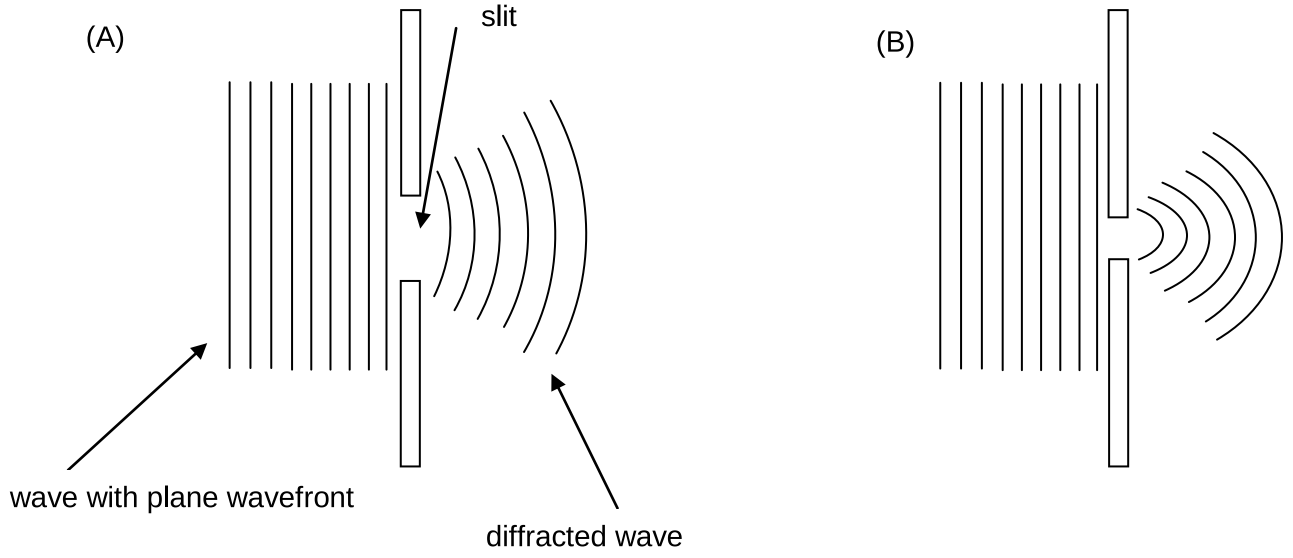
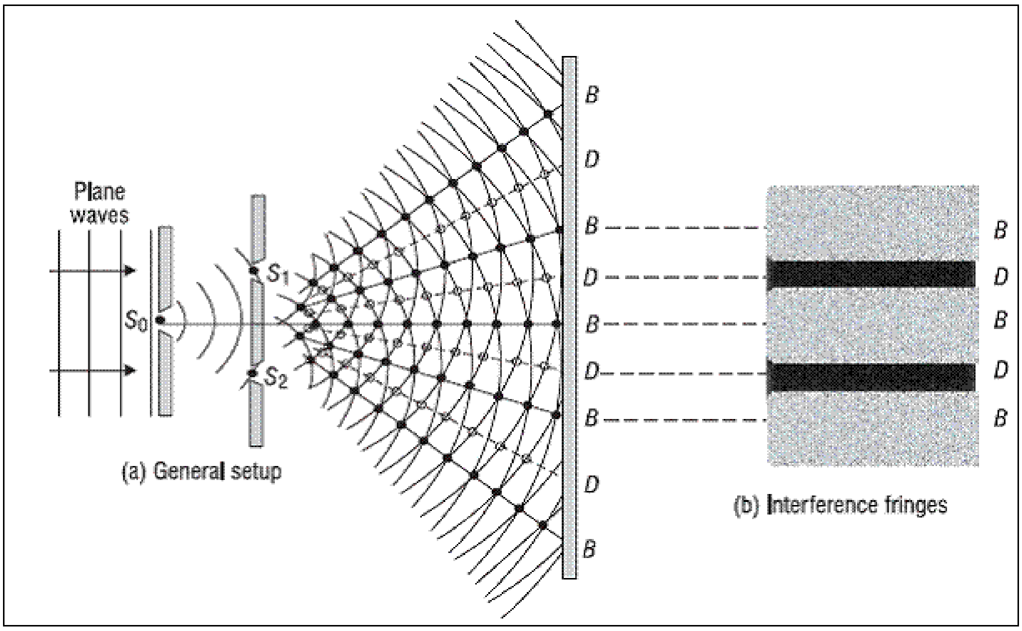
DIFFRACTION

If a wave encounters a barrier that has an opening of dimensions similar to the wavelength, the portion of the wave that passes through the opening will spread out (diffract) into the region beyond the barrier. The narrower the slit, the greater the diffraction.



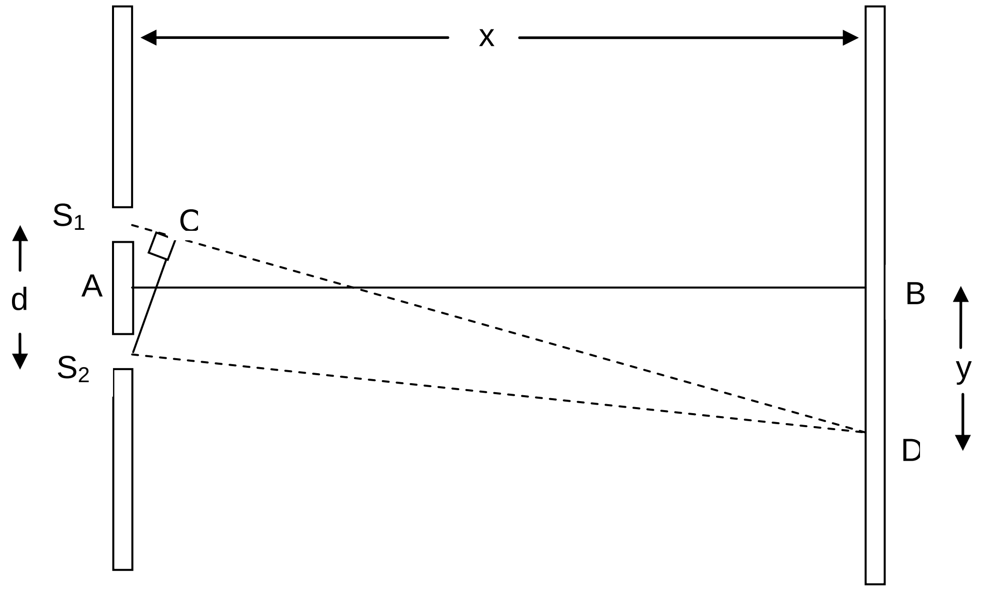
Young's double slit interference experiment

Young's experiment demonstrates the interference of light waves. The figure below shows the basic arrangement of Young's experiment. Light from a distant monochromatic source spreads via diffraction to illuminate two slits S_1 and S_2 in a screen. Diffraction of the light by these two slits sends overlapping circular waves into the region beyond the screen, where the waves from one slit interfere with those from the other slit.



No evidence for the interference can be seen except a viewing screen C is placed such as to intercept the light. On the screen C, points of interference maxima form visible bright rows called bright fringes or maxima. Dark regions called dark fringes or minima result from destructive interference and appear between adjacent pairs of maxima. The pattern of bright and dark fringes on the screen is called an interference pattern. To determine the locations of the fringes in Young's double-slit interference experiment, let us work with the diagram below:

$$\Delta p = p_1 - p_2 = dsin\theta$$



Consider light reaching the point D at a distance y from the central axis AB as shown above. The separation of the two slits is represented by d, and the screen is located at a distance x from the slits. The line S_2C is drawn so that the distances CD and P_2 (or S_2D) are equal. Therefore the angle $S_1S_2C = \theta$, and the difference Δp in the path length of light coming from S_1 and S_2 is given by

$$\Delta p = p_1 - p_2 = dsin\theta$$

Constructive interference will occur at D when this difference in path length is equal to

$$0, \lambda, 2\lambda, 3\lambda \ldots \ldots \ldots \ldots \ldots, n\lambda$$

where λ is the wavelength of the light.

Therefore the conditions for bright fringes are given by

$$dsin\theta = n\lambda; n = 0, 1, 2, 3 \ldots \ldots \ldots ..$$

where $d = slit\ separation, \theta = angle\ fringe\ makes\ with\ the\ axis$

The condition required for the formation of dark fringes at D will be satisfied when the path difference is

$$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots \ldots \ldots \ldots \ldots$$

Under these conditions, destructive interference will cause the waves to cancel out. Thus dark fringes will occur when

$$dsin\,\theta = n\frac{\lambda}{2}; n = 1, 3, 5 \ldots \ldots \ldots \ldots ..$$

The above equations for bright and dark fringes can be written more compactly by expressing them in terms of the measurable distances x and y. For small angles,

$$\sin\theta = \tan\theta = \frac{y}{x}$$

Which implies;

Bright fringes: $\frac{yd}{x} = n\lambda; \quad n = 0, 1, 2, 3 \ldots \ldots \ldots \ldots$

Dark fringes: $\frac{yd}{x} = n\frac{\lambda}{2}; \quad n = 1, 3, 5, 7 \ldots \ldots \ldots \ldots$

In experiments designed to measure the wavelength of light, x and d are known initially. The distance to any particular fringe can be measured and then used to determine the wavelength.

Examples

1. In Young's experiment, the two slits are 0.04 mm apart and the screen is located 2m away from the slits. The third bright fringe from the centre is displaced 8.3 cm from the central fringe,

$$\frac{yd}{x} = n\lambda; \quad n = 0, 1, 2, 3 \ldots \ldots \ldots \ldots$$

$$\frac{yd}{x} = n\frac{\lambda}{2}; \quad n = 1, 3, 5, 7 \ldots \ldots \ldots \ldots$$

a. Determine the wavelength of the incident light.

b. Where will the second dark fringe appear?

Ans: [redacted]

2. Light from a laser has a wavelength of 632 nm. Two rays from this source follow paths that differ in length. What is the minimum path difference required to cause

a. Constructive interference?

b. Destructive interference?

Ans: [redacted]

Bright bands occur whenever the waves arriving from the two slits interfere constructively. Dark bands occur when destructive interference takes place. At point B in the centre of the screen, light travels the same distances P_1, and P_2 from each slit. The difference in path length $\Delta p = 0$ and constructive interference results in a bright central band.

Assignment

3. Young's double slit experiment is performed in air with light of

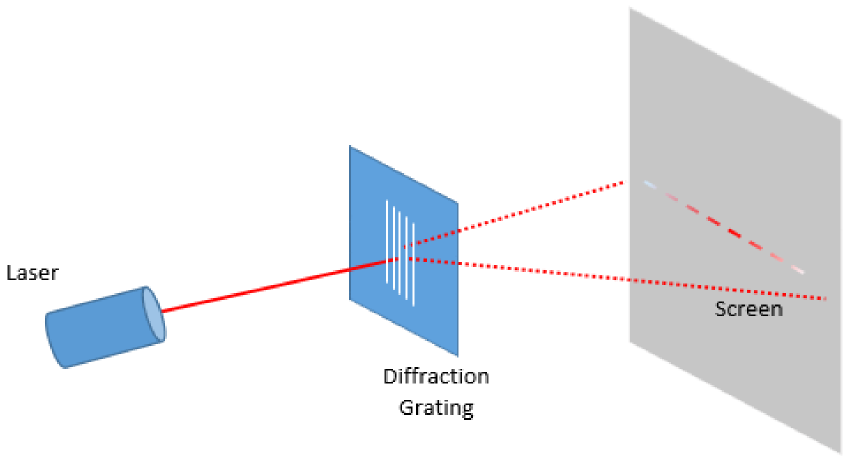
a) frequency 6.0 x 10^{14} Hz. If the slits are separated by 0.2 mm and the screen kept 1m from the slits, find the fringe width.

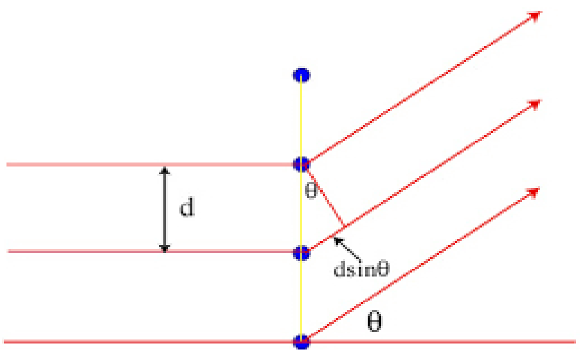
b) wavelength 3.0×10^{-7} m. If the slits are 0.4 mm apart and the distance of the slits to the screen is 1.5 m, what is the separation of the fringes?

Ans: [redacted]

Diffraction grating

If many parallel slits similar to those in Young's experiment are spaced regularly and of the same width, a brighter and sharper diffraction pattern can be obtained. Such an arrangement is known as a diffraction grating. Gratings are made by ruling several parallel grooves on a glass plate with a diamond point. Most laboratory gratings are ruled from 10,000 to 30,000 lines per inch. A parallel beam of monochromatic light striking a diffraction grating is diffracted in a manner similar to that in Young's experiment. A diffraction grating is illustrated in the diagram below.





Only a few slits are shown, each separated by a distance d. Each slit acts as a source of secondary wavelets called Huygens's wavelets. A central bright image of the source is formed on the screen. Other bright fringes will also be formed at a given inclination from the grating. The first bright line formed on either side of the central image is called the first-order fringe, the second is called the second-order fringe etc. The condition for the formation of these bright fringes is the same as that derived for Young's experiment. Therefore, we can write the grating equation as

$$d \sin \theta_n = n\lambda; \quad n = 1, 2, 3 \ldots \ldots \ldots \ldots$$

where d=spacing of slits

λ= wavelength of incident light

θ_n= deviation angle for the nth bright fringe

The first-order fringe occurs when n=1. This image occurs when the paths of diffracted rays from each slit differ by an amount equal to one wavelength. The second-order spectrum occurs when the paths differ by two wavelengths.

Question

A diffraction grating having 20,000 lines per inch is illuminated by parallel light of wavelength 589 nm. What are the angles at which the first - and second – order bright fringes occur?

Ans: [redacted]

$$d \sin \theta_n = n\lambda; \quad n = 1, 2, 3 \ldots \ldots \ldots \ldots$$

Polarization of Transverse Waves

Light is an electromagnetic (e.m) wave. It consists of electric and magnetic fields at right angles to each other and moving perpendicular to the direction of travel of the light wave. The plane of oscillation of the electric and magnetic fields may vary its orientation (although the fields remain at right angles to each other) as the wave propagates. Polarization refers to the orientation of the plane of the electric field as the wave travels.

Light that is polarized has the electric field oscillating in one direction only e.g. vertically, horizontally, diagonally etc. Most naturally occurring light is un-polarized because the electric field component is oscillating randomly in about every direction possible. To change unpolarized light to polarized light, a material such as a Polaroid filter is used. Such a material will allow light to pass through in only one orientation and block out all other orientations.

Polarization may be measured with a polarimeter. Polarized sunglasses work by blocking out glare from the sun. Glare from the sun is usually due to light reflected from the ground, water surfaces, etc into a person’s eyes. Polarized sunglasses will allow light of all orientation except that from the glare to pass through.