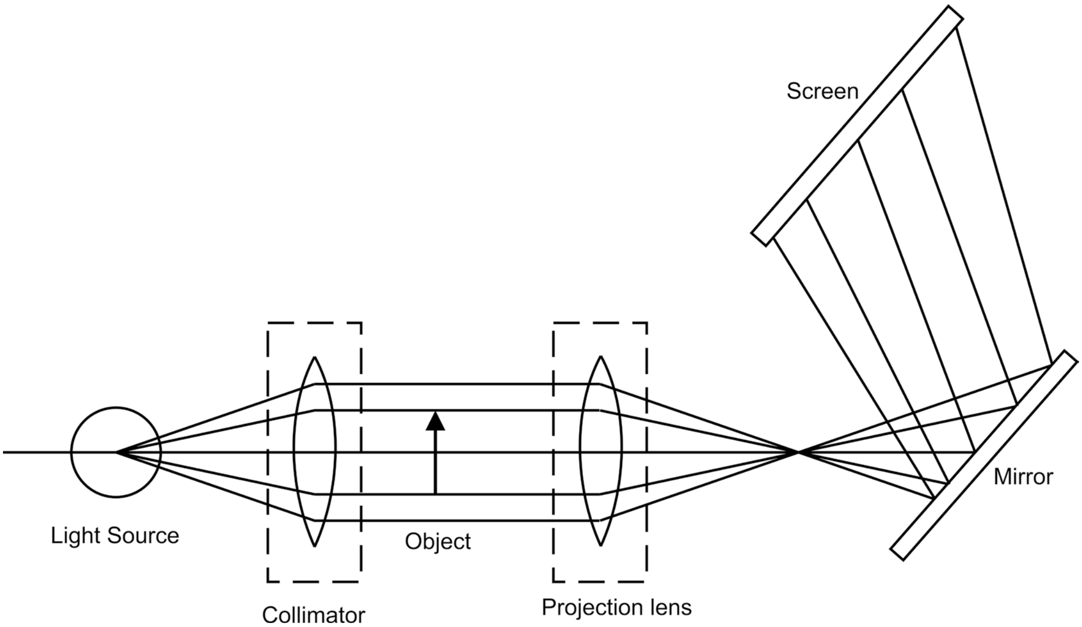


Fig 2.13 Optical projection system

Ques. For a compound microscope the focal length of Objective and eyepiece 3 centimeters and 6 centimeter 6 centimeters respectively. The distance between eyepiece and objective is 28 centimeters. Calculate the distance of object from objective lens and magnification of image, when the image seen from eye is formed at 25 cm from the eyepiece.

Solution:

Given that f_o= 3 cm, f_e= 6cm, v_e = 25 cm and $v_o + u_e$ = 28 cm

(i) First, we find u_e by lens equation

$\Rightarrow 1/v_e - 1/u_e = 1/f_e$

$\Rightarrow 1/-25 - 1/u_e = 1/6$

$\Rightarrow -1/u_e = 1/6 + 1/25$

$\Rightarrow -1/u_e = 31/150$

$\Rightarrow u_e = -150/31$

[here negative sign indicates that the image is between objective and eyepiece]

Now we will find v_o

As $v_o + u_e = 28$ cm

$\Rightarrow v_o = 28 - 150/31$

$\Rightarrow v_o = 718/31$ cm

From lens equation

$1/v_o - 1/u_o = 1/f_o$

$\Rightarrow 31/718 - 1/u_o = 1/3$

EXAMPLE 2.5

EXAMPLE 2.5

$\Rightarrow 1/u_o = 31/718 - 1/3$

$\Rightarrow 1/u_o = -687/2154$

$\Rightarrow u_o = -2154/687 = -3.14$ cm

The distance between object and objective lens is 3.14 cm

(ii)

The magnifying power of compound microscope id given by

$m = (-v_o/u_o)[1 + D/f_e]$

$\Rightarrow m = -(718/31) \times (687/2154)[1 + 25/6]$

$\Rightarrow m = -(718/31) \times (687/2154)[31/6]$

$\Rightarrow m = -38.2$

Here negative sign shows that the final image is inverted.

EXAMPLE 2.6

Ques. The focal length of objective and eyepiece of telescope is 150 cm and 5 cm respectively. Find the distance between objective and eyepiece if the telescope is at normal adjustment.

Solution: Given, f_e = 5cm and f_o = 150cm

If the telescope is at normal adjustment, then the image of objective formed at the focus of eye piece.

Hence the distance between objective and eyepiece = $f_e + f_o$ = 5 + 150 = 155 cm

UNIT SUMMARY

- The angle of incidence is equal to angle of reflection.
- The light ray bends towards normal when it moves from rarer to denser medium and vice versa.
- Combination of convex lens is used to design microscope and telescope.
- TIR is responsible for travelling of light ray in Optical fiber.
- The power of lens in inverse of focal length.

EXERCISES

Multiple Choice Questions

2.1 For an optical instrument (like a telescope) given magnifying power is:

a. Maximum for normal adjustment
b. Maximum for near point adjustment
c. Same for both the above cases
d. Independent of any adjustments

2.2 A convex lens of focal length 2/3 m forms inverted image twice in size of the object, the distance of the object from the lens is:

a. 0.5 meters
b. 0.166 meters
c. 0.33 meters
d. 1 meter

2.3 An object is placed at a distance of 20 centimeters from a convex lens of focal length 10 centimeter, the image is formed on the other side of the lens at a distance:

a. 20 cm
b. 10 cm
c. 40 cm
d. 30 cm

2.4 Total internal reflection can occur when light passes from a denser to rarer medium and

a. angle of incidence can have any value
b. angle of incidence is equal to critical angle
c. angle of incidence is greater than critical angle
d. angle of incidence is less than critical angle

2.5 Light passes from air into a liquid the angle of incidence is 60 degrees. There is deviation of 15 degrees in the path of light ray. The refractive index of the liquid is:

a. 1.5
b. 1.33
c. 1.22
d. 1.63

Answers of Multiple Choice Questions
2.1 (a), 2.2 (c), 2.3 (a), 2.4 (c), 2.5 (c)

Short and Long Answer Type Questions

Category-I

1. Give four examples of reflection and refraction in daily life.
2. Explain the phenomena of reflection of light with diagram.
3. Sate the Snell's law of refraction of light with diagram.
4. Differentiate between refraction and reflection of light on any four points.
5. Define the following terms: refractive index, normal, angle of incidence, angle of refraction, Image, real image and virtual image.
6. Differentiate between, real image and virtual image on any four points.
7. Write the rules of image formation with any one example each for mirror and lens.
8. Derive lens formula for image formation in thin lens. Apply lens formula to describe the image formation in convex lens or concave lens (one example each).
9. Define the term power of lens with unit.
10. Explain magnification of lens. Derive the formula for magnification of image using lens formula.
11. Explain defects of lens with diagram.
12. Describe TIR with necessary conditions and ray diagram. Explain the working of optical fiber.
13. Give two examples of applications of TIR in daily life.
14. Derive relation between angle of incidence with refractive index of medium.

15. Explain the working of simple microscope with ray diagram. Derive the relation for magnifying power of Simple microscope.
16. Explain the working of compound microscope with ray diagram. Derive the relation for magnifying power of compound microscope.
17. Differentiate between Simple and compound microscope on any four points.
18. Explain the working of astronomical telescope. Draw ray diagram for normal adjustment.
19. Derive the relation for magnifying power of astronomical telescope.
20. Define resolving power of telescope. State the factors on which resolving power of telescope depends.

Category-II

1. The focal length of the objective and the eyepiece of a microscope are 1 centimeter and 2 centimeter's respectively. If the distance between these lenses be 12 centimeter and the final image is formed at infinity, then calculate:
    a. Distance of the object from the objective
    b. Linear magnification produced by the objective
    c. Magnifying power of the microscope
2. The focal length of the objective and the eyepiece of an astronomical telescope are 60 centimeters and 5 centimeters respectively calculate the magnifying power and the length of the telescope when the final image is formed at infinity.
3. An object is placed at a fixed distance from a screen. When a convex lens is placed between the objects and the screen at 15 centimeters from the object then an image is formed on the screen having a size 5 times the size of the object. Calculate the focal length of the lens and the distance between the object and the screen.

PRACTICAL

There are four laboratory experiment(s) which are related to this unit.

- To verify laws of reflection from a plane mirror/ interface.
- To verify laws of refraction (Snell's law) using a glass slab.
- To determine focal length and magnifying power of a convex lens.
- Study of an optical projection system (OHP/LCD) - project report.

Practical 3 - Laws of reflection

P3.1Practical Statement

To verify laws of reflection from a plane mirror/interface

P3.2 Practical Significance

Reflection phenomena shown by light rays has numerous examples and applications in daily life, such as image formation in plane mirror, convex mirror, periscope, telescope and microscope. This experiment will help learner to observe the phenomena of reflection from experimental point of view and measure the angles incidence and reflection.

P3.3 Relevant Theory

Refer Section : 2.1.1 of this unit

P3.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:
PrO1: Measure the angle of incidence and reflection in reflection phenomena

P3.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

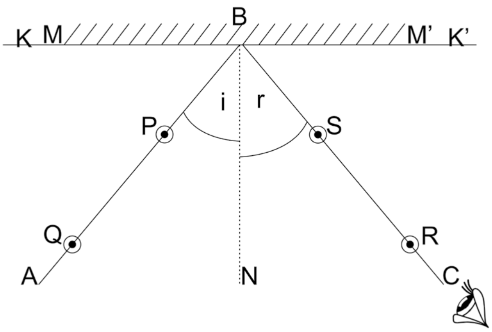


Fig P3.1

P3.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
	Soft board, white sheet of paper, pins, push pins, plane mirror, pencil, protractor and ruler				

P3.7 Precautions

1. Plane mirror should be hold vertical throughout the experiment.
2. Pins used as object and for image tracing should be placed vertical.

P3.8 Suggested Procedure

1. Fix A4/A3 size white paper on the board.
2. Draw two perpendicular line on paper (KK' and BN).
3. Place the mirror vertically on line, KK'. (The perpendicular BN to this line is normal)
4. Draw a line (AB) making angle 30^0 (= i) with normal.
5. Place two pins, P and Q at distance of 2 cm on line AB
6. Place two other pins R and S on other side of normal in such a way that pins R, S and images of P and Q lie on the same line and there is no parallax between pins and images.

7. Remove pins R and S and join the dots with a straight line.
8. Measure and record angle of reflection r.
9. Repeat procedure 4, 5, 6 and 8 for angles i = 35^0, 40^0, 45^0 and 50^0
10 Record the results in a table.

P3.9 Observations and Calculations

Sr. No	Angle ABN	Angle CBN
1		
2		
3		
4		
5		
6		

P3.10 Results and/or Interpretation

(to be filled by student)

1. ....

P3.11Conclusions and/or Validation

(to be filled by student)

1. ....

P3.12 Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give the least count of the protractor used in experiment?
2. Is the size of pin and its image is same?
3. If we keep the pins on normal, then the image will be formed at which position?
4. Give the reasons for error in experiments.

P3.13 Suggested Learning Resources

- https://phet.colorado.edu/en/simulation/bending-light
- https://www.youtube.com/watch?v=QZFfm05ZOek

P3.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Arranging Set up for experiment		
2	Measuring angles properly		
3	Team work		
Product related: ….. Marks* (…….%)			
4	Result and conclusion		
5	Timely submission of report		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 4 - Laws of Refraction

P4.1 Practical Statement

To verify laws of refraction (Snell's law) using a glass slab.

P4.2 Practical Significance

Refraction phenomena shown by light rays when passes through optically transparent medium has numerous examples and applications in daily life such as image formation in convex lens, concave lens, prism and optical instruments. This experiment will help learner to observe the phenomena of refraction from experimental point of view and measure the angles incidence and refraction.

P4.3 Relevant Theory

Refer section : 2.1.2 of this unit

P4.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:
PrO1: Measure the angle of incidence and refraction in refraction phenomena

P4.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

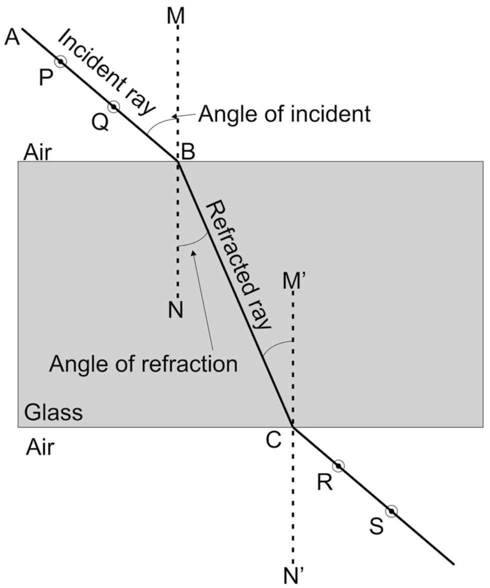


Fig P4.1

P4.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
	Soft board, white sheet of paper, pins, push pins, plane mirror, pencil, protractor and ruler				

P4.7 Precautions

1. Plane mirror should be hold vertical throughout the experiment.
2. Pins used as object and for image tracing should be placed vertical.

P4.8 Suggested Procedure

1. Fix A4/A3 size white paper on the board.
2. Place the rectangular glass slab at center of paper and trace its edges.
3. Remove the glass slab.
4. Draw a normal to any one side of rectangle drawn by tracing edges of glass slab (MN).
5. Draw a line (AB) making an angle 30^0 (= i) with normal.
6. Place the glass slab again.
7. Place two pins, P and Q at distance of 5 cm on line AB.
8. See the image of these two pins from the opposite side of glass slab.
9. Place two other pins R and S on other side of glass slab such that they are in line with the images of P and Q

10. Remove the glass slab.
11. Remove pins R and S and join the dots with a straight line touching the rectangle at C.
12. Draw a normal at point(M' N') C and join point B and C.
13. Measure and record angle of refraction ∠ r i.e angle NBC.
14. Repeat procedure 5 to 13 for angles ∠ i = 35^0, 40^0, 45^0 and 50^0
15. Record the results in a table.

P4.9 Observations and Calculations

Sr. No	∠ ABM (angle of incidence)	∠ CBN (angle of refraction)
1		
2		
3		
4		
5		
6		

P4.10 Results and/or Interpretation

(to be filled by student)

1. ....

P4.11 Conclusions and/or Validation

(to be filled by student)

1. ....

P4.12 Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give the least count of the protractor used in experiment?
2. If we replace glass slab with water, predict the change in angle of refraction?
3. Is emergent ray is parallel to incident ray, if yes give reasons.?
4. Can we do this experiment without protractor?

P4.13 Suggested Learning Resources

- http://cdac.olabs.edu.in/?sub=74&brch=9&sim=37&cnt=1

P4.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators	Weightage	Marks Awarded
Process related: …. Marks* (…….%)		

1	Arranging Set up for experiment		
2	Measuring angles properly		
3	Team work		
Product related: ….. Marks* (…….%)			
4	Result and conclusion		
5	Timely submission of report		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 5 - Convex lens

P5.1 Practical Statement

To determine focal length and magnifying power of convex lens.

P5.2 Practical Significance

Conve2x lenses are commonly used in eyeglasses for correcting hypermetropia / farsightedness and for image formation in microscope and telescope. The power of convex lens depends on its focal length. This experiment will help learner to use convex lens for image formation and find its focal length.

P5.3 Relevant Theory

Refer Section : Table 2.3 and 2.1.5 of this unit

P5.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Determine the focal length and magnifying power of a given convex lens.

P5.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

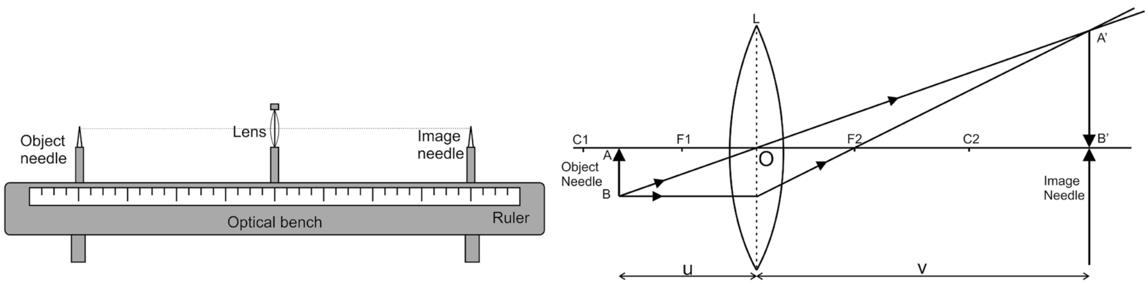


Fig P5.1

P5.6 Resources Require

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Re-marks (if any)
			Make	Details	
	Optical bench, Uprights, a convex lens, lens holder, optical needle and a meter scale.				

P5.7 Precautions

1. Tips of the object needle, image needle and center of the lens should lie at the same height.
2. Parallax should be removed before taking reading.
3. Placement of object needle should be such that experiment is performed for real images only.
4. Apply index correction in measurements.

P5.8 Suggested Procedure

1. Measure the rough focal length of convex lens by observing the image of distant object on plain paper.
2. Keep fixed upright at the center of optical bench.
3. Fix the lens holder with lens in fixed upright.
4. Adjust the lens so it is vertical and perpendicular to the length of the optical bench.
5. Mount a thin optical needle (object needle) in a movable upright.
6. Mount the thick optical needle (image needle) in a movable upright on the other side of lens on the optical bench.
7. Adjust the height of the image needle in line with the optical center of the lens.
8. Put a knitting needle of known distance between the lens and object needle tip.
9. Measure the distance between the object needle and lens from the index at the base of upright.
10. Put knitting needle between the lens and image needle tip.
11. Measure the distance between the image needle and lens from index.
12. Measure index correction from steps 8 to 11 (index correction means to measuring actual distance).
13. Fix the object needle upright at a distance nearly 1.5 times the rough focal length of the lens (fix u).
14. Set the height of the object needle in line with the optical center of the lens.
15. Note the position of object needle upright from the index marked on the base of the upright.
16. Observe the inverted image of object needle from the other side (tip of image of object needle in line with tip of image needle)
17. Move eye right or left. If the tips of image and image needle separates (due to parallax), then
18. Change the distance of image needle, until the parallax removed.
19. Note this position of image needle (find v).
20. Change the position of object needle by 1 to 2 cm.
21. Repeat the steps 11 to 14.
22. Find v for at least five different values of u

23. Plot graph between -u (as x) and v (as y) in second quadrant (rectangular hyperbola).
24. Draw a line making 45^0 angle with x or y axis.
25. Note the coordinates of point at which the line intersects the hyperbola.
26. Calculate the focal length of convex lens.
27. Calculate the magnifying power of lens using formula, m = 25/f

P5.9 Observations and Calculations

Length of knitting needle x = …. cm

Distance between the object needle and the lens, when knitting needle is placed between them y = ...cm

Distance between the image needle and the lens, when knitting needle is placed between them z = ...cm

Index correction for the object distance u, x – y = ...cm

Index correction for the image distance v, x – z = ...cm

Index reading of lens upright, F = ...cm

Sr. No	Reading of		Observed Distance (cm)		Actual Distance [(cm) (after subtracting index correction)]	
	Object needle (O)	Image needle (I)	u = F – O	v = I – F	u	v
1						
2						
3						
4						
5						
6						

f = (coordinate of point of intersection of line and hyperbola)/2

f = ………cm and m = 25/f

P5.10 Results and/or Interpretation

(to be filled by student)

1. ....

P5.11 Conclusions and/or Validation

(to be filled by student)

1. ....

P5.12 Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Describe the change in parallax when the object needle is moved in either side from its position?
2. Give the source of index error.
3. Can we take Convex lens of 40 cm in the present experiment?

P5.13 Suggested learning resources

- https://phet.colorado.edu/en/simulations/bending-light

P5.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Arranging Set up for experiment		
2	Measuring index correction		
3	Removal of parallax		
4	Handling of instrument.		
5	Team work		
Product related: ….. Marks* (…….%)			
6	Result and conclusion		
7	Timely submission		
8	Graph plot		
9	calculations		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 18 - Optical Projection system

(Suggestive template for project report)

P18.1 Title

Study of an optical projection system (OHP/LCD).

P18.2 Rationale

(Importance of LCD projector and reason for doing project in 100-150 words)

P18.3 Literature Review

(Existing status, knowledge required to complete the chosen task in about 200 to 500 words)

P18.4 Methodology

(Procedure to be followed in brief in about 200 to 500 words)

P18.5 Resources used

Sr. No	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Qty	Remarks (if any)
	Make	Details		
1				
2				
3				
4				

P18.6 Outcomes (presentation of collected data, findings etc.)

P18.7 Learning from this project (in about 200 to 400 words)

P18.8 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Literature survey		
2	Methodology		
3	Interaction during project work		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Outcomes		
6	Timely submission of project report		
7	Project presentation		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course

- How to remove the lens aberrations?
- Timeline of invention of microscope and telescope.
- Working of LCD projector.

Refraction and lenses

Applications

- Image formation and magnification of lens helps in removing defects of eye and it is one of the very big application of optics to mankind.
- Lens and mirrors are used to make optical Instruments.
- Cameras, Mobile camera and digital camera are the outcomes of image formations by lens.
- Optical fiber, used in telecommunication, medical and other engineering application and is based on TIR of light

Use of ICT

- The student can visit the following url for details on image formation by lenses
- https://courses.lumenlearning.com/physics/chapter/25-6-image-formation-by-lenses/

Design innovative Practical /Projects/ Activities

- Collect convex and concave lens of different dimensions from the laboratory or market. Find the methods so that the lens and mirror can be differentiated as a convex or concave lens or mirror.
- Prepare detail report on a microscope and telescope used in laboratory.

Inquisitiveness and Curiosity Topics

- Image formation and magnification of lens helps in removing defects of eye and it is one of the very big application of optics to mankind.
- Lens and mirrors are used to make optical Instruments.
- Cameras, Mobile camera and digital camera are the outcomes of image formations by lens.
- Optical fiber, used in telecommunication, medical and other engineering application and is based on TIR of light.
- Reason for large size of the telescope.
- Is optical microscope the only instrument to see the magnified image objects?.

REFERENCES & SUGGESTED READINGS

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- Ajoy Ghatak, "Optics", 4th ed.,McGraw- Hill, 2010.

3 Electrostatics

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Coulombs law of forces between charges and its vector form
- Electric lines of force and their properties
- Electric flux
- Electric flux and electric potential difference
- Gauss' law and its applications
- Capacitors and its types
- Effect of dielectric materials on capacitance of capacitors

Applications of Electrostatics in daily life are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. Micro project activity is suggested which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book. Industrial applications and real life applications on variety of aspects and inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning

RATIONALE

Electrostatics is a branch of physics which deals with the force between static charges and it has number of applications. Thundering and lightning are the most common examples of electrical discharge. Either it is printing of paper or high voltage generation through Van dee Graaff generator both are among the engineering applications of electrostatics. Capacitors are active components and act as energy storage devices and filters in electrical and electronic circuits respectively. This unit will explain the basics of electrostatics, electric field, Gauss' law to find electric field and capacitors which will help to comprehend the engineering applications of electrostatics and solve the problems related to electrostatics.

PRE-REQUISITES

- **Mathematics:** Trigonometric functions, Algebra, calculus, vectors
- **Physics:** Concept of Charge, Potential energy, Force
- **Other's:** Basic technology of computer and use of mobile application

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U3-O1: Explain Coulomb force between two charges and electric field due to static charge.

U3-O2: Predict the potential difference between two points for a given charge distribution.

U3-O3: Apply Gauss' Law to find electric field due to given charge distribution.

U3-O4: Find the capacitance of a given parallel plate capacitor.

U3-O5: Determine the capacitance for a given combinations of capacitors.

Unit-3 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U3-O1	-	-	3	2	-	1
U3-O2	-	-	3	1	1	1
U3-O3	-	-	3	1	-	1
U3-O4	-	-	3	1	1	1
U3-O5	-	-	3	1	-	1

3.1 COULOMB'S LAW

Activity

Rub one end of two glass rods with silk and rub a plastic rod with fur. Suspend one glass rod with thread and one by one,

- Bring the other glass rod near to the suspended glass rod and
- Bring plastic rod near to the suspended glass rod.

Observe the nature of force between rods in both cases.

Charge is a common term, which is also used in our daily life. We say that we have to charge mobile, but actually we are charging battery of mobile by connecting it through charger to mains power supply and hence energize the battery of mobile. The physical quantity charge in static form and the phenomena related to static charges has been explained in this unit. Some of the common examples of the phenomena observed due to static charge is as follows:

- In dry weather, while walking on woolen carpet, if we touch the metal doorknob, a spark is produced.
- Lightning
- Static cling, causes papers to stick to one another.

The vast amount of charge in materials is hidden as it contains equal amount of positive and negative charge. When these charges [positive/negative] are equal in amount body is said to be electrically neutral. But when the amount of charge is unequal, body is said to be positively or negatively charged. The body is said to be electrically neutral when the positive and negative are equal in amount. Once the amount is unequal, then the body is said to be charged. As in activity you have observed that there is force of attraction or repulsion between the charged bodies. Coulomb's law gives the magnitude of the force acting between like and opposite charges.

Interesting Facts

- Charles Augustin Coulomb, a French scientist, measured the electric forces between tiny charged spheres in 1885. In this mechanism, he developed Coulomb's law, an electric analogue of Newton's Universal Gravitational Law.

According to Coulomb's law, the force of attraction or repulsion between two stationary point charges is directly proportional to the product of the magnitude of their charges and inversely proportional to the square of the distance between them. This force acts on the line that connects the two charges. Consider two charges q_1 and q_2, separated by distance r then according to Coulomb's law.

$$F \;\alpha\; q_1 q_2 \qquad ...(3.1)$$

$$F \;\alpha\; \frac{1}{r^2} \qquad ...(3.2)$$

Combining Eq 3.1, 3.2 $\quad F \;\alpha\; \frac{q_1 q_2}{r^2}$

$$F = K\frac{q_1 q_2}{r^2} \qquad ...(3.3)$$

Where K is constant of proportionality and called as electrostatic constant.

When two charges are placed in free space then K in S.I. unit is given by

$$K = \frac{1}{4\pi\varepsilon_0} = 9\times10^9\, Nm^2/C^2$$

Coulomb's Law

Where ε_0 is called permitting of free space. Eq. 3.3 can be re written as

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \qquad ...(3.4)$$

Vector Form

Consider two charges q_1 and q_2 placed r distance apart, then

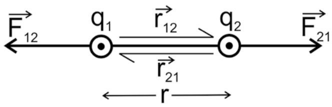


Fig 3.1 Coulomb force between charges

By Coulomb's law

Force on charge q_2 due to q_1 is

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{12} \qquad \left[\because \hat{r}_{12} = \frac{\vec{r}_{12}}{|\vec{r}_{12}|} \Rightarrow \hat{r}_{12} = \frac{\vec{r}_{12}}{r}\right] \qquad ...(3.5)$$

Force on charge q_1 due to q_2 is

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{21} \qquad \left[\because \hat{r}_{21} = \frac{\vec{r}_{21}}{|\vec{r}_{21}|} \Rightarrow \hat{r}_{21} = \frac{\vec{r}_{21}}{r}\right] \qquad ...(3.6)$$

Since $\quad \hat{r}_{21} = -\hat{r}_{12}$

So $\quad \vec{F}_{21} = -\vec{F}_{12}$

But $\quad |\vec{F}_{21}| = |\vec{F}_{12}| \qquad ...(3.7)$

As a result, Coulomb's law of force is in accord with Newton's third law of motion.

3.1.1 Unit of charge

SI unit Coulomb is the SI unit of charge. If the force between two similar charges ($q_1 = q_2$) is 9×10^9 N placed 1m apart then in free space or vacuum then charges are said to be Unit Charges (or one Coulomb).

One stat coulomb (esu): If there are two similar charges ($q_1 = q_2$) at 1 cm distance, which repels each other in vacuum by a force of 1 dyne, then charges are said to be of 1 esu.

$$1\ coulomb = 3 \times 10^9\ stat\ coulomb$$
$$= 3 \times 10^9\ esu\ of\ charge$$

3.1.2 Electric field

Let us consider a source charge and in its vicinity, we have kept a unit positive charge, then the force experienced by a unit positive test charge at that point, without altering the position of the source charge, is characterized as the electric field or electric field strength 'E' at that point or in other words force per unit charge is the electric field at the point.

According to above statement, Electric field strength (E)

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q_0} \quad ...(3.8)$$

Dimension of E is, E = [$MLT^{-3}A^{-1}$] { As unit of $E = \frac{N}{C}$ }

Consider a point charge q at the origin and we want to find the electric field strength "E" at a point P, let us imagine a test charge q_o at P

Then Electric field at point P is

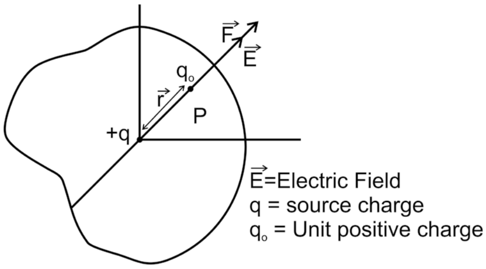


Fig 3.2 Electric field due to point charge

$$\vec{E} = \frac{\vec{F}}{q_0}\hat{r}$$

But by Coulomb's law,

$$\vec{F} = \frac{1}{4\pi\varepsilon_o}\frac{qq_o}{r^2}\hat{r}$$

So

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \quad ...(3.9)$$

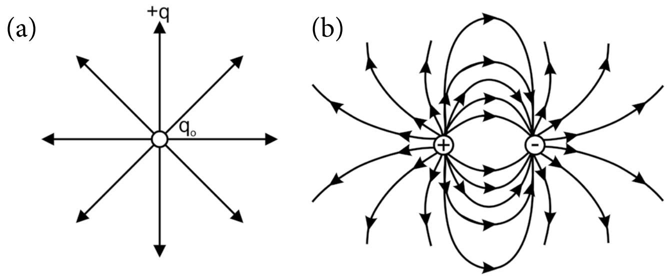
The direction of electric field is same as the direction of Coulomb force.

Note: If we put a positive charge in an electric field then the force on positive charge is in the direction of the applied electric field and if we keep a negative charge in an electric field then the force on negative charge is in the opposite direction of the applied electric field.

3.1.3 Electric lines of force and their properties

If q_o is source positive charge and the unit positive charge 'q' is free to travel then it will move away from the said source charge along the straight line connecting the unit positive charge's center and the said positive charge (Fig 3.3 a). An electric line of force is a curve along which the unit positive charge moves away from the specified positive charge. The electric lines of for two equal and opposite charge kept at a distance is shown in Fig.3.3 b. The tangent drawn on the electric line of force at a point will give direction of electric field at that point.

- The field lines never intersect each other because if they intersect at a point then at that point there will be two directions of electric field.
- The field lines run perpendicular to the charge's surface.
- Both the magnitude of the charge and the number of field lines are proportional.
- The field lines begin (diverge) from the positive charge and conclude (converge) to the negative charge.



Electric Field Lines

Fig 3.3 Electric lines of force

3.1.4 Electric flux (ϕ)

The total number of electric lines of force passing through a specific area inside an electric field is a measure of the electric flux through that area.

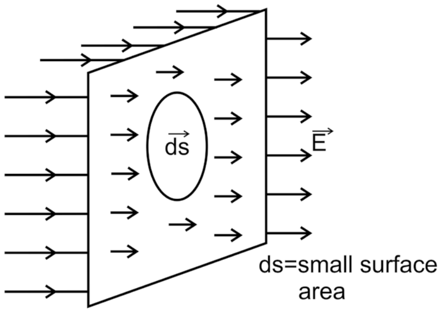


Fig 3.4 Electric flux passing through surface

$$\overrightarrow{ds} = \textit{small surface area}$$

$$d\phi = \vec{E}.\overrightarrow{ds} \qquad ...(3.10)$$

If ***ds*** make an angle θ with electric field (E)

Then electric flux through ***ds*** is

$$d\phi = E\,ds\cos\theta \qquad ...(3.11)$$

For whole surface $\int d\phi = \int Eds\cos\theta$

$$\phi = \int Eds\cos\theta \qquad ...(3.12)$$

Electric flux is a scalar quantity

Unit of ϕ = unit of E × unit of S

$$= N/C \times m^2$$

$$= Nm^2/C$$

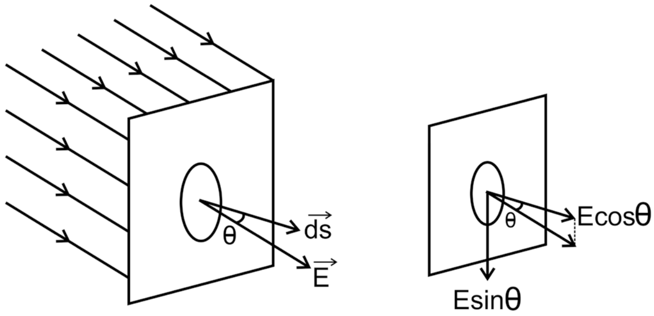


Fig 3.5 Electric flux passing through surface making angle with Electric field

3.1.5 Electric Potential (V)

Let q is a positive charge and q_0 is unit positive charge at infinite distance from q. The amount of work done in moving a unit positive test charge from infinity to a point P against the electric field is electric potential at point P.

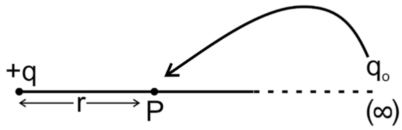


Fig 3.6 Electric potential due to point charge

$$\textit{Electric Potential} = \textit{Work done / charge}$$

$$V = \frac{W}{q_0} \qquad ...(3.13)$$

if

$$W = 1J, \; q_0 = 1C$$

$$V = \frac{1J}{1C} = 1\,volt$$

The electric potential at a point in an electric field is said to be 1 volt, if one Joule of work is done in moving a unit positive charge from infinity to that point against the electrostatic force.

Electric Potential due to a point charge.

Consider a positive charge q placed at the origin O. Now we will find the electric potential at point P at distance r from charge q.

According to definition of electric potential, the amount of work done to bring q_o from infinity to that point P is equal to electric potential.

Consider q_0 at a point 'A' ,then

$$F = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{x^2} \qquad ...(3.14)$$

small work done in displacing charge q0 from A to B is

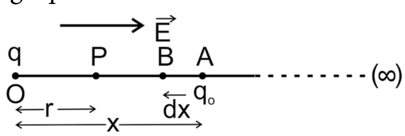


Fig 3.7 Work done in displacing charge

$$dw = \vec{F}.\overrightarrow{dx}$$
$$dw = Fdx\cos(180)$$
$$dw = -Fdx$$
$$dw = -\frac{1}{4\pi\varepsilon_0}\frac{qq_0}{x^2}dx$$
$$\int dw = -\frac{1}{4\pi\varepsilon_0}qq_0\int_{\infty}^{r}\frac{1}{x^2}dx$$
$$W = \frac{-qq_0}{4\pi\varepsilon_0}\int_{\infty}^{r}x^{-2}dx$$

then
$$W = \frac{-qq_0}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_{\infty}^{r}$$

Total work done to move q_0 from ∞ to P
$$W = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

and
$$\frac{W}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$
$$\left[\frac{W}{q_0} = V \ \textit{Electric potential}\right]$$
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \qquad ...(3.15)$$

3.1.6 Electric Potential difference

The amount of work done to move a unit positive charge q_0 from one point to another point inside the electric field is known as electric potential difference".

So
$$V = V_B - V_A = W_{AB} \qquad ...(3.16)$$

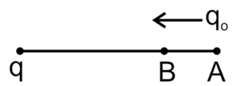


Fig 3.8 Electric potential difference

3.1.7 Gauss' Law

Till now, the magnitude of electric field and electric flux has been calculated for point charge. The picture will be quite different when there is charge distribution instead of single charge. The contribution to electric field at a point from each charge has to be taken in consideration for a charge distribution. Gauss' law provides a simple solution to calculate electric field from charge distribution.

Gauss' law states that "the total electric flux (ϕ) passing through any "closed surface" is $\frac{1}{\varepsilon_o}$ times of charge enclosed by the surface"

$$\phi = \frac{1}{\varepsilon_o}\times q \qquad ...(3.17)$$

Consider +q charge at the center of sphere of radius r then electric flux by small surface of sphere is given by

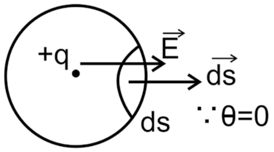


Fig 3.9 Depiction of Gauss' law

Then

$$d\phi = \vec{E}.\vec{ds}$$
$$d\phi = Eds\cos\theta$$
$$d\phi = Eds \quad (as\,\theta = 0)$$

Electric flux through whole surface is

$$\int d\phi = \int Eds$$
$$\phi = E\int ds$$
$$\left[\because E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\right]$$
$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\int ds$$
$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\times 4\pi r^2 \qquad ...(3.18)$$

So,

$$\phi = \frac{1}{\varepsilon_0}\times q$$

With the help of Gauss' law, electric field can be calculated by calculating the net electric flux coming out from closed surface.

3.1.8 Applications of Gauss' law

(a) Electric field due to an infinitely long straight charged wire.

Consider a thin infinitely long straight wire having a uniform linear charge density 'λ' (quantity of charge per unit length. First, we find the direction of electric field by line charge distribution. Let us consider a point P at r distance from point O in linear charge distribution. We can also assume two small charge element dl at x distance above and below point O. From the Fig 3.10, the resultant electric field at point P due to both charge element is perpendicular to the line charge.

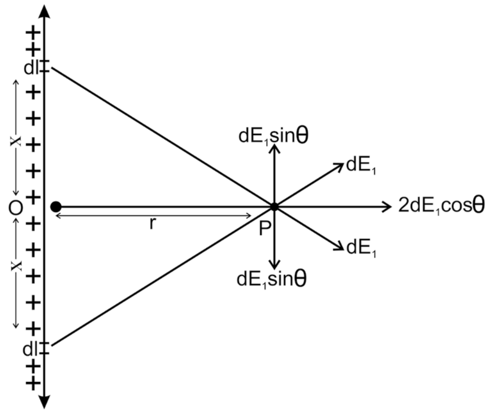


Fig 3.10 Direction of electric field due to long straight charged wire

Hence by symmetry, the field "E" of the line charge is directed normally outwards and its magnitude is determined with help of Gauss' law.

To determine the field at a distance r from the line charge we choose a cylindrical Gaussian surface of radius r and length l. It consists of three surface S_1, S_2 and S_3

First, we calculate for S_3 surface, let us consider a small surface ds in S_3 and electric flux through surface ds,

$$d\phi = \vec{E}.\vec{ds}$$

For whole cylindrical surface

$$\int d\phi = \oint \vec{E}.\vec{ds}$$

$$\phi = \int Eds\cos\theta \qquad \because \theta = 0$$

$$\phi = E\int ds$$

$$\phi = E\times 2\pi rl \qquad ...(3.19)$$

Also, by Gaussian Theorem

$$\phi = \frac{q}{\varepsilon_o} \qquad ...(3.20)$$

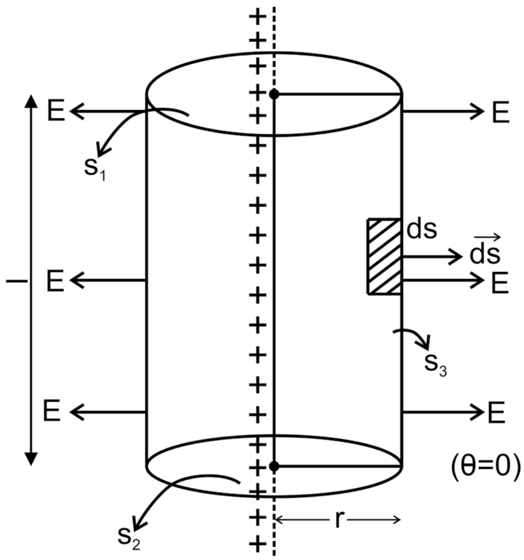


Fig 3.11 Electric field due to an infinitely long straight charged wire by Gauss' law

Equating Eq 3.19 and 3.20

$$E\times 2\pi rl = \frac{q}{\varepsilon_o}$$

$$E = \frac{1}{2\pi\varepsilon_o}\frac{q}{rl} \qquad \left[\because \frac{q}{l} = \lambda, linear\ charge\ density\right]$$

$$E = \frac{1}{2\pi\varepsilon_o}\frac{\lambda}{r} \qquad ...(3.21)$$

The magnitude of the outward electric field at any point on surface S_3 is given by Eq. 3.21

The Magnitude of electric field at Surface S_1 and S_2 will be zero as the angle between the electric field vector and the area vector of each surface is 90^0.

(b) Electric field due to uniformly charged plane sheet.

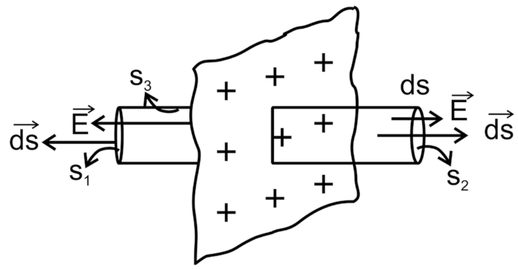


Fig 3.12 Electric field due to uniformly charged plane sheet

Consider +q charge is given to an infinite sheet so that charge will uniformly distributed over the surface having surface charge density 'σ' (quantity of charge per unit area).

Due to uniform distribution of charge, electric field can be calculated by drawing a Gaussian surface in the form of cylinder. The cylinder consists of surface S_1, S_2 and S_3. First, we calculate for Surface S_1 and S_2

So electric flux through ds on both surface (S_1 and S_2)

$$d\phi = 2\vec{E}.\vec{ds}$$

For whole sheet,

$$\int d\phi = 2\int Eds\cos(0)$$

$$\phi = 2E\int ds$$

$$\left[\int ds = Stotal\ surface\ Area\right]$$

then

$$\phi = 2ES \qquad ...(3.22)$$

Also, by Gauss' Law

$$\phi = \frac{q}{\varepsilon_o}$$

$$2ES = \frac{q}{\varepsilon_o}$$

$$E = \frac{q}{2\varepsilon_o S}$$

$$\left[Surface\ charge\ density\ \sigma = \frac{q}{S}\right]$$

$$E = \frac{\sigma}{2\varepsilon_o} \qquad ...(3.23)$$

The Magnitude of electric field at Surface S_3 is zero as the angle between the electric field vector and the area vector of surface S_3 is 90^0

(c) Electric field due to a uniformly charged sphere

Consider a sphere of metal of radius R when charge q is given to it, then charge will uniformly distribute over the surface, so it surfaces charge density is

$$\sigma = \frac{q}{4\pi R^2} \quad \Rightarrow q = 4\pi R^2\sigma$$

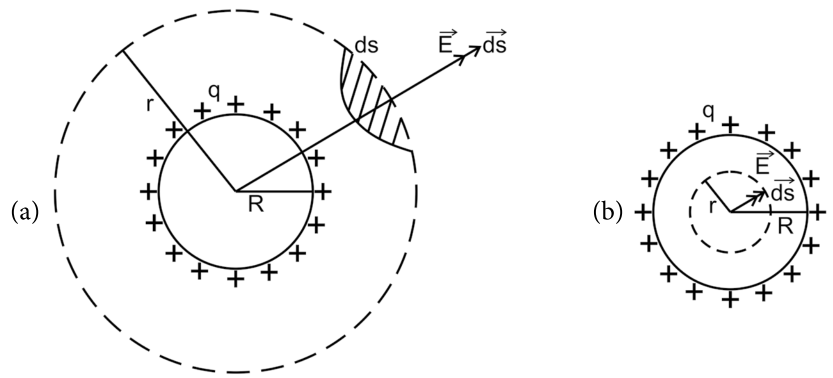


Fig 3.13 Electric field due to uniformly charged sphere

(i) Electric field outside of sphere (Fig. 3.13a)

Draw a Gaussian spherical surface of radius r (r > R), and calculate electric flux by small area ds

$$d\phi = \vec{E}.\vec{ds}$$

For whole surface

$$\int d\phi = \int \vec{E}.\vec{ds}$$

$$\phi = \int E_1 ds \cos(0)$$

$$\phi = E_1 \int ds$$

$$\phi = E_1 \times 4\pi r^2 \qquad ...(3.24)$$

Also, by Gauss' law

$$\phi = \frac{q}{\varepsilon_o}$$

So by Eq 3.24

$$E_1 \times 4\pi r^2 = \frac{q}{\varepsilon_o}$$

$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2} \qquad ...(3.25)$$

$$\because q = 4\pi R^2 \sigma$$

So,

$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{4\pi R^2\sigma}{r^2}$$

$$E_1 = \frac{R^2\sigma}{\varepsilon_o r^2} \qquad ...(3.26)$$

(ii) Electric field on the surface of sphere

In Eq 3 .26 Put r = R

$$E_2 = \frac{\sigma}{\varepsilon_o} \qquad ...(3.27)$$

(iii) Inside the sphere, consider a surface inside sphere of radius r<R (Fig. 3.13b)

As the charge is uniformly distributed on surface of sphere of Radius R

Hence $\because q = o$

Then by Gauss' law $E_3 = o$

There is no charge inside the sphere of radius r

Therefore, the electric field at any point inside the metallic sphere is zero.

EXAMPLE 3.1

Ques. Two very small charged sphere having charge of 2 micro coulomb and 4 microcoulomb respectively placed 20 cm apart from each other. Calculate.

(i) Force between spheres

(ii) Change in force, if charges are doubled and separation is halved.

Solution:

Given : q_1 = 2 micro coulomb = 2×10^{-6} C and q_2 = 4 microcoulomb = 4×10^{-6} C

r = 20 cm = 0.2 m

(i) $$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$\Rightarrow F = 9 \times 10^{9} \times 2 \times 4 \times 10^{-12} / 0.2 \times 0.2$

$\Rightarrow F = 1800 \times 10^{-3} = 1.8$ N

(ii) If charges are doubled and separation is halved then

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{2q_1 \times 2q_2}{\left(\frac{r}{2}\right)^2}$$

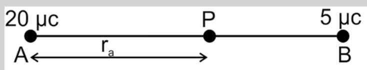
$$F_1 = 16 \times \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$F_1 = 16 \times F$$

Hence, $F_1 = 16 \times 1.8$ N = 28.8N

EXAMPLE 3.2

Ques. Two points A and B in air are 8 cm apart and having point charges of + 20 μc and + 5 μc respectively. Determine the position of the point from point A at which the resultant field is zero.



Solution:

Let p is resultant point between A and B, the electric field due to charge + 20 μc and + 5 μc is equal and opposite direction at point P and it is r_a distance from A

Electric field at resultant point P due to charge at point A is

$$E_1 = \frac{1}{4\pi\varepsilon_0}(20 \times 10^{-6}) / (r_a)^2$$

Electric field at resultant point P due to charge at point B is

$$E_2 = \frac{1}{4\pi\varepsilon_0}(5 \times 10^{-6}) / (0.08 - r_a)^2$$

$E_1 = E_2$

$$\frac{1}{4\pi\varepsilon_0}(20 \times 10^{-6}) / (r_a)^2 = \frac{1}{4\pi\varepsilon_0}(5 \times 10^{-6}) / (0.08 - r_a)^2$$

$(20 \times 10^{-6}) / (r_a)^2 = (5 \times 10^{-6}) / (0.08 - r_a)^2$

$4 / (r_a)^2 = 1 / (0.08 - r_a)^2$

$2/ (r_a) = 1 / (0.08 - r_a)$

$0.16 - 2 r_a = r_a$

$r_a = (0.16/3)$ m = 5.33 cm

Hence the point P is 5.33 cm from point A

EXAMPLE 3.3

Ques. Calculate the potential at a point P due to a charge of 5 μ C located 5 cm away in air. Calculate the work done to bring charge 1 μ C to that point.

Solution:

Given q = 5 × 10^{-6} C, r = 5 cm = 0.05 m

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

V = 9 × 10^9 × 5 × 10^{-6}/ 0.05

V = 9 × 10^5 Volts

Work done to bring Charge q = 1μ C = 1 × 10^{-6} C, to point P is

Work done W = qV

W = 1 × 10^{-6} × 9 × 10^5 V = 0.9 Joule

EXAMPLE 3.4

Ques. A circular sheet of diameter 5 cm placed in a uniform electric field of 50N/C with its normal making an angle 30° with the field. Calculate electric flux through the sheet.

Solution:

Given: diameter = 5 cm, hence r = 2.5 cm = 0.025 m

E = 50N/C and angle =30^o $\phi = \int E ds \cos\phi$

$\phi =$ E × πr^2 × cos(30)

$\phi =$ 50 × 3.14 × $(0.025)^2$ × √3/2

$\phi =$ $0.085\, Nm^2/C$

3.2 CAPACITORS AND ITS WORKING

Till now, in this unit electrostatic force, electric field, electric potential and method to find electric field and flux by charge distribution have been discussed in detail. In this section capacitor and its working will be explained, in which all the concepts discussed earlier in the unit will be applied. A capacitor is an arrangement consisting of two conductors separated by a distance. It is used to store the charges. There can be free space, air or dielectric material between the conductors.

Principle of a Capacitor

Consider a positively charged plate A of a metal placed near an uncharged plate B, due to induction, negative charge develops on plate B on the face near to the plate A and positive charge on another face of B. If we connect plate B to ground then, the positive charge on plate B will flow to the ground. There will be only negative charge on plate B, due to this potential of plate A decreases. To raise the potential of plate A, it can acquire more charges. Such a system of storing charges made up of two conductors is called a capacitor.

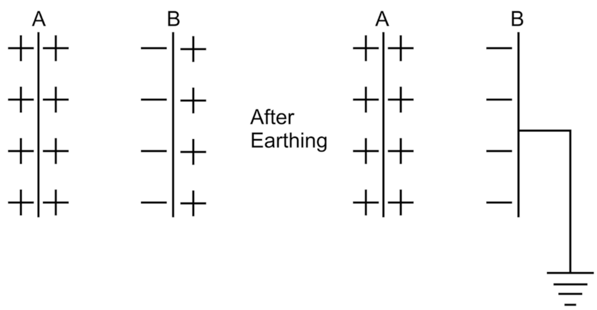


Fig 3.14 Capacitor

3.2.1 Types of capacitors

Capacitors are distinguished based on following:

- **Shape of electrodes**
    - Parallel plate, spherical and cylindrical
- **Materials between electrodes**
    - Dielectric (nonpolar) and Electrolytic (polar capacitor)
- **Capacitance**
    - Fixed and variable capacitor

Fig. 3.15 gives the symbols for capacitors

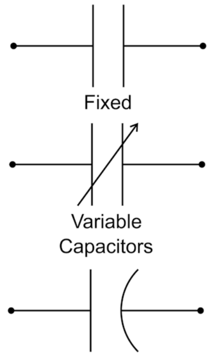


Fig 3.15 Type of capacitor

3.2.2 Capacitance and its units

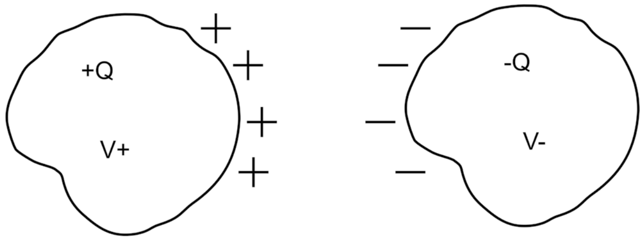


Fig 3.16 Charge on capacitor

Usually, a capacitor consists of two conductor having charges +Q and -Q. For a given capacitor the charge (Q) on the capacitor is proportional to the potential difference (V)

So, $$Q \alpha V$$

$$Q = CV$$

$$C = \textit{Capacitance of the capacitor}$$

also $$C = \frac{Q}{V}$$

When V = 1 volt $$C = Q$$

So, the capacitance of capacitor may be defined as the charge required to increase the potential of conductor by unit.

$$\because Q = CV$$

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

When $$Q = 1C, \quad V = 1volt$$

Then, $$C = \frac{1C}{1volt} = 1F \text{ (Farad F)}$$

one microfarad : $$1\mu F = 10^{-6} F$$

One Picofarad $$1pF = 10^{-12} F$$

3.2.3 Parallel plate capacitor

It consists of two large plane parallel conducting plates, separated by a small distance d

Electric field between the plates

$$E = \frac{\sigma}{\varepsilon_o} \qquad \sigma = surface\ charge\ density$$

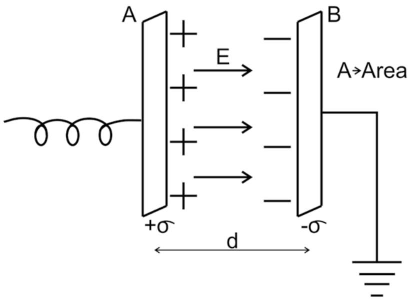


Fig 3.17 Parallel plate capacitor

For a uniform electric field

$$E = \frac{V}{d} \quad \Rightarrow V = Ed$$

So

$$V = \frac{\sigma}{\varepsilon_o} \times d \quad \left\{\sigma = \frac{Q}{A}\right\}$$

$$V = \frac{Qd}{\varepsilon_o A} = \frac{Qd}{\varepsilon_o A}$$

$$\because Q = VC$$

$$C = \frac{Q}{V} = \frac{Q}{\frac{Qd}{\varepsilon_0 A}} \quad \Rightarrow C = \frac{\varepsilon_o A}{d}$$

Thus, for a parallel plate capacitor,

$$C \;\alpha\; A \textit{ area}$$

$$C \;\alpha\; \frac{1}{d} \textit{ distance}$$

$$C \;\alpha\; \varepsilon_0 \textit{ permittivity of medium between plates.}$$

3.2.4 Series and parallel Combination of capacitors

Capacitance in series

When the negative plate of one capacitor is connected to positive plate of second and negative of second to the positive of third and so on, the capacitor is said to be connected in series.

The potential across the capacitors is

$$V_1 = \frac{Q}{C_1},\ V_2 = \frac{Q}{C_2},\ V_3 = \frac{Q}{C_3}$$

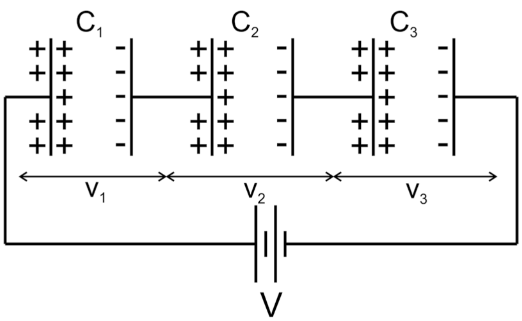


Fig 3.18 Capacitors in series

Since Total potential V is

$$V = V_1 + V_2 + V_3$$

Or

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

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

Where C is the total capacitance.

Capacitance in parallel

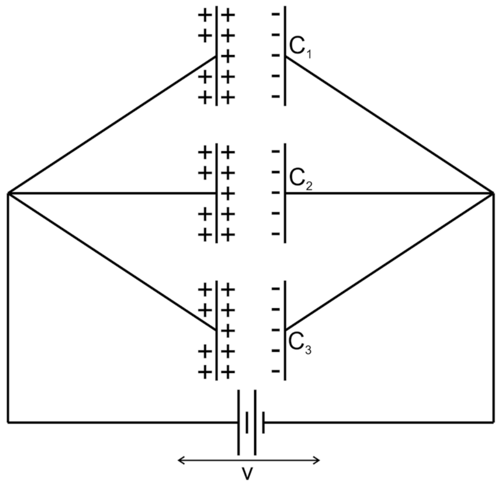


Fig 3.19 Capacitors in parallel

When the positive plate of all capacitors is connected to one common point and the negative plate to another common point. The capacitors are said to be connected in parallel.

All the capacitors have a common potential difference V but different charges given by

$$Q_1 = C_1V,\ Q_2 = C_2V,\ Q_3 = C_3V$$

$$\because Q = Q_1 + Q_2 + Q_3$$

Or

$$CV = C_1V + C_2V + C_3V$$

$$C = C_1 + C_2 + C_3$$

$$C = \textit{Total Capacitance}$$

3.2.5 Dielectric and its effect on Capacitance.

Dielectric are insulating materials such as ceramic, mica, glass, plastics, and the oxides of various metals. When dielectrics are placed in an electric field E (say inside a parallel plate capacitor) electric polarization occurs i.e. the positive charges within the dielectric are displaced minutely in the direction of the electric field, and the negative charges are displaced minutely in the direction opposite to the electric field. Due to the separation of charge, or polarization, the net electric field

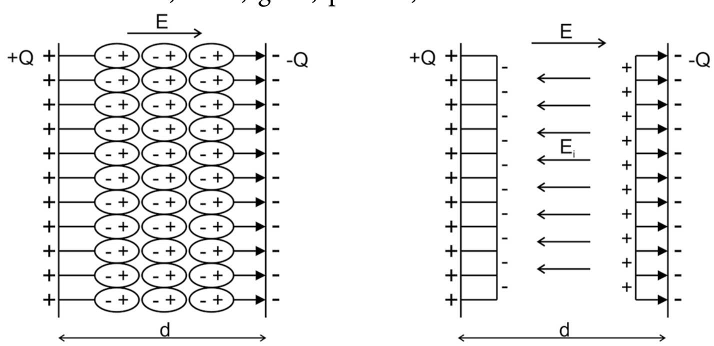


Fig 3.20 Dielectrics in capacitor

inside the dielectric reduces because the electric field developed inside the dielectric is opposite to electric field E. As, net electric field decreases the V between plates decreases and the capacitance is increased. Each dielectric material is characterized by dielectric constant 'K'. It is the ratio of electrical permitting of material with that of air. The dielectric constant of air is 1 and for other insulators greater than 1.

Capacitance of capacitor is given by

$$C_0 = \frac{\varepsilon_o A}{d}$$

If we insert a dielectric medium (with dielectric constant K) between the plates then capacitance increases by K times,

$$C = \frac{K\varepsilon_o A}{d}$$

$$C = KC_0$$

3.2.6 Dielectric breakdown

Dielectric materials are electrical insulators that is, they prevent the flow of current. Dielectric breakdown is the phenomenon of failure of an insulating material to prevent the flow of current. When applied electrical field increases to a certain value ionization takes place inside the material which creates large number of electrons and ions. Electrical discharge taking place in air is an example of dielectric break down which takes place at electric field 3×10^6 V/m.

In a parallel plate capacitor, if we increase the voltage across the plates, the electric field also increases. The breakdown voltage is the voltage at which the dielectric failure occurs. Every capacitor which we buy from market or available in laboratory has some maximum voltage value, we cannot use the capacitors beyond that voltage, otherwise the dielectric breakdown occurs in capacitors and the dielectric material is no longer electrically insulating.

EXAMPLE 3.5

Ques. Three capacitor C_1, C_2, C_3 are connected to a 12V battery, find the charge on the three capacitors

Solution:

In the given figure C_2 and C_3 are in parallel and connected in series with C_1

First resultant capacitance C' due to parallel combination of C_2 and C_3 is

$C' = C_2 + C_3$

$C' = 10\mu F + 10\mu F = 20\ \mu F$

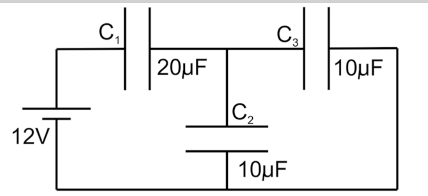
Total capacitance of circuit C is series combination of C' and C_1

$1/C = 1/C_1 + 1/C'$

$1/C = 1/20\mu F + 1/20\mu F$

$1/C = 2/20\mu F$

$C = 10\mu F$



The Charge Q in circuit will be

$Q = CV$

$Q = 10\mu F \times 12\ V = 120 \times 10^{-6}$ C

Same Q will be at C_1 and C'

As C_2 and C_3 are same the Q will be divided equally on C_2 and C_2

Hence Charge on C_1 is 12×10^{-5} C, on C_2 is 6×10^{-5} C and on C_3 is 6×10^{-5} C

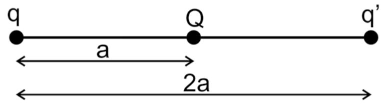
UNIT SUMMARY

- Coulomb force between charges is inversely proportional to square of distance.
- Electric field is a vector quantity.
- Electrical potential is scalar quantity.
- Gauss theorem helps in determining the electric field from charge distribution.
- Capacitance of capacitor depends on area of electrodes and dielectric constant of material between electrodes.

EXERCISES

Multiple Choice Questions

3.1 Charges q, Q and q' are placed along X-axis as shown in figure. The charge q is in equilibrium. Ratio of Q\q' is



a. -4
b. +4
c. 1/4
d. -1/4

3.2 1 Volt is equal to
a. 300 esu
b. 1/300 esu
c. 3×10^8 esu
d. 3×10^9 esu

3.3 The dielectric constant K of an insulator can be
a. 4
b. -4
c. 0
d. 0.4

3.4 If the distance between two charged particles is halved, the Coulomb force between them be comes
a. One- half
b. One-fourth
c. Double
d. Four times

3.5 The work done in carrying a charge of 5μC from a point A to B is 8 mJ. The difference of potential between A and B
a. 160 V
b. 16 V

c. 1.6 k V
d. 16 k V

3.6 The electric field intensity due to an infinite, uniformly charged sheet at distance r from the sheet is

a. $E \alpha r$
b. $E \alpha r^{-1}$
c. $E \alpha r^{-2}$
d. E *is independent of* r

3.7 One Gram hydrogen has 6×10^{23} atoms. Imagine that all the nuclei are put at the north pole of the earth and the electrons at the south pole of the earth (radius 6400 km). The force between charges is

a. 1.0×10^{6} N
b. 5.0×10^{5} N
c. 2.5×10^{5} N
d. 2.0×10^{6} N

3.8 A parallel plate capacitor is charged and then isolated. The effect of increasing plate separation is

	Charge	Potential	Capacitance
a.	constant	constant	decreases
b.	increases	increases	decreases
c.	constant	decreases	increase
d.	constant	increases	decrease

Answers of Multiple Choice Questions
3.1 (a), 3.2 (b), 3.3 (a), 3.4 (d), 3.5 (c), 3.6 (d), 3.7 (d), 3.8 (d)

Short and Long Answer Type Questions

Category-I

1. State Coulomb's law of electrostatic force.
2. Define SI unit and CGS unit of charge and find relation between them.
3. Explain the vector form of Coulomb's law.
4. Explain the concept of electric field with derivation.
5. State the method used to find the direction of electric filed with examples.
6. Draw the line of electric field coming out from positive and negative charge. Explain the concept of electric flux with diagram.
7. Define the term electric potential with unit.
8. Derive an expression for electrostatic potential energy.
9. Derive the relation of electrostatic potential energy. Write SI unit of electrostatic potential energy.

10. Explain Gauss' law and its mathematical form.
11. Define the term capacitance with unit.
12. Explain the working of capacitor with diagram.
13. Explain the types of capacitors with diagram.
14. Derive a relation for capacitance of parallel plate capacitor.
15. Derive relation of resultant capacitance for series and parallel combinations of capacitors.
16. Describe the role of dielectric materials in capacitors.
17. Determine the electric field produced by following charge distributions by applying Gauss' law:
    a. Liner charge distribution
    b. Plane charge distribution.
    c. Charges distributed on spherical surface.
18. Find the number of electrons that will carry 1 coulomb of charge.
19. Find the electrostatic force acting between two charges of 2 μC each and are 4 cm apart.
20. Find the magnitude and direction of electric filed at point 'p', which is at 5 cm from – 10 μC charge.
21. Consider three equal charges placed at the vertices of an equilateral triangle of side 1 cm, find the resultant force on the charge Q at the centroid of triangle.
22. If 100 J of work done in moving an electric charge of 4C from a point, where potential is -10V to another point where potential is V volt. Find the value of V.

Category-II

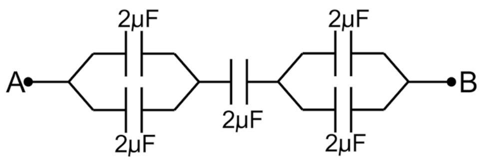
1. Compare electrostatic force between two protons with gravitational force.

$$m_p = 1.67\times10^{-27}\,kg,\quad G = 6.67\times10^{-11}\,\frac{Nm^2}{kg^2},\quad e = 1.6\times10^{-19}\,C$$

2. Four-point charges $q_A = 4\mu c$, $q_B = -10\mu c$, $q_C = 4\mu c$, $q_D = -10\mu c$, placed at the corner of a square ABCD of side 5cm. Calculate the force on a charge of 1μC placed at the center of the square.

3. A point charge + 20μc is 10 cm directly above the center of square sheet of side 20 cm. Calculate electric flux through the square sheet. Also find the flux from the square sheet if the charge is 5cm above the center of square sheet.

4. Calculate the equivalent capacitance between points A and B of combination.



PRACTICAL

There is one laboratory experiment which is related to this unit.

- To study dependence of capacitance of a parallel plate capacitor on various factors and determine permittivity of air at a place.

Practical 10 - Parallel plate capacitor

P10.1Practical Statement

To study the dependence of capacitance of a parallel plate capacitor on various factors and determine permittivity of air at a place.

P10.2 Practical Significance

Capacitors are active components in electrical circuit which are used in AC circuits to introduce phase delay and in filter circuits to pass AC and block DC current. Besides these there are number of applications of capacitors. This experiment helps students to vary the capacitance of parallel plate capacitors and determine the factors affecting the capacitance of parallel plate capacitor.

P10.3 Relevant Theory

Refer: Section 3.2.3 of this unit

P10.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Determine the variation in capacitance of parallel plate capacitor with area of plates and their separation.

PrO2: Use capacitor to find the permittivity of air.

P10.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

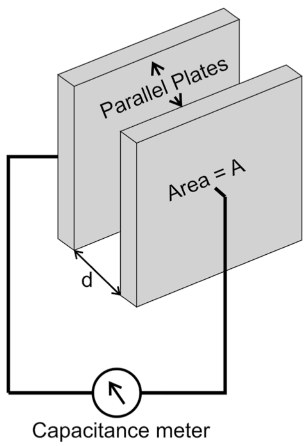


Fig P10.1

P10.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	Parallel plate capacitor	01			
2	Capacitance meter	03			
3	Connecting wires	03			

P10.7 Precautions

1. Connections should be tight.
2. Plates of capacitors should be parallel
3. Measure distance accurately.

P10.8 Suggested Procedure

For measuring the effect of distance (d)

1. Measure the area of plates.
2. Keep plate at separation say 5 cm.
3. Charge capacitor with DC supply of 10V.
4. Make connection as per circuit diagram in Fig P10.1.
5. Measure capacitance C with capacitance meter or multimeter.
6. Gradually decrease the distance between the plates and measure C.

For measuring the effect of Area (A)

1. Fix separation between plate say 2 cm.
2. Charge capacitor with DC supply of 10V
3. Measure capacitance C with capacitance meter or multimeter.
4. Slide one of the plates of capacitor laterally.
5. Note the change in capacitance.
6. Repeat step 4 and 5 for five observations.

P10.9 Observations and Calculations

Least count of capacitance meter = ...

Area of plates = ... Separation between plates = ... cm

TABLE 1 for measuring the effect of d

Sr. No	Area of plates	Capacitance
1		
2		
3		
4		

TABLE 2 for measuring the effect of A

Sr. No	Separation between plates	Capacitance
1		
2		
3		
4		

Plot Graph 1 between C v/s 1/d and ε = slope /A

Plot Graph 2 between C v/s A and ε = slope $\times$ d

P10.10 Results and/or Interpretation

(to be filled by student)

1. ....

2. ....

P10.11 Conclusions and/or Validation

(to be filled by student)

1. ....

2. ....

P10.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Is the voltage between plate changes if we change 'd' (distance between plates).
2. Give the reasons for errors in the present experiment.
3. Is the charge on capacitors changes, if we change 'd' (distance between plates).

10.13 Suggested Learning Resources

- https://phet.colorado.edu/en/simulation/capacitor-lab-basics

10.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of capacitance		
3	Measurement of A and d		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Graph plot and calculations		
6	Result and conclusion		
7	Timely submission of report		
8	Answer to Practical related questions		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course

- Quantization of charges
- Superposition of electric field.

Applications

Capacitors are used

- In AC circuits to introduce phase delay for example in fan.
- In filter circuits to pass AC and block DC.
- As a charge storage device in generators.
- To set frequency of output signals in wave form generator circuits

Use of ICT

The student can visit the following url for simulations in electrostatics

- https://phet.colorado.edu/en/simulation/balloons-and-static-electricity
- https://phet.colorado.edu/en/simulation/charges-and-fields
- https://phet.colorado.edu/en/simulation/coulombs-law
- https://phet.colorado.edu/en/simulation/capacitor-lab-basics

Design innovative Practical /Projects/ Activities

- Collect polar and non-polar capacitor available in local market or laboratory of different capacitance and voltages. Prepare list of capacitances, voltage or any other parameter observed in capacitors.
- Take one polar capacitor say 10 μF. try to find what is inside the capacitor.
- Design a parallel plate capacitor with metal plates. List out the difficulties in measuring the capacitance of designed capacitor.

Inquisitiveness and Curiosity Topics

- Is the gravitational force and electrostatic force between two protons or two electrons is equal?
- Examples of points charge in nature.
- Polar and nonpolar capacitor
- Does an isolated charged capacitor, remains charged forever?

REFERENCES & SUGGESTED READINGS

- H C Verma, “Concepts of physics”1st ed., vol. 2, Bharti Bhawan,1992.
- Richard Feynman *et al* “The Feynman lectures on Physics”, 6th ed. vol1, Addison-Wesley, 1963.
- R K Gaur and S L Gupta “Engineering Physics”, 8th ed., Dhanat Rai , 2011.
- Resnick Halliday and Krane, “Physics” 5th ed. vol1,Wiley, 2014.

4 Current Electricity

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Electric current
- Relation of electric current and drift velocity
- Difference between direct and alternating current
- Resistance and specific resistance
- Combinations of resistances
- Ohm's Law
- Kirchhoff's current and Voltage law
- Wheatstone bridge and its application as meter bridge
- Concept of emf and terminal potential difference
- Heating effects of current and electrical power

Applications of current electricity in daily are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. Micro project activity is suggested which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book. Industrial applications and real life applications on variety of aspects, inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Electricity is a branch of physics deals with the phenomenon related to flow of charge that is current. Concept of resistance, current, types of currents and electromotive force & the principle which relates these concept helps to understand the working of any electrical network, electronic circuits, power of appliances and their applications. This unit will explain the basics of current electricity and related topics which will help diploma students to solve the various problems related to current electricity.

PRE-REQUISITES

- **Mathematics:** Trigonometric functions, Algebra, Vectors, Geometry

- **Physics:** Charge, Electrochemical cell, Electric potential, Energy
- **Other's:** Basic technology of computer and use of mobile application

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U4-O1: Differentiate between direct and alternating currents.

U4-O2: Find the resultant resistance of a given combinations of resistances.

U4-O3: Apply Ohm's and Kirchhoff's law to solve a given circuit problem.

U4-O4: Apply Wheatstone bridge principle to find resistance of unknown wire.

U4-O5: Differentiate between electromotive force and terminal potential difference.

U4-O6: Explain heating effect of current, electric power and electrical energy with applications.

Unit-4 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES (1-Weak Correlation; 2-Medium correlation; 3-Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U4-O1	-	-	-	3	-	1
U4-O2	-	-	-	3	-	1
U4-O3	-	-	-	3	2	1
U4-O4	-	-	-	3	2	1
U4-O5	-	-	-	3	2	1
U4-O6			-	3	2	1

4.1 ELECTRIC CURRENT AND ITS UNITS

In previous unit, the force on static charge due to other charges and electric field due to charge and distribution of charge has been explained. In the present unit the phenomena related to charge in motion is under consideration. The branch of physics which deals with the study of charge in motion is called current electricity. The motion of charge (in present context it will be free electrons) in metallic wires is due to presence of external electric field.

Electric current is defined as the rate of flow of electric charge (say electrons) through a cross-section of a conductor.

$$Electric\ current = \frac{Total\ charge\ flow}{Time\ Taken} = q/t \quad ...(4.1)$$

Also,

$$I(Ampere) = \frac{1Coulomb}{1Sec} = 1C/s$$

It is SI unit of current. CGS unit of current is statampere, 1 A = 3 $\times 10^9$ statampere

Direction of current

As analogues to flow of water (which flows from high level to low level) and flow of heat (from higher temperature to lower temperature) the convention of flow of current is from positive terminal (higher potential) to negative terminal (lower potential).

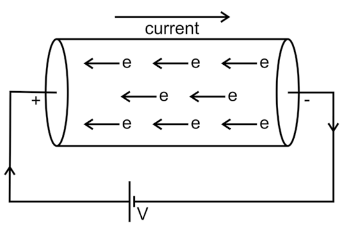


Fig. 4.1 Direction of electrical current

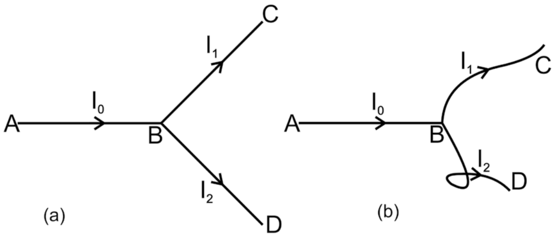


Fig. 4.2 Depiction of electric current as scalar quantity

Current is a scalar quantity: The Fig. 4.2 is an example for demonstrating that the current magnitude is independent of direction. In Fig. 4.2 a and 4.2 b the direction of path BC and BD after junction point B are different but still the division of current (I_0) between these two path (I_1 and I_2) will remain unaltered after junction point. The flow of current is independent of direction .

Electric current in conductor: A metallic conductor contains large number free electrons (nearly 10^{23}). Due to thermal energy these free electrons flow randomly in every direction. Therefore, the average thermal velocity of electron is zero.

If $\vec{u}_1, \vec{u}_2, \vec{u}_3, ..., \vec{u}_n$ are the thermal velocities of n electrons,

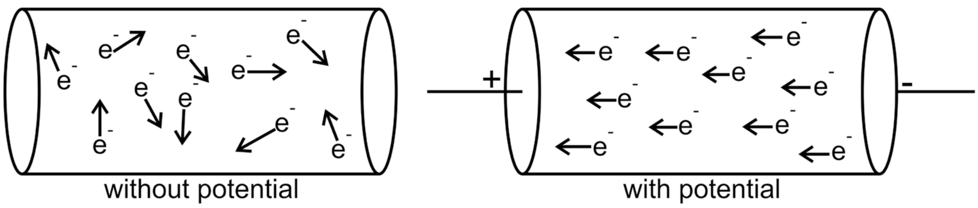


Fig. 4.3 Electric current in conductor

Then, $$\vec{u}_{av} = \frac{\vec{u}_1 + \vec{u}_2 + \vec{u}_3 + ... + \vec{u}_n}{n} = 0 \quad ...(4.2)$$

When we apply an external electric field, the free electron moves towards positive terminal of supply following zig zag path (due to initial thermal velocity and collision with ion and electrons). The average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field applied is called as **Drift velocity** (v_d).

Relation between Current and Drift velocity

DC current Builder

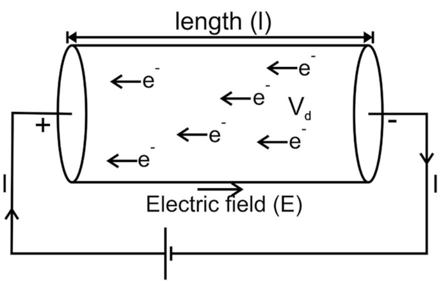


Fig. 4.4 Current and drift velocity

Let us consider a conductor of length l and area of cross-section A, hence volume of conductor is Al, If n is density of electron, then Total no. of free electrons are Aln

∵ e is charge of one electron, $q = Alne$

∴ total charge of free electron

Let V = potential difference across conductor

And $$E = \frac{V}{l}$$

Due to this electric field, free electrons move with drift velocity (v_d) towards positive end.

Time taken by free electron to travel from one end of conductor to other will be

$$t = \frac{l}{v_d} \qquad \text{...(4.3)}$$

$$I = \frac{q}{t} = \frac{Alne}{l/v_d} = Anev_d \qquad \text{...(4.4)}$$

$$I = Anev_d \qquad \text{...(4.5)}$$

Hence current in a conductor depends upon the area of cross section, charge per unit volume and drift velocity.

4.2 DIRECT AND ALTERNATING CURRENT

The flow of current in a conductor depends upon the nature of electric field present at the ends of the conductor. The magnitude and direction of current varies as per the electric field at the end of conductor. On the basis of this concept the current can be divided in two types:

Direct current (DC)

If current is flowing in a wire AB such that the flow of current is unidirectional, that is the current always flows from point A to B, even if the magnitude of current changes the, direction of current does not change. Such type of current is known as DC current. Direct current is of two type: variable and fixed DC. In variable the magnitude of current changes with time, whereas in fixed DC the magnitude of current does not changes with time.

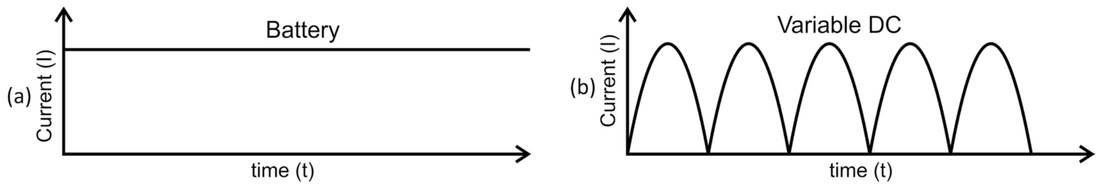


Fig. 4.5 Direct current

Eg : Current flowing in wire , when battery is connected as supply.

Alternating current (AC)- When both the magnitude and direction of current changes, such type of current is known as alternating current. In an alternating current the magnitude changes continuously and the direction changes periodically.

Eg : Flowing of current in house hold wire, or current flowing in wire when connected with AC mains.

The Fig. 4.6 of AC current reminds you the concept of wave discussed in UNIT 1. Similar to wave the AC has frequency and time period. The frequency of the ac mains in our household is 50Hz and time period is 20 ms

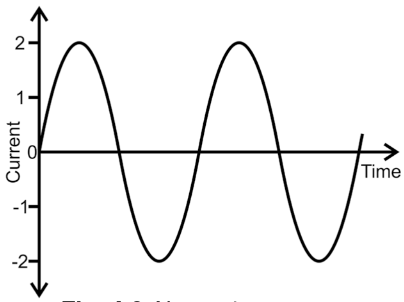


Fig. 4.6 Alternating current

4.3 RESISTANCE (R) AND ITS UNITS

Current is a rate flow of the charges and when the charge particle that is electron moves in the conductor, it collides with the other electron and ions in the conductor. There is a repulsive force from electrons and attractive force form ions, which creates a hurdle or obstruction in the path of electron. This obstruction in the flow of charge can be measured as a property of material and is known as electrical resistance. Resistance is measured in ohms (Ω).

The resistance of metals (for example copper and aluminum) is very low of the order of 10^{-3} Ω, whereas the resistance of insulating material (for example wood, plastics etc) is very high of the order of 10^{6} Ω.

4.4 SPECIFIC RESISTANCE (ρ)

The flow of charge in any metallic wire can be compared with flow of liquid through a pipe, if the length of pipe is increased then the flow decreases and when the area of cross section increases then the flow of liquid increases. As the resistance is an obstruction of flow of charges, Hence the resistance of any metallic wire is directly proportional to the length (l) of wire and inversely proportional to the area of cross section (A) of wire.

$$R \;\alpha\; l$$

$$R \;\alpha\; \frac{1}{A}$$

$$R \;\alpha\; \frac{l}{A}, \qquad R = \frac{\rho l}{A} \qquad ...(4.6)$$

ρ is specific resistance and it depends upon the property of material of wire and temperature.The unit of specific resistance can be calculated as follows

$$\rho = \frac{RA}{l} \qquad ...(4.7)$$

$$\text{Unit of } \rho = \frac{ohm-m^2}{m} = ohm - m$$

$$\text{Dimensional formula of } \rho = \frac{RA}{l} = \frac{\left[M^1L^2T^{-3}A^{-2}\right]L^2}{L}$$

$$= \left[ML^3T^{-3}A^{-2}\right]$$

Specific resistance of silver is minimum, and its value is 1.6×10^{8} Ωm at 20°C. The specific resistance of quartz is maximum, and its value is ~ 10^{17} Ωm at 20°C .Resistance depends upon the physical dimension of given body such as length and area of cross section, whereas specific resistance also known as resistivity, which is intrinsic property of given material and does not depend upon the shape and size of the given body. If we take a wire of square cross section, of unit length and unit area of cross section than Eq. 4.7 can be re written as

$$\rho = R$$

Hence, magnitude of specific resistance of given material is equivalent to magnitude of resistance of a cube made up of same material with unit dimensions.

4.5 CONDUCTANCE (G)

As resistance is measure obstruction of flow of charge, conductance is measure of ease with which charge flows through a substance. The conductance is reciprocal of resistance. It is denoted by G and Its unit is mho (inverse of ohm) or siemens (S).

$$G = 1/R$$

4.6 SPECIFIC CONDUCTANCE (κ)

As conductance is the reciprocal of resistance, similarly the specific conductance of given material is reciprocal of specific resistance or resistivity of that material. It is denoted by κ (kappa) It unit is Siemens/meter (S/m).

Formula for specific conductance or conductivity,

$$\kappa = G(l/A) \qquad ...(4.8)$$

(As it is reciprocal of resistivity)

4.7 SERIES AND PARALLEL COMBINATIONS OF RESISTANCE

As we know that, $R = \dfrac{\rho l}{A}$

If we take two wire of same material and same area of cross section and length l_1 and l_2

Then resistance of first wire is given by, $R_1 = \dfrac{\rho l_1}{A}$

And resistance of second wire is given by, $R_2 = \dfrac{\rho l_2}{A}$

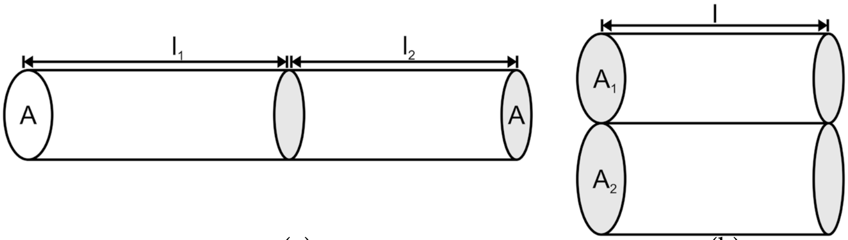


Fig. 4.7 Series and parallel combinations of resistances

If we connect the two wires in series that is , through same area of cross section, than total resistance (R) of combined wires will be (Fig. 4.7 a)

$$R = \frac{\rho l}{A}$$

$$R = \frac{\rho(l_1 + l_2)}{A} = \frac{\rho l_1}{A} + \frac{\rho l_2}{A}$$

$$R = R_1 + R_2 \qquad ...(4.9)$$

Now ,

If we take two wire of same material and same length l but different area of cross section A_1 and A_2

Then resistance of first wire is given by, $R_1 = \dfrac{\rho l}{A_1}$

And resistance of second wire is given by, $R_2 = \dfrac{\rho l}{A_2}$

If we connect the two wires in parallel that is, along the length, than total resistance (R) of combined wires will be (Fig. 4.7 b)

$$R = \frac{\rho l}{A} = \frac{\rho l}{(A_1 + A_2)}$$

$$R = \frac{1}{(A_1 / \rho l + A_2 / \rho l)}$$

$$R = \frac{1}{(1/R_1 + 1/R_2)}$$

$$\frac{1}{R} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \qquad ...(4.10)$$

Eq.4.9 and Eq. 4.10 give the resultant resistance for series and parallel combinations of resistance respectively. The same can be derived with the help of Ohm's law in coming section.

4.8 FACTORS AFFECTING THE RESISTANCE OF WIRE

The following factors affects the resistance of given wire:

- **Length** $R \,\alpha\, l$
  if the length increases the resistance increases
- Area of cross-section $R \,\alpha\, \frac{l}{A}$
  if the area of cross section increases the resistance decreases
- **Nature of material**
  Resistance depends upon the resistivity of material of given wire, two wire made of different material but of same length and same area of cross section, have different resistance.
- **Temperature of conductor**
  The resistance also depends upon the temperature of the conductor. Conductors have positive temperature coefficient of resistance (α). i.e. their resistance increases as the temperature increases.

Mathematically α = change in resistance / (original resistance x Change in temperature)

$$\alpha = (R_2 - R_1)/\{R_1 \times (t_1 - t_2)\}$$

Where, R_2 and R_1 are resistances at temperatures t_2 ^{0}C and t_1^{0}C respectively.

$$\because\ l = l_1 + l_2$$

4.9 CARBON RESISTANCES AND COLOR CODING

Many materials are used to make resistance, metals and alloys such as nichrome, brass, platinum, and tungsten alloys are also used for this purpose. These materials have low electrical resistivity. With the help of these metals low resistance having more current capacity can be made but It is very difficult to make high resistance resistor with this metal alloy because it will be very bulky. Hence to make resistors of high resistance material, carbon is a good alternate. Such type of resistances, made of carbon are known as carbon resistances. They are small and can provide high resistance.

The value of carbon resistor can be determined by decoding the color code. **In the system of colour coding**, strips of different colours are given on the body of the resistor, The colours on strips are noted from left to right.

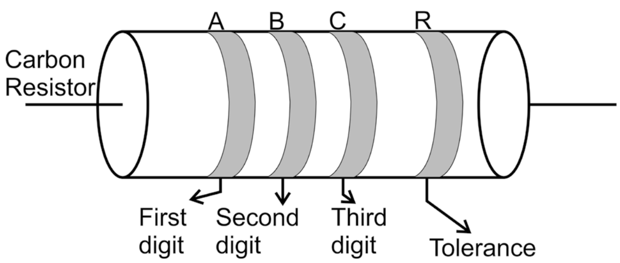


Fig. 4.8 Colour coding of carbon resistor

We have to identify the colours of the strips (A, B and C) on carbon resistor and each colour correspond to certain digit (from 0-9). After identifying the colour the resistance value can be determined as follows:

1. A - First digit of resistance in Ohm
2. B - Second digit of resistance in Ohm
3. C - No. of zero which follow A & B
4. R - % accuracy of resistance

COLOUR (A, B)	INITIAL LETTER	Corresponding Digit or number	MULTIPLIER (C)	COLOUR (R)	Tolerance
Black	B	0	10^0	Gold	±5%
Brown	B	1	10^1	Silver	±10 %
Red	R	2	10^2	No colour	±20%
Orange	O	3	10^3		
Yellow	Y	4	10^4		
Green	G	5	10^5		
Blue	B	6	10^6		
Violet	V	7	10^7		
Grey	G	8	10^8		
White	W	9	10^9		
Gold			10^{-1}		
Silver			10^{-2}		

Table 4.1: Colour code of carbon resistors

To remember the value of colour coding used for carbon resistor, the following can be remembered **B B ROY** of **G**reat **B**ritain has **V**ery **G**ood **W**ife wearing **G**old **S**ilver necklace.

4.10 OHM'S LAW AND ITS VERIFICATION

Statement: The current (I) flowing through a conductor is directly proportional to the potential difference (V) applied across the end of the conductor provided that all the physical conditions and temperature remains constant.

$$I \propto V \quad or \quad V \propto I$$

$$V = RI$$

$$R = \frac{V}{L} \qquad ...(4.11)$$

Ohm's Law

The constant of proportionality R is resistance of conductor.

Suppose we have conductor of length l and area of cross section A, the end of conductor is connected to a variable DC voltage source (0- V). If we change the voltage of the voltage source the potential difference across the end of conductor varied from 0- V. For each voltage, we measure the current flowing inside the conductor. There is increase in current, if we increase the voltage across the conductor. The graph plotted between the voltage and current will be straight line and the reciprocal of slope of curve is the resistance of conductor.

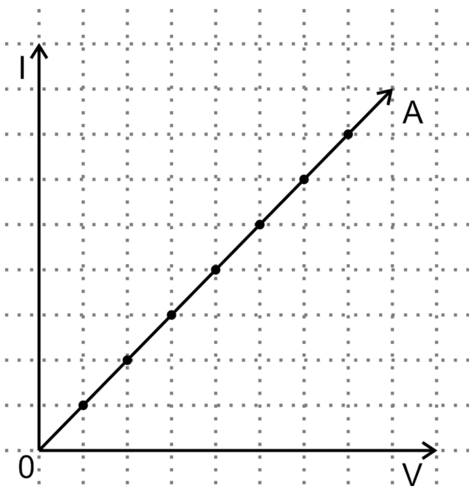


Fig. 4.9 Voltage V/s current graph

Applications of Ohm's Law

1. With the help of Ohm's law the current in a given circuit can be calculated.
2. If a circuit consists of number of elements, then voltage across each element can be measured using Ohm's law.

3. Equivalent resistance in series and parallel combination of resistance can also calculated by applying Ohms law as follows:

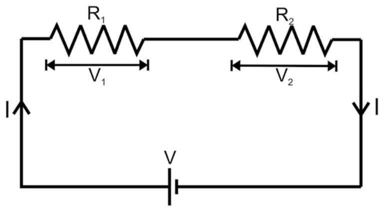
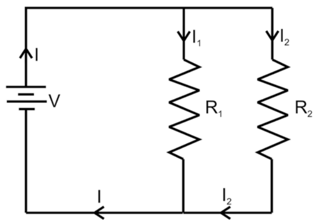
	Series combination As V = IR (R = total resistance) $V_1 + V_2 = IR$ $IR_1 + IR_2 = IR$ (current is same in both resistance as they are connected in series) Therefore, $R = R_1 + R_2$
	Parallel combination V = IR (R = total resistance, I is current in circuit) $I_1R_1 = V$ and $I_2R_2 = V$ (Voltage is same across both resistance as they are connected in parallel) $I_1 = V/R_1$ and $I_2 = V/R_2$ $V = (I_1 + I_2)$ R (As $I = I_1 + I_2$) $V = (V/R_1 + V/R_2)R$ $1/R = 1/R_1 + 1/R_2$

Table 4.2

4.11 KIRCHHOFF'S LAWS

Kirchhoff's law assists us in analyzing a given circuit. Kirchhoff gave two laws, one for voltage (KVL) and other for current (KCL). KVL and KCL helps us to find voltage and current respectively in a given circuit.

Kirchhoff's current law (KCL)

Note: (i) Node or junction is a point where two or more branches meet in a circuit.

(ii) The current flowing towards the node or junction is taken positive and the current flowing away from the node or junction is taken negative.

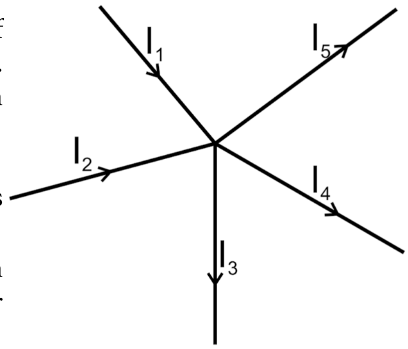


Fig. 4.10 Kirchhoff's Current Law

The algebraic sum of all currents meeting at a junction or node is equal to zero. Physically, this law states that charge cannot collect at a node; whatever enters must go out.

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$
$$I_1 + I_2 = I_3 + I_4 + I_5 \quad ...(4.12)$$

KIRCHHOFF'S VOLTAGE LAW (KVL)

According to the voltage law, the sum of voltages around each closed loop in a circuit is equal to zero or the summation of all the voltage source in a given loop is equal to summation of the product of current and resistance in a given loop. The closed loop may be define as: start at a node and trace a path across the circuit that leads back to the original node. The sign of voltage of any element is taken according to the direction of current in that element. The sign is taken positive, if the direction of traversal is

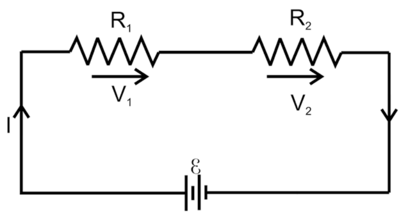


Fig. 4.11 Kirchhoff's Voltage Law

in the direction of current and vice versa. The sign of voltage source is taken negative if the direction of traversal is from negative to positive and vice versa.

$$-\varepsilon + V_1 + V_2 = 0$$

$$\varepsilon = V_1 + V_2 = I(R_1 + R_2)$$

$$I = \varepsilon / (R_1 + R_2) \qquad ...(4.13)$$

or $$\sum V = \sum IR \quad \text{for the loop}$$

4.12 WHEATSTONE BRIDGE AND ITS APPLICATIONS

Interesting facts

This method was first suggested by a British physicist sir, Charles. F. Wheatstone in 1843.

Statement: It is an arrangement of four resistance used to determine one of these resistances quickly and accurately, in terms of remaining three resistance.

When bridge is balanced then point B and Point D both are at the same potential and no current flows through galvanometer. It means deflection in galvanometer is zero.

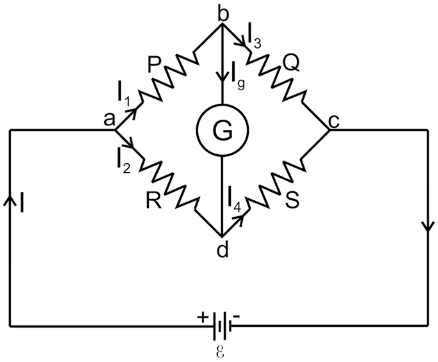


Fig. 4.12 Wheatstone's bridge

For the loop abda $$I_1P + GI_g - I_2R = 0$$

$$I_3Q - I_4S - GI_g = 0$$

For the loop bcdb $$I_g = 0$$

$$I_1P = I_2R$$

In balance conditions $$I_3Q = I_4S$$

then $$...(4.14)$$

$$P/Q = R/S \qquad ...(4.15)$$

On dividing Eq 4.14 with Eq 4.15

$$\{\because I_g = 0,\ \therefore I_1 = I_3 \text{ and } I_2 = I_4\} \qquad ...(4.16)$$

Advantages

- It is a null method, hence the internal resistance of voltage source and resistance of galvanometer does not affect the null point.
- As there is no involvement of voltage and current measurement, therefore the characteristics of measuring instrument does not affect the measurement.
- The unknown resistance can be measured with high accuracy, by increasing the ratio of resistance in arm P and Q.

Application of Wheatstone bridge: Slide wire bridge

Meter bridge or slide wire bridge is the simplest application of the Wheatstone bridge, used to measure an unknown resistance. It consists of a 1m long manganin or constant an wire of uniform cross-sectional area stretched and clamped with metallic strips bent at right angles. The metallic strips has two gaps where two resistors (one known (R) and one unknown (S))can be connected. The endpoints where the wire is clamped are connected to a cell or a battery or voltage source through a key. One end of a galvanometer is connected to the metallic strip midway between the two gaps. The other end of the galvanometer is connected to a

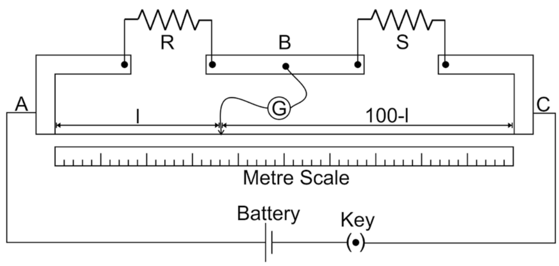


Fig 4.13 Meter bridge

'jockey'. The jockey is moved along the wire and balancing point is determined. At a particular position of jockey, current in galvanometer becomes zero. Let the balancing length is l. Then

$$\frac{R}{S} = \frac{R_{cm} l}{R_{cm}(100-l)} = \frac{l}{100-l}$$ {where R_{cm} is the resistance per unit length of wire}

$$S = (100\text{-}l)\, R/l \quad \text{...(4.17)}$$

4.13 CONCEPT OF TERMINAL POTENTIAL DIFFERENCE AND ELECTRO MOTIVE FORCE

Cell is a device which converts chemical energy into electrical energy. It consists of two electrodes and electrolytes. Learners must have understood the concept of cell in electrochemistry. Cell acts as a voltage source to provide current in external load. Electromotive force or emf (ε) of a cell is the maximum potential difference between two electrode of the cell when no current is drawn from the cell.

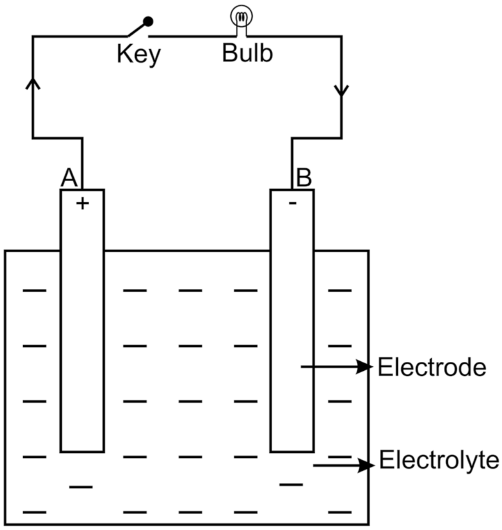


Fig. 4.14 Electric cell

Each voltage source say DC voltage source, battery or a cell has some internal resistance (r) which is resistance offered by the electrolyte and electrodes of a cell to the passage of electric current through the cell. The internal resistance (r) of cell depends upon number of factors such as area of electrode, distance between electrode, concentration of electrolyte and temperature.

Whenever a load is connected to cell than the voltage on load is always less than the emf, hence terminal Potential difference of a cell is defined as the potential difference between the two electrodes of a cell in a closed circuit. It is denoted by V and measured in volt.

Always $V < \varepsilon$

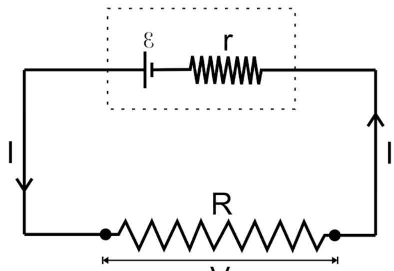


Fig. 4.15 emf and terminal potential difference

By Ohm's Law,

Magnitude of current, $I = \dfrac{\varepsilon}{R+r}$

Potential difference across r, $V_r = Ir$

Voltage across load (V) is, $V = \varepsilon - V_r = \varepsilon - Ir$

$$r = \frac{\varepsilon - V}{I}$$ (in open circuit I = 0, then V = ε)

Also, potential difference across R,

$$V = IR, \; I = \frac{V}{R}$$

Hence $$r = \frac{(\varepsilon - V)}{V} \times R \qquad ...(4.18)$$

From Eq 4.18 we can calculate internal resistance of cell.

4.14 HEATING EFFECT OF CURRENT

Interesting fact:

- The resistance of wire of the electric bulb is very low, still they are given 220 V.

Whenever electric current passes through a conductor, the temperature of the conductor increases due to heat produced the by electric current. If the potential difference across conductor is V and I current flows through conductor AB of resistance R for time t then,

The work done by electric field to move charge from A to B in the conductor is

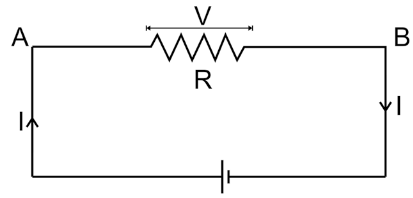


Fig. 4.16 Heating due to electric current in circuit

$$W = V \times q \qquad (V = IR)$$
$$W = IR \times It (q = It)$$
$$W = I^2Rt \qquad ...(4.19)$$

The above work done changes into heat energy to overcome the resistance offered by the conductor,

$$H = W = I^2Rt$$

Hence i) H is proportional to I^2, for given resistance R

ii) H is proportional to R, for given I

iii) H is proportional to t, for a given resistance R and current I

The law stated above is known as Joule's law of Heating.

4.15 ELECTRIC POWER

The rate at which an appliance converts electrical energy into other forms of energy is known as electric power.

Example : The power of electric bulb is the rate at which it converts electrical energy into light. A bulb of high power consumes more electrical energy and gives more light energy as compared to the bulb of low power. The appliances in our house hold consumes electrical power as per their functioning.

$$P = \frac{W}{t} = \frac{VIt}{t} = VI \, J/s \qquad ...(4.20)$$

$$\text{Power (in watt)} = \text{Volt} \times \text{Ampere}$$
$$1 \text{ watt} = 1 \text{ Ampere – Volt}$$

Bigger units of power are kW and MW

$$1 \text{ kW} = 10^3 \text{ W}, \qquad 1 \text{MW} = 10^6 \text{ W}$$

and $$1 \text{ horse power (hp)} = 746 \text{ watt}$$

$$P = VI \quad \text{and} \quad V = IR, \quad I = V/R$$

Therefore $$P = I^2R$$

or $$P = V^2/R \qquad ...(4.21)$$

4.16 ELECTRIC ENERGY AND ITS UNITS

The total work done by the source of emf in maintaining an electric current in the circuit for a given time is called as electric energy consumed in the circuit.

$$\text{Electric Energy } W = VIt = P.t$$
$$\text{Electric Energy} = \text{Electric power} \times \text{time}$$
$$\text{Electric Energy in Joule} = 1 \text{ volt} \times 1 \text{ amp} \times 1 \text{ sec}$$
$$= 1\text{watt} \times 1 \text{ sec}$$

Commercial unit of electric energy is kilowatt – hour (kWh)

$$1 \text{ kWh} = (1000W)(60 \times 60s)$$
$$= 3.6 \times 10^6 J$$

4.17 ADVANTAGES OF ELECTRIC ENERGY OVER OTHER FORMS OF ENERGY

- Electrical energy can be easily transformed into other forms of energy- like
  - heat in heaters and oven,
  - light in electrical bulb and Tube-lights,
  - mechanical energy in electric motors grinder,
  - chemical energy in cell or battery charging.
- Ease of control: Through electrical switches and circuits
- Flexible : Easily Transported through wires
- Efficient and Reliable

EXAMPLE 4.1

Ques. If 1 ampere of current flows in a given wire having uniform area of cross section 0.05 cm^2 along length 50 cm. Find specific resistance and specific conductance of material of given wire if the voltage across two ends of wire is 5 volts.

Solution:

Given $A = 0.05 \text{ cm}^2 = 0.05 \times 10^{-4} \text{ m}^2$, $l = 50$ cm $= 0.5$ m, $I = 1$ ampere and $V = 5$ volts

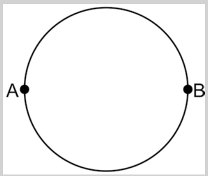
First we find R, $R = V/I = 5/1 = 5\ \Omega$

Specific resistance $\rho = (R \times A)/l = (5 \times 0.05 \times 10^{-4})/(0.5) = 0.5 \times 10^{-4} = 5 \times 10^{-5}\ \Omega\text{-m}$

Specific conductance $(\kappa) = 1/\rho = 1/(5 \times 10^{-5}) = 2 \times 10^4$ S/m.

EXAMPLE 4.2

Ques. If a wire of 10 cm length and having resistance 10 ohm is bend in the form of circle such that both end of wire are connected. Find the resistance between any two point along its diameter.



Solution:

Given length = 10 cm = 0.1m, $R = 10\ \Omega$

The wire is bend in form of circle

The resistance (R) between point A and B

Will be equivalent to parallel combination of resistance of upper half wire and lower half.

Resistance of half wire = 5 ohm

Therefore,

$1/R = 1/5 + 1/5 = 2/5$

$R = 2.5$ ohms

EXAMPLE 4.3

Ques. A wire of length l and area of cross section A, has been stretched such that its length is doubled and volume remains constant with uniform area of cross section throughout stretched wire. Find the resistance of stretched wire if resistance of unstretched wire is 2 Ohm.

Solution:

Let the resistance, radius and area of unstretched wire is R_1, r_1 and A_1 respectively

And the resistance, radius and area of stretched wire are R_2, r_2 and A_2 respectively

So Volume of unstretched wire $V_1 = \pi r_1^2 l$ and Volume of stretched wire $V_2 = \pi r_2^2 \times 2l$

As $V_1 = V_2$

$\Rightarrow \quad \pi r_1^2 l = \pi r_2^2 2l$

$\Rightarrow \quad r_2^2 = r_1^2/2$

now $R_1 = \rho l/A_1$, $R_2 = \rho \times 2l/A_2$,

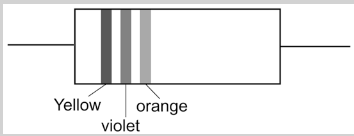
$R_2/R_1 = (2l \times \rho/A_2) / (\rho l/A_1) = 2\,A_1/A_2 = 2 \times \pi r_1^2 / \pi r_2^2 = \{2 \times (2\,r_2^2)\}/(r_2^2) = 4$

$\Rightarrow$ Therefor $R_2 = 4R_1$ and hence $R_2 = 8$ ohm

EX 4.4

Ques. Find the resistance of following carbon resistor from colour coding

Solution:

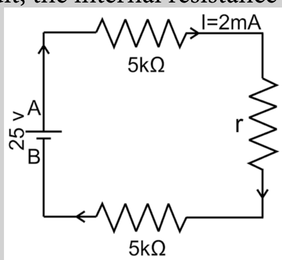


From colour code Yellow - 4,Violet-7 and Orange-3

Hence Resistance = 47×10^3 ohm = 47 k ohm

EXAMPLE 4.5

Ques. Using Kirchhoff's law, find the voltage across 'r' in given circuit, the internal resistance of voltage source is zero.



Solution:

Let us consider loop from A B A as follows

From Kirchhoff Law

$V_1 + V_2 + V_3 - 25V = 0$

$V_1 + V_2 + V_3 = 25V$

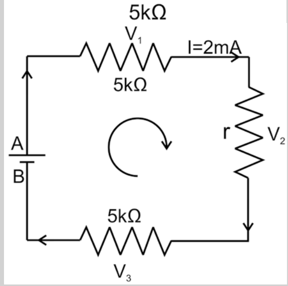
$V_1 = 5 \times 10^3\ \Omega \times 2 \times 10^{-3}A = 10V$

$V_2 = ?$

$V_3 = 5 \times 10^3\ \Omega \times 2 \times 10^{-3}A = 10V$ (By Ohms Law)

Hence, $10V + V_2 + 10\ V = 25\ V$

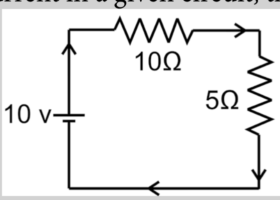
$V_2 = 25V - 20\ V = 5\ V$

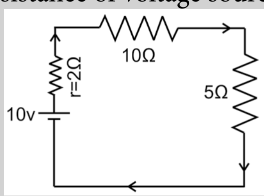


EXAMPLE 4.6

Ques. Find the current in a given circuit, the internal resistance of voltage source is 2 Ω

Solution:





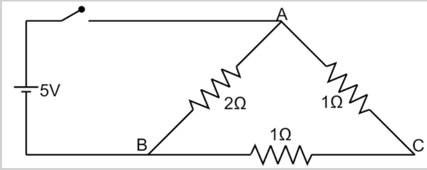
The given circuit can be re drawn as the internal resistance is in series with voltage source.

The total resistance of (R)circuit will be R = 2 + 10 + 5 = 17 Ω

Current in the circuit = 10/17 = 0.59 A

EXAMPLE 4.7

Ques. Find the energy dissipated in the following circuit if the switch is open for 30 sec.



Solution: First we find the current in the circuit and for that we find the total resistance of circuit

The resistance of arm AC and BC are in series, hence the resistance of arm ACB = 1 + 1 = 2Ω

The resistance of ACB is parallel to AB then the resultant resistance R is

1/R = 1/2 + 1/2 = 1 Ω, R = 1Ω

Current (I) in circuit = 5/1 = 5 ampere

Energy (E) dissipated in the form of heat in 30 sec is, $E = I^2R\ t = 5^2 \times 1 \times 30 = 750$ joule

UNIT SUMMARY

- The rate of flow of charge is called current.
- In direct current only the magnitude of current changes, whereas in AC current magnitude and as well direction of current also changes.
- Resistivity and conductivity are the characteristic of material and does not depends upon the shape of the material body but depends on temperature.
- The current flowing in a wire is proportional to applied voltage, provide that the physical condition does not change.
- Wheatstone bridge is used to find the unknown resistance precisely.
- Terminal potential difference is always less than the emf of cell.
- If 3.6×10^6 J of electrical energy is consumed then, the reading of commercial electric meters will be raised by 1 unit.

EXERCISES

Multiple Choice Questions

4.1 Conductance is reciprocal of

a. Inductance
b. Capacitance
c. Resistance
d. Reluctance

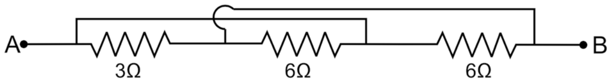
4.2 The curve representing Ohms law is a (when physical condition does not change):

a. Linear
b. Cosine function
c. Parabola
d. Hyperbola

4.3 The SI unit of current is

a. ampere
b. volt
c. ohms
d. siemens

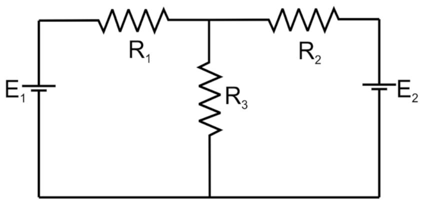
4.4 The equivalent resistance of a circuit between A and B is



a. 3 Ω
b. 6Ω
c. 2/3 Ω
d. 3 /2Ω

4.5 In the circuit shown in figure E_1 = 5 V, E_2 = 10 V R_1 = R_2 = 5 Ω and R_3 = 10 Ω respectively. The current through the resistance R3 is

a. 2/5 A
b. 1/5 A
c. 4/5 A
d. 3/5 A



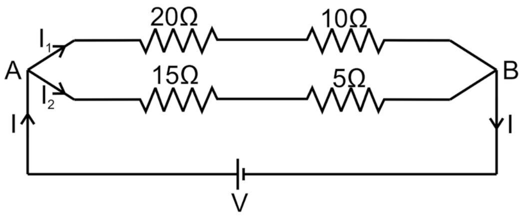
Answers of Multiple Choice Questions
4.1 (c), 4.2 (a), 4.3 (a), 4.4 (d), 4.5 (d)

Short and Long Answer Type Questions

Category-I

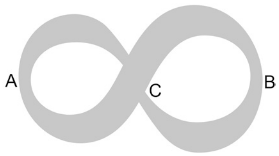
1. Describe electric current with SI and CGS units.
2. Differentiate between DC and AC with diagrams.
3. Explain the following terms with units and mathematical relation.
   a. Resistance
   b. Conductance
   c. Resistivity
   d. Conductivity
4. Find the resultant resistance due to series and parallel combination of resistances.
5. Explain the factors affecting the resistance of wire.
6. Explain Ohm's law with diagram.
7. Describe Kirchhoff's law of current and voltages (KCL and KVL).
8. Explain principle of Wheatstone bridge.
9. Explain construction and working of meter bridge

10. Explain Joul's law of heating with mathematical relation between energy and current.
11. Differentiate between emf and terminal potential difference.
12. Find the formula for the internal resistance of voltage source in terms of emf and load resistance.
13. List advantages of electric energy over other forms of energy.
14. Find the equivalent resistance between points A and B in the following circuit diagram.



Category-II

1. If a wire of 10 cm length and having resistance 10 Ohm is bend in the form of figure of "8" The wire is without insulation. Find the resistance between the two point A and B. If the wire is insulated will there be any change in resistance between A and B?



2. Every voltage source has some internal resistance, Analyze the effect of internal resistance on the load current and terminal voltage of cell with examples.
3. In meter bridge experiment, analyze the effect of change in dimensions of wire on balancing length with examples.
4. Predict voltage vs current curve when the current flowing in conductor increases and the temperature of wire also increases.

PRACTICAL

There are four laboratory experiment(s) which are related to this unit

- To verify Ohm's law by plotting graph between current and potential difference.
- To verify laws of resistances in series and parallel combination.
- To find the frequency of AC mains using electrical vibrator.
- To verify Kirchhoff's law using electrical circuits.

Practical 6 - Ohm's law

P6.1 Practical Statement

To verify Ohm's law by plotting graph between current and potential difference.

P6.2 Practical Significance

Measurement of electric current, voltage and resistance in a given electrical circuit is an essential requirement for diploma engineers of every branch. Ohm's law helps to design electrical circuits and this experiment helps to find the relation between voltage, current and resistance of a given electrical circuit.

P6.3 Relevant Theory

Refer: Section 4.10 of this unit

P6.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use Ohm's law to find current, voltage and resistance of given circuit.

P6.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

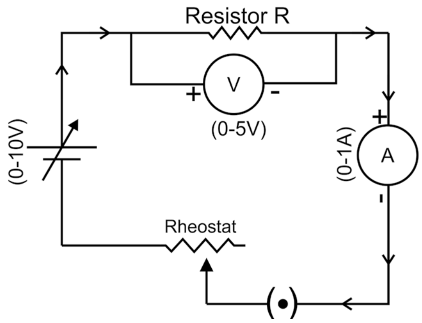


Fig P6.1

P6.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
	Variable DC Power supply 0-10 V	01			
	Ammeter 0-1 A, Voltmeter 0- 10 V	01			
	Rheostat 500 Ohm	01			
	Key	01			
	Resistance Wire 1 meter Nichrome	01			

P6.7 Precautions

1. Connections should be tight.
2. All the components should be placed such that they can be properly connected.
3. The pointer of ammeter/voltmeter should coincide with zero mark.
4. Check the power supply before connection.
5. Check connection with the help of teacher.
6. Connect ammeter in series and voltmeter in parallel.
7. The key should be inserted only while taking readings.

P6.8 Suggested Procedure

1. Make connections as per circuit diagram in Fig. P6.1.
2. Note the LC and range of Ammeter and voltmeter.
3. Switch on power supply and close key.

4. Keep the position of rheostat at maximum resistance.
5. Note the reading of ammeter and voltmeter.
6. Change the position of variable arm of rheostat gradually.
7. Note the corresponding change in reading of ammeter and voltmeter.
8. Repeat the step from 6 to 7 eight times.
9. Plot the graph between electric current (I) along X-axis and voltage (V) along Y-axis.
10. Plot graph and find the slope of line.

P6.9 Observations and Calculations

Least count of ammeter = ... Range of ammeter = ...

Least count of voltmeter = ... Range of voltmeter = ...

Sr. No	I (Ampere)	V- (Volts)	R = V/I

Mean R = ...

Slope of graph : ....

P6.10 Results and/or Interpretation

(to be filled by student)

1. ....

P6.11 Conclusions and/or Validation

(to be filled by student)

1. ....

P6.12 Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give least count of ammeter and voltmeter used in experiment.
2. Give reasons to connect voltmeter in parallel to resistance wire.
3. Give reasons to keep rheostat at maximum resistance.
4. Is the resistance of wire and circuit remains constant through out the experiment?

P6.13 Suggested Learning Resources

- amrita.olabs.edu.in/?sub=1&brch=6&sim=22&cnt=2

P6.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of voltage and electric current		
3	Calculation of resistance of wire		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 7 - Series and parallel combination of Resistances

P7.1 Practical Statement

To verify laws of resistances in series and parallel combination.

P7.2 Practical Significance

Series and parallel circuit connections are employed in electrical equipment. Current controlling devices and fuses are connected in series with a voltage source. Use of parallel circuits is found in lighting fixtures in our house hold. The applications of series and parallel circuits connection can be evidently seen in our homes and industry. In this experiment, resistive wires are connected in series & parallel and equivalent resistance of circuit is determined using ohm's law.

P7.3 Relevant Theory

Refer: Section 4.7 and 4.10 of this unit

P7.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use the principle of series and parallel combination of resistances in solving a given circuit problem.

P7.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

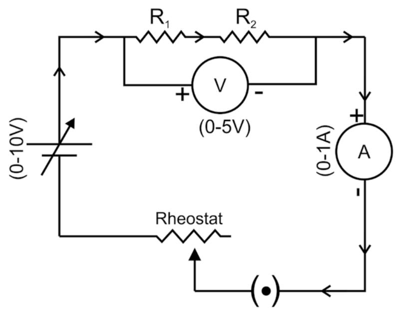


Fig P7.1

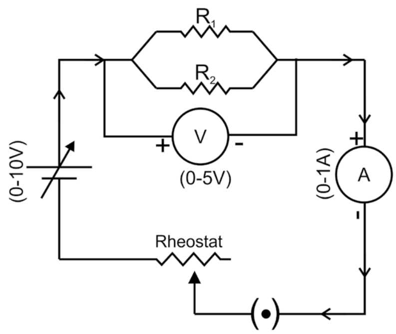


Fig P7.2

P7.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Re- marks (if any)
			Make	Details	
1	Variable DC Power supply (0-10 V), Voltmeter 0- 10 V, Rheostat 500 Ohm, Key, Ammeter 0-1 A	01			
2	Resistance Wire (length 1 meter, Nichrome)	2			

P7.7 Precautions

1. Connections should be tight.
2. All the component should be placed such that they can be properly connected.
3. The pointer of ammeter/voltmeter should coincide with zero mark.
4. Check the power supply before connection.
5. Check connection with the help of teacher.
6. Connect ammeter in series and voltmeter in parallel.
7. The key should be inserted only while taking readings.

P7.8 Suggested Procedure

1. Connect the circuit according to the circuit diagram (Fig. P7.1) with R_1 only.
2. Vary current in the circuit using rheostat.
3. Record the observations from voltmeter and ammeter in equal intervals.
4. Take five observations.
5. Calculate the resistance of given wire by ohm's law as per the formula.
6. Find mean resistance $R_{1.}$
7. Repeat the steps 1 to 6 to calculate resistance R_2.
8. Connect the two resistances R_1 and R_2 in series combination as per the circuit diagram (Fig. P7.1).
9. Repeat the steps 2 to 6 to calculate equivalent resistance R_s by experiment.

10. Calculate equivalent resistance R_s by theory using formula.
11. Connect two resistances R_1 and R_2 in parallel combination as per the circuit diagram (Fig. P7.2).
12. Repeat the steps 2 to 6 to calculate equivalent resistance R_p by experiment.
13. Calculate equivalent resistance R_p by theory using formula.

P7.9 Observations and Calculations

Least count of ammeter = ... Range of ammeter = ...
Least count of voltmeter = ... Range of voltmeter = ...

Table 1: For R_1 and R_2

Sr. No	I (ampere)	V- (volts)	R_1= V/I	I (ampere)	V- (volts)	R_2= V/I
1						
2						
3						
4						

Mean R_1 = ... Mean R_2 = ...

Table 2: For series and parallel combinations R_1 and R_2

	Series Combination			Parallel Combination		
Sr. No	I (ampere)	V- (volts)	R_1= V/I	I (ampere)	V- (volts)	R_2= V/I
1						
2						
3						
4						
5						

R_s by Theory = $R_1 + R_2$ = ...; Rs by experiment (from Table 2) = ...
R_p by Theory = $R_1 \times R_2/(R_1 + R_2)$ = ...; Rp by experiment (from Table 2) = ...

P7.10 Results and/or Interpretation

(to be filled by student)

1. ....

P7.11 Conclusions and/or Validation

(to be filled by student)

....

P7.12 Practical related Questions

(Use separate sheet for answer)

Note*:* Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give least count of ammeter and voltmeter used in experiment.

2. Give reasons to connect voltmeter in parallel to resistance wire.
3. Give reasons to keep rheostat at maximum position in the beginning of experiment.
4. Is the resistance of wire and circuit remains constant through out the experiment?

P7.13 Suggested Learning Resources

- amrita.olabs.edu.in/?sub=1&brch=5&sim=168&cnt=2
- https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab

P7.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of voltage and electric current		
3	Calculation of resistance of series and parallel combinations of resistances		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 8 - AC mains

P8.1 Practical Statement

To find the frequency of AC main using electrical vibrator

P8.2 Practical Significance

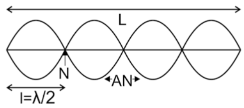
House hold electrical circuits are supplied with AC mains of 220 Volts and 50 Hz. In AC currents magnitude and direction of current changes with time. This experiment helps to find the frequency of AC mains and also demonstrate formation of standing waves, variation of velocity of mechanical waves with tension on string and resonance phenomenon.

P8.3 Relevant Theory

When a string of mass per unit length 'm' is connected to the vibrating rod of the electrical vibrator (supplied with AC mains) and stretch with tension T, the string vibrates in segments. The frequency of the stretched string is the same as of the vibrating rod, which is vibrating with the frequency of AC mains. Then if 'l' is the length of one loop of this vibrating string, its frequency of vibration is given by

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

Where, T (tension in the string) = Mg, M = Total mass (mass of the pan + mass placed on pan), l = length of one loop, g = acceleration due to gravity and m = mass per unit length of the string.



Formation of standing waves

P8.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Determine the frequency of AC mains using electrical vibrator.

P8.5 PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

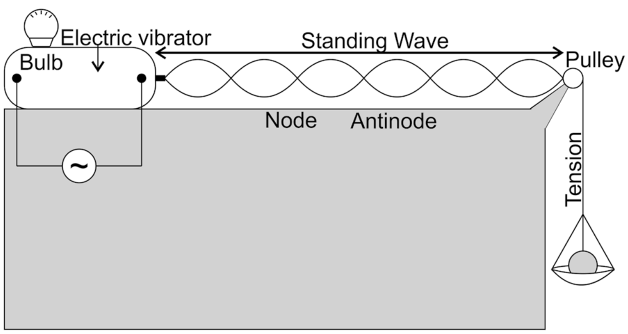


Fig P8.1

P8.6 RESOURCES REQUIRED

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
	Electrical Vibrator, String, Pan, weight box, a stand with clamp and pulley and meter scale.	01 each			

P8.7 Precautions

1. Load mass on a pan gradually.
2. The string should be uniform.
3. Measurement should be taken, when the amplitude of the loops is maximum.
4. Add mass of pan for calculations if any.

P8.8 Suggested Procedure

1. Switch on vibrator by connecting plug to AC mains.
2. Add some weight on pan say 20 grams.
3. Adjust the length of the string to get loops (4 or 5).
4. Set the length for maximum amplitude.
5. Note no. of loops and mass on the pan and length of the string.
6. Repeat the same adjustment for different mass and no. of loops.
7. Calculate the frequency of AC mains '*f*'.

P8.9 Observations and Calculations

Mass of Pan =..........grams, Mass per unit length of string =..........

Sr. No	No. of loops *(n)*	Length of String (L)	Length of one loop (l = L/n)	Mass on Pan	Tension (T = Mg)
1					
2					
3					
4					
5					

Frequency of A.C. mains = ...

Mean = ...

P8.10 Results and/or Interpretation

(to be filled by student)

1. ....

P8.11 Conclusions and/or Validation

(to be filled by student)

1. ....

P8.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions to ensure the achievement of pre-defined course outcomes.

1. Give reasons for formation of loops?
2. At the pulley end, whether node or antinode is formed? Give reasons.
3. Predict the change in the formation of loops if the mass per length of string is increased.

4. Predict the type of waves on string in this experiment with reasons. Whether they are electro magnetic or mechanical waves?
5. Give reason to add bulb in electrical vibrator.

P8.13 Suggested Learning Resources

- http://www.olabs.edu.in/?sub=1&brch=6&sim=151&cnt=4

P8.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Change length of string for formation of loops for maximum amplitude (resonance)		
2	Taking measurement		
3	Safety measures during experiment		
4	Individual and team work		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 9 - Kirchhoff's law

P9.1 Practical Statement

To verify Kirchhoff's law using electric circuits.

P9.2 Practical Significance

Kirchhoff's laws are used to analyze a given circuit. Two Kirchhoff's laws, one for voltage Kirchhoff's voltage law (KVL) and one for current Kirchhoff's current law (KCL) helps us to find voltage and current respectively in a given circuit. This experiment helps students to experimentally measure the sum of current at nodes and voltage across different components in a loop.

P9.3 Relevant Theory

Refer: Section 4.11 of this unit

P9.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use Kirchhoff's law to find current and voltage across elements in a given circuit.

P9.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

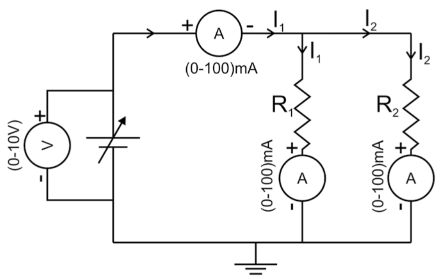


Fig P9.1

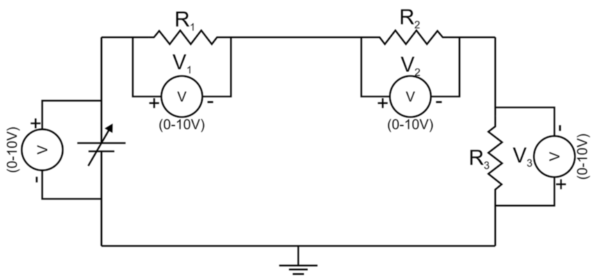


Fig P9.2

P9.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Re-marks (if any)
			Make	Details	
1	Variable DC Power supply 0-10 V	01			
2	Ammeter 0-500 mA	03			
3	Voltmeter 0-10 V	04			
4	Resistances 100Ω, 220Ω , 330Ω, 1000Ω 2200Ω, 3300Ω	06			
5	Key	01			

P9.7 Precautions

1. Connections should be tight.
2. All the component should be placed such that they can be properly connected.
3. The pointer of ammeter/voltmeter should coincide with zero mark.
4. Check the power supply before connection.
5. Check connection with the help of teacher.
6. Connect ammeter in series and voltmeter in parallel.
7. The key should be inserted only while taking readings.

P9.8 Suggested Procedure

For KCL

1. Make connection as per circuit diagram in Fig P9.1.
2. Note the LC and range of Ammeter and voltmeter.

3. Switch on power supply and close key.
4. Note the reading of ammeters for I, I_1 and I_2.
5. Change the voltage of power supply and repeat step 4.

For KVL

6. Make connection as per circuit diagram in Fig P9.2.
7. Switch on power supply and close key.
8. Note the reading of voltmeter for V, V_1,V_2 and V_3
9. Change the voltage of power supply and repeat step 8.

P9.9 Observations and Calculations

Least count of ammeter 1 = ...
Least count of ammeter 2 = ...
Least count of ammeter 3 = ...
Least count of voltmeter = ...

Range of ammeter 1 = ...
Range of ammeter 2 = ...
Range of ammeter 3 = ...
Range of voltmeter = ...

Table 1 for KCL

Sr. No	Voltage (V)	I_1	I_2	I	$I_1 + I_2$
1					
2					
3					
4					
5					

Least count of voltmeter = ...
Least count of voltmeter 1 = ...
Least count of voltmeter 2 = ...
Least count of voltmeter 3 = ...

Range of voltmeter = ...
Range of voltmeter 1 = ...
Range of voltmeter 2 = ...
Range of voltmeter 3 = ...

TABLE 2 for KVL

Sr. No	Voltage (V)	V_1	V_2	V_3	$V_1 + V_2 + V_3$
1					
2					
3					
4					
5					

P9.10 Results and/or Interpretation

(to be filled by student)

1. ....

P9.11 Conclusions and/or Validation

(to be filled by student)

1. ....

P9.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give least count of ammeter and voltmeter used in experiment.
2. Is resistance of circuit in Fig 1 will be less than or greater than the individual resistance?
3. Can we find the internal resistance of the voltage source by this experiment.

P9.13 Suggested Learning Resources

- https://vlab.amrita.edu/?sub=1&brch=75&sim=217&cnt=1

P9.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of voltage and electric current		
3	Handling of instrument		
Product related: ….. Marks* (…….%)			
4	Result and conclusion		
5	Timely submission of report		
6	Answer to Practical related questions		
	Total	100%	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course

- Current density.
- Ohms law in differential form.

Applications

- All the gadgets and computer devices have digital circuits and they work on DC voltage.
- Ac current is used in house hold circuits.
- Heating effect of current is used in thermal devices

Use of ICT

The student can visit the following url for simulation in current electricity

- https://phet.colorado.edu/en/simulation/ohms-law

Ohm's Law simulation

Design innovative Practical /Projects/ Activities

- Prepare model to demonstrate Ohm's law.
- Prepare model to demonstrate series and parallel combinations of resistances.

Inquisitiveness and Curiosity Topics

- Does voltage versus current relation is always linear?
- Reasons for using carbon resistance.
- Can we find the internal resistance of our mobile phone battery?
- Operating and actual resistance of tungsten bulb

REFERENCES & SUGGESTED READINGS

- H C Verma, "Concepts of physics" 1st ed., vol. 2, Bharti Bhawan, 1992.
- Richard Feynman *et al* "The Feynman lectures on Physics", 6th ed. vol1, Addison-Wesley, 1963.
- R K Gaur and S L Gupta "Engineering Physics", 8th ed., Dhanat Rai, 2011.
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5 Electromagnetism

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Diamagnetic, Paramagnetic and Ferro magnetic materials.
- Magnetic field, magnetic intensity and Magnetization.
- Faraday's law of electromagnetic induction.
- Lorentz force on moving charge in magnetic field.
- Force on current carrying wire and coil placed in magnetic field.
- Moving coil galvanometer.
- Conversion of galvanometer in ammeter and voltmeter.

Applications of electromagnetism in daily are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. Micro project activity is suggested which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book. Industrial applications and real life applications on variety of aspects, inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Electromagnetism is a branch of physics deals with the concept of magnetism, electromagnetic induction and application of electromagnetic induction. Generation of electric power and conversion of renewable and non-renewable energy in to electrical energy are the ultimate applications of electromagnetic induction. Many measuring equipment works on the principle generation of magnetic field due to electric current. Conversion of mechanical energy into electrical energy or electrical energy to mechanical energy is an application of electromagnetic induction. This unit will explain the basics of Electromagnetism and related topics which will help to comprehend the engineering applications of Electromagnetism and solve the problems related to Electromagnetism.

PRE-REQUISITES

- **Mathematics:** Trigonometric functions, Algebra, Calculus, vectors

- **Physics:** Magnets, Magnetic dipole, Electric current
- **Other's:** Basic technology of computer and use of mobile application

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U5-O1: Select a given material on the basis magnetic properties.
U5-O2: Explain magnetic field, magnetization and Faraday's Laws of electromagnetic induction.
U5-O3: Apply Lorentz force to find the direction of moving charge in magnetic field.
U5-O4: Predict the force acting on current carrying rectangular coil placed in magnetic field.
U5-O5: Explain the construction and working of moving coil galvanometer.
U5-O6: Convert a given galvanometer into ammeter and voltmeter of desired range.

Unit-5 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES					
	(1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U5-O1	-	-	-	-	3	1
U5-O2	-	-	1	-	3	1
U5-O3	-	-	-	1	3	1
U5-O4	-	-	-	1	3	1
U5-O5				1	3	1
U5-O6	-	-	-	1	3	1

5.1 TYPES OF MAGNETIC MATERIALS

As per Oersted's Experiment the current carrying wire acts a magnet. Apart from heating effect of current as explained in previous unit, there is magnetic effect of current also. Materials are made up of atoms and in atoms there are electrons. Electrons can be considered as tiny magnets with magnetic moment. There are two kind of electron motion: orbital and spin (Fig.5.1). Atoms contains many electrons spinning about its own axis and rotating around nucleus. The magnetic moment of electrons associated with each kind of motion is a vector quantity, perpendicular to the orbit and parallel to the axis of spin of electrons. The magnetic moment of atom is calculated as the vector sum of moment of all electrons.

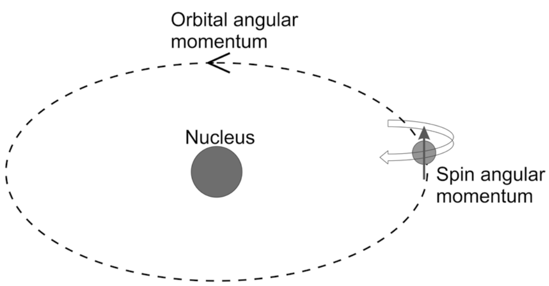


Fig 5.1 Orbital and spin angular momentum associated with electrons

5.1.1 Dia, para and ferromagnetic materials with their properties

(a) Diamagnetic materials:

In diamagnetic materials, the atom has no net magnetic moment, because the magnetic moment of each electron is arranged in such a way that they cancel out each other. Such materials are known as diamagnetic materials. These materials are repelled by magnetic field. These materials are also known as negative magnetic materials. The monoatomic (He, Ne, A, etc.) and polyatomic gases (H_2, N_2, etc.) and NaCl, diamond, Si, Ge are examples of diamagnetic materials.

(b) Paramagnetic materials:

In Paramagnetic materials, the atom has net magnetic moment because of partial cancellation of magnetic moment of individual electrons. Such materials have magnetic moment due to the presence of unpaired electrons. When an external magnetic field is applied, magnetic moment of unpaired electrons align parallel to applied magnetic field, causing a net magnetic moment. The materials with unpaired electrons such as Al, FeO, Oxygen, Titanium, are the examples of paramagnetic materials.

(c) Ferromagnetic materials:

In ferromagnetic materials, there is a net magnetic moment due to the presence of unpaired electrons. When an external magnetic field is applied, these magnetic moments are aligned parallel to the applied filed. It results in the increase in magnetization of the materials.

In the non-magnetized state, atomic dipoles in small regions of the ferromagnetic materials called domains are aligned in the same direction (Fig. 5.2a). The domain exhibits a net magnetic moment even in the absence of external magnetic field. On applying external magnetic field these domains all align themselves in the direction of the applied field (5.2 b). In this way, the material is strongly magnetized in a direction parallel to the magnetizing field.

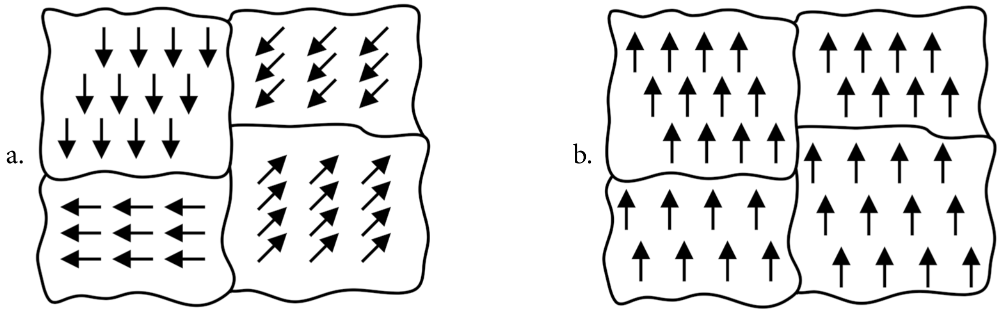


Fig 5.2 Ferromagnetic materials

5.1.2 Magnetic field and units

Consider a bar magnet consisting of magnetic poles (North and South poles) around the end (Figure.5.3). If we put another bar magnet near to this magnet, there will be force of attraction or repulsion between poles, depending upon the nature of the two poles. The force of attraction or repulsion is directly proportional to the product of the pole strengths of corresponding poles and inversely proportional to the square of the distance between the two poles. This force is also known as Coulomb magnetic force. (like electrostatic force between two charges.)

Mathematically

$$F \;\alpha\; m_1 \times m_2 \quad ...(5.1)$$

$$F \;\alpha\; 1/r^2 \quad ...(5.2)$$

$$F = k m_1 m_2 / r^2 \quad ...(5.3)$$

$k = \mu_0 / 4\pi = 10^{-7}$ Henry/meter, and m_1 and m_2 in SI unit that is Amp × m, r in meter and μ_0 is magnetic permeability of free space

An isolated unit positive charges exists, whereas an isolated magnetic pole doesn't exists, but still if we consider an isolated north pole of unit pole strength(m) and kept it at a point 'P' near to the bar magnet or a current carrying conductor (acting as magnet) then the force on north pole of unit pole strength is the magnetic field due to bar magnet or a current carrying conductor at that point.

$$B = F/m \quad ...(5.4)$$

$$\text{Dimensional formula of } B = MLT^2/AL = MA^{-1}T^{-2}$$

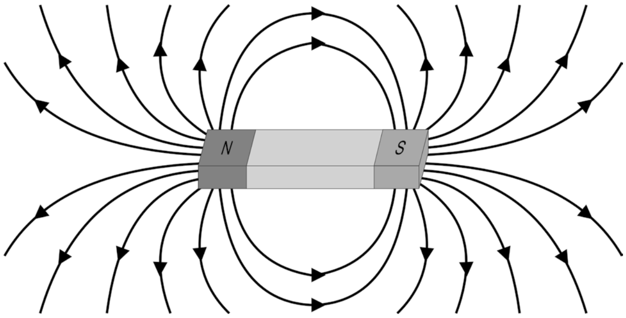


Fig. 5.3 Magnetic field due to bar magnet

The CGS unit of magnetic field is Gauss. The SI unit of magnetic field is Tesla. The magnetic field strength of earth is 3.05×10^{-5} Tesla

$$1\ Tesla = 10^4\ Gauss$$

5.1.3 Magnetic intensity

It is represented by H. The magnetic field intensity is the ratio of magnetic field with the permeability.

For free space $H = B/\mu_0$ ...(5.5)

Or $B = \mu_0 H$

The SI unit of magnetic intensity is Amp / meter

5.1.4 Magnetic lines of force

The magnetic force existing around the magnet can be explained in terms of the magnetic lines of force (Fig. 5.4). Magnetic field lines originate from the north pole and merge to the south pole of a bar magnet. They do not intersect each other and the strength of the magnetic field is defined as the number of lines of force passing through a unit area perpendicular to the field.

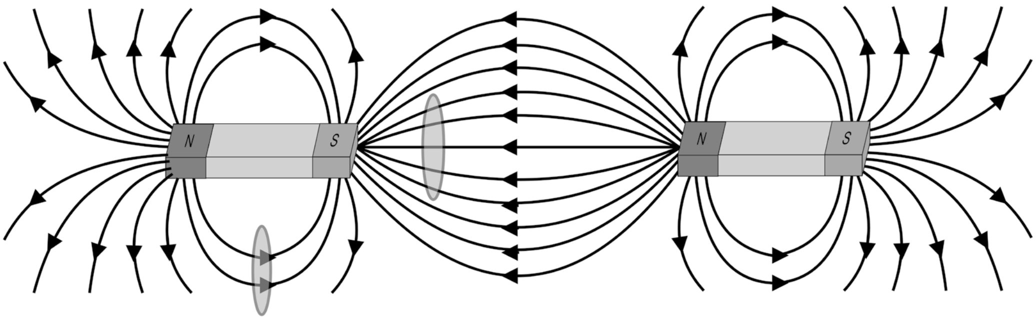


Fig. 5.4 Magnetic lines of force originating from bar magnet

5.1.5 Magnetic flux and units

In Fig 5.4, two surfaces of equal area have been drawn, one near to the pole and another at equidistance from the both poles. The no of lines passing through the surface near to the pole is more as compare to another surface. The number of magnetic lines passing though unit area is known as magnetic flux. It is clear from above figure that the magnetic flux will be more when magnetic field is more.

Mathematically $\textit{Magnetic flux} = \oint \vec{B}.\vec{ds}$ ...(5.6)

S I Unit of magnetic flux is Weber. The magnetic field B is also known as magnetic flux density and its unit is Weber/m^2 also, which is equivalent to Tesla.

5.1.6 Magnetization

When a magnetic material is placed in a magnetizing field, it gets magnetized. The magnetic moment developed per unit volume in magnetizing material is known as intensity of magnetization of magnetization or Magnetization (I)

$$I = M/V \qquad ...(5.7)$$

where, V is the volume of the material, with length 2l and area of cross section A

As Magnetic moment m × 2l { m is pole strength and 21 is length of magnet}

We can write Eq. 5.7 as,

$$I = m \times 2l/V = m/(V/2l) = m/A \qquad ...(5.8)$$

Thus, magnetization (I) can also be defined as the pole strength per unit area of cross section. The unit of I is Ampere / meter.

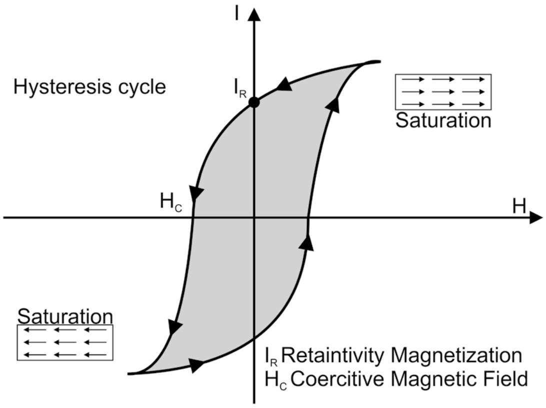


Fig. 5.5 Magnetization curve

The variation of I with H is known as magnetization curve. The diamagnetic, and paramagnetic materials have a linear relation between I and H curve and retain no magnetization when the field is removed. The ferromagnetic materials show nonlinear relationship curve between I and H. At large magnetic field when magnetization becomes constant is known as saturation (I_S). In ferromagnetic materials, I do not reduce to zero when applied field is removed and it is known as retentivity of material (I_R). The field has to be applied in opposite direction to remove the magnetization and this applied field is called coercive magnetic field (H_C).

5.2 CONCEPT OF ELECTROMAGNETIC INDUCTION

Activity

- Take a coil made up of copper wire. Connect the ends of coil to a galvanometer. Now bring a permanent magnet near to coil and move it inside and outside the coil. Observe the reading in galvanometer.

In unit 4, It is given that there is a heating effect when a current pass through a wire. Similarly, a current-carrying wire produces a magnetic field around the wire. When current flows through a wire wounded in the form of coil i.e. solenoid then magnetic field is developed around the solenoid and solenoid behaves like a bar magnet.

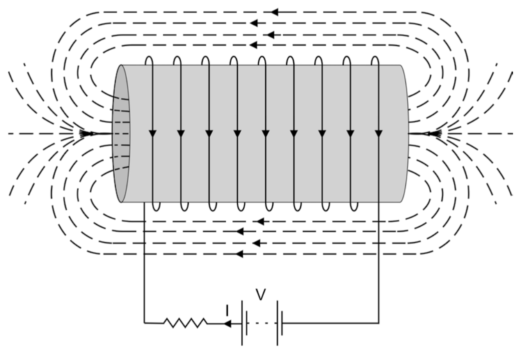


Fig 5.6 Magnetic field due to solenoid

On the other hand, if we bring a permanent magnet near a closed coil connected with galvanometer and move the magnet towards one of the ends of coil then electric current passes through the coil and deflection is observed in galvanometer. It demonstrates the presence of electric current due to movement of magnet. Hence electric current produces magnetic field and a moving manet produces electric current. This phenomenon is known as Electromagnetic induction.

5.2.1 Faraday's laws

In 1831, Michel Faraday has given two laws of electromagnetic induction. They are stated as follows:

I Law: "Whenever the magnetic flux linked with closed circuit changes, an emf is induced in the circuit, the induced emf persists only, as long as there is change in magnetic flux".

If we have a near by magnet and a coil and there is a relative motion between them that is either coil is moving, or magnet is moving. Due to relative motion of the coil, the coil cuts the magnetic flux coming out of the magnet and this produces an induced emf across the coil.

II Law:" The magnitude of the induced emf is proportional to rate of change of magnetic flux, linked with the closed circuit".

Mathematically, $emf(e) = -kd\phi / dt$

where, k is proportionality constant and negative sign indicates that the induce emf opposes the change of flux.

5.2.2 Lorentz force (force on moving charge in magnetic field)

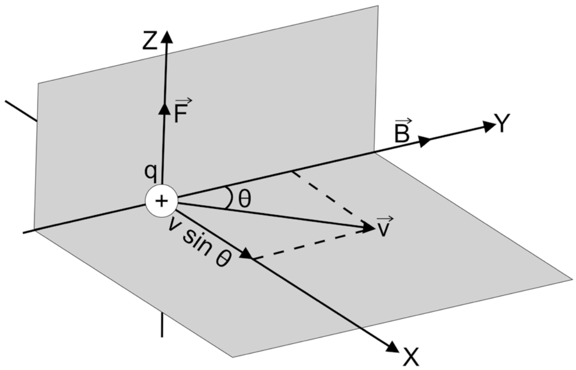


Fig. 5.7 Force on a moving charge in magnetic field

Let us consider a magnetic field (B) along y direction and a charge (q) moving in xy plane with velocity (v) making an angle θ with the direction of magnetic field. The moving charge will experience a force in the direction perpendicular to motion of charge and magnetic field. This force is known as Lorentz force.

The Lorentz force depends upon following factors

$$F \propto B$$

$$F \propto q$$

$$F \propto v \sin\theta \quad \{v \sin\theta \text{ is perpendicular component of velocity}\}$$

Hence $F = qvB\sin\theta$ ...(5.9)

In case if θ is 90 degree. $F = qvB$

Also Eq .5.9 can be rewritten as $\vec{F} = q(\vec{v} \times \vec{B})$

Case I: If a particle is moving in a direction parallel to magnetic field (θ = 0) then the magnitude of force will be 0.

Case II: If a particle is moving in a direction perpendicular to magnetic field (θ = 90), then the particle will move in circular path in a plane perpendicular to the direction of magnetic field. Also, if a particle is moving perpendicular to magnetic field than the force only changes the direction of motion of particle, the magnitude of velocity remain unaltered.

Case III: If a particle is moving in a direction, which is making angle with magnetic field, the particle will move in a helical path.

5.2.3 Force on current carrying conductor

In the above section, it has been explained that a moving charge experience Lorentz force in a magnetic field. As we know that the rate of flow of charge is current and If the current carrying conductor is kept in magnetic field it will also experience a force. To find the value of that force let us consider a current (I) is flowing is conductor of length (L) and area of cross section (A) with (n) no of charge per unit volume and placed in magnetic field (B). The force due to magnetic field in small length element dl will be given by Lorentz force,

$$dF = qvB\sin(\theta)$$

$$q \text{ is the charge in element} = (nAdl)e$$

$$v \text{ is the velocity of electron in element} = v_d \qquad \{\text{drift velocity}\}$$

θ is the angle between magnetic field and v_d

Force on current carrying conductor

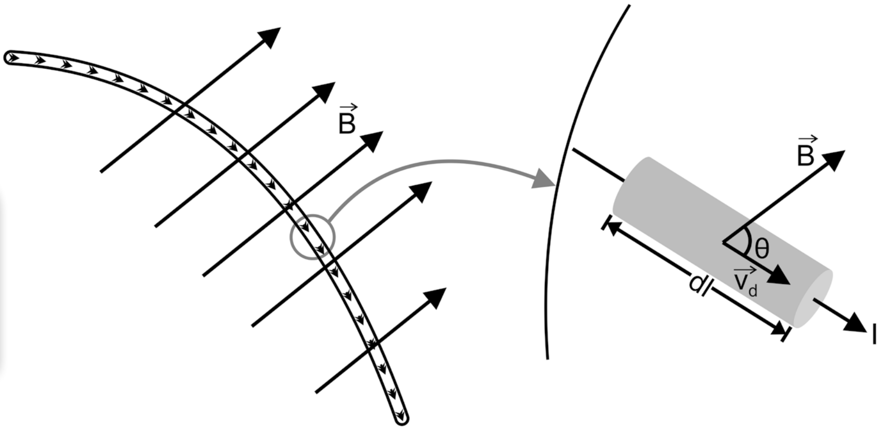


Fig. 5.8 Force on current carrying conductor

Hence

$$dF = (nAdl)e \times v_d \times B\sin(\theta)$$

$$dF = (nAe \times v_d)\, dl \times B\sin(\theta)$$

$$dF = I \times dl \times B\sin(\theta) \qquad [I = nAevd]$$

on integrating over complete length $\vec{F} = I(\vec{l} \times \vec{B})$ ...(5.10)

5.2.4 Force on rectangular coil placed in magnetic field

Let us consider a current carrying rectangular loop PQRS, placed in magnetic field. The direction of magnetic field and a current loop is such that the normal ($\hat{n}$) to the plane of loop making an angle θ with $\vec{B}$. As described in previous section there will be force in each side of current loop i.e., PQ, QR, RS and SP . Namely F_1, F_2, F_3 and F_4 respectively. For simplicity let us consider that the angle between $\hat{n}$ and $\vec{B}$ is zero then,

$$\vec{F_1} = I\left(l\left(-\hat{k}\right)\times B\hat{j}\right) = IlB(\hat{i})$$

$$\vec{F_1} = I\left(l\left(-\hat{k}\right)\times B\hat{j}\right) = IlB(\hat{i})$$

$$\vec{F_3} = I\left(l\left(\hat{k}\right)\times B\hat{j}\right) = IlB(-\hat{i})$$

$$\vec{F_4} = I\left(l\left(-\hat{i}\right)\times B\hat{j}\right) = IlB(-\hat{k})$$

Than resultant force on coil is zero and if the angle between $\hat{n}$ and $\vec{B}$ is 90° then,

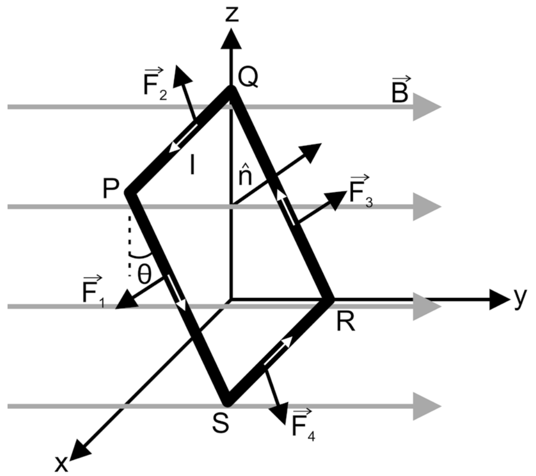


Fig. 5.9 Force on rectangular coil placed in magnetic field

$$\vec{F_1} = I\left(l\left(\hat{j}\right)\times B\hat{j}\right) = 0$$
$$\vec{F_2} = I\left(l\left(\hat{i}\right)\times B\hat{j}\right) = IlB(\hat{k})$$
$$\vec{F_3} = I\left(l\left(\hat{j}\right)\times B\hat{j}\right) = 0$$
$$\vec{F_4} = I\left(l\left(-\hat{i}\right)\times B\hat{j}\right) = IlB(-\hat{k})$$

Hence due to presence of two equal and opposite forces F_2 and F_4 acting in opposite direction a couple acts on the coil and produces torque (τ), causes the coil to deflect and is given by,

$$\tau = \textit{Force} \times \textit{perpendicular distance between the Forces}$$
$$\tau = IlB \times b$$
$$\tau = I(lb)B = IAB \quad \text{...(5.11)}$$

In vector form,
$$\tau = I(\vec{A}\times\vec{B}) \quad \text{...(5.12)}$$

The force is maximum when area vector $\vec{A}$ (normal to the plane of coil) and $\vec{B}$ are perpendicular, and it decreases as the angle between Area vector and $\vec{B}$ decreases.

5.2.5 Moving coil galvanometer: Principle, construction and working,

A galvanometer is a device for measuring small electrical currents. It is a device that gives a deflection in the magnetic needle whenever the current passes through it. Moving coil galvanometers are the most often used galvanometers for current measurement. It's an electromagnetic device that can detect electric currents as low as a few microamperes.

If a current carrying coil is placed in a magnetic field it experiences magnetic torque. The current through the coil is directly proportional to the angle through which coil is deflected due to magnetic torque.

Construction:

The moving coil galvanometer consists of a rectangular coil made of thin insulated copper wire, wounded on a metallic frame. The rectangular coil is free to rotate about a fixed axis. The coil is suspended freely in a uniform radial magnetic field through a phosphor-bronze strip, connected to a movable torsion head. To make the field radial cylindrical soft iron core is symmetrically positioned inside the coil to improve the strength of the magnetic field. The lower part of the coil is attached to a phosphor-bronze spring having a small number of turns. The other end of the spring is connected to binding screws. When we pass current in coil there will be oscillation and as per arrangement in this case the oscillation is damped oscillation as discussed in unit 1. The spring is used to produce a counter torque which balances the magnetic torque and hence helps in producing a steady angular deflection. A plane mirror which is attached to the suspension wire, along with a lamp and scale arrangement, is used to measure the deflection of the coil. Zero-point of the scale is at the center.

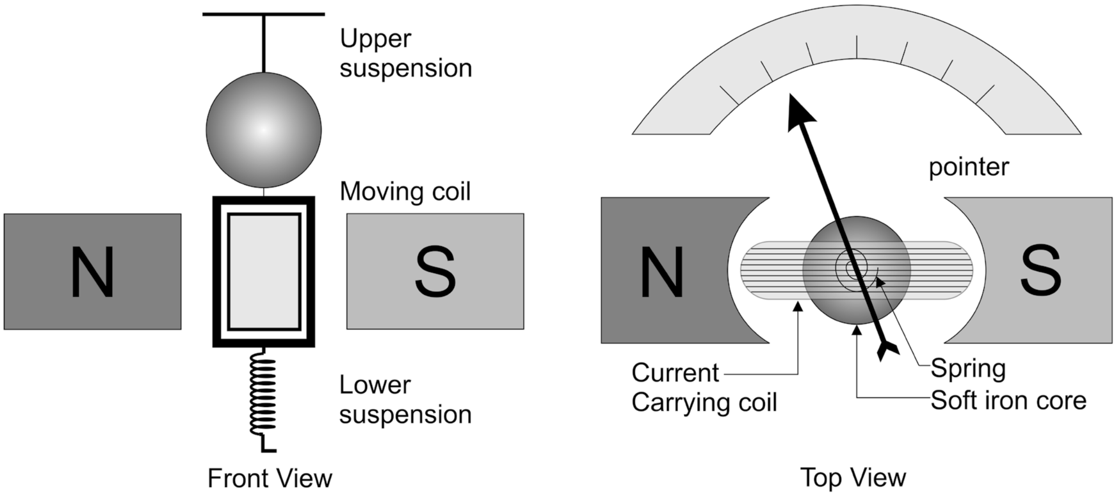


Fig. 5.10 Moving coil galvanometer

If a current I flows through a rectangular coil (Fig. 5.11) with a cross-sectional area of A and N turns. The coil receives a torque when it is put in a uniform radial magnetic field B. Consider a single turn 'PQRS' of a rectangular coil with a length of l and width of b. This coil is suspended in a magnetic field with a strength of B, with the coil's plane parallel to the magnetic field. Because the sides PQ and SR are parallel to the magnetic field's direction, as they do not experience any magnetic field's effective force. The sides PS and QR are perpendicular to the direction of field and experience an effective force F given by

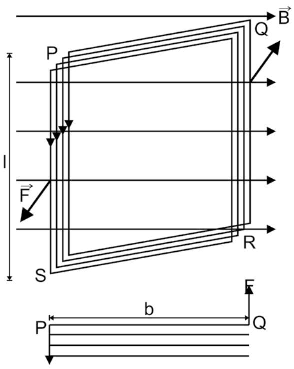


Fig. 5.11 Force on rectangular coil in moving coil galvanometer

$$F = BIl$$

Due to presence of two equal and opposite forces F couple, a couple acts on the coil and produces torque (τ), causes the coil to deflect and the torque acting on 'N' turns of the coil is given by

{using Eq. 5.11} $$\tau = NIAB \quad ...(5.13)$$

The coil rotates because of torque and the phosphor bronze strip twists. In turn, the spring S attached to the coil produces a counter torque or restoring torque kθ which results in a steady angular deflection. At equilibrium condition:

$$k\theta = NIAB \quad ...(5.14)$$

Here k is called as the torsional constant of the spring . The deflection or twist θ is measured as the value indicated on a scale by a pointer which is connected to the suspension wire.

$$\theta = (NAB / k)I \quad ...(5.15)$$

Therefore,

$$\theta \; \alpha \; I$$

The quantity NAB/k is a constant for a given galvanometer. Hence the deflection in galvanometer is directly proportional to the current that flows through it. The moving coil galvanometer is a highly sensitive instrument and is used to detect the presence of current in any given circuit. The galvanometer can be used to measure:

a) the value of current in the circuit by connecting a low resistance in parallel.

b) the voltage by connecting high resistance in series.

5.3 CONVERSION OF A GALVANOMETER INTO AMMETER AND VOLTMETER

Any galvanometer which we get in the market or available in laboratory has two specific parameters. The current Ig for full scale deflection (FSD) and resistance of galvanometer due to resistance of wire of coil. If we know these two parameters, we can convert galvanometer in to ammeter and voltmeter of given desired range.

(i) Conversion of galvanometer into ammeter

A galvanometer is converted into an ammeter by connecting a low resistance called as shunt parallel to galvanometer coil. Shunt resistance is selected as per requirement of the desired range of the ammeter and by connecting shunt the total resistance becomes very low, due to parallel combination of resistances. Ammeter is always connected in series to measure the electric current flowing in the circuit. The current passing though ammeter is divided into two parts: Ig passes through galvanometer coil and remaining current (I-Ig) passes through shunt , as given in Fig . 5.13. The voltage across the galvanometer and shunt resistance is equal, due to the parallel connection. Therefore,

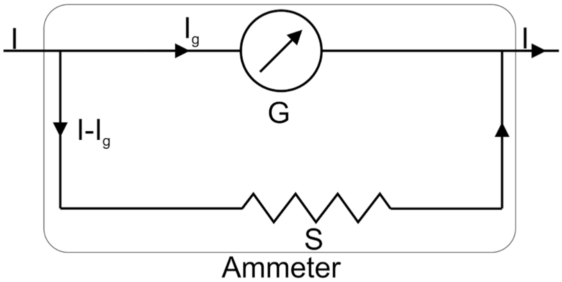


Fig. 5.12 Conversion of galvanometer into ammeter

$$G I_g = (I - I_g)S$$

or $$S / G = I_g / (I - I_g) \quad ...(5.16)$$

Where, G – Resistance of the galvanometer coil, I – Total current passing through the circuit, I_g – Total current passing through the galvanometer which corresponds to full-scale reading or full-scale deflection, S – Value of shunt resistance.

Whenever we connect shunt to galvanometer, maximum current passes through the shunt and low current passes through the galvanometer. The deflection in galvanometer is an indication of current in the circuit. The resistance of ammeter is very low and for ideal ammeter the resistance should be zero.

Example: If we have a galvanometer of 25 (I_g) micro ampere FSD and having resistance 1500 Ohm (G). If we have to convert it in to ammeter of 2.5 ampere (I) then the shunt resistance will be,

$$S = G \times I_g / (I - I_g) = 1500 \times (25 \times 10^{-6}) / (2.5 - 25 \times 10^{-6})$$

$$\Rightarrow \quad S = 1500 \times \{(25 \times 10^{-6}) / 2.5\}$$

$$\Rightarrow \quad S = 15000 \times 10^{-6} = 15 \times 10^{-3} = 15 \text{ milliohm}$$

(ii) Conversion of galvanometer into voltmeter

A galvanometer is converted into a voltmeter by connecting high resistance in series. As voltage across two parallel point is same, hence voltmeter is always connected in parallel to the component in a given circuit, whose voltage we have to measure. A suitable high resistance is selected, depending on the range of the voltmeter. In the given circuit, G = Resistance of the galvanometer, R = Value of high resistance,

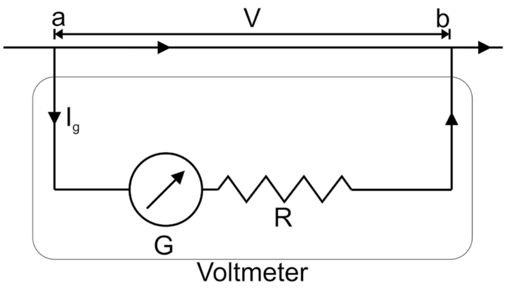


Fig. 5.13 Conversion of galvanometer into voltmeter

I = Total current passing through the circuit, I_G = Total current passing through the galvanometer which corresponds to a full-scale deflection, V = Voltage drops across the series connection of galvanometer and high resistance.

When current I_g passes through the series combination of the galvanometer and the high resistance R; the voltage drop across the branch ab is given by:

Galvanometer to voltmeter

$$V = G.I_g + R.I_g$$
$$V/I_g = G + R$$
$$R = (V/I_g)\text{-}G$$

The value of R can be obtained using the above equation.

Example: If we have a galvanometer of 25 (I_g) micro ampere FSD and having resistance 1500 Ohm (G). If we have to convert it in to voltmeter of 2.5 Volt (I) then the series resistance will be,

$R = \{2.5 / (25 \times 10^{-6})\} - 1500$

$R = 100000 - 1500 = 98{,}500$ Ohm = 98.5 Kiloohm

EXAMPLE 5.1

Ques. A point charge of 2.5C is moving perpendicular to magnetic field of 10 amp / meter with a velocity 20 m / s. Find the Lorentz force acting on charge of a charge.

Solution:

Given q = 2.5 C, B = 10 amp / m and v = 20 m/s

As . F = q v B sin (θ) = q v B {As θ = 90°}

F = 2.5 × 10 × 20 = 500 N

EXAMPLE 5.2

Ques. Find the force on a current carrying conductor of length 20 cm having current 5 A and the magnetic field 4 Amp / meter. The angle between magnetic field and direction of current is 45°.

Solution:

Given l = 0.2m, I = 5 A and B = 4 A/m

As F = BIL sin θ,

F = 4 × 5 × 0.2 × sin (45°) = 2.8 N

EXAMPLE 5.3

Ques. A rectangular loop of size 20 cm × 40 cm is placed in uniform vertical magnetic field of 0.60 Weber / m^2 . Find the flux when the plane of loop is (a) vertical and (b) horizontal.

Solution:

The flux passing through the loop is $\phi = B\,A\cos(\theta)$

Where θ is the angle between normal to loop and magnetic field

For (a) θ = 90° as the normal to the loop is perpendicular to magnetic field

Hence $\phi = 0$

In (b) θ = 0° as the normal to the loop is parallel to magnetic field

Hence $\phi = 0.60 \times 0.2 \times 0.4 = 4.8 \times 10^{-2}$ weber

Ques. When a shunt of 3 ohms is attached to a Galvanometer, the deflection reduces to 1 / 10th. If an additional shunt of 3 ohms is added. Find reduction in the deflection.

Solution:

Given S = 3 ohm, $I_g / I = 1 / 10$

As, $I_g / I = S / (S + G)$

$\Rightarrow 1 / 10 = 3 / (3 + G)$

$\Rightarrow 3 + G = 30$

$\Rightarrow G = 27$ ohms

Now If we add Additional shunt 3 ohm than the new shunt (S') will be

$1 / S' = 1 / 3 + 1 / 3 = 2 / 3$

$\Rightarrow S' = 3 / 2$

Now reduce in current will be

$I_g / I = S' / (S' + G)$

$\Rightarrow I_g / I = 3 / 2 / \{(3 / 2) + 27\}$

$\Rightarrow I_g / I = 3 / 2 \times 2 / 57$

$\Rightarrow I_g / I = 1 / 19$

EXAMPLE 5.4

UNIT SUMMARY

- The ratio of magnetic field to magnetic field intensity is magnetic permeability.
- Magnetic flux passing through a surface is equal to the product of magnetic field , area of surface and cos of the angle between magnetic field and normal to the surface.
- Direction of Lorentz force is perpendicular to the direction of motion of electron and magnetic field.
- A changing electric field produces magnetic field and vice versa.
- Galvanometer is converted into voltmeter by adding large resistance in series.
- Galvanometer is converted into ammeter by adding shunt in parallel.

EXERCISES

Multiple Choice Questions

5.1 When a material is used in a magnetic field B, a magnetic moment proportional to B but oppo site in direction is induced. The material is

a. Diamagnetic
b. Paramagnetic
c. Ferromagnetic
d. Antimagnetic

5.2 Out of the following ………………… is ferromagnetic material

a. Aluminum
b. Quartz
c. Nickel
d. Bismuth

5.3 The unit of Magnetic permeability is

a. henry / metre
b. henry
c. henry / sq. m
d. It is dimensionless

5.4 A conductor of length 'L' has current 'I' passing through it, when it is placed parallel to a magnetic field. The force experienced by the conductor will be

a. Zero
b. BLI
c. B^2LI
d. BLI^2

5.5 Out of the following, select a vector quantity

a. Relative permeability
b. Magnetic field intensity
c. Flux density
d. Magnetic potential

5.6 Strength of magnetic field is also known as

a. Flux
b. Density
c. Magnetic strength
d. Magnetic flux density

5.7 Find the Lorentz force acting on a particle having charge 1C and velocity of 2m / s, moving in a perpendicular magnetic field of magnitude 2 Tesla.

a. 2 N
b. 4 N
c. 6 N
d. 1 N

Answers of Multiple Choice Questions
5.1 (a), 5.2 (c), 5.3 (a), 5.4 (a), 5.5 (b), 5.6 (d), 5.7 (b)

Short and Long Answer Type Questions

Category-I

1. Differentiate between Dia, para and ferromagnetic materials with examples.
2. Explain the concept of magnetic field with mathematical relation and diagram.
3. Write SI unit of magnetic field and find its dimensional formula.
4. Describe the term Magnetic intensity. Give its relation with magnetic field.
5. Explain Magnetic flux with diagram. Write the equation relating magnetic field and magnetic flux. Give units of Magnetic flux.

6. Explain Faraday' s law of electromagnetic induction with suitable diagram.
7. If a charge is moving in perpendicular magnetic field. Derive equation for the Lorentz force acting on Charge particle.
8. Derive a relation for Force acting on:
    a. Current carrying conductor
    b. Rectangular coil placed in uniform magnetic field.
9. Explain construction and working of moving coil galvanometer.
10. Explain the method to convert galvanometer to ammeter and voltmeter.
11. A square loop of size 40 cm × 40 cm is placed in uniform vertical magnetic field of 10 Weber/m^2. Find the flux when the normal to the plane of loop is making 45° with magnetic field.
12. A galvanometer has a resistance of 40 Ohm and a current of 1 mA is required for full scale deflection. Calculate the resistance required to convert the galvanometer in to:
    a. Ammeter of 500 mA range
    b. Voltmeter of 2 V

PRACTICAL

There are three laboratory experiment(s) which are related to this unit

- To find the resistance of a galvanometer by half deflection method.
- To convert a galvanometer into an ammeter.
- To convert a galvanometer into a voltmeter.

Practical – 11 Half deflection method

P11.1 Practical Statement

To find resistance of a galvanometer by half deflection method.

P11.2 Practical Significance

A galvanometer is a sensitive electrical device for measuring small electrical currents. It gives a deflection whenever the current passes through it. The internal resistance of galvanometer is an important parameter and it is used to convert galvanometer into voltmeter and ammeter. This experiment helps student to find resistance of galvanometer.

P11.3 Relevant Theory

For half deflection method following circuit is made:

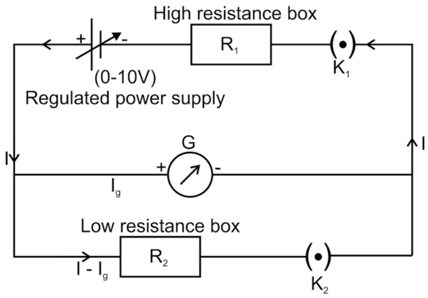


Fig P11.1

When R_1 is connected in circuit (K_1 is closed) and R_2 is not added (or K_2 is open) then current I_1 passing through the circuit and through galvanometer also is

$I_1 = E/(R_1 + G)$, where G is resistance of galvanometer

Now K_2 is closed and R_2 is adjusted such that the deflection in galvanometer is half or the current in galvanometer is $I_1' = I_1/2$ and current (I_2) in circuit is given by,

$I_2 = E/[R_1 + GR_2/(G + R_2)]$

Also, $GI_1' = R_2(I_2 - I_1')$

Hence, $I_1' = I_2R_2/(G + R_2)$

On simplifying

$I_1' = ER_2/[R_1(R_2 + G) + R_2G]$

As $I_1' = I_1/2$

$ER_2/[R_1(R_2 + G) + R_2G] = E/[2(R_1 + G)]$

On simplification

$G = R_1R_2/(R_1 - R_2)$

P11.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use half deflection method to find the resistance of a given galvanometer

P11.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

As given in Section P11.3 of this experiment

P11.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	Moving coil galvanometer	01			
2	DC power supply (0-10 V)	01			
3	Resistance box – Range 0 - 10 kΩ	01			
4	Resistance box – Range 0 – 200 Ω	01			
5	One way key	02			

P11.7 Precautions

1. Connections should be tight and clean.
2. Remove parallax while reading galvanometer.
3. The current in galvanometer should not be increased above full scale deflection (FSD) of galvanometer.

P11.8 Suggested Procedure

1. Make circuit as per the circuit diagram in Fig. P11.1
2. From the high resistance box (1-10 kΩ), remove 10 kΩ key and close the key K_1

3. Adjust the resistance R_1 from this resistance box to get FSD on the galvanometer.
4. Note the value of resistance R_1.
5. Insert the key K_2.
6. Adjust the value of R_2, such that the deflection is exactly half as observed in step 3.
7. Note down the value of R_2 and remove plug K_2.
8. Repeat the steps from point number 3 to 7 by changing R_1 (The deflection may be less than FSD).

P11.9 Observations and Calculations

Least count of voltmeter = ... FSD of galvanometer = ... DC supply Voltage = ...V

Sr. No	R_1 (ohms)	R_2 (ohms)	$G = R_1R_2/(R_1 - R_2)$
1			
2			
3			
4			
5			

Mean G=.........

P11.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P11.11 Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P11.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Can we measure the figure of merit of galvanometer by this experiment?.
2. Give the reasons for error in the present experiment.

P11.13 Suggested Learning Resources

- http://www.olabs.edu.in/?sub=1&brch=6&sim=152&cnt=2

P11.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of resistance of galvanometer		
3	Selection of R_1 and R_2		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 12 - Galvanometer to ammeter

P12.1 Practical Statement

To convert a galvanometer into an ammeter.

P12.2 Practical Significance

Ammeter is a current measuring device and is connected in series to measure the current of given circuit. A moving coil galvanometer can be converted into ammeter of desired range by adding shunt. In this experiment the students will convert the given galvanometer into ammeter.

P12.3 Relevant Theory

Refer: Section 5.3 of this unit

P12.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Convert a given galvanometer into ammeter of desired range.

PrO2: Make measuring instrument as per requirements.

P12.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

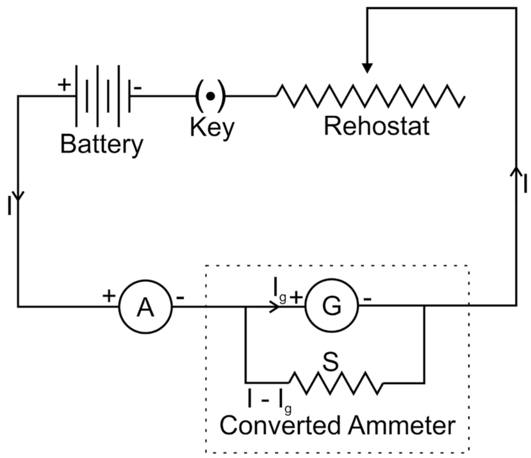


Fig P12.1

P12.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	A Galvanometer	01			
2	Shunt resistance/ low resistance box	03			
3	DC power supply (0-10V) and Connecting wires	01			
4	Ammeter (0-1 A)	01			
5	Rheostat and a key	1 each			

P 12.7 Precautions

1. Connections should be tight.
2. Handle the instrument carefully.
3. Rating of shunt resistance should be taken care off.

P 12.8 Suggested Procedure

1. Note FSD of Galvanometer.
2. Measure the internal resistance of galvanometer with multimeter.
3. Calculate the shunt resistance theoretically for desired ammeter (say 500mA)
4. Connect the shunt (low resistance box) parallel to galvanometer.

5. Make connection as per circuit diagram in Fig P12.1.
6. Note the reading in standard ammeter and the converted ammeter.
7. Adjust the shunt in case of difference between the readings of both meters.
8. Vary the current in the circuit and note readings from the meters.

P12.9 Observations and Calculations

FSD of galvanometer : .... internal resistance of galvanometer : ....

Theoretical calculation for shunt

Sr. No	Galvanometer converted into ammeter reading (I)	Ammeter reading (I')	Error = I' – I
1			
2			
3			
4			
5			

Value of shunt by experiment..........

P12.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P12.11 Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P12.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Predict the change in converted ammeter, if shunt is increased.
2. Give Least count of given voltmeter.
3. Give reasons to use additional ammeter in circuit.

12.13 Suggested Learning Resources

- http://amrita.olabs.edu.in/?sub=1&brch=6&sim=26&cnt=4basics

12.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Theorityical calculation of shunt		
3	Adjust shunt from resistance box		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. **Marks Awarded**			**Signature of Teacher with date**
Process Related	Product Related	Total	

Practical 13 - Galvanometer to voltmeter

P13.1 Practical Statement

To convert a galvanometer into a voltmeter.

P13.2 Practical Significance

Voltmeter is a voltage measuring device and is connected in parallel to measure the voltage between two points of given circuit. A moving coil galvanometer can be converted into voltmeter of desired range by adding high resistance in series. In this experiment the students will convert the given galvanometer into voltmeter.

P13.3 Relevant Theory

Refer: Section 5.3 of this unit

P13.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Convert a given galvanometer into voltmeter of desired range.

PrO2: Make measuring instrument as per requirements.

P13.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

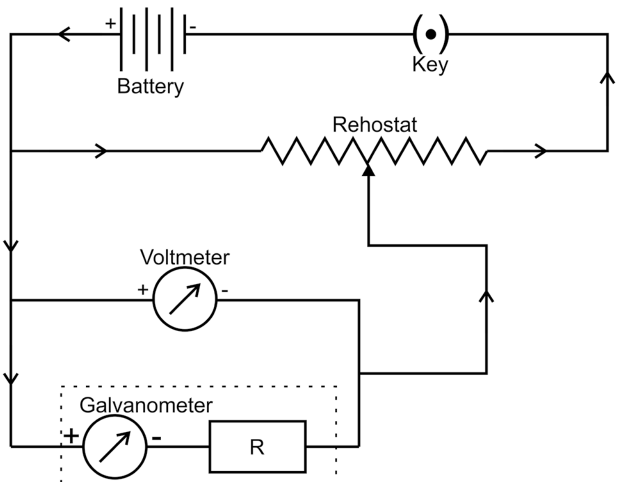


Fig P13.1

P13.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/ Tools/ Instruments with broad specifications (to be filled by the student)		Re-marks (if any)
			Make	Details	
1	Galvanometer	01			
2	High resistances/ high resistance box	01			
3	DC power supply (0-10V) and Connecting wires	01			
4	Voltmeter (0-10 V)	01			
5	Rheostat and a key	1 each			

P13.7 Precautions

1. Connections should be tight.
2. Handle the instrument carefully.

P13.8 Suggested Procedure

1. Note FSD of Galvanometer.
2. Measure the internal resistance of galvanometer with multimeter.
3. Calculate the high resistance theoretically for desired voltmeter (say 5V)
4. Connect the high resistance (high resistance box) in series to galvanometer.
5. Make connection as per circuit diagram in Fig P13.1.

6. Note the reading in standard voltmeter and the converted voltmeter.
7. Adjust the high resistance in case of difference between the readings of both meters.
8. Slide the variable arm of rheostat and change the voltage across galvanometer.
9. Measure the voltage with both meters (converted voltmeter and voltmeter).

P13.9 Observations and Calculations

FSD of galvanometer

Sr. No	Galvanometer converted into Voltmeter reading (V)	Voltmeter reading (V')	Error = V' – V
1			
2			
3			
4			
5			

Theoretical calculation for high resistance

Value of high resistance by experiment..........

P13.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P13.11 Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P13.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Predict the change in converted voltmeter, if the series high resistance increased or decreased.
2. Give Least count of given voltmeter.
3. Give reasons to use additional voltmeter in circuit.
4. Give reasons to add the voltmeter in parallel.

P13.13 Suggested Learning Resources

- https://www.robolab.in/conversion-of-galvanometer-to-voltmeter/

P13.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of high resistance		
3	Adjust high resistance from resistance box		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. **Marks Awarded**			**Signature of Teacher with date**
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course

- Difference between analog and digital device
- Superconducting magnets.
- Magnetic field measuring instruments.

Applications

- Lorentz force is applied to move particle in circular motion in accelerator.
- Galvanometer is sensitive device used to measure low currents.

Use of ICT

The student can visit the following url for simulation in electromagnetism

- https://phet.colorado.edu/en/simulation/faradays-law

Faraday's Law

Design innovative Practical /Projects/ Activities

- Prepare model to demonstrate electromagnetic induction to glow LED.
- Prepare model to demonstrate Faraday's law with magnet and galvanometer.

Inquisitiveness and Curiosity Topics

- Earth's magnetic field and earth as Magnet.
- Superconducting magnets
- Can we have Gauss Law in magnetism also?

REFERENCES & SUGGESTED READINGS

- H C Verma, "Concepts of physics" 1st ed., vol. 1, Bharti Bhawan, 1992
- Richard Feynman et al "The Feynman lectures on Physics", 6th ed. vol1, Addison-Wesley, 1963
- R K Gaur and S L Gupta "Engineering Physics", 8th ed., Dhanpat Rai, 201
- Resnick Halliday and Krane, "Physics" 5th ed. vol1,Wiley, 2014
- https://phys.libretexts.org

6 Semiconductor Physics

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- Classification of solids based on band theory
- Intrinsic and extrinsic semiconductors
- pn junction diode
- Formation of depletion layer
- Forward and reverse bias characteristics of diode
- Application of diose as rectifier
- Transistor and its applications
- Photocell and solar cell

Applications of semiconductor physics in daily are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. After the related practical, based on the content, there is a suggested micro project activity which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book.

Industrial applications and real life applications on variety of aspects and inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Semiconductors materials are used in all the electronics and electrical devices which we are using in household, offices and industries. Silicon is a type of semiconductor material, which is used for making the IC's, which is the basic requirement to make computers, mobile and other electronic devices. As a diploma engineer of any branch it is required to have knowledge of semiconductors and semiconductor devices. This unit will help the students to apply the basic concepts of semiconductor physics and devices in various engineering applications.

PRE-REQUISITES

- **Mathematics:** Algebra

- **Physics:** Conductance, Ohm's law, Kirchhoff law, Transformer, Center tape transformer.
- **Other's:** Basic technology of computer and use of mobile application.

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U6-O1: Distinguish between metal, semiconductors and insulators based on band theory of solids.

U6-O2: Differentiate between extrinsic and intrinsic semiconductors.

U6-O3: Use diode as half wave and full wave rectifier.

U6-O4: Explain the working of transistors and its types.

U6-O5: Explain working principle of photocells and solar cells.

Unit-6 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U6-O1	-	-	1	1	-	3
U6-O2	-	-	1	1	-	3
U6-O3	1	-	1	1	1	3
U6-O4	-	-	1	1	1	3
U6-O5			1	1	1	3

6.1 ENERGY BANDS IN SOLIDS

In previous Units 4 and 5, the materials introduced are conductors for flowing current, magnetic materials for producing magnetic fields and Insulators as dielectric in capacitors in Unit 3. In the present unit semiconducting materials are discussed in detail. Solid state materials can be divided in three categories as per their conductivity, namely insulator, semiconductor and conductor. The variation in electrical conductivity, even if the state of matter is the same, has been a question of research since the inception of observations of physical phenomena related to conductivity, heat conductance and magnetism.

Free electron theory proposed for the said question gives explanation mainly for metallic properties but not able to explain all the three types of solids. Band theory of solid based on quantum mechanics is the theory presently used by scientists and theoreticians working in the field of solid states.

As a learner you are aware of discrete energy states available for electrons in an isolated atom say 1 s 2s 2p 3s and so on. The picture of energy levels will be quite different when a large number of atoms are surrounded, to an atom.

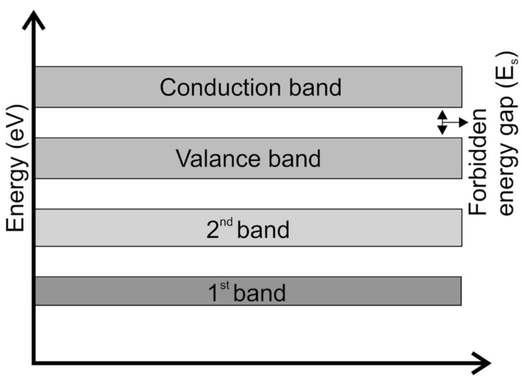


Fig 6.1 Energy bands in solids

Let us try to find how many numbers of atoms surround one atom? As per molar concept, 1 mole of any substance consists of N = 6.023×10^{23} (Avogadro number) of atoms and molecules. Hence 18 grams of water or 28 grams of silicon consists of N molecules of water or N atoms of silicon respectively. 1 gm of silicon consists of N/28 atoms. In such atoms the energy levels are not sharp but each level is divided in N levels as per the Band theory of solids. These energy levels form energy band known as energy bands in solids

As displayed in Fig. 6.1, each level, 1s 2s 2p… are divided into numbers of levels and band of energies is available for electrons. Fig 6.1 is a simplified form of actual diagram of energy vs momentum of electrons in solids. The y axis corresponds to the variation of energy in electron volt (1 eV = 1.6 × 10^{-19} J).

The top most filled band is known as the valence band and the energy band available after the valence band is the conduction band. The electrons bound to the atoms will remain in the valence band and in all the other bands having energy less than the valence band. The electrons detached from atoms and moving freely in the solids are free electrons. The conduction band contains such free electrons, also known as conduction electrons.

6.2 TYPES OF MATERIALS (INSULATOR, SEMICONDUCTOR, CONDUCTOR)

Based on conductivity solids can be classified in three categories namely conductor semiconductor and insulator. Based on theory of energy bands, they can also be classified as follows:

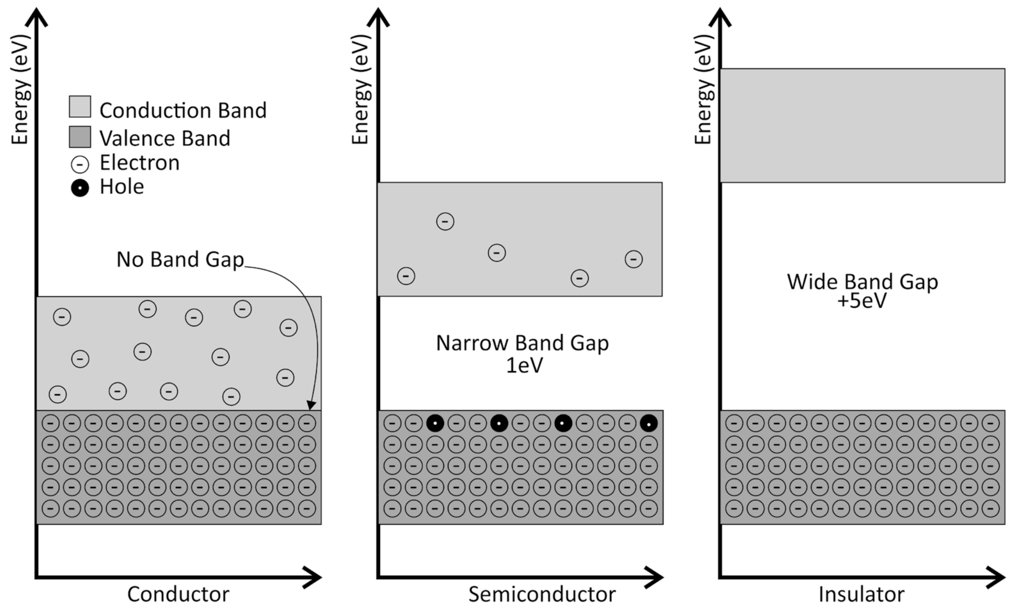


Fig 6.2 Energy band diagram for conductor, semiconductor and insulator

- The energy difference between the top energy level of the valence band and lowest energy level of conduction band is the energy gap.
- The number of electrons available in the conduction band of material decides the conductivity of that material.
- In metals the valence band and the conduction band overlaps. The electron available in the valence band requires very less energy to transit from valence band to conduction band. In conductors large number of electrons are available in conduction band. The conductivity in conductors decreases with increase in temperature as it increases the electron collisions.
- In semiconductors there is a small energy gap between the valence band and the conduction band and it is of the order of **1eV**. The electron available in the valence band transits to the conduction band through thermal agitations. The number of electrons in the conduction band in

semiconductors are less, hence the conductivity of semiconductors is less. The conductivity in semiconductors increases with increase in temperature as it increases the number of electrons in the conduction band.

- In insulators there is a large energy gap between the valence band and the conduction band of the order of **6eV**. No electrons are available in the conduction band and it requires a large amount of energy for the valence band electrons to transit in the conduction band. Hence the conductivity of the insulator is almost zero.

6.3 INTRINSIC AND EXTRINSIC SEMICONDUCTORS.

The elements such as silicon (Si) and germanium (Ge) in group IV A of the periodic table are natural semiconductors and called as intrinsic semiconductor.

Si and Ge are semiconducting materials in elemental state. Si and Ge are tetravalent, having four electrons in the valence shell. Each atom forms a covalent bond with other four neighboring atoms and there is no free electron at 0^0 K. At 0^0 K intrinsic semiconductor are insulators and as we increase temperature, due to thermal excitation the valence bond breaks and as per energy band diagram the electron from valence band transit to conduction band. Leaving a vacancy of electrons known as 'holes' in the valence band. In Intrinsic semiconductor there are two types of mobile charge carriers that are electrons and holes. Both are equal in number. The number of electrons in the conduction band depends upon the temperature. If temperature increases the number of electrons and holes increases. The atomic arrangement and energy band diagram for Si and Ge is given in Fig. 6.4.

Semiconductors

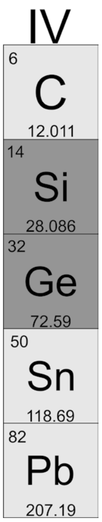


Fig 6.3 Fourth group of periodic table

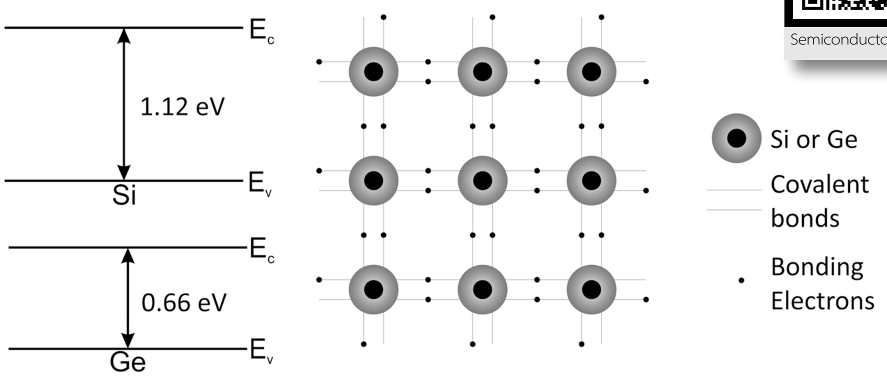


Fig 6.4 Covalent bond in Si and Ge

The band gap of Si and Ge is 1.12 and 0.66 eV respectively. The Ge is more sensitive to temperature as compared to Si. Hence the device made up of Ge are more temperature sensitive, this the reason most of the semiconductor devices are made up of Si.

At normal temperature that is 27 ^{0} C or 300 K, the thermal energy of maximum number of electrons is ½ kT, where k is Boltzmann constant and T is temperature in absolute scale is 0.0026 eV, hence very few electrons have energy equal to or more than band gap energy , which will jump to **conduction** band. Therefore, the conductivity of semiconducting material is very low at room temperature.

In intrinsic semiconductors

$n = p = n_i$ & $np = n_i^2$ {under thermal equilibrium}

where, n= concentration of conducting electron and p = concentration of holes

The value of ni for Silicon at T = 300°K is 1.5 × 1010 cm^{-3}

As, pure semiconductor has very low conductivity at room temperature and If we want to increase conductivity the temperature has to be increased, which is not a feasible solution. To increase conductivity of semiconductor material at room temperature, other elements are added as impurity. Such semiconductors are known as extrinsic semiconductors.

The process of adding an impurity element in a pure semiconductor element is known as doping. The doping concentration is 1 part per million or 1 ppm. For every 1 million (10^6) atoms of silicon , one atom of impurity element is added. There are two types of extrinsic semiconductors:

Note : By adding 1ppm impurity atoms, the total number of impurity atom in one gram silicon will be: 28 grams of silicon contains— 6.023×10^{23} atoms

1 gm of silicon contains—(6.023×10^{23}/ 28) atoms

If we add impurity 1 ppm then,

Number of impurity atoms—(6.023×10^{17}/ 28)atoms ~ 10^{17} atoms impurity in one gram.

p type semiconductors: When trivalent element is added as impurity in pure semiconductors, then the semiconductor is known as p type semiconductor. The elements of group III such as Aluminum, boron and indium are added as impurity for p type semiconductors. In p type semiconductors, the impurity atom is surrounded by four silicon atoms. The trivalent impurity atom has three valence electrons and forms covalent bonds with three Si atoms and one valence electron of fourth silicon atom remains unpaired. This unpaired electron of Si is attracted by trivalent impurity atoms and creates vacancy of electron in silicon atom i.e. hole. The trivalent impurity atoms act as immobile negative ions as they accept one electron and are known as acceptors. There are few additional holes and electrons due to thermal excitation also. Hence in p type semiconductors we have three types of charge carriers, majority of holes, minority electrons and immobile negative ions.

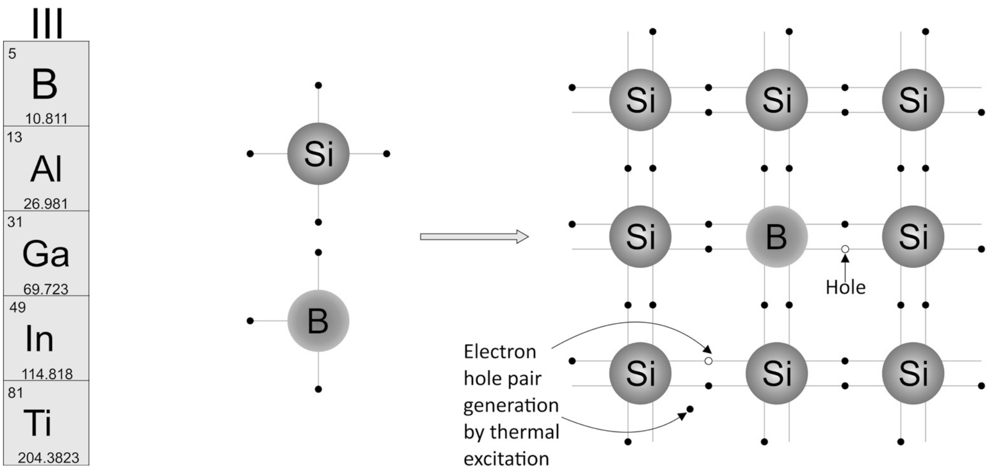


Fig 6.5 p type semiconductor

n type semiconductors: When a pentavalent element is added as impurity in pure semiconductors, then the semiconductor is known as n type semiconductor. The elements of group V such as phosphorous, Arsenic and Antimony are added as impurity for n type semiconductors. In n type semiconductors, the impurity atom is surrounded by four silicon atoms. The pentavalent impurity atom has five valence electrons and forms covalent bonds with four Si atoms and the fifth valence electron remains unpaired.

This unpaired electron of impurity is detached from the impurity atom and creates free electrons. The pentavalent impurity atoms act as immobile positive ions as they have donated one electron and are known as donors. There are few additional holes and electrons due to thermal excitations also. Hence in n type semiconductors we have three types of charge carriers, majority of electrons, minority holes and immobile positive ions.

In extrinsic semiconductors $n_o \times p_o = n_i^2$

where, n_o= concentration of conducting electron and p_o= concentration of holes

In p type semiconductors $p_o >> n_o$ and in n type semiconductor $n_o >> p_o$

Note : Learners should have a clear understanding that p and n type semiconductors are neutral. Overall sum of positive and negative charge in p and n type semiconductors is zero.

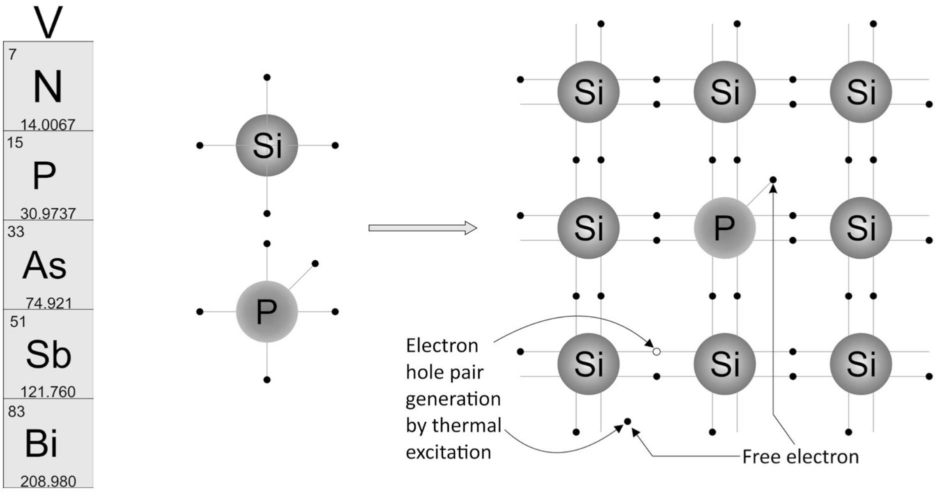


Fig 6.6 n type semiconductor

6.4 p-n JUNCTION

In the previous section, the p and n type of semiconductors materials have been introduced. When we make a junction of p and n type of materials by means of a special fabrication method, then this junction is known as p-n junction as shown in Fig 6.7. The junction is made such that there is no physical gap between two materials and mobile charge carriers can diffuse from one region to another. In p-n junction the majority and minority charge carriers diffuse from n region to p region and vice versa.

Say for majority charge carriers, the electron diffuses form n to region p and holes from region p diffuses to region n. Due to this diffusion, holes and electrons neutralize each other near the junction. There is depletion (shortage) of mobile charge carriers in the junction. A layer is formed at a junction and is known as depletion layer. In the depletion layer due to loss of majority charge carriers in n and p there will be immobile negative ions in p and immobile positive ions in n. This layer of ions creates an electric field directed from n to p. As the field in the region starts developing, the diffusion rate

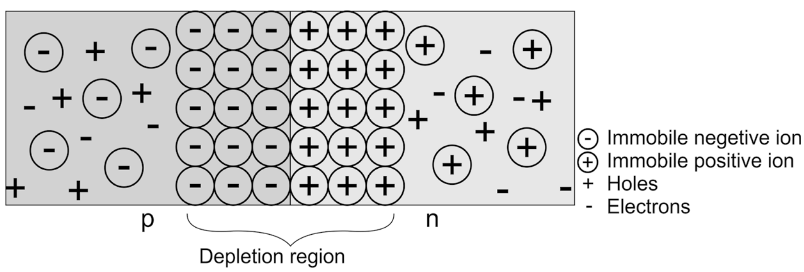


Fig 6.7 Depletion region in pn junction

decreases, as the force due to electric field on holes is in the direction of electric field and on electrons in the direction opposite to electric field. The diffusion will cease when the field sufficiently develops to stop the motion of holes and electrons. A potential is developed and is known as potential barrier or depletion potential. Charges can travel from one region to another only if they have sufficient energy to overcome the potential barier. The p region is at higher potential than the n region in the depletion layer.

6.5 JUNCTION DIODE AND V-I CHARACTERISTICS

If we add two metallic terminals at two open ends of p-n junction through ohmic contact (no resistance between metallic wire and semiconductor), than this two terminal device, used in circuits is known as p-n junction diode. It is represented by symbol given in Fig. 6.8 (b).

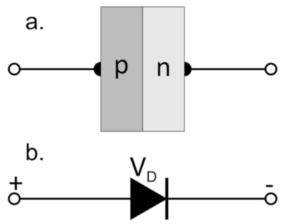


Fig 6.8 pn junction diode and its symbol

When supply is not connected across the diode, no current flows through it. External biasing or supply is required to flow the current through the diode. There are two ways in which external DC supply can be connected to diode.

Forward biasing: When positive terminal of the battery or DC power supply is connected to p and negative terminal of battery or DC power supply is connected to n, then this biasing is known as forward biasing.

Note : A resistance should be connected in circuit to control the current.

Reverse biasing: When positive terminal of the battery or DC power supply is connected to n and negative terminal of battery or DC power supply is connected to p. then this biasing is known as reverse biasing.

In forward biasing, the electric field due to external supply is opposite to the field developed across the junction. When a diode is forward biased, it does not start conduction instantaneously, but after a particular forward voltage, current flows through diode and this particular voltage is known as knee voltage. The knee voltage of Si and Ge diode is 0.7 V and 0.3 V respectively. When a diode is in forward bias, the voltage across diode will be equal to its knee voltage. The current (I_D) flows in forward bias is of the order of milliampere. The direction of flow of current across diode in forward bias is from p to n.

In reverse biasing, the electric field due to external supply is in the direction of the field that develops across the junction. Due to reverse bias voltage, height of potential barrier and width of depletion layer increases. Majority charge carrier cannot cross the junction but minority charge carrier i.e. holes in n type and electrons in p type can cross the junction and very small amount of current flows through diode. This current is of the order of micro ampere (10^{-6} Ampere) and its value does not increase or decrease with reverse bias voltage. This current is known as reverse saturation current (I_S). The direction of current across diode in reverse bias is from n to p. Hence the reverse bias V-I characteristics is drawn in III quadrant.

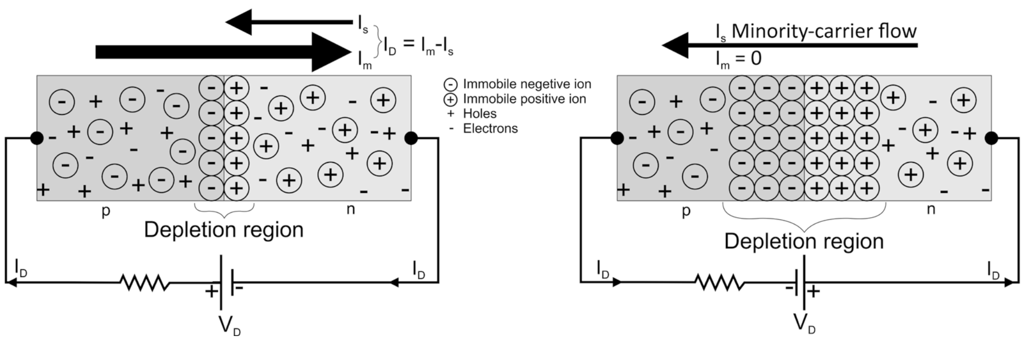


Fig 6.9 (a) Diode in forward and reverse bias

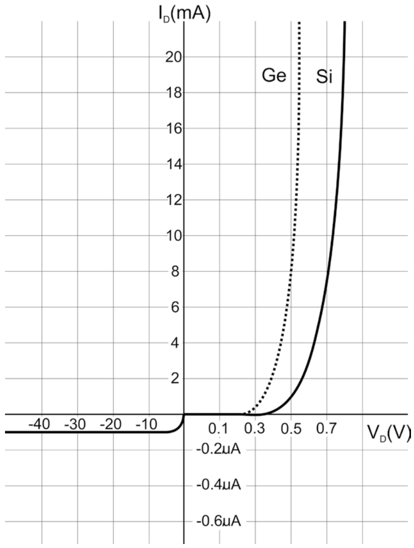


Fig 6.9 (b) Forward and reverse bias characteristics

Ideally the resistance of diodes in forward bias is zero and very high in reverse bias. The diode can be considered as short when used in forward bias and open when used in reverse bias.

6.6 TYPES OF JUNCTION DIODE

The junction diode can be classified by the V-I characteristics and working, which depends on following factors:

a. Doping concentration
b. Semiconductor material used
c. Construction
d. Type of junction material

Doping Concentration:

If the doping concentration more than 1ppm then the diode is known as a highly doped diode. one example of a highly doped diode is the Zener diode. Due to increase in doping the depletion layer of such diodes is very thin as compared to normal junction diodes. Zener diodes can be used as voltage regulator.

Semiconductor material used :

In place of silicon or Germanium, if we use compound semiconductors such as GaAs, then the working of junction diodes depends upon the material used. The diodes made up of GaAs are used as Light emitting diode (LED) and photodiode. The LED in forward bias is used as an indicator and conversion of electrical signal into optical signal. Photodiodes are used in reverse bias to convert optical signals into electrical signals.

Construction:

Working of junction diodes depends on its construction also. If the thickness of p and n side of junction is different say the p side is very thin as compared to n side or vice versa. Such types of junction are used to construct solar cells, which convert optical energy into electrical energy.

Type of junction material:

In place of semiconductor - semiconductor junction, metal – semiconductor junction is used to form a junction diode. Schottky diode is an example of metal semiconductor junction., which is used in power electronic circuits.

6.7 DIODE AS RECTIFIER

The supply which we get in our house is AC supply also known as AC mains. Most of the devices and electronics circuits work on DC supply. There is a need to convert AC into DC for a number of applications.

As from the V-I Characteristics of junction diode, it is clear that the diode conducts current, when used in forward bias. This can be applied to design a circuit to convert the AC voltage into DC voltage, known as rectifier. If we use AC voltage supply in place of DC voltage supply in Fig. The diode will be in forward bias during positive cycle of AC and reverse bias in negative cycle of AC.

Half wave rectifier

In a Half wave rectifier, a step down transformer is used to scale down the AC voltage (say from 220 V to 12V), this AC signal is given to a circuit where a diode is connected in series with resistance (R). The diode will be in forward bias for one half cycle and in reverse bias in another half cycle. The voltage across the diode in forward bias is low (equal to knee voltage), then the total voltage will appear on Resistance R as per Kirchhoff's law. In reverse bias no current or very less current will flow, hence the voltage across resistance R is very low and all the voltage will appear on diode. Fig 6.10(a) Shows the circuit of the Half wave rectifier. The input and output waveform is also displayed in Fig 6.10(b). The voltage appearing on the R is variable DC voltage and further given to filter circuits to convert variable DC into constant DC

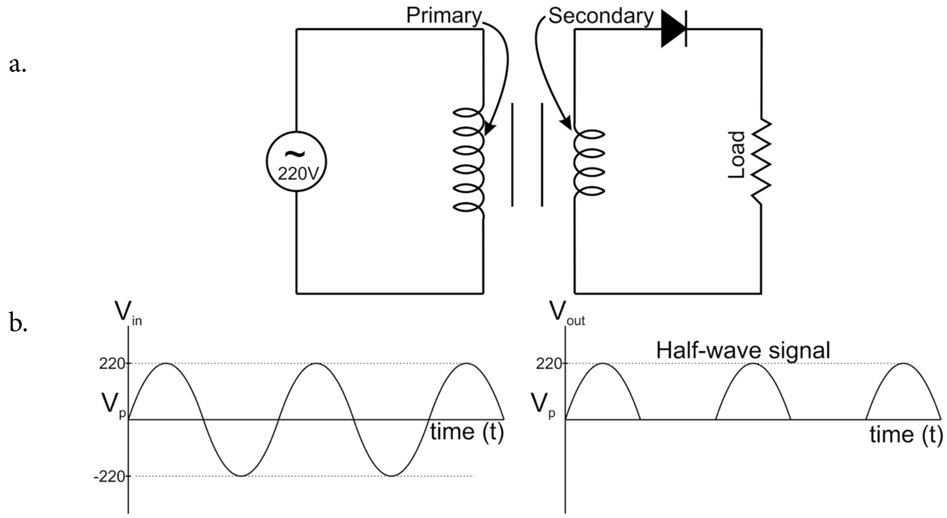


Fig 6.10 Half wave rectifier

Full wave rectifier (center taped)

In a Half wave rectifier, only one-half cycle is used to convert AC signal to DC signal. If we use a center tapped step down transformer and two diodes then a full wave of AC can be rectified. In a full wave rectifier, the AC signal is given to a circuit with two diodes and one load resistance (R). In the first Half cycle, the first diode is in forward bias and the second diode is in reverse bias. The situation will be reversed In next half cycle. The voltage will appear across resistance R in both half cycles. Fig 6.11 (a)Shows the circuit of full wave rectifiers. The input and out waveform is also displayed in Fig 6.11(b). The voltage appearing on the R is variable DC voltage and further given to filter circuits to convert variable DC into constant DC.

a.

b.

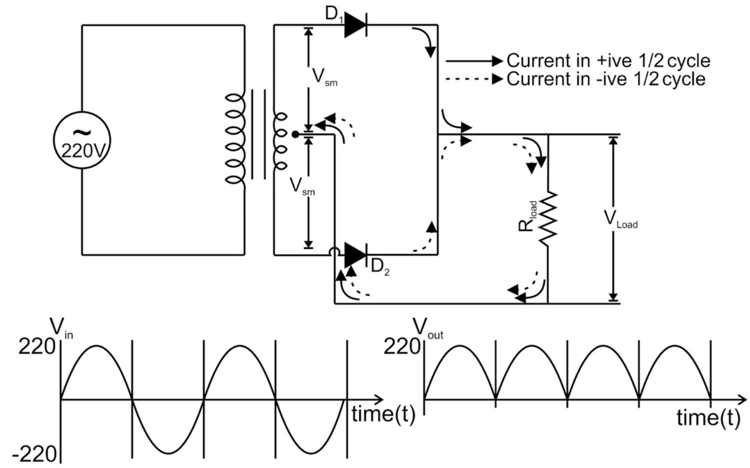


Fig 6.11 Full wave rectifier

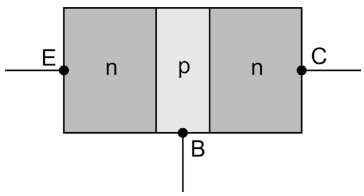
6.8 TRANSISTOR

A transistor is a three-terminal device, it consists of two p-n junctions, which is created by either keeping n type material in between two p type material regions or p type material in between two n type regions. Unlike diodes the thickness of n and p regions is different. The three terminals of transistors are known as base, emitter and collector. The doping of the base region is low as compared to the emitter and collector region. The thickness of the base region is also less as compared to emitter and collector. There are two p-n junctions formed in transistors namely emitter- base junction and collector- base junction. For normal working of transistors the emitter- base junction is kept in forward bias and collector-base junction in reverse bias. As we know, for a junction the resistance is low in forward bias and high in reverse bias. The current passing through the emitter and collector is the same and it sees different resistance in the emitter base region and collector base region, hence there is transfer of resistance, therefore this device is known as a transistor.

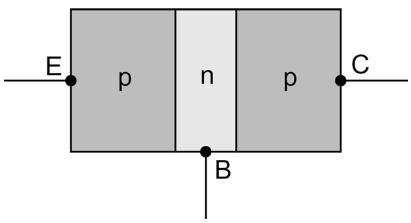
6.9 TYPES OF TRANSISTORS

There are two types of transistor

- **npn:** emitter and collector is n type and base is p type



- **pnp:** emitter and collector is p type and base is n type



Symbols of pnp and npn transistors

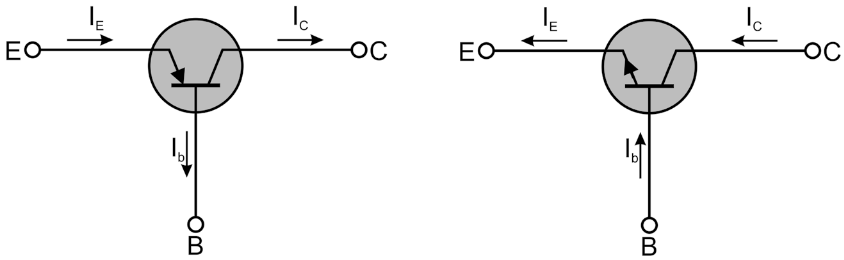


Fig 6.12 npn and pnp transistor and their symbols

Operation of transistors:

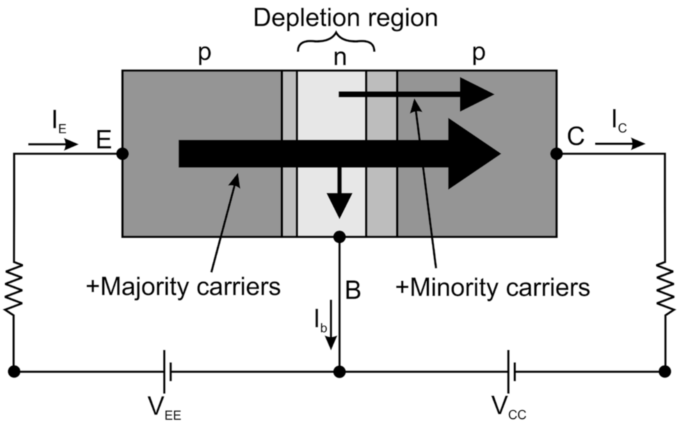


Fig 6.13 Operation of transistor

As discussed earlier, for a transistor biasing the emitter- base junction is kept in forward bias and Collector base junction is kept in reverse bias. As from junction characteristics, when a junction is in forward bias the voltage across the diode is of the order of 0.7 volt (if Si is used) and current is in milliampere and in reverse bias the current is in micro ampere and the junction voltage is equal to the applied voltage. In transistor, emitter current flows from emitter to base and as the base junction is very thin, very small base current flows from base and maximum part of emitter current flows through the collector. Large current flows across the collector - base junction, which is having more voltage (V_{CC}), hence power is amplified in transistors.

$$I_e = I_c + I_b$$

$$I_e \sim I_c$$

6.10 SOME ELECTRONIC APPLICATIONS OF TRANSISTOR

- Voltage amplifier
- Current amplifier
- As a switch
- For designing different types of logic gates circuits
- As basic building block of operational amplifier

6.11 PHOTOCELLS

Photoconductive materials are semiconductors whose conductivity increases in the presence of photons. The electron in the valence band absorbs photons and jump to the conduction band. As a result the number of electrons in the conduction band increases in the presence of photons or light. GaAs is an example of photoconductive materials.

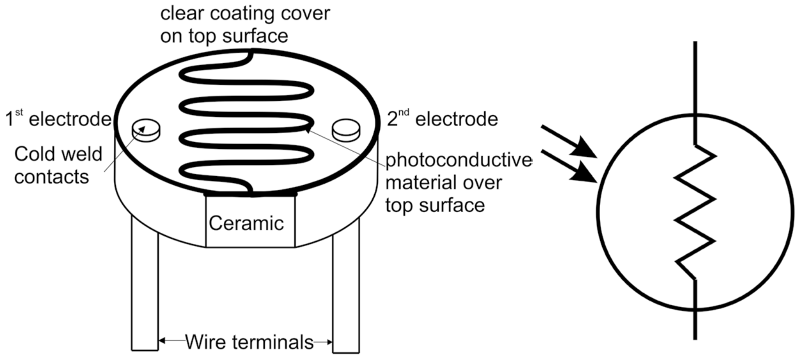


Fig 6.14 Photocell

A photoconductive cell is a two terminal semiconductor device, the resistance between terminals varies with the intensity of light. The fig 6.14 shows the construction of a photocell. Photoconductive materials used in photocell are CdS and CdSe. The photocell does not have a junction like other junction devices such as photodiodes. A thin layer of the photoconductive material is deposited on a ceramic substrate. Two metal terminal are connected at the ends of thin layer to connect photoconductive cell in circuit. The resistance of a thin layer of material, typically is of the order of 100 k Ohm and reduced to 100 Ohms when illuminated with light. It can be used for number of applications as follows:

- Automatic Headlight Dimmer
- Night Light Control
- Street Light Control

6.12 SOLAR CELLS

A solar cell is also a junction device, which is used to convert light energy into electrical energy. The schematic of the solar cell is given in Fig 6.15. The n region of the solar cell is thin as compared to the p region unlike normal p-n junction diodes. This junction is kept in light in a way that the n region is exposed to light. The valence band electron absorbs photons and moves into the conduction band. Due to this a large number of free electrons and holes are available in n region. As the n layer is very thin, the depletion layer electric field separates the holes and electrons and forces electrons to remain in the n region and diffuse the holes in the p region . A positive potential is developed at p and negative potential is developed at n terminal and current will flow when an external resistance is added between p and n terminal. The voltage developed across terminals without load is known as open circuit voltage (V_{OC}) is of the order of 0.5 V and the maximum load current also known as short circuit current (I_{SC}) is of the order of few mA, which increases as the intensity of light increases and absorption of photons in solar cell increases. The direction of current inside solar cell is from n to p, hence the V-I characteristics is drawn in IV quadrant.

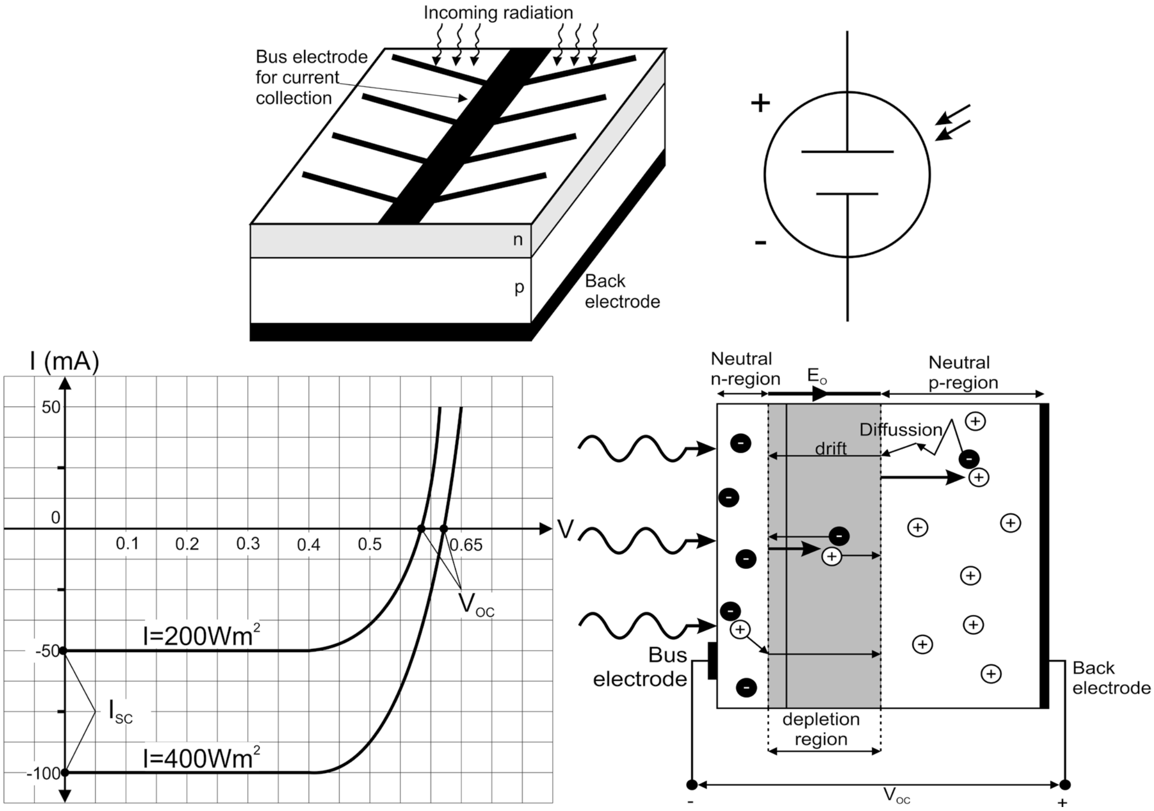


Fig 6.15 Solar cell : construction, symbol and V-I characteristics

Application of solar cell

The voltage developed across solar cells and the maximum load current which can be drawn from solar cells is not enough to run any device, therefore series and parallel combinations of solar cells are used for practical purposes and are known as solar panels. Solar panels has number of engineering applications:

- Power generation
- Water filtration plant
- Solar chargers

EXAMPLE 6.1

Ques. Find the number of pentavalent (Arsenic) ions in 1 gram of Silicon, when 1.2 ppm is doping concentration

Solution:

28grams of silicon contains = 6.023×10^{23} atoms of Si

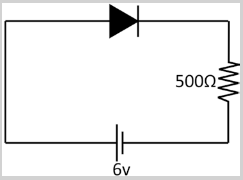
1 gm of Si contains = $6.023 \times 10^{23} / 28$ atoms of Si = 2.15×10^{22} atoms

Now doping concentration is 1.2 ppm it means for every 1.2 million atoms of silicon there is one Arsenic (As) atom

Number of As atoms in one gram of silicon = $2.15 \times 10^{22} / 1.2 \times 10^{6} = 1.79 \times 10^{16}$ atom/positive ions

EXAMPLE 6.2

Ques. Find the current in the following circuit, if the Si diode is used and its knee voltage is 0.7 V?



Solution:

Given $V_d = 0.7$ V as diode is in forward bias

As per Kirchhoff Law-- $6V = V_d + Vr$

$Vr = 6 - 0.7 = 5.3$ V

The voltage across the resistance is 5.3 V

Hence current in the circuit I = 5.3/500 = 0.0106 A = 10.6 mA

UNIT SUMMARY

- In semiconducting material there is small energy gap between Valence band and conduction band.
- In intrinsic semiconductors trivalent and pentavalent impurities are added to increase conductivity at room temperature.
- Diode can be used for half and full wave rectification.
- Diode and Transistor are basic building blocks of electronic circuits.
- Solar cell is basic building block of solar panel which converts light energy into electrical energy.

EXERCISES

Multiple Choice Questions

6.1 The band gap of Ge semiconductors is

a. 0.5eV
b. 0.7eV
c. 2.1eV
d. 1.2eV

6.2 The following types of charge is NOT present in p type semiconductors

a. Immobile positive ions
b. Immobile negative ions
c. mobile holes
d. mobile electrons

6.3 Select the correct statement

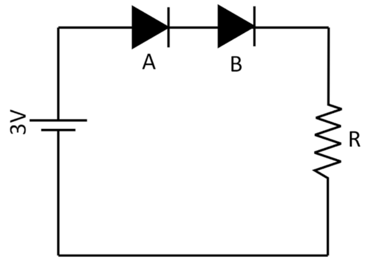
a. No current flows across diode used in reverse bias.
b. Same current flows across diode in reverse bias and forward bias.
c. Small current flows across diode used in reverse bias due to minority charge carriers.
d. Small current flows across diode used in reverse bias due to majority charge carriers

6.4 The V-I characteristics of solar cell is drawn in

a. I quadrant

b. II quadrant
c. III quadrant
d. IV quadrant

6.5 Find the voltage across R in following circuit if Ge diode is used ($V_D = 0.3V$)



a. 3V
b. 2.7V
c. 0V
d. 2.4V

Answers of Multiple Choice Questions
6.1 (b), 6.2 (a), 6.3 (c), 6.4 (d), 6.5 (d)

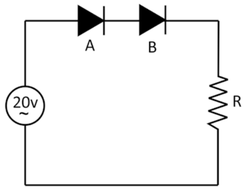
Short and Long Answer Type Questions

Category-I

1. Write the names of any five semiconducting materials.
2. Give two examples each of trivalent and pentavalent impurities.
3. Distinguish between conductors, semiconductors and insulators on the basis of band theory of solids.
4. Differentiate between extrinsic and intrinsic semiconductors on any four points.
5. Differentiate between p and n type extrinsic semiconductors on any four points.
6. Explain the p-n junction in detail with diagram. Describe depletion layer.
7. Explain the working of p-n junction diode and draw its current voltage (I-V) characteristics.
8. Define the term knee voltage. Write the value of knee voltage for Si and Ge diode.
9. List applications of diodes based on its V-I characteristics.
10. Draw circuit diagram for half wave rectifier and explain its working with input and output wave form.
11. Draw circuit diagram for full wave rectifier (center taped) and explain its working with input and output wave form.
12. Explain the construction and working of Transistor with suitable diagram.
13. Explain types of transistor with symbol.
14. Explain working principle of photoconductive cell.
15. Explain working principle of Solar cell with diagram
16. Give two applications of Solar cell in daily life.

Category-II

1. Draw the output wave forms at point A and B in following circuit, (the diodes used in circuit are Silicon diodes – (Vd = 0.7 V)



2. Giver reasons to draw the V-I characteristics of solar cell in IV quadrant.

PRACTICAL

There are two laboratory experiment(s) which are related to this unit

- To draw V-I characteristics of a semiconductor diode (Ge, Si) and determine its knee voltage.
- To verify inverse square law of radiations using a photo- electric cell.

Practical 14 - V-I Characteristic of diode

P14.1 Practical Statement

To draw V-I characteristics of a semiconductor diode (Ge, Si) and determine its knee voltage.

P14.2 Practical Significance

p-n junction diode is used in rectifier, clipping, clamping and voltage multiplier circuits. Diode is also used in designing logic circuits. The V- I characteristics of diode decides its working and applications. In this lab experience, students will determine the forward bias and reverse bias characteristics and also determine the knee voltage

P14.3 Relevant Theory

Refer: Section 6.4 of Unit 6

P14.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Determine V-I Characteristics of Si/Ge diode.

PrO2: Find the knee voltage of Si/Ge diode.

P14.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

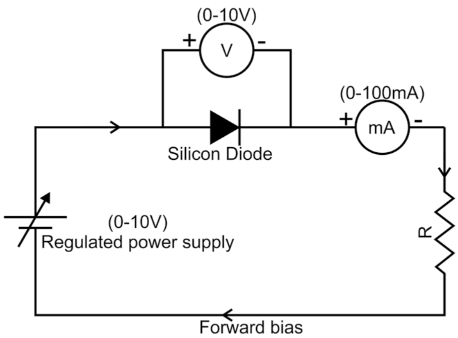


Fig P14.1

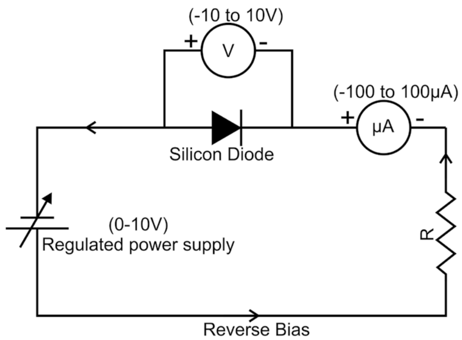


Fig P14.2

P14.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	DC power supply (0-10V)	01			
2	Voltmeter (0-10V)	01			
3	Ammeter (0-100 mA)/(0±100 μA)	02			
4	Resistor (100 ohm, 1 kohm)	2			
5	Connecting wires				

P14.7 Precautions

1. Connections should be tight.
2. Handle the instrument carefully.
3. The current flowing through the diode should not exceed the maximum current as per specifications of diode.
4. Connect voltmeter and Ammeter as shown in the circuit diagram.

P14.8 Suggested Procedure

Forward bias characteristics

1. Connect the p-n Junction diode (Si/Ge) in forward bias as shown in Fig. P14.1.
2. Vary the supply voltage (V_s) in steps of 0.1V.
3. Note the voltage across diode (Vd)
4. Note the corresponding values of forward bias current (I_D).
5. Plot a graph of forward current (I_D) Vs forward voltage (V_D)
6. Find the voltage on x- axis where the forward current (I_D) increases rapidly.
7. Note this voltage as the knee voltage or cut in voltage of the diode.

Reverse bias characteristics

8. Connect the p-n Junction diode (Si/Ge) in reverse bias as shown in Fig. P14.2.
9. Vary the supply voltage (V_s) in steps of 0.5 V.
10 Note the voltage across diode (V_R)
11 Note the corresponding values of reverse current (I_s).
12. Plot a graph of reverse current (I_s) and V_R.

P14.9 Observations and Calculations

LC of Voltmeter = ... LC of ammeter = ...

Table 1

Sr. No	Forward Voltage (V_D) (volts)	Forward current (I_D) (mA)
1		
2		
3		
4		
5		
6		

Table 2

Sr. No	Reverse Voltage (V_R) (volts)	Reverse current (I_S) (μA)
1		
2		
3		
4		
5		
6		

P14.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P14.11Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P14.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give the ideal value of knee voltage for the Si and Ge diode used.
2. Give the steps to identify the p and n terminals of diode using multimeter.
3. Give reasons for using micro ammeter in a reverse bias mode.
4. State the specifications of diode used in this lab experiment.

P14.13 Suggested Learning Resources

- http://www.olabs.edu.in/?sub=1&brch=6&sim=233&cnt=4

P14.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	Measurement of Forward and reverse bias current and voltages.		
3	Plotting graph and finding knee voltage		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

Practical 15 - Inverse square law of radiation

P15.1 Practical Statement

To verify inverse square law of radiations using a photo-electric cell.

P15.2 Practical Significance

A photoconductive cell is a two terminal semiconductor device, the resistance between terminals varies with the intensity of light. It is used for number of applications such as Automatic Headlight Dimmer, Night Light Control and Street Light Control. This experiment will help students to find the variation of Intensity with distance of between light source and photo-electric/ photoconductive cell.

P15.3 Relevant Theory

Refer: Section 6.4 of Unit 6 for photoconductive cell.

The intensity (I) of the light source at point 'O' to an observer at point 'P' from a source is inversely proportional to the square of the distance between the observer and source. In case of photoconductive cell, the intensity of light falling on cell decides the magnitude of photocurrent passing through the photo cell. Hence the magnitude of photocurrent also inversely proportional to square of the distance between source and photocell.

$I \alpha 1/d^2$

P15.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Find relation between the intensity of light radiation with distance.

P15.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

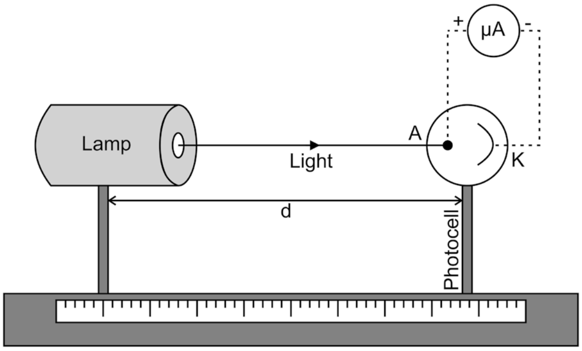


Fig P15.1

P15.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	DC power supply (0-10V)	01			
2	Photocell	01			
3	Ammeter 0-100 μA	01			
4	Connecting wires, meter scale				

P15.7 Precautions

1. Connections should be tight.
2. Handle the instrument carefully.
3. Stray light should be avoided on photocell.
4. The photocell and lamp should be in line and vertical.

P15.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P15.1
2. Keep lamp and photo cell at distance. (d = 12 cm)
3. Switch on the lamp.
4. Note the current in ammeter.
5. Keeping lamp/cell at fix point, decrease the distance between lamp and cell and note change in current.
6. Repeat the step 5 for five times.
7. Plot a graph of current (I) Vs $1/d^2$

P15.9 Observations and Calculations

LC of ammeter = …………… Position of photocell = ……… cm (x_1)

Sr. No	Position of lamp (x_2)	$d = x_1 - x_2$	I in Circuit (micro Ampere)	$1/d^2$
1				
2				
3				
4				
5				

Plot Graph between I v/s $1/d^2$

P15.10 Results and/or Interpretation

(to be filled by student)

1. ……………………………………………………………………………………………………
2. ……………………………………………………………………………………………………

P15.11Conclusions and/or Validation

(to be filled by student)

1. ……………………………………………………………………………………………………
2. ……………………………………………………………………………………………………

P15.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Explain the concept of solid angle in present experiment.
2. Give the source of errors in present experiment.
3. State the specifications of photocell used in this lab experience.
4. State the current in the circuit when there was no light on photocell.

P15.13 Suggested Learning Resources

- https://vlab.amrita.edu/index.php?sub=1&brch=195&sim=840&cnt=1

P15.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Making of electrical connection		
2	set up of experiment		

3	Plotting graph		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to Practical related questions		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			**Signature of Teacher with date**
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course:

- Direct and indirect Bandgap semiconductors.
- Compound semiconductors.
- Filter circuits.

Use of ICT

The student can visit the following url for simulation in semiconductors

- http://www.olabs.edu.in/?sub=1&brch=6&sim=233&cnt=4

Design innovative Practical /Projects/ Activities

- Design a half wave rectifier with low frequency and low voltage source using diode and display out put in galvanometer or LED.
- Design logic gates using diodes.
- Find Open circuit voltage and short circuit current of a solar cell.

Inquisitiveness and Curiosity Topics

- Does diode always conduct in forward bias?
- Reason for adding III and V group elements only to intrinsic semiconductors.
- Applications of pn junction diode when used in reverse bias.
- Methods for making p-n junctions in industries.
- Does reverse saturation current varies with temperature?

REFERENCES & SUGGESTED READINGS

- H C Verma, "Concepts of physics" 2st ed., vol. 1, Bharti Bhawan, 1992.
- Richard Feynman *et al* "The Feynman lectures on Physics", 6th ed. vol1, Addison-Wesley, 1963.
- R K Gaur and S L Gupta "Engineering Physics", 8th ed., Dhanpat Rai, 2011.
- Resnick Halliday and Krane, "Physics" 5th ed. vol1, Wiley, 2014.
- Robert L Boylestad and L Nashelsky," Electronic Devices and circuit Theory", 10 edition, Prentice Hall, 2009.

7 Modern Physics

UNIT SPECIFICS

This unit is concentrated on the following main aspects:

- LASER
- Difference between laser and ordinary light
- Interaction of radiation with matter
- Necessary conditions to produce lasers
- Components of Laser
- Ruby, He-Ne and diode laser
- Optical fiber and its types
- Nano particles and nanomaterials
- Nanotechnology Introduction
- Applications of Lasers, optical fiber and nanotechnology.

Applications of lasers, optical fibers and nanotechnology in daily are discussed for creating interest and activities are suggested for comprehension of topics. Application based solved problems, multiple-choice questions and questions of lower and higher order cognitive level of Bloom's taxonomy are given in the unit so that one can go through them for practice, which will help in reinforcement of learning. QR codes of video links have been provided for various topics which can be scanned for relevant supportive knowledge.

QR codes for simulation of concepts and principles are also provided in the unit, so that students can do hands-on practice to simulate the available simulation model. The students can vary the different parameters in simulation model for in depth understanding of topic. Micro project activity is suggested which will help in attaining course outcomes. The "Know More" section has been judiciously designed so that the supplementary information provided in this part becomes beneficial for the users of the book. Industrial applications and real life applications on variety of aspects, inquisitiveness and curiosity topics are also included in the unit to motivate learner for future learning.

RATIONALE

Lasers, optical fibers and nanotechnology are the recent advancements in physics in last century. Applications of lasers, optical fibers and nanotechnology can be found in every discipline of engineering. As a diploma engineer of any branch it is required to have knowledge of the relevant applications of laser, optical fiber and nanotechnology. This unit will help the students to comprehend the basic concepts of laser, fiber optics and nanotechnology.

PRE-REQUISITES

- **Mathematics:** Algebra, Trigonometry
- **Physics:** Energy band gap, Energy levels, Atomic energy levels, Ray optics, Total internal reflection, p-n junctions
- **Other's:** Basic technology of computer and use of mobile application

UNIT OUTCOMES

List of outcomes of this unit are as follows:

U7-O1: Differentiate between spontaneous and stimulated emission of light radiation.

U7-O2: Explain the construction and working of Ruby, He- Ne and Diode laser.

U7-O3: Find numerical aperture of a given fiber.

U7-O4: Explain the propagation of light in different types of optical fibers.

U7-O5: Explain nanotechnology and change in properties of materials at nanoscale.

U7-O6: Comprehend the engineering applications of Laser, Fiber optics and Nanotechnology.

Unit-7 Outcome	EXPECTED MAPPING WITH COURSE OUTCOMES					
	(1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U7-O1	1	-	1	1	-	3
U7-O2	1	-	1	1	-	3
U7-O3	-	1	-	-	-	3
U7-O4	-	1	-	-	-	3
U7-O5	1	-	-	-	1	3
U7-O6	1	1	1	1	1	3

7.1 LASERS

Interesting fact

- Concept of LASER was given by Einstein in the early of 20^{th} century but the first LASER was demonstrated in 1960 by Maiman

LASER is acronym of "Light amplification by stimulated emission of radiation" and it is like other light sources such as electric bulb, CFL, tube light and lamp with some unique properties which make it different and special source of light. Now a days we found laser light sources in most of the places in daily life. We have laser in printing devices, barcodes machine, cutting tools, garment industry, hospitals, research labs etc. We find lasers of different colour and different power levels.

For science and engineering applications, there was a need of light source with high monochromaticity and high intensity, laser light fulfils all such requirements. Laser light differs from ordinary light source. Some of the properties of laser light source are:

- High mono-chromaticity {laser consists of only one colour light or single wavelength}
  - As white light consists of light from 4000 A° to 7000 A°, it is not monochromatic, sodium light consist of light of two wave length 5890 A° and 5896 A° ($\Delta\lambda = 6$ A°), it is considered as mono chromatic and Laser is highly monochromatic that is the $\Delta\lambda = 0.01$A° or less.
- High temporal coherence. {All the waves associated in beam are in phase}

- Directional {laser light moves in one direction only}
- Low divergence {The divergence of laser light or spread of beam is very less}
- High power {laser light has high power as the intensity is high}

In Unit 2 we have used the ray model of light to explain the phenomena related to light. In present topic we use particle nature of light or photon picture of light radiation. Light has dual nature. Certain phenomena shown by light radiation can be explained only by using wave nature of light radiation such as interference and diffraction, where several phenomena such as photo electric effect can be explained by particle nature. In particle picture of light radiation is made up of quanta of energy known as photon with energy ($E = h\nu$), where h (6.67×10^{-34} J) is plank constant and ν is the frequency of light radiation.

7.1.1 Energy Level

As briefed in unit 6 that there is availability of energy bands for electrons present in solids and sharp energy levels for electrons in an isolated atom. Electrons in an atom transits between these levels by absorbing and releasing energy in the form of photons or of when an energetic electron collides with atom. As per Bohr theory of atoms the energy levels available for electron in an atom are discrete. For example, the energy level in hydrogen atom is given in Fig. 7.1

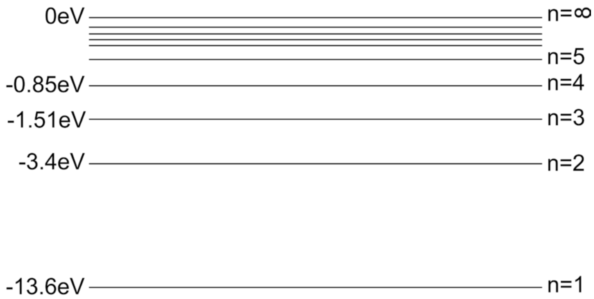


Fig 7.1 Energy level diagram of hydrogen atom

The atoms of different elements will have different energy levels and the picture will be quite different from Fig 7.1 as there is change in number of electrons in each type of atoms. In solids instead of sharp energy levels energy bands are available.

7.1.2 Ionization and Excitation potential

The lowest energy state available in atom for an electron is known as ground state. All the energy states above the ground level are known as excited energy states. The energy required to excite an electron from ground state to any of the excited state is known as excitation energy. If an electron in hydrogen atom is to be excited from ground to first excited state then, $-3.4 - (-13.6\text{eV}) = 10.2$ eV energy is required, hence 10.2 eV is the first excitation energy that is required to excite to first excited level ($n = 1$).The energy required to excite the electron to $n = \infty$, or to knock out the electron from atom is known as ionization energy, in case of hydrogen atom the ionization energy is 13.6eV.

If an electron is accelerated by 1 V of potential difference than it acquires 1 eV energy. The excitation of electron from ground state to excited state can be done by colliding it with electron having the energy required for excitation. Therefore, potential required to give energy to electron so that it can excite the electron available in atom to any of the excited state is known as excitation potential. The potential required to give energy to electron to create ionization of atom is known as ionization potential. Ionization potential required for ionization of hydrogen atom is 13.6 V and excitation potential required to excite electron from ground state to first excited state is 10.2 V.

7.1.3 Spontaneous and Stimulated emission

In previous section, it has been explained that the energetic electron excites the electron from ground state to excited state. In this section we will comprehend the phenomena which takes place when light interacts with matter. A photon having energy equal to the difference of energy between the excited state and the ground state can also excite the electron from ground to excited state. This phenomenon is known as optical absorption.

$$E = h\nu = E_2 - E_1 \qquad ...(7.1)$$

The electron excited to higher energy level, has a definite lifetime in excited state and is of the order of 10^{-7} seconds. The atoms from excited state transits from excited energy level to ground level and in this process, it releases a photon of energy $E_2 - E_1$, this phenomenon is known as spontaneous emission. There is no phase relation between the photons emitted from consecutive spontaneous emission.

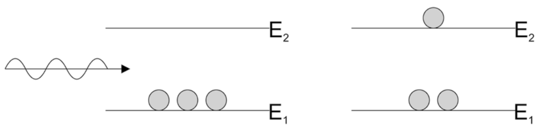


Fig 7.2 Optical Absorption

If an electron is in excited state and before transition to ground state, it interacts with photon of energy $E_2 - E_1$, than it is forced to come to ground state or the photon stimulates the excited electron transit to ground state. In this process two photons identical in all respect are emitted and the phenomenon is known as stimulated emission. Both the photons have same energy, same direction and same phase. Stimulated emission creates coherent photons.

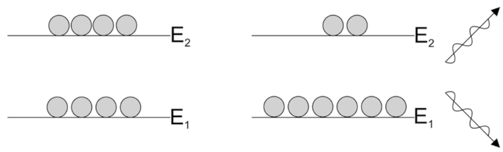


Fig 7.3 Spontaneous Emission

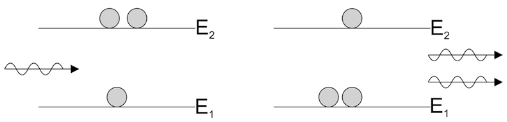


Fig 7.4 Stimulated Emission

Note: The phenomena of stimulated and spontaneous emission have been explained by electron transition. In some of the literature it has also been explained by excitation of atoms.

The phenomena of stimulated emission must be amplified for producing a laser.

7.1.4 Population inversion

As explained in the previous sections that laser is highly monochromatic and the there should be more and more stimulated emission to produce laser. The probability of stimulated emission is more if the electrons stay in the excited state for more time. Let us see this in more detail, the excited energy levels has a width as shown in the following diagram.

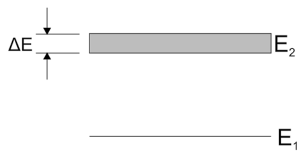


Fig 7.5 Width of excited energy level

As from equation (7.1) $\qquad E_2 - E_1 = h\Delta\nu$

The light radiation coming out due to transition from E_2 to E_1 will have spectral width i.e. it consists of range of frequencies. Hence it will affect the monochromaticity. Secondly due to width of energy level the time for which the electron stays in excited state is also less. For more stimulated emission we require large number of atoms in the excited state. The excited energy level for which the width is very less are known as metastable states. The lifetime of atoms in metastable state is of the order of 10^{-3} sec. Hence when atoms are excited to such excited level they stay there for more time and in between, through proper mechanism, large number of atoms can be excited to this state. Such that the number of atoms in excited state is more than the number of atoms in ground state. This condition is known as population inversion (inverse to the normal condition). The presence of metastable state in energy levels of any material, make that material suitable for producing laser.

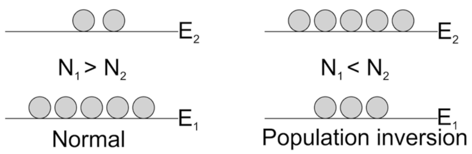


Fig 7.6 : Number of atoms in excited state in normal and population inversion conditions

Let N_2 is the number of atoms in E_2 level and N_1 is atoms in ground state,

In normal state, $N_1 >> N_2$, but In population inversion $N_2 >> N_1$, due to population inversion a large amount of atoms can be simultaneously deexcited to ground state and a coherent intense light beam can be produced.

7.1.5 Pumping method

Pumping method is also known as pumping scheme. As we have seen that to produce laser we should have stimulated emission and for stimulated emission we should have population inversion and the method with which we create population inversion is known as pumping method. Two types of pumping methods or pumping mechanism is used in lasers.

a. Three level

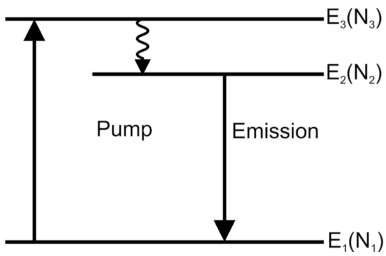
b. Four level.

In three level pumping mechanism the atoms are excited to higher energy level above metastable state, through optical absorption or electrical excitation. The optical absorption is achieved providing external source of light radiation. The photons from external source excite the ground level atoms to exited level. Whereas in electrical excitation, energetic electrons collides with ground state atoms and excite them to excited level.

The atoms from the higher energy levels transit to metastable state, where population inversion is created. From metastable state the large number of atoms transits to ground level and this transition is amplified to produce laser. In three level method the laser light is due to transition between metastable state and ground state (Fig 7.7 a). As all the atoms are in ground state in normal conditions, it is very difficult to make ground state empty. Once the population inversion is created and intense beam came out, then it takes time to again create population inversion in thee level systems.

In four level pumping mechanism the atoms are excited to higher energy level above metastable state, through optical absorption or electrical excitation. The atoms from the higher energy levels transit to metastable state, where population inversion is created. From metastable state the large number of atoms transits to a unstable excited level above the ground level and this transition is amplified to produce laser. In four level method the laser light is produced due to transition between metastable state and unstable excited state (Fig 7.7 b). As the excited state above, ground level is unstable hence remain empty and population inversion can easily be created in four level method as compare to three level pumping method.

a.



b.

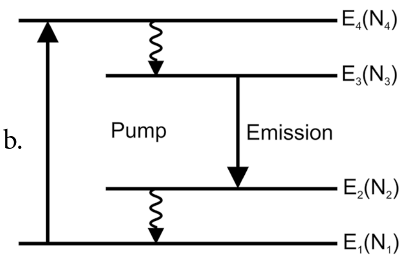


Fig 7.7 Three and four level pumping schemes

7.1.6 Optical feedback

Till now, it has been established from previous sections that to produce laser, we must have metastable state in materials for more stimulated emissions and population inversion. The only thing left is amplification. Light radiation of desired wave length has to be amplified, that brings the atoms from metastable state (due to population inversion) to ground state (in three level) or lower excited state (in four level). In lasers, the mechanism used to amplify light radiation is known as optical feedback. The material which is having metastable state or the materials whose atoms transitions create lasers is known as active medium. The active medium is kept in an optical cavity known as optical resonator. The optical resonator is a cylindrical shape glass enclosure having plane mirrors at both the ends. One mirror is 100 % reflective and another is 50% reflective. The pumping source in case of optical method is kept outsides the optical resonator.

The photons emitting out from materials are emitted in every direction. The photos having directions perpendicular to plane mirrors, remains in optical cavity for long time. As they get reflected in same directions every time. The length of optical cavity is few centimeters. The speed of light is 3×10^{10} cm/s. Hence these photons will have thousands of roundtrips between the two mirrors in one second.

During travel in each round trip such photons will generate additional photons through stimulated emission. The process of amplification is achieved during travel of photons in optical cavity, as shown in Fig.7.8. The intensity of the beam grows with each travel of light photons, until it reaches an equilibrium level. The mirror with 100% reflectivity reflects nearly the entire incident light, while the mirror with 50% reflectivity (the output mirror) reflects some light and transmits a portion as the laser beam.

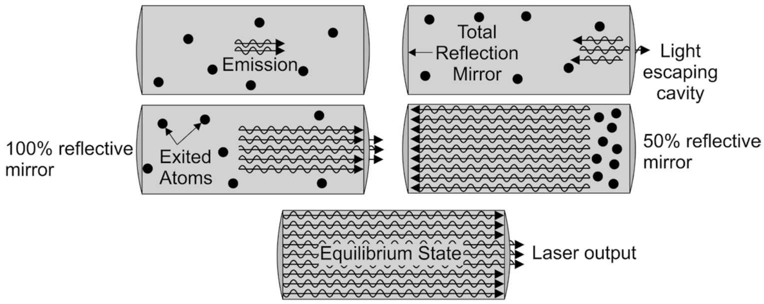


Fig 7.8 Optical resonator

7.1.7 Types of Lasers

To create laser light source following is essentially required and are known as component of lasers:

a. Active medium: solid and gas

b. Pumping method: three level and four level

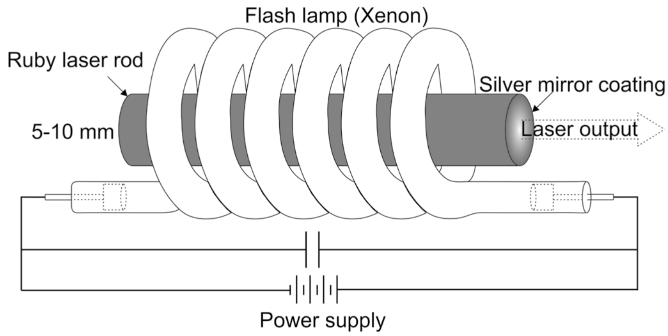
c. Optical resonator: As per active medium

The types of lasers can be differentiated based on components used in lasers. The working of any laser can be explained based on active medium used, pumping method applied, energy level diagram, design of optical resonator and wavelength of outcoming radiation.

7.1.7.1 Ruby laser

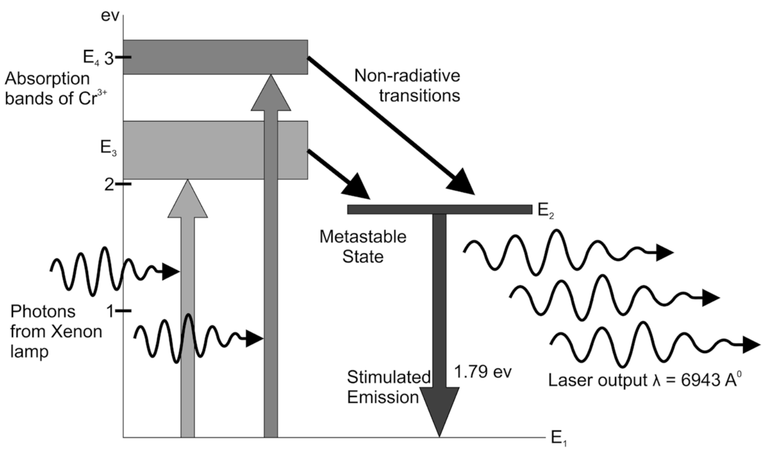
Quality	Description
Active medium	Solid: Ruby rod(Al_2O_3) doped with 0.5% Chromium atoms, Cr^{3+} (active material) Solid state laser
Pumping method	Xenon Flash lamp 80 W
Pumping scheme used	Three level
Optical resonator	The end of rod are polished act as mirror
Wavelength	6943 A°

Construction



a.

Energy level diagram



b.

Fig 7.9 Construction of ruby laser and energy level diagram of ruby laser

The Xenon lamp illumination gives photons of wave length 5500 A° and 4000 A° which excites Cr atoms from ground to E_3 and E_4, the atom from these states transits to E_2 (metastable)state. Population inversion is established in E_2 and E_1. Spontaneous emission from E_2 gives photon of 6943 A°. This photon travels across ruby rod, reflected from mirrors and the photon travelling perpendicular to mirror stimulates an atom sitting in E_2 level and gives two photons of 6943A°. This process of amplification is repeated and results in amplified beam of wavelength 6943A°. Efficiency of ruby laser is very low, and output is pulse laser not continuous laser.

7.1.7.2 He- Ne Laser

Quality	Description
Active medium	Gas: He: Ne (10:1) Gas Laser
Pumping method	Electrical High frequency signal
Pumping scheme used	Four level
Optical resonator	Quartz tube
Wavelength	6328A°

Working :

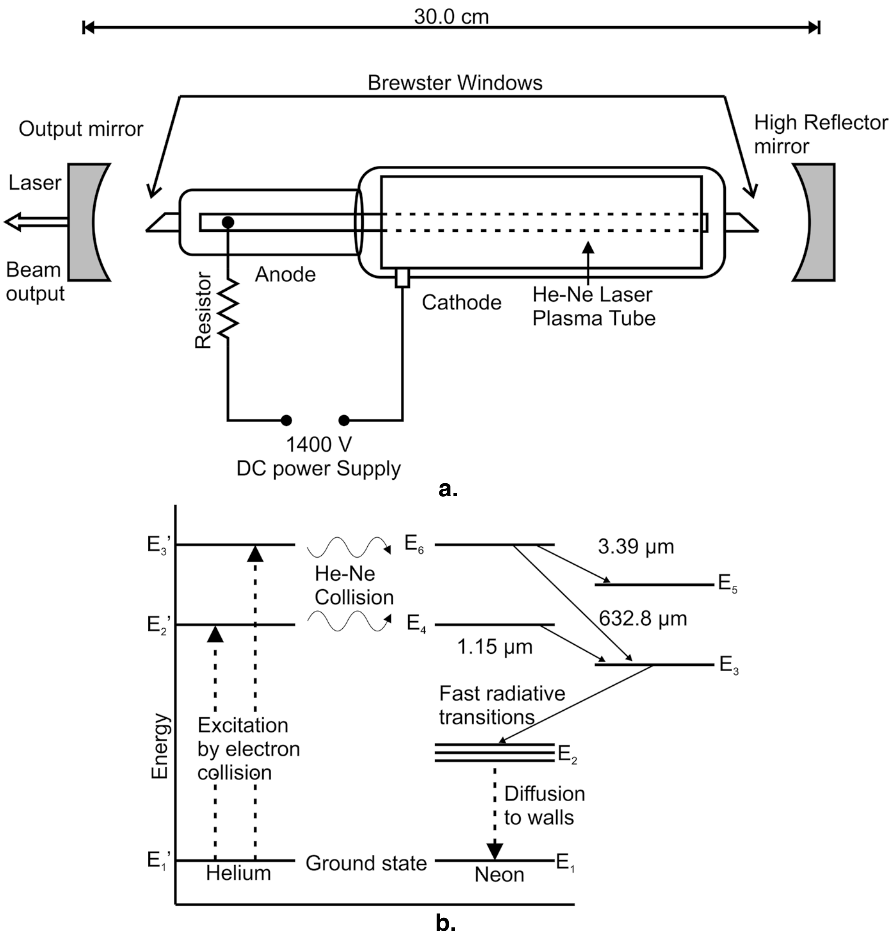


Fig 7.10 Construction of He-Ne laser and energy level diagram of He-Ne laser

Working

By electronic discharge methods, the helium atoms are excited to E_2' and E_3' level (metastable states) through collision with electrons. These excited atoms of He collides elastically to Ne ground atoms and excite then directly to E_4 and E_6 levels. Ne atoms from E_6 and E_4 level make transitions to E_3 with emission of photons and these photons travels in gas mixture. The photons traveling parallel to the axis of tube are reflected back and forth by mirror connected at the end of tube and start simulated emission of excited neon atom. This process continues and coherent radiation is built up in the tube. When the beam become sufficiently intense a portion of it come out in the form of laser.

7.1.7.3 Semiconductor laser

Quality	Description
Active medium	Solid :p-n junction diode (semiconducting material- GaAs)
Pumping method	Electrical current
Pumping scheme used	Band to band transitions
Optical resonator	The end of depletion region is cleaved, form an optical resonator
Wavelength	6328A°

Working:

The laser diode is also p-n junction diode as explained in unit 6. One of the p-n junction which is used to convert electrical energy into light energy is LED. When light emitting diode (LED) is in forward bias majority charge carriers in p-n junction combines and gives light radiation. The light which we get from LED is not coherent. The diode laser is modified version of LED. It is very much cost effective and miniature version of laser.

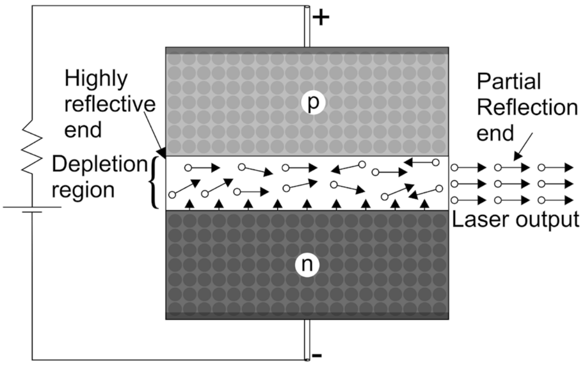


Fig 7.11 Diode laser

The diode laser is p-n junction like other diodes and there is depletion region at junction. The ends of junction region that is the ends of depletion region are cleaved such that they act as mirrors and small optical cavity of micro meter size is formed as shown in Fig 7.11. The refractive index of depletion region is also small as compare to p and n region. This helps in optical trapping of photons in the junction region. The material used for laser diode has high doping as compare to material used in LED. There are large number of electrons in conduction band and holes in valence band in n and p semiconductors respectively used in diode laser. When laser diode is forward biased, the electrons and holes combine to give photons, which are trapped and reflected back and forth in optical cavity in the junction. This initiate stimulated emission of the conduction band electrons in the junction, which gives additional directional photons. The process continues until an amplified laser beam come out from diode laser. The wave length of laser diode is calculated from energy band gap of the material used in diode. The diode laser has less monochromaticity, coherency and power as compare to He Ne laser, but still has versatile use due to its small size.

7.1.8 Laser characteristics

- **Highly directional:** Laser source emits light radiations only in one direction. It is highly directional. The ordinary source emits light radiation in all direction.
- **Monochromatic:** Laser light is highly monochromatic, the wavelength spread of laser light is of the order of 0.01 A°, whereas ordinary light white light source has wavelength spread (Fig 7.12 a) of 3000 A° (Fig 7.12 a).
- **Coherent:** Laser light is highly coherent. We can observe interference phenomena bylaser beam. All the waves composing laser beam have same phase (Fig 7.12 b).
- **Divergence:** The divergence or angular spread of laser beam is very small as compare to conventional light sources. The laser beam travel large distance with almost same beam size.
- **High intensity:** In laser beam the energy is concentrated in a very small region. The keychain laser or the laser used in laboratory, having milliwatt power, but still damage our eye on direct exposure.

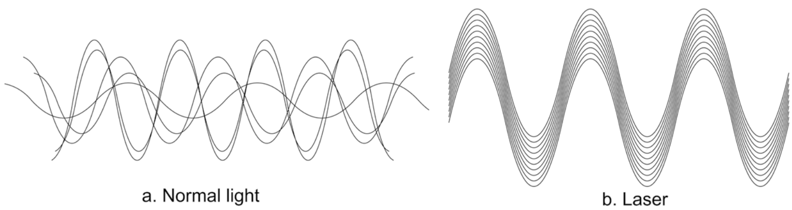


Fig 7.12 Normal and laser light

7.1.9 Engineering and medical applications of lasers

- **Bar code readers:**
  - To read data using barcode technology, it must first be scanned with a laser and then analysed. Scanners, often known as lasers, are used to read barcodes. They measure the light reflected by linear barcode technology and can tell the difference between white and black lines.

- **CD/DVD Player:**
  - CD/ DVD player, consists of miniature laser beam (a semiconductor diode laser) and a small photo cell. A CD/DVD player reads digital information stored on a CD/DVD in the form "bumps" and "pits" near its surface to encode digital or binary data. Laser that falls on a bump is reflected but light that strikes on "pit" not reflected, hence the digital signal is encoded with corresponding reflection in photocell.

- **Computer printers:**
  - In laser printer, laser beam is used to transfer the pattern of image or text on a negatively charged drum. The areas where, laser is not passed is positively charged and attracts the negatively charged toner to create the replica of image on paper.

- **Laser shows:**
  - High power different coloured laser beam is used in laser shows.

- **Holography:**
  - Hologram is a 3 D image of object uses coherent property of laser used. Now a days, 3D image of person can be created at distant place by using digital holography

- **Position and motion control:**
  - Laser light reflection is used for precise motion control

- **Fibre optic communications:**
  - As optical fibre uses light signal for transmission, diode lasers are used to convert digital signal into optical signal.

- **Material processing:**
  - As the size of laser beam is very small and having high power, precise metal cutting can be done with the help of lasers. Lasers is also used to make pattern on metal surface.

- **Medical:**
  - Infrared lasers are used to remove a very thin layer of skin (0.1 mm). They take advantage of the presence of water in the skin to provide a capacity to remove skin and body tissue in the absence of pigment in general.
  - Laser hair removal is one of the most common application in cosmetic procedures. Laser beams fall on hair follicles. Pigment in the follicles absorb the light. This absorption destroys the hair.
  - For retina operation, visible laser is used. Visible light is transparent to the cornea and crystalline lens can be focused with eye's lens on the retina. The most popular visible laser is the green argon laser.

- Blood less surgery can be done by using Laser.
- Lasers are useful in cancer diagonisis.

7.2 FIBER OPTICS

In last century, scientist and engineers have tried to design and improve communication systems, so that messages can be sent to long distances without any disturbances or noise. Message can be sent from transmitter to receiver via guided medium or unguided medium. Mobile and DTH TV signals we receive through unguided medium. The landline phone signals we receive from guided medium. Copper wire was majorly used for transfer of audio signals in guided medium but there are following drawbacks in using cooper wire for transmission:

- Copper is metal, it will catch noise and same will be received at receiver end.
- The velocity of electrical signal in copper is around 5000m/s.
- The copper wire capacitance also affects the transmission of signals.

With the invention of lasers, a power light source is available and can be used for communication purpose. Audio signals can be converted into light signals and transmitted to longer distances. There is requirement of guiding media for light signals similar to copper wire for electrical signal. Optical fiber made up of silica or glass serve this purpose. The optical fiber has brought revolution in communication systems and have number of other engineering applications. The branch of physics related with the science and technology used in optical fiber is known as Fiber optics. The thickness of human hair is around 100- 200 micrometer. The thickness of optical fiber is normally equal to thickness of human hair.

7.2.1 Introduction to optical Fibers

Optical fibers are fibers or wire type cylindrical structures made up of glass or silica. It is also known as fiber of glasses. As glass is transparent material and allow light wave to pass through it and act as insulator, similarly optical fibers allows light signals to pass through it and as insulator it does not catches any electromagnetic wave as noise.

Optical fiber consists of

- Solid cylindrical glass rod called the **core**, through which light in the form of light or optical signal propagates. Diameter of core is 5 micrometers to 100 micrometers.
- Surrounded by another coaxial cylindrical structure made of glass of lower refractive index called the **cladding.** The diameter of cladding is usually 125 micrometers.
- Protective covering : To provide mechanical strength to this core-cladding arrangement, other coaxial surrounding called the buffer coating and jacketing. Buffer jacket diameter is around 250 micrometers.

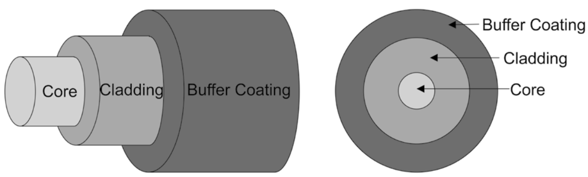


Fig 7.13 Construction of optical fiber

7.2.2 Light propagation, acceptance angle and numerical aperture

The light wave propagates in optical fiber with total internal reflection (TIR) phenomenon. TIR and light propagation has been explained in detail in unit 2. Fig 7.14 gives the representation of light propagation in optical fiber.

Applying Snell's law at the medium1-core interface

...(7.2)

From the Fig $$n_0 \sin\alpha = n_1 \sin\theta$$

after substitution for θ $$\theta = \frac{\pi}{2} - \theta_C$$

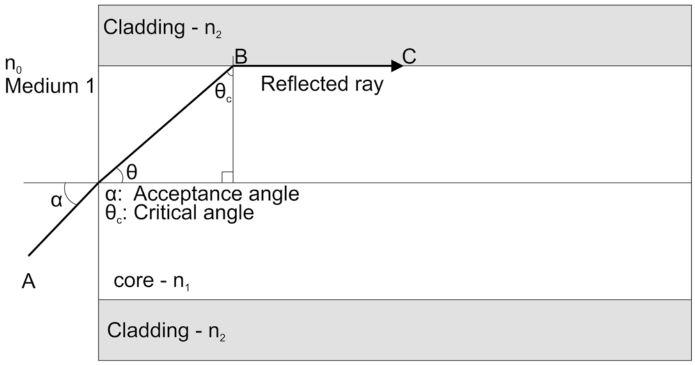


Fig 7.14 Light propagation in optical fiber

$$\sin\alpha = \frac{n_1}{n}\cos\theta_C$$

$$\cos\theta_C = \sqrt{1-\sin^2\theta_C}$$

$$\sin\theta_C = \frac{n_2}{n_1}$$

$$\cos\theta_C = \sqrt{1-\frac{n_2^2}{n_1^2}}$$

$$\sin\alpha = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \quad ...(7.3)$$

Since $n_0 = 1$ for the initial medium 1 from which the light is launched. The angle α is indicative of light accepting capability of the optical fiber.

For an optical fiber in air, with core refractive index n_1 and cladding refractive index n_2 and having an acceptance angle of α is given by

$$NA = \sin\alpha = \sqrt{n_1^2 - n_2^2} \quad ...(7.4)$$

The α here is the maximum acceptance angle, if the angle of incidence is less than α, then only light wave will travel through fiber. If the angle is more than α, then the light wave will not have TIR and hence cannot propagate through Fiber.

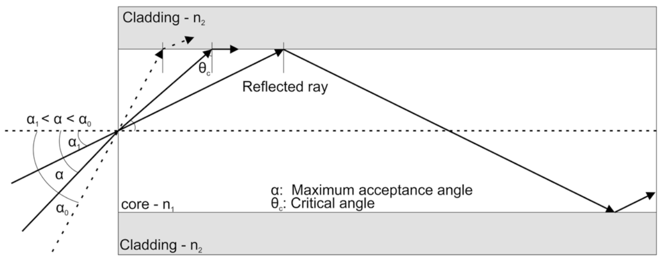


Fig 7.15 TIR in optical fiber

Numerical aperture (NA) is the most fundamental characteristics of an optical fiber. It Indicates the light collecting efficiency of an optical fiber. More the value of N.A. better is the fiber. For greater values of N.A. the difference on the right hand side of Eq. 7.4 has to be maximized. For maximizing the difference, either the refractive index of the core (n_1) has to be increased or the refractive index of the cladding (n_2) has to be reduced. Since the core used is always glass, the value of its refractive index n_1 is thus fixed (approximately 1.5). If we make $n_2 = 1$, we would then get the maximum possible N.A. for an optical fiber. But then we are basically talking about removing the cladding because, if there is a cladding, the value of n_2 will always be greater than 1.

7.2.3 Fiber types

Optical fiber can be broadly classified, based on two factors and they are:

- Refractive index profile
- Number of modes

Refractive index profile

Based on refractive index profile the fiber can be divided in two categories:

A. Step index fiber

As, refractive index of core and cladding equals to n_1 and n_2 respectively and $n_1 > n_2$. The refractive index of core is uniform throughout its diameter. There is a sudden change in the refractive index at core cladding interface and cladding also has the constant refractive index n_2.

If the core radius is r_1 and cladding radius is r_2 and we plot the refractive index vs distance from core axis than this refractive index profile look like steps and such types of fibers are known as step index fibers.

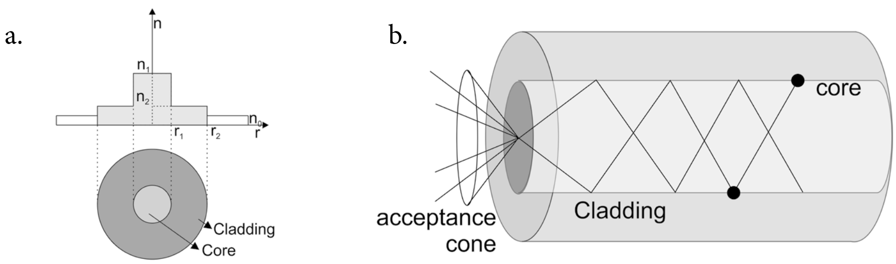


Fig 7.16 Refractive index profile and light propagation step index fiber

In step index fiber, the light rays propagate in straight lines through TIR. The light ray entering at same time in step index fiber at different angles of incidence travel different path in fiber and emerges out in different times in and this phenomenon known as pulse dispersion. The rays which enters with more angle of incidence travel more distance as compared to the rays entering with less angle of incidence.

B. Graded index fiber

The refractive index of core is not uniform. The refractive index of core n_1 decreases gradually from the center of core as a function of the core radius. At the core cladding interface, the refractive index shows sudden decrease in refractive index and n_2 will remain constant or uniform w.r.t. radial distance after core cladding interface.

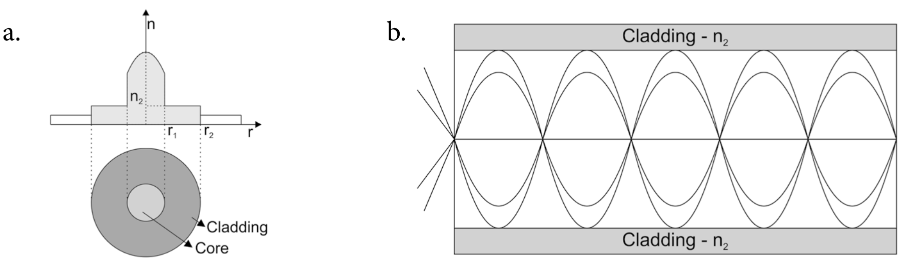


Fig 7.17 Refractive index profile and light propagation Graded index fiber

When a light ray enters in graded index fiber, due to gradual variation in refractive index from core axis to core cladding interface the light rays move in curved path instead of straight path. The rays which enters fiber with more angle of incidence travel more distance in the region where refractive index is less, hence more velocity and less time as compare to the rays entering with less angle of incidence. The path of travelling for the two rays having different angle of incidence is different but the time taken for both rays to emerge out from fiber is same. The pulse dispersion is low in Graded index fiber.

Number of modes

Based on mode of propagation of light the optical fibers can be divided in two categories:

- Single mode fibers
- Multimode fibers

Single mode fiber

In single mode fiber only one mode of light propagation is allowed for light propagation in fiber. The diameter of core is 5 micrometer and cladding diameter is around 50 micrometers. It is step index fiber. Fabrication of such fiber is very difficult. As there is only single mode there is no pulse dispersion. It is suitable for long distance communication.

Multi-mode fiber

Number of modes is allowed for light propagation in multimode fiber. The diameter of core is 50 micrometer and cladding diameter is around 100 micrometers. Multi-mode fiber can be a step index fiber or graded index. As there are number of modes allowed in this fiber, there is pulse dispersion in fiber (which can be minimized in case of graded index fibers). The fabrication of multimode fiber is less difficult as compare to Single mode fiber.

7.2.4 Applications in telecommunication, medical and sensors

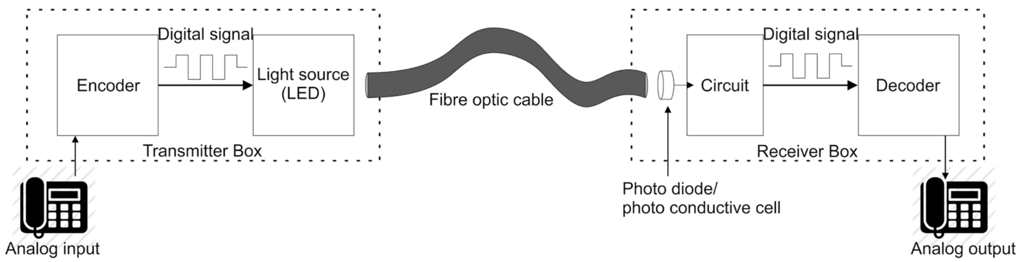


Fig 7.18: Optical fiber communication system

Fig 7.18, Shows schematic of optical fiber communication systems and it has following advantages over other communication systems

- More information carrying capacity
- Smaller size and weight
- Availability of raw material for fiber.
- Faster signal propagation
- External light could not enter fiber as it is well protected.
- No external electromagnetic signal pickup as fiber is nonmetallic.
- Corrosion is less severe than copper wire.

Medical applications

- **Endoscope:** Internal organs and tissues can be seen through bodily orifices by using endoscope made up of multifiber. Endoscopes are used by doctors to explore symptoms including nausea and gastrointestinal pain, confirm diagnosis using biopsies, and give medical treatment.

- Optical coherence tomography (OCT), a form of biomedical sensor, is a medical imaging technique that uses imaging sensors to collect micron-scale, three-dimensional pictures from within optical scattering medium such as biological tissue.

Sensors

Fiber optic sensors are used as transducers for various physical phenomena such as strain and temperature measurements. Fiber sensors are specially designed sensors in which there is shift in the frequency of the incident and reflected wave on applying pressure and temperature. Theses sensors work in extreme conditions where normal sensors cannot be used. Fiber based High voltage and high current sensors can be used in extreme harsh conditions. As fiber is insulator there is immunity to electromagnetic interference.

7.3 NANOSCIENCE AND NANOTECHNOLOGY: INTRODUCTION

In unit 4, materials having electrical properties that is metals or conductors have been introduced, in unit 5 magnetic materials are briefed and in unit 6 semiconducting materials and devices made up of semiconducting materials have been explained. Till now during your previous and present courses of physics, the phenomenon related to materials big in size or bulk materials have been discussed. The specific properties by which a solid-state material is characterized does not depend on size, for example specific resistance.

The resistivity of copper wire of 1 mm^2 area of cross section and length 1 meter or 1 cm or 1 mm or even I micrometer is same. Is the resistivity of wire will be same if we take wire of 1 nanometer length?

The answer of the above question created a new body of knowledge or a new field of science and technology known as Nano science and Nanotechnology. Nanotechnology is the recent advancement in every field of engineering. Nanotechnology is an interdisciplinary and a general-purpose technology. Presently Nanotechnology is the fastest growing technology in 21^{st} century and having applications in nearly each and every field of engineering.

History

The concept of nanotechnology was first introduced by famous physicist and Noble laureates Richard Feynman's. As per his quotes "The principle of physics as far as I can see do not speak against the possibility of maneuvering things atom by atom. In principle it can be done but in practice it has not been done" and "There is plenty of room at the bottom". Eric Drexler has introduced the term nanotechnology in his book "engine of creation". Drexler make direct comparison between macroscopic machine part and component of biological cell.

Interesting Facts

- Entire Encyclopedia Britannica could be written on the head of pin
- All the world book could fit in pamphlet

Nanoscience is the study of phenomena and manipulations of materials at atomic (0.5 nm), molecular (1-5nm) and macromolecular (5-100 nm) scales and Nanotechnology can be defined as design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer (10-9) scale.

7.3.1 Nanoparticles and nanomaterials

Nano word taken form the Greek word "dwarf" and means $10^{-9,}$ or one billionth. In present context nano refers to 10^{-9} meters, or 1 nanometer (nm) and also

1nm = 1/1,00,00,00,000 meter or one billionth of a meter

1millimeter = (1/1000) meter

1micrometer = (1/1000) millimeter

1nanometer = (1/1000) mirometer

Nanomaterials are materials having dimensions in Nano Scale (10^{-9} m) or at least one dimension in Nano scale. Fig 7.19 gives comparison of nanosized material with bulk material. Fullerene is a nano-material and it is compared with earth and football.

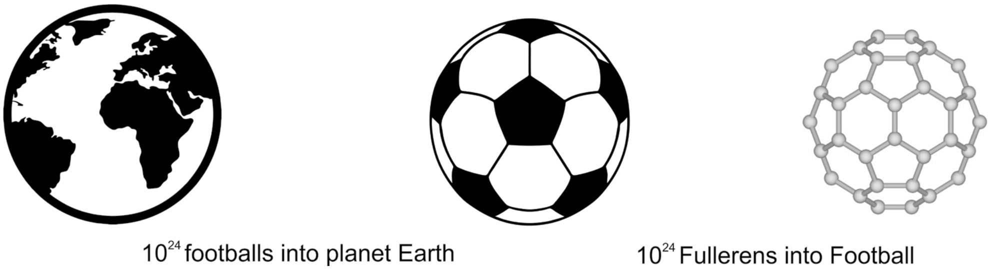


Fig 7.19 Comparison of nanomaterial with bulk material

Thus the material need not be so small that it cannot be seen, it can be a large surface or a long wire whose thickness is in the scale of Nanometers.

- Materials that are Nano scale in one dimension are layers, such as a Thin films or Surface coatings.
- Materials that are Nano Scale in two dimensions include Nano wires and Nano tubes.
- Materials that are Nano scale in three dimensions are particles for example precipitates, colloids and quantum dots (Small particles of Semiconductor Materials and such particle are known as Nano particles.

Advantages of small things

- Faster
- Lighter
- Cheaper
- Get into small shapes
- More Energy efficient
- Different properties at small scale

7.3.2 Properties at Nanoscale

The nanomaterials are different. The properties shown by nano size material is different from those shown by material in bulk size. Following are the properties, which changes due to size reduction in Nano meter range.

- Melting point depression
  - Reduction of melting point of a material with size
- Lattice Constant
  - Lattice constant of nanoparticle depends on size and shape.
- Mechanical properties
  - High stiffness and high strength
  - Density of defects in nanotubes is less
  - Deformation
- Electrical Properties
  - Metals become insulator
  - CNT shows semiconducting and metallic property

- Optical Properties
  - Gold nanoparticles are green
  - Semiconducting nanoparticle absorption (Tunable)
- Inactive to more chemically active
- Metallic to non metallic
- Ferro magnetic to paramagnetic

The properties of Nano Materials are very much different from those at a larger scale.

Two principal factors cause the properties of Nano Materials to differ significantly from other materials.

- **Increased relative surface area**. As shown in following Fig that the surface to volume ration increases when we take particle in smaller dimensions (Fig 7.20).
- **Quantum confinement effect**. The electrons in nanomaterial are restricted to move in a region of nanometer size and this is known as quantum confinement.

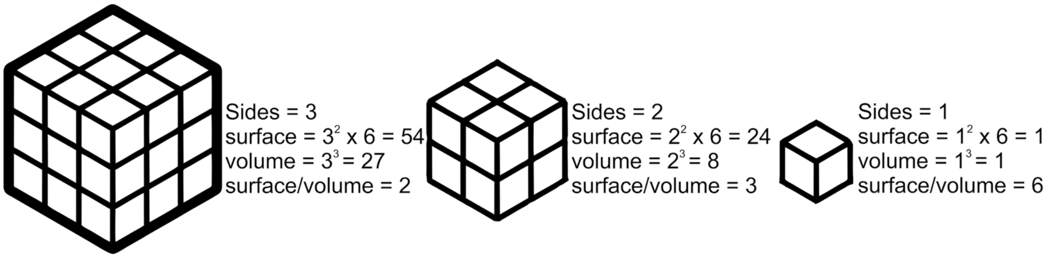


Fig 7.20 Variation of surface to volume ratio

These factors can charge or enhance properties such as reactivity, strength and electrical characteristics**.**

7.3.3 Nanotechnology

Nanotechnology can be defined as synthesis (fabrication), characterization (determine size and properties) and finding applications of material, having at least one dimension in nanoscale.

Synthesis of nanomaterials: There are two approaches for synthesis of nanomaterials.

Top down: Approach to the nanoscale dimension starting with the bulk scale materials by physical breaking of the source material through high energy processes. Example : Ball milling, Mechanical attrition.

Bottom up: Approach to the nanoscale dimension starting with the atomic scale materials by chemical method and other synthesis processes. Example: chemical precipitation, Chemical vapour deposition.

Characterisation of nanomaterials

After making nanomaterials, next process is to measure the dimensions of the material made and measure the change in the properties this is known as characterisation of nanomaterials.

Examples : STM, SEM, AFM are the instruments used for Nanomaterial characterisation.

7.3.4 Nanotechnology based devices and applications

Nanotechnology based devices are the devices using nanomaterials as components or the size of devices is in the nanometre range. Such devices have vast engineering and medical applications.

Devices using nanomaterials

Sensors

Sensors based on nanotechnology can detect very minute amounts of chemical vapours. In nanotechnology-based sensors, several types of detecting elements, such as carbon nanotubes, zinc oxide nanowires, can be used. Nanotubes, nanowires, and nanoparticles are so small, only a few gas molecules are needed to affect the electrical characteristics of the sensing element.

Solar Cell

Silver nanowires, titanium dioxide nanoparticles, and an infrared-absorbing polymer are combined to create a solar cell that is roughly 70% transparent to visible light.low-cost and high-efficiency flexible solar cells can be produced by using nanowires covered with zinc oxide. Combination of carbon nanotubes and buckyballs is used to produce solar cells.

Batteries

Increasing the battery's available power and reducing the charging time are the two requirements for good batteries. Nanoparticles are coated on the surface of an electrode to provide these benefits. This increases the electrode's surface area, allowing more current to pass between the electrode and the battery's chemicals.

Fuel cell

Nanotechnology is being utilized in fuel cells to lower the cost of catalysts that make hydrogen ions from fuels like methanol and to enhance the efficiency of membranes that separate hydrogen ions from other gases like oxygen.

7.3.5 Nanometer size devices

SET

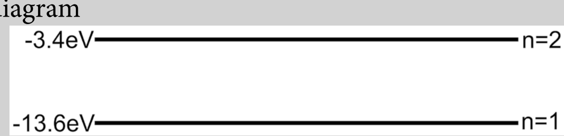
The single electron transistor (SET) is a new type of switching device that uses controlled electron tunneling to amplify current. The dimensions of SET are in nanometer range.

Quantum well and quantum dot laser

Quantum well and quantum dot lasers are semiconductor lasers that uses quantum dots and quantum well as the active laser medium in the light emitting region.

EXAMPLE 7.1

Ques. Find the wavelength of photon, emitted by transition of electron from E_2 to E_1 in the following diagram



Solution:

Energy of photon (E) = $E_2 - E_1$= -3.4 eV – (– 13.6eV)= 10.2 eV = $10.2 \times 1.6 \times 10^{-19}$ Joule

$E = h\nu = hc/\lambda$

$\lambda = hc/E = (6.67 \times 10^{-34} \times 3 \times 10^{8})/(10.2 \times 1.6 \times 10^{-19}) = 1.226 \times 10^{-7}\text{m} = 1226 \times 10^{-10}\text{m}$

= 1226 A°

EXAMPLE 7.2

Ques. Find the Numerical aperture of fiber if n_2 = 1.62 and n_1 = 1.6. Find the maximum angle of incidence when fiber is kept in water.

Solution:

Given n_2 = 1.62 and n_1 = 1.60

$$NA = \sqrt{\left((1.62)^2 - (1.60)^2\right)} = 0.253$$

NA in water = NA in Air/1.33 = 0.19

Maximum angle of incidence in water, $\alpha = \sin^{-1}(0.19) = 10.88°$

UNIT SUMMARY

- Laser is monochromatic and coherent source of light.
- Active medium, pumping method and optical resonator are required to construct laser.
- Optical fibers are fibers of glass.
- Light propagates in optical fiber by the TIR phenomenon.
- Nanomaterials are the materials having at least one dimension in nanometer range.
- The physical and chemical properties of materials changes at nanoscale.
- Laser, optical fiber and nanotechnology have applications in every field of science and engineering.

EXERCISES

Multiple Choice Questions

7.1 The wave length of ruby laser is

a. 6328A°
b. 6439A°
c. 6329A°
d. 6943A°

7.2 He Ne laser is a --------- level laser system

a. four
b. three
c. two
d. five

7.3 The life time of electrons in metastable state is of the order of

a. 10^{-5}seconds.
b. 10^{-6}seconds.
c. 10^{-3}seconds.
d. 10^{-8}seconds.

7.4 If band gap of material used in diode laser is 3.2 eV, the wavelength of outcoming radiation is

a. 3807 A°
b. 3784 A°
c. 3874 A°
d. 38 47A°

7.5 If optical fiber is used in water, its NA

a. Always decreases.
b. Always increases.
c. Remain same
d. Sometime increases and sometime decreases.

7.6 1 nanometer is equals to

a. (1/1000)micrometer
b. 10 A°
c. 10^{-9} meter
d. All of the above

Answers of Multiple Choice Questions
7.1 (d), 7.2 (a), 7.3 (c), 7.4 (c), 7.5 (a), 7.6 (d)

Short and Long Answer Type Questions

Category-I

1. Differentiate between ordinary light and laser on any five points using examples.
2. Explain the concept of ionization and excitation potentials with example.
3. Distinguish between spontaneous and stimulated emission with the help of energy level diagram.
4. Differentiate between three level and four level pumping schemes on any three points.
5. Explain population inversion and its necessity to produce laser.
6. Explain the construction and working of optical resonator with diagram.
7. Explain the working of following lasers with construction, principle of working and energy level diagram.
   a. Ruby Laser
   b. He Ne Laser
   c. Diode laser
8. Write five applications of laser in engineering.
9. Define the terms acceptance angle and numerical aperture.
10. Derive relation between numerical aperture and refractive indices of core and cladding respectively.
11. Draw diagram for light propagation in optical fiber.
12. Differentiate between step index and graded index fibers.
13. Give two applications of optical fibers in the following
    a. Telecommunication
    b. Medical
    c. Sensors.
14. Give reasons for using optical fiber in place of copper wire for communication.
15. Explain construction of optical fiber with neat diagram.
16. Describe the term Nanotechnology and Nanoscience.
17. Define the term Nanoparticles.
18. Explain the difference in properties of Nanomaterials from bulk materials.
19. Write five applications of Nanotechnology based devise with examples.

PRACTICAL

There are two laboratory experiment(s) which are related to this unit

- To measure the wave length of He-Ne/ diose laser using a diffraction grating.
- To measure numerical aperture (NA) of an optical fiber.

Practical 16 - Wave length of He Ne Laser

P16.1 Practical Statement

To measure wavelength of a He-Ne/diode laser using a diffraction grating.

P16.2 Practical Significance

Visible light spectrum wavelength ranges from 4000A° – 7000A°. Diffraction phenomena is used for measurement of wavelength of a light color. Laser is coherent source of light. This experiment will help student to measure the wave length of light using diffraction grating.

P16.3 Relevant Theory

A grating is an optical device, in which N number of parallel slits are formed on transparent material. It is an arrangement of N parallel slits of width of the order of wavelength of light. When light passes through these slits, diffraction phenomenon occurs. The diffraction maxima are observed at angle θ and is given by:

Grating Equation: (For maxima) $(a+b)\sin\theta = n\lambda$

Where, $(a + b)$ = grating element, θ = angle of diffraction n =order of diffraction pattern and λ=wave-length of light falling on grating.

Hence $$\lambda = \frac{(a+b)\sin\theta}{n}$$

P16.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Use diffraction phenomenon and grating to find the wave length of He-Ne/ diode Laser.

P16.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

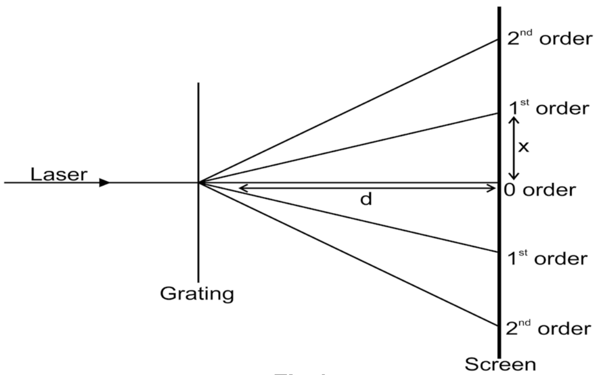


Fig 1

P16.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	Diffraction gratings of different grating element (100, 300 & 600 lines/mm), grating stand	01			
2	Meter scale	01			
3	Helium Neon / Diode laser	01			

P16.7 Precautions

1. Do not see laser directly with naked eye.
2. Handle the instrument carefully.
3. Take the distance between two orders carefully.

P16.8 Suggested Procedure

1. Set the laser such that it spot on the white paper screen, placed at 1- 1.5 m meters away.
2. Mark the position of the observed spot on the paper.
3. Place the 100 lines/mm diffraction grating in front of the laser beam.
4. Measure the distance between the screen and grating.
5. Measure the distance between the zero order maxima and consecutive maxima formed on screen.
6. Repeat the steps 3 to 5 for the other two diffraction gratings i.e. 300 lines/mm and 600 lines/mm on the slide.
7. Calculate the diffraction angle and Wavelength of Laser.

P16.9 Observations and Calculations

1. Grating element = 100 lines/mm, Distance between screen and grating (D) =

S. No.	Diffraction order Maxima (n)	Distance from zero order maxima (x)	Diffraction angle = x/D
1	First order (n = 1)		
2	Second order (n = 2)		
3	Third order (n = 3)		
4	Fourth order (n = 4)		

2. Grating element = 300 lines/mm, Distance between screen and grating (D) =

S. No.	Diffraction order Maxima (n)	Distance from zero order maxima (x)	Diffraction angle = x/D
1	First order (n = 1)		
2	Second order (n = 2)		
3	Third order (n = 3)		

3. Grating element = 600 lines/mm, Distance between screen and grating (D) =

S. No.	Diffraction order Maxima (n)	Distance from zero order maxima (x)	Diffraction angle = x/D
1	First order (n = 1)		
2	Second order (n = 2)		

Mean of wavelenght (λ) =

P16.10 Results and/or Interpretation

(to be filled by student)

1. ....

2. ....

P16.11 Conclusions and/or Validation

(to be filled by student)

1. ....

2. ....

P16.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give reasons for observing a smaller number of order, when grating element decreases.
2. Can this experiment be perform by using any other light source?
3. Give the source of errors in present experiment.

P16.13 Suggested Learning Resources

- https://vlab.amrita.edu/index.php/index.php?sub=1&brch=189&sim=334&cnt=4

P16.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Set up of experiment		
2	Measurement of Angles		
3	Safety measures		
4	Handling of instrument		

Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			**Signature of Teacher with date**
Process Related	Product Related	Total	

Practical 17 - Optical Fibre

P17.1 Practical Statement

To measure numerical aperture (NA) of an optical fiber.

P17.2 Practical Significance

Numerical aperture of optical fiber is the light gathering ability of optical fiber. IF numerical aperture is more than more light rays can travel through fiber This experiment will help student to measure the Numerical aperture of given optical fiber.

P17.3 Relevant Theory

Section 7.2 of unit 7 Modern Physics

P17.4 Practical Outcomes (PrO)

The practical outcomes are derived from the curriculum of this course:

PrO1: Find Numerical aperture of a given fiber.

P17.5 Practical Setup (Drawing/Sketch/Circuit Diagram/Work Situation)

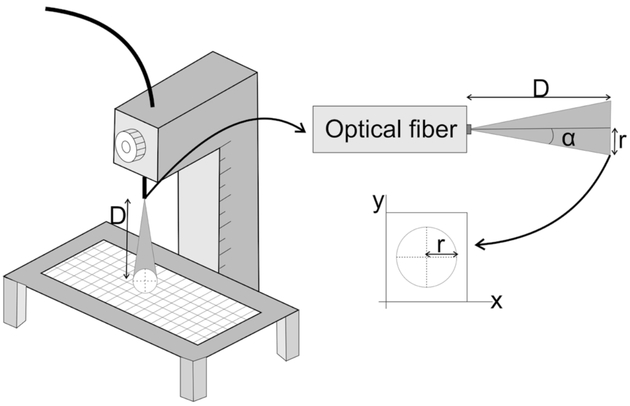


Fig 1

Numerical Aperture,

$$NA = \sin\alpha = \frac{r}{\sqrt{r^2 + D^2}}$$

r is radius of circle and D is distance between graph paper and optical fiber.

P17.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Qty	Actual Resources used Machines/Tools/ Instruments with broad specifications (to be filled by the student)		Remarks (if any)
			Make	Details	
1	Optical fiber (length one meter)	01			
2	Wooden stand for height variation	01			
3	Helium Neon / Diode laser	01			
4	Graph paper	01			

P17.7 Precautions

1. Do not see laser directly with naked eye.
2. Handle the instrument carefully.
3. Fiber should be stable while measurement.

P17.8 Suggested Procedure

1. Mount one end of optical fiber in wooden stand as shown in figure.
2. Place He-Ne /Diode laser as source very closed to other end of fiber.
3. The emitted light comes in the form a cone as shown in figure.
4. Measure the radius of circle formed on graph paper.
5. Measure the distance (D) between the fiber and graph paper.
6. Repeat the steps 4 and 5 by varying the D.
7. Use formula as given above for calculations.

P17.9 Observations and Calculations

S.No.	Distance between fiber and graph paper (cm)	Radius of circle (r)	Numerical aperture
1			
2			
3			
4			
5			

Mean NA =

P17.10 Results and/or Interpretation

(to be filled by student)

1. ....
2. ....

P17.11 Conclusions and/or Validation

(to be filled by student)

1. ....
2. ....

P17.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Is the acceptance angle varies by varying distance between the screen and optical fiber?
2. Can this experiment be perform by using any other light source?
3. Give the source of errors in present experiment.

P17.13 Suggested Learning Resources

- https://vlab.amrita.edu/index.php/index.php?sub=1&brch=189&sim=334&cnt=4

P17.14 Suggested Assessment Scheme

(to be filled by teacher)

The given performance indicators should serve as a guideline for assessment regarding process and product related marks.

Performance indicators		Weightage	Marks Awarded
Process related: …. Marks* (…….%)			
1	Set up of experiment		
2	Measurement of R and D		
3	Safety measures		
4	Handling of instrument		
Product related: ….. Marks* (…….%)			
5	Result and conclusion		
6	Timely submission of report		
7	Answer to the practical related question		
	Total	**100%**	

* Marks and percentage weightages for product and process assessment will be decided by the teacher.

Name of the Student:……………………………………………….. Marks Awarded			Signature of Teacher with date
Process Related	Product Related	Total	

KNOW MORE

Following topics relevant to this unit are suggested for strengthening students' existing knowledge and adds interest in the applied physics course:

- Time line of developments of Laser and Nanotechnology
- Concept of Modes formation in Fiber
- Synthesis and characterization techniques for nanomaterials.

Use of ICT

The student can visit the following url for simulation in lasers

- https://phet.colorado.edu/en/simulation/legacy/lasers

Design innovative Practical /Projects/ Activities

- Find wavelength of keychain diode laser and green laser available in market (under guidance of teacher).
- Prepare a model to demonstrate TIR in water or glass.
- Find surface to volume ratio of objects (square, sphere, cuboid shape) of different dimensions.

Inquisitiveness and Curiosity Topics

- Can aluminum act as insulator?
- Colour of gold nano particle is green and red ?
- How White light LED are made?
- Whether the Numerical aperture of fiber changes, when it is used in water?

REFERENCES & SUGGESTED READINGS

- H C Verma, "Concepts of physics" 2st ed., vol. 1, Bharti Bhawan,1992.
- Richard Feynman *et al* "The Feynman lectures on Physics", 6th ed. vol1, Addison-Wesley, 1963.
- R K Gaur and S L Gupta "Engineering Physics", 8th ed., Dhanpat Rai, 2011.
- Resnick Halliday and Krane, "Physics" 5th ed. vol1, Wiley, 2014.

TABLE OF PHYSICAL CONSTANTS

Table I: Table of Physical Constants

Physical Constant	Symbol	Value of Physical Constant
Gravitational Constant	G	6.67×10^{-11} $Nm^2 kg^{-2}$
Velocity of Light in Vacuum	c	$3 \times 10^8 ms^{-1}$
Charge of electron	e	1.6×10^{-19} C
Mass of proton	m_p	1.67×10^{-27} kg
Mass of electron	m_e	9.10×10^{-31} kg
Permittivity of free space	ε_0	8.85×10^{-12} Fm^{-1}
Coulomb law constant (Electrostatic constant) in vacuum	$1/4\pi\varepsilon_0$	9×10^9 N m^2C^2
Avogadro number	N	6.023×10^{23}
Radius of earth	R	6.38×10^6 m

Appendices

APPENDIX-A: Assessments Aligned to Bloom's Level

- Bloom's Taxonomy – It has been coupled into following two categories for development of Questions for this Quadrant as given below:

Category I Questions	Category II Questions *- Higher Order Thinking Skills*
Bloom's Level 1: Remember Bloom's Level 2: Understand Bloom's Level 3: Apply	Bloom's Level 4: Analyse Bloom's Level 5: Evaluate Bloom's Level 6: Create

APPENDIX-B: Index for Practical

Sr. No.	Page No	Name of the Experiment	Date			Marks	Signature
			Actual	Repeat	Record		
1		To determine and verify the time period of a cantilever					
2		To determine velocity of ultrasonic in different liquids using ultrasonic interferometer					
3		To verify laws of reflection from a plane mirror/ interface.					
4		To verify laws of refraction (Snell's law) using a glass slab.					
5		To determine focal length and magnifying power of a convex lens.					
6		To verify Ohm's law by plotting graph between current and potential difference.					
7		To verify laws of resistances in series and parallel combination.					
8		To find the frequency of AC main using electrical vibrator.					

Sr. No.	Page No	Name of the Experiment	Date			Marks	Signature
			Actual	Repeat	Record		
9		To verify Kirchhoff's law using electric circuits.					
10		To study the dependence of capacitance of a parallel plate capacitor on various factors and determines permittivity of air at a place.					
11		To find resistance of a galvanometer by half deflection method.					
12		To convert a galvanometer into an ammeter.					
13		To convert a galvanometer into a voltmeter.					
14		To draw V-I characteristics of a semiconductor diode (Ge, Si) and determine its knee voltage					
15		To verify inverse square law of radiations using a photo-electric cell.					
16		To measure wavelength of a He-Ne/diode laser using a diffraction grating.					
17		To measure numerical aperture (NA) of an optical fiber.					
18		Study of an optical projection system (OHP/LCD) - project report.					

Annexures

Annexure-I Some General and Specific Instructions when Working in the Laboratory

General Instructions

In spite of Psychomotor domain and cognitive domain learning, there is ample scope of learning in Affective domain, hence following instruction has to be followed while working in Laboratory

1. In the laboratory, work quietly and cautiously. {Discipline}
2. Remember the main purpose of doing any experiment is to make faithful measurements.
3. Always share equally all the steps of the work with your partner. {Team work}
4. Presentations of data in tabular form, graphs and calculations should be done correctly and sincerely.
5. Be always honest at the time of recording and representing the experimental data. {Ethics}
6. It is very important to keep in mind that never make up readings or doctor them to get a better fit of the graph as per theory. If any reading appears incorrect, you have to repeat the measurement again and again to find the source of error. {Ethics}
7. At the time of drawing the graph all the data obtained from experiment are to be properly plotted.
8. It is a fact that the objective of the laboratory is learning and also a verification of the knowledge that you have gathered. The experiments are designed properly for the purpose of illustrating different phenomena in all the important areas of Physics.
9. By doing the experiment with your own interest only it is possible to be familiar with all the fine points and to expose you to measuring instruments.
10. Always perform the experiment with an attitude of learning and with your interest to verify the theoretical knowledge that you have gathered.
11. Be very particular to arrive in time in the laboratory and always with proper preparation with a clear knowledge about the experiment. {Time management}

Specific Instructions

1. When working in the laboratory for collecting data of your experiment, it is important to note all the measured data neatly in the notebook.
2. The recorded data entered in the notebook have to confirm by your instructor before leaving the laboratory.
3. All the students doing the same experiment have to maintain individual copy of the recorded data. The laboratory notebook is required to bring in the laboratory regularly when you come for doing the experiment.
4. Graphs are to be drawn properly at the end of each of experiment.
5. For this you need to know how to optimize on usage of graph paper. Remember all the repeated data are to be accommodated on a single graph sheet.
6. Graphs are to be labelled properly along with the axes showing the corresponding units.
7. During the working hours in the laboratory you are supposed to fully utilize the duration and do not leave the laboratory before the completion of the working hours. If you finish early, you may spend the remaining time to complete the calculations and graphs drawing and for that in the laboratory you are supposed to come equipped with calculators, pencils and scale.

References for Further Learning

Lists of some of the books are given below which may be used for further learning of the subject (both theory and practical) by the interested students:

Text Book of Physics for Class XI & XII (Part-I, Part-II); N.C.E.R.T., Delhi.

- Applied Physics, Vol. I and Vol. II, TTTI Publications, Tata McGraw Hill, Delhi.
- Concepts in Physics by HC Verma, Vol. I & II, Bharti Bhawan Ltd. New Delhi.
- Engineering Physics by PV Naik, Pearson Education Pvt. Ltd, New Delhi.
- Modern approach to Applied Physics-I and II, AS Vasudeva, Modern Publishers.
- A Textbook of Optics, N Subramanyam, Brij Lal, MN Avahanulu, S Chand and Company Ltd.
- Introduction to Fiber Optics, Ajoy Ghatak and K Thyagarajan, Cambridge University Press India Pvt. Ltd, New Delhi.
- Nanoscience and Nanotechnology, KK Choudhary, Narosa Publishing House, Pvt. Ltd. New Delhi.
- Nanotechnology: Importance and Applications, M.H. Fulekar, IK International Publishing House Pvt. Ltd, New Delhi.
- e-books/e-tools/ learning physics software/websites etc.

Online resources:

- https://www.vlab.co.in
- http://www.olabs.edu.in
- https://phet.colorado.edu
- https://www.physicsclassroom.com
- https://www.robolab.in

Note: The above online learning resources are acknowledged for providing creative commons license for their usage.

CO and PO Attainment Table

Course outcomes (COs) for this course can be mapped with the programme outcomes (POs) after the completion of the course and a correlation can be made for the attainment of POs to analyze the gap. After proper analysis of the gap in the attainment of POs necessary measures can be taken to overcome the gaps.

Table for CO and PO attainment

The data filled in the above table can be used for gap analysis.

Course Outcome	Attainment of Programme Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)						
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7
CO-1							
CO-2							
CO-3							
CO-4							
CO-5							
CO-6							

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