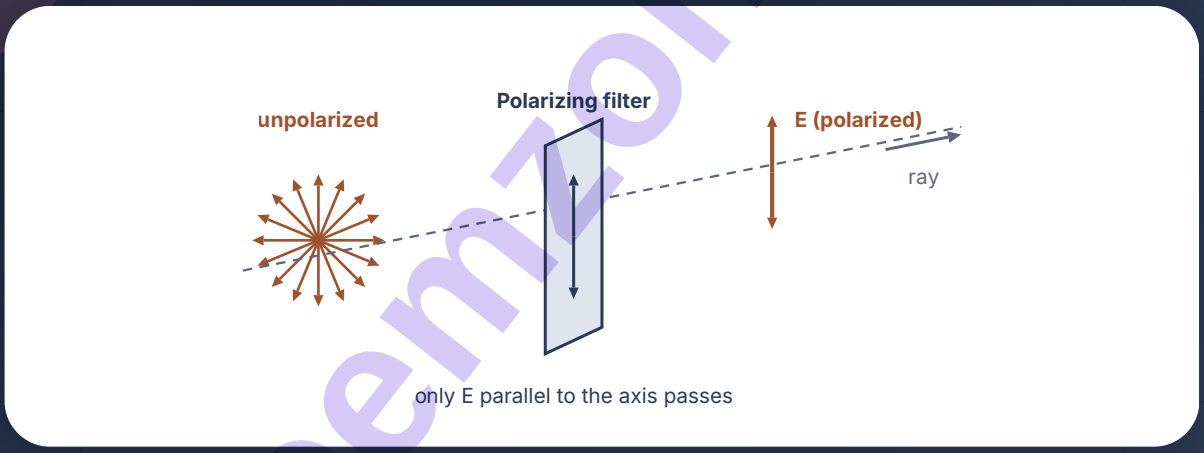
PHYSICS · CLASS 11 · NEW SYLLABUS

UNIT 8

Physical Optics and Gravitational Waves

Complete Study Booklet



Long Questions | Short Questions | MCQs | Solved Exercise

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PART A

Long Questions

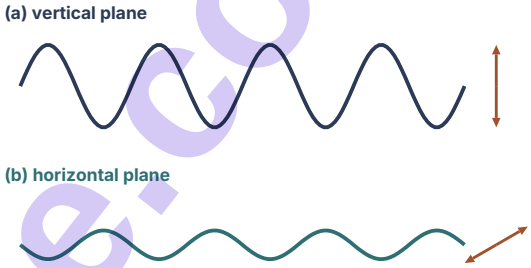
Q1 **Define polarization of light. How does polarization of electromagnetic waves occur? Also classify the types of polarization.**

> **Polarization** is the process by which the electric (and magnetic) vibrations of light waves are restricted to a single plane. It is shown only by **transverse** waves such as light, not by longitudinal waves such as sound.

Explanation

Interference and diffraction prove the wave nature of light but do not show whether light waves are longitudinal or transverse. Polarization shows that they are **transverse**.

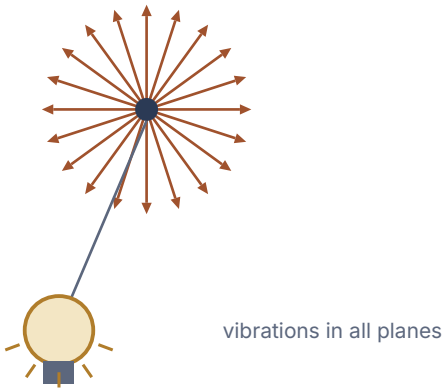
In a transverse wave on a stretched string, the particles vibrate perpendicular to the direction of propagation — vertically, horizontally or in any other direction. In each case the wave is said to be polarized. The **plane of polarization** contains the direction of vibration and the direction of propagation.



Transverse waves on a string polarized (a) vertically (b) horizontally

Light from an oscillating charge consists of a varying electric field E with a magnetic field B at right angles to it. Ordinary light has vibrations in all possible planes — it is **unpolarized**. If the vibrations are confined to one plane, the light is **polarized**.

Unpolarized sources: sunlight, incandescent and fluorescent bulbs, candle flame or fire.



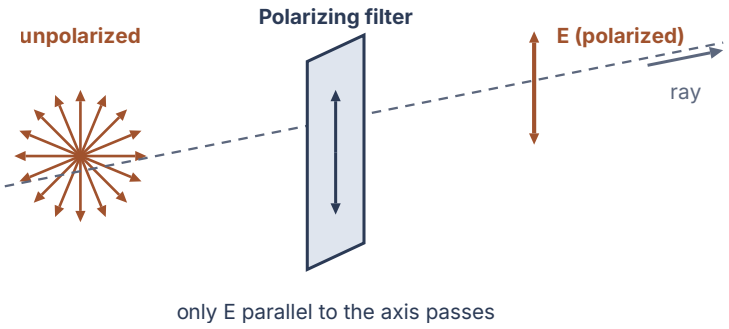
Unpolarized light: vibrations in all planes

Methods of polarizing light

1. Passing light through a polarizing filter (e.g. a Polaroid sheet).
2. Using a polarizing beam splitter.
3. Using certain optical crystals (e.g. calcite, quartz).

The most common method is a polarizing filter. Only the component of E **parallel to the filter's axis** passes; all others are blocked, so the transmitted light is polarized.

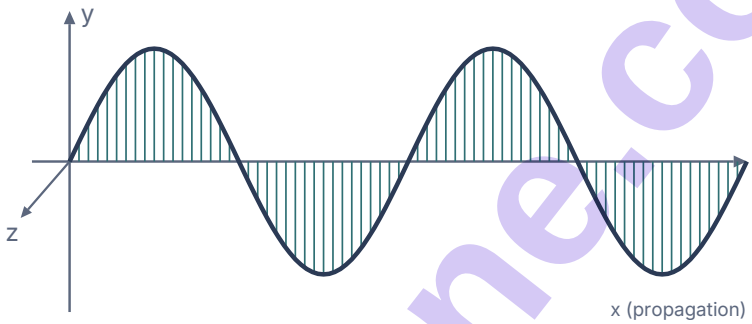
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Polarization of light using a polarizing filter

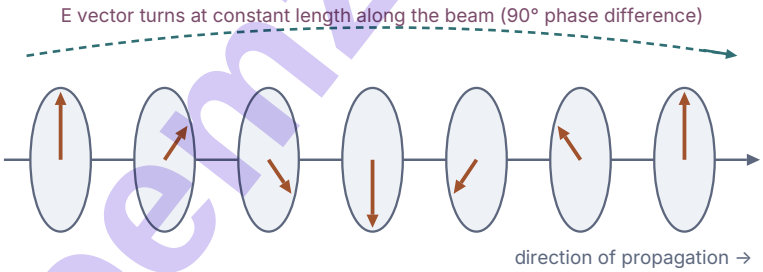
Types of polarization

(i) Linear polarization: E oscillates in a single plane. *Example:* light passing through a polarizing filter such as sunglasses.



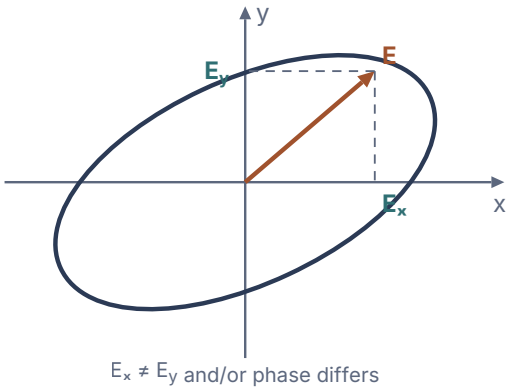
Linear polarization of light

(ii) Circular polarization: E rotates in a circle — clockwise (right-handed) or anticlockwise (left-handed) — as the wave travels. *Example:* light reflected from a CD or DVD.



Circular polarization of light

(iii) Elliptical polarization: a combination of linear and circular, where the tip of E traces an ellipse. The two components E_x and E_y are unequal and/or differ in phase by an arbitrary angle θ. *Example:* light passing through a stressed plate or a wave plate.

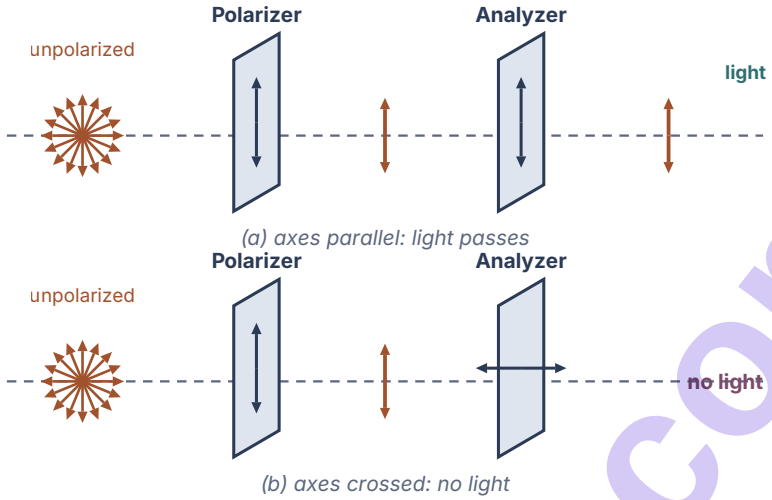


Elliptical polarization

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Q2 How can plane-polarized light be produced and detected? What does it prove?

Light from an ordinary bulb (or the Sun) is unpolarized, because its electric vibrations are randomly oriented.



Polarizer and analyzer: light waves are transverse

When unpolarized light falls on a Polaroid sheet (the **polarizer**), the transmitted light is plane polarized. If a second Polaroid (the **analyzer**) is placed with its axis parallel to the first, the light passes through. As the analyzer is slowly rotated about the beam, the light gets dimmer and **disappears** when the axes are perpendicular. On further rotation it reappears, and is brightest when the axes are parallel again.

Conclusion: this proves light waves are **transverse**. Longitudinal waves would never be cut off, even with crossed Polaroids.

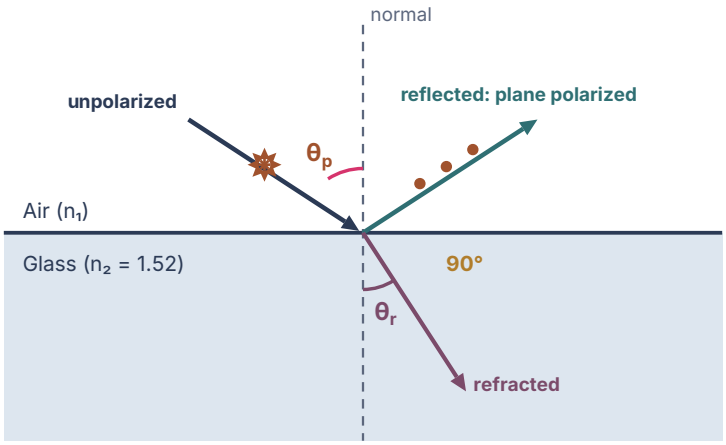
Ponder Upon

Light reflected from a smooth water surface is partially polarized parallel to the surface — which is why polarized sunglasses cut glare from lakes.

Q3 How can polarized light be obtained by reflection? Explain.

In 1808 Malus discovered that ordinary light becomes polarized when it is **reflected** from a plane sheet of glass. Viewed through a slowly rotating Polaroid, the reflected light is almost completely cut off at one position. For glass the best angle of incidence is about **57°**, at which the reflected ray is plane polarized.

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Plane polarization by reflection

Light reflected from a table top also becomes darker through a rotated Polaroid, showing it is partially plane polarized.

Q4 State and explain Brewster's law.

> When light is incident on a surface at a particular angle (Brewster's angle), the reflected light is polarized in a plane perpendicular to the plane of incidence.

The angle of incidence at which the reflected light is almost plane polarized is the **polarizing angle**. At this angle the reflected and refracted rays are **at right angles** (figure in Q3), so with $i = \theta_p$:

$$\theta_p + \theta_r = 90^\circ \Rightarrow \theta_r = 90^\circ - \theta_p$$

By Snell's law:

$$n_1 \sin\theta_p = n_2 \sin\theta_r = n_2 \sin(90^\circ - \theta_p) = n_2 \cos\theta_p$$

$$\frac{\sin\theta_p}{\cos\theta_p} = \frac{n_2}{n_1} \Rightarrow \tan\theta_p = \frac{n_2}{n_1}$$

This is **Brewster's law**. If medium 1 is air ($n_1 = 1$), then $\tan\theta_B = n$: the tangent of the polarizing angle equals the refractive index of the medium. This angle θ_p is also called the Brewster angle θ_B.

Interesting Information

Malus's law is used to study the polarization of light in biological systems, such as by cell membranes.

Q5 State and explain Malus's law.

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The intensity I of plane-polarized light after passing through an analyzer is directly proportional to the square of the cosine of the angle θ between the transmission axes of the analyzer and the polarizer.

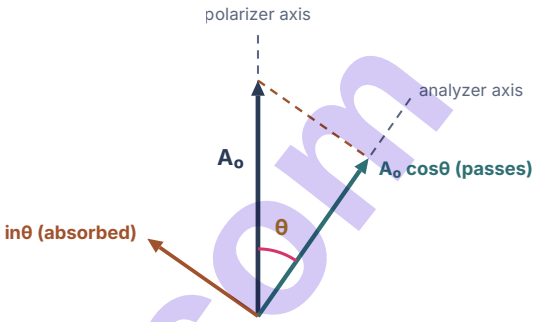
$$I \propto \cos^2\theta \Rightarrow I = I_0 \cos^2\theta$$

I_0 is the intensity of the polarized light incident on the analyzer (after the polarizer).

Explanation

An analyzer is simply a second polarizer placed after the first. Rotating it changes the intensity of the light that gets through.

When polarized light of amplitude A_0 reaches the analyzer at angle θ, it is resolved into two components: $A_0 \cos\theta$ (parallel to the analyzer axis) and $A_0 \sin\theta$ (perpendicular). The $A_0 \sin\theta$ component is absorbed; only $A_0 \cos\theta$ passes.



Resolution of amplitude at the analyzer

$$A = A_0 \cos\theta, \quad I \propto A^2 \Rightarrow I = A_0^2 \cos^2\theta = I_0 \cos^2\theta \quad (I_0 = A_0^2)$$

Crystals such as tourmaline and calcite confine light vibrations to one plane; such materials are used as Polaroids. Light can also be polarized naturally by reflection, refraction and scattering.

Extreme angles

1. **θ = 0°:** $I = I_0$ — all the light from the polarizer passes.
2. **θ = 90°:** $I = 0$ — the light is completely cut off (crossed polarizers).

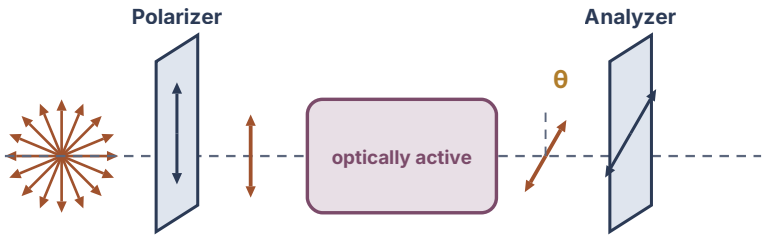
Tidbit

Unpolarized light passes through a foggy atmosphere. What is the polarization of the scattered light?
Partially polarized.

Q6 **What is optical activity? State applications of polarization in different fields.**

Optical activity is the ability of some substances to rotate the plane of polarization of light passing through them. The rotation is detected with an analyzer.

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plane of polarization is rotated by θ

Optical activity

Substances that do this are **optically active**: quartz crystals, cinnabar (HgS), sugar solution, insulin and collagen. The amount and direction of rotation depend on:

1. the type of substance;
2. its concentration;
3. the distance the light travels through it;
4. the wavelength of light.

It arises from the asymmetric (e.g. helical) shape of the molecules. A few millimetres of such a crystal rotates the plane by many degrees. Sugar and tartaric acid rotate the plane when in solution, which is used to find their **concentration**.

Importance of polarization

1. **Optics and photonics:** polarized sunglasses, LCD screens and optical communication systems.
2. **Imaging and microscopy:** reduces glare and improves contrast, especially in microscopy and medical imaging.
3. **Medicine:** cancer diagnosis, tissue imaging and laser surgery, by distinguishing tissue types.
4. **Astronomy:** analysing polarized light from distant stars and the cosmic microwave background.
5. **Other fields:** biology, chemistry and communication systems.

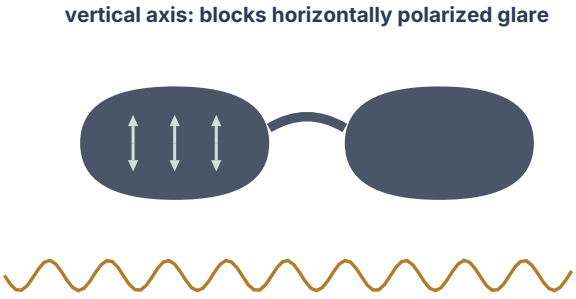
Q7 What is a Polaroid? Explain two main applications of polarization of light.

A **Polaroid** (polarizing filter) is a commercial sheet that transmits light vibrating in only one plane, working by selective absorption.

(i) Sky photography

A camera photographing clouds is fitted with a Polaroid. Polarizers reduce the glare and haze caused by scattering of light by small particles in the atmosphere, and enhance contrast by blocking excessive bright white light while letting other colours through — giving a brighter, more detailed image.

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Action of polarized sunglasses and filters

(ii) Stress analysis of materials (photoelasticity)

When a transparent material (plastic, glass) is stressed, its molecular structure changes, which affects how it interacts with light and produces interference fringes. Shining polarized light through it and analysing the change in polarization lets researchers:

- map the stress patterns in the material;
- identify weaknesses or defects;
- study its optical properties and predict how it will behave.

This technique, **photoelasticity**, is widely used in engineering, materials science and quality control.

Q8 What are gravitational waves? Describe the basic types of gravitational waves.

> **Gravitational waves (GWs)** are ripples in the fabric of spacetime, produced by violent cosmic events such as colliding black holes or neutron stars. They travel at the speed of light and carry information about their source. A gravitational wave stretches and compresses space, and can be observed by measuring the change in length between two objects.

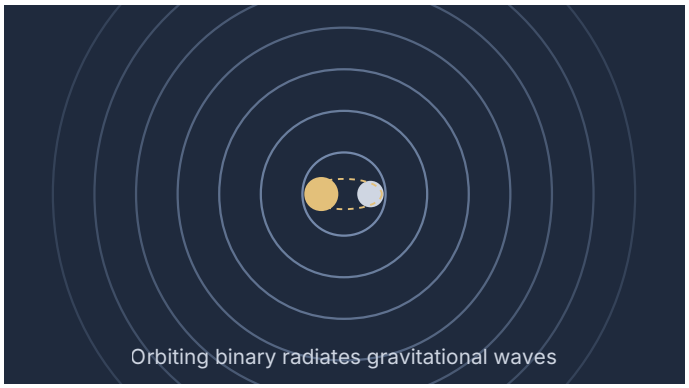
Analogy: a stone thrown into a pond makes ripples on the water surface (spacetime) that travel outward, carrying information about the stone (the cosmic event). They are detected at the shore (by gravitational-wave observatories).

Prediction and detection

Gravitational waves were predicted by Albert Einstein’s general theory of relativity (1916). In it, gravity is not a force but a **curvature of spacetime** caused by massive bodies — like a heavy object making a dent in a mattress. They were first detected in 2015 (announced in 2016).

A **binary system** is two compact objects — black holes, neutron stars or white dwarfs — orbiting each other and emitting gravitational waves.

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Binary system radiating gravitational waves

Four basic types

1. **Continuous GWs:** from a single massive object spinning at a constant rate (e.g. a neutron star), with constant frequency and amplitude. White-dwarf binaries also produce them.
2. **Compact binary inspiral GWs:** from binary neutron stars, binary black holes, or a neutron star and black hole orbiting each other; frequency and amplitude rise gradually.
3. **Burst GWs:** from violent events like supernovae, gamma-ray bursts or cosmic strings.
4. **Stochastic GWs:** weak, random signals from the superposition of many distant sources (e.g. from the Big Bang); the hardest to detect.

Production

Every accelerating mass produces gravitational waves, even vehicles and aeroplanes, but on Earth the masses and accelerations are far too small to detect. Orbiting binaries emit waves detected by observatories such as **LIGO** (USA) and **Virgo** (Cascina, Italy). The waves carry information about mass, spin and merger dynamics, radiate in all directions at the speed of light, and weaken with distance.

Characteristics

They depend on the masses of the objects, the orbital period and frequency, and the **eccentricity** e of the orbit: e = 0 circular; 0 < e < 1 elliptical; e = 1 parabolic; e > 1 hyperbolic.

Spacetime distortion (tidal forces)

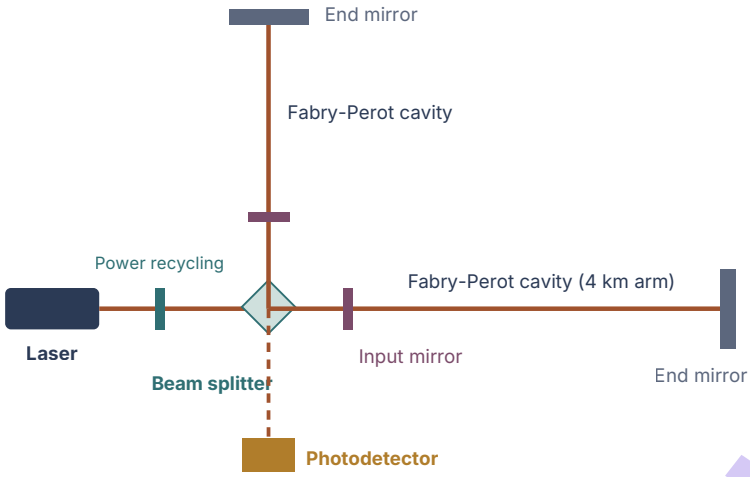
A passing gravitational wave periodically stretches and compresses a body perpendicular to the wave's direction — like tides caused by the Moon and Sun. The effect depends on the wave's strength and the body's mass and size. Waves from distant mergers reaching Earth have tiny amplitudes, about 10^{-21} to 10^{-22} m, so extremely sensitive instruments are needed. They let us study strong-field gravity, test general relativity and explore the universe in new ways.

Q9 What are interferometers? Describe the basic Michelson (LIGO) interferometer in detail.

An **interferometer** is a very sensitive optical instrument that uses the interference of LASER (Light Amplification by Stimulated Emission of Radiation) beams to measure tiny changes in distance between mirrors — such as those caused by passing gravitational waves. Such detectors are called **LIGO** (Laser Interferometer Gravitational-Wave Observatory).

Compared with an ordinary interferometer, LIGO is (a) about 1000 times larger and (b) uses a LASER instead of a normal light source.

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Basic LIGO interferometer

Basic components

1. **Laser** — a stable, high-intensity beam of light.
2. **Power-recycling mirror** — reflects light that has already travelled through the instrument back in, “recycling” it.
3. **Beam splitter** — divides the beam into two perpendicular beams.
4. **Mirrors** — reflect the beams, forming two perpendicular arms.
5. **Fabry-Perot cavity** — two facing mirrors that increase the effective path length.
6. **Photodetector** — measures the returning beams and detects tiny phase shifts.
7. **Arm cavities** — build up the laser light, increasing sensitivity.

Working

The laser beam is split into two perpendicular beams that travel down two identical arms, bounce off the end mirrors and return to be recombined. A passing gravitational wave changes the arm lengths very slightly, creating a phase shift between the beams. The recombined beams form an interference pattern measured by the photodetector; the tiny shift alters the pattern, revealing the wave.

On **14 September 2015** LIGO observed gravitational waves for the first time — from a collision of two black holes about 1.3 billion years ago, as predicted by Einstein 100 years earlier. Rainer Weiss, Barry C. Barish and Kip S. Thorne received the 2017 Nobel Prize for this work. Team member **Nergis Mavalvala**, a professor at MIT, is from Pakistan.

Q10 Write a brief note on Virgo detection.

Virgo is another facility for measuring gravitational waves, run by the European Gravitational Observatory (EGO) at Cascina near Pisa, Italy. Like LIGO it is an interferometer, but with **3 km** arms (LIGO’s are 4 km). It is named after the Virgo cluster — about 1500 galaxies some 50 million light years away, in the constellation Virgo, visible in the night sky in March, April and May. (One light year $\approx 9.5 \times 10^{12}$ km.) Virgo has helped detect gravitational-wave events, with its first detection in **2017**.

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Formula Sheet

#	Formula	Description
1	$\tan \theta_p = n_2/n_1$ (= n for air)	Brewster's law
2	$\theta_p + \theta_r = 90°$	Reflected ⊥ refracted at Brewster angle
3	$I = I_0 \cos^2\theta$	Malus's law
4	$A = A_0 \cos \theta$	Amplitude through analyzer
5	$I = I_0/2$	Unpolarized light through one polarizer
6	$c = f\lambda$	Speed of light / gravitational waves

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PART B

Short Questions

Exercise Short Questions

8.1 Why are Polaroid sunglasses better than ordinary sunglasses?

Polaroid sunglasses block **horizontally polarized** light, which cuts glare from reflecting surfaces such as water, snow or roads. Ordinary sunglasses only reduce the overall intensity and do not block glare. Polaroids are more comfortable and improve visibility, especially in bright sunlight or while driving.

8.2 Is light from the sky partially polarized? How is it so?

Yes. Sunlight scattered by the atmosphere (Rayleigh scattering) becomes partially polarized, because scattering makes the light vibrate in particular directions. Polarization is strongest at 90° from the Sun, so the sky appears differently polarized depending on the viewing angle.

8.3 How is Malus's law used in everyday life?

(i) It explains how the intensity of polarized light changes through a filter at different angles. (ii) Photography — to control glare. (iii) LCD screens — to adjust brightness. (iv) Sunglasses — to reduce unwanted light. (v) Designing devices that manage light intensity for visual comfort.

8.4 What are the applications of Brewster's angle?

(i) Making anti-glare coatings for lenses and camera filters. (ii) Reducing unwanted reflections. (iii) Designing polarizing sunglasses and optical instruments that minimize glare and improve image clarity.

8.5 What is spacetime curvature?

The bending of space and time around massive objects such as planets and stars, as described by Einstein's general relativity. This curvature is gravity: objects move along curved paths instead of straight lines. It explains planetary orbits and the bending of light near stars.

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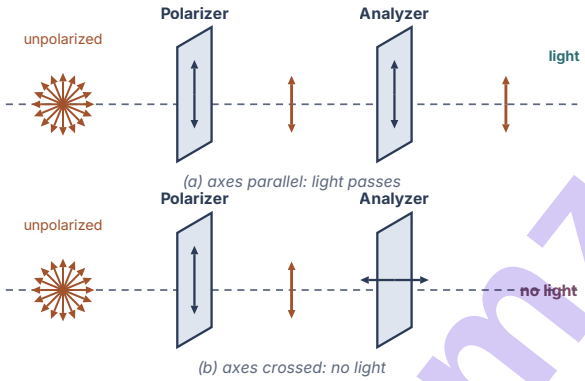
SLO-Based Additional Short Questions + Past Papers (Punjab Boards)

Q1 **What are optically active crystals? Give examples.**

Crystals that rotate the plane of polarization of plane-polarized light passing through them, e.g. quartz and sodium chlorate.

Q2 **What is the function of a polarizer and an analyzer?**

Unpolarized light passed through a Polaroid becomes plane polarized — so it is called the **polarizer**. When this light passes through a second Polaroid that is rotated, the intensity varies between maximum and minimum, showing the light is plane polarized. The second Polaroid is the **analyzer**.



Q3 **What do you mean by a Polaroid?**

A commercial polarizer that works by selective absorption. It is used in sunglasses and car windscreens.

Q4 **What aspect of the nature of light is proved by polarization?**

Polarization occurs only for transverse waves. Since light can be polarized, light waves are **transverse**.

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PART C

Multiple Choice Questions

Exercise MCQs

1 **The phenomenon of polarization of light is:**

(a) the process of scattering of light

(b) the property of light to vibrate in a specific plane

(c) the ability of light to travel in a straight line

(d) the phenomenon of light changing colour

2 **Malus's law states that:**

(a) intensity is directly proportional to the square of the cosine of the angle between the light wave and the analyzer

(b) intensity is directly proportional to the square of the sine of that angle

(c) intensity is directly proportional to that angle

(d) intensity is inversely proportional to that angle

3 **The intensity of (unpolarized) light when it passes through a polarizer:**

(a) increases

(b) decreases

(c) remains the same

(d) becomes zero

4 **The angle between the light wave and the analyzer is called the:**

(a) polarization angle

(b) refraction angle

(c) reflection angle

(d) azimuth angle

5 **The key purpose of an analyzer in a polarization experiment is:**

(a) to polarize the light

(b) to measure the intensity of light

(c) to change the direction of light

(d) to filter out unwanted light

6 **The mathematical form of Malus's law is:**

(a) $I = I_0 \cos^2\theta$

(b) $I = I_0 \sin^2\theta$

(c) $I = I_0 \tan^2\theta$

(d) $I = I_0 \cot^2\theta$

7 **The effect of increasing the angle between the light wave and the analyzer (0° → 90°) on intensity is:**

(a) the intensity increases

(b) the intensity decreases

(c) the intensity remains the same

(d) the intensity becomes zero

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8 **Maximum intensity in a polarization experiment occurs when the light wave and analyzer are:**

(a) perpendicular
(b) parallel
(c) at 45°
(d) at 60°

9 **Unwanted light that interferes with vision is termed:**

(a) haze
(b) glare
(c) contrast
(d) flare

10 **Who predicted the existence of gravitational waves?**

(a) Galileo Galilei
(b) Albert Einstein
(c) Isaac Newton
(d) Leonardo da Vinci

11 **What are gravitational waves?**

(a) electromagnetic waves
(b) mechanical waves
(c) ocean waves
(d) ripples in the fabric of spacetime

12 **The primary method used to detect gravitational waves is:**

(a) optical telescopes
(b) radio telescopes
(c) LASER interferometry
(d) gravitational lensing

13 **Which of the following is a primary source of gravitational waves?**

(a) binary black hole merger
(b) solar flares
(c) earthquake
(d) solar wind

Answer Key — Exercise MCQs

1	b	2	a	3	b	4	a	5	b	6	a
7	b	8	b	9	b	10	b	11	d	12	c
13	a										

Hints

Q3: an ideal polarizer passes half the intensity of unpolarized light ($I_0/2$). Q7: $I = I_0\cos^2\theta$ falls as θ increases. Q8: $\cos^2 0° = 1$.

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SLO-Based Additional MCQs + Past Papers (Punjab Boards)

1 **Longitudinal waves do not exhibit:**

(a) reflection
(b) refraction
(c) diffraction
(d) polarization

2 **Which of the following cannot be polarized?**

(a) sound waves
(b) light waves
(c) X-rays
(d) infrared rays

3 **Polarization of light shows that light is:**

(a) corpuscular in nature
(b) made of extremely short waves
(c) longitudinal waves
(d) transverse waves

4 **A Polaroid is:**

(a) a device used in a polarimeter
(b) a light filter
(c) a device used to analyse polarized light
(d) all of these

5 **Light can be polarized by:**

(a) selective absorption
(b) reflection
(c) scattering
(d) all of these

6 **We can polarize light by passing it through:**

(a) glass
(b) a Polaroid
(c) a prism
(d) water

7 **Polarized sunglasses decrease glare on a sunny day because they:**

(a) completely absorb the light
(b) have a special colour
(c) refract the light
(d) block a portion of light

8 **Confining a beam of light to vibrate in one plane is called:**

(a) interference
(b) diffraction
(c) polarization
(d) total internal reflection

9 **To distinguish between transverse and longitudinal waves, ___ is used:**

(a) refraction
(b) interference
(c) polarization
(d) diffraction

10 **An unpolarized beam of transverse waves is one whose vibrations:**

(a) are confined to a single plane
(b) take place in all directions
(c) take place in all directions perpendicular to the direction of propagation
(d) take place parallel to the direction of propagation

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11 **Optically active crystals are:**

(a) quartz
(b) sodium chlorate
(c) calcite
(d) both (a) and (b)

12 **Bending of light around the edges of an obstacle is called:**

(a) refraction
(b) polarization
(c) interference
(d) diffraction

Answer Key — Additional MCQs

1	d	2	a	3	d	4	d	5	d	6	b
7	d	8	c	9	c	10	c	11	d	12	d

Hints

Q4: a Polaroid is a light filter used in polarimeters and to analyse polarized light — so all of these. Q10: vibrations of an unpolarized transverse wave occur in all directions in the plane perpendicular to propagation.

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PART D

Solved Exercise

Exercise Numericals

8.1 Unpolarized light of intensity I_0 falls on a polarizing sheet. Find the intensity of light that is not transmitted.

A polarizer transmits half of unpolarized light:

$$I_{transmitted} = \frac{I_0}{2}$$

$$\mathbf{I_{not\ transmitted} = I_0 - \frac{I_0}{2} = \frac{I_0}{2}}$$

8.2 A polarized beam passes through a polarizer at 45°. Find the transmitted intensity if the initial intensity is 100 W m^{-2}.

Given: $I_0 = 100\ W\ m^{-2}$ • $\theta = 45°$

$$I = I_0 \cos^2\theta = 100 \times (1/\sqrt{2})^2 = 100 \times 0.5$$

$$\mathbf{I = 50\ W\ m^{-2}}$$

8.3 A light wave passes through a polarizer with its electric field at 30° to the axis. If the amplitude is 10 units, what is the amplitude after the polarizer?

Given: $A_0 = 10$ units • $\theta = 30°$

$$A = A_0 \cos\theta = 10 \times \cos 30° = 10 \times 0.866$$

$$\mathbf{A = 8.66\ units}$$

8.4 What angle between the direction of polarized light and the axis of a Polaroid will reduce its intensity by 85%?

Given: $I = 0.15\ I_0$

$$\frac{I}{I_0} = \cos^2\theta = 0.15 \Rightarrow \cos\theta = \sqrt{0.15} = 0.387$$

$$\mathbf{\theta = \cos^{-1}(0.387) \approx 67.2°}$$

The notes give 67.5°; $\cos^{-1}(0.387)$ is 67.2°.

8.5 Unpolarized light of 15 W m^{-2} falls on two polarizers with axes at 50° and 20° from the vertical. Find the intensity transmitted through both.

Given: $I_0 = 15\ W\ m^{-2}$ • $\theta = 50° - 20° = 30°$ between axes

$$I_1 = \frac{I_0}{2} = 7.5\ W\ m^{-2}$$

$$\mathbf{I_2 = I_1 \cos^2 30° = 7.5 \times (0.866)^2 \approx 5.63\ W\ m^{-2}}$$

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8.6 **Two polarizing sheets are parallel (maximum intensity). Through what angle must either sheet be rotated to halve the intensity?**

$$\frac{I_0}{2} = I_0 \cos^2\theta \Rightarrow \cos\theta = \frac{1}{\sqrt{2}}$$

$\theta = 45°$

8.7 **A glass plate of refractive index 1.5 in air is used as a polarizer. Find the polarizing angle and the angle of refraction.**

Given: n = 1.5

$\tan\theta_p = n \Rightarrow \theta_p = \tan^{-1}(1.5) \approx 56.3°$

$\theta_r = 90° - 56.3° = 33.7°$

8.8 **At what angle of incidence will light reflected from water (n = 1.33) be completely polarized?**

$\theta_p = \tan^{-1}(1.33) \approx 53°$

8.9 **Unpolarized light falls on a stack of four polarizing sheets, each rotated 30° clockwise relative to the previous one. What percentage of the incident intensity is transmitted?**

First sheet: $I_1 = \frac{I_0}{2}$

Each of the next three sheets is at 30° to the one before ($\cos^2 30° = \frac{3}{4}$):

$$I_4 = \frac{I_0}{2} \times \left(\frac{3}{4}\right)^3 = \frac{27}{128} I_0$$

$\frac{27}{128} \times 100 \approx 21.1\%$

27/128 = 0.211, so 21.1% (the notes print 21.9%).

8.10 **A polarizer and an analyzer have their axes at 60°. What fraction of the initial intensity emerges?**

$$I = I_0 \cos^2 60° = I_0 \times 0.25$$

$\frac{I}{I_0} = 0.25$ (one quarter)

8.11 **Gravitational waves have a wavelength of 3000 km. Find their frequency if they move at the speed of light.**

Given: $\lambda = 3 \times 10^6$ m • $c = 3 \times 10^8$ m s^{-1}

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{3 \times 10^6}$$

f = 100 Hz

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Constructed Response Questions

8.1 Write down some applications of plane-polarized light.

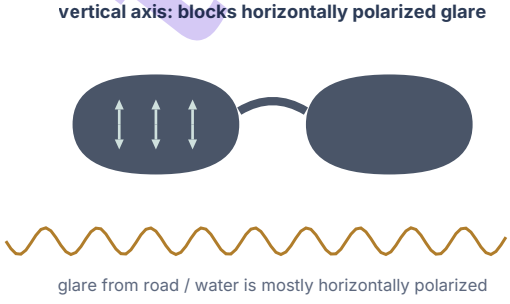
Plane-polarized light is used in Polaroid sunglasses to reduce glare, in photography to improve clarity, and in LCD screens. Circularly polarized light is used in 3D movie glasses, optical communication systems and some kinds of microscopy.

8.2 Would it be possible to use a polarizer as an analyzer? If yes, give at least two examples.

Yes. (i) In cameras, a polarizing filter blocks reflected glare to improve clarity. (ii) In laboratories, a polarizer detects the polarization state of light, e.g. when studying stress patterns. (iii) In sunglasses, the lenses act as analyzers to block polarized glare from water or roads.

8.3 Explain how Malus's law is used in the design of polarized sunglasses. How do they reduce glare from reflecting surfaces? Give an example.

Malus's law shows how intensity depends on the angle between the light's polarization and the filter axis ($I = I_0\cos^2\theta$). Glare from water or roads is mostly horizontally polarized, so sunglasses with a vertical transmission axis ($\theta \approx 90°$ to the glare) block most of it. For example, while driving, road glare is reduced, giving clearer and safer vision.



8.4 How would the sky appear if there were no atmosphere?

With no atmosphere there would be no scattering of sunlight. The sky would look **black**, and stars would be visible even in the daytime — as astronauts see from the Moon.

8.5 What is the significance of detecting gravitational waves?

It confirms Einstein's general theory of relativity and gives a new way to observe the universe. Gravitational waves let scientists study black-hole mergers and neutron-star collisions, giving information that cannot be obtained from light alone.

8.6 How are tidal forces formed?

Tidal forces come from the Moon's and Sun's gravitational pull on the Earth. The side nearer the Moon is pulled more strongly, forming a bulge; the far side is pulled less, forming another bulge. This difference in force stretches the Earth and causes tides.

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Comprehensive Questions

8.1 **Define polarization. How does polarization of EM waves occur? Classify the types.**

See **Long Question Q1**.

8.2 **How can plane-polarized light be produced and detected? What does it prove?**

See **Long Question Q2**.

8.3 **How can polarized light be obtained by reflection?**

See **Long Question Q3**.

8.4 **State Malus's law and explain the intensity formula.**

See **Long Question Q5**.

8.5 **What is a Polaroid? Explain two main applications of polarization.**

See **Long Question Q7**.

8.6 **What are gravitational waves? Describe their basic types.**

See **Long Question Q8**.

8.7 **What is an interferometer? Describe the basic Michelson interferometer.**

See **Long Question Q9**.

8.8 **What is meant by optical activity? Discuss.**

See **Long Question Q6**.

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