TOPIC 1 Wavefront

SQ 15.1.1 What is light?

Definition

Light is a type of energy which produces the sensation of vision.

SQ 15.1.2 What did Huygens propose about light?

Answer

In about 1678 Huygens, an eminent Dutch scientist, proposed that light energy from a luminous source travels in space by means of wave motion.

SQ 15.1.3 Which experiment established the wave theory of light?

Answer

Young's interference experiment, performed in 1801, proved the wave nature of light and thus established Huygens' wave theory.

SQ 15.1.4 What did Maxwell propose about light?

Answer

In 1860 Maxwell proposed that light consists of electromagnetic waves. Oscillating electric charges produce changing electric and magnetic fields that mutually regenerate each other and can propagate through vacuum.

SQ 15.1.5 What is the dual nature of light?

Answer

The quantum mechanical explanation revealed that light has both wave and particle characteristics depending on the experiment. It propagates as an electromagnetic wave but interacts with matter as discrete, massless particles called photons.

SQ 15.1.6 Define a wavefront.

Definition

A wavefront is an imaginary surface that connects all the points where the waves have the same phase of vibration.

SQ 15.1.7 Name the three types of wavefronts.

Types

Plane wavefronts, circular wavefronts and spherical wavefronts.

SQ 15.1.8 Describe plane wavefronts and give examples.

Answer

Plane wavefronts are represented as a straight line.

Examples

Light waves from distant stars, and water waves in a ripple tank.

SQ 15.1.9 Describe circular and spherical wavefronts.

Circular Wavefronts

They are represented by circles, as formed in water inside a pond.

Spherical Wavefronts

They are formed in three-dimensional space by a sound or light wave.

SQ 15.1.10 What is the shape of wavefronts from a point source?

Answer

For a point source in space the wavefronts are always spherical, spreading out in all directions. For very large distances, like light rays coming from the Sun, these wavefronts can be assumed as planes.

SQ 15.1.11 What is the shortest distance between two wavefronts?

Answer

The shortest distance between wavefronts is always equal to the wavelength of the wave.

SQ 15.1.12 What is the direction of energy transfer of a wave?

Answer

The direction of transfer of energy of a wave is always perpendicular to any point on the surface of a given wavefront.

SQ 15.1.13 Define a ray.

Definition

A line at right angle to a wavefront which shows its direction of travel is called a ray.

SQ 15.1.14 How are plane wavefronts produced?

Answer

Plane wavefronts are produced by a plane source or by any source at a distant point. If a source of light is placed at the focal point of a lens, plane wavefronts are formed on the other side of the lens.

TOPIC 2 Huygens' Principle

SQ 15.2.1 State Huygens' principle.

Statement

Every point of a wavefront may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the wave.

SQ 15.2.2 How is the new wavefront found using Huygens' principle?

Method

The new wavefront at a later time is found by constructing a surface tangent to the secondary wavelets, which is called the envelope of the wavelets.

SQ 15.2.3 **Describe the geometrical construction of a new wavefront.**

Construction
In time t the wavefront travels a distance vt. Several circles of radius vt, which are traces of spherical wavelets, are constructed centred at points along the original wavefront.

Result
The trace of the envelope of these wavelets is the new wavefront.

SQ 15.2.4 **What is the advantage of Huygens' model?**

Answer
All the results obtained from Huygens' principle can also be obtained from Maxwell's equations, but Huygens' simple model is easier to use.

TOPIC 3 Interference

SQ 15.3.1 **Define interference.**

Definition
When two coherent waves meet in a region, they reinforce each other at some points and cancel each other at some other points, forming a pattern called interference.

SQ 15.3.2 **State the three basic conditions for two waves to produce interference.**

Conditions
The waves must be of the same type, for example sound waves can only interfere with sound waves.
The waves must be coherent, having a constant phase difference.
The waves must be moving in the same direction.

SQ 15.3.3 **Define coherent sources.**

Definition
Coherent sources emit waves that have a constant phase difference. The two waves can only have a constant phase difference if their frequencies are the same and remain constant.

SQ 15.3.4 **Give everyday examples of interference of light.**

Examples
Haloes of light around street lamps or the moon on a foggy night.
Bright and dark bands of light seen when looking through fabric at a bright source of light.

SQ 15.3.5 **Why would two loudspeakers on different signal generators not give a steady pattern?**

Reason
With slightly different frequencies, the sound waves might start off in phase but would soon go out of phase. We would hear loud, then soft, then loud again, and the interference pattern would keep shifting around the room.

SQ 15.3.6 **How are two loudspeakers made coherent?**

Answer
By connecting the two loudspeakers to the same signal generator, we can be sure that the sound waves they produce are constantly in phase with one another. They then act as two coherent sources.

SQ 15.3.7 **Why can two separate lasers not be used to produce interference?**

Reason
Laser light can be thought of as being made up of many separate bursts of light. We cannot guarantee that these bursts from two lasers will always be in phase with one another.

SQ 15.3.8 **How is the problem of coherence overcome in the laser experiment?**

Method
The problem is overcome by using a single laser and dividing its light using two slits. The slits then act as two coherent sources of light.

SQ 15.3.9 **What would be observed if the sources were not coherent?**

Answer
The interference pattern would be constantly changing, far too fast for our eyes to detect. We would simply see a uniform band of light without any definite bright and dark regions.

TOPIC 4 Interference of Microwaves

SQ 15.4.1 **Describe the apparatus used to observe interference of microwaves.**

Apparatus
A microwave transmitter of 2.8 cm wavelength is directed towards a double gap in a metal barrier, and a probe receiver is used to detect the waves in the region beyond.

SQ 15.4.2 **How is the microwave interference pattern detected?**

Method
The microwaves are diffracted at the two gaps so that they spread out into the region beyond. By moving the probe around, it is possible to detect regions of high intensity, which is constructive interference, and low intensity, which is destructive interference.

SQ 15.4.3 **How may the output of the microwave probe be observed?**

Answer
The probe may be connected to a meter, or to an audio amplifier and loudspeaker to give an audible output.

SQ 15.4.4 **Why is the microwave interference pattern easily measurable?**

Reason
Because microwaves have wavelengths comparable to the size of the metal barrier apparatus, the pattern is easily observable and measurable.

SQ 15.4.5 Write the conditions for maxima and minima in microwave interference.

Path Difference

$\Delta x = d \sin\theta$

Maxima

$\Delta x = m\lambda$

Minima

$$\Delta x = \left(m + \frac{1}{2}\right)\lambda$$

SQ 15.4.6 Why does a microwave oven door have a metal grid?

Answer

A microwave oven has a metal grid in the door to keep the microwaves in and let the light out.

SQ 15.4.7 Describe a simple arrangement to show interference of light.

Arrangement

Light from a laser is directed through two slits, which are two clear lines on a black slide separated by a few millimetres. A series of equally spaced dots of light are seen on the screen.

SQ 15.4.8 What are interference fringes?

Definition

The bright dots seen on the screen are referred to as interference fringes. They are regions where light waves from the two slits arrive in phase, giving constructive interference, while the dark regions in between result from destructive interference.

SQ 15.4.9 How can we check that light reaches the screen from both slits?

Method

Mark a point on the screen where there is a dark fringe, then carefully cover one slit.

Observation

The pattern of interference fringes disappears and a broad band of light appears, so the point that was dark is now bright. Covering the other slit shows the same effect.

TOPIC 5 Young's Double-Slit Experiment

SQ 15.5.1 What did Thomas Young show with his experiment?

Answer

Thomas Young performed his experiment in 1801 and used it to show the wave nature of light.

SQ 15.5.2 Describe Young's double-slit experiment.

Description

A beam of light is shone on a pair of parallel slits placed at right angles to the beam. Light diffracts and spreads outwards from each slit, and the light from the two slits overlaps on a screen.

Result

An interference pattern of bright and dark bands called fringes is formed on the screen.

SQ 15.5.3 Why is a laser used in the modern form of Young's experiment?

Answer

A laser produces intense coherent light. Passing a single beam of laser light through the two slits readily gives sources whose phase difference remains constant.

SQ 15.5.4 Explain why a bright fringe is formed at the centre of the pattern.

Explanation

At the central point the two rays of light have travelled the same distance, so the path difference is zero.

Result

If they were in phase when they left the slits, they will be in phase on arrival, so they interfere constructively and a bright fringe is observed.

SQ 15.5.5 Explain the formation of the first dark fringe.

Explanation

At the mid-point of the first dark fringe, the light from one slit travels slightly further, so the two rays are in antiphase with a phase difference of 180°.

Condition

The path difference must be half a wavelength, so the two rays interfere destructively.

SQ 15.5.6 Explain the formation of the next bright fringe.

Explanation

At the mid-point of the next bright fringe, the ray from one slit has travelled an extra distance equal to a whole wavelength.

Result

The path difference is a whole wavelength, so the two rays are in phase, they interfere constructively and a bright fringe is seen.

SQ 15.5.7 What assumption simplifies the analysis of Young's experiment?

Assumption

The distance L from the slits to the screen is so large in comparison with the slit separation d that the rays from the two slits may be considered parallel.

Justification

The slit separation is typically a few millimetres while the screen may be a metre or more away.

SQ 15.5.8 Write the path difference in Young's double-slit experiment.

Formula

Path difference $= d \sin\theta$

Here θ is the angle between a line from the slits to the screen and the normal to the plane of the slits.

SQ 15.5.9 Write the condition for constructive interference in Young's experiment.

Formula

$d \sin\theta = m\lambda$

Here

$m = 0, 1, 2, 3, \ldots$

SQ 15.5.10 **Write the condition for destructive interference in Young's experiment.**

Formula

$$d\sin\theta = \left(m+\frac{1}{2}\right)\lambda$$

Here

$m = 0, 1, 2, 3, \ldots$

SQ 15.5.11 **Write the position of the mth bright fringe from the centre.**

Formula

$$y_m = \frac{m\lambda L}{d}$$

SQ 15.5.12 **Write the position of the mth dark fringe from the centre.**

Formula

$$y_m = \left(m+\frac{1}{2}\right)\frac{\lambda L}{d}$$

For the first order dark fringe

$m = 0$

SQ 15.5.13 **Why can sin θ be replaced by tan θ in Young's experiment?**

Reason

The distances y_m are often much smaller than the distance L from the slits to the screen, so θ is very small and $\sin\theta \approx \tan\theta$.

SQ 15.5.14 **Define fringe spacing and derive its expression.**

Definition

The distance between two consecutive bright fringes is called the fringe width or fringe spacing.

Derivation

$$\Delta y = y_{m+1} - y_m = \frac{(m+1)\lambda L}{d} - \frac{m\lambda L}{d}$$

Result

$$\Delta y = \frac{\lambda L}{d}$$

SQ 15.5.15 **How does slit separation affect the fringe spacing?**

Answer

The distance between adjacent bright bands is inversely proportional to the separation d between the slits. The closer together the slits are, the more the pattern spreads out.

SQ 15.5.16 **Are Young's results valid only for visible light?**

Answer

No. The results are valid for any type of wave, provided that the resultant wave from two coherent sources is detected at a point far away in comparison to the separation d.

SQ 15.5.17 **Slits 0.25 cm apart with a screen 100 cm away use light of 519 nm. Find the third order dark fringe position.**

Solution

Using

$$y = \left(m+\frac{1}{2}\right)\frac{\lambda L}{d}$$

with

$m = 2$

Calculation

$$y = \left(2+\frac{1}{2}\right)\frac{1.0\times 519\times 10^{-9}}{0.25\times 10^{-2}}$$

Result

$y = 5.9\times 10^{-4}\,\mathrm{m}$

TOPIC 6 Interference in Thin Films

SQ 15.6.1 **Define a thin film.**

Definition

A film whose thickness is of the order of the wavelength of light is called a thin film.

SQ 15.6.2 **Why are coloured bands seen on an oil film or soap bubble?**

Reason

Light waves are reflected from the front and back surfaces of the thin film. Constructive interference between the two reflected waves, which have different path lengths, occurs in different places for different wavelengths.

SQ 15.6.3 **Describe the two reflections in a thin film.**

Description

Light shining on the upper surface of a thin film of thickness t is partly reflected at the upper surface. Light transmitted through the upper surface is partly reflected at the lower surface.

Result

The two reflected waves come together at a point on the retina of the eye.

SQ 15.6.4 **Why do we see coloured patterns in a thin film?**

Reason

Different colours have different wavelengths, so the interference may be constructive for some colours and destructive for others.

SQ 15.6.5 **What causes the complex shapes of coloured patterns in a thin film?**

Answer

The complex shapes of the coloured patterns result from variations in the thickness of the film.

SQ 15.6.6 **Write the path difference for a thin air wedge between two glass plates.**

Answer

The path difference between the two waves is just twice the thickness t of the thin air film at each point, that is $2t$.

SQ 15.6.7 **What is expected at the line of contact of two glass plates?**

Expectation
Where the plates are in contact there is practically no path difference, so a bright area is expected.
Observation
When the experiment is carried out, a dark fringe is found there instead.

SQ 15.6.8 **What does the dark fringe at the line of contact suggest?**

Answer
It suggests that one of the reflected waves has undergone a half cycle phase shift during its reflection, so the two waves are half a cycle out of phase even though they have the same path length.

SQ 15.6.9 **From where can this phase shift be predicted?**

Answer
This phase shift can be predicted from Maxwell's equations and the electromagnetic nature of light.

TOPIC 7 Newton's Rings

SQ 15.7.1 **Define Newton's rings.**

Definition
When a thin air film enclosed between a plano-convex lens and a glass plate is viewed with monochromatic light, alternate bright and dark circular interference fringes are formed. These were studied by Newton and are called Newton's rings.

SQ 15.7.2 **How are Newton's rings formed?**

Formation
When a plano-convex lens is placed on a flat glass plate, a thin air film forms between them. Light from a monochromatic source reflects off both the top and bottom surfaces of this air film.
Result
The reflected rays interfere constructively giving bright rings, or destructively giving dark rings, depending on the path difference and phase shift.

SQ 15.7.3 **Give the uses of Newton's rings.**

Uses
Newton's rings can be used to calculate the wavelength of monochromatic light and to determine the radius of curvature of lenses. They are also used in precision optics to detect surface irregularities.

SQ 15.7.4 **Why are different colours seen on the surface of a soap bubble?**

Answer
The different colours seen on the surface of a soap bubble are due to the interference of white light falling on and reflecting from it.

TOPIC 8 Diffraction Grating

SQ 15.8.1 **What is the effect of increasing the number of slits in an interference experiment?**

Answer
Keeping the spacing of adjacent slits constant, increasing the number of slits gives interference patterns in which the maxima are in the same positions but progressively narrower.

SQ 15.8.2 **Why are narrow maxima useful?**

Reason
Because these maxima are so narrow, their angular position, and hence the wavelength, can be measured to very high precision.

SQ 15.8.3 **Define a diffraction grating.**

Definition
An array of a large number of parallel slits, all with the same width and spaced equal distances d between centres, is called a diffraction grating.

SQ 15.8.4 **Who constructed the first diffraction grating and how are gratings made?**

Answer
The first diffraction grating was constructed by Fraunhofer using fine wires. Gratings can be made by using a diamond point to scratch many equally spaced grooves on a glass surface.

SQ 15.8.5 **Define grating spacing.**

Definition
The spacing d between the centres of adjacent slits is called the grating spacing. It is the reciprocal of the number of slits per unit length.

SQ 15.8.6 **What are far-field or Fraunhofer conditions?**

Definition
We assume that the pattern is formed on a screen far enough away that all rays emerging from the grating and going to a particular point on the screen can be considered to be parallel.

SQ 15.8.7 **Write the condition for principal maxima with a diffraction grating.**

Formula
$d\sin\theta = n\lambda$
Here
$n = 0, \pm1, \pm2, \pm3, \ldots$

SQ 15.8.8 **How is the wavelength of light determined using a diffraction grating?**

Method
The grating spacing d is found from the number of lines per unit length, and the grating is illuminated with monochromatic light. The diffraction angle θ is measured for a particular order n.
Formula
$\lambda = \dfrac{d\sin\theta}{n}$

SQ 15.8.9 **Find the grating spacing for a grating with 600 lines per mm.**

Solution
$d = \dfrac{1\,\text{mm}}{600}$

Result

$d = 1.67 \times 10^{-6}\,\text{m}$

SQ 15.8.10 **What are first-order and second-order lines?**

Definition

The
$n = \pm 1$
lines are called the first-order lines, the
$n = \pm 2$
lines are the second-order lines, and so on.

SQ 15.8.11 **What is observed when a grating is illuminated with white light?**

Answer

Each value of n corresponds to a continuous spectrum in the pattern. Long wavelengths at the red end lie at larger angles than the shorter wavelengths at the blue end.

SQ 15.8.12 **How many slits per millimetre do visible-light gratings usually have?**

Answer

Gratings for use with visible light of wavelength from 400 to 700 nm usually have about 1000 slits per millimetre, so d is of the order of 1000 nm.

TOPIC 9 Diffraction of X-rays by Crystals and Bragg's Law

SQ 15.9.1 **What is the wavelength of X-rays?**

Answer

X-rays are a type of electromagnetic radiation of much shorter wavelength, about 10^{-10} m.

SQ 15.9.2 **Why is a crystal used as a diffraction grating for X-rays?**

Reason

To observe diffraction, the grating spacing must be of the order of the wavelength of the radiation used. The regular array of atoms in a crystal forms a natural diffraction grating with spacing typically about 10^{-10} m.

SQ 15.9.3 **Who initiated the study of crystal structure by X-rays?**

Answer

The study of the atomic structure of crystals by X-rays was initiated in 1914 by W. H. Bragg and W. L. Bragg with remarkable achievements.

SQ 15.9.4 **What did the Braggs find?**

Answer

They found that a monochromatic beam of X-rays was reflected from a crystal plane as if it acted like a mirror.

SQ 15.9.5 **Derive the path difference in Bragg's law.**

Derivation

The beam reflected from the lower plane travels an extra distance compared with the beam reflected from the upper plane.

Since
$BC = d \sin\theta$
and
$B'C = d \sin\theta$

Result

Path difference $= 2d\sin\theta$

SQ 15.9.6 **State and write Bragg's equation.**

Statement

For reinforcement, the path difference should be an integral multiple of the wavelength.

Formula

$2d\sin\theta = n\lambda$

SQ 15.9.7 **What does n represent in Bragg's equation?**

Answer

The value of n is referred to as the order of reflection.

SQ 15.9.8 **What is the use of Bragg's equation?**

Use

It can be used to determine the interplanar spacing between similar parallel planes of a crystal, if X-rays of known wavelength are allowed to diffract from the crystal.

SQ 15.9.9 **Give the biological applications of X-ray diffraction.**

Applications

X-ray diffraction has been very useful in determining the structure of biologically important molecules such as haemoglobin, an important constituent of blood, and the double helix structure of DNA.