$$Z_F = \frac{a^2}{\lambda}$$

Where,

Aperture width, a = 4 mm = 4 $\times 10^{-3}$ m

Wavelength of light, λ = 400 nm = 400 $\times$ 10^{-9} m

$$Z_F = \frac{\left(4\times10^{-3}\right)^2}{400\times10^{-9}} = 40 \text{ m}$$

Therefore, the distance for which the ray optics is a good approximation is 40 m.

Question 10.11:

The 6563 Å H_α line emitted by hydrogen in a star is found to be red shifted by 15 Å. Estimate the speed with which the star is receding from the Earth.

Answer

Wavelength of H_α line emitted by hydrogen,

λ = 6563 Å

= 6563 $\times$ 10^{-10} m.

Star's red-shift, $(\lambda' - \lambda) = 15\ \text{Å} = 15\times10^{-10}\ \text{m}$

Speed of light, $c = 3\times10^8$ m/s

Let the velocity of the star receding away from the Earth be v.

The red shift is related with velocity as:

$$\lambda' - \lambda = \frac{v}{c}\lambda$$

$$v = \frac{c}{\lambda}\times(\lambda' - \lambda)$$

$$= \frac{3\times10^8\times15\times10^{-10}}{6563\times10^{-10}} = 6.87\times10^5 \text{ m/s}$$

Therefore, the speed with which the star is receding away from the Earth is 6.87 $\times$ 10^5 m/s.

Question 10.12:

Explain how Corpuscular theory predicts the speed of light in a medium, say, water, to be greater than the speed of light in vacuum. Is the prediction confirmed by experimental determination of the speed of light in water? If not, which alternative picture of light is consistent with experiment?

Answer

No; Wave theory

Newton's corpuscular theory of light states that when light corpuscles strike the interface of two media from a rarer (air) to a denser (water) medium, the particles experience forces of attraction normal to the surface. Hence, the normal component of velocity increases while the component along the surface remains unchanged.

Hence, we can write the expression:

$c\sin i = v\sin r$ ... (i)

Where,

i = Angle of incidence

r = Angle of reflection

c = Velocity of light in air

v = Velocity of light in water

We have the relation for relative refractive index of water with respect to air as:

$$\mu = \frac{v}{c}$$

Hence, equation (i) reduces to

$$\frac{v}{c} = \frac{\sin i}{\sin r} = \mu \qquad \text{... (ii)}$$

But, $\mu > 1$

Hence, it can be inferred from equation (ii) that $v > c$. This is not possible since this prediction is opposite to the experimental results of $c > v$.

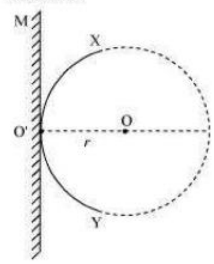
The wave picture of light is consistent with the experimental results.

Question 10.13:

You have learnt in the text how Huygens' principle leads to the laws of reflection and refraction. Use the same principle to deduce directly that a point object placed in front of a plane mirror produces a virtual image whose distance from the mirror is equal to the object distance from the mirror.

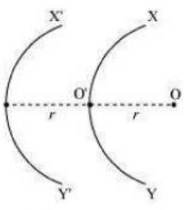
Answer

Let an object at O be placed in front of a plane mirror MO' at a distance r (as shown in the given figure).



A circle is drawn from the centre (O) such that it just touches the plane mirror at point O'. According to Huygens' Principle, XY is the wavefront of incident light.

If the mirror is absent, then a similar wavefront X'Y' (as XY) would form behind O' at distance r (as shown in the given figure).



$X'Y'$ can be considered as a virtual reflected ray for the plane mirror. Hence, a point object placed in front of the plane mirror produces a virtual image whose distance from the mirror is equal to the object distance (r).

Question 10.14:

Let us list some of the factors, which could possibly influence the speed of wave propagation:

(i) Nature of the source.

(ii) Direction of propagation.
(iii) Motion of the source and/or observer.
(iv) Wave length.
(v) Intensity of the wave.
On which of these factors, if any, does
(a) The speed of light in vacuum,
(b) The speed of light in a medium (say, glass or water), depend?
Answer
(a) Thespeed of light in a vacuum i.e., 3×10^8 m/s (approximately) is a universal constant. It is not affected by the motion of the source, the observer, or both. Hence, the given factor does not affect the speed of light in a vacuum.
(b) Out of the listed factors, the speed of light in a medium depends on the wavelength of light in that medium.

Question 10.15:
For sound waves, the Doppler formula for frequency shift differs slightly between the two situations: (i) source at rest; observer moving, and (ii) source moving; observer at rest. The exact Doppler formulas for the case of light waves in vacuum are, however, strictly identical for these situations. Explain why this should be so. Would you expect the formulas to be strictly identical for the two situations in case of light travelling in a medium?
Answer
No
Sound waves can propagate only through a medium. The two given situations are not scientifically identical because the motion of an observer relative to a medium is different in the two situations. Hence, the Doppler formulas for the two situations cannot be the same.
In case of light waves, sound can travel in a vacuum. In a vacuum, the above two cases are identical because the speed of light is independent of the motion of the observer and the motion of the source. When light travels in a medium, the above two cases are not identical because the speed of light depends on the wavelength of the medium.

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