Interference

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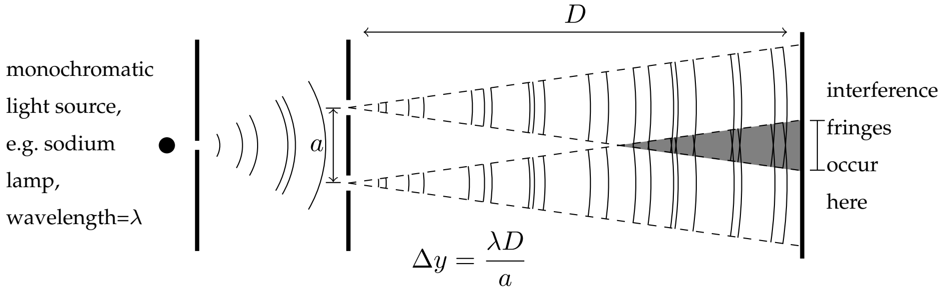
Interference is the name given to the superposition of waves which are in the same place at the same time. Interference happens whenever waves meet, but in order for the effects of interference to be observed, the waves must have a **constant phase relationship** (waves which have this property are given the special name *coherent*; the phase difference may be zero, but does not have to be) and also have appoximately the same amplitude (so that the interference effects have good contrast). This can lead to a pattern of areas where the waves add up to give a wave which is bigger (constructively interfere) and areas where they add together to make a wave which is smaller (destructively interfere).

Young's fringes

The first optical demonstration of interference (providing strong support for the wave theory of light) was provided by Thomas Young in 1801.[1] Interference effects can be demonstrated using a double-slit system, in which diffraction occurs at each slit, and an interference pattern is observed where the two coherent beams of light overlap on a screen.

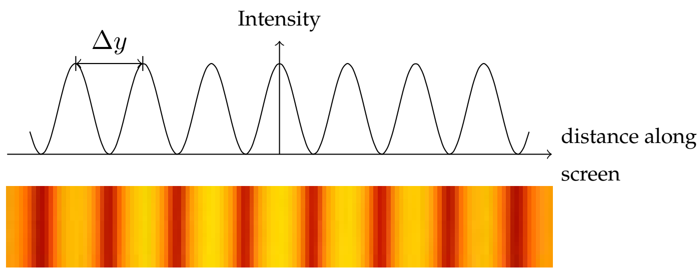
[1] Young's experiment was very similar to the setup here, but he actually used a white light source.



NB The diagram is not to scale: the slit separation is hugely exaggerated.

When considering light[2], the interference pattern is a series of alternate bright and dark fringes (called interference fringes), which are equally spaced and aligned parallel to the slits. The distance between two adjacent bright maxima (or adjacent dark minima) is called the fringe width, Δy.

[2] Note that a double-slit situation can arise with any kind of wave, e.g. water waves interfering in a wave tank beyond two openings in a barrier; sound waves from two coherent speakers; the coherent signals from two radio transmitters.



If the slit separation is a and the observation point is a distance D away (see diagram), then the width of the fringes Δy is given by

$$\Delta y = \frac{\lambda D}{a}.$$

In a typical experiment, the slits are about 0.1 mm wide and about $a = 0.7$ mm apart. Distance D would be about 1.3 m and if a sodium lamp were used ($\lambda = 589$ nm) the fringe spacing Δy would be about 1.1 mm. Values of a and Δy would be measured with a micrometer eyepiece, and D would be measured with a ruler.

Young's slits with laser light

The main problem in producing interference is the sources: they must be coherent. When light is emitted by a source it is due to electrons jumping between energy levels within individual atoms in the source. These jumps occur randomly (except in lasers), and each gives rise to a photon of radiation, which is a extremely short burst of radiation lasting, typically, for 10^{-9} s. Because interference requires a *constant* phase difference, the two waves producing the interference would need to have come from the same point on the same source, and within 10^{-9} s of each other.

This is why, with a monochromatic source such as a sodium lamp, the light first has to diffract from a narrow slit before passing through the double slit arrangement.Because this first slit is narrow, two photons passing through it will come from the same point on the source, and so long as the path between the source and the first slit is short, they will have done so within 10^{-9} s of each other. This makes the two slits into separated coherent sources, allowing interference to be observed beyond them where the light overlaps.

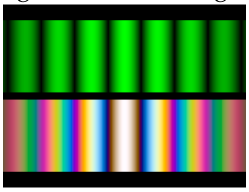
Until the laser was invented, it was thought that no two totally independent sources could ever produce an observable interference pattern. With incoherent sources, which emit photons with rapidly varying phases, interference will still occur, but the resulting interference pattern changes so rapidly that it seems like uniform illumination. Lasers, however, make electrons jump between levels in a different way, meaning that they can have much longer coherence times, and interference from independent lasers has been observed and photographed. Since the laser is a coherent source of monochromatic light, there is no need for a first slit, and the laser can be aimed directly at the double slit arrangement.

Origin of the interference pattern

The central bright fringe is equidistant from both slits, and so the beams of light from the two slits have equal length—the *path difference* is zero—meaning that they reach the screen in phase and constructively interfere. The first dark fringes on either side of this bright fringe arises when the light ray from one slit has to travel $\frac{\lambda}{2}$ further than the light ray from the other slit. This means that these rays are out of phase and so cancel out or destructively interfere. The next bright fringe is formed because the path difference between light is one wavelength λ, and so on…

White light pattern

If white light is used, the fringes are coloured. The colour at any point depends on how each wavelength of light in the visible spectrum is interfering at that point. Each wavelength produces its own fringe system, and the combined effect is given by adding the fringes which would be produced by each individual wavelength together. Note that the pattern produced by red light will have a larger spacing than that of blue light as it has a larger wavelength.



The central bright fringe is where the path difference is zero, which is of course true for all wavelengths. This means that the central bright band is produced in the same place for all of the interference patterns, and so it is white.