Vidya Jyothi Institute of Technology

(Accredited by NBA, Approved by AICTE New Delhi)
Aziz nagar Gate, C.B. Post, Hyderabad-500 075

DEPARTMENT OF HUMANITIES AND SCIENCES

REGULATION	:	R18
BATCH	:	2018-22
ACADEMIC YEAR	:	2018-19
PROGRAM	:	I- B.Tech
YEAR/SEM	:	I- year / I
COURSE NAME	:	Applied Physics
COURSE CODE	:	A21003

COURSE COORDINATOR:

H.O.D

NAME OF THE FACULTY: **Dr. M. Lakshmi**

DESIGNATION : **Assistant Professor**

COURSE FILE INDEX

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Vision and Mission of Institution

Vision & Mission of Institution

Vision

- To develop into a reputed Institution at National and International level in Engineering, Technology and Management by generation and dissemination of knowledge through intellectual, cultural and ethical efforts with human values.
- To foster Scientific temper in promoting the world class professional and technical expertise.

Mission

- To create state-of-the-art infrastructure facilities for optimization of knowledge acquisition.
- To nurture the students holistically and make them competent to excel in the global scenario.
- To promote R&D and consultancy through strong industry-institute interaction to address the societal problems.

Vision and Mission of Department

Department of Electronics and Communication Engineering

Vision

- The Electronics & Communication Engineering department intends to be a leader in creating the high quality engineers in the field of electronics and associated technologies to cater to national and global technological needs promoting the human prosperity and well being.

Mission

- Providing an infrastructural and conducive environment to the students, faculty and researchers for attaining domain knowledge and expertise in electronics & communication engineering.
- Enable the students to develop into outstanding professionals with high ethical standards capable of creating, developing and managing global engineering enterprises.
- Inculcate the spirit of lifelong learning by interacting with outside world and strengthen professional, communication skills.

POs & PSOs

Programme Outcomes (PO's)

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization for the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling to complex engineering activities, with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with the society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Programme Specific Outcomes (PSOs)

PSO1: To impart knowledge in the field of Electronics & Communication Engineering by training the students in contemporary technologies which meet the needs of industry.

PSO2: To confide information on thrust areas of semiconductor technologies for students to pursue research in their field of interest.

Course Content

Course Content
Applied Physics

Unit – I	**Wave Optics:** Principle of Superposition, coherence and methods to produce coherent sources, Interference - Interference in thin films by reflection, Newton's Rings. Diffraction – Fraunhofer and Fresnel Diffraction, Farunhofer diffraction due to single slit, Plane Diffraction Grating, resolving power of Grating. Polarization – Polarization of light waves, Plane of vibration, plane of polarization, Double refraction, Nicol's Prism, Applications of Polarization.
Unit – II	**Free electron theory and Introduction to Quantum Mechanics:** Classical free electron Theory, Electrical Conductivity and Ohm's Law – Drawbacks Introduction to quantum physics: Black body radiation and Planck's Law(Qualitative), wave-particle duality, de-Broglie hypothesis of matter waves, Heisenberg uncertainty principle, time independent Schrodinger equation, Born interpretation of wave function, particle in an infinite potential well (one dimension).
Unit – III	**Band theory of solids and semiconductors:** Kronig-Penny model(Qualitative), E-k diagram, Energy bands in solids, classification of materials into metals, semiconductors, and insulators, Effective mass, Density of States(Qualitative), Fermi distribution function, Fermi level and its importance. Intrinsic semiconductors, carrier concentration in intrinsic semiconductors, energy band diagram and position of Fermi level in intrinsic semiconductors, equation for electrical conductivity of semiconductors, extrinsic semiconductors.
Unit – IV	**Semiconductor Devices :** Direct and indirect band-gap semiconductors, Formation of p-n junction, energy diagram of PN junction, I-V characteristics of PN junction diode, Photo diode, solar cell-efficiency, light emitting diode and their characteristics, semiconductor laser: device structure and characteristics, Hall effect and its applications.
Unit – V	**Fiber Optics and Lasers :** Introduction, total internal reflection, acceptance angle and numerical aperture, step and graded index fibers, applications of optical fibers. Introduction to interaction of radiation with matter: stimulated absorption, spontaneous emission and stimulated emission, Einstein's coefficients and their relations, characteristics of a laser, important components of a laser: active medium, pumping source, optical resonator. Population inversion, Ruby laser, He-Ne laser, applications of lasers.

COURSE OUTCOMES (COs)

Course Outcomes (COs):

At the end of the course the student will be able to

1. Identify various optical phenomena of light
2. Describe the basic principles of quantum mechanics
3. Classify solids based on the band theory
4. Elucidate the characteristics of semiconductors and semiconductor devices
5. Explain the working principle of lasers and optical fibers

COs Mapping with POs & PSOs

Mapping of Course outcomes with POs & PSOs

Articulation matrix of Course outcomes Mapping with Pos & PSOs

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	2	2	2	2	2	1	1			2	1	3	1	2
CO2	2	2	2	1	2					1		3	2	2
CO3	3	2	2	1	2		1			1		3	2	2
CO4	3	2	2	1	2		2			1		3	2	2
CO5	2	2	2	2	2	1	1			2	1	3	2	2

Student list

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

B TECH I YEAR: BRANCH : ELECTRONICS & COMMUNICATION ENGINEERING-

SECTION - A

S.No	Hall Ticket No.	Name of the Candidate
1	18911A0401	AKULA NAGENDER
2	18911A0402	ALURI SHRAVANI
3	18911A0403	AMMANNAGARI SRIVANI
4	18911A0404	ANJURI DURGA RAM PRASAD
5	18911A0405	ANNAMANENI DRUVI
6	18911A0406	ARPULA PRAKASH
7	18911A0407	BAIRAPOGU RANJITH KUMAR
8	18911A0408	BALA SHRAVYA DEVARAPU
9	18911A0409	BOGGULA NARENDER REDDY
10	18911A0410	CHIKINE PRANEETH KUMAR
11	18911A0411	CHINTABATHINA RAHUL
12	18911A0412	DAMMALAPATI NIVED KUMAR
13	18911A0413	DUDYALA VINOD KUMAR
14	18911A0414	ETACHETTU VENKATESH GOUD
15	18911A0415	GADE KARTHIK
16	18911A0416	GOLLAMUDI SAI LIKHITHA
17	18911A0417	GONNURU AKHILA SAI
18	18911A0418	JAMPANI AMARESH
19	18911A0419	JAVVAJI VISHNU KUMAR
20	18911A0420	K KOTESWARA RAO
21	18911A0421	K RADHAKRISHNA
22	18911A0422	KAMMARI RAVI TEJA
23	18911A0423	KANKATA ROHAN SETH
24	18911A0424	KANNAM VENKATA SAI
25	18911A0425	KOTHAKAPU SHASHIVARDHAN REDDY
26	18911A0426	KURUVA NIHARIKA
27	18911A0427	KYATHAM SANDEEP YADAV
28	18911A0428	LAKNAPURAM PRANEETH KUMAR REDDY
29	18911A0429	M RAKESH
30	18911A0430	MACHA VINAY KUMAR
31	18911A0431	MADHAM SHETTY MEGHANA
32	18911A0432	MADIHA FAREHA FAIYYAZ
33	18911A0433	MADURAI HIRANMEIH
34	18911A0434	MAHAJAN SHARANMAI
35	18911A0435	MALAPATI GREESHMANTH REDDY

36	18911A0436	MANGIPUDI ROHIT
37	18911A0437	MARIYALA BHARADWAJ
38	18911A0438	MASIPEDDI VIKRAM RAO
39	18911A0439	MENDE SRAVAN KUMAR YADAV
40	18911A0440	MOHD ZEESHAN KAREEM
41	18911A0441	MUNAGALA VARUN
42	18911A0442	NAGABHAIRAVA SAKETH
43	18911A0443	NAKKA RANJITH KUMAR
44	18911A0444	NIKHIL TEJA MANDAN
45	18911A0445	P AKHILESH REDDY
46	18911A0446	P SAI SUDHEER CHARY
47	18911A0447	PAKANATI SHARATH KUMAR
48	18911A0448	PAPAGARI SANGEETHA
49	18911A0449	RAGHUPATHI PRIYANKA
50	18911A0450	RAVULAKOLA LAVANYA
51	18911A0451	S ABHISHEK GOUD
52	18911A0452	SAYAM SHRAVIKA
53	18911A0453	SINDHUJA GALLA
54	18911A0454	SUGALI HEMANTH KUMAR NAIK
55	18911A0455	TALLURI PARVASH CHOUDHARY
56	18911A0456	TANKALA LEELA PRAKASH
57	18911A0457	TANNIRU BHARATH KUMAR
58	18911A0458	TATTIKOTA EASWARI LAKSHMI SAI EAPSITA
59	18911A0459	UPPULA AJAY
60	18911A0460	VINAYAKA SANJANA

HOD

Time Table

Vidya Jyothi Institute of Technology

(An Autonomous Institution)

DEPARTMENT OF HUMANITIES AND SCIENCES

I- YEAR /I- SEM Time Table
Faculty: Dr. M. Lakshmi

Academic Year : 2018-2019
Sub: Applied Physics

Time/Day	I 9:00-10:00	II 10:00-11:00	III 11:00-12:00	12:00-12:45	IV 12:45-01:45	V 01:45-02:45	VI 02:45-03:45
MON					ECE-A		
TUE							
WED				LUNCH		ECE-A	ECE-A
THU							
FRI	ECE-A						
SAT							

HOD

Lesson Plan

Vidya Jyothi Institute of Technology

(An Autonomous Institution)

DEPARTMENT OF HUMANITIES AND SCIENCES

Lesson Plan

Course : Applied Physics

Name of the Faculty : Dr. M. Lakshmi

Academic year: 2018-19

Year and Semester : B. Tech I year, I Semester

Branch-Section: ECE-A

Course Outcomes:

1. Identify various optical phenomena of light.
2. Discuss the basic principles of quantum mechanics.
3. Classify solids based on the band theory.
4. Elucidate the characteristics of semiconductors and semiconductor devices.
5. Explain the working principle of optical fibers and lasers.

S.No	Topic	No. of classes	Total No. of classes	Text book(Volume)-Page No.	Teaching Aids required
	UNIT I- Wave Optics				
1	Introduction, Principle of Superposition, Coherence	1		TB1(I)-1.1-1.4	Black Board
2	Interference - Interference in thin films by reflection	1		TB1(I)-1.6-1.8	Black Board &LCD
3	Newton's Rings	1		TB1(I)-1.13-1.18	Black Board &LCD
4	Diffraction – Fraunhofer and Fresnel Diffraction	1		TB1(I)-1.2-2.2	Laser and grating, Black Board &LCD
5	Farunhofer diffraction due to single slit	1		TB1(I)-2.3-2.6	Black Board &LCD
6	Plane Diffraction Grating	1	10	TB14(I)-2.10-2.14	Black Board
7	Resolving power of Grating	1		TB1(I)-2.14	Black Board

	(qualitative)				
8	Polarization – Polarization of light waves, Plane of vibration, plane of polarization	1		TB1(I)-3.1-3.3	Polarizer, Black Board
9	Double refraction, Nicol's Prism	1		TB1(I)-3.10-3.12	Black Board &LCD
10	Applications of Polarization	1		TB1(I)-3.20	Black Board &LCD
UNIT-2 Free electron theory and Introduction to Quantum Mechanics					
11	Classical free electron Theory	1	11	TB1(II Ed)-7.1-7.2	Black Board
12	Electrical Conductivity and Ohm's Law	1		TB1(II Ed)-7.2-7.3	Black Board
13	Drawbacks	1		TB1(II Ed)-7.5	Black Board
14	Introduction to quantum physics: Black body radiation- Planck's Law(Qualitative)	1		TB1(II Ed)-5.23-5.25	Black Board& LCD
15	Wave-particle duality, de-Broglie hypothesis of matter waves	2		TB1(II)-1.2-1.4	Black Board
16	Heisenberg uncertainty principle	1		TB1(II)-1.9-1.10	Black Board
17	Time independent Schrodinger equation	1		TB2-3.10-3.11	Black Board
18	Born interpretation of wave function	1		TB1(II)-1.17	Black Board
19	Particle in an infinite potential well (one dimension)	2		TB1(II)-1.17-1.20	Black Board
UNIT-3 Band theory of solids and semiconductors					
20	Kronig-Penny model (qualitative treatment	1	11	TB1(II)-1.29-1.32	Black Board
21	E-k diagram	1		TB1(II)-1.32-1.33	Black Board
22	Energy bands in solids	1		TB1(II)-.35-1.36	Black Board
23	Classification of materials into metals, semiconductors, and insulators	1		TB1(II)-1.36-1.37	Black Board
24	Effective mass	1		TB1(II)-1.33-1.34	Black Board
25	Density of States(qualitative treatment), Fermi distribution function, Fermi level	1		TB2-4.12-4.19	Black Board

	and its importance				
26	Intrinsic semiconductors, carrier concentration in intrinsic semiconductors	2		TB1(II)-2.3-2.7	Black Board
27	Energy band diagram and position of Fermi level in intrinsic semiconductors	1		TB1(II)-2.8	Black Board
28	Equation for electrical conductivity of semiconductors	1		TB1(II)-2.9-2.10	Black Board
29	Extrinsic semiconductors (qualitative treatment)	1		TB1(II)-2.21-2.22	Black Board
UNIT-4 Semiconductor Devices					
30	Direct and indirect band-gap semiconductors	1	10	TB1(II)-2.29-2.30	Black Board
31	Formation of PN junction	1		TB1(II)-2.31-2.32	Black Board
32	Energy diagram of PN junction	1		TB1(II)-2.33-2.35	Black Board
33	I-V characteristics of PN junction diode	1		TB1(II)-2.38-2.39	Black Board
34	Photo diode	1		TB2-9.28,9.29	Black Board
35	Solar cell-efficiency	1		TB1(II)-2.40-2.42	Black Board
36	Light emitting diode and their characteristics	1		TB2-10.36-10.40	Black Board
37	Semiconductor laser: device structure and characteristics	1		TB1(II)-4.20-4.23	Black Board &LCD
38	Hall effect and its applications	2		TB2-10.15-10.18	Black Board
UNIT-5 Fiber Optics and Lasers					
39	Introduction, total internal reflection	1		TB1(I)-5.1-5.2	Black Board &LCD
40	Acceptance angle and numerical aperture	1		TB1(I)-5.3-5.4	Black Board &LCD
41	Step and graded index fibers,	1		TB1(I)-5.8-5.10 & 5.15-5.25	Black Board &LCD
42	Applications of optical fibers	1			
43	Introduction to interaction of radiation with matter: stimulated	1		TB1(I)-4.1-4.2	Black Board &LCD

	absorption, spontaneous emission and stimulated emission		11		
44	Einstein's coefficients- relation	1			
45	Characteristics of a laser, Population inversion	1		TB1(I)-4.6-4.14	Black Board &LCD
46	Important components of a laser: active medium, pumping source, optical resonator	1		TB1(I)-4.9	Black Board &LCD
47	Construction and working of Ruby laser	1		TB1(I)-4.18-4.20	Black Board &LCD
48	Construction and working of He-Ne laser	1		TB1(I)-4.15-4.18	Black Board &LCD
49	Applications of lasers.	1		TB1(I)-4.24-4.29	Black Board &LCD
Total number of classes			53		

Text books:

1. Engineering Physics Volume I & II, by P K Palanisamy : SciTech publication.
2. Engineering Physics by V Rajendran, McGraw Hill Education.

Reference books:

1. Engineering Physics by S O Pillai, Sivakami, New Age International (P) Limited.
2. Physics Volume I & II, Resnick and Halliday, John Wiley and sons, Inc.

Signature of faculty

Signature of HOD

ACADEMIC CALENDAR

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY (AUTONOMOUS)

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(Aziz Nagar, C.B.Post, Hyderabad -500075)

ACADEMIC CALENDAR FOR I B.Tech I & II SEMESTER FOR THE YEAR 2018-19

FIRST SEMESTER		Commencement of Class work :	
	FROM	**TO**	**DURATION**
Orientation Programme	16-07-2018	28-07-2018	2 Weeks
I Spell of Instruction	30-07-2018	08-09-2018	6 Weeks
I Mid Examinations	10-09-2018	11-09-2018	3 Days
II Spell of Instructions	13-09-2018	12-10-2018	4 Weeks & 2 Days
Dussehra Holidays	13-10-2018	21-10-2018	9 Days
II Spell of Instructions Continuation	22-10-2018	14-11-2018	3 Weeks & 3 Days
II Mid Examinations	15-11-2018	17-11-2018	3 Days
Preparation & Practical Examinations	19-11-2018	24-11-2018	1 Week
End Semester Examinations	26-11-2018	08-12-2018	2 Weeks
Semester Break	10-12-2018	15-12-2018	1 Week
SECOND SEMESTER		Commencement of Class work : 17-12-2018	
I Spell of Instruction	17-12-2018	10-01-2019	3 Weeks 4 Days
Sankranthi Holidays	11.01.2019	16.01.2019	6 Days
I Spell of Instruction Continuation	17.01.2019	16.02.2019	4 Weeks 3 Days
I Mid Examinations	18-02-2019	20-02-2019	3 Days
II Spell of Instruction	21-02-2019	17-04-2019	8 Weeks
II Mid Examinations	18-04-2019	20-04-2019	3 Days
Preparation & Practical Examinations	22-04-2019	27-04-2019	1 Week
End Semester/Supplementary Examinations	29-04-2019	11-05-2019	2 Weeks
Summer Vacation	13-05-2019	29-06-2019	7 Weeks
Commencement of class work for II Year I Sem will be from 01-07-2019			

DIRECTOR

Course Delivery Plan

Vidya Jyothi Institute of Technology

(An Autonomous Institution)

DEPARTMENT OF HUMANITIES AND SCIENCES

Course Delivery Plan

Course : Applied Physics
Name of the Faculty : Dr. M. Lakshmi
Year and Semester : B. Tech I year, I Semester

Academic year: 2018-19
Branch-Section: ECE-A

Course Outcomes:

1. Identify various optical phenomena of light.
2. Discuss the basic principles of quantum mechanics.
3. Classify solids based on the band theory.
4. Elucidate the characteristics of semiconductors and semiconductor devices.
5. Explain the working principle of optical fibers and lasers.

S.No	Topic	Expected Date of Completion	Actual Date of completion	Teaching Aid/ Teaching Methodology
UNIT I- Wave Optics				
1	Introduction, Principle of Superposition, Coherence	8/8/2018	8/8/2018	Black Board& LCD
2	Interference – Interference in thin films by reflection	8/8/2018	8/8/2018	
3	Newton's Rings	10/8/2018	10/8/2018	
4	Diffraction – Fraunhofer and Fresnel Diffraction	13/8/2018	13/8/2018	
5	Farunhofer diffraction due to single slit	17/8/2018	17/8/2018	
6	Plane Diffraction Grating	20/8/2018	20/8/2018	
7	Resolving power of Grating (qualitative)	22/8/2018	22/8/2018	

8	Polarization – Polarization of light waves, Plane of vibration, plane of polarization	22/8/2018	22/8/2018	
9	Double refraction, Nicol's Prism	24/8/2018	24/8/2018	
10	Applications of Polarization	27/8/2018	27/8/2018	
UNIT-2 Free electron theory and Introduction to Quantum Mechanics				
11	Classical free electron Theory	29/8/2018	29/8/2018	BlackBoard& LCD
12	Electrical Conductivity and Ohm's Law	29/8/2018	29/8/2018	
13	Drawbacks	31/8/2018	31/8/2018	
14	Introduction to quantum physics: Black body radiation- Planck's Law	27/8/2018	27/8/2018	
15	Wave-particle duality, de-Broglie hypothesis of matter waves	3/9/2018	3/9/2018	
16	Heisenberg uncertainty principle	5/9/2018	5/9/2018	
17	Time independent Schrodinger equation	5/9/2018	5/9/2018	
18	Born interpretation of wave function	7/9/2018	7/9/2018	
19	Particle in an infinite potential well (one dimension)	10/9/2018	10/9/2018	
UNIT-3 Band theory of solids and Semiconductors				
20	Kronig-Penny model (qualitative treatment	12/9/2018	12/9/2018	Black Board& LCD
21	E-k diagram	12/9/2018	12/9/2018	
22	Energy bands in solids	14/9/2018	14/9/2018	
23	Classification of materials into metals, semiconductors, and insulators	17/9/2018	17/9/2018	
24	Effective mass	19/9/2018	19/9/2018	
25	Density of States(qualitative treatment), Fermi distribution function, Fermi level and its importance	19/9/2018	19/9/2018	
26	Intrinsic semiconductors, carrier concentration in intrinsic semiconductors	24/9/2018& 26/9/2018	24/9/2018& 26/9/2018	

27	Energy band diagram and position of Fermi level in intrinsic semiconductors	26/9/2018	26/9/2018	
28	Equation for electrical conductivity of semiconductors	28/9/2018	28/9/2018	
29	Extrinsic semiconductors	01/10/2018	01/10/2018	
UNIT-4 Semiconductor Devices				
30	Direct and indirect band-gap semiconductors	03/10/2018	03/10/2018	Black Board& LCD
31	Formation of PN junction	03/10/2018	03/10/2018	
32	Energy diagram of PN junction	05/10/2018	05/10/2018	
33	I-V characteristics of PN junction diode	08/10/2018	06/10/2018	
34	Photo diode	10/10/2018	10/10/2018	
35	Solar cell-efficiency	10/10/2018	10/10/2018	
36	Light emitting diode and their characteristics	12/10/2018	12/10/2018	
37	Semiconductor laser: device structure and characteristics	24/10/2018	24/10/2018	
38	Hall effect and its applications	24/10/2018	24/10/2018	
UNIT-5 Fiber Optics and Lasers				
39	Introduction, total internal reflection	26/10/2018	26/10/2018	Black Board& LCD
40	Acceptance angle and numerical aperture	29/10/2018	29/10/2018	
41	Step and graded index fibers	31/10/2018	31/10/2018	
42	applications of optical fibers	31/10/2018	31/10/2018	
43	Introduction to interaction of radiation with matter: stimulated absorption, spontaneous emission and stimulated emission	2/11/2018	2/11/2018	
44	Einstein's coefficients- relation	5/11/2018	5/11/2018	
45	Characteristics of a laser , Population inversion	7/11/2018	7/11/2018	

46	Important components of a laser: active medium, pumping source, optical resonator	7/11/2018	7/11/2018	
47	Construction and working of Ruby laser	9/11/2018	9/11/2018	
48	Construction and working of He-Ne laser	12/11/2018	12/11/2018	
49	Applications of lasers.	14/11/2018	14/11/2018	
Total no. of Classes		**53**		

Signature of Faculty

Signature of HOD

Mid Question Papers

(I & II)

Vidya Jyothi Institute of Technology (Autonomous)

(Accredited by NAAC & NBA, Approved By A.I.C.T.E., New Delhi, Permanently Affiliated to JNTU, Hyderabad)
(Aziz Nagar, C.B.Post, Hyderabad -500075)

I Year B.Tech, I Semester I Mid Examination

Branch: ECE,CSE & IT	Duration: 90Min
Sub: Applied Physics	Marks: 20
Date: 14.09.2018	Session: AN

Note : This paper contains two **PART- A** and **PART -B**

PART -A is compulsory which carries 6 Marks

PART- B consists of 3 questions. Answer all the questions

Bloom's Level:

Remember	I
Understand	II
Apply	III
Analyze	IV
Evaluate	V
Create	VI

	PART-A (3Q×2M =6Marks)	Course Outcomes CO	PO	Bloom's Level	Marks
ANSWER ALL THE QUESTIONS					
1.	Two interfering beams have amplitude ratios of 3:1, calculate the intensity ratio of bright and dark fringes.	1	1,2,3	3	2
2.	Write the difference between a matter wave and an electromagnetic wave.	2	1,12	4	2
3.a)	Differentiate Fresnel and Fraunhofer diffraction.	1	2	4	1
b)	Calculate the minimum energy of free electron trapped in a 1 dimensional box of width 0.2 nm	2	1,2,3,4	3	1

	PART-B (5+5+4= 14 Marks)	Course Outcomes CO	PO	Bloom's Level	Marks
ANSWER ALL THE QUESTIONS					
4.i.	Explain interference in thin film with a neat diagram and derive the condition for dark and bright fringe.	1	1	2	5
	[OR]				
ii.a)	Describe the construction and working of a Nicol's prism	1	1	2	3
b)	For a grating, the angle of diffraction for the second order principal maximum for the wave length 5×10^{-5} cm is 30°. Find the number of lines per cm of the grating.	1	1,12	3	2
5. i.a)	Derive Ohm's law based on Drude and Lorentz free electron theory.	2	1	3	5
	[OR]				
ii.a)	Describe the concept of de-Broglie hypothesis - matter waves and derive the expression for de-Broglie wavelength	2	1,2,3,12	2	3
b)	Determine the wavelength of matter wave associated with electron accelerated by a potential of 1600V.	2	2,3,4	3	2
6.i)	Discuss the Kronig-Penny model for the motion of an electron in a periodic potential.	3	1,2,12	3	4
	[OR]				
ii)	Derive an expression for effective mass of an electron.	3	1,4,12	3	4

Vidya Jyothi Institute of Technology (Autonomous)

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(Aziz Nagar, C.B.Post, Hyderabad -500075)

I Year B.Tech I Semester II Mid Examination

Branch: ECE,CSE & IT	Duration: 90Min
Sub: Applied Physics	Marks: 20
Date: 19.11.2018	Session: AN

Note : This paper contains two **PART- A** and **PART -B**

PART -A is compulsory which carries 6 Marks

PART- B consists of 3 questions. Answer all the questions

Bloom's Level:

Remember	I
Understand	II
Apply	III
Analyze	IV
Evaluate	V
Create	VI

	PART-A (3Q×2M =6Marks)	Course Outcomes CO	Course Outcomes PO	Bloom's Level	Marks
ANSWER ALL THE QUESTIONS					
1.	Calculate the wavelength of radiation emitted by LED made up of GaAs with band gap energy 1.43 eV	4	3,5	4	2
2.	Write the characteristics of laser.	5	1, 3	3	2
3.a)	Write the applications of solar cell	4	3,5	3	1
b)	What is the basic principle of an optical fiber?	5	1	2	1

	PART-B (5+5+4= 14 Marks)	Course Outcomes CO	Course Outcomes PO	Bloom's Level	Marks
ANSWER ALL THE QUESTIONS					
4.i.	Derive an expression for the density of electrons in the conduction band of an intrinsic semiconductor	3	1,12	3	4
	[OR]				
ii.a)	Derive an expression for the density of holes in the valence band of an intrinsic semiconductor	3	1,12	3	4
5. i.a)	Explain in detail about Hall Effect and also list out its applications.	4	1, 3,5	3	5
	[OR]				
ii.a)	Draw the V-I characteristic curve of a PN junction diode and explain.	4	1,12	2	4
b)	Write any two applications of Photodiode.	4	3,5	3	1
6.ia)	Explain the construction and working of He-Ne laser.	5	1,12	3	4
b)	Write any two applications of laser.	5	1,3,5	3	1
	[OR]				
ii)	Classify and explain the types of optical fibers	5	1,3,12	4	5

Assignments (I&II)

Unit Wise Assignments (With different Levels of thinking – Blooms Taxonomy and Course Outcomes)

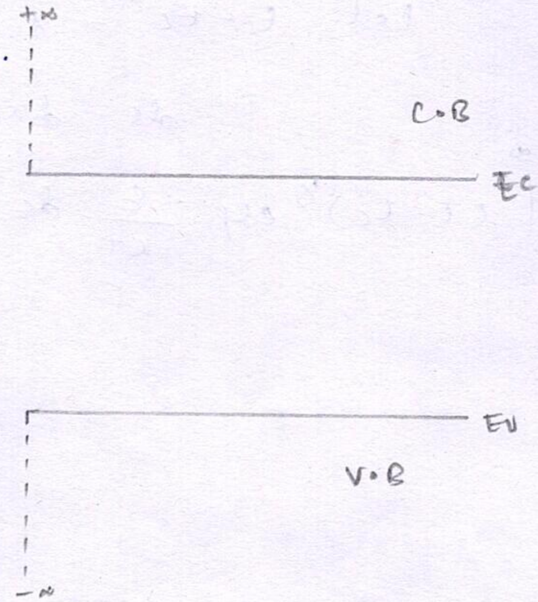
Unit – I		**CO's**	**BL**
1	Explain Newton rings experiment	1	2
2	Differentiate Fresnel and Fraunhofer diffraction	1	2
3	Describe construction and working of Nicol's prism	1	2
Unit – II			
1	Explain Matter waves and their properties.	2	2
2	Derive Schrödinger's time independent wave equation.	2	3
3	Describe in detail about Classical free electron theory.	2	2
4	Elucidate the physical significance of wave function.	2	2
Unit – III			
1	Derive an expression for the carrier concentration in N-type semiconductor.	3	3
2	Explain the concept of effective mass.	3	2
3	Describe Kronig-Penny model	3	2
4	Classify the materials based on band gap.	3	4
Unit – IV			
1	Explain Hall effect and its applications.	4	2
2	Describe the characteristics of Solar cell and LED	4	2
3	Differentiate direct and indirect band gap semiconductors	4	2
Unit – V			
1	Derive expressions for the numerical aperture and acceptance angle of an optical fiber.	5	3
2	List out applications of Lasers	5	2

A. Srivani 18911A0403 (ECE-A)

(1) Derive Concentration of electrons in case of intrinsic semi conductor.

<u>Carrier concentration in intrinsic semi-conductors</u>.

The total no. of charge carriers (i.e, no. of electrons in conduction band and no. of holes in valence band). per unit volume of the material is known as charge carrier concentration.



<u>Concentration of electrons</u>:

$$dn = Z(E)\, f(E)\, dE$$

$$\int dn = \int_{Ec}^{\infty} Z(E)\, f(E)\, dE$$

$$n = \int_{Ec}^{\infty} Z(E)\, f(E)\, dE \quad \text{— (1)}$$

where $Z(E)$ is the density of states.

$$Z(E) = \frac{4\pi}{h^3}(2m_e^*)^{3/2}(E - Ec)^{1/2} \quad \text{— (2)}$$

$$f(E) = \frac{1}{1 + \exp \frac{E - E_F}{KT}} \quad [\because 1 \text{ is neglected}]$$

$$= \frac{1}{\text{Exp}\ \frac{E - E_F}{KT}}$$

$$= \exp -\left(\frac{E - E_F}{KT}\right)$$

$$f(E) = \exp\left(\frac{E_F - E}{KT}\right) \quad \text{— (3)}$$

Sub ② and ③ in ①

$$n = \int_{E_C}^{\infty} \frac{4\pi}{h^3} (2m_e^*)^{3/2} (E-E_C)^{1/2} \cdot \exp\left(\frac{E_F - E}{KT}\right) \cdot dE$$

$$n = \frac{4\pi}{h^3} (2m_e^*)^{3/2} \exp \cdot \frac{E_F}{KT} \int_{E_C}^{\infty} (E-E_C)^{1/2} \exp\left(\frac{-E}{KT}\right) dE \quad \text{— ④}$$

Let $E - E_C = x = E - x + E_C$

$$dE = dx.$$

$$\int_{E_C}^{\infty} (E-E_C)^{1/2} \exp \frac{-E}{KT} dE = \int_0^{\infty} x^{1/2} \exp -\left(\frac{x+E_C}{KT}\right) dx.$$

$$= \exp -\frac{E_C}{KT} \int_0^{\infty} \exp \frac{-x}{KT} dx.$$

$$= \exp -\frac{E_C}{KT} \times (KT)^{3/2} \frac{\pi^{1/2}}{2} \quad \text{— ⑤}$$

$$\left[\because \int_0^{\infty} x^{1/2} \exp . \frac{x}{KT} dx = (KT)^{3/2} \frac{\pi^{1/2}}{2} \right]$$

Sub this integration in above eq. ⑤ in ④

$$n = \frac{4\pi}{h^3} (2m_e^*)^{3/2} \exp \frac{E_f}{KT} \times \exp -\frac{E_C}{KT} (KT)^{3/2} \frac{\pi^{1/2}}{2}$$

$$\boxed{n = 2\left(\frac{2m_e^* \pi KT}{h^2}\right)^{3/2} \exp\left[\frac{E_F - E_C}{KT}\right]}$$

This equation represents the concentration of electrons in conduction band.

② Derive concentration of holes in intrinsic semi-conductor.

No. of holes a valency band

$$dP = Z(E)\,(1 - F(E))\,dE \quad \text{—— ①}$$

$$P = \int Z(E)\,(1 - F(E))\,dE$$

$$Z(E) = \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V - E)^{1/2} \quad \text{—— ②}$$

$$F(E) = \frac{1}{1 + \exp\frac{E - E_F}{kT}}$$

$$1 - F(E) = \left(1 - \frac{1}{1 + \exp\frac{E - E_F}{kT}}\right)^{-1}$$

$$= 1 - \left(1 - \exp\frac{E - E_F}{kT}\right)$$

$$= 1 - 1 + \exp\frac{E - E_F}{kT}$$

$$1 - F(E) = \exp\left(\frac{E - E_F}{kT}\right) \quad \text{—— ③}$$

Sub ② and ③ in ①

$$P = Z(E)\,(1 - F(E))\,dE$$

$$= \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V - E)^{1/2}\exp\left(\frac{E - E_F}{kT}\right)dE$$

$$= \frac{4\pi}{h^3}(2m_h^*)^{3/2}\exp\frac{-E_F}{kT}\int (E_V - E)^{1/2}\exp\frac{E}{kT}\,dE \quad \text{—— ④}$$

let $E_v - E = x \Rightarrow E_v - x = E$

$-dE = dx.$

$$\int_{-\infty}^{E_v} (E_v - E)^{1/2} \exp \frac{E}{kT} \, dE = \int_{\infty}^{0} x^{1/2} \exp \frac{E_v - x}{kT} \, - dx.$$

$$= \exp \frac{E_v}{kT} \int_{0}^{\infty} x^{1/2} \exp - \frac{x}{kT} \, dx.$$

$$= \exp \frac{E_v}{kT} \cdot (kT)^{3/2} \frac{\pi^{1/2}}{2} \quad \text{—⑤}$$

Sub ⑤ in ④

$$P = \frac{4\pi}{h^3} (2m_h^*)^{3/2} \exp - \frac{E_F}{kT} \times \exp \frac{E_v}{kT} \times (kT)^{3/2} \frac{\pi^{1/2}}{2}$$

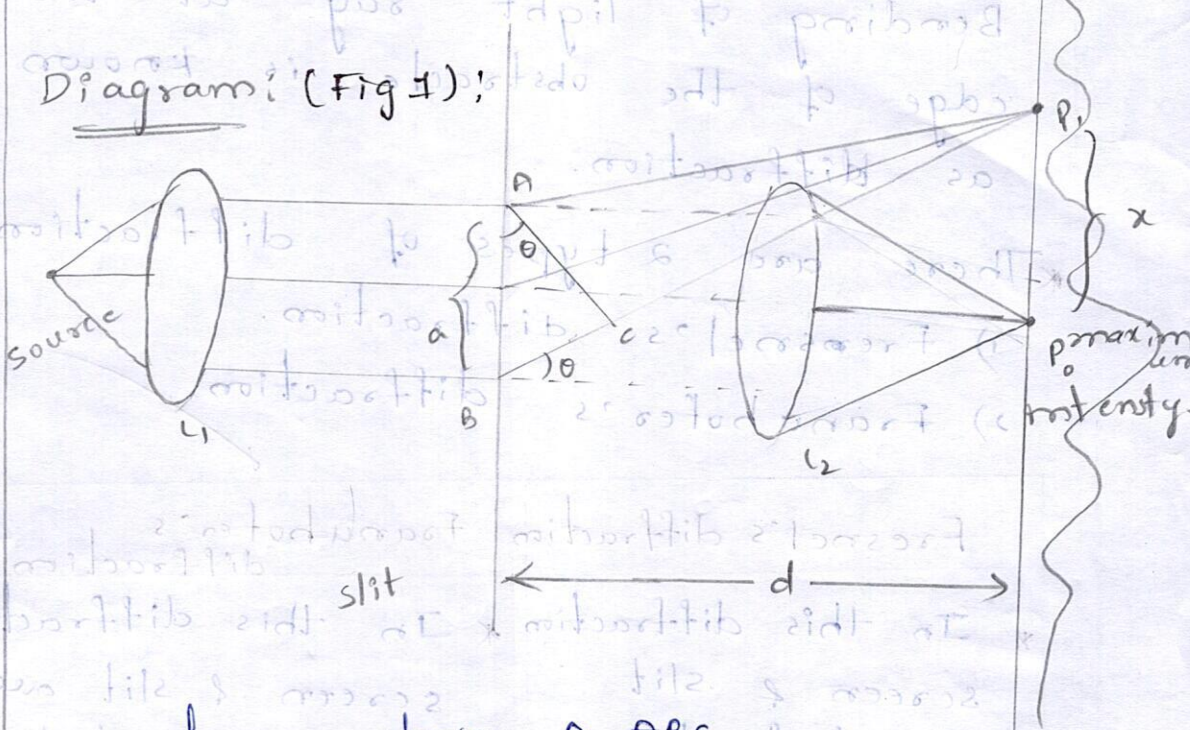
$$\boxed{P = 2 \left(\frac{2 m_h^* \pi kT}{h^2} \right)^{3/2} \exp \frac{E_v - E_F}{kT}}$$

This equation represents the concentration of holes in valency band.

Single slit diffraction:

Single slit diffraction experiment explamed by Franuhofer's:

Diagram: (Fig 1):



from above Δ ABC

$(\because AB = a)$

$$\sin\theta = \frac{BC}{AB}$$

$$\sin\theta = \frac{BC}{a}$$

$$BC = a\sin\theta$$

BC is path difference $BC\ (\Delta) = a\sin\theta$

$$\therefore \Delta = a\sin\theta$$

when two lights are difracted at edge of obstracle then the path difference is $\lambda/2$

$$\therefore \Delta = a\sin\theta + \lambda/2 \rightarrow (1)$$

case 1|

Condition for maximum|

The path difference for constructive interference $\Delta = n\lambda \rightarrow (2)$

equating (1) & (2) eqns,

we get,

$$n\lambda = a\sin\theta + \lambda/2$$

$$a\sin\theta = n\lambda - \lambda/2$$

$$= \lambda(2n-1)/2$$

$$\boxed{a\sin\theta = (2n-1)\lambda/2}$$

case 2|

Condition for minimum|

The path difference for destructive interference is $\Delta = (2n+1)\lambda/2 \rightarrow (3)$

equating (1) & (3) eqns, we get,

$$(2n+1)\lambda/2 = a\sin\theta + \lambda/2$$

$$2n\lambda + \lambda/2 = a\sin\theta + \lambda/2$$

$$\boxed{a\sin\theta = n\lambda}$$

* In Diffraction

from above eqn we get can take $\sin\theta \approx \theta$

$$a\theta = n\lambda$$

From First order, lineal eqn

we get, $n=1$

then $a\theta = \lambda$

$$\theta = \frac{\lambda}{a} \rightarrow (4)$$

from fig 1!

$$\sin\theta = \frac{P_1P_0}{d}$$

$\because P_1P_0 = x$

$$\theta = \frac{P_1P_0}{d}$$

$$\theta = \frac{P_1P_0}{d} = \frac{x}{d} \rightarrow (5)$$

equating (4) & (5) eqn we get,

$$\frac{\lambda}{a} = \frac{x}{d}$$

$$a = \frac{\lambda d}{x}$$

5/5

EAPSITA
18911A0458
ECE A

Q. Differentiate Spontaneous & Stimulated emissions.

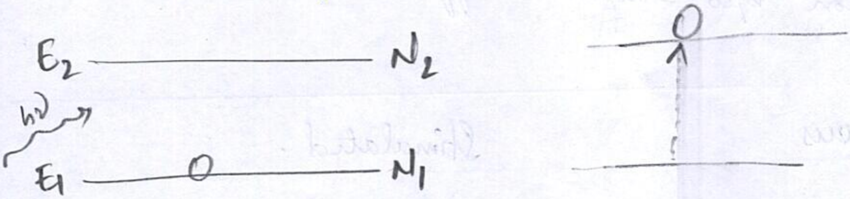
Q. Derive the relation b/w Einstein coefficients.

Spontaneous	Stimulated.
→ After lifetime of excited atom it falls down to ground state emitting some energy i.e radiation.	When atom is in excited state, an extra photon is supplied such that atom becomes highly unstable & falls down to the ground state before its lifetime.
→ emits one photon	→ emits two photons
→ Slow process	→ Quick process
→ Intensity is low	→ Intensity is high
→ Directionality is poor (i.e incoherent)	→ Directionality is high (i.e coherent)
→ Spreading is more	→ Spreading is less.
→ Broad spectrum	→ Narrow Spectrum
Ex: Ordinary light, sun, stars...etc.	Ex: LASER

2. Einstein Coeff:

Case I

Absorption of radiation



Shifting Probability (P_{12}) from $E_1 \rightarrow E_2$ depends on number of atoms in first level and supplied energy density.

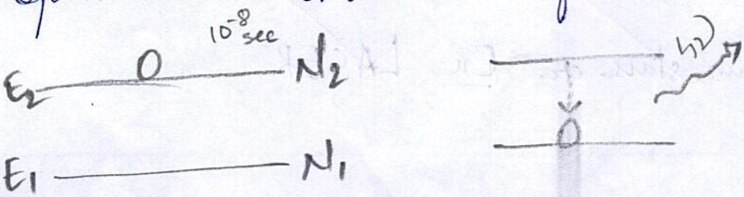
$$P_{12} \propto N_1 u(\nu)$$

$$P_{12} = B_{12} N_1 u(\nu) \quad \text{——} \quad (1)$$

where B_{12} is the Einstein coefficient of absorption of radiation.

Case - II

Spontaneous emission of radiation



Shifting probability (P_{21}) from $E_2 \rightarrow E_1$ depends on number of atoms in level-II.

$$P_{21}(sp) \propto N_2$$

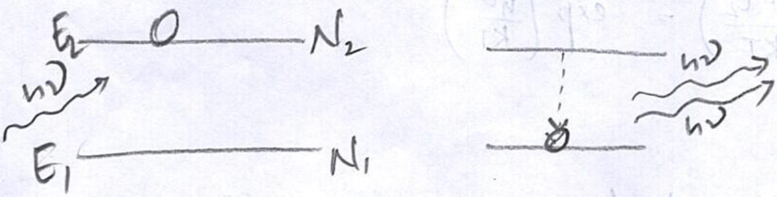
$$P_{21}(sp) = A_{21} N_2 \quad \text{---} (2)$$

where

A_{21} is Einstein coefficient for spontaneous emission of radn.

Case - III

Stimulated emission



Shifting probability (P_{21}) depends on number of atoms in second level and amount of energy density supplied.

$$P_{21}(st) \propto N_2 u(\nu)$$

$$P_{21}(st) = B_{21} u(\nu) \quad \text{---} (3)$$

where

B_{21} is Einstein coefficient for stimulated emission of radiation

$\therefore$ Total downward transition $P_{21} = P_{21}(sp) + P_{21}(st)$

$$= A_{21} N_2 + B_{21} N_2 u(\nu)$$

At equilibrium

$$P_{12} = P_{21}$$

$$B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$$

$$u(\nu)\left[B_{12}N_1 - B_{21}N_2\right] = A_{21}N_2$$

$$u(\nu) = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

$\div B_{21}N_2$ ~~anbs~~.

$$\Rightarrow u(\nu) = \frac{A_{21}N_2 / B_{21}N_2}{\frac{B_{12}N_1}{B_{21}N_2} - 1}$$

According to Boltzmann

$$\frac{N_1}{N_2} = \exp\left(\frac{E_1 - E_2}{KT}\right) = \exp\left(\frac{h\nu}{KT}\right)$$

$$\therefore \text{Above eqn} \rightarrow u(\nu) = \frac{A_{21}/B_{21}}{\left(\frac{B_{12}}{B_{21}}\right)\exp\left(\frac{h\nu}{KT}\right) - 1} \quad \text{—— (4)}$$

According to Planck

$$u(\nu) = \frac{8\pi h\nu^3/c^3}{\exp\left(\frac{h\nu}{KT}\right) - 1} \quad \text{—— (5)}$$

Comparing (4) & (5) $\rightarrow$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

$$\Rightarrow \boxed{\frac{A_{21}}{B_{21}} \propto \nu^3} \quad \text{—— (6)}$$

$$\Rightarrow \frac{B_{12}}{B_{21}} = 1$$

$$\rightarrow \boxed{B_{12} = B_{21}} \quad \text{—— (7)}$$

5/5

$\therefore$ (6) & (7) represent the relations b/w Einstein coefficients.

D. Nived Kumar
Roll. No: 18911A0412

Date: 25/08/2018

Diffraction:

The bending nature of a wave at the edge of an obstacle is called Diffraction.

Diffraction is two types:

1) Fresnel diffraction
2) Franhoffer diffraction

Fresnel Diffraction	Franhoffer Diffraction
1) The distance b/w the Screen and source is finite	1) The distance b/w the screen and Source is infinite
2) The wave is in the form of cylindrical (or) spherical	2) The wave is in the form of parallel
3) The lenses are not required	3) Lenses are required.

Single-Slit diffraction:

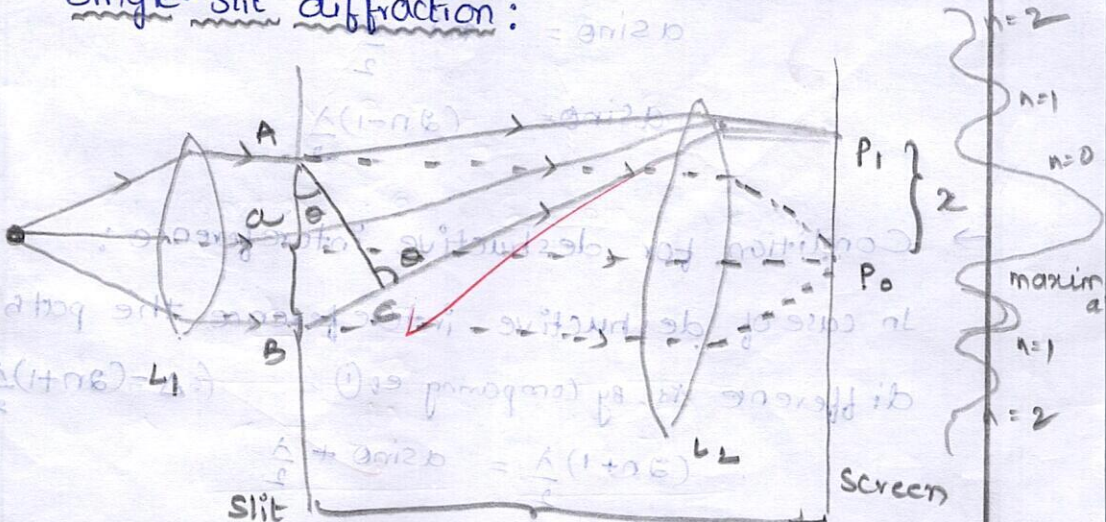


figure-1

from Δ^{le} ABC;

$$\sin\theta = \frac{BC}{AC}$$

$$\sin\theta = \frac{BC}{a}$$

$$\Delta = BC = a\sin\theta$$

The path difference b/w two diffracted rays when they passing through an edge of obstacle is $\left(\frac{\lambda}{2}\right)$.

Δ

$\therefore$ The total path difference is:

$$\Delta = a\sin\theta + \frac{\lambda}{2} \quad \text{—} \; (1)$$

→ The condition for constructive interference:

In case of constructive intereference the path difference is, By comparing eq (1); $(\because \Delta = n\lambda)$

$$n\lambda = a\sin\theta + \frac{\lambda}{2}$$

$$a\sin\theta = n\lambda - \frac{\lambda}{2}$$

$$a\sin\theta = (2n-1)\frac{\lambda}{2}$$

→ Condition for destructive intereference:

In case of destructive intereference the path differene is, By comparing eq (1); $\left(\because \Delta = (2n+1)\frac{\lambda}{2}\right)$

$$(2n+1)\frac{\lambda}{2} = a\sin\theta + \frac{\lambda}{2}$$

$$(2n+1)\frac{\lambda}{2} = a\sin\theta + \frac{\lambda}{2}$$

$$\frac{2n\lambda}{2} + \frac{\lambda}{2} = a\sin\theta + \frac{\lambda}{2}$$

$$n\lambda = a\sin\theta$$

If $\sin\theta$ is very small angle $\sin\theta \approxeq \theta$, then above equation becomes;

$$a\sin\theta = n\lambda$$

$$a\theta = n\lambda$$

for first order maxima $(n=1)$; above eqn becomes;

$$a\theta = \lambda$$

$$\therefore \theta = \frac{\lambda}{a} \quad \text{--- (2)}$$

from figure (1);

$$\sin\theta = \frac{P_0P_1}{d}$$

$$\Rightarrow x = d\sin\theta \qquad (\because \sin\theta \approxeq \theta)$$

$$x = d\theta$$

$$\Rightarrow \theta = \frac{x}{d} \quad \text{--- (3)}$$

By comparing (2) & (3) eqn's, we get;

$$\frac{\lambda}{a} = \frac{x}{d}$$

$$\Rightarrow \boxed{x = \frac{d\lambda}{a}} \; ; \; \boxed{a = \frac{d\lambda}{x}}$$

ok

5/5

Previous End semester Question papers

Vidya Jyothi Institute of Technology (Autonomous)

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(Aziz Nagar, C.B.Post, Hyderabad -500075)

Subject code: A21003 | **R18**

I B. Tech I SEM REGULAR EXAMINATION – DECEMBER 2018

APPLIED PHYSICS

(COMMON TO ECE, CSE & IT)

Time: 3hrs **Max.Marks:75**

Note: This question paper contains two PARTs A and B.

PART A is compulsory which carries 25 marks. Answer all questions.

PART B consists of 5 questions. Answer all the questions.

PART - A

ANSWER ALL THE QUESTIONS **25 M**

1. Explain coherence and write in brief the methods to produce coherent sources [3M]
2. Write a note on polarization. [2M]
3. Calculate de-Broglie wavelength of an electron accelerated by potential of 100V and 300V. [3M]
4. Write about Heisenberg's Uncertainity principle. [2M]
5. Write in brief the importance of Fermi Distribution function [3M]
6. Write about E-K diagram. [2M]
7. Write in brief Direct and Indirect bandgap semiconductor materials [3M]
8. List out the advantages of LED [2M]
9. Draw the refractive index profile of SIF and GIF optical fibers [2M]
10. Write in brief the characteristics of laser. [3M]

PART-B

ANSWER ALL THE QUESTIONS **5QX10M=50M**

11.i). Explain in detail about Newton rings experiment [10M]

(OR)

ii). Discuss in detail the diffraction of light due to single slit and get the necessary conditions.[10M]

12.i). Explain in detail Davisson and Germer Experiment with a neat diagram [10M]

(OR)

ii). Show that the energies of a particle in the one dimensional potential box are quantized [10M]

13. i). Derive an expression for the carrier concentration of an intrinsic semiconductor [10M]

(OR)

ii). Discuss in detail Kronig-Penny Model and give the conclusions [10M]

14.i). Explain in detail Hall Effect and give the applications in brief [10M]

(OR)

ii). a) Explain how a PN junction is formed [5M]

b) Draw and explain the V-I characteristic curve of a PN junction diode [5M]

15. i) a). Discuss in detail the optical fiber losses [5M]

b) Write the applications of optical fibers. [5M]

(OR)

ii). Explain in detail He-Ne laser and give the applications [10M]

VJIT(A)

Course End Survey

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY
(Accredited by NAAC & NBA, Approved by AICTE New Delhi & Permanently Affiliated to JNTUH)
Aziz Nagar Gate, C.B. Post, Hyderabad-500 075.

Department of Humanities & Sciences
Course End Survey Form

COURSE EXIT SURVEY FOR INDIRECT ATTAINMENT

Academic year: 2018-2019 **Regulations: R 18**

Name of the student		**Year & Sem**	**I Yr I Sem**
Roll number		**Subject**	**Applied Physics**

Dear Student,

We need your help in evaluating the courses offered, by responding the short survey below.

Your feedback is very valuable for us in order to continually improve our program. The aim of this survey is to evaluate how well each of the courses has prepared you to have necessary skills.

Your responses will be kept confidential and will not be revealed to anyone outside the department without your permission.

Please indicate (√) the level to which you agree with the following criterion:

(1: Low 2: Moderate 3: High)

Name of The Course:English		**RATING**		
After completing this course the student must demonstrate the knowledge and ability to		3	2	1
CO 1	Identify various optical phenomena of light			
CO 2	Describe the basic principles of quantum mechanics			
CO 3	Classify solids based on the band theory			
CO 4	Elucidate the characteristics of semiconductors and semiconductor devices			
CO 5	Explain the working principle of lasers and optical fibers			

Any other comments / suggestions:

____

____

____

Signature

Content beyond Syllabus

Topics beyond Syllabus

S. No	Name of the Topic
1	The Dual nature of light
2	Bloch Theory
3	Fiber-Optic communication system
4	Photo electric effect
5	Compton effect

DUAL NATURE OF LIGHT

Light waves have dual nature (wave-particle), wave nature according to Maxwell's electromagnetic wave theory and particle nature according to Max-Planck's quantum theory.

Two natures of light are like the two faces of a coin. In anyone phenomena only its one nature appears. The wave nature of light is seen in phenomena such as diffraction, interference and polarization. On the other hand, in phenomena such as Compton Effect and the photoelectric effect, radiation behaves as a particle known as the photon.

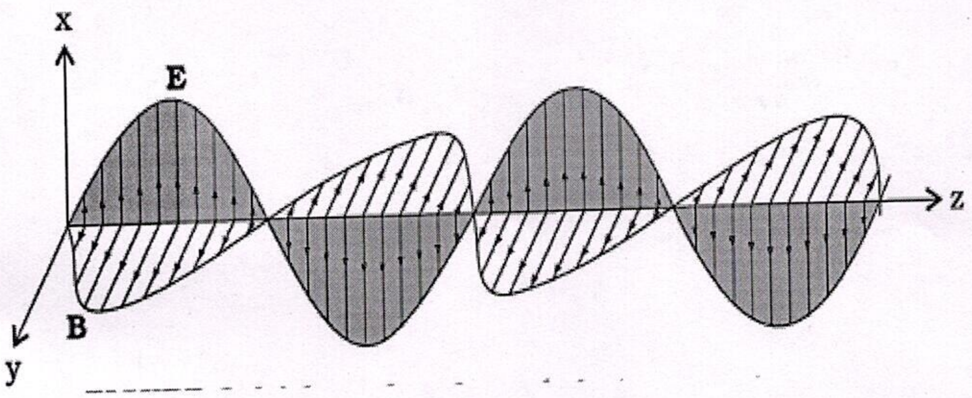


FIGURE. A linearly polarised electromagnetic wave, propagating in the *z*-direction with the oscillating electric field E along the *x*-direction and the oscillating magnetic field B along the *y*-direction.

PHOTOELECTRIC EFFECT

Hertz's observations

The phenomenon of photoelectric emission was discovered in 1887 by Heinrich Hertz (1857-1894), during his electromagnetic wave experiments. In his experimental investigation on the production of electromagnetic waves by means of a spark discharge, Hertz observed that high voltage sparks across the detector loop were enhanced when the emitter plate was illuminated by ultraviolet light from an arc lamp. Light shining on the metal surface somehow facilitated the escape of free, charged particles which we now know as electrons. When light falls on a metal surface, some electrons near the surface absorb enough energy from the incident radiation to overcome the attraction of the positive ions in the material of the surface. After gaining sufficient energy from the incident light, the electrons escape from the surface of the metal into the surrounding space.

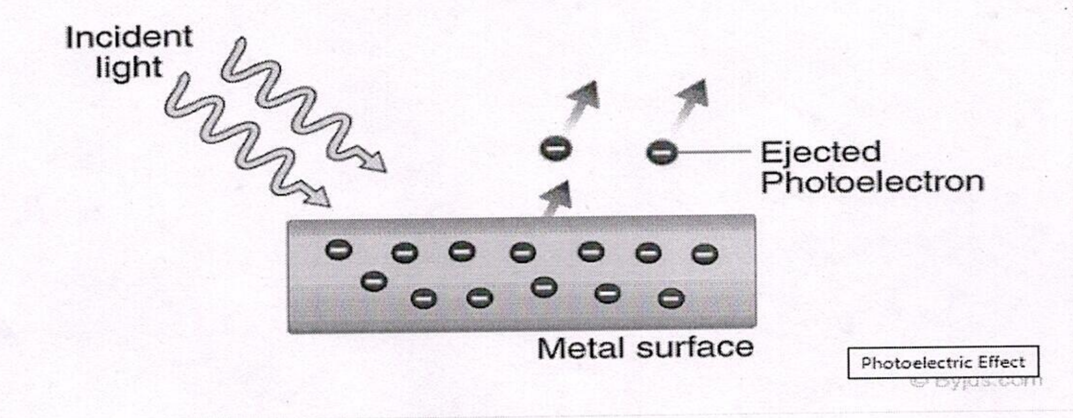
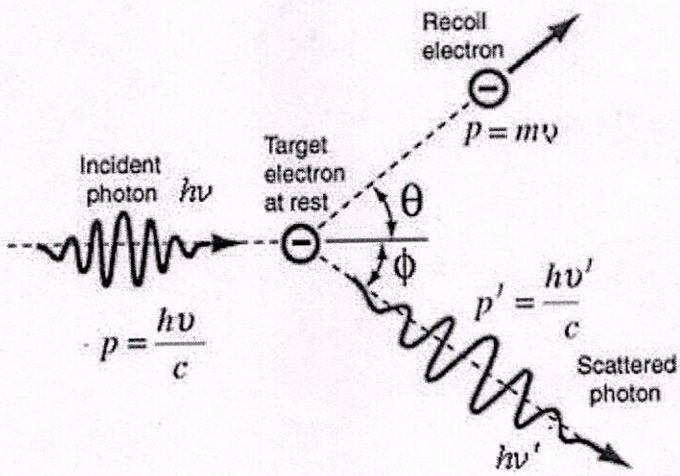


FIGURE. Photoelectric Effect

COMPTON EFFECT

Compton effect, increase in wavelength of X-rays and other energetic electromagnetic radiations that have been elastically scattered by electrons; it is a principal way in which radiant energy is absorbed in matter. The effect has proved to be one of the cornerstones of quantum mechanics, which accounts for both wave and particle properties of radiation

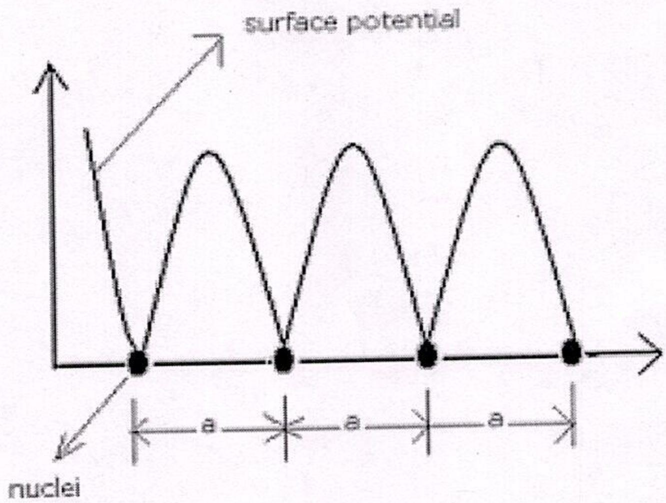


The American physicist Arthur Holly Compton explained (1922; published 1923) the wavelength increase by considering X-rays as composed of discrete pulses, or quanta, of electromagnetic energy. In the Compton effect, individual photons collide with single electrons that are free or quite loosely bound in the atoms of matter. Colliding photons transfer some of their energy and momentum to the electrons, which in turn recoil. In the instant of the collision, new photons of less energy and momentum are produced that scatter at angles the size of which depends on the amount of energy lost to the recoiling electrons. Because of the relation between energy and wavelength, the scattered photons have a longer wavelength that also depends on the size of the angle through which the X-rays were diverted. The increase in wavelength, or Compton shift, does not depend on the wavelength of the incident photon.

BLOCH THEORY

Electrons in a periodic potential - Bloch theory:

A crystalline solid consists of a lattice, which is composed of a large number of ion cores at regular intervals, and the conduction electrons that can move freely throughout the lattice. The conduction electrons move inside periodic positive ion cores. Hence instead of considering uniform constant potential as we have done in the electron theory, we have to consider the variation of potential inside the metallic crystal with the periodicity of the lattice as shown fig. The potential is minimum at the positive ion sites and maximum between the two ions.



Awarded the 1952 Nobel Prize for "their development of new ways and methods for nuclear magnetic precision measurements

Felix Bloch
(1905-1983, Swiss)

BLOCH FUNCTIONS

F. Bloch proved the important theorem that the solutions of the Schrödinger equation for a periodic potential must be of a special form:

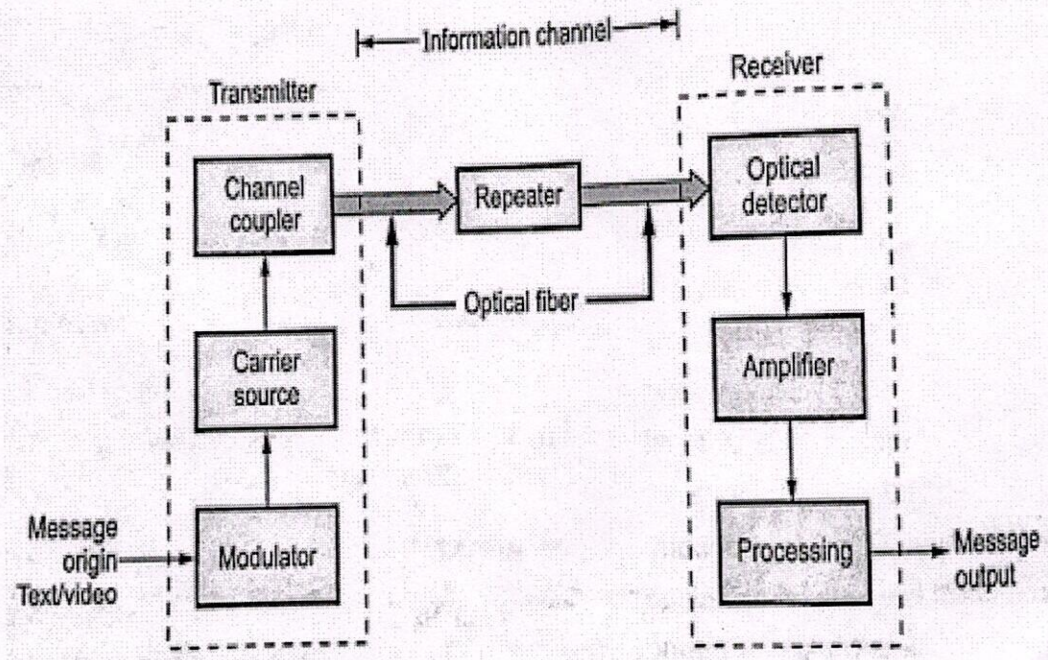
$$\psi_{\mathbf{k}}(\mathbf{r}) = u_{\mathbf{k}}(\mathbf{r}) \exp(i\mathbf{k} \cdot \mathbf{r}) \ , \tag{7}$$

where $u_{\mathbf{k}}(\mathbf{r})$ has the period of the crystal lattice with $u_{\mathbf{k}}(\mathbf{r}) = u_{\mathbf{k}}(\mathbf{r} + \mathbf{T})$. The result (7) expresses the Bloch theorem:

> The eigenfunctions of the wave equation for a periodic potential are the product of a plane wave $\exp(i\mathbf{k} \cdot \mathbf{r})$ times a function $u_{\mathbf{k}}(\mathbf{r})$ with the periodicity of the crystal lattice.

A one-electron wavefunction of the form (7) is called a Bloch function and

FIBER-OPTIC COMMUNICATION SYSTEM



Teaching Learning Methods

The commonly practiced methods are:

1. Interactive Learning

   Plickers cards activity

2. Collaborative Learning

   Think -Pair - Share

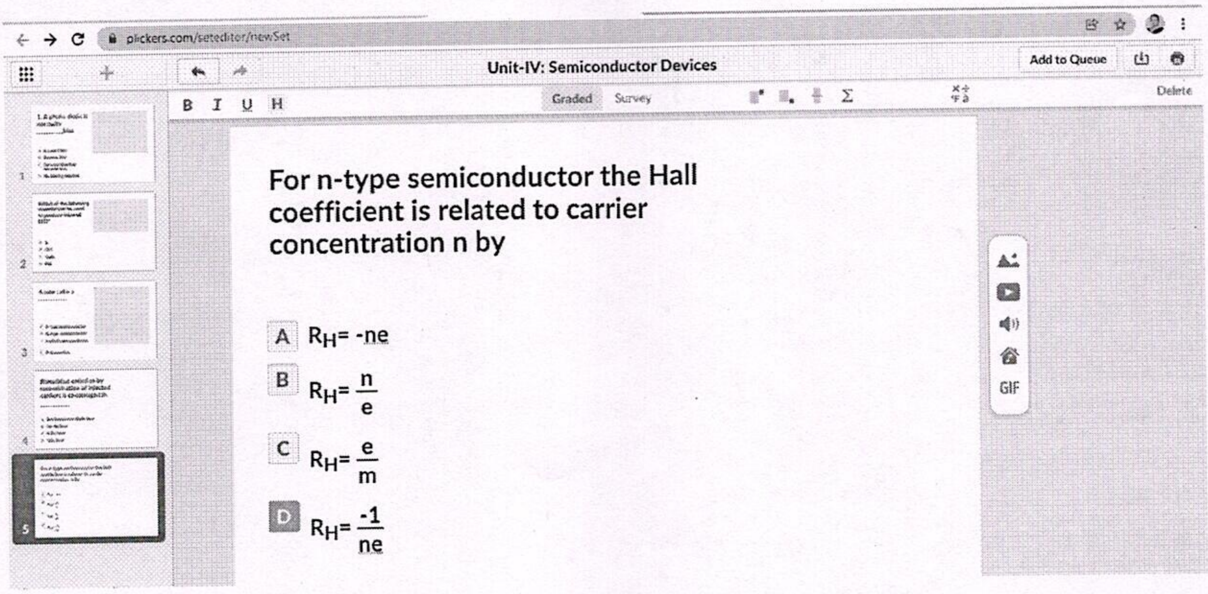
3. Project Based Learning

   Science projects & models

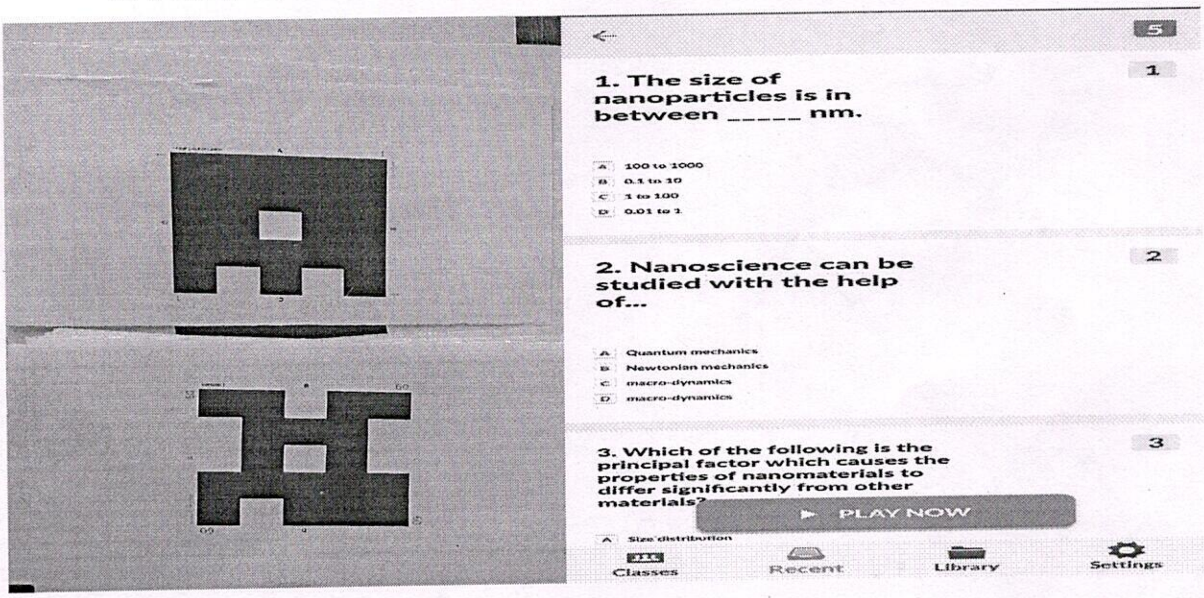
4. Case studies and Analysis

Some other aids like

1. Seminar by students
2. Creating Research groups and Clubs
3. NPTEL Lectures and Virtual lab Videos



Interactive learning- Plicker cards



Unit-IV: Semiconductor Devices

1 1. A photo diode is normally .... bias

A Forward bias
B Reverse bias
C Forward bias than Reverse bias
D No biasing required

2 Which of the following material can be used to produce infrared LED?

A Si
B CdS
C GaAs
D PbS

3 A solar cell is a ....

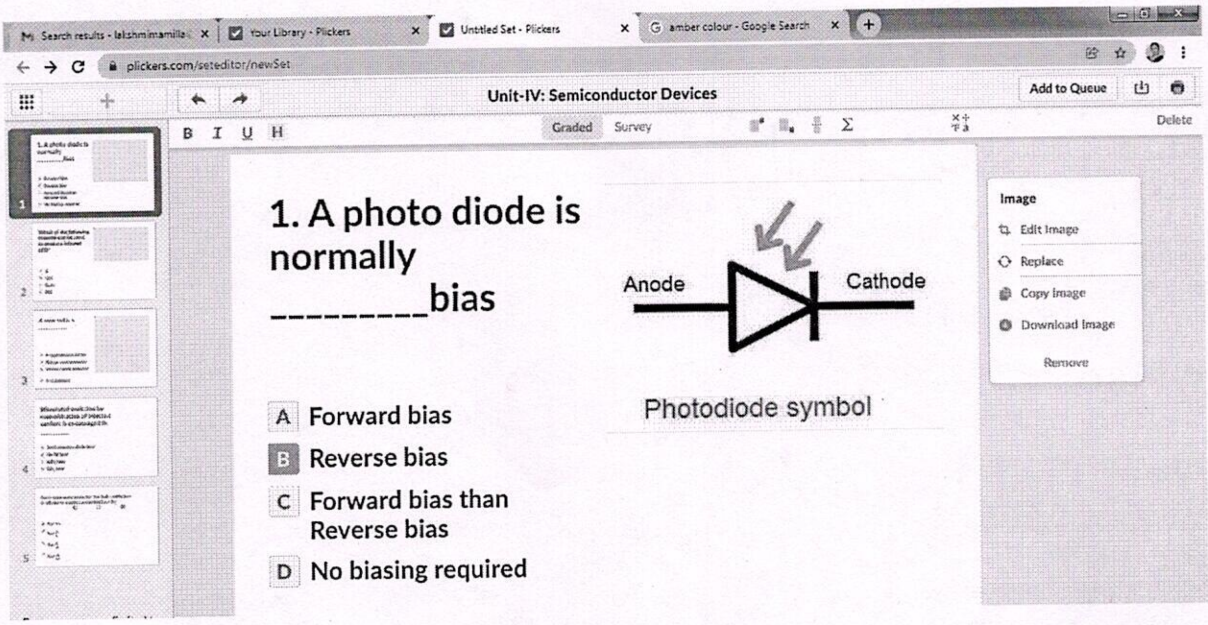
A P-type semiconductor
B N-type semiconductor
C Intrinsic semiconductor
D P-N Junction

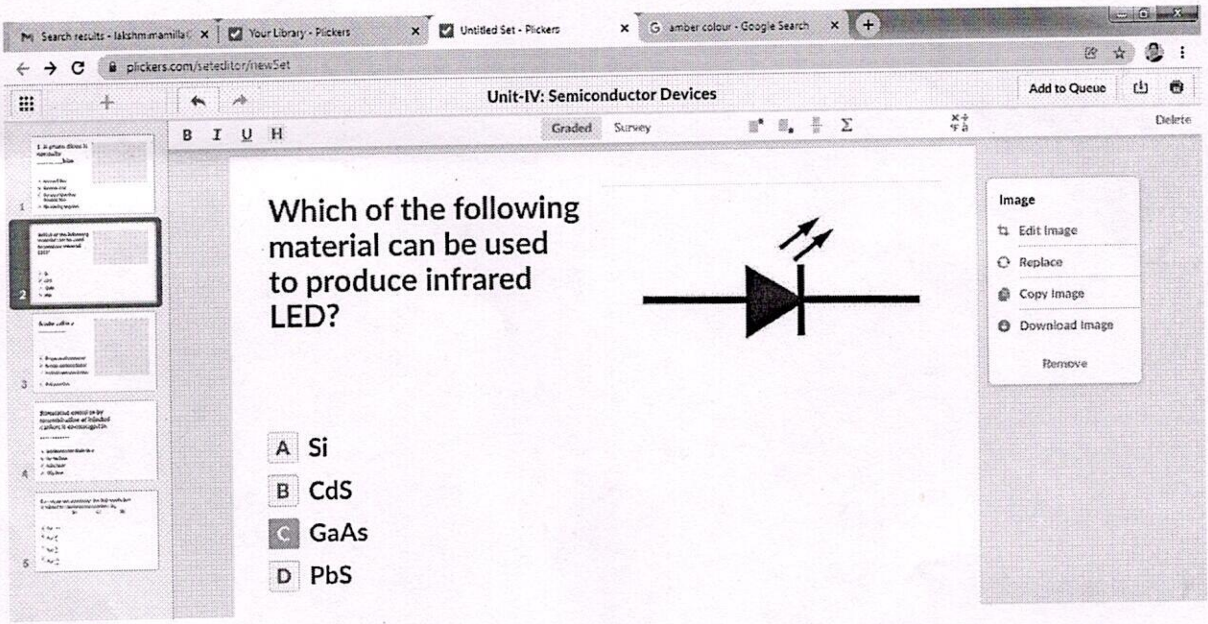
4 Stimulated emission by recombination of injected carriers is encouraged in ....

A Semiconductor diode laser
B He-Ne laser
C Ruby laser
D CO_2 laser

5 For n-type semiconductor the Hall coefficient is related to carrier concentration n by B) C) D)

A $R_H = -ne$
B $R_H = \frac{n}{e}$
C $R_H = \frac{e}{m}$
D $R_H = \frac{-1}{ne}$


Unit-IV: Semiconductor Devices
Graded
Survey
Add to Queue
Delete
1. A photo diode is normally _________bias
Anode
Cathode
Photodiode symbol
A Forward bias
B Reverse bias
C Forward bias than Reverse bias
D No biasing required
Image
Edit Image
Replace
Copy Image
Download Image
Remove


Unit-IV: Semiconductor Devices
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Survey
Add to Queue
Delete
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A Si
B CdS
C GaAs
D PbS
Image
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Replace
Copy Image
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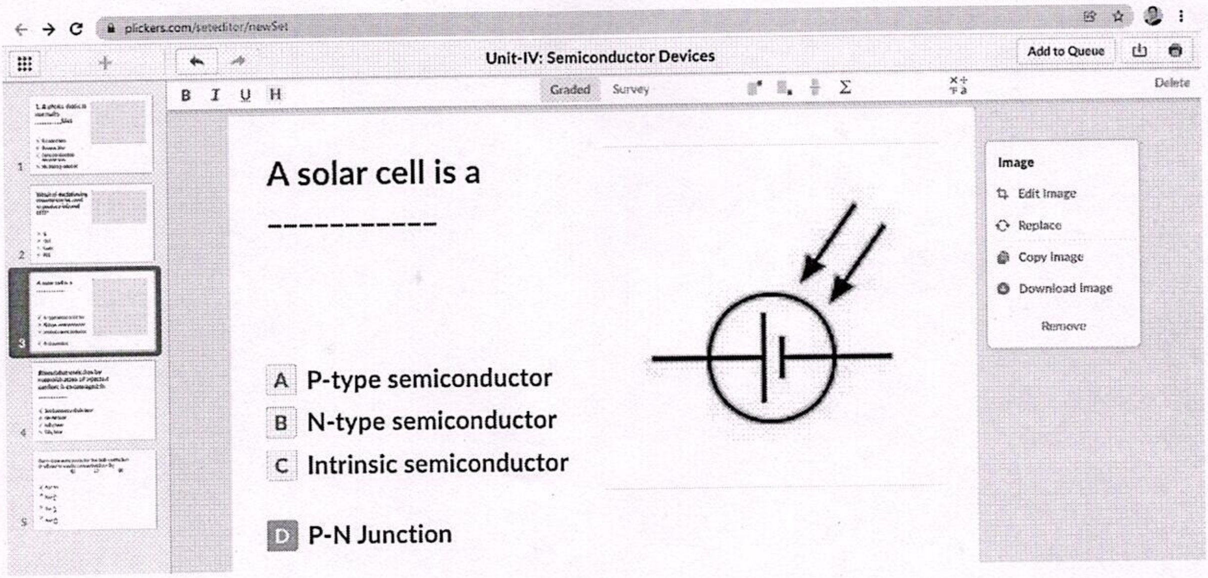
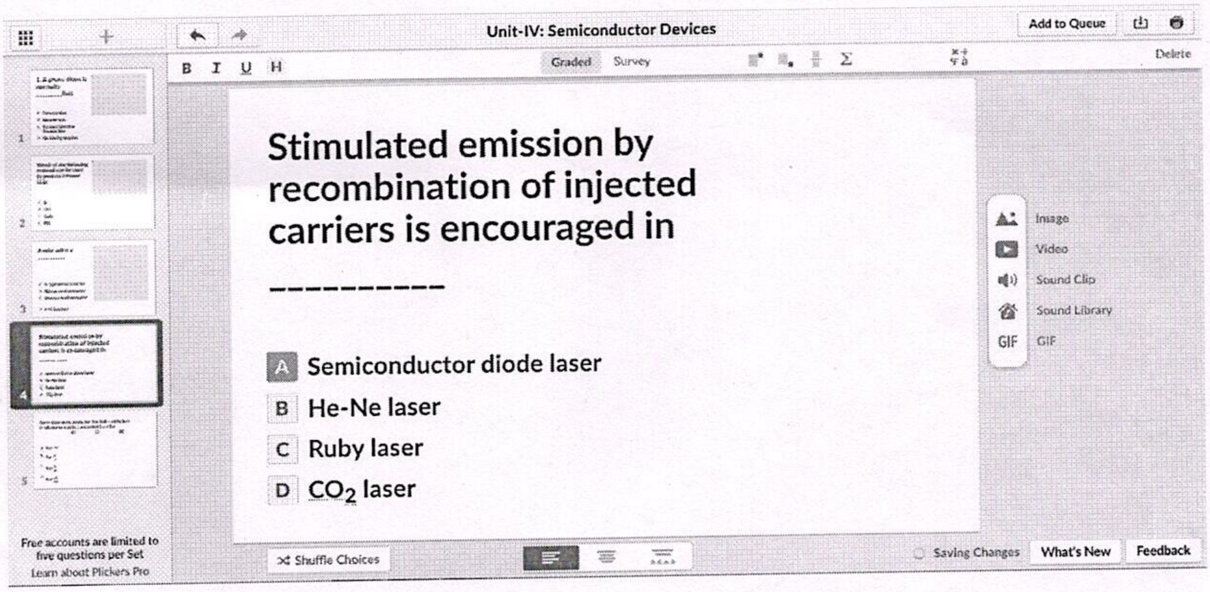

plickers.com/seteditor/newSet
Unit-IV: Semiconductor Devices
Add to Queue
B I U H
Graded
Survey
Delete
A solar cell is a
____
A P-type semiconductor
B N-type semiconductor
C Intrinsic semiconductor
D P-N Junction
Image
Edit Image
Replace
Copy Image
Download Image
Remove


Unit-IV: Semiconductor Devices
Add to Queue
B I U H
Graded
Survey
Delete
Stimulated emission by recombination of injected carriers is encouraged in
____
A Semiconductor diode laser
B He-Ne laser
C Ruby laser
D CO_2 laser
Image
Video
Sound Clip
Sound Library
GIF
Free accounts are limited to five questions per Set
Learn about Plickers Pro
Shuffle Choices
Saving Changes
What's New
Feedback

Innovative/ Student Centric Teaching Method Form

Faculty Name: Dr. M. Lakshmi

Course: Applied Physics

Class-Section: ECE-A

Mode of Innovative Teaching Mode: Think-pair-share (TPS)

Description about the mode:

Think-pair-share (TPS) is a collaborative learning strategy where students work together to solve a problem or answer a question about an assigned reading. This strategy requires students to

(1) Think individually about a topic or answer to a question; and

(2) Share ideas with classmates.

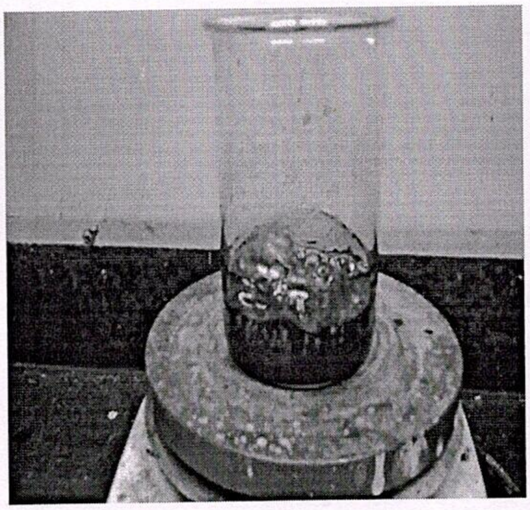
Topic Handled: Interference of Light

- What is interference of waves and its types?
- Give some examples of interference in real life?
- What are the practical applications of interference?

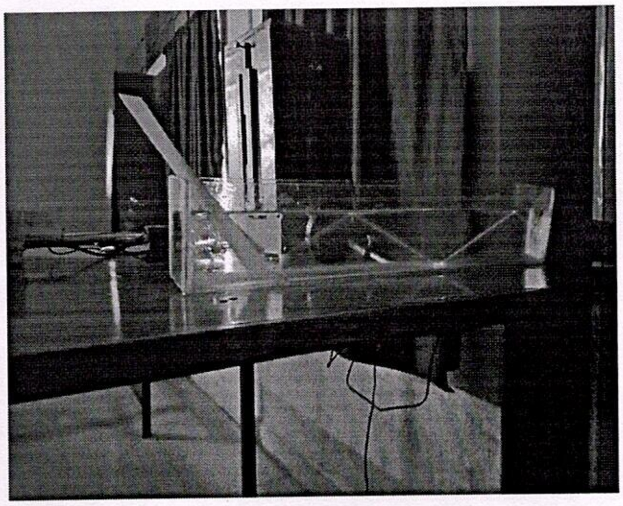
Outcome of the teaching mode:

Students can understand the wave nature of light and apply this knowledge for practical applications of interference

Experimental learning



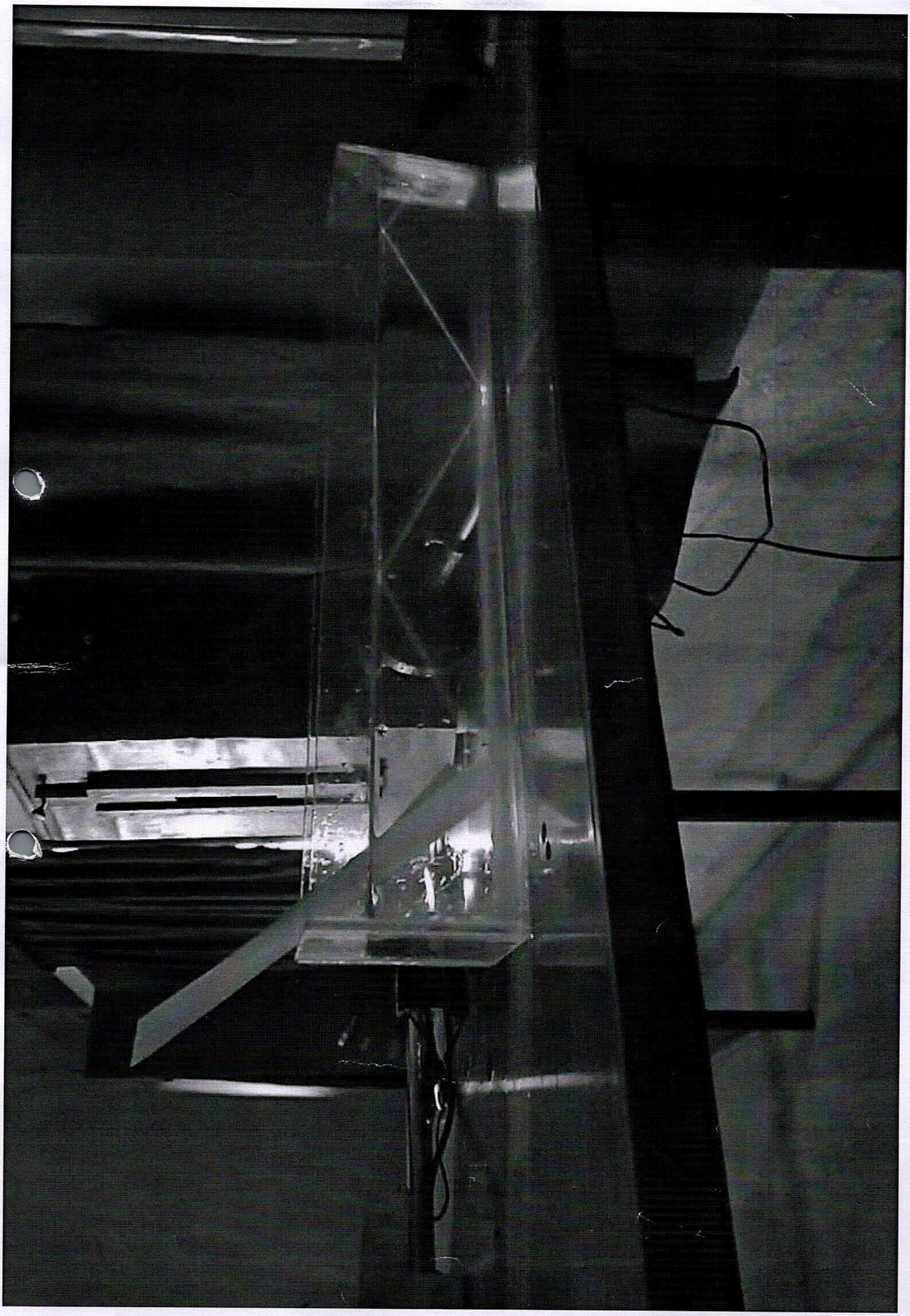
Sol-Gel Method

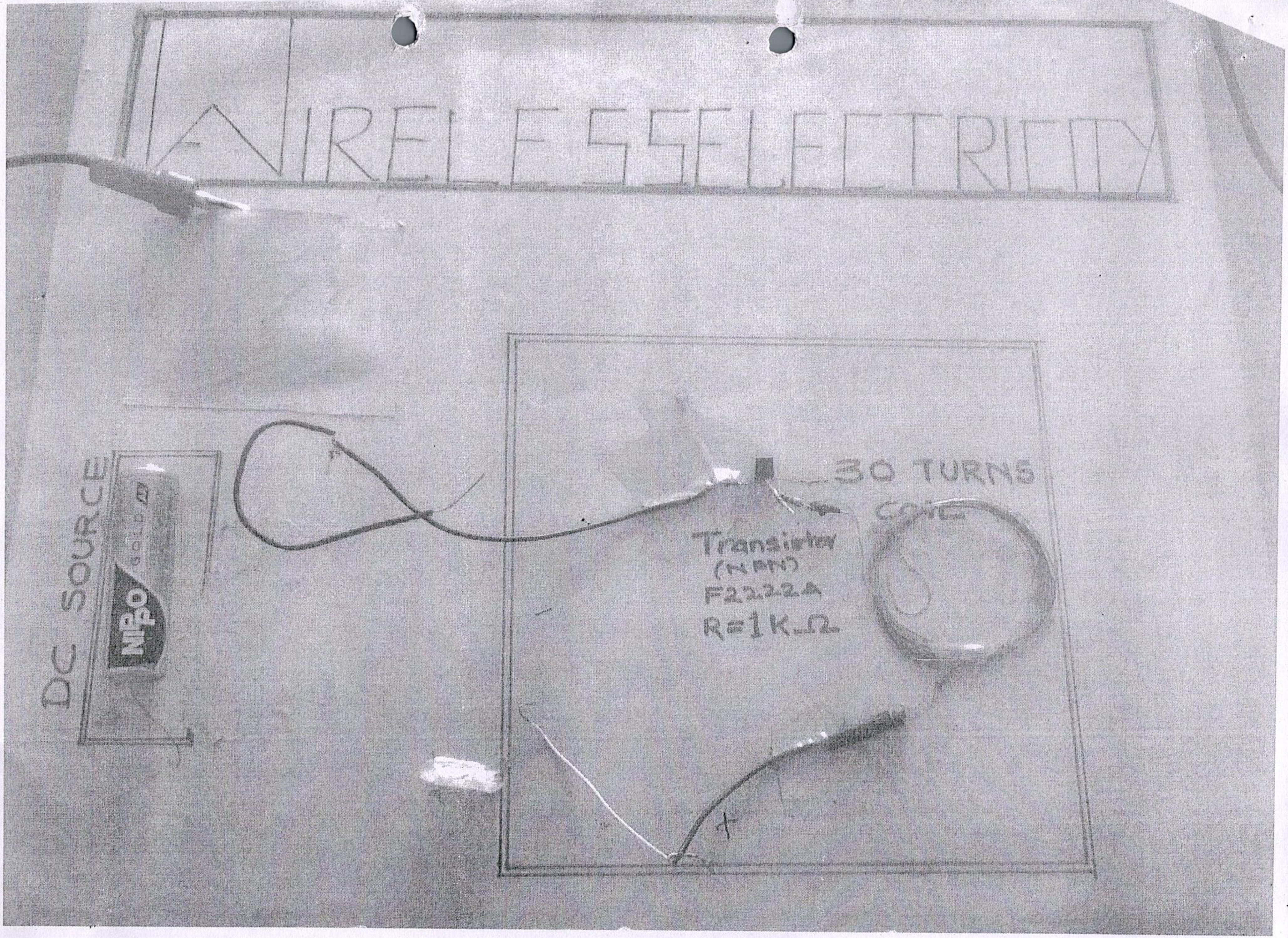


TIR of Laser rays to understand working of Optical fiber

Virtual lab Experiments - URLs

- 1. **Magnetic field along the axis of a circular coil carrying current**
  home->physical sciences->electricity & magnetism virtual lab->magnetic field along the axis of a circular coil carrying current
  http://vlab.amrita.edu/?sub=1&brch=192&sim=972&cnt=1
- **2.Thermo Couple-Seebeck Effect**
- home->physical sciences->heat & thermodynamics virtual lab->thermo couple-seebeck effect
- http://vlab.amrita.edu/?sub=1&brch=194&sim=351&cnt=1
- 3. **Melde's String Apparatus**
- home->physical sciences->harmonic motion and waves virtual lab->melde's string apparatus
- http://vlab.amrita.edu/?sub=1&brch=201&sim=882&cnt=1
- 4. **A.C Sonometer**
- home->physical sciences->harmonic motion and waves virtual lab->a.c sonometer
- http://vlab.amrita.edu/?sub=1&brch=201&sim=366&cnt=1
- 5. **Newton's Rings-Wavelength of light**
- home->physical sciences->laser optics virtual lab->newton's rings-wavelength of light
- http://vlab.amrita.edu/?sub=1&brch=189&sim=335&cnt=1




WIRELESS ELECTRICITY
DC SOURCE
NIPPO
GOLD
30 TURNS COIL
Transistor (NPN)
F2222A
R=1KΩ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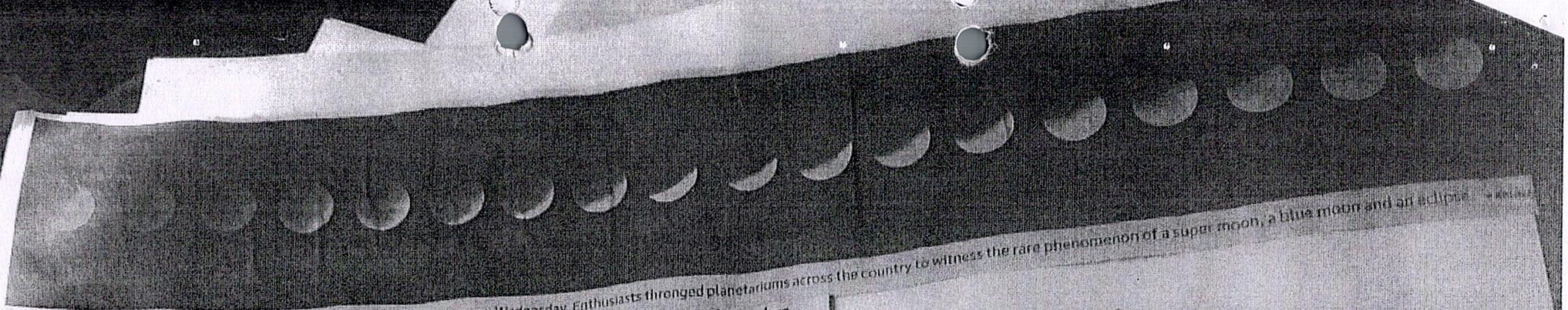
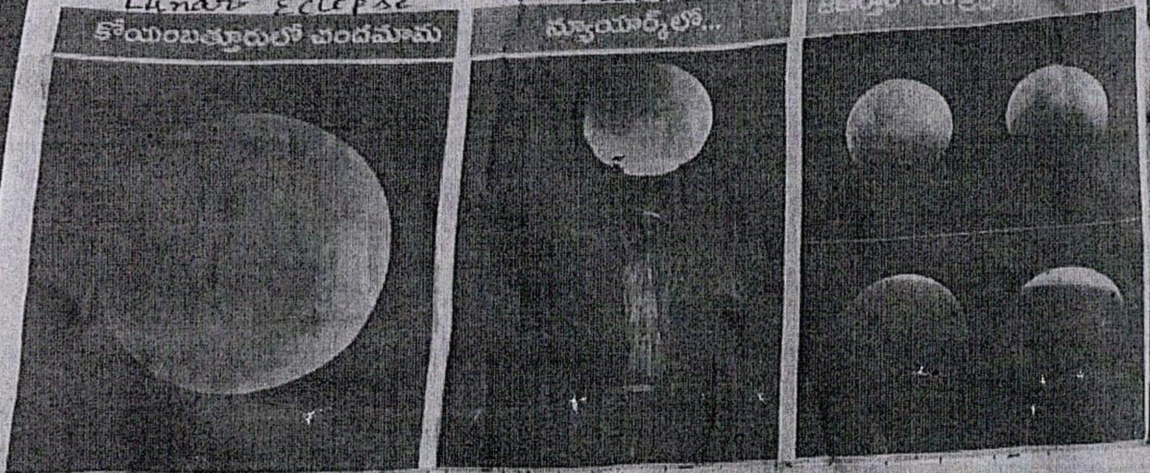


Moonstruck: The moon as seen in Mumbai between 6.50 p.m. and 8.40 p.m. on Wednesday. Enthusiasts thronged planetariums across the country to witness the rare phenomenon of a super moon, a blue moon and an eclipse.

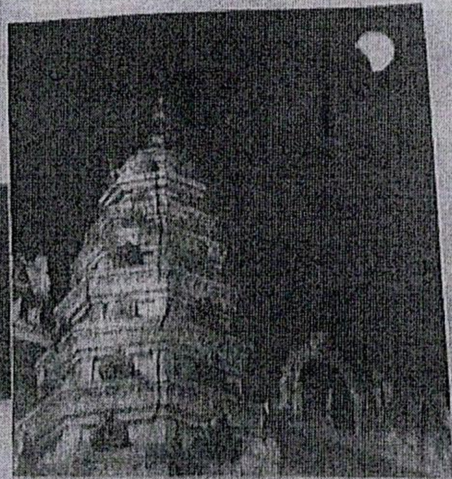
Lunar eclipse at various places on the earth



బ్లడ్‌మూన్..
సూపర్

సంపూర్ణ చంద్రగ్రహణం సందర్భంగా బుధవారం రాత్రి ట్యాంక్‌బండ్, కరీంనగర్‌లలో ఇలా కనువిందు చేసిన సూపర్ బ్లూ బ్లడ్‌మూన్

- వివరాలు 11లో



$E = h\nu$

$E = \frac{hc}{\lambda} \Rightarrow \boxed{E \propto \frac{1}{\lambda}}$

A lunar eclipse & Blood Moo[n] concept is explained in th[e] class room by using abov[e] equation and Raeyleigh scatte[ring]

Think, Pair, Share

Name 1	
Name 2	

Question set in the class	My ideas & thoughts on this	Partner's ideas & thoughts on this	What we have refined & choose to write

Course Attainment

Department of Humanities and Sciences
Vidya Jyothi Institute of Technology(Autonomous)
(Accredited by NAAC, Approved By A.I.C.T.E., New Delhi, Permanently Affiliated to JNTU, Hyd)
(Aziz Nagar, C.B.Post, Hyderabad -500075)

ATTAINMENT SHEET

Academic Year: 2018-2019 | I B.TECH I SEM | Regulation: R-18

Course Name: Applied Physics | Course Code: A21003

Name of the Faculty: Dr. M. Anand Pandarinath | Branch:ECE

S.No	Reg.No	MID I Threshold 60%									MID II Threshold 60%									Threshold 60%
				PART-A				PART-B					PART-A				PART-I			
		ASM - I (5M)	DESCRIPTIVE	Q1 (2M)	Q2 (2M)	Q3 A (1M)	Q3 B (1M)	Q4 (5M)	Q5 (5M)	Q6 (4M)	ASM -II (5M)	DESCRIPTIVE	Q1 (2M)	Q2 (2M)	Q3 A (1M)	Q3 B (1M)	Q4 (4M)	Q5 (5M)	Q6 (5M)	End Exam (75M)
1	18911A0401	5	17	1	1	1	1	4	5	4	5	15	0	2	0	1	3	4	5	37
237	18911A04Q0	5	10		2			2	3	3	5	11	1	1				4	5	10
Average marks		4.7	15.318	1.7	1.9	1.0	1.0	4.0	4.2	3.6	4.7468	15.136	1.8	1.8	0.9	0.9	3.3	4.2	4.6	46.5
No of students attemped		237	236	198	203	191	191	194	223	223	237	235	208	200	191	190	173	204	226	237
%of students scored 60%		97	77.5424	81.31	92.12	96.86	96.34	85.57	91.48	91.03	97.0464	78.7234	88.46	85.50	94.76	92.63	78.03	88.24	94.69	66.24
CO ATTAINMENT LEVEL		3	3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3	3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0

ASSESSMENT OF COs FOR THE COURSE

CO	Method	value	Avg	CO Attainment (Internal)	CO Attainment (End Exam)	Overall CO Attainment
	ASM I	3				
	MID I - PART A - Q1	3.0				

CO 1	MID I - PART A - Q3 A	3.0	3.0			
	MID I - PART B - Q4	3.0				
CO 2	ASM I	3	3.0			
	MID I - PART A - Q2	3.0				
	MID I - PART A - Q3 B	3.0				
	MID I - PART B - Q5	3.0				
CO 3	ASM I	3	3.0	3.00	2.00	2.25
	ASM II	3.0				
	MID I - PART B - Q6	3.0				
	MID II - PART B - Q4	3.0				
CO 4	ASM II	3	3.0			
	MID II - PART A - Q1	3.0				
	MID II - PART A - Q3 A	3.0				
	MID II - PART B - Q5	3.0				
CO 5	ASM II	3	3.0			
	MID II- PART A - Q2	3.0				
	MID II - PART A - Q3 B	3.0				
	MID II - PART B - Q6	3.0				

Course Closure Report

Vidya Jyothi Institute of Technology

(An Autonomous Institution)

DEPARTMENT OF HUMANITIES AND SCIENCES

Regulation	:	R-18
Academic Year	:	2018-19
Program	:	B. Tech
Year/ Sem	:	I / I
Course Name	:	Applied Physics
Course Code	:	A21003
Contact Hours	:	3Lectures / 1Tutorial / 4Credits
No. of Students	:	60

No. of lecture classes taken	53
No. of tutorial classes taken	11
Course delivery modes	Lectures, Demonstration
Technology utilization	PPT, video lectures
Assessment Tools	Internal Mid Examinations, Assignments, End Exam

OVERALL ATTAINMENT (80% DIRECT + 20% INDIRECT)	
DIRECT	2.25
INDIRECT	2.81
OVERALL ATTAINMENT	2.42

Course Material

Applied Physics

I Year, I semester

Course Outcomes:

1. Identify various optical phenomena of light
2. Discuss the basic principles of quantum mechanics
3. Classify solids based on the band theory
4. Elucidate the characteristics of semiconductors and semiconductor devices
5. Explain the working principle of optical fibers and lasers

---

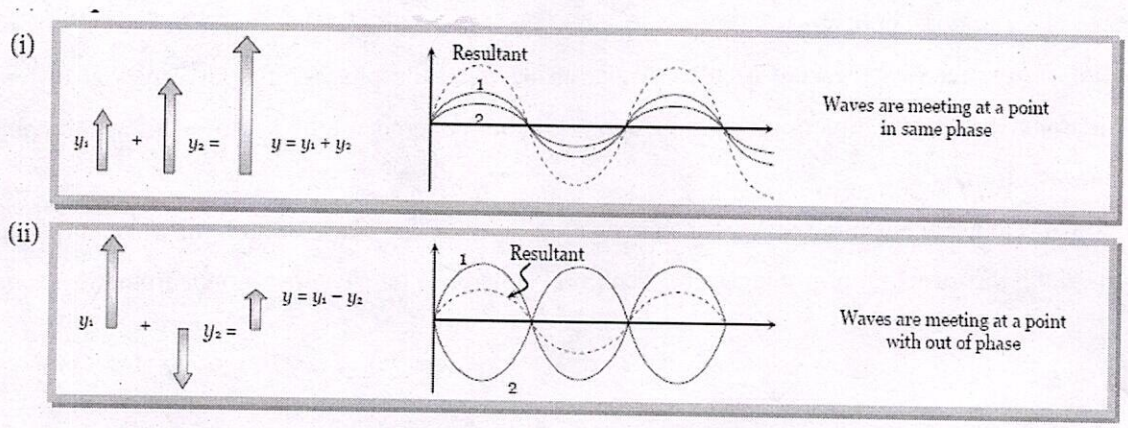
UNIT – I:
Wave Optics:
Course Outcome: Identify various optical phenomena of light.

Principle of Superposition, coherence. Interference - Interference in thin films by reflection, Newton's Rings. Diffraction – Fraunhofer and Fresnel Diffraction, Farunhofer diffraction due to single slit, Plane Diffraction Grating, resolving power of Grating (qualitative treatment). Polarization – Polarization of light waves, Plane of vibration, plane of polarization, Double refraction, Nicol's Prism, Applications of Polarization.

Principle of Superposition:-

When two or more waves are passing through the same medium at the same time, the resultant displacement at any point is equal to vector sum of the displacements of individual waves. This is called **superposition principle**.

$$Y = \vec{Y_1} + \vec{Y_2} + \vec{Y_3} ....$$



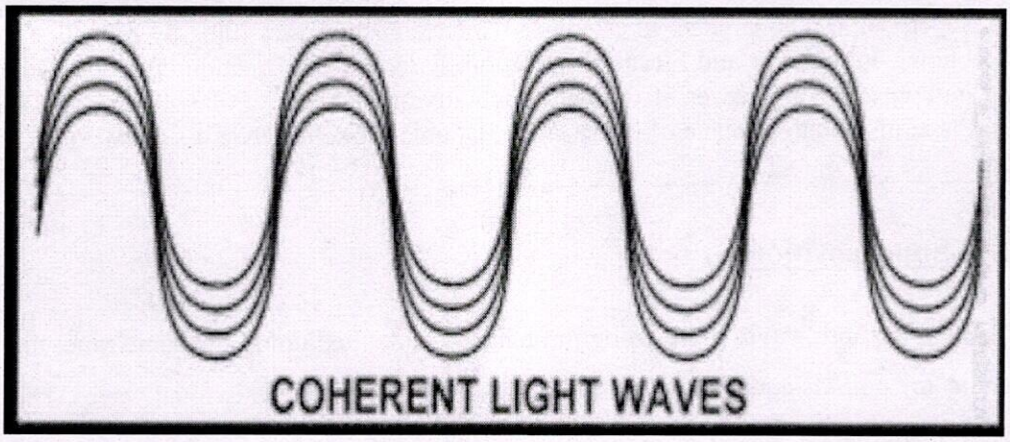
Coherent source:-

The sources of light which emits continuous light waves of the same wavelength, same frequency and in same phase or having a constant phase difference are called coherent sources.

Coherent waves:-

Two light waves which are having same wavelength, same frequency and in same phase or having a constant phase difference are called **coherent waves**. This phenomenon is known as **coherence**

Ex: - Laser light is highly coherent

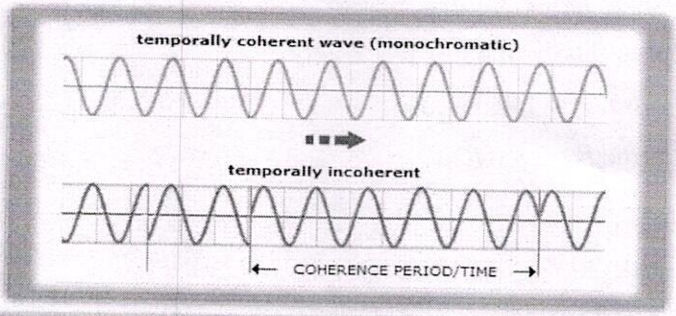


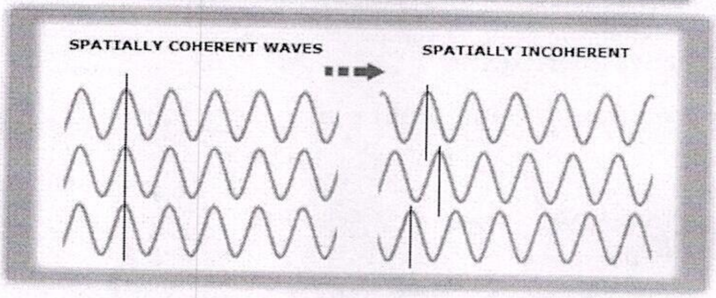
The light waves which are highly coherent if they maintain

1) Spatial coherence and
2) Temporal coherence.

Spatial coherence is a measure of the correlation between the phases of light waves at different points transverse to the direction of propagation. Spatial coherence tells us how uniform the phase of the wave front is.

Temporal coherence is a measure of the correlation between the phases of a light wave at different points along the direction of propagation. Temporal coherence tells us how monochromatic a source is.





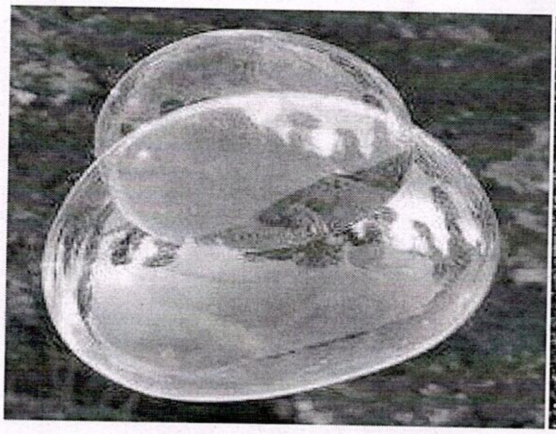
Coherent waves can be obtained by two methods.

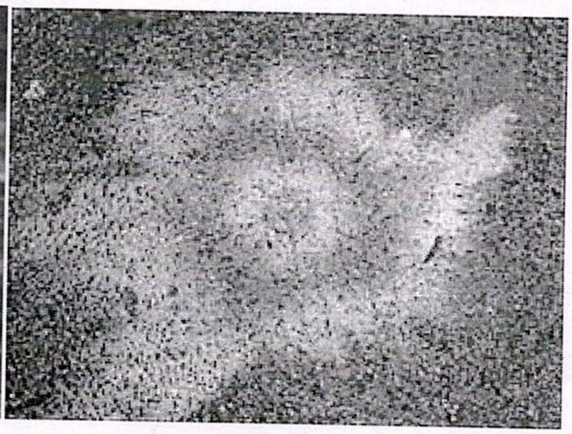
1) Division of wave front: The incident wave front is divided into two or more wave fronts.
   Eg: young's double slit experiment
2) Division of amplitude: The amplitude or intensity of incident light is divided by partial reflection.
   Ex: Newton's rings.

Interference:-

When coherent light waves are superimposed, then the resultant intensity is modified in the region of superposition is called **interference.**

Ex: Colours observed on soap bubbles, oil film formed on water when viewed under sunlight, etc.





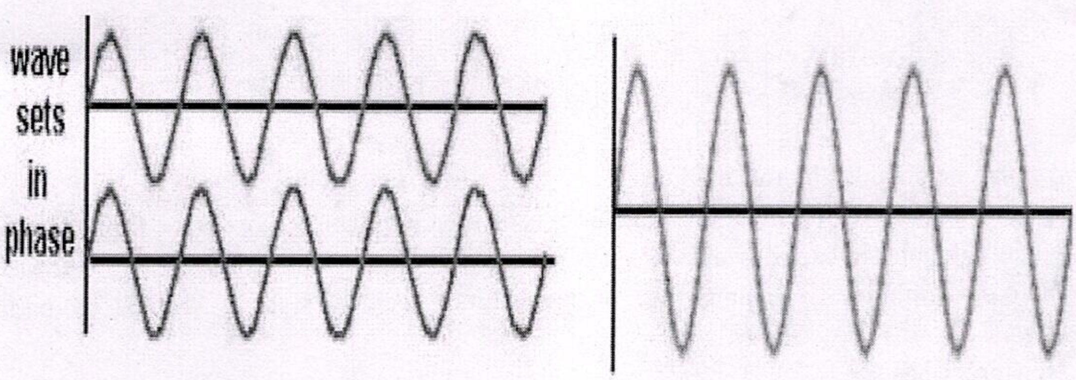
The Nature of Interference is classified into 2 types:

- Constructive Interference
- Destructive Interference

Constructive Interference:-

If two **in-phase** waves are superimposed with each other, the resultant intensity is maximum. This is known as **Constructive Interference**

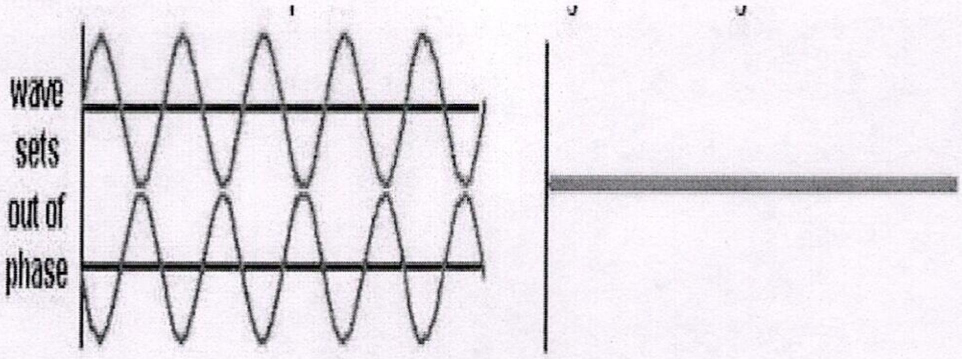
Condition: Path difference between the waves **(Δx) = nλ**

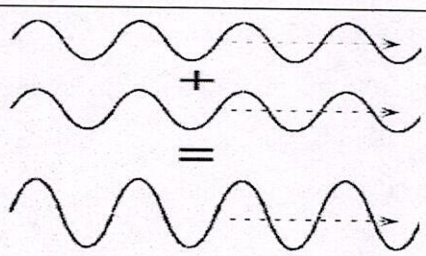
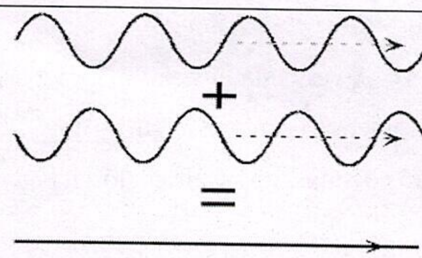


Destructive Interference:-

If two **out-of-phase** (or opposite phase) waves are superimposed with each other, the resultant intensity is minimum. This is known as **destructive Interference**

Condition: Path difference between the waves **(Δx) = (2n$\pm$1)λ/2**



Constructive interference	Destructive interference
	
1) If two in phase waves interfere, gives constructive interference.	If two out of phase waves interfere, gives destructive interference
2) Path difference between the waves at the point of observation $\Delta = n\lambda$	Path difference between the waves at the point of observation $\Delta = (2n \pm 1)\lambda/2$
3) Phase difference between the waves at the point of observation $\emptyset = 0°$ or $2n\pi$	phase difference between the waves at the point of observation $\emptyset = 180°$ or $(2n \pm 1)\pi$
4) Resultant intensity is maximum.	Resultant intensity is minimum.
5) Bright bands or fringes can be observed	Dark bands or fringes can be observed

Conditions for sustained Interference of Light Waves:-

For sustained interference of light to occur, the following conditions must be met:

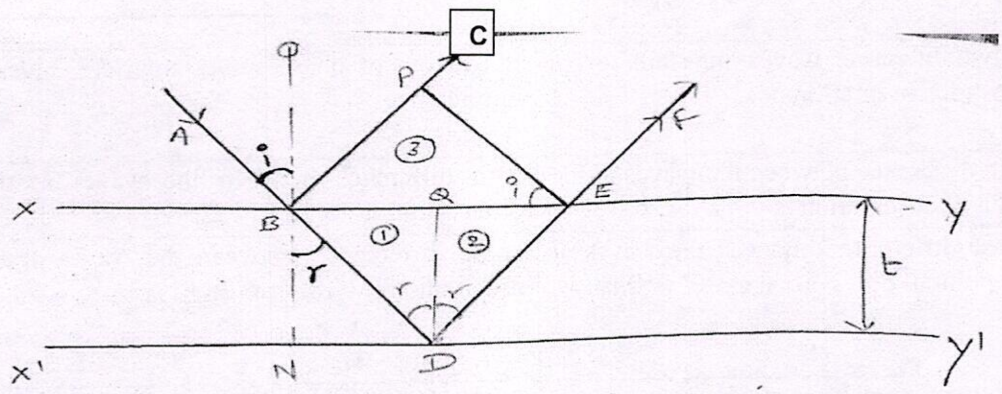
1. The two sources of light must be coherent
2. Amplitudes and intensities of the two sources must be nearly equal to produce sufficient contrast between maxima and minima.
3. The source must be small enough that it can be considered a point source of light.
4. The two sources must be very close to each other to produce wide fringes.
5. The sources should emit light waves continuously.
6. The sources must be monochromatic.

<u>**Interference in thin film (by reflected rays)**</u>:-

Thin - film:

A very thin layer of material and its thickness is ranging from fractions of a nanometer to several micrometers is known as **thin-film.**

Ex: coatings, glass, air enclosed between two transparent sheets, and soap bubble, etc.



- Let us consider a thin film of thickness 't' bound by two surfaces XY and X'Y'. Let "μ" be the refractive index of the material of thin film.
- In thin film, the interference of light is due to superposition of light reflected from top and bottom surface of the film.
- A ray of light AB incident on surface XY(top surface) at an angle 'i' is partially reflected along BC and partially refracted along BD. Let the angle of refraction be "r".
- At the surface X'Y'(bottom surface), the ray is again reflected along DE.
- The rays BC and EF constitute reflected system and interfere to produce interference pattern.
- To find the path difference between these reflected rays, a line perpendicular to BC is drawn, labeled as PE.

  From the figure, path difference = (BD+DE) in the medium - BP in air

  = (BD+DE) μ - BP ------ (1) (for air, μ=1)

In Δ^{le} BDQ,

$$\cos r = \frac{DQ}{BD} = \frac{t}{BD}$$

$$BD = \frac{t}{\cos r} = DE$$

$$BD+DE = \frac{t}{\cos r} + \frac{t}{\cos r}$$

$$BD+DE = \frac{2t}{\cos r} \text{ ----------- (2)}$$

In Δ^{le} BPE, $\sin i = \frac{BP}{BE}$

$BP = BE \sin i$

$BP = (BQ+QE) \sin i$ -------- (3) [From Fig. BE= BQ+QE]

In Δ^{le} BDQ, $\tan r = \frac{BQ}{DQ} = \frac{BQ}{t}$

$BQ = t \tan r = QE$

$BQ+QE = t \tan r + t \tan r$

$BQ+QE = 2t \tan r$

Therefore, equation (3) become

$BP = 2t. \tan r. \sin i$

According to snell's law, $\mu = \frac{\sin i}{\sin r}$

$\sin i = \mu \sin r$

$BP = 2t \frac{\sin r}{\cos r} \mu \sin r$

$$BP = 2\mu t \frac{\sin^2 r}{\cos r} \text{ ------------ (4)}$$

Now, substitute equation (2) & (4) in equation (1)

Therefore Path difference $(\Delta) = \frac{2\mu t}{\cos r} - \frac{2\mu t \sin^2 r}{\cos r}$

$= \frac{2\mu t}{\cos r}(1 - \sin^2 r)$

$= \frac{2\mu t}{\cos r} \cos^2 r$

$= 2 \mu t \cos r$

Since, BC is reflected from a denser medium, it undergoes an additional phase change of "φ" or path difference of "λ/2".

Hence, Path Difference between BC & EF

$$\mathbf{\Delta = 2\, \mu t \cos r - \frac{\lambda}{2}} \text{ ....(1)}$$

- **Condition for Bright band:**

Condition for constructive interference, path difference = n λ

The thin film appears bright, if path difference is 2 μt cosr - λ / 2 = n λ

$$2\ \mu t\ \cos r = (2n+1)\ \lambda / 2 \quad \text{where, } n = 0,1,2,\ldots..$$

- **Condition for Dark band:**

Condition for constructive interference, path difference = (2n+1) λ / 2

The thin film appears dark, if path difference

$$2\ \mu t\ \cos r - \lambda / 2 = (2n+1)\ \lambda / 2$$

$$2\ \mu t\ \cos r = (n+1)\ \lambda$$

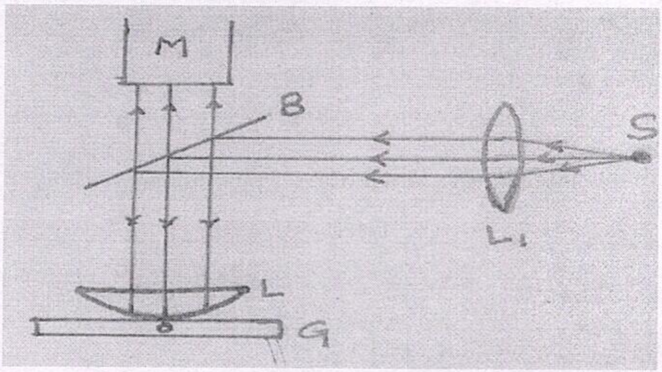
or

$$2\ \mu t\ \cos r = n\lambda \qquad \text{where } n = 0,1,2,\ldots\ldots$$

Newton's Rings experiment:

When a plano-convex lens with its convex surface is placed on a plane glass plate, an air film of increasing thickness is formed between these two. The thickness of the film at the point of contact is zero. If monochromatic light is allowed to fall normally and the film is viewed in the reflected light, alternate dark and bright circular rings are seen. These circular rings were discovered by Newton. Hence, these are called Newton's Rings.

Experimental arrangement:



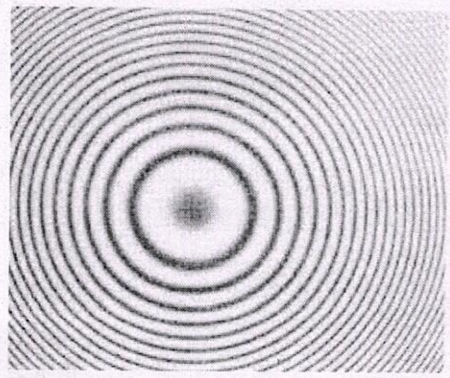
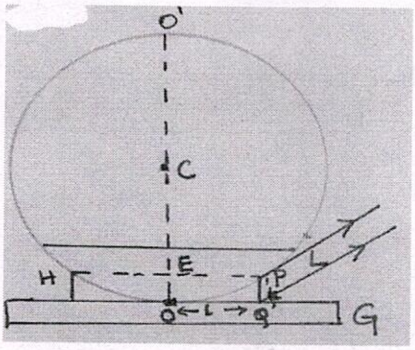


Fig. Experimental arrangement is as shown in figure and Newton's rings

- L is plano convex lens placed on an flat glass plate G. The lens touches the glass plate at 'O'.
- S be the monochromatic source of light falls on a on a glass plate B held at 45^0inclination.
- The glass plate B reflects part of light incident on it towards the air film enclosed between the lens L and glass plate G. A part of light reflected from bottom surface of the lens L and top surface of glass plate G.
- These reflected rays interfere and produce an interference pattern in the form of circular rings (Newton's Rings).
- These rings can be viewed by microscope M.



The path difference between the reflected rays is **$(\Delta) = 2\ \mu t \cos r + \lambda / 2$**

For Air medium, $\mu = 1$

For normal incidence, $r=0$, $\cos r = 1$

Path difference $(\Delta) = 2\ (1)(t)\ (1) + \lambda / 2$

$= 2t + \lambda / 2$

Path difference $(\Delta) = 2t + \lambda / 2$ -------------- (1)

<u>Case 1: Condition for central dark spot</u>:-

From Equation (1)

Path difference $(\Delta) = 2t + \lambda / 2$

at point of contact 'O' , $t=0$

Path difference $(\Delta) = 2\ (0) + \lambda / 2$

$= 0 + \lambda / 2$

Path difference $(\Delta) = \lambda / 2$

If path difference is equal to $\lambda / 2$, it leads to destructive interference.

Hence, **central spot is always dark.**

Case 2: Condition for bright rings (constructive interference):

Path difference(Δ) = $2t + \lambda / 2$ ------(1)

Condition for constructive Interference is $\Delta = n\lambda$ -----(2)

From eq.1 and 2

$$2t + \lambda / 2 = n\lambda$$

$$\mathbf{2t = (2n-1)\,\lambda / 2} \text{ -----------(3)}$$

Case 3: Condition for dark rings (destructive interference):

Path difference (Δ) = $2t + \lambda / 2$ ------(1)

Condition for destructive Interference is $\Delta = (2n+1)\lambda/2$ -----(2)

From eq.1 and 2

$$2t + \lambda / 2 = (2n+1)\lambda/2$$

$$\mathbf{2t = n\lambda} \text{ -----------(4)}$$

Determination of Wavelength of given light source using Newtons rings:

Let us consider the curved surface of lens as an arc of the circle whose center is at C and radius is 'R' and λ the wavelength of light used.

From ΔCNP

$CP^2 = CN^2 + NP^2$

$R^2 = (R-t)^2 + r_n^2$

$R^2 = R^2 + t^2 - 2Rt + r_n^2$

(t^2 is neglected)

$2Rt = r_n^2$

$t = r_n^2 / 2R$

substitute t value in eqn. (4)

$2 \times r_n^2 / 2R = n\lambda$

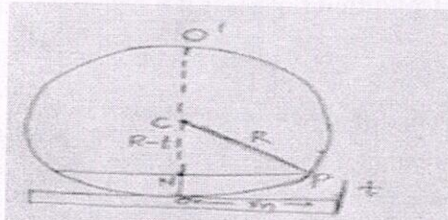


Fig ③

$r_n = \sqrt{nR\lambda}$

r_n is radius of n^{th} dark ring

The diameter of the nth dark ring is

$D_n = 2\, r_n = 2\sqrt{nR\lambda}$

$D^2_n = 4nR\lambda$

Similarly, the diameter of m^{th} ring dark ring is

$D^2_m = 4mR\lambda$

By subtracting above equations,

$D^2_m - D^2_n = 4mR\lambda$

Or $\lambda = \frac{D^2 m - D^2 n}{4(m-n)R}$

Hence by measuring the diameter of rings of different order, Knowing the radius of curvature of lens R, we can determine the 'λ' of given monochromatic source.

OR

Knowing the wavelength of light, radius of curvature of lens can be calculated.

DIFFRACTION

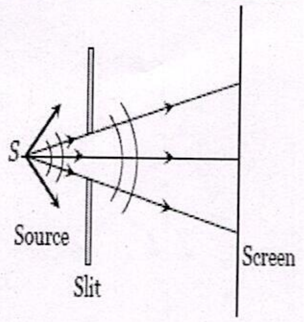
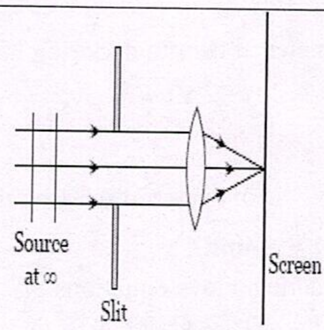
Definition: The bending of light waves around the edges of an obstacle/aperture is called **diffraction**.

Condition for Diffraction: Diffraction phenomenon can be observed when the size of obstacle/aperture is comparable to wavelength of light.

Types of diffraction:

The diffraction phenomenon is divided into two types

1. Fresnel diffraction
2. Fraunhofer diffraction

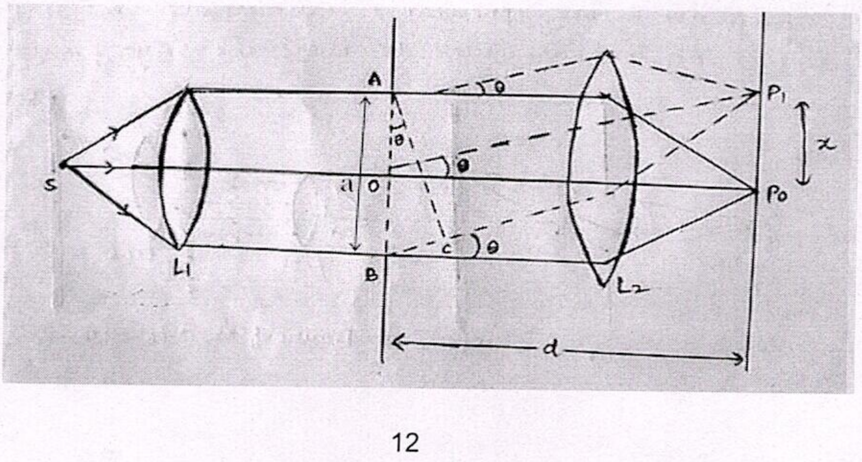
Fresnel diffraction	Fraunhofer diffraction
	
In this diffraction, either source or screen or both kept at **finite** distance from obstacle	In this diffraction, source and screen are effectively at **infinite** distance from obstacle.
This is near- field diffraction	This is far- field diffraction
In this case, incident wave front is either spherical or cylindrical.	In this case, incident wave front is a plane.
Experiment is simple but analysis is difficult.	Experiment is simple but analysis also simple.
lens are not required to study the diffraction	To study the diffraction, lenses are necessary

Fraunhofer diffraction due to single slit:

Introduction:

In Fraunhofer diffraction incident wave front must be plane wave front, hence two lenses are used one is collimating and another is converging.

Experimental arrangement:



- Let S be the monochromatic source of light.
- L_1 be the collimating lens of focal length f at a distance from source, so that lens produces the parallel beam of rays.
- AB is the slit of width 'a'.
- The light passing through the slit is collected by lens L_2 which forms image on screen as shown in figure.

Working:

- Let us consider a plane wave front incident normally on the slit AB, each and every point on wave front acts as secondary source of light waves from the source travels after AOB in all possible directions.
- The undiffracted light travel straight and focus on the screen at point Po. Since all the light waves have travelled the same optical distance, there is no path difference between them and they produce the constructive interference and hence, point Po appears bright with maximum intensity. This is known as **central maxima**
- The diffracted rays at angle θ are focused at point P_1. The intensity distribution at point P_1 depends on the path difference between the secondary wavelets, which are produced at point A and point B
- From figure, the path difference between diffracted rays $\Delta = BC$

From Δ ABC,

$$\sin\theta = \frac{BC}{AB} = \frac{BC}{a}$$

$$BC = a \sin\theta$$

or $\boldsymbol{\Delta = a \sin\theta}$

Where, a = slit width, θ = angle of diffraction

Condition for Minima:

If path difference $\Delta = \lambda, 2\lambda, 3\lambda, \ldots\ldots,$

Point P_1 appears with minimum intensity called minima

Therefore the General condition for minima is

$$\mathbf{a\sin\theta_n = n\lambda} \quad \ldots\ldots\ldots\ldots(1)$$

Where, n= 1,2,3,.......

θ_n= corresponding directions of n^{th} minima

Condition for Maxima:

If path difference is odd multiple of $\frac{\lambda}{2}$, ie. $\Delta = \frac{3\lambda}{2}, \frac{5\lambda}{2}, \frac{7\lambda}{2}, \ldots\ldots (2n+1)\frac{\lambda}{2}$

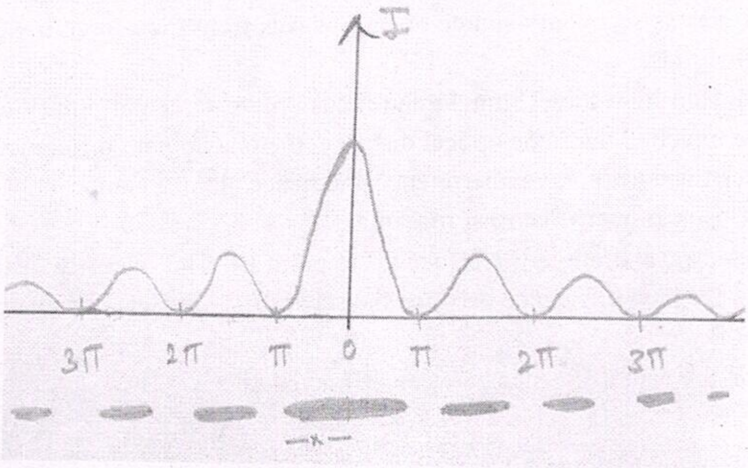
Point P_1 appears bright called maxima

Therefore the General condition for maxima is

$$a\sin\theta_n = (2n+1)\frac{\lambda}{2} \ldots\ldots\ldots\ldots (2)$$

Where, n= 1,2,3,……., θ_n= corresponding directions of n^{th} maxima

Diffraction pattern due to single slit consists of central maxima and secondary maximas and minimas on both sides is shown in the following figure.



Calculation of the slit width:

W.K.T , From eqn (1)

$$a \sin\theta = n\lambda$$

$$\sin\theta = \lambda/a \qquad \text{(n=1 for first order)}$$

From fig: $\sin\theta = x/d$ (From ΔOP_0P_1)

Therefore, from above equations,

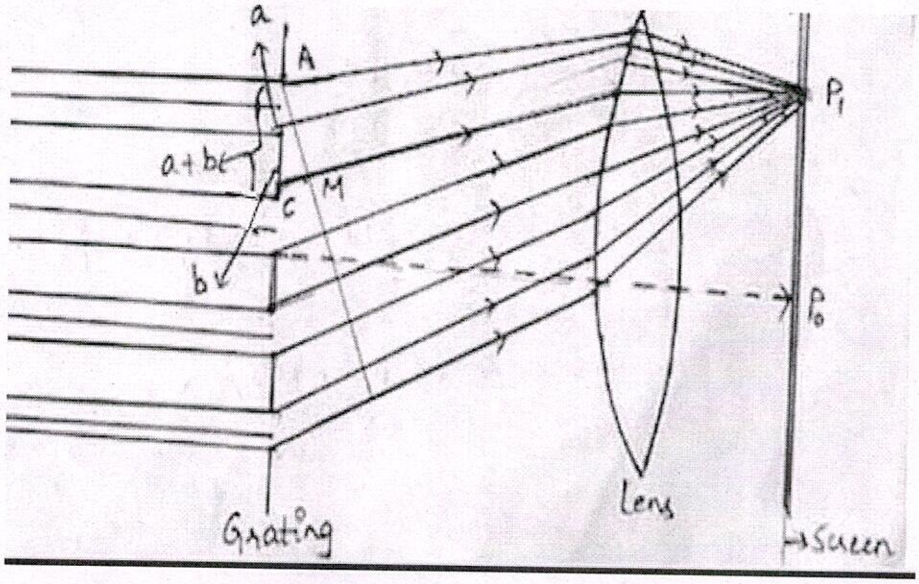
$$\lambda/a = x/d$$

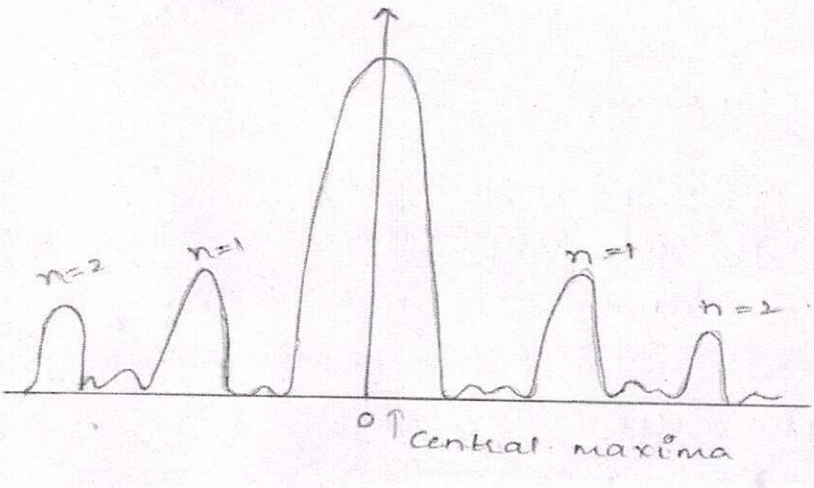
$$\mathbf{a = d\lambda/x}$$

Where, **a** is slit width

Fraunhofer diffraction due to N- slit (Diffraction Grating):-

- Diffraction grating is nothing but closely placed multiple slits (N-slits).
- Grating is a transparent material (glass plate) on which ruling are made with a diamond point, they are parallel this type of grating is called plane transmission grating.
- The rules are opaque and the space between the rules acts as a slit. The combined equal width of ruling and slit is called **grating element**.
- When light passes through the grating, each slit diffracts the light and the diffracted light waves are combined to produce sharper maxima on the screen as shown in the following figure.





- Let AB represents slit of width 'a' and BC represents opaque ruling of width 'b' each. ie. (a+b) is combined width of slit and ruling is called grating element.
- Let a plane wave front be incident normally on the grating. The slits act as secondary source of lights gives secondary waves.
- These waves spread in all directions on either side of the grating.
- The secondary waves are travelling same direction as that of the incident rays focused at point P_0. They reinforce constructively and hence point P_0 is position of central bright maxima.
- Now let us consider secondary diffracted waves moving in a direction which makes an angle θ with respect normal to grating and reaching at point P_1 as shown in figure.
- The intensity at point P_1 is depends on the path difference between the diffracted rays

From figure,

The grating element (AC) = a+b

The path difference is CM

From Δ ACM, $\sin\theta = \frac{CM}{AC} = \frac{CM}{(a+b)}$

$$CM = (a+b)\sin\theta$$

Path difference (Δ) = CM = (a+b) sinθ ------------ (1)

Condition for the maximum at point P_1 is

Path difference (Δ) = n λ ------------ (2)

From equations (1) & (2)

$$(a+b)\sin\theta = n\lambda \qquad \text{Where, } n = 1, 2, 3, \ldots\ldots$$

$$\sin\theta = \frac{n\lambda}{(a+b)}$$

$$\sin\theta = nN\lambda$$

Where, $\frac{1}{(a+b)}$ = N called number of lines per unit width of the grating.

$$\boldsymbol{\lambda = \frac{\sin\theta}{nN}}$$

By using above equation, we can find out the wavelength (**λ**) of the light source.

Calculation of maximum number of orders possible with grating

W.K.T $\sin\theta = nN\lambda$

The maximum possible value of θ is 90^0 ie. $\sin 90^0=1$

above equation become, $1= nN\lambda$

$$(n)_{max} \leq \frac{1}{N\lambda}$$

Therefore above relation gives the maximum number of orders possible by the grating which is having N no. of lines per unit width.

Resolving power of Grating:-

One of the important properties of a diffraction grating is its ability to resolve spectral lines which have nearly the same wavelengths.

The resolving power of a grating is defined as its ability to form separate spectral lines of two very closely spaced wavelengths

(or)

Resolving power of grating is defined as the ratio of the wavelength (λ) of a line in the spectrum to the least difference in wavelength ($d\lambda$) of the next spectral line.

$$\text{Resolving power of grating} = \frac{\lambda}{d\lambda}$$

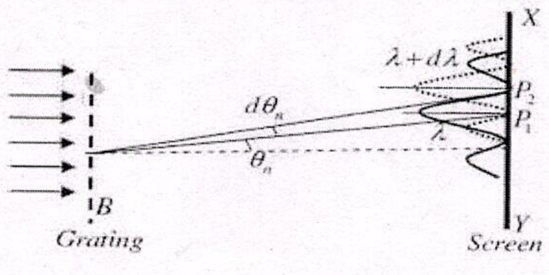
Let parallel beam of light of two wavelengths λ and $\lambda + d\lambda$ are incident normally on grating

$$\textbf{Resolving power of grating} = \frac{\lambda}{d\lambda} = nN$$

where, n is the order of the spectrum,

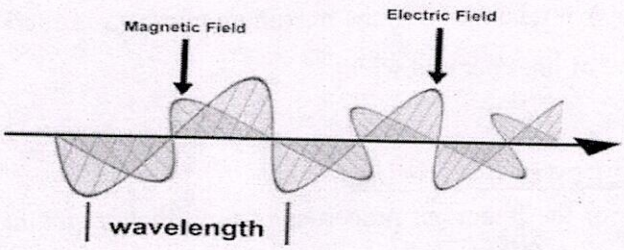
N is the no. of lines on the grating

Therefore, resolving power of the grating is directly proportional to total no. of lines on the grating. By increasing the no. of lines on grating, we can get good resolving power.



POLARIZATION

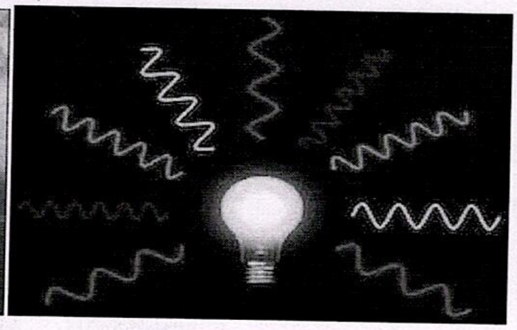
The phenomenon of polarization, establishes the transverse nature of light. Light is electromagnetic in nature. It consists of oscillating electric and magnetic fields perpendicular to each other and also to the direction of propagation of the wave.



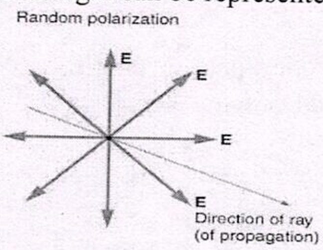
Unpolarized light :-

In case of ordinary light, oscillations or vibrations are at random. Hence, this light is known as **unpolarized light.**

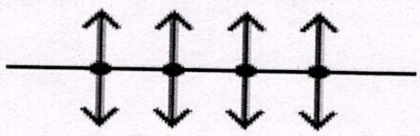
Ex: Ordinary light (bulb, sunlight, candle…..)



unpolarized light can be represented as follows



(OR)



Polarized light :-

If oscillations or vibrations are confined to only one direction, then this light is known as **polarized light**

Pictorial representation of polarised light shown figure (A) and (B)

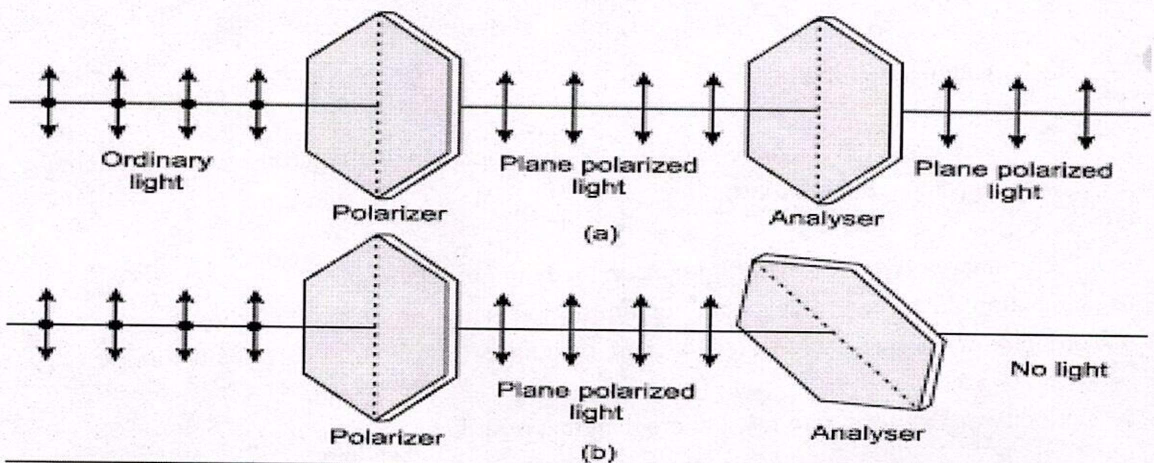
(Vibrations in the plane of paper) (A)

(Vibrations ⊥ to the plane of paper) (B)

- Vertical component
  The vibrations along the plane of paper (Fig A).
- Horizontal component
  Vibrations perpendicular to plane of paper (Fig B)

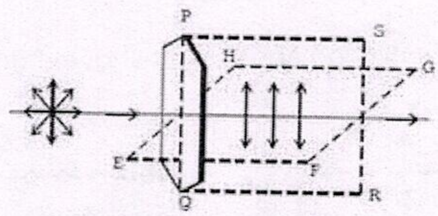
Polarization:-

The process by which an unpolarized light is converting into plane polarized light is known as **polarization**.



<u>Plane of Vibration</u>: The plane in which the vibrations occur is called plane of vibrations (plane PQRS).

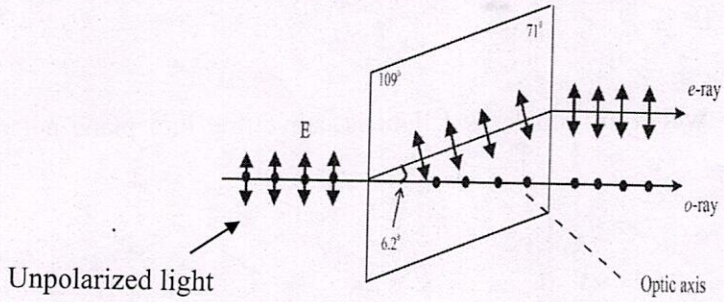
<u>Plane of polarization</u>: The plane which is perpendicular to the plane of vibrations is called plane of polariazation (plane EFGH).



PQRS = Plane of vibration
EFGH = Plane of polarization

Double Refraction (Birefringence):

When unpolarized light passes through certain anisotropic crystals, the refracted ray split into two rays one is ordinary ray (O-ray) and another ray is extraordinary ray (E-ray). Both rays are plane polarized lights. This phenomenon is known as **double refraction**.



The crystals which are showing this phenomenon are called as double refracting crystals examples calcite, quartz, tourmaline

- The ordinary ray travels with the same velocity in all directions
- the extraordinary ray travels with non uniform velocity (not same in all directions)
- ordinary ray refractive index (μ_o) is more than the extraordinary ray refractive index (μ_e)

$$(\mu_o) > (\mu_e)$$

- Velocity of Extraordinary ray is more than that of ordinary ray

$$(V_e) > (V_o)$$

Nicols Prism:-

Nicol's Prism is a device which is used to produce and analyze the plane polarized light. This was invented by William Nicol, in the year 1828.

Construction:-

A calcite crystal whose length is three times of its breadth is taken. The end faces of the crystal are cut down in such a way that angles in the principle section become 68° and 112° instead of 71° and 109°. The crystal is then cut in to two halves along the diagonal and two cut faces are well polished and cemented together by using Canada balsam which is a transparent material. The refractive index of a Canada balsam is lies between the refractive index of ordinary and extra-ordinary rays.

i.e, Refractive index of O-ray (μ_o) = 1.658

Refractive index of Canada balsam (μ_{CB}) = 1.55

Refractive index of O-ray (μ_e) = 1.486

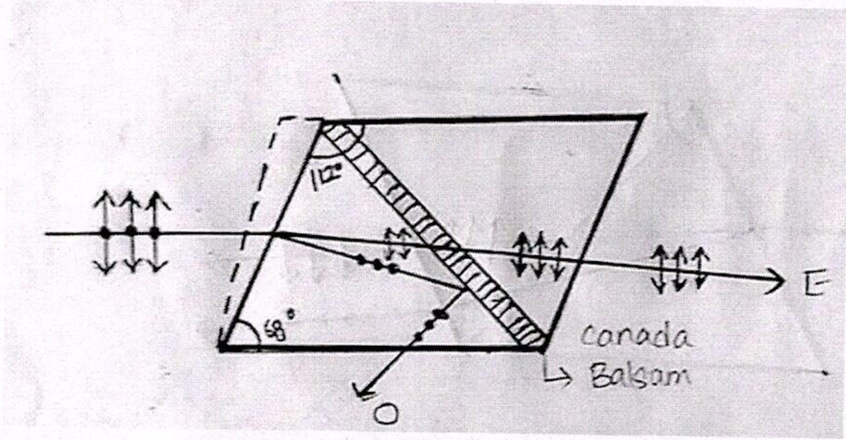


Fig. Nicol's Prism

Working:-

When an unpolarized light is incident on Nicol's prism, it splits in to ordinary ray (O-ray) and extraordinary (E-ray). Canada balsam is rarer medium for O-ray. Because of the shaping of the crystal face, the O-ray is incident on the Canada balsam at an angle greater than critical angle and suffers total internal reflection and leaves the crystal through its side as shown in figure. The

E-ray is transmitted through the Canada balsam and emerges out of the Nicol's prism. Hence, in this way we can use Nicol's prism to produce the plane polarized light.

Therefore, Nicols prism can be used to produce and analyze the plane polarized light.

Applications of Polarization:

The phenomenon of polarization has many practical applications in daily life

- The polarized sun-glasses are used to eliminate the glare of light
- The intensity of light coming inside the aero plane can be controlled using polaroids
- The polaroids are used to improve colour contrast in old oil paints
- polaroids are used to produce three-dimensional moving pictures (3D movies)
- They are used for enhancing visibility of digital displays
- They are used in calculators, watches, monitors of laptop which have LCD screens

Lecture Notes

Course/Subject :Applied Physics

UNIT :II

Topic : Free electron theory and Introduction to Quantum Mechanics.

Course Outcome :At the end of the course, the student will be able to discuss the basic principles of Quantum Mechanics.

Syllabus: *Classical free electron Theory, Electrical Conductivity and Ohm's Law – Drawbacks. Introduction to quantum physics: Black body radiation and Planck's Law(qualitative treatment), wave-particle duality, de-Broglie hypothesis of matter waves, Heisenberg uncertainty principle, time independent Schrodinger equation, Born interpretation of wave function, particle in an infinite potential well (one dimension).*

Introduction to electron theory

The electron theory aims to explain the structure and bulk properties of solids through their electronic structure. The electron theory is applicable to all solids i.e., both metals and non metals. It explains the electrical, thermal and magnetic properties of solids etc. The theory has been developed in three main stages.

The classical free electron theory

The classical free electron theory was introduced by P. Drude in 1900 and developed by Lorentz in 1909. According to this theory, the metals containing the free electrons and obey the laws of classical mechanics.

The quantum free electron theory

Somerfield developed this theory in 1928. According to this theory the free electrons obey quantum laws and are called fermions. According to this theory, the free electrons moving inside a solid experience a constant potential field.

The zone theory

Bloch stated this theory in 1928. According to this theory, the free electrons moving inside a solid or metal, experiences a periodic potential field due to the positive ion core in the lattice.

CLASSICAL FREE ELECTRON THEORY:

Introduction: After the discovery of electron, this theory was developed to explain some of the thermal and electrical properties of metals.

According to this theory, a metal is made up of positive ions arranged in the form of 3-dimensional lattice. The valence electrons of metal atoms move randomly inside the lattice of these positive ions just like gas molecules inside a container. Hence they are called free electrons or electron gas. These electrons are responsible for electrical conductivity and hence called conduction electrons.

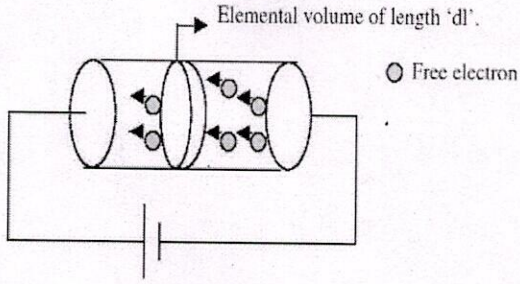
The classical free electron theory is based on the following postulates or assumptions

1. The valence electrons of atoms are free to move about the whole volume of the metal, like the molecules of a perfect gas in a container.
2. The free electrons move in random direction and collide with either positive ions fixed to the lattice and the collisions are elastic in nature i.e., there is no loss of energy.
3. The movement of free electrons obeys laws of classical mechanics.
4. The free electrons move in a completely uniform potential field due to ions fixed in the lattice
5. When an electric field is applied to the metal, the free electrons are accelerated in the direction opposite to the direction applied electric field.

Motion of free electrons in the presence of applied electric field:

Drift velocity

If no electric field is applied on a conductor, the free electrons move in random directions, just as gas molecules move randomly in a gas container. They collide with each other and also with the positive ions. Since the motion is completely random, average velocity in any direction is zero. If a constant electric field is established inside a conductor, the electrons experience a force F = -eE due to which they move in the direction opposite to direction of the field. As a result, **in addition to the random velocity, the electrons gain an additional velocity due to the applied electric field. This velocity is called drift velocity "V_d".**



Consider a conductor subjected to an electric field E in the x-direction. The force on the electron due to the applied electric field F= -eE -------(i)

According to Newton's law, F= m dv_d/dt ---------(ii)

From equations (i) and (ii)

$-eE = m dv_d/dt$

$dv_d = - \frac{-eE}{m} dt$

By Integrating above equation,

$V_d = \frac{-eE}{m}\tau +$ Constant

When t = 0, $V_d = 0$ Therefore Constant = 0

$\mathbf{V_d = \frac{-eE}{m}\tau}$--------------- (1)

Electrical conductivity

Consider a wire of length 'dl' and area of cross section 'A' subjected to an electric field E. If n is the number of electrons,

Total amount of charge dq= - neA.dl

Rate of flow of charge $\frac{dq}{dt} = -neA. \frac{dl}{dt}$

Therefore $I = \frac{dq}{dt} = -neAV_d$

Current density $J = \frac{I}{A}$

$J = -neAV_d/A$

$J = -neV_d$

Substituting V_d value, from (1)

$$J = -ne\left(\frac{-eE}{m}\tau\right)$$

$J = (ne^2\tau/m)E$--------------- (2)

According to Ohm's law, $J = \sigma E$ --------(3)

From equations (2) and (3)

Therefore **$\sigma = ne^2\tau/m$** -------------- (4)

Where **σ is Electrical conductivity** of the material.

Mobility:

Mobility of a charge carrier (electron) is defined as the ratio of the drift velocity to the electric field.

$\mu = V_d/E$

Substituting V_d from (1),

$\mu = (e\tau/m)E / E$

$\mu = e\tau/m$ -------------- (5)

Substituting this in equation (4),

$[\sigma = ne^2\tau/m$

$= ne\,(e\tau/m)]$

$\sigma = ne\mu$ ------------- (5)

Relaxation time

When the field E is switched off, due to the collision of the electrons with lattice ions and lattice defects, their velocity will start to decrease. This process is called relaxation. The relaxation time (τ) is the time required for the drift velocity to reduce to (1/e) of its initial value.

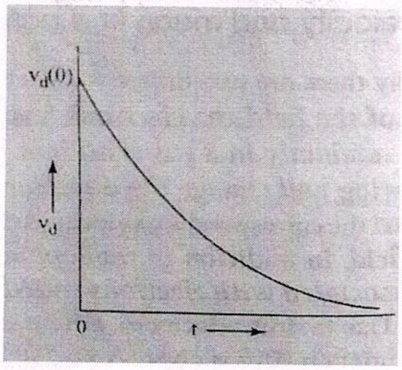


Fig: Relaxation of electrons after electric field is cut off

$V_d(t) = V_d(0) \exp(-t/\tau)$

Let $t = \tau$, then above equation become

$V_d(t) = V_d(0) \exp(-\tau/\tau)$

$$\mathbf{V_d(t) = \frac{Vd(0)}{e}}$$

Mean free path

The average distance traveled by an electron between two successive collisions is called mean free path of the electron.

Merits of Classical Free Electron theory:

- It verifies Ohm's law
- It explains the electrical and thermal conductivities of metals
- It derives Wiedmann-Franz law: i.e. the ratio of thermal conductivity to electrical conductivity of a metal is directly proportional to absolute temperature.

  $K/\sigma \propto T$

  or

  $K/\sigma T = L$, where L is a constant called Lorentz number.
- It explains optical properties of metals

Drawbacks of Classical free electron theory

Classical free electron theory has the following drawbacks

- The phenomena such as photoelectric effect, Compton Effect and spectral distribution of blackbody radiation could not be explained by classical free electron theory
- According to this theory, $K/\sigma T = L$, a constant (Wiedmann-Franz law) for all temperatures. But this is not true at low temperatures.
- The theoretically predicted value of specific heat of a metal does not agree with the experimentally obtained value.
- Electrical conductivity of semiconductors and insulators couldn't be explained by this theory
- Ferromagnetism couldn't be explained by this theory.

Introduction to quantum physics:

Black body radiation and Planck's law (Qualitative)

When a blackbody is heated, it radiates electromagnetic waves of all possible wavelengths. The distribution of total radiated energy among different wavelengths is called spectral distribution of energy.

The energy distribution among various wavelengths at different temperatures of the black body is as shown in the figure.

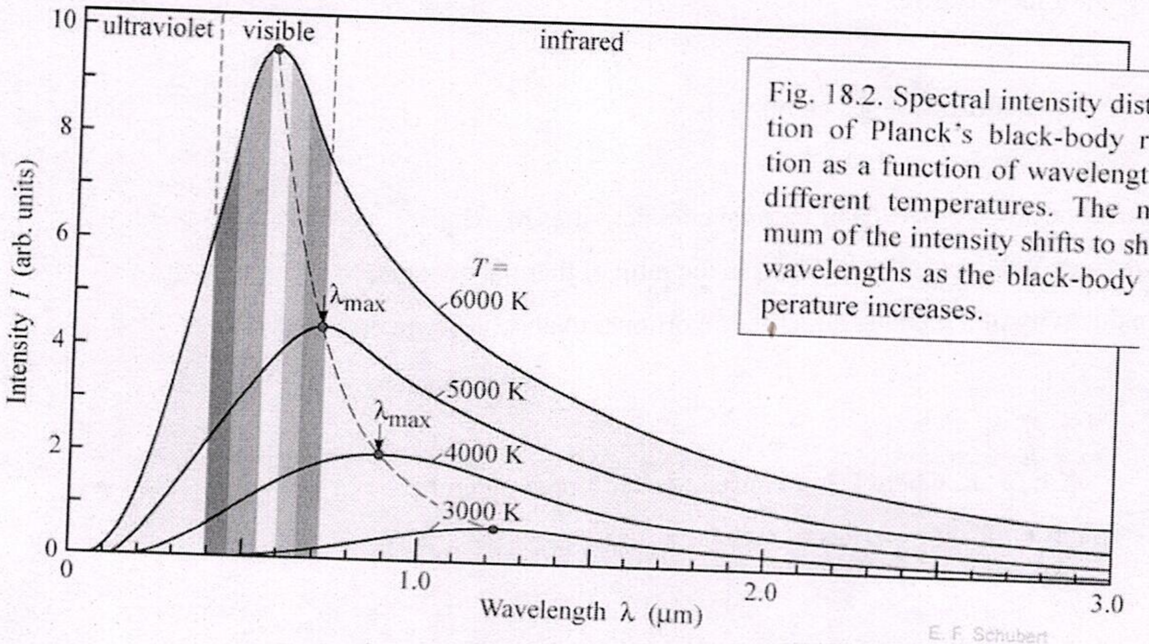


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

The following observations are made from the graphs:

1. The total energy emitted by the black body is proportional to the fourth power of the temperature of the black body.
2. At a particular temperature, most of the energy is emitted at/within a particular wavelength (λ_m).
3. As the temperature is increased, the wavelength corresponding to the maximum energy shift towards shorter wavelengths.

To explain these experimental observations, the scientist Wein in 1893 derived the following relation by applying the wave theory,

$$\text{The amount of energy contained in the range of } d\lambda \text{ is}$$

$$dE = E_\lambda d\lambda = \frac{Ce^{-a/KT}}{\lambda^5} d\lambda$$

These relations were found to be valid at shorter wavelengths but not for longer wavelengths.

Later the scientists Rayleigh and Jeans developed a theory for spectral distribution by applying electrodynamics and statistical mechanics and derived the following relation for energy density

$$dE = E_\lambda d\lambda = \frac{8\Pi KT}{\lambda^4} d\lambda$$

But this relation was found to be valid for longer wavelengths and not for shorter wavelengths.

Hence in 1900, Max Planck introduced the idea of quantum nature of radiation and derived the equation for spectral distribution which was found to be valid for all wavelengths of black body radiation.

Planck's Radiation Law

Max Planck developed quantum theory of radiation based on the following assumptions

a) A black body contains simple harmonic oscillators of atomic dimensions and all possible frequencies. Such oscillators are called Planck oscillators.
b) The energy of these Planck oscillators is quantized and is equal to $nh\upsilon$, where υ is the frequency of oscillation, h is the Planck's constant and n is the integer.
c) A Planck oscillator of frequency υ can radiate or absorb energy in terms of $h\upsilon$.

Max Planck derived the following relation for spectral distribution of black body radiation

$$E_\lambda d\lambda = \frac{8\Pi hc}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda KT}} - 1}d\lambda$$

This relation was found to be valid for all wavelengths of black body radiation spectrum.

Wave particle duality and de-Broglie hypothesis:

Light or radiation has dual nature i.e., particle nature (Ex: Compton Effect and photo electric effect) and wave nature (Ex: interference and diffraction). This idea of dual nature of radiation was extended to material particle by the scientist de-Broglie in 1924 and put forward the hypothesis.

de-Broglie hypothesis:

Any moving particle has got a wave associated with it. Such waves are named as **matter waves** or **de-Broglie matter waves.**

Expression for the wavelength of matter wave:

de-Broglie derived the expression for the wavelength of matter wave based on the quantum nature of radiation and using Einstein's mass-energy relation.

According to quantum theory of radiation, radiation is composed of photons and the energy of a photon is given by $E = h\upsilon$--------------(1)

where υ is the frequency of radiation.

Considering photon as particle, let 'm' be the mass of the photon, then according to Einstein's mass-energy relation,

$$E = mc^2\text{--------------(2)}$$

Equating equations 1 and 2 $h\upsilon = mc^2$

but $\upsilon = \frac{c}{\lambda}$ therefore $\frac{hc}{\lambda} = mc^2$

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

Extending the theory to material particle of mass 'm' moving with velocity 'v', the wavelength of associated matter wave is,

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

Characteristics of Matter waves:

Since wavelength of matter wave is $\lambda = \frac{h}{mv}$

1. Lighter the particle, greater is the wavelength associated with it.
2. Lesser the velocity of the particle, longer the wavelength associated with it.
3. Matter waves depend up on velocity of the particle, (For v = 0, $\lambda = \infty$. This means that only with moving particle, matter waves is associated).
4. Matter waves do not depend up on charge of the particle
5. It can be proved that matter waves travel faster than light.

   We know that $E = mc^2$ and $E = h\upsilon$,

   $$h\upsilon = mc^2$$

   $$\upsilon = \frac{mc^2}{h} \text{----------(1)}$$

   The wavelength of matter wave is $\lambda = \frac{h}{mv}$ ----------(2)

   Therefore the velocity of matter wave (say v_m) is

   $$v_m = \lambda\upsilon$$

   $$= \frac{h}{mv}\frac{mc^2}{h}$$

   $$Vm = \frac{c^2}{v}$$

   As the particle velocity '**v**' cannot exceed velocity of light, $\mathbf{v}_m$ is greater than the velocity of light.

6. Matter waves do not exhibit both natures (particle nature and wave nature) simultaneously.
7. The wave nature of matter introduces an uncertainty in the finding the position and momentum of the particle when both are determined simultaneously (Heisenberg uncertainty principle).

HEISENBERG UNCERTAINITY PRINCIPLE

According to classical mechanics, a moving particle at any instant has a fixed position in space and a definite momentum which can be determined simultaneously with any desired accuracy. The classical point of view represents an approximation which is adequate for the objects of appreciable size, but not for the particles of atomic dimensions.

Since a moving particle has to be regarded as a de-Broglie group, there is a limit to the accuracy with which we can measure the particle properties. The particle may be found anywhere within the wave group, moving with the group velocity. If the group is narrow, it is easy to locate its position but the uncertainty in calculating its velocity or momentum increases. On the other hand, if the group is wide, its momentum can be estimated satisfactorily, but the uncertainty in finding the location of the particle is great.

Heisenberg stated that the simultaneous determination of exact position and momentum of a moving particle is impossible.

If Δx is error in the measurement of position of the particle along X-axis, Δp is Error in the measurement of momentum

Then $$(\Delta x).(\Delta p) \geq \hbar/2$$

Where $\hbar = h/2\Pi$ and h is Plank's constant

The above relation represents the uncertainty involved in measurement of both the position and momentum of the particle.

The uncertainty relation between energy and time is given below.

If the time during which a system occupies a certain state is not greater than Δt, then the energy of the state cannot be known within ΔE,

$$\text{i e } (\Delta E)(\Delta t) \geq \hbar / 2$$

SCHRODINGER's TIME INDEPENDENT WAVE EQUATION:

Schrödinger, in 1926, developed wave equation for the matter wave associated with moving particles. One of its forms can be derived by simply incorporating the de Broglie wavelength expression into the classical wave eqn.

Let us consider a particle of mass 'm' moving with velocity 'v' is associated with a group of matter waves. Let ψ(x, t) be the displacement of the matter wave and x, y, z be the coordinates of the particle.

The classical wave equation in space is given by

$$\frac{\partial^2 \Psi}{\partial t^2} = V^2 \left(\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} \right) -------- (1)$$

$$or\ \frac{\partial^2 \Psi}{\partial t^2} = V^2 \nabla^2 \Psi -------- (2)$$

$$where \nabla^2 = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right) is\ called\ the\ Laplacian\ operator.$$

The general solution of the above equation is

$\Psi = \Psi_0 \sin(\omega t) = \Psi_0 \sin(2\pi \nu t)$ -----------(3)

Where Ψ_0 is the amplitude.

Differentiating Ψ w.r.to t,

$$\frac{\partial \Psi}{\partial t} = 2\pi\nu\Psi_0 \cos(2\,\pi\nu t)$$

$$\frac{\partial^2 \Psi}{\partial t^2} = -4\pi^2\nu^2\Psi_0 \sin(2\,\pi\nu t) = -4\pi^2\nu^2\Psi -------- (4)$$

Substituting 4 in 2, we get

$$-4\pi^2\nu^2\Psi = \mathrm{v}^2\nabla^2\Psi$$

We know that, $\nu = c/\lambda$ or $\nu = v/\lambda$ (for matter waves),

Above Equation becomes, $-4\pi^2 \frac{V^2}{\lambda^2}\Psi = v^2\nabla^2\Psi$

Implies $\nabla^2\Psi + \frac{4\pi^2}{\lambda^2}\Psi = 0$

Substituting $\lambda = \frac{h}{mV}$ we get

$$\nabla^2\Psi + \frac{4\pi^2(m^2v^2)}{h^2}\Psi = 0 \text{ - - - - - - - }(5)$$

and total energy(E) = K.E.(K)+P.E.(V)

$$E = (½)mv^2 + V$$

$$(½)mv^2 = (E-V), \text{ implies } m^2v^2 = 2m(E-V).$$

Substituting in equation 5,

$$\nabla^2\Psi + \frac{4\pi^2\{2m(E-V)\}}{h^2}\Psi = 0$$

$$\nabla^2\Psi + \frac{\{2m(E-V)\}}{\hbar^2}\Psi = 0 \text{ - - - - - - - - }(6)$$

This is the Schrödinger Time Independent Wave Equation.

Physical Significance of Wave Function:

Max Born in 1926 gave a satisfactory interpretation of the wave function Ψ associated with a moving particle. He postulated that the square of the magnitude of the wave function $|\Psi|^2$ (or $\Psi\Psi*$, $\Psi*$ is complex conjugate of Ψ), evaluated at a particular point represents the probability of finding the particle at the point.

$|\Psi|^2$ is called the probability density and Ψ is the probability amplitude. Thus the probability of the particle within an element volume dv is $|\Psi|^2$dv. Since the particle is certainly somewhere, the integral at $|\Psi|^2$ dv over all space must be unity i.e.

$$\iiint |\Psi|^2 \, dv = 1$$

In one dimension, say along x axis

$$\int |\Psi|^2 \, dx = 1$$

A wave function that obeys the above equations is said to be normalized.

An acceptable wave function should fulfill the following requirements (limitations)

1. It must be finite everywhere.
2. It must be single valued.
3. It must be continuous and have a continuous first derivative everywhere.

PARTICLE IN ONE DIMENSIONAL POTENTIAL BOX:

Consider a particle of mass 'm' moving along the x-axis between x=0 and x=a inside a one-dimensional box of infinite height and width

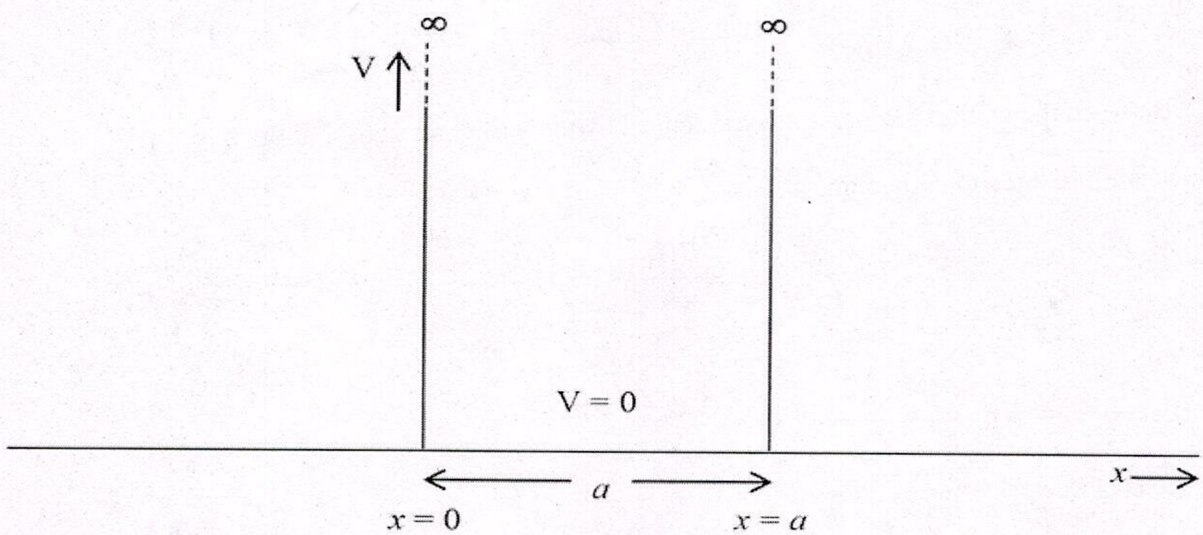


Fig. Particle in a potential well of infinite height.

Assume that the particle is freely moving inside the box. The motion of the particle is restricted by the walls of the box. The particle is bouncing back and forth between the walls of the box at x = 0 and x = a. For a freely moving particle at the bottom of the potential well, the potential energy is very low. Since the potential energy is very low, moving particle energy is assumed to be zero between x =0 and x =a.

The potential energy of the particle outside the walls is infinite due to the infinite P.E outside the potential well.

The particle cannot escape from the box

i.e. $V = 0$ for $0 < x < a$

$V = \infty$ for $0 \geq x \geq a$

Since the particle cannot be present outside the box, its wave function is zero

i e $|\psi|^2 = 0$ for $x = a$ & $x = 0$

The Schrödinger time independent wave equation in one – dimension

$$\frac{d^2\psi^2}{dx^2} + \frac{\{2m(E-V)\}}{\hbar^2}\Psi = 0 - - - - - - (1)$$

Between the walls, the potential experienced by the particle is zero, i.e., V=0

Therefore equation 1 becomes

$$\frac{d^2\psi^2}{dx^2} + \frac{2mE}{\hbar^2}\Psi = 0 - - - - (2)$$

Let $\frac{2mE}{\hbar^2} = K^2$ ------------(3)

Eqn.(2)becomes $\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2}\Psi = 0 - - - - (4)$

Eqn. (4) is similar to eq. of harmonic motion and the general solution of above eqn. is written as

Ψ(x)=Asinkx + Bcoskx-------------------- (5)

Where A, B and k are unknown quantities.

To find A and B, we apply the boundary conditions,

a) When x=0, Ψ(x)=0. Substituting in equation 5, we get

0=0+B, implies B=0 and

equation (5) becomes

Ψ(x)=Asinkx -----------------(6)

b) When x=a, Ψ(x)=0

equation (6) Asin Ka=0.

Since A≠0, SinKa=0

This is possible when Ka = n Π

or **k = nΠ/a** --------- (7)

Substituting the value of k in eqn. (3)

$$\frac{2mE}{\hbar^2} = \left[\frac{n\pi}{a}\right]^2$$

$$or \quad \boldsymbol{E_n = \frac{n^2\pi^2\hbar^2}{2ma^2} = \frac{n^2h^2}{8ma^2}} \quad \text{-------(8)}$$

The wave eqn. (equation 6) can be written as

$$\Psi(x) = A\sin\left(\frac{n\pi}{a}\right)x \text{------------------(9)}$$

To find the value of A, we apply the normalization condition. As the electron is definitely present between the two walls, the probability that the particle is found inside the box is unity.

$$\int_0^a |\Psi(x)|^2 dx = 1$$

$$\int_0^a \left|A sin\left(\frac{n\pi}{a}\right)x\right|^2 dx = 1$$

$$A^2 \int_0^a sin^2\left(\frac{n\pi x}{a}\right) dx = 1$$

$$A^2 \int_0^a \frac{1}{2}\left[1 - cos\left\{\frac{2n\pi x}{a}\right\}\right] \quad dx = 1$$

Or $$\frac{A^2}{2}\left[x - \frac{a}{2\pi n} sin \frac{2\pi n x}{a}\right]_0^a = 1$$

$$\frac{A^2}{2} = 1 \ or \ A = \sqrt{\frac{2}{a}}$$

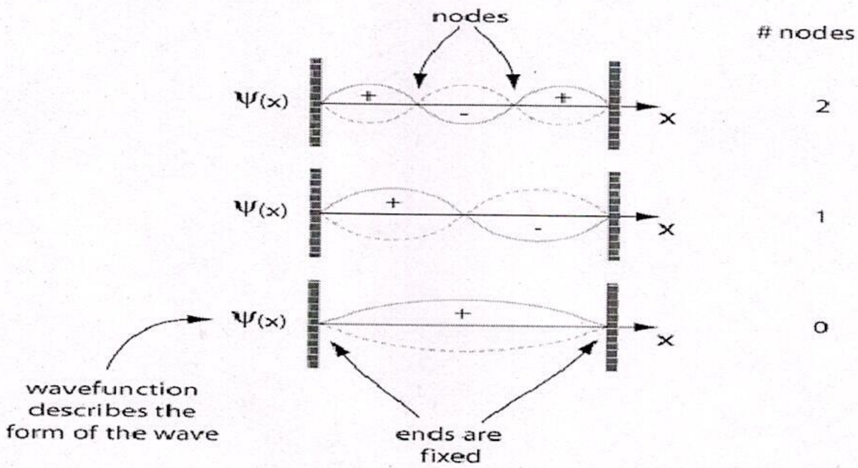
The normalized wave functions and corresponding energies En, are called eigen functions and eigen values.

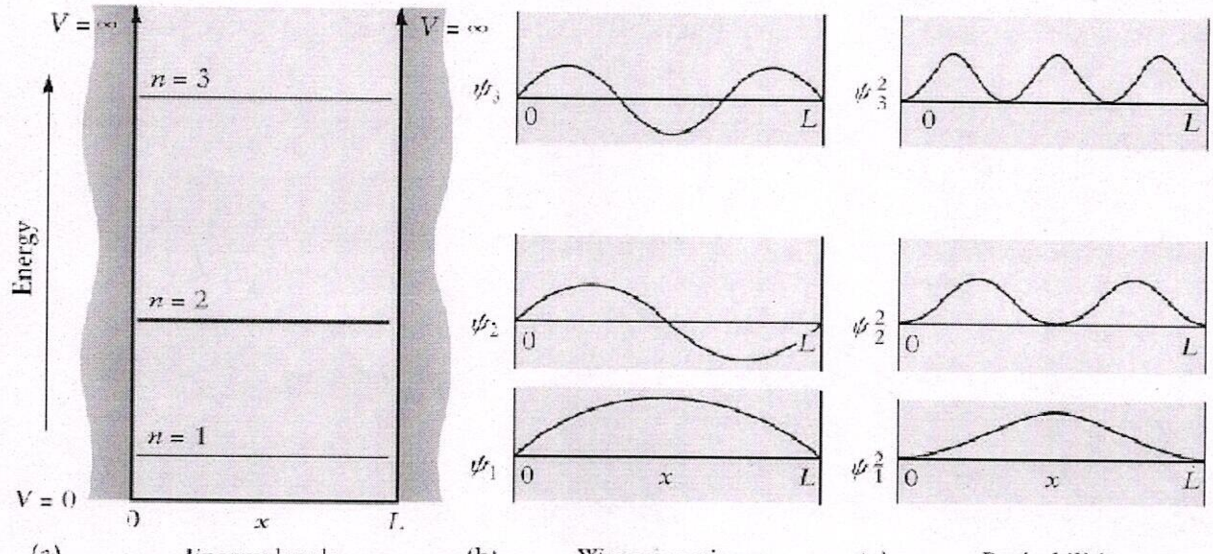
Substituting the value of A in equation 9, we get

$$\Psi(x) = \sqrt{\frac{2}{a}} sin\left(\frac{n\pi}{a}\right)x - - - - - - -(10)$$

Eqn. (8) represents an energy level for each value of n and the corresponding wave function is given in eqn. (10). Therefore the particle in the box can have discrete values of energies which are quantized.

The normalized wave functions Ψ1, Ψ2, Ψ3 given by eqn (10) are plotted.





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Note: Distance between the walls is taken as **"a" or "L"**

Lecture Notes

Course/Subject : Applied Physics

UNIT : III

Title : BAND THEORY OF SOLIDS & SECONDUCTORS.

Course Outcome : Classify solids based on the band theory

Syllabus:

Kronig-Penny model(qualitative treatment), E-k diagram, Energy bands in solids, classification of materials into metals, semiconductors, and insulators, Effective mass, Density of States(qualitative treatment), Fermi distribution function, Fermi level and its importance.
Intrinsic semiconductors, carrier concentration in intrinsic semiconductors, energy band diagram and position of Fermi level in intrinsic semiconductors, equation for electrical conductivity of semiconductors, extrinsic semiconductors (qualitative treatment).

Kronig – Penny Model:-

According to Kronig-penny theory the electrons move in a periodic potential produced by the positive ion cores. The potential energy of the electron varies periodically with the periodicity of positive ion core and potential energy of electron is zero at the positive ion sites (near the nucleus of the posiotive ion) and maximum between the two ions. The two positive ions are separated by the interatomic distance 'a' as shown in fig.

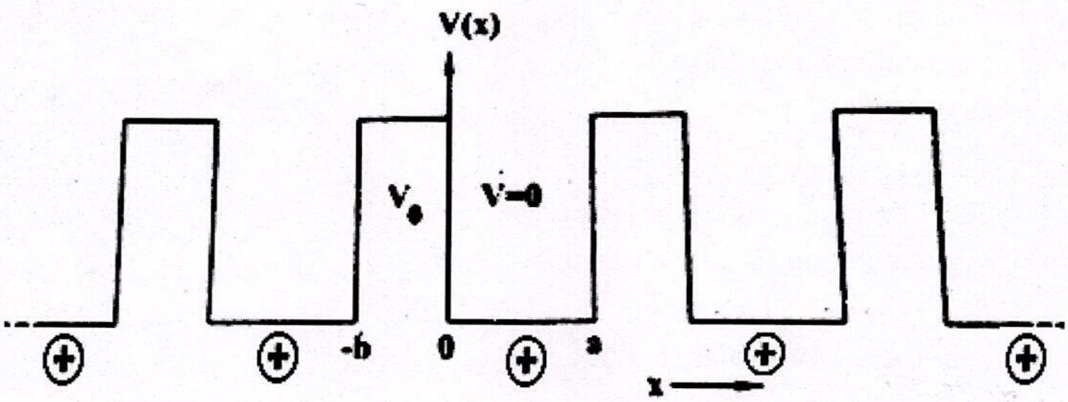


Fig. One dimensional Periodic potentials in a crystal

From the fig.:

The variation of P.E of electron,

$V(x) = \{ 0$, for Region-I, $0<x<a$

$\{ V_0$, for Region-II, $-b<x<0$

Here we have two regions.

Region-I:- $0<x<a$

The 1-dimensional Schroedinger Time Independent wave equation is,

$$\frac{d^2\Psi}{dx^2}+\frac{2m}{\hbar^2}(E-V(x))\Psi = 0$$

Since, $V(x) = 0$, $\frac{d^2\Psi}{dx^2}+\frac{2m}{\hbar^2}E\Psi = 0$

Consider, $\frac{2m}{\hbar^2}E = \alpha^2$

Then, $\frac{d^2\Psi}{dx^2}+\alpha^2\Psi = 0$ ---------------------(1)

Region-II:- $-b<x<0$

The 1-dimensional Schroedinger Time Independent wave equation is,

$$\frac{d^2\Psi}{dx^2}+\frac{2m}{\hbar^2}(E-V(x))\Psi = 0$$

$$\frac{d^2\Psi}{dx^2}+\frac{2m}{\hbar^2}(E-V_0)\Psi = 0 \quad [\text{since } V(x) = V_0]$$

$$\frac{d^2\Psi}{dx^2}-\frac{2m}{\hbar^2}(V_0-E)\Psi = 0 \quad [\text{since } V_0 >> E]$$

Consider, $\frac{2m}{\hbar^2}(V_0-E) = \beta^2$

Then, $\frac{d^2\Psi}{dx^2}-\beta^2\Psi = 0$ ---------------------(2)

The solutions of equations (1) & (2) can be obtained by using Bloch theorem

i.e., $\Psi_K(x)= e^{\pm iKx}U_K(x)$..................(3)

and $U_K(x) = U_K(x+a)$

Differentiating equation(3) w. r.to. 'x' twice and substituting in eqns (1)&(2) and applying boundary conditions and solving,

we get the solution,

$$\boxed{\frac{P}{\alpha a}\sin \alpha a + \cos \alpha a = \cos Ka} \text{..............(4)}$$

It is also called as Kronig – Penny equation.

Where, P = Scattering power of the potential barrier

$$P = \frac{maV_0\omega}{\hbar^2} \; ; \; V_0\omega = \text{Barrier strength.}$$

Kronig – Penny Graph :-

The left hand side of equation (4) is plotted as a function of 'αa' for the value of $P= 6\pi$ as shown in fig. Coska imposes a limitation on the values of the left side function .i.e. from +1to -1.

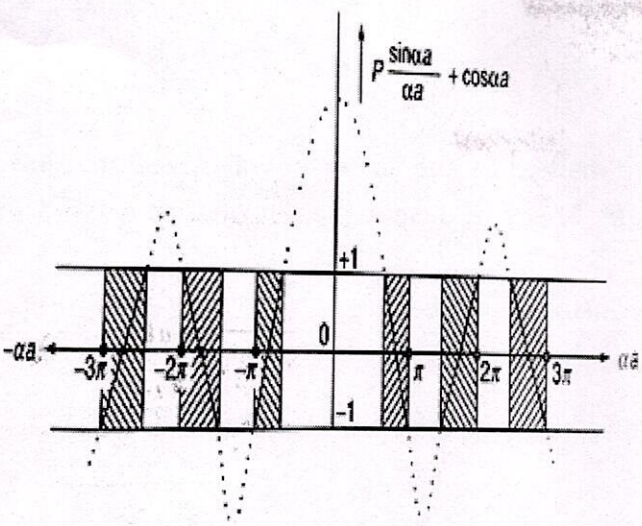


Fig.1

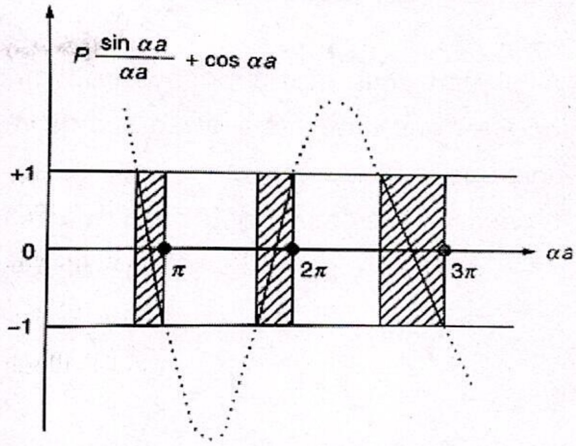


Fig.2

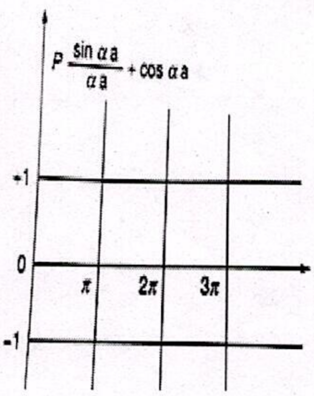


Fig.3

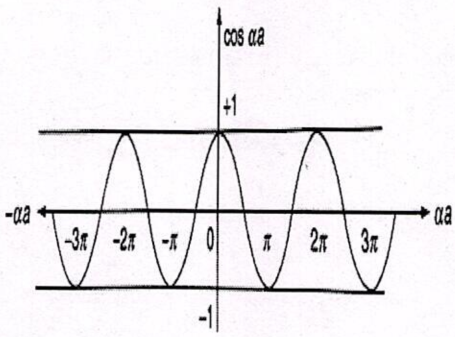


Fig.4

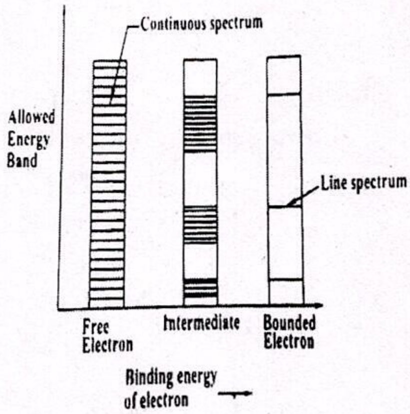


Fig.5

Conclusions-

(i). The energy spectrum has a number of allowed energy and forbidden energy bonds, as shown fig. 1.

(ii). As the value of ' αa ' increases the width of the allowed ENERGY band increases and width of the forbidden band decreases as shown in fig. 2.

(iii). As $P \rightarrow \infty$, the allowed energy band becomes infinitely narrow and the energy spectrum a line spectrum as shown in fig. 3.

(iv) As scattering power (P) increases, the strength of potential barrier increases and the width of the allowed energy band decreases.

(v) When $P \rightarrow 0$ then electrons move freely over the lattice without energy potential. Hence all the energies are allowed to the electrons and produce the continuous spectrum as shown in fig. 4

(vi) Thus by varying P from 0 to ∞, we get the energy spectra of all energies as shown in fig. 5.

Brilliouin Zones (or) E-K Diagram:-

Brillouin zones are the boundaries that are marked by the values of waves vector K, in which the electrons can have allowed energy values. These represent the allowed values of K of the electrons in 1D, 2D & 3D.

We have, the energy of the electron in a constant potential box is,

$$E = \frac{n^2h^2}{8ma^2} \text{ ... .(1), Where a = length of the box.}$$

$$\text{But, } K = \frac{n\pi}{a} \quad » \quad \boxed{K^2} = \frac{n^2\pi^2}{a^2}$$

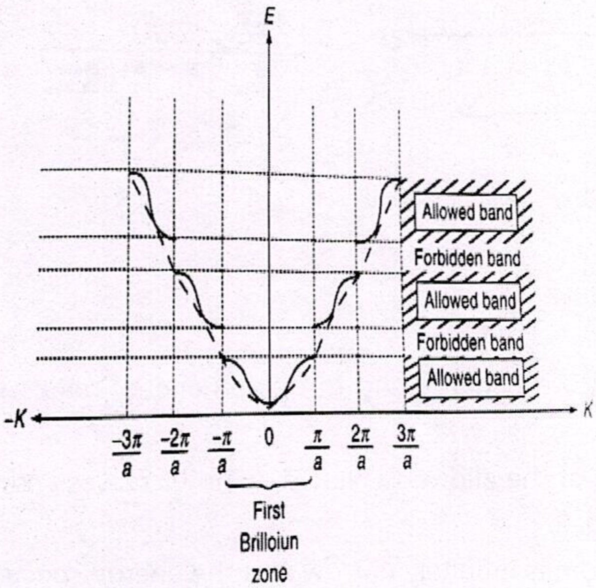
$$\frac{n^2}{a^2} = \frac{K^2}{\pi^2} \text{.......(2)}$$

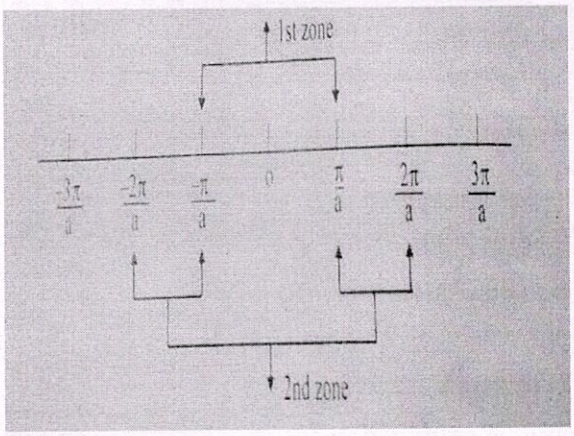
Substitute eqn. (2) in (1), we get

$$: \quad E = \frac{K^2h^2}{8m\pi^2}; \text{ i.e., } \boxed{E \propto K^2} \text{..It represents Parabolic equation.}$$

Graph:-

A graph is drawn between the total energy (E) and the wave vector k, for various values of k. i.e, $K = \frac{n\pi}{a}$; n = ±1, ±2, ±3,.....





Conclusions:- From graph

1[st] Brillouin Zone (1BZ):- $-\frac{\pi}{a}$ to $\frac{\pi}{a}$

2[nd] Brillouin Zone (2BZ):- $-\frac{\pi}{a}$ to $\frac{-2\pi}{a}$ and $\frac{\pi}{a}$ to $\frac{2\pi}{a}$

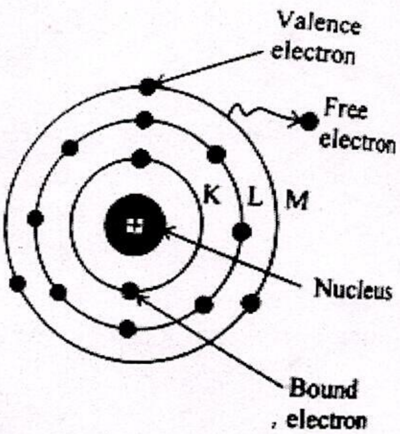
Similarly 3[rd], 4[th] Brillouin Zones can be obtained.

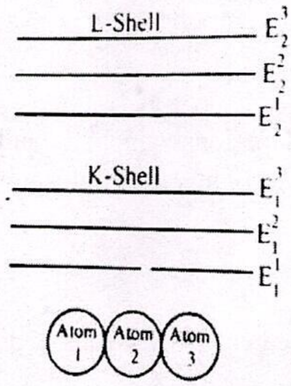
Brillouin Zones are separated by forbidden gap.

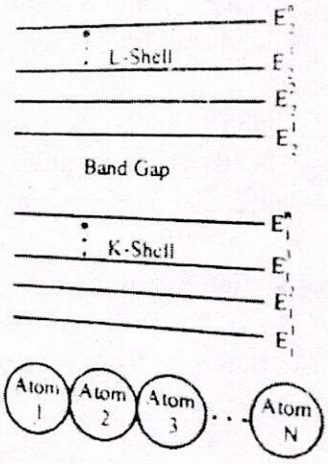
Origin of Energy band formation in Solids:-

Band theory of solids explains, the formation of energy bands and determines whether a solid is a conductor, insulator or a semi conductor.

Energy Bands:-







When two atoms of equal energy levels are brought closer together, the original energy levels E_1& E_2 splits each into two energy levels. i.e., the K- shell energy E_1 splits into E_1^1& E_1^2 , similarly the L-shell energy E_2 splits into E_2^1& E_2^2

When 3-atoms are brought closer together, the original energy levels E_1& E_2 splits into 3 energy levels as E_1^1, E_1^2, E_1^3& E_2^1, E_2^2, E_2^3 respectively. Therefore, if 'N' no. of atoms of equal levels are brought closer to form a solid, then forms a closely spaced continuous energy levels, called as <u>energy bands.</u>

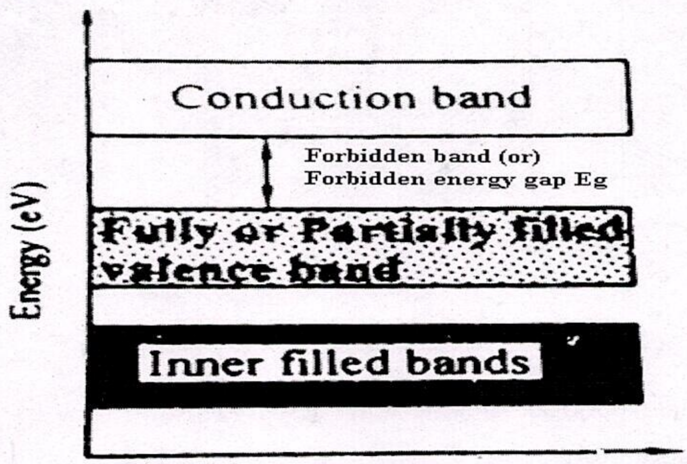


fig.3-Energy level diagram

Energy Level (or) Band Diagram:-

Energy band can also defined as, the range of energies possessed by an electron in a solid. It consists of (i) Inner filled bands. (ii) Valence bands.(iii) Conduction bands.(iv) Forbidden band (or) energy gap.

<u>(i) Inner filled bands:-</u> During the formation of energy bands the inner filled energy levels forms a energy band called as inner filled bands. It is completely filled with electrons.

(ii) Valence bands:-

The electrons in the outermost orbits of atoms forms a energy band, called as valence band. It is completely filled (or) partially filled with electrons, based on the type of materials.

(iii) Conduction band:-

If the electrons come out from valence band for conduction, then they forms a energy band, called as Conduction band. It is partially filled (or) empty band.

(iv) Forbidden band:-

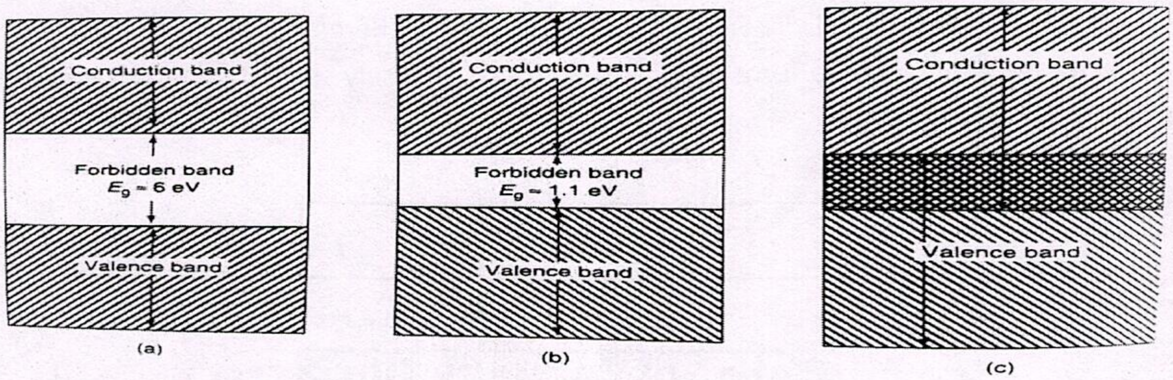
Energy bands are separated by small regions which do not allow any energy levels. Such regions between the energy bands are called as forbidden energy gap or forbidden bands.

Classification of Solids:-

Based on band theory, arrangement of electrons and forbidden energy gap, the solid materials are classified into 3 types.

They are ,

1. Conductors
2. Insulators ,
3. Semi conductors



1) Conductors:-

Solid materials which conduct electric current when potential difference is applied across them, are known as Conductors.

In conductors, the forbidden energy gap is zero (Eg = 0) i.e., both valence band & conduction band overlap with each other as shown in Fig.1.

In conduction band plenty of free electrons are available. These electrons move freely from valence band to conduction band & constitute electrical current.

Ex:- Cu, Al,Fe,....etc.

2) Insulators:-

Solid materials which don't conduct electric current are known as insulators.

In insulators, the forbidden energy gap is very high (Eg> 3 eV). Due to this electrons cannot jump from valence bond to conduction band. In insulators, the valence electrons are bound tightly to their parent atom.

At 0k, the valence bond is completely filled & energy gap between C.B & V.B is of the order of 10ev. The resistivity of insulator is of the order of 10^7 Ω-m.

Ex:- Glass, wood, plastic

3) Semi conductors:-

Solid materials, whose electrical conductivity lies between conductors & insulators are called as semi conductors. Conductivity of semi conductors is in the order of 10^4 to 10^{-4} mho m^{-1}.

In semi conductors, the forbidden energy gap is very small (Eg= 1.1ev or Eg < 3 eV).

Ex:-Ge, Si.

For Ge, forbidden energy gap (Eg) = 0.72 eV and Si, Eg = 1.1 eV

At T = 0 k, semi conductor becomes an insulator.

*****Distinguish between Conductors, Semiconductors and Insulators :-**

Conductors	Semiconductors	Insulators
1.valence band and conduction bands overlap with each other	1. valence band and conduction bands do not overlap with each other	1. valence band and conduction bands do not overlap with each other
2.Forbidden Energy gap is zero i.e., Eg = 0	2. energy gap is very small i.e., Eg= 1.1ev or Eg < 3 eV	2. energy gap is very high i.e., Eg> 3 eV).
3. Conductivity is vey high	3. Conductivity is medium	3. Conductivity is very less or zero
4. Resistivity is very less	4. Resistivity is medium	4. Resistivity is very high
5.They have +ve temperature Coefficient of resistance	5. They have -ve temperature Coefficient of resistance	5. They have -ve temperature Coefficient of resistance
6. Charge carriers are electrons	6. Charge carriers are electrons and holes	6. No Charge carriers
7. Ex:- Cu, Al,Fe,....etc.	7. Ex:-Ge, Si.	7. Ex:- Glass, wood, plastic

Effective mass of the electron:

When an electron in a period potential is accelerated by an electric field (or) magnetic field, then the mass of the electron is called effective mass (m*).

Let an electron of charge 'e' and mass 'm' moving inside a crystal lattice of electric field (E).

According to Newton's law

Electrical force on the electron F = m^* a --------------(1)

Considering the free electron as a wave packet , the group velocity v_g corresponding to the particle's velocity can be written as

$$V_g = \frac{d\omega}{dk} = \frac{d(2\Pi\nu)}{dk} = 2\Pi\frac{d\nu}{dk} = (\frac{2\Pi}{h})\frac{d(h\nu)}{dk} = \frac{1}{\hbar}\frac{dE}{dk} \text{ ---------(2)}$$

where, the energy E = hυ and $\hbar = \frac{h}{2\Pi}$

$$\text{Acceleration } a = \frac{dv_g}{dt} = \frac{d(\frac{1}{\hbar}\frac{dE}{dk})}{dt} = \frac{1}{\hbar}\frac{d^2E}{dk.dt} = \frac{1}{\hbar}(\frac{d^2E}{dk.dk})(\frac{dk}{dt}) = \frac{1}{\hbar}(\frac{d^2E}{dk^2})(\frac{dk}{dt}) \longrightarrow (3)$$

Since ħk = p

ħ(dk/dt) = (dp/dt) [F= (dp/dt)]

ħ(dk/dt) = F

(dk/dt) = F/ ħ

Equation (3) become

$$\therefore a = \frac{1}{\hbar^2}(\frac{d^2E}{dk^2})F$$

Substitute 'a' value in equation (1)

$$m^* = [\frac{\hbar^2}{(\frac{d^2E}{dk^2})}] \text{---------------(4)}$$

This equation indicates that the effective mass is determined by $\frac{d^2E}{dk^2}$.

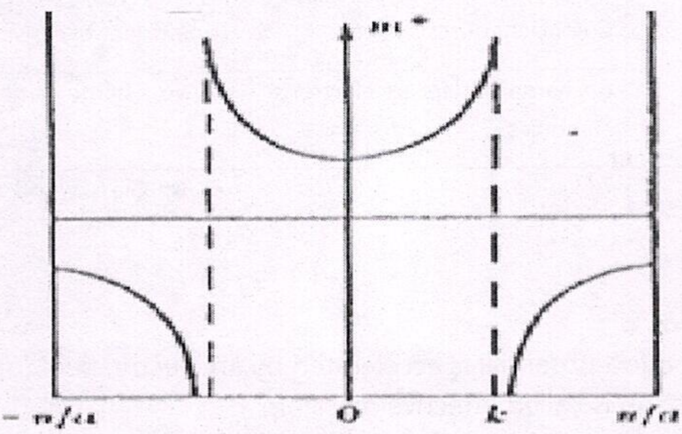


Fig. Effective mass as a function of k

Density of states:-

The number of energy states per unit volume is known as **density of energy states.**

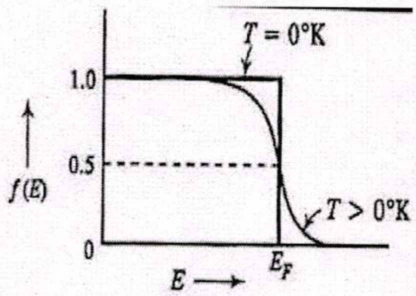
Density of energy states $g(E)\,dE = \frac{4\pi}{h^3}(2m)^{3/2}(E)^{1/2}dE$

Fermi Dirac Distribution:-

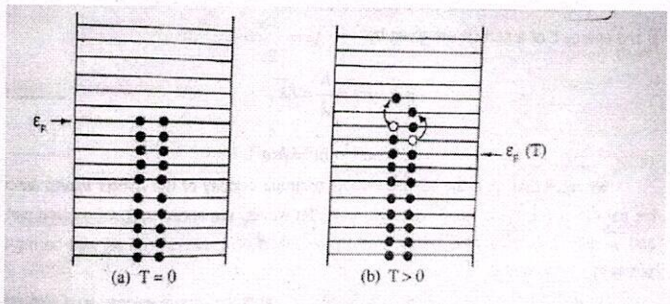
A metal piece contains very large number of electrons. Each electron possesses quantized energy states and obeys Pauli's exclusion principle. Hence they satisfy Fermi-Dirac statistics. The probability F(E) of an electron occupying energy level E_i is given by

$$F(E_i) = \frac{1}{\exp(\frac{E_i - E_f}{kT}) + 1}$$

Where $F(E_i)$ is called Fermi function which is defined as the probability of electron occupation in the given energy state (E_i) at thermal equilibrium. E_f is Fermi energy, E_i is energy of i^{th} state and k is Boltzmann constant.



VARIATION OF f(E) WITH E



:The effect of temperature on the occupation of energy levels of electrons in a crystal.

The plot of F(E) Vs E is as shown in fig.

Conclusions: At **T=OK,** the Fermi Dirac distribution of electrons can be understood mathematically from the following two cases.

Case -1: If $E>E_F$, $e^{\frac{(E_i-E_F)}{kT}} = \infty$

Therefore, $F(E_i)= 1/\infty$ then $F(E_i)=0$. It indicates that energy levels above Fermi level are empty.

Case -2: If $E<E_F$, $e^{\frac{(E_i-E_F)}{kT}} =0$ then $F(E_i)=1$. It indicates that energy levels below Fermi levels are full of electrons. The Fermi level is a boundary energy level which separates the filled energy state and empty states at 0k. The energy of the highest filled state at 0K is called Fermi Energy E_F and the energy level is known as Fermi Level.

Case-3: At T>OK, if $E_i=E_F$ then $F(E_i)=1/2$. i.e 50%. Therefore Fermi level is the energy level for which the probability of filled states is 50% at any temperature.

2. When **T>0**, $F(E_F)<1$ for $E_i<E_F$

$F(E_i)>0$ for $E_i>E_F$

$F(E_i)=\frac{1}{2}$ for $E_i=E_F$

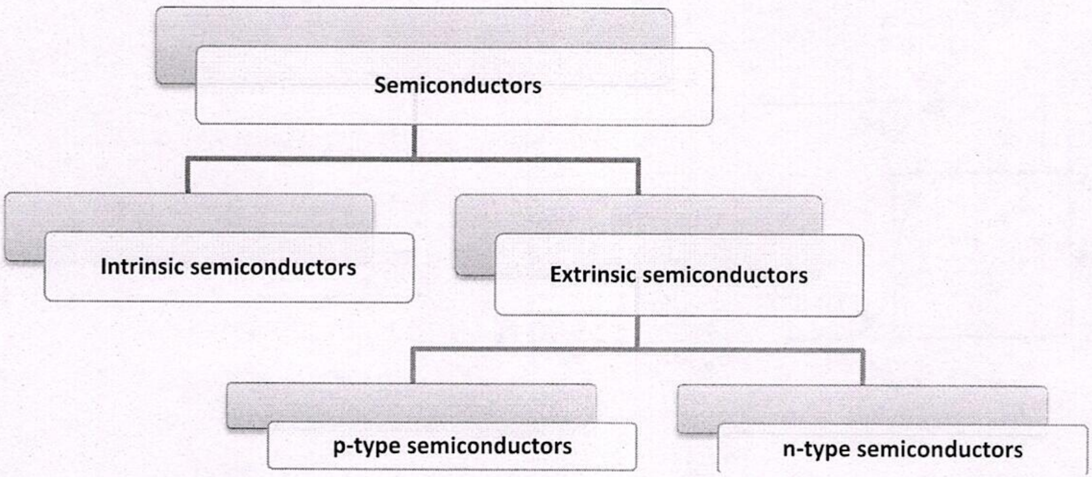
As temperature increases more and more electrons jump to the levels above E_F leaving vacancies as shown in the fig.

3. The electrons in the levels above E_F and vacancies in the levels below E_F are responsible for conduction in semiconductors.
4. If the temperature is raised further, the resistance of the metals increases due to decrease of mobility.
5. At **T>OK,** the Fermi energy level decreases.

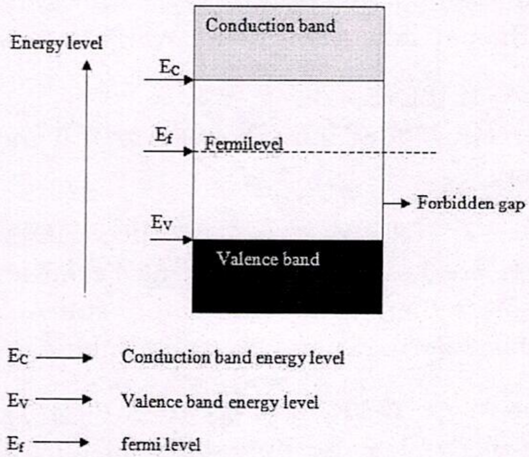
Semiconductors:-

The materials which have electrical conductivity lies between conductors and insulators are called semiconductors. In these materials electorns and holes both are responsible for electrical conduction.

semiconductors mainly classified as follows



Intrinsic semiconductors:-



A pure semiconductor which is not doped is termed as intrinsic semiconductor. In Si crystal, the four valence electrons of each Si atom are shared by the four surrounding Si atoms. An electron which may break away from the bond leaves deficiency of one electron in the bond. The vacancy created in a bond due to the departure of an electron is called a hole. The vacancy may get filled by an electron from the neighboring bond, but the hole then shifts to the neighboring bond which in turn may get filled by electron from another bond to whose place the hole shifts, and so on thus in effect the hole also undergoes displacement inside a crystal. Since the hole is associated with deficiency of one electron, it is equivalent for a positive charge of unit magnitude. Hence in a semiconductor, both the electron and the hole act as charge carriers.

In an intrinsic semiconductor, for every electron freed from the bond, there will be one hole created. It means that, the no: of conduction electrons is equal to the no: of holes at any given temperature. Therefore there is no predominance of one over the other to be particularly designated as charge carriers.

A broken covalent bond creates an electron that is raised in energy, so as to occupy the conduction bond, leaving a hole in the valence bond. Both electrons and holes contribute to overall conduction process.

In an intrinsic semiconductor, electrons and holes are equal in numbers.

Thus $n = p = n_i$

(Fig.Fermi Level in Intrinsic Semiconductor)

Where n is the number of electrons in the conduction band in a unit volume of the material (concentration), p is the number of holes in the valance band in a unit volume of the material. And n_i, the number density of charge carriers in an intrinsic semi conductor. It is called intrinsic density.

Carrier concentration in intrinsic semi conductors:-

Density of Electrons:-

The number of electrons available between energy intervel E and E+dE is given by

dn = p (E) g (E) dE ---------------------(1)

where P(E) is the probability of occupation of an electron in the energy state E

g(E) dE is the density of electrons in the energy level E and E+dE

If E_c is the energy corresponding to the bottom of the conduction band, to calculate the density of electrons integrate the equation (1) between the limits E_c and $\propto$

i.e. $n = \int_{E_c}^{\infty} dn = \int_{E_c}^{\infty} p(E)g(E)dE$

But we know that , $p(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{KT}\right)}$

For all possible temperatures $E - E_f >> KT$

So $p(E) = \exp\left(\dfrac{-(E-E_F)}{KT}\right) = \exp\left(\dfrac{E_F - E}{KT}\right)$

And g(E) dE = $\frac{4\pi}{h^3}(2m)^{3/2}(E)^{1/2}dE$

The electron in the conduction band is not free electron so m =m*, and if we consider the minimum energy of the electrons in the conduction band as E_c, then

$$g(E)\,dE = \left(\frac{4\pi}{h^3}\right)2^{3/2}(m_e^*)^{3/2}(E-E_c)^{1/2}dE$$

$$\therefore n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2}\exp\left(\frac{E_f-E}{KT}\right)dE$$

$$= \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp\left(\frac{E_f}{KT}\right)\int_{E_c}^{\infty}(E-E_c)^{1/2}\exp\left(\frac{-E}{KT}\right)dE$$

Put $E-E_c = x$

$E = E_c + x$

$dE = dn$

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp\left(\frac{E_f}{KT}\right)\int_{E_c}^{\infty}x^{1/2}\exp\frac{-(E_c+x)}{KT}dx$$

$$= \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp\left(\frac{E_f-E_c}{KT}\right)\int_{E_c}^{\infty}x^{1/2}\exp\left(\frac{-x}{KT}\right)dx$$

$$\int_{E_c}^{\infty}x^{1/2}\exp\left(\frac{-x}{KT}\right)dx = (KT)^{3/2}\frac{\pi^{1/2}}{2}$$

Hence $n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\left(\exp\frac{E_f-E_c}{KT}\right)(KT)^{3/2}\frac{\pi^{1/2}}{2}$

The number of electron per unit volume of the material is given by

$$n = 2\left(\frac{2\pi m_e^* KT}{h^2}\right)^{3/2}\exp\left(\frac{E_f-E_c}{KT}\right)$$

Density of holes:

Let dp be the number of holes or vacancies in the energy interval E and E+ dE in the valance band

dp = g(E) (1-p(E) dE

where g(E) dE is the density of energy states in the energy interval E and E+dE and 1-p(E) is the probability of existence of a hole

$$1-p(E) = 1-\left[\frac{1}{1+\exp\left(\frac{E-E_F}{KT}\right)}\right]$$

For $E-E_F >> KT$, $1-p(E) = \exp\left(\frac{E-E_F}{KT}\right)$

$$g(E)\,dE = \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V-E)^{1/2}dE$$

where m_h^* is the effective mass of hole

Since E_v is the energy of the top of the valance band

$E = (E_v - E)$

$$P = \int_{\infty}^{E_v} \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V - E)^{1/2} exp\left(\frac{E_F}{KT}\right) dE$$

$$= \frac{4\pi}{h^3}(2m_h^*)^{3/2} exp\left(\frac{-E_F}{KT}\right)\int_{\infty}^{E_v}(E_v - E)^{1/2} exp\left(\frac{E}{KT}\right) dE$$

Put $E_v - E = x$

$E = (E_v - x)$

$dE = -dx$

$$= \int_{\infty}^{E_v}(E_v - E)^{1/2} \exp\left(\frac{E}{KT}\right) dE = -\int_{-\infty}^{0} x^{1/2} \exp\left(\frac{E_V - x}{KT}\right) dx$$

$$= \exp\frac{E_v}{KT}\int_0^{\infty} x^{1/2} \exp\left(\frac{-x}{KT}\right) dx$$

$$= \exp\frac{E_v}{KT}(KT)^{3/2}\frac{\pi^{1/2}}{2}$$

Hence $P = \frac{4\pi}{h^3}(2m_h)^{3/2} exp\left[\frac{E_V - E_F}{KT}\right](KT)^3 \frac{\pi^{1/2}}{2}$

$$P = 2\left(\frac{2\pi m_h^* KT}{h^2}\right)^{3/2} exp\left[\frac{E_V - E_F}{KT}\right]$$

In intrinsic semi conductors, $n = p = n_i$ is called intrinsic carrier concentration

$$n_i^2 = np = 4\left(\frac{2\pi KT}{h^2}\right)^3 \left(m_c^* m_h^*\right)^{3/2} exp\left(\frac{E_V - E_c}{KT}\right)$$

$$= 4\left(\frac{2\pi KT}{h^2}\right)^3 \left(m_c^* m_h^*\right)^{1/2} exp\left(\frac{-Eg}{KT}\right)$$

Where $E_c - E_v = Eg$ is the for bidden gap

Hence $ni = \sqrt{n_i^2} = 2\left(\frac{2\pi KT}{h^2}\right)^{3/2} \left(m_c^* m_h^*\right)^{3/4} exp\left(\frac{-Eg}{2KT}\right)$

Fermi level in intrinsic semi conductors:-

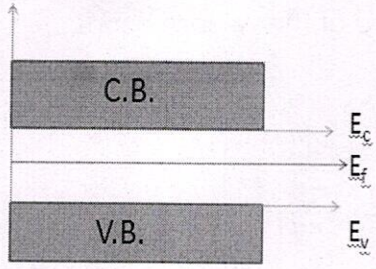
In Intrinsic semiconductors, n=p

$$2\left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2} e^{(E_f - E_c)/KT} = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2} e^{(E_v - E_f)/KT}$$

Let us assume , $m^*_e = m^*_h$

$$e^{(E_f - E_c)/KT} = e^{(E_v - E_f)/KT}$$

$$E_f = \left[\frac{E_c + E_v}{2}\right]$$



The Fermi energy level for intrinsic semiconductor is lies at the middile of the enengy gap.

Electrical conductivity in intrinsic semi conductors:-

In case of semiconductors, electrical conductivity is

$$\sigma = ne\,\mu_e + pe\,\mu_h$$

Intrinsic semiconductors, $n=p=n_i$

$$\sigma = n_i\,e\,\mu_e + n_i\,e\,\mu_h$$

$$\sigma = n_i\,e\,(\mu_e + \mu_h)$$

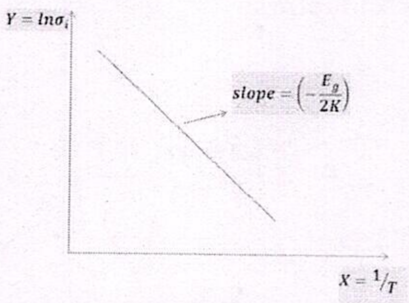
$$\sigma_i = (\mu_e + \mu_h)\,2e\left[\frac{2\pi KT}{h^2}\right]^{3/2}(m_e^* m_p^*)^{3/4}\left[e^{-(E_g)/2KT}\right]$$

$\sigma_i =$ A [exp (-Eg/2KT)]

apply ln on both sides

$\ln\sigma_i = \ln A - Eg/2KT$

In case of semiconductors, electrical conductivity (σ) is directly proportional to the temperature(T)

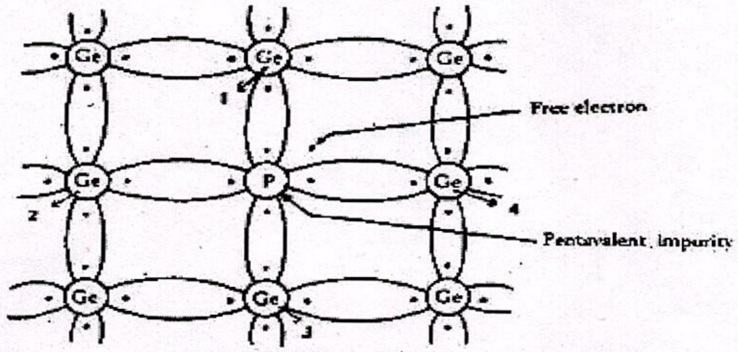


EXTRINSIC SEMICONDUCTORS :-

Intrinsic Semiconductors are rarely used in semiconductor devices as their conductivity is not sufficiently high. The electrical conductivity is extremely sensitive to certain types of impurity. It is the ability to modify electrical characteristics of the material by adding chosen impurities that make extrinsic semiconductors important and interesting.

Addition of appropriate quantities of chosen impurities is called doping, usually, only minute quantities of dopants (1 part in 10^3 to 10^{10}) are required. Extrinsic or doped semiconductors are classified into two main types according to the type of charge carries that predominate. They are the n-type and the p-type.

N-TYPE SEMICONDUCTORS:

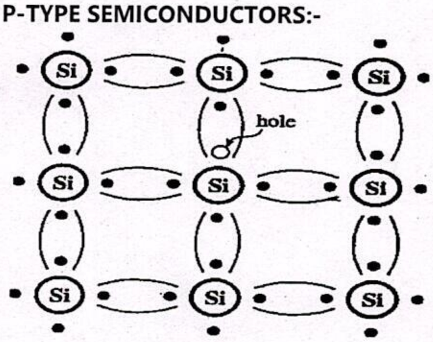


n-type semiconductor

Doping with a pentavalent impurity like phosphorous, arsenic or antimony the semiconductor becomes rich in conduction electrons. It is called n-type the bond structure of an n-type semiconductor is shown in Fig.

Even at room temperature, nearby all impurity atoms lose an electron into the conduction band by thermal ionization. The additional electrons contribute to the conductivity in the same way as those excited thermally from the valence bond. The essential difference between the two mechanisms is that ionized impurities remain fixed and no holes are produced. Since pentavalent impurities donate extra carrier electrons, they are called donors.

P-TYPE SEMICONDUCTORS:-



FORMATION OF HOLE DUE TO DOPING

p-type semiconductors have holes as majority charge carries. They are produced by doping an intrinsic semiconductor with trivalent impurities (e.g. boron, aluminum, gallium, or indium). These dopants have three valence electrons in their outer shell. Each impurity is short of one electron for covalent bonding. The vacancy thus created is bound to the atom at 0 K. It is not a hole. But at some higher temperature an electron from a neighboring atom can fill the vacancy leaving a hole in the valence bond for conduction. It behaves as a positively charge particle of effective mass m_h^*. The bond structure of a p-type semiconductor is shown in Fig.

Dopants of the trivalent type are called acceptors, since they accept electrons to create holes above the top of the valence bond. The acceptor energy level is small compared with thermal energy of an electron at room temperature. As such nearly all acceptor levels are occupied and each acceptor atom creates a hole in the valence bond.

In extrinsic semiconductors, there are two types of charge carries. In n-type, electrons are more than holes. Hence electrons are majority carriers and holes are minority carries. Holes are majority carries in p-type semiconductors; electrons are minority carriers.

is of the order of 10^{-6}m. The potential difference across the depletion region is called the potential barriers.

Energy diagram of PN diode:

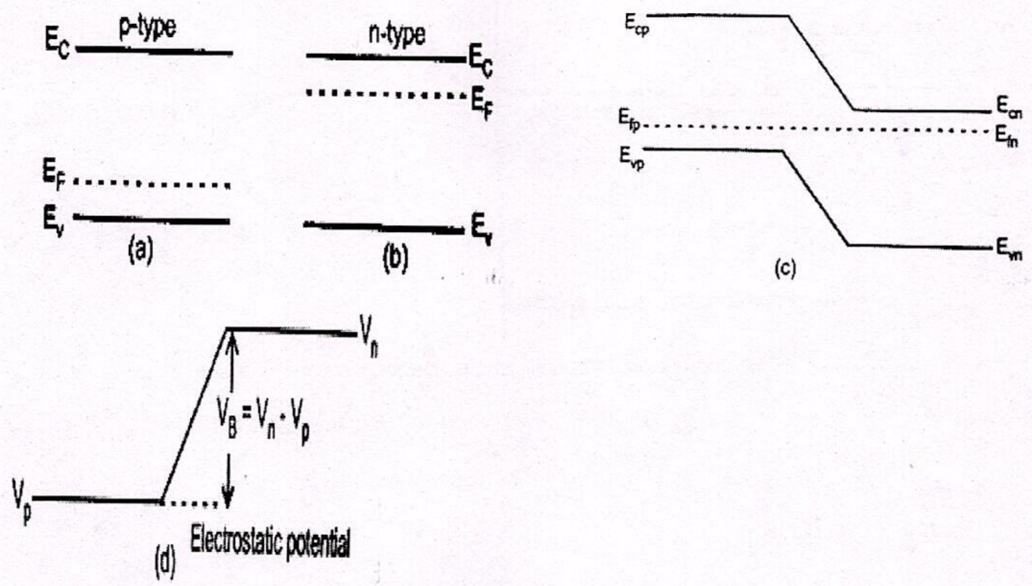


Fig: (a) and (b) Energy level diagram of p-type semiconductors respectively (c)Energyleveldiagramof PN junction and (d) formation of potential barrier across the junction

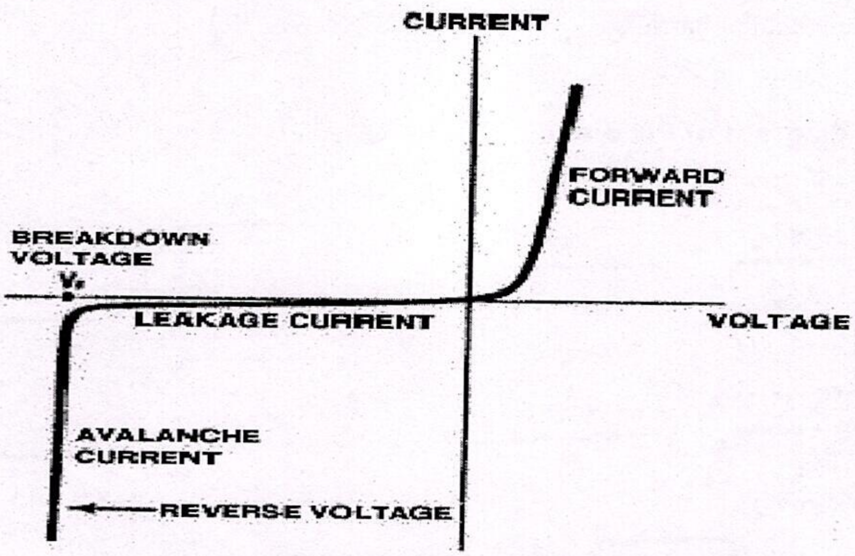
V-I Characteristics of a junction diode:

Graphs drawn between bias voltage and circuit current of a junction diode are called characteristics of the diode.

1. Forward Bias:-

This is obtained by plotting a graph between forward bias voltage and circuit current. The forward voltage is gradually increased in steps and corresponding current readings are noted. A graph is then plotted between voltage and current.

Practically no current flows until the barrier voltage is overcome. Once the external voltage exceeds the barrier voltage, the current increases rapidly, approximately exponentially.



V-I characteristics of a real diode

***Fig**: V-I Characteristics of a PN junction*

2. Reverse Bias:-

The reverse voltage is gradually increased in steps and corresponding readings are noted. A graph is ploted between voltage and current. With reverse bias the reverse current remains very small over a long range, increasing very slightly with increasing bias.

If the reverse bias is made very high, the covalent bonds near the junction breakdown and a large number of electron hole pairs are liberated,the reverse current then increases abruptly to a large value. This is known as 'Avalanche breakdown' and may damage the junction by excessive heat generated unless the current is limited by external circuit. This phenomenon is used in making zener diodes.

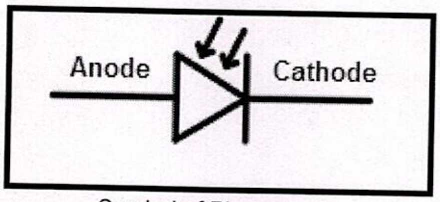
The maximum voltage that a junction diode can bear without breakdown is called zener voltage or reverse breakdown voltage.

Effect of temperature according to diode equation, I = Io $\left(e^{\frac{ev}{\eta kt}} - 1 \right)$

circuit current increases with increase of temperature for 10^{O}c raise of temperature the current nearly doubles for Ge and Si.

Photo diode:

A **photodiode** is a semiconductor p-n junction device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode.



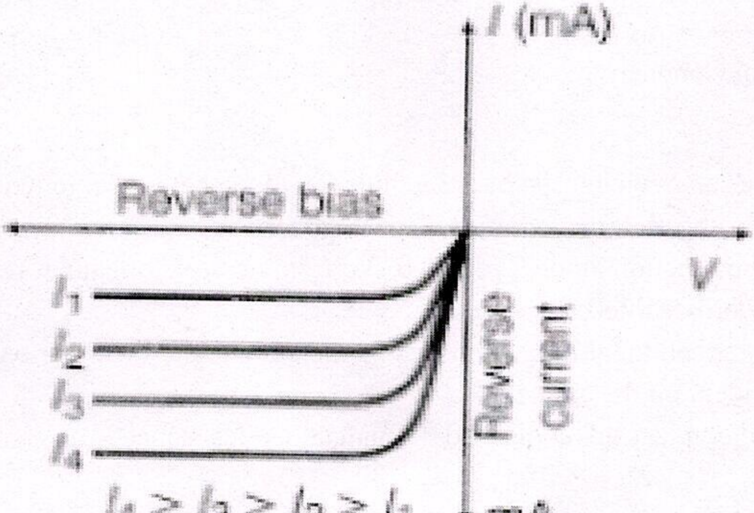
Symbol of Photo diode

The function of the photo diode junction is the opposite an LED function. In an LED, photons are released in response to the current flow through the junction. In a photo diode, the photons are absorbed resulting in the generation of the carriers that manifest as current through the junction.

When a photon of sufficient energy strikes the diode, it creates an electron–hole pair. If the absorption occurs in the junction's depletion region, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

V-I characteristics of photodiode :

The characteristics of the photodiode are shown clearly in the following figure. A photodiode is operated in a reverse bias mode. Photocurrent is nearly independent of reverse bias voltage which is applied. For zero luminance, the photocurrent is almost zero as shown in the figure.

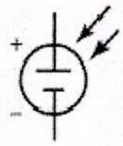


Applications

- Photodiodes are used in safety electronics such as fire and smoke detectors.
- Photodiodes are used in numerous medical applications. They are used in instruments that analyze samples, detectors for computed tomography and also used in blood gas monitors, pulse oximeters.
- Photodiodes are used in solar cell panels.
- Photodiodes are used in consumer electronics devices such as compact disc players, remote control devices, exposure meters in camera, photo sensors

SOLAR CELL:

A special p–n junction diode which converts sun light into electrical energy is known as ***solar cell or photo voltaic device.***



Symbol of solar cell

Materials:

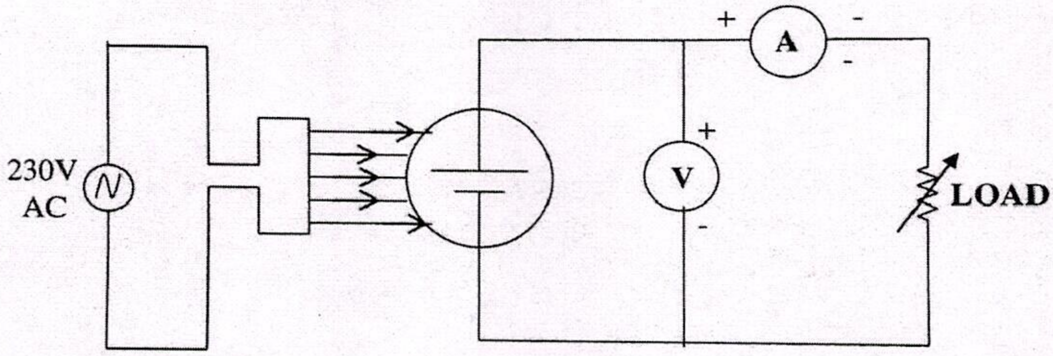
Main considerations while selecting a material for solar cell fabrication:

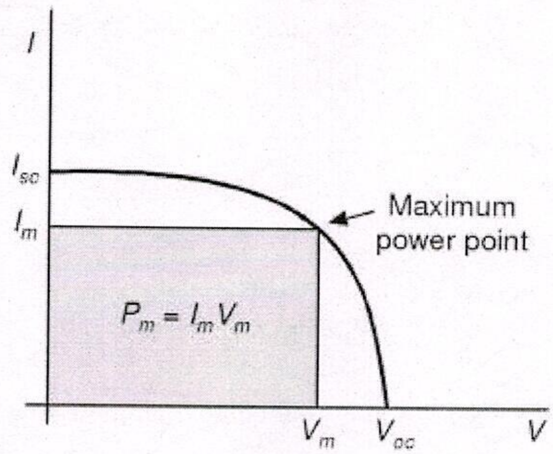
- Band gap (1 to 2eV)
  Semiconductors commonly used for making solar cells are
  Si(1.1eV), GaAs(1.43eV), CdTe(1.45eV).
- High optical absorption.
- Electrical Conductivity.

Construction:

- A simple solar cell consist of a p-n junction diode having large junction surface to absorb large radiation.
- In this p-n junction diode n-region ($0.3x10^{-6}$m) is very thin and p-region ($100x10^{-6}$m) is thick.
- In the solar cell the thin region is called the emitter and the other base, light incident on the emitter.
- *N*i plated contacts are connected through a load resistance.

I - V Characteristics:





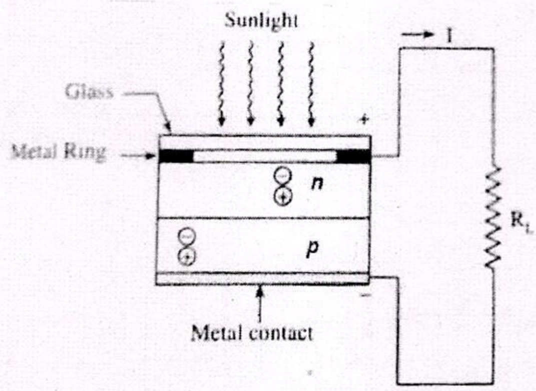
An *I-V* characteristic of a solar cell with the maximum power point.

The I – V characteristics of solar cell can be determined by connecting load resistance across the voltmeter in series with ammeter. By keeping the light intensity constant we will vary the load resistance in a sequential manner to observe corresponding voltmeter and ammeter reading. A graph is plotted by taking voltage and current along Xand Y axis with the given scale. An exponential curve decay in power is obtained. The curve passes through three significant points.

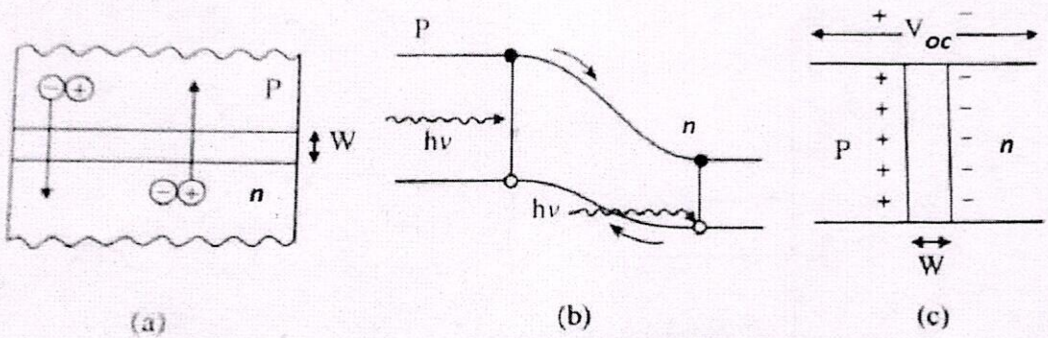
A. ***Short circuit current(I_{SC}):*** It occurs on a point of the curve where the voltage is zero. At this point the power output of the solar cell is zero.

B. ***Open circuit voltage (V_O):*** It occurs on a point of the curve where the current is zero. At this point the power output of the solar cell is zero. *The product of above two quantities(I_{SC} x V_O) gives the* ***ideal power*** *of the cell.*

C. ***Maximum Power (P_{max}):*** The cell delivers the maximum power, where the product I_mV_m is maximum. The position of the maximum power is the area of the largest rectangle that can be formed in the V – I curve.



Working:



Working of a solar cell

Three steps are involved in working of a solar cell, when light falls on it.

***1. Generation of charge carriers (electron-hole pair)*:**

When light energy falls on a p-n junction diode, photon collide with valence electrons and impart them sufficient energy enabling them to leave their parent atoms. Thus, electron – hole pairs are generated in both ***p*** and ***n*** sides of the junction.

2. Separation of charge carriers:

The electron from p-region diffuse through the junction to a n-region and holes from n-region diffuse through the junction to the p-region due to electric field of depletion layer. Thus, hole and electrons are separated out. The accumulation of electron and holes on the two sides of the junction gives rise to open circuit voltage(Voc).

3. Collection of charge carriers:

The flow of electrons and holes constitutes the minority current. The d.c is collected by the metal electrodes and flows through the external load (RL). The d.c is directly proportional to the illumination and also depends on the surface are being exposed to light.

Solar Cell Efficiency:

The efficiency is the most commonly used parameter to represent the performance of a solar cell

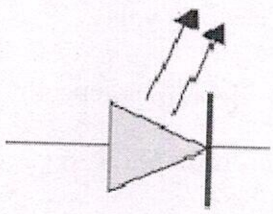
Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. The efficiency of solar cell depends upon climate and latitude

solar cells are used in solar panels, power calculators, watches, irrigation systems,

Solar cells are also used extensively in satellites and space vehicles as most important long duration power supply.

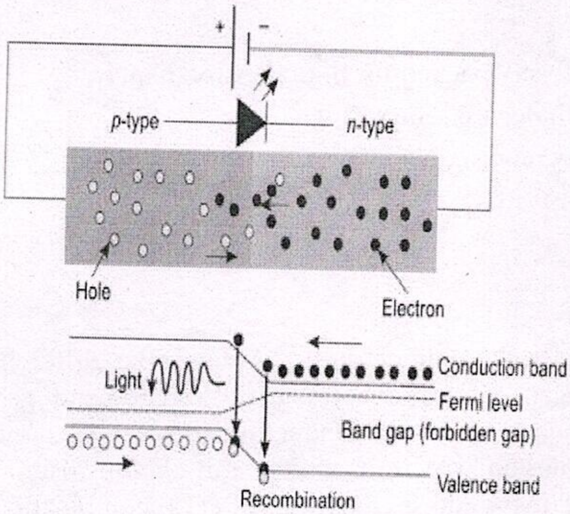
Light Emitting Diode (LED):

LED is a p–n junction device which emits light when forward biased, by a phenomenon called electro luminescence in the in the UV, Visible or IR regions of the electromagnetic spectrum. The quanta of light energy released are approximately proportional to the band gap of the semiconductors.

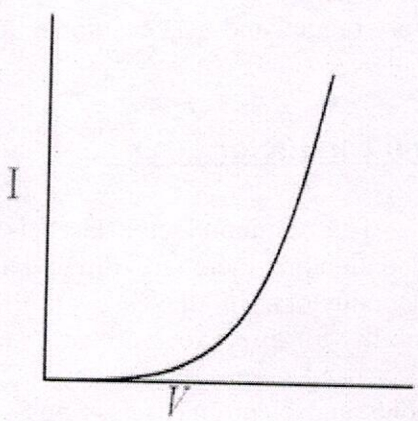


Symbol of LED

Principle & Working:



Representation of recombination of electron-hole pairs in LEDs



When a voltage is applied across a p-n junction(Forward biased),the electron crosses p-n junction from the n – type semiconducting material to p – type semiconductor material. These free electrons stay in conduction band(higher energy state) for a few seconds and while holes present in the valence band. The electron make downward transition from conduction band , recombine with the majority holes in the valence band (spontaneous emission) . During the recombination, the difference in the energy is given up in the form of light radiation. i.e. photon. The energy of light radiation depends on the strength of the recombination. The emitted light is very small in intensity and is of the order of microampere range. Similar, action takes place in n-region also. Under reverse bias no photons emitted.

The wavelength of emitted photon is

$$\lambda = \frac{hc}{E_g}$$

Where, $h = plancks\ constant\ (6.625 \times 10^{-34}\ JS)$

$$\lambda = \frac{hc}{E_g} = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8} \times 10^{10}}{1.602 \times 10^{-19} E_g} = \frac{12400}{E_g}\ \overset{\circ}{A}$$

Where, Eg is the energy gap in electron volt.

Therefore, colour of the emitted light depends on the type of material used.

Advantages of LEDs in electronic Display

1) Output is bright and the intensity can be controlled easily by varying current.
2) They can be operated over a wide range of temperature 0 to 700 C
3) Very fast response time in the order of ns and hence very useful as source for optical Communication.
4) Available in different colors.
5) Very small in size and hence can be closely packed for high density display.
6) As long life (about 105 hours) and high degree reliability.
7) Very rugged and hence suitable for any environment.

Semi conductor laser :

The semiconductor laser is also called diode laser. Among the different semiconductors there are direct band gap semiconductors and indirect band gap semiconductors. In the case of direct band gap semiconductors, there is a large possibility for direct recombination of holes and electrons which emit photons. But in indirect band gap semi conductors like silicon and germanium, direct recombination of holes and electrons is less possible and hence there is no effective emission of photons. A well know example of a direct band gap semiconductor is GaAs.

Let Eg be the energy gap of a material, then it emits a photon of wavelength (λ) is given the relation

$$\lambda = \frac{Ch}{E_g} \qquad \rightarrow (1)$$

Where C is the velocity of light and h is the Planck's constant

The equation (1) is reduced to

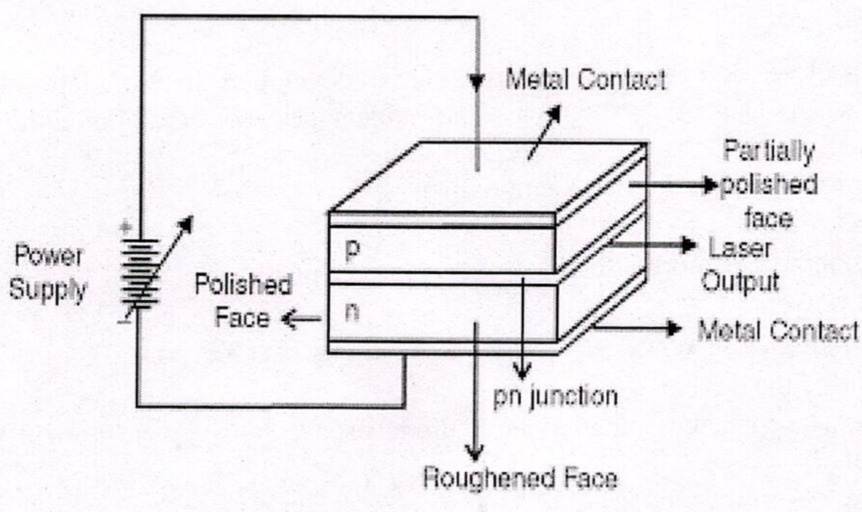
$$\lambda = \frac{1.24}{E_g}\ \mu m \qquad \rightarrow (2)$$

Where E_g is expressed in eV

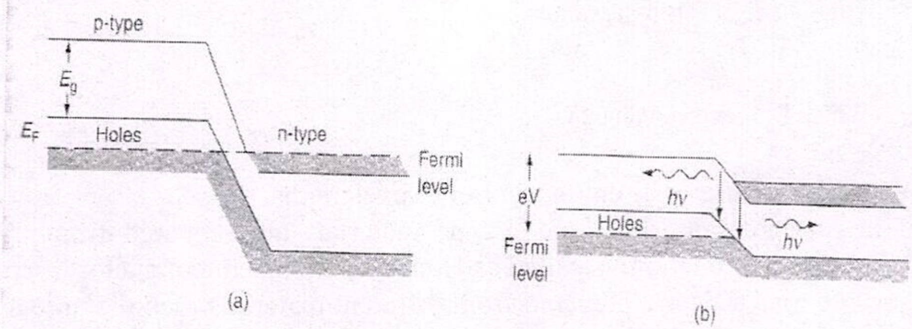
As Eg increases, it emits shorter wavelengths. Diode lasers are always operated in forward bias. If p and n type materials are prepared from the same material then the p-n junction, is called as Homo junction semiconductor laser source. If p and n type materials are prepared from different materials then they are called as Hetero junction semi conductor laser source.

Construction of GaAs Semiconductor diode laser

Construction of GaAs Semiconductor diode laser The basic mechanism responsible for light emission from a semi conductor is the recombination of electrons and holes at p-n junction when a current is passed through the diode. The active medium is a p-n junction diode made from crystalline Gallium Arsenide . The p-region and n-region in the diode are obtained by heavily doping with suitable do pants. At the junction the sides through which emitted light is coming out are well polished and parallel to each other. Since the refractive index of GaAs is high, the reflectance at the material air interface is sufficiently large so that the external mirrors are not necessary to produce multiple reflections. When a current is passed through a p-n junction p region being positively biased, holes are injected from p-region into n-region and n-region being negatively biased electrons are injected from n-region into p-region and is shown in following figure.



The connections in this p-n junction circuit are called forward bias. The electrons and holes recombine and release of light energy takes place in or near the junction. In the case of GaAs homo junction which has an energy gap of 1.44eV gives a laser beam of wavelength around $8600A^0$ the electron-hole recombination takes place in the active region of the device. When the junction is forward biased, a large amount of the order of 104 amp/cm^2 is passed through the narrow junction. Thus the electrons (holes) are injected from n side to p side (p side to n side) respectively.



The electrons are minority charge carriers in p-side and holes are the minority charge carriers in n-side. The continuous injection of charge carriers creates the population inversion of minority carriers is n and p side respectively. The excess minority charge carries diffuse away from the region recombining with majority carriers of the n and p type material, resulting in the release of photons. Further, the emitted photons increase the recombination of injected electrons from the n-region and holes in p-region by inducing more recombinations thus the stimulated emission takes place more effectively. The efficiency of a laser emission increases when the device is cooled.

The drawbacks of homojunction lasers

1. Only output is obtained
2. The threshold current density is very large(400amps/mm^2)
3. Electromagnetic confinement is poor.
4. Output has more beam divergence, poor coherence.

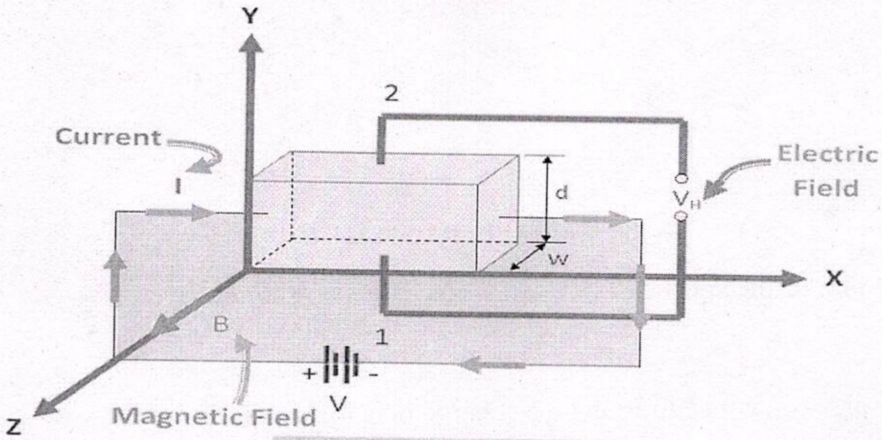
To overcome these deficiencies, scientists have developed heterojunction laser sources like GaAs/GaAlAs structures. The advantages of heterojunction laser structures are:

1. Low threshold current density(5-10amp/mm^2)
2. The output is continuous
3. Carrier confinement is more effective there by less beam divergence.
4. High output power.
5. Narrow beam, high coherence, high mono chromaticity is achieved.
6. Long lifetime of the device
7. Very stable. Hence hetero junction laser diode used extensively in optical fiber communication

HALL EFFECT:

When a magnetic field is applied perpendicular to a current carrying conductor or semiconductor, a voltage (electric field) is developed across the specimen in a direction perpendicular to both the current and magnetic field . This phenomenon is called **Hall Effect** and generated voltage is called as the ' Hll voltage'.

Hall Effect finds important applications in studying the electron properties of semi conductor, such as determination of carrier concentration and carrier mobility. It also used to determine whether a semi conductor is n-type, or p- type.



Hall Effect

THEORY:

Consider a rectangular slab of an n-type Semiconductor carrying current in the positive x-direction. The magnetic field B is acting in the positive direction as indicated in fig: above. Under the influence of the magnetic field, electrons experience a force F_L given by

$$F_L = - Bev \quad \text{---------------} \ (1)$$

Where e = magnitude of the charge of the electron

v = drift velocity

Applying the Fleming's Left Hand Rule, it indicates a force F_H acting on the electrons in the negative y-direction and electron are deflected down wards. As a consequence the lower face of the specimen gets negatively charged (due to increases of electrons) and the upper face positively charged (due to loss of electrons). Hence a potential V_H, called the Hall voltage appears between the top and bottom faces of the specimen, which establishes an electric field E_H, called the Hall field across the conductor in negative y-direction. The field E_H exerts an upward force F_H on the electrons. It is given by

$$F_H = -eE_H \quad \text{-------------(2)}$$

F_H acts on electrons in the upward direction. The two opposing forces F_L and F_H establish equilibrium under which

$$F_L = F_H$$

Using eqns (1) and (2)

$$-Bev = -eE_H$$

$$E_H = Bv \quad \text{-------------- (3)}$$

If'd' is the thickness of the Specimen, $E_H = \frac{V}{d}$

$$V_H = E_H\, d = Bvd \quad \text{from eqn (3) ------------------------ 4}$$

If ω is the width of the specimen in z- direction. The current density $J = \frac{I}{wd}$

$$\text{But } J = nev = \rho v \quad \text{-------------------- 5}$$

Where, n = electron concentration , ρ = charge density

$$\rho v = \frac{I}{wd}$$

$$\Rightarrow v = \frac{I}{\rho wd} \quad \text{----------------(6)}$$

Substitute equationn(6) in (4), we get

$$V_H = BI / \rho\omega$$

$$\text{(or) } \rho = \frac{BI}{V_H w}$$

Thus, by measuring V_H, I, and ω and by knowing B, the charge density ρ can be determined.

Hall Coefficient:

The Hall field E_H, for a given material depends on the current density J, and the applied field B

i.e., $E_H \propto JB$

$$E_H = R_H JB$$

Where R_H is called the Hall Coefficient

Since, $V_H = BI / \rho\omega$

$$E_H = \frac{V_H}{Jwd}$$

Mobility of charge carriers:

The mobility μ is given by $\mu = \frac{V}{E}$

But $J = \sigma E = nev = \rho v$

$\therefore \sigma E = \rho v$

or $E = \frac{\rho v}{\sigma}$

$$\Rightarrow \quad \mu = \frac{\sigma}{\rho} = \sigma R_H \quad (\because 1/\rho = R_H)$$

σ is the conductivity of the semi conductor.

Applications of Hall effect:-

a) Determination of the type of Semiconductor: The Hall Coefficient R_H is negative for an n-type Semiconductor and positive for a p-type material. Thus, the sign of the Hall coefficient can be utilized to determine whether a given Semiconductor is n or p type.

b) Determination of Carrier Concentration: Equation relates the Hall Coefficient R_H and charge density is

$R_H = 1/\rho = -1/ne$ (for n-type)

$R_H = 1/\rho = 1/pe$ (for n-type)

Thus, $n = 1/eR_H$

and $P = 1/eR_H$

c) Determination of mobility: According to equation the mobility of charge carriers is given by , $\mu = \sigma|R_H|$

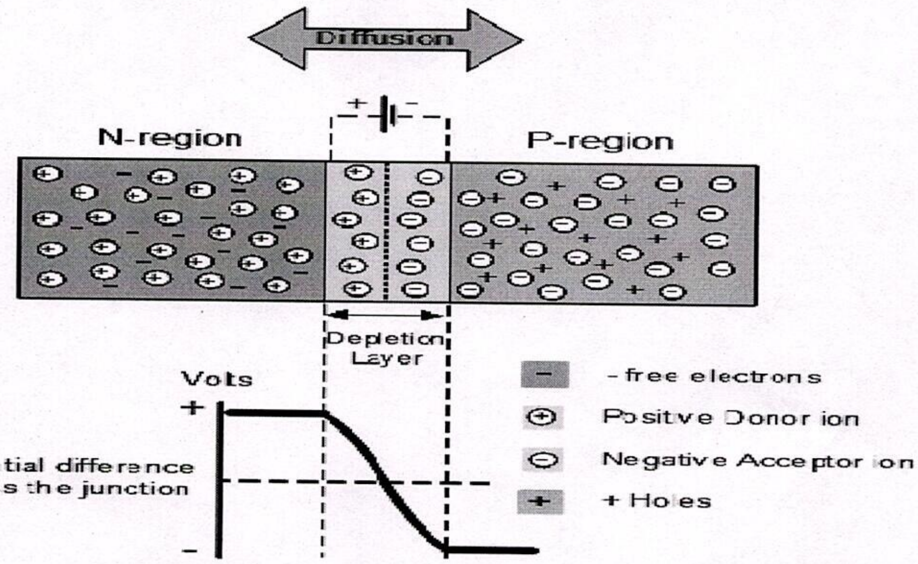
Determination of σ and R_H leads to a value of mobility of charge carriers.

d)Measurement of Magnetic Induction (B):- The Hall Voltage is proportional to the flux density B. As such measurement of V_H can be used to estimate B.

$$B = \frac{V_H d}{I R_H}$$

Formation of P-N Junction diode:-

Junction diode is formed by placing of P type crystal in contact with n-type crystal and subjecting to high pressure so that it becomes a single piece. The surface of contact of P and N-type crystals is called junction. A P-N Junction is shown in fig. The P type region has (positive) holes as majority carriers. Similarly N-type region has (negative) electrons as majority charge carriers.



In addition to these majority carriers, there are few minority charge carriers in each region. The P-region contains a few electrons while the n region contains a few holes. So holes diffuses from P –side to n-side and electrons from n side to p side.

Holes leaving and electrons entering the P-side make it negative. Similarly holes entering and electrons leaving the n-region make it positive. Thus, there is net negative charge on the p side of the junction and net positive charge on n-side. This produces an electric field across the junction. Equilibrium is established when the field becomes large enough to stop further diffusion of the majority charge carriers. The field helps the minority carries to move across the junction.

The region on either side of the junction which becomes depleted (free) of the mobile charge carries is called the depletion region. The thickness of this region

UNIT-IV
SECONDUCTOR DEVICES

Direct and indirect band gap semiconductors:-

In a **direct band gap semiconductor**, minimum-energy state in the conduction band (CB -minima) and the maximum-energy state in the valence band (VB-maxima) occur at the same value of momentum (k) in the Brillouin zone.
Best example of direct band gap semiconductors are GaAs, InAs, InSb, CdSe, ZnS

In case of direct band semiconductor electron in conduction band (CB) minima , recombine directly with the holes in valence band (VB) maxima without change in momentum (k-value) as well as kinetic energy, so energy will be emitted in the form of light (Photon) , this phenomenon is called as "SPONTANEOUS EMISSION"

Relative carrier life time of charge carriers is small in case of direct band gap semiconductor

If the k-vectors (Propagation constant or wave vector) are the different for minimum-energy state in the conduction band (CB -minima) and the maximum-energy state in the valence band (VB-maxima) then, it is called a "**Indirect band gap semiconductor**". Best examples of indirect band gap semiconductors are Si and Ge.

In case of indirect band gap semiconductors during excitation there is change in momentum, K.E. as well as direction and path of electron. In this semiconductors energy emits in the form of heat (Phonon).

Carrier life time in case of indirect band gap semiconductor is greater than the carrier life time of direct band gap semiconductor

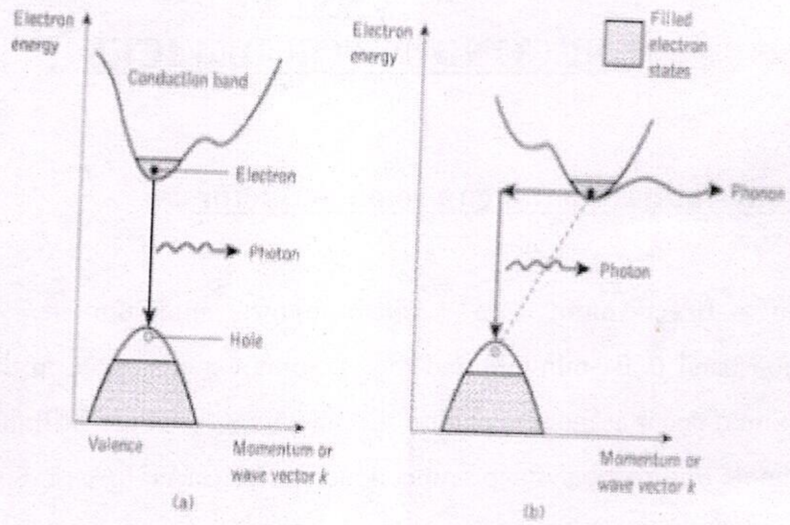


Fig. Energy-momentum (E-k) diagrams of (a) direct band gap semiconductor, (b) indirect band gap semiconductor

Difference between direct band gap semiconductor and indirect band gap semiconductors:-

Direct band gap semiconductor	**Indirect band gap semiconductor**
minimum-energy of conduction band and maximum-energy of valence band have same k-value	minimum-energy of conduction band and maximum-energy of valence band have different k-values
In this semiconductors energy emits in the form of light (Photon).	In this semiconductors energy emits in the form of heat (Phonon).
Life-time of charge carriers is very less	Life-time of charge carriers is more
Examples: GaAs, InAs, InSb, CdSe, ZnS	Examples: Si, Ge

UNIT-V:

Fiber Optics and Lasers:

Introduction, total internal reflection, acceptance angle and numerical aperture, step and graded index fibers, applications of optical fibers.

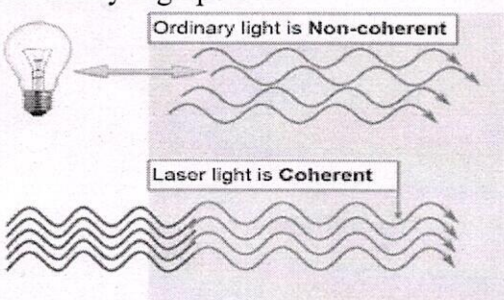
Introduction to interaction of radiation with matter: stimulated absorption, spontaneous emission and stimulated emission, characteristics of a laser, Population inversion, components of a laser: active medium, pumping source, optical resonator. Construction and working of Ruby laser and He-Ne laser. Applications of Lasers.

LASERS

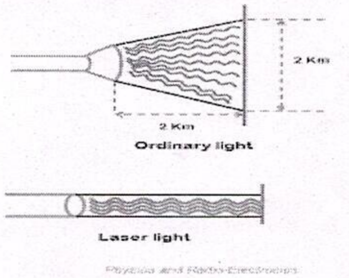
LASER acronym Light Amplification by stimulated Emission of radiation

Characteristics of Lasers:

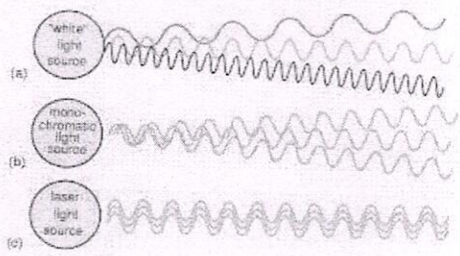
1. **Coherence:** Laser has high degree of coherence. All the photons have same amplitude, frequency and are in phase. Due to high coherence it results in an extremely high power.



2. **Directionality:** ordinary light is highly divergent where as laser light is highly directional. Angular spread of ordinary light is 1Km/Km
Where as laser light is 1Cm/km



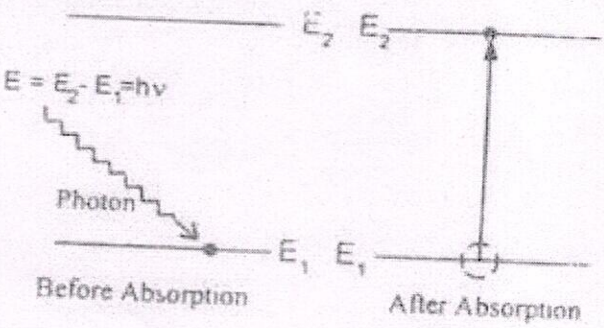
3. **Monochromaticity:** Laser beam is highly monochromatic (Single wavelength) than other sources of light. The laser beam spreads over very small frequency range where as ordinary light spreads over a large frequency range.



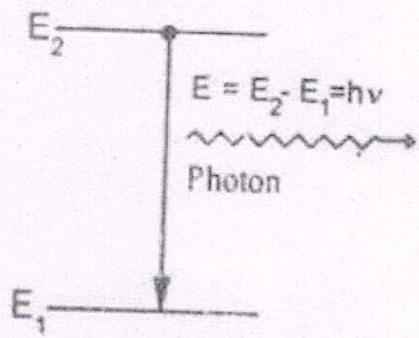
4. **High Intensity:** The intensity of laser light is thousand times more intense than an ordinary light.

Stimulated absorption, Spontaneous and stimulated emission:

1. **Stimulated absorption**: An atom in lower level of energy E1 goes to higher energy level E2 , when it absorps a photon whose energy is equal to E2-E1, this is known as stimulated absorps.

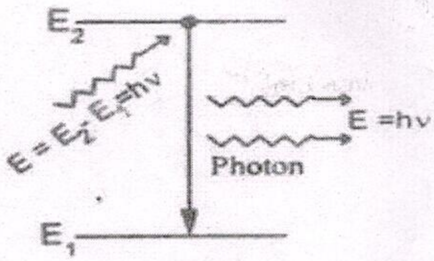


2. **Sponteneous Emission**: when the atom absorbs a photon energy it returns to ground state by emitting photon of energy $E=E_2-E_1=hv$, The emission occurs without any help from surrounding radiation this is known as spontaneous emission.



The spontaneous emission emits 1 photon is random and an incoherent .

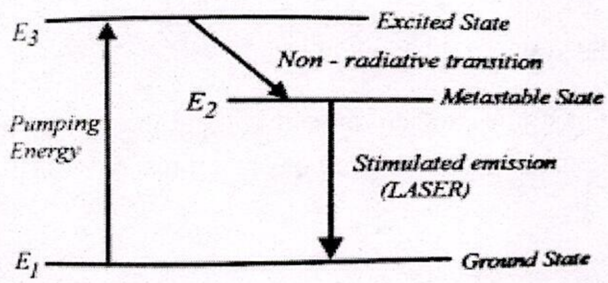
3. **Stimulated emission**: The atom in the excited state can also return to the ground state by trigging or inducement of photon of energy which is equal to energy of incident photon ie. $E=E_2-E_1=hv$, is known as stimulated emission.



Thus results into 2 photons of coherent and directional.

Population inversion and Metastable state:

Population inversion: The process by which the population of higher energy state is made more than that of specified lower energy state is called as population inversion. ie. $N_2>N_1$.



The population inversion can't be achieved into 2 level energy system, so let us consider 3 level energy system of energy levels E_1, E2 and E_3. Here E_2 is metastable state suppose an appropriate energy of external source is applied to the system as a result some of atoms excite from lower energy state to higher energy state most of excited atoms undergoes spontaneous down word transition to state E_1 , while some have transition to state E_2 but the probability of transition from E_2 to E_1 is low, because atoms can stay longer time in E_2 state that population increases in E_2 than E_1 state thus a state is reached when $N_2>N_1$, So population inversion achieved.

Note: Life time of higher energy state is 10^{-8} s and Life time of metastable state is 10^{-3} s

Metastable state:

It is the energy state in which atoms can stay longer time hence population inversion can achieve called metastable state.

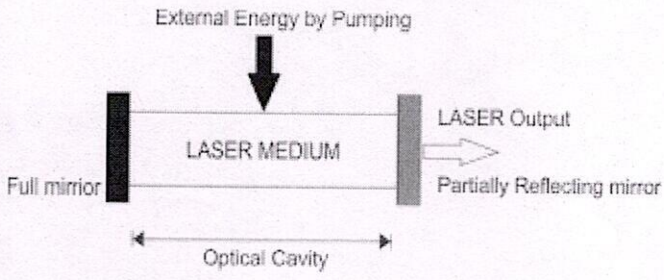
Main components of Laser:

There are 3 main components of Laser.

1. Active medium

2. Energy Source

3. Optical resonator



Components of LASER

1. Active medium: A system in which population inversion can achieved is called active medium.

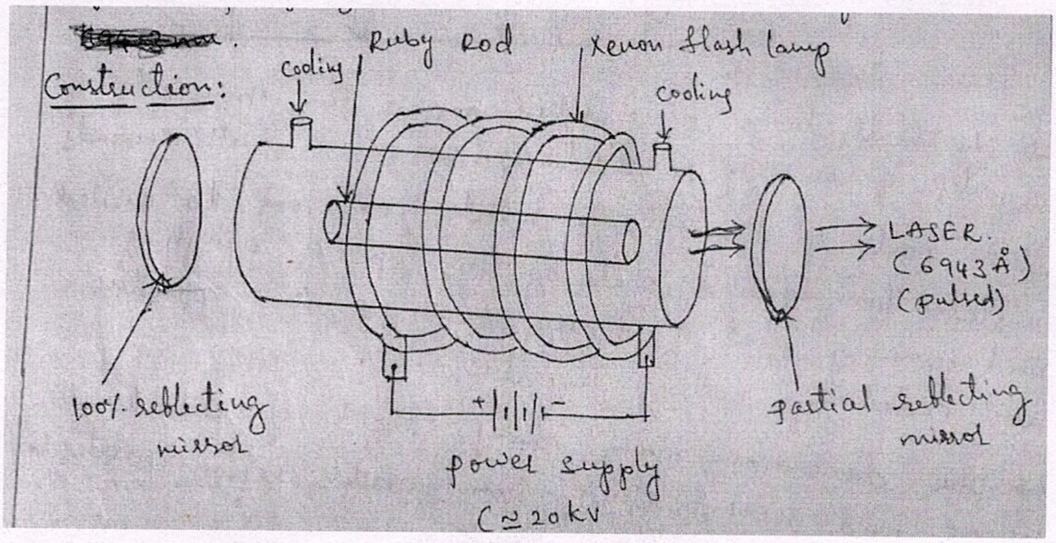
2. **Energy Source**: The energy source raise the system to the excited state

3. **Optical resonator**: The optical resonator constitutes an active medium kept in between a 100% reflecting mirror and partially reflecting mirror. The function of optical resonator is to increase the intensity of laser beam.

RUBY LASER

Introduction

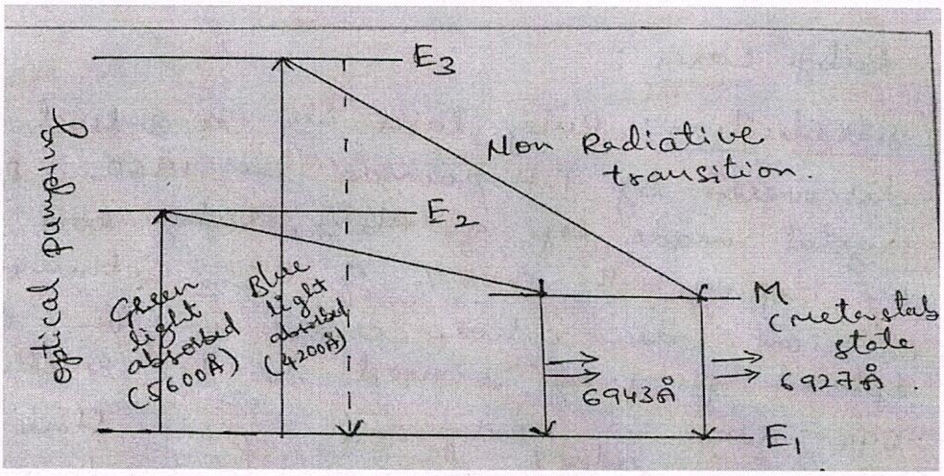
- Ruby laser is a 3-level solid state laser discovered by T.H.Maiman in 1960. Ruby rod is a crystal used as active medium and the laser out put is 694.3nm.



Construction:

- Ruby is crystal made up of Al_2O_3.
- Ruby rod can be prepared by doping Cr_2O_3 with 0.05% of chromium oxide.
- Chromium ions Cr^{3+} are **active centre** in ruby crystal.
- Ruby rod is cylindrical rod nearly 10cm long and 0.5cm in diameter.
- The ends of ruby rods are grounded and polished such that ends of ruby faces are exactly parallel and also perpendicular to axis of rod. Ends of ruby rod acts as internal mirrors, one end acts as 100% reflecting and other end acts as partially reflecting mirror, so its acts like optical resonator.
- Optical pumping source used as xenon flash lamp which is wounded spirally over ruby rod and connected to power supply as shown in figure.

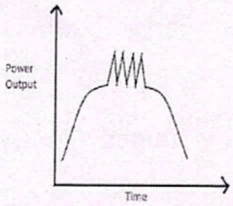
Working:



- The flash lamp is switched on, a few thousands of joules of energy is dishcharged in few milli seconds.
- A part of this energy excites Cr^{3+} ions to excited state from ground state ie. by optical pumping and remaining part of energy heats up the device and cooled by cooling apparatus.
- The chromium atoms absorbs light of wavelength 5600 Å and 4200 Å from visible region excites to E_2 and E_3 energy states respectively.
- From E_2 and E_3 energy states o non radiative transition takes place and accumulations of excited atoms increases at metastable state and achives population inversion.

- The lasing action is trigged by the spontaneously emiited photos, results stimulated emission from metastable state to ground state.
- The photons travelling parallel to ruby rod are used for stimulation while photos moving random come out from ruby rod in the form of heat.
- The stimulated photons are allowed to under go multiple reflection by optical resonator. Hence the intense beam of wavelength 6943 Å emerges out to corresponding absoption of Cr_3 with corresponding transition from M to E_1
- Thus LASER beam comes out from partially reflecting mirror with directionality, high coherence and out put is in the form of pulses.

Out put beam characteristics:



Once flash lamp is fired within 0.5sec population exceeds the threshold value and stimulated emission repeats itself many times. Hence out put consists spikes about 1μs, so out put is in pulsed form.

Applications:

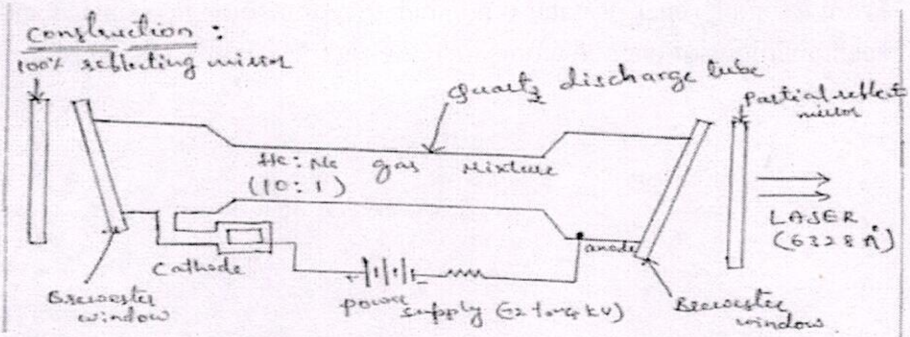
- It is used in holography.
- It is used in LIDAR.
- It is used in remote sensing.
- It is used in Ophthalmology.
- It is used in drilling small areas.
- In military, used as target designators and range finders.

He-Ne LASER:

Introduction: He-Ne is the gas laser discovered by Ali Javan in December 1960, in Bell laboratory. This is designed to get continuous out put beam.

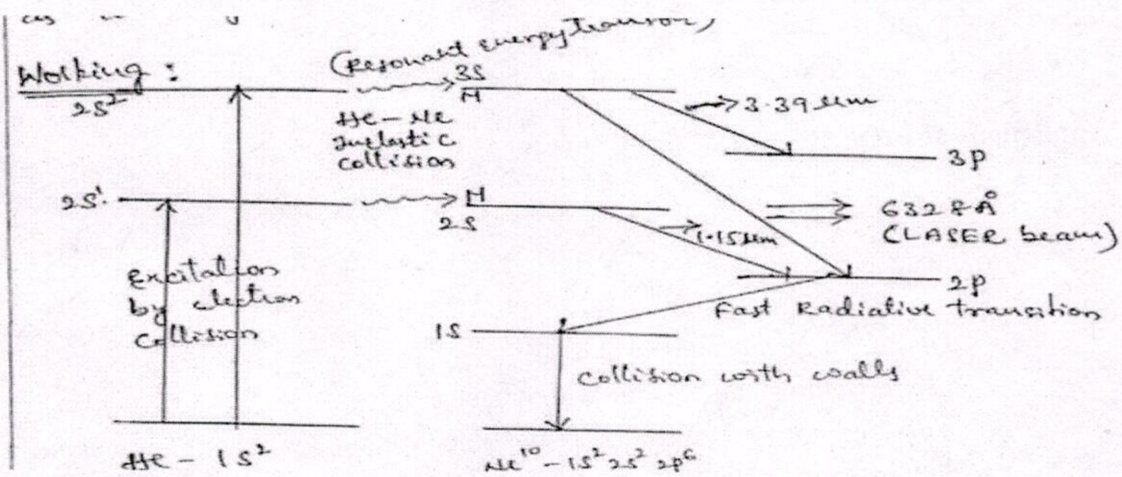
Here He-Ne gas is the active medium, Ne are the active centres achieves the population inversion and stimulated emission takes place of wavelength 632.8 nm. Or 6328 Å

Construction :



- It consists of a glass discharge tube which is made up of quartz and filled with the mixture of helium and neon in the ratio of 10:1 under low pressure i.e the number of Helium atoms are greater than the number of Neon atoms.
- Here Ne atoms are active centres.
- The **electrical discharge** is used as pumping source through anode and cathode which are present at the ends of discharge tube and connected to a direct current or radio frequency discharge created by applying a high voltage (~2 to 4kv).
- The ends of the discharged tube is tilted by an angle called Brewster angle called Brewster windows it is used to produce plane polarized light from perpendicular polarized light.
- Two mirrors are kept at the ends of the discharge tube one is 100% reflecting mirror and another is partial reflecting mirror, which is act like optical resonator. as shown in figure.

Working:



- Switch on battery , by electrical discharge in a gas tube the helium atoms are excited from ground state to higher energy state ($2S^1$ &$2S^2$), the excitation occurs due to the collision of discharged electrons with atoms.
- The excited helium atoms collide with neon atoms which have closer energy levels as that of helium energy levels.
- Therefore helium atoms deliver energy to neon atoms by the process known as resonant collision energy transfer.
- This resonant energy transfer takes place because the corresponding energy levels of helium $2S^1$ &$2S^2$ to closer energy levels of neon 2S & 3S respectively.
- The probability of energy transfer from neon to helium decrease because of high pressure in He than Ne.
- Some helium atoms dexcited and they come back to ground state .

- The laser transition takes between two sets of sub energy levels (3S & 2S) and (2P &3P)
- The first resonant energy transfer made from 2S2 to 3S and stimulated emission takes place between 3S and 2P gives 6328 Å wavelength of radiation.
- Stimulated emission between 3S to 3P gives 3.39μm and 2S to 2P gives 1,15μm of radiation lies in infrared region and its absorbed by quartz discharge tube.
- Atoms under goes the transition from 2P to 1S & 1S to ground state by non radiative transition.
- Since electron density in 3S and 2S level of neon always greater than the other levels of neon. We get continuous LASER out put of wavelength 6328 Å with few milli watts of 0.5mW to 100Mw.

Applications :

- Due to high power it is used in open air communication.
- It is used to produce holograms.
- Widely used in in laboratories for all interferometric experiments.
- Widely used in metrology in surveying.
- He –Ne laser scanner used to read bar decoder.

Applictions of LASER

1. Laser in industry :

   Welding :

   - Dissimilar metal can be welded.
   - Micro welding can be done with great ease.
   - Very high rating of welding are possible (10Kw CO_2 laser 5mm thickness stainless steel plates can be welded at speed of 10cm/sec).

   Cutting :

   - Any desired shape cuts easily, complicated cuts made easy with laser.
   - Cut finish use to be very smooth required no further treatment such as grinding and polishing.
   - With high power CO_2 laser glass, quartz and diamonds can be cut easily.

   Drilling :

   - Lasers are used to drill holes in difficult to drill material such as ceramic, etc.
   - Hole of micron order can be easily drilled .
2. Laser in electronic industry:
   - Scribbling: drawing fine lines in brittle ceramic and semiconductor wafers scribbling done with laser.
   - Soldering: thin sheets 25 micron can soldered without any damage of sheets.
   - Trimming: film register trimming made easy with laser.

3. Laser in medicine:
   - Ophthalmologist using for eye treatment.
   - For cataract removal lasers are used.
   - Lasers scalps are used for bloodless surgeries.
   - Lasers are used angioplasty for removal artery block in heart.
   - In dermatology laser are used to remove freckles , acne , birth marks and tattoos.

   - Lasers are used in destroying kidney stones and gall stones.
   - Used in cancer diagnosis and therapy.

4. Lasers in scientific fields and military:
   - Laser in metrology survey to measure distance like earth to moon .
   - Lasers act like weapon, target finder and ranging.
   - Lasers are used to guide missiles.
   - Lasers used to find the enemy targets.

5. Lasers in communication:
   - It is widely used in open air communication (satellite), because it is free from dust , fog and rain.

6. Laser in other fields:
   - Used as laser scanner in super market to scan bar code.
   - Used in storage technique of CD player to increase storage capacities.

Fiber Optics

Introduction

An opticalfiber is a flexible,transparent cable made by drawing glass (silica) or plastic to a cylindrical wireof diameter slightly thicker than that of a human hair.

Fibers are used instead of metal wires because signals travel along them with less loss

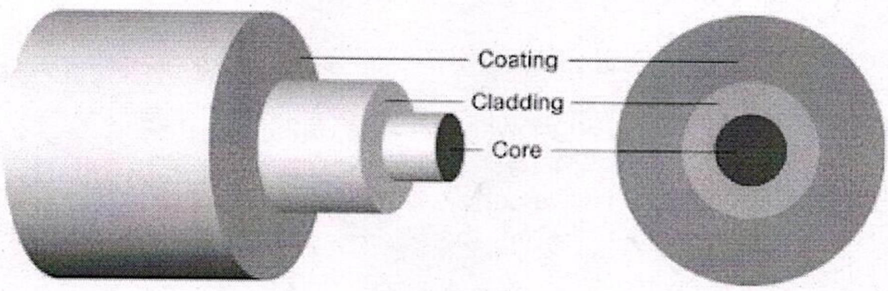
Fibers are immune to electromagnetic interference, a problem from which metal wires suffer.

Fibers are also used for illumination and imaging, and are often wrapped in bundles so they may be used to carry light into, or images out of confined spaces.

Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

Components of an optical fiber

A typical optical fiber comprises three main co-axial sections: Core, Cladding and outer Jacket/protective buffer coating.



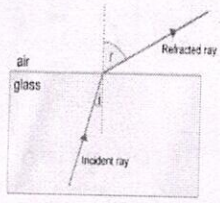
Core:The innermost cylindrical region which carries light. It is the denser medium and is made up glass/ plastic.

Cladding: The middle layer, which serves to confine the light to core. It is the rarer medium as its refractive index is slightly less than that of core.

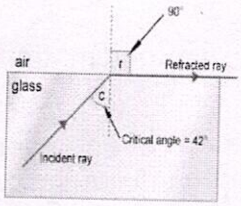
Outer jacket/ Protective buffer coating: The outermost layer which protects the fiber from physical damage and environmental effects.

Principle of optical fiber: Optical fibers work on the principle of total internal reflection.

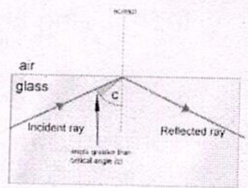
- ➢ When light travels from denser to rarer medium, it refracts away from the normal.



- ➢ At a particular angle of incidence, Called critical angle,the refracted ray traces the boundary such that angle of refraction becomes 90^0.



- ➢ When the angle of incidence of the light ray is greater than the critical angle then no refraction takes place. Instead, all the light is reflected back into the denser material . This Phenomenon is called **total internal reflection**.



So for total internal reflection to occur

- ❖ The light must travel from a denser medium to a rarer medium.
- ❖ Angle of incidence should be greater than the critical angle.

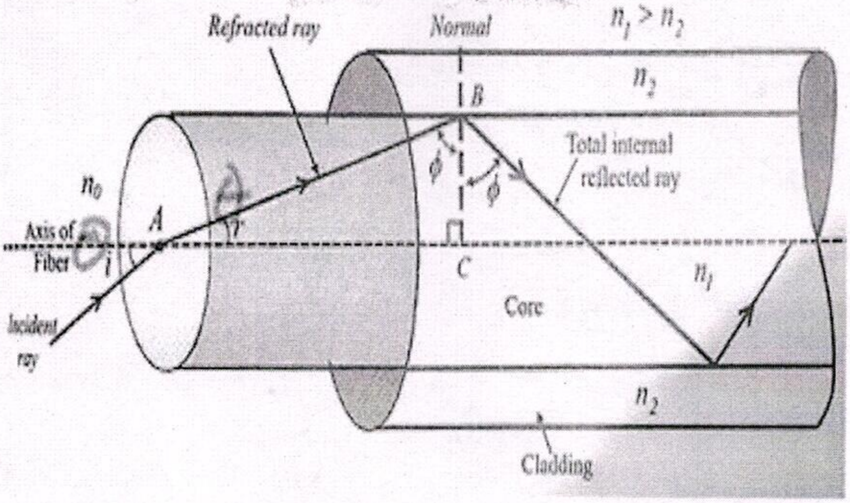
Acceptance angle and Numerical aperture

The maximum possible launching angle with the axis of the fiber up to which a light ray accepted into the core of the fiber is called ***acceptance angle***. By rotating the acceptance angle about the core axis, a cone will be appeared and is called **acceptance cone**. The light rays that enter the fiber beyond acceptance cone refracts into cladding.

The sine of the acceptance angle is called **numericalaperture**.So it is a measure of light collecting capacity of given optical fiber.

Expression for Numerical aperture and Acceptance angle:

Consider an ***optical fiber*** which consists of a core with refractive index n_1 and a cladding withrefractive index n_2 such that ($n_1 > n_2$). The refractive index of the launching medium is n_0. Let us consider a light ray enters the fiber making an angle θ_i with its axis. AB is the refracted ray that makes an angle θ_r with the axis and strikes core-cladding interface at an angle ϕ, which is greater than critical angle ϕ_c. Thus, it undergoes total internal reflection at the interface.



It is clear from the figure that as the value of angle $\boldsymbol{\theta}_i$ increases, $\boldsymbol{\theta}_r$ will also increase and $\boldsymbol{\phi}$ will decrease.For light propagation through the fiber, it is compulsory that the value of angle $\boldsymbol{\phi}$ should not be less than critical angle $\boldsymbol{\phi}_c$. Thus we may increase the incident angle $\boldsymbol{\theta}_i$ up to a certain value that is acceptance angle $\boldsymbol{\theta}_{max}$.

Now, by applying Snell's law at the launching end

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0} \quad \text{or} \quad \sin\theta_i = \frac{n_1}{n_0}\sin\theta_r \qquad (1)$$

But in right angled triangle ABC, $\sin\theta_r = \sin(90^\circ - \emptyset) = \cos\emptyset$

$$\therefore \quad \sin\theta_i = \frac{n_1}{n_0}\cos\emptyset \qquad (2)$$

When $\phi = \phi_c$ then $\theta_i = \theta_{max}$

$$\text{Thus,} \quad \sin\theta_{max} = \frac{n_1}{n_0}\cos\emptyset_c \qquad (3)$$

Now, applying Snell's law at core-cladding interface,

$$\frac{\sin \emptyset_c}{\sin 90^\circ} = \frac{n_2}{n_1} \qquad \text{or} \qquad \sin \emptyset_c = \frac{n_2}{n_1}$$

or $$\sqrt{(1 - cos^2 \emptyset_c)} = \frac{n_2}{n_1}$$

or $$1 - cos^2 \emptyset_c = \frac{{n_2}^2}{{n_1}^2}$$

$$\therefore \quad \cos \emptyset_c = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_1} \qquad (4)$$

Hence, $$\sin \theta_{max} = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_o} \qquad (5)$$

Therefore acceptance angle

$$\theta_{max} = \sin^{-1} \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_o}$$

For air $n_o = 1$

$$\boxed{\theta_{max} = \sin^{-1} \sqrt{{n_1}^2 - {n_2}^2}} \qquad (6)$$

Fractional refractive index change or relative refractive index

Fractional refractive index change or relative refractive index is the ratio of difference between the refractive index of core and cladding to the refractive index of core. It is denoted by Δ. *i.e.*

$$\Delta = \frac{(n_1 - n_2)}{n_1} \tag{7}$$

Δ is always positive and generally of the order of 1/100.

Numerical aperture

It is a very important parameter, which is a measure of amount of light that can be accepted by the fibre. It is defined as the sine of the acceptance angle, *i.e.*,

$$NA = \sin\theta_{max} = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_0} \tag{8}$$

For air $n_0 = 1$

$$\therefore \quad NA = \sin\theta_{max} = \sqrt{{n_1}^2 - {n_2}^2} \tag{9}$$

Now, $${n_1}^2 - {n_2}^2 = (n_1 + n_2)(n_1 - n_2) = \frac{(n_1 + n_2)}{2}\frac{(n_1 - n_2)}{n_1} 2n_1$$

We can take approximately $\frac{(n_1 + n_2)}{2} \approx n_1$ and since $\Delta = \frac{(n_1 - n_2)}{n_1}$

$$\therefore \quad {n_1}^2 - {n_2}^2 = 2n_1^2\Delta$$

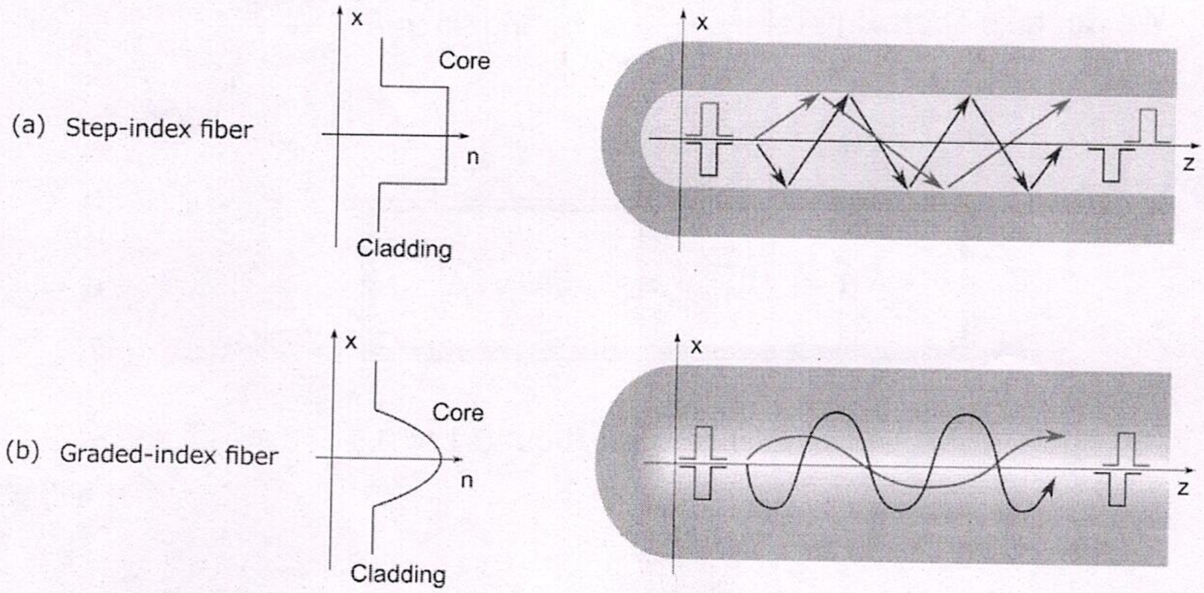
Or

$$NA = \sqrt{{n_1}^2 - {n_2}^2} = n_1\sqrt{2\Delta}$$

The values of NA typically range from about 0.1 to 0.5.

Step index fiber

1. Step index fiber is a fiber in which the core is with uniform refractive index and there is a sharp decrease in the index of refraction at the cladding.
2. Step index fiber is found in two types, that is mono mode fiber and multimode fiber.
3. Index profiles are in the shape of step.
4. The light rays propagate in *zig–zag* manner inside the core.
5. Signal distortion is more in case of high-angle rays in multimode step index fiber. In single mode step index fiber, there is no distortion.
6. This fiber has lower bandwidth.
7. The diameter of the core is between 50-200μm in the case of multimode fiber and 10μm in the case of single mode fiber.
8. Attenuation of light rays is more in multimode step index fibers but for single mode step index fibers, it is very less.
9. Less expensive.
10. NA of multimode step index fiber is more whereas in single mode step index fibers, it is very less.
11. Pulse broadening and inter modal dispersion are present.



Graded index fiber

1. Graded index fiber is a type of fiber where the refractive index of the core is maximum at the center and decreases towards core-cladding interface.
2. Graded index fiber is of only one type, that is, multimode fiber.
3. Index profiles is in the shape of a parabolic curve (for $\alpha=2$).
4. The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis.
5. Signal distortion is very low even though the rays travel with different speeds inside the fiber.
6. This fiber has higher bandwidth.
7. The diameter of the core is about 50μm in the case of multimode fiber.
8. Attenuation of light rays is less in graded index fibers.
9. Highly expensive.
10. NA of graded index fibers is less.
11. No pulse broadening and inter modal dispersion.

Applications of Optical Fiber

Optical fibers find applications in various fields. Some of them are

- **Medical**
  Used as light guides, imaging tools and also as lasers for surgeries.
- **Defence/Government**
  Used as hydrophones for seismic waves and SONAR , as wiring in aircraft, submarines and other vehicles and also for field networking.
- **Telecommunications**
  Fiber is used for transmission of information from transmitter to receiver.
- **Networking**
  Used to connect users and servers in a variety of network settings and help to increase the speed and accuracy of data transmission.
- **Industrial/Commercial**
  Used as sensory devices to make temperature, pressure and other measurements and as wiring in automobiles and in industrial settings.
- **Broadcast/CATV**
  Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet and other applications.