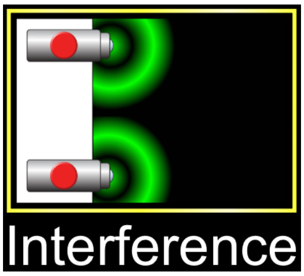
3.4.2 Coherence and Young's double slits

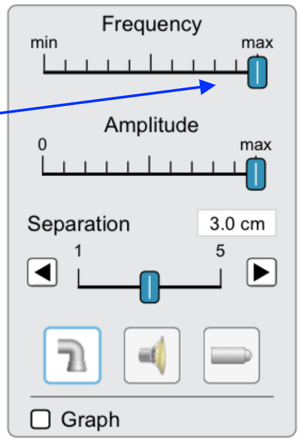
PhET SIM

Open the following simulation:

https://goo.gl/G3ErJs

Choose the interference 

simulation.

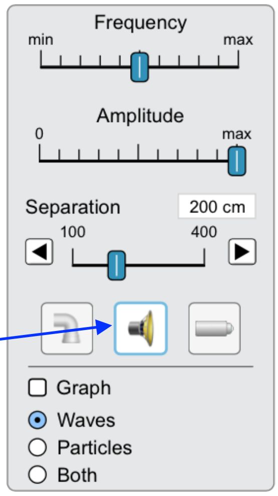


And select a high frequency.

You will observe an interference pattern.

For water waves, we can produce an interference pattern from two sources that are producing waves with the same frequency and with a constant phase difference. In this case the wave sources are producing waves with a zero phase difference (they are in phase – the drops are falling at the same time). An interference pattern would also be observed if the drops from the two sources were out of phase, provided that the phase difference was kept constant. The interference pattern, in this case, would be shifted. (Unfortunately, in this simulation we can't change the phase relationship between the two sources.). When waves from two sources have the same frequency and a constant phase difference, we say they are <u>coherent</u>.

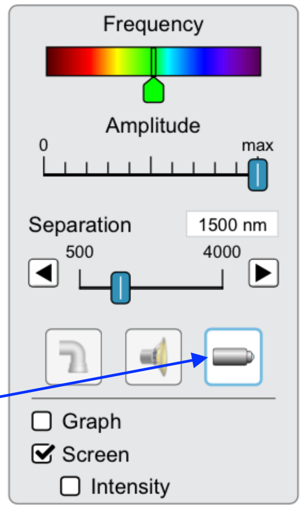
You can also observe a similar interference pattern for sound (select sound tab on the simulation), using two speakers. This is because the speakers are producing waves of the same frequency and a constant phase difference (again, they are in phase). The two sources are coherent.



sound selection

(1) ✐ What do you think you would hear if you moved you ear from top to bottom through the interference pattern?

If you now click the light tab and choose two sources of light, you will see the same interference pattern. In fact, two light sources will not produce an interference pattern in practice! This is because light sources (excluding lasers) produce light which is not coherent.



(2)✐What happens to the intensity pattern on the screen when you change from violet light (shorter wavelength) to red light (longer wavelength)? (The bright areas are called bright fringes.)

(3)✐What happens to the separation of bright fringes on the screen when you increase the separation of the two light sources?

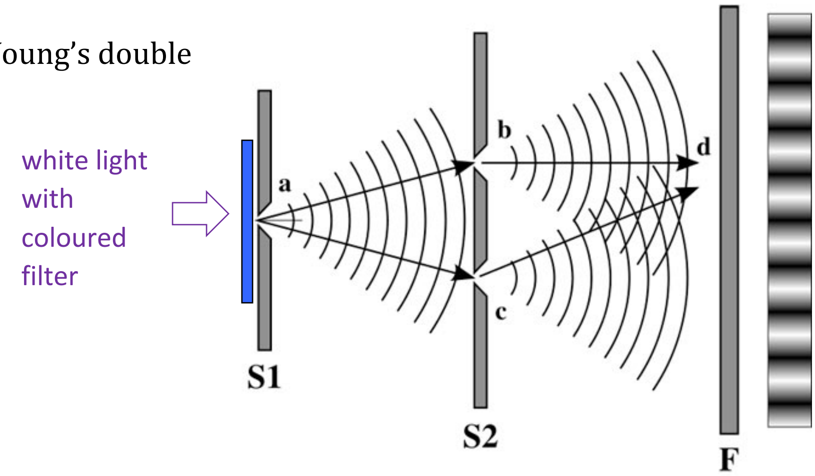
Coherency

There are two conditions for coherency – waves must have 1) the same frequency, and 2) a constant phase difference.

The first condition can be easily met. For example, LEDs produce photons of one frequency, or we could use a coloured filter in front of a white light source. The second condition is more difficult. Light sources produce discrete photons in a random manner. This means that photons are streaming out with all different phase relationships. The resulting interference pattern becomes smeared out.

Young's double slits

Let's take a look at the Young's double slit experiment:



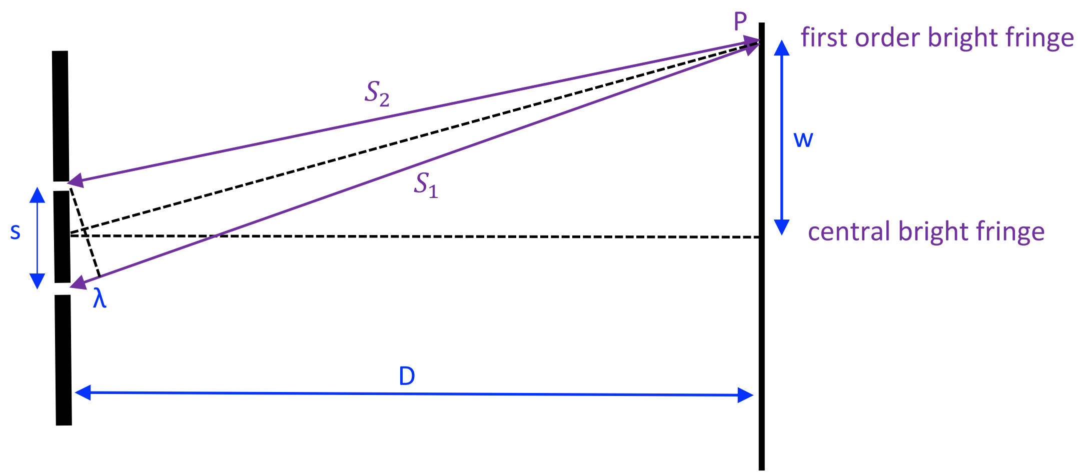
White light is passed through a coloured filter. The filtered light is of one frequency. Next, the light passes through one slit. Because we effectively have a point source of light, photons arriving at the double slit will have a constant phase difference (in this case, zero) determined by the path difference between the single slit and the two slits. In this case the path lengths are the same.

This setup ensures that photons passing through both slits are coherent. Hence, an interference pattern is produced on the screen.

The other solution is to use laser light. Lasers produce monochromatic (single frequency), coherent light and can be used to illuminate double slits directly.

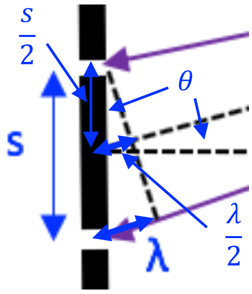
Double slit calculations

If we look in plan view at the double slit experiment:



Where s = slit separation, D = slit to screen distance, w = separation of high intensity (bright fringe) on the screen, λ = wavelength of light, S_1 and S_2 are path lengths from slits to screen.

We know that constructive interference will occur at P if the path difference $S_1 - S_2$ is a multiple of whole wavelengths. The first order bright fringe will occur when there is one wavelength difference.



If we zoom in on the area of the slits:

We can see that the angles θ, shown, are the same. We can use the trigonometric functions for these angles.

$$\sin\theta = \frac{\lambda/2}{s/2} = \frac{\lambda}{s}$$

$$\tan\theta = \frac{w}{D}$$

Now we use the small angle approximation (which is justified for D large compared to s). The small angle approximation says that $\sin\theta = \tan\theta$. Hence we can write:

$$\frac{\lambda}{s} = \frac{w}{D}$$

This is usually rearranged to show the separation of bright fringes:

$$w = \frac{D\lambda}{s}$$

(4)✏Calculate the separation of bright fringes (w) for red light (λ = 700nm) passing through double slits with a spacing $s = 1 \times 10^{-4}$m? The distance between the slits and screen D=5m.

(5)✏Looking at the formula, how would making D smaller affect the spacing of bright fringes?

(6)✏Looking at the formula, how would increasing the frequency affect the spacing of bright fringes? (Hint: how is frequency related to wavelength?)