Physics 30 Unit C - EMR

Interference of Waves:

Diffraction and Polarization

Lesson 6

POS Checklist:

- ☐ describe, qualitatively, diffraction, interference and polarization.
- ☐ describe, qualitatively, how the results of Young's double-slit experiment support the wave model of light.
- ☐ solve double-slit and diffraction grating problems.
- ☐ compare and contrast the visible spectra produced by diffraction gratings and triangular prisms.

Wave vs. Particle

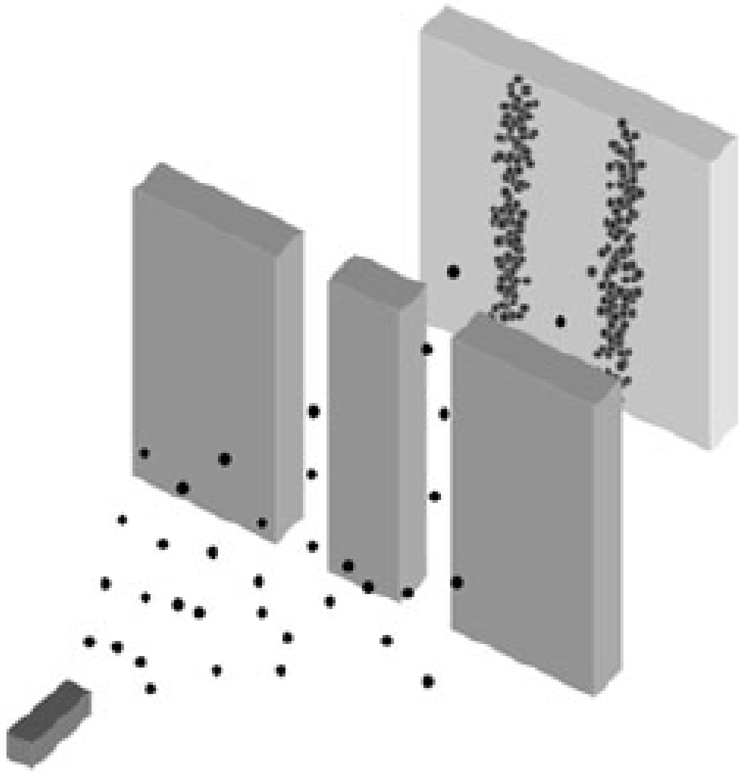
One of the key debates in the pre-1900 world of physics was:

Is light a wave or a particle?

We have already seen some strong evidence of the wave nature with reflection and refraction. Another case for waves is through the principle of **diffraction**.

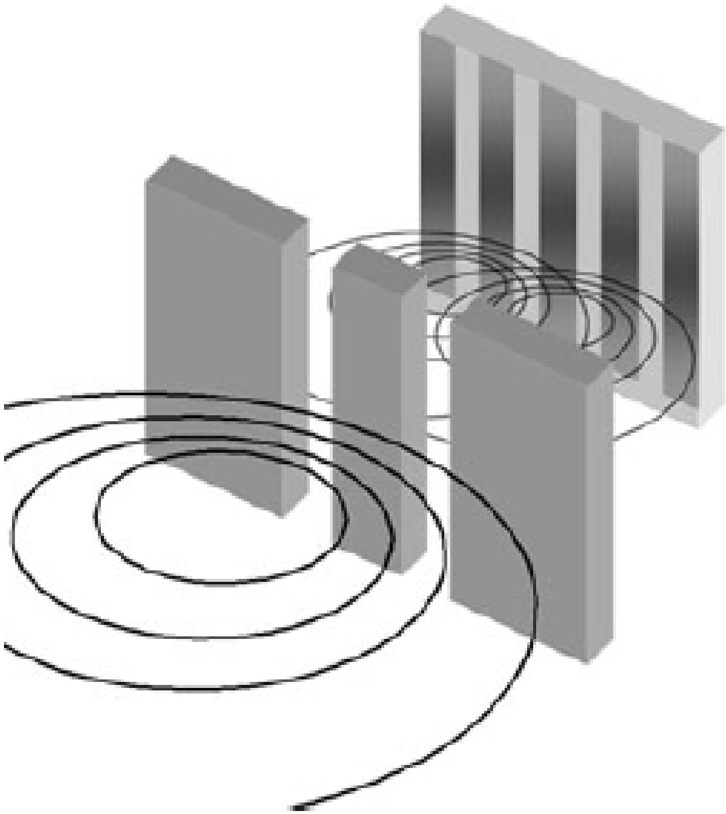
Diffraction

To understand diffraction, consider a barrier (a wall or a piece of paper) with two slits in it. What would happen if we shot some particles at the barrier?



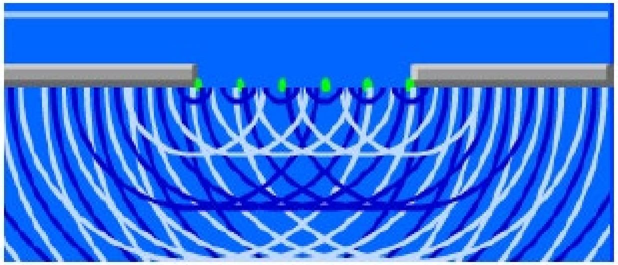
Some of the particles would pass through the slits, others would be stopped. A pattern of lines would be found on the barrier, like the diagram.

If the experiment was repeated with waves instead of particles, the results would look as follows:



This bending of waves is called diffraction. It was first explained by Christian Huygens in the late 17th century.

Huygens theorized that one wave could be broken into many tiny wavelets. When some of the wavelets travel through the spaces, they interfere, constructively or destructively, to produce interference patterns on the screen.

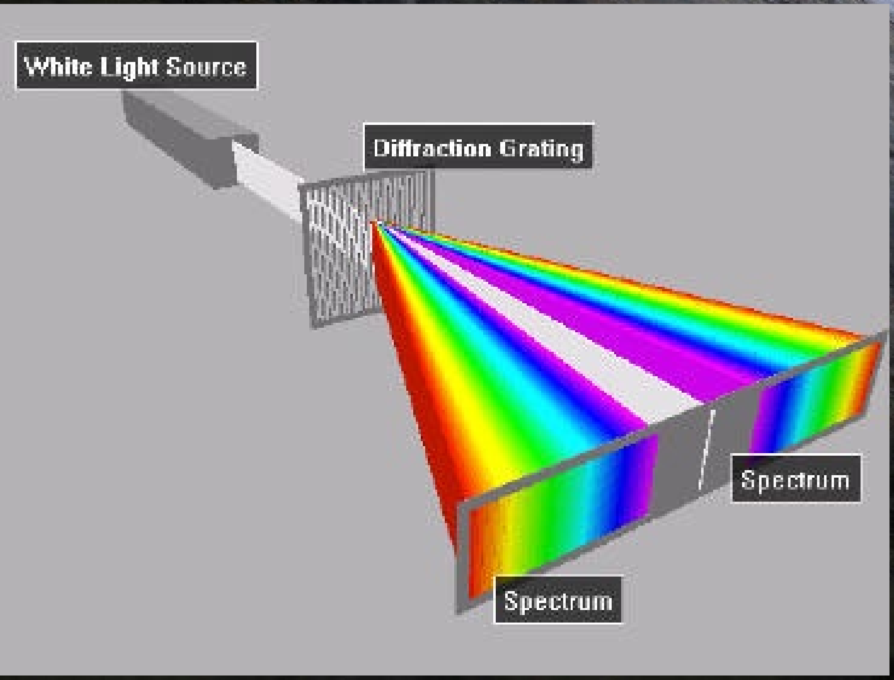


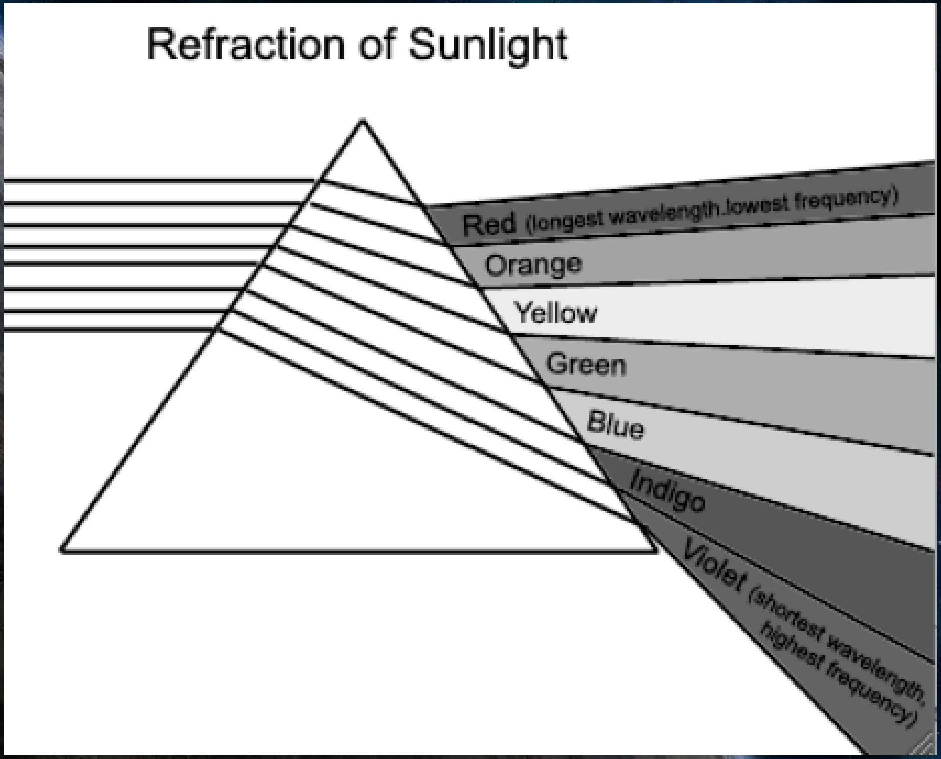
Interference

- **Recall that waves interfere (superposition) in a predictable way.**
- **Where two crests meet we have maximum displacement of the medium which is called an antinode.**
- **Where a crest meets a trough we have complete destructive interference and a node is formed.**

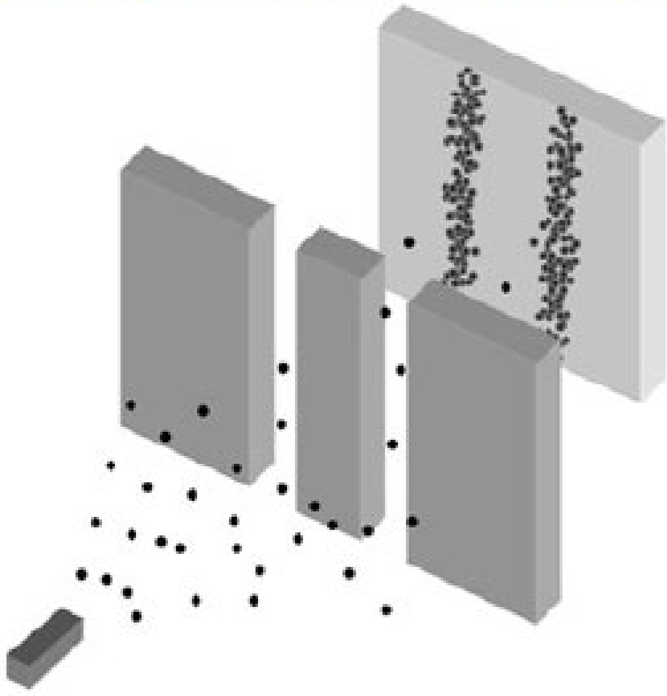
Dispersion Compared to Diffraction

- Notice the order of colors.

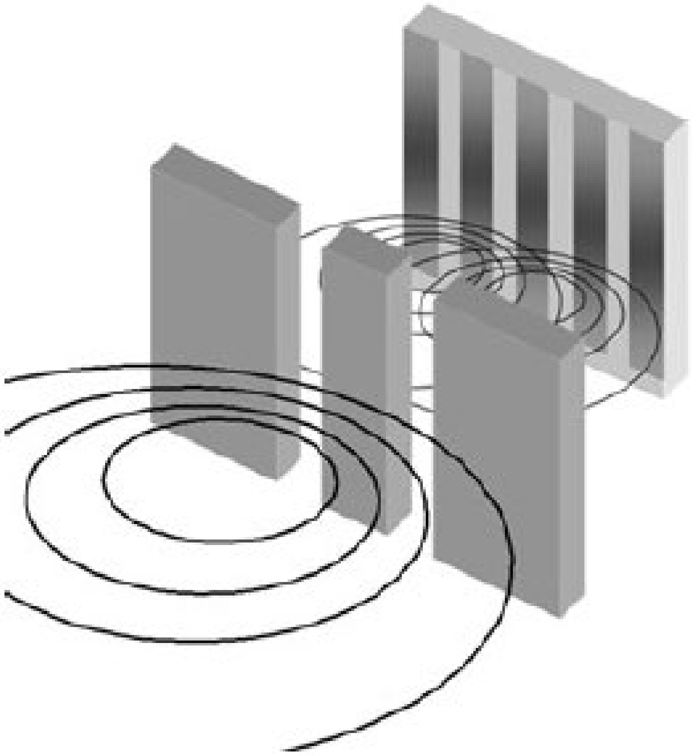




As scientists knew the behaviour of particles and waves through a double slit:



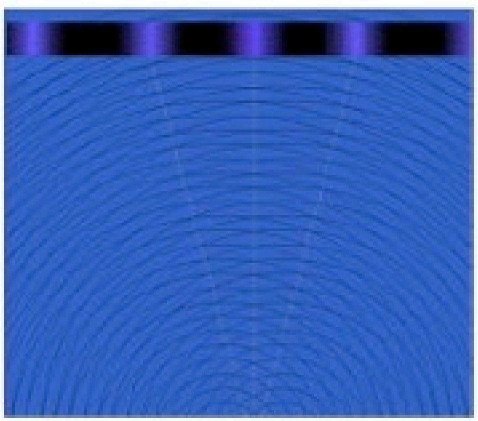
particles



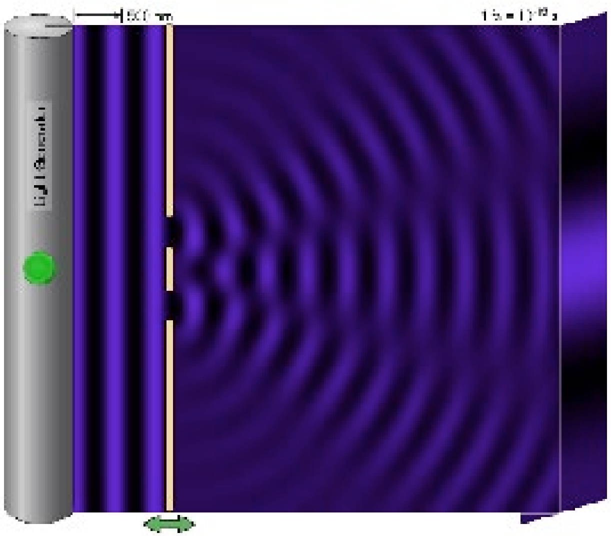
waves

...we can use this rig to test whether EMR is a particle or a wave.

Thomas Young was the first to try this experiment successfully with light. This has become known as the double-slit experiment.



Classic Version

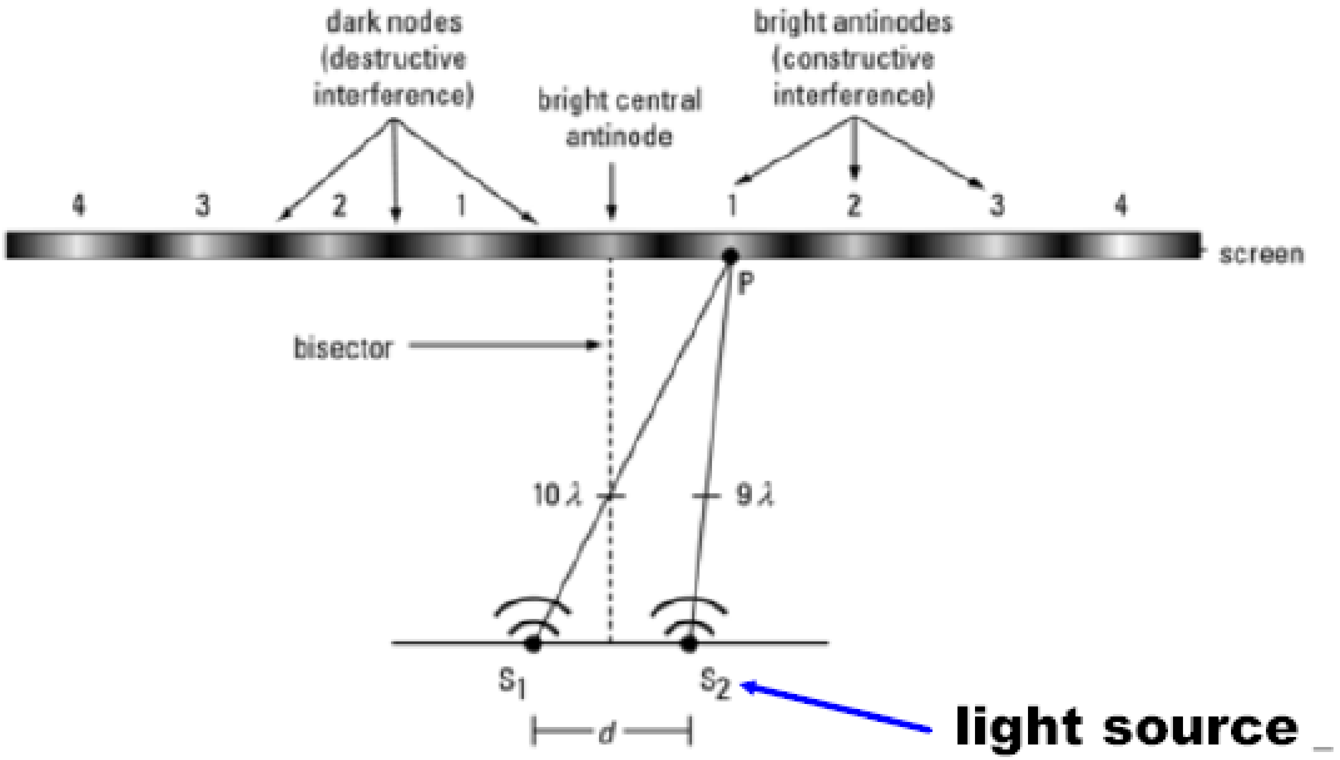


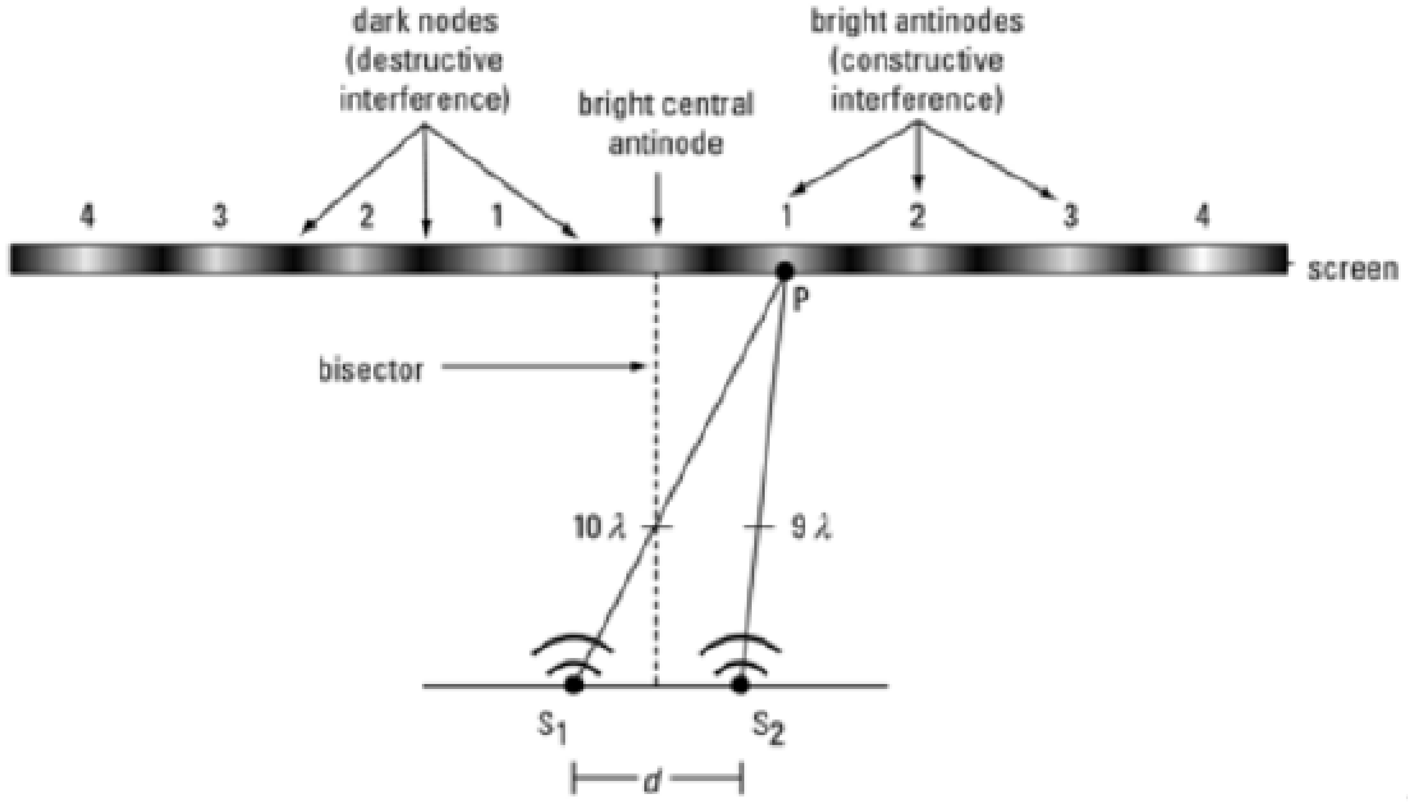
More Modern Version

Double Slit Applet

Veritasium Double Slit Experiment

In the double slit experiment, a source of light is positioned in front of a barrier with two slits, S_1 and S_2. As the light hits these slits, it diffracts and breaks into two wave crests. These crests then interfere, causing areas of constructive interference and areas of destructive interference, on the screen.

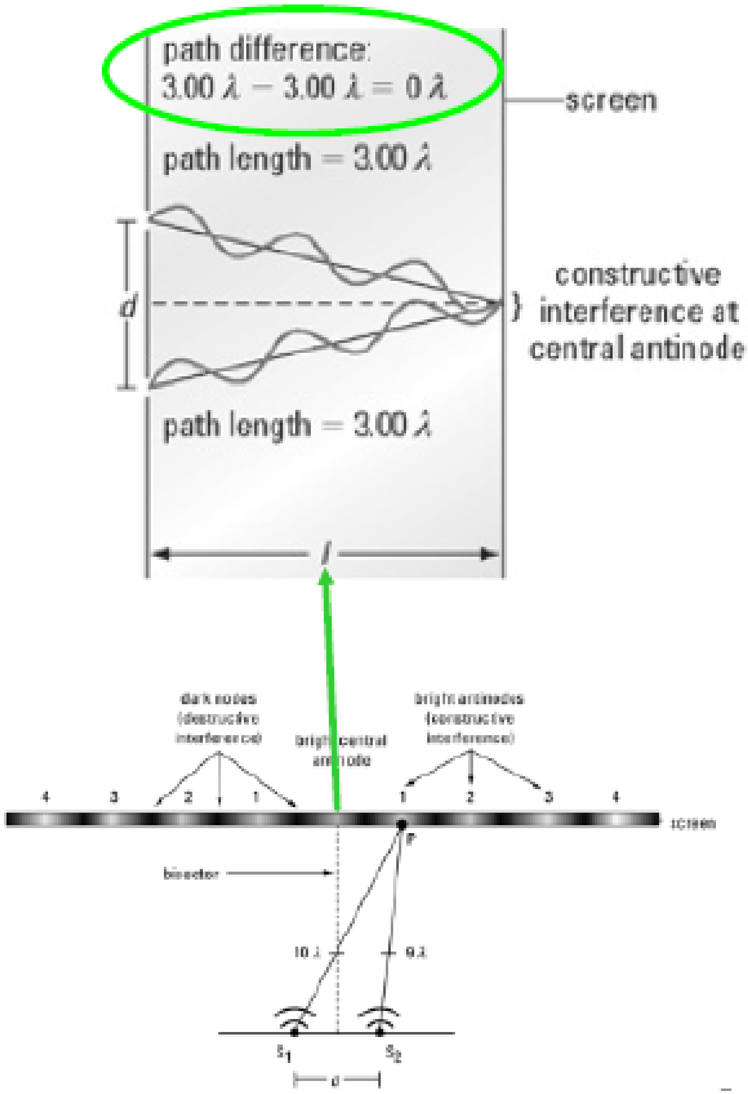




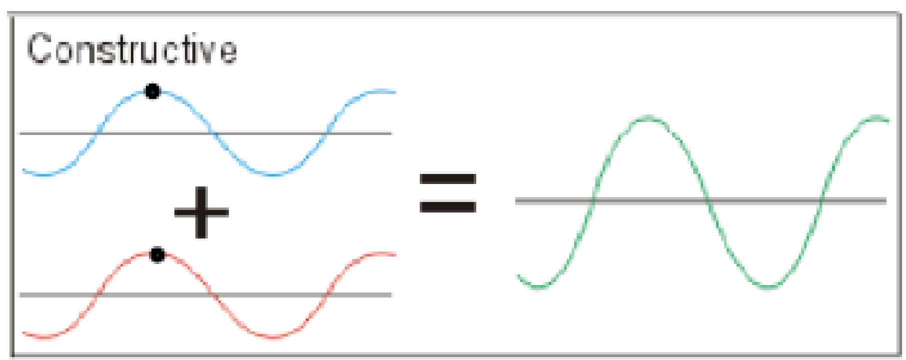
The areas of constructive interference show up as bright spots (called maximums/antinodes).
The areas of destructive interference show up as dark spot (called minimums/nodes).

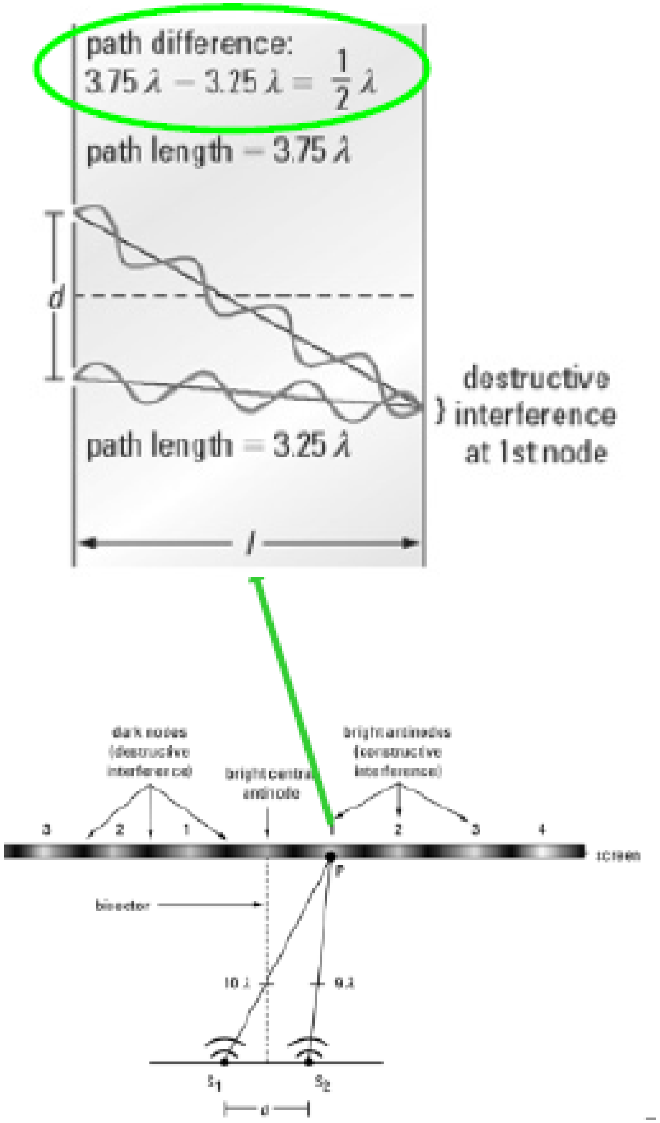
Understanding the Interference Pattern

In order to produce a bright spot (antinode), the waves must constructively interfere with one another. Let's look at one place where this happens:

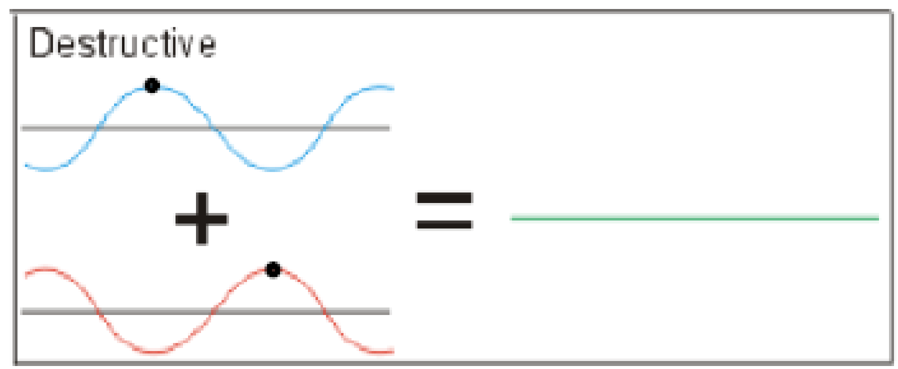


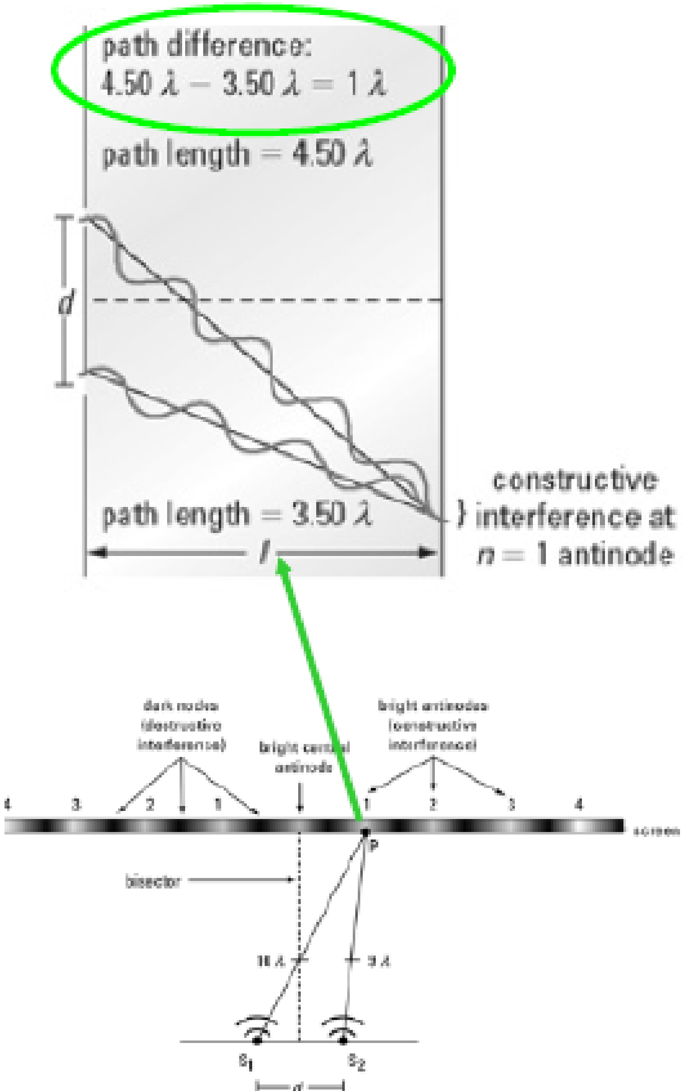
The middle bright spot is called the central antinode. Here, the waves constructively interfere because they have traveled exactly the same distance from each slit.



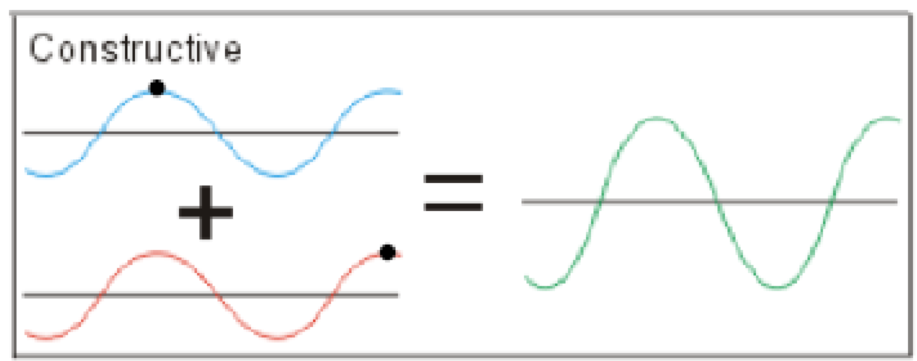


At the first dark spot (node), the waves destructively interfere because they are exactly 1/2 of a wavelength apart.





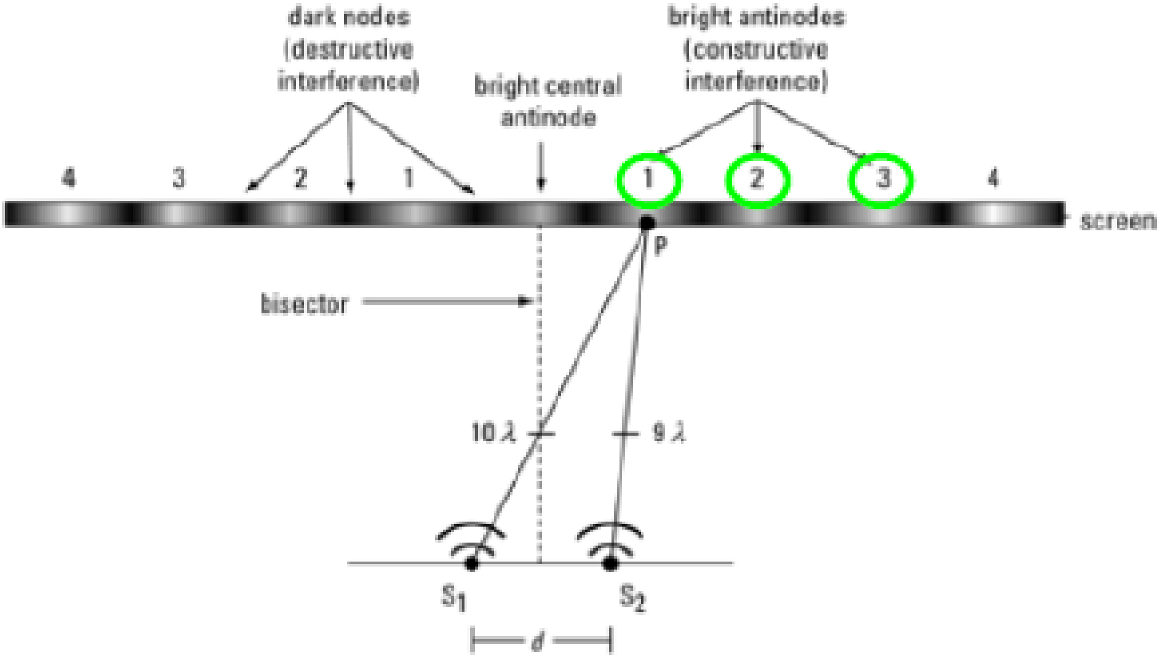
At the first bright spot to the right or left of the central antinode, the waves have a difference of one wavelength, and there is more constructive interference.



Wave Particle Duality and the Double Slit Experiment

Mathematical Description

From the diagram, we see number the antinodes 1, 2, 3, etc in either direction starting from the central antinode.



Diffraction

- **In most practical situations, the angle of diffraction can be difficult to measure because it is small. The equation is used in these situations:**
- **Here, the angle of diffraction is approximated by $\tan\theta = x/L$**
- **This approximation works because for small angles, $\sin\theta \approx \tan\theta$.**

$$\lambda = \frac{dx}{nl}$$

- where
- λ = wavelength
- d = distance between slits
- l = distance from slits to antinode**
- x = distance between fringes

**NOTE: l = distance to central maximum only if $\Theta < 10^\circ$

Example

- 1. Light falls on a pair of slits 1.28×10^{-5} m apart. The maxima are 4.11×10^{-2} m apart and the screen is 1.00 m from the slits. What is the wavelength and color of the light?
- 2. Monochromatic yellow light, wavelength 580nm, shines on a pair of slits. The second dark spot is 21.8cm from the central anti-node on a wall that is 5.00 m away. What is the separation of the slits?

Diffraction Grating

- **A device consisting of transparent glass with opaque scratches placed very close together such that it acts like multiple slits.**
- **The formula for this device is**

$$\lambda = \frac{d \sin\theta}{n}$$

If we measure the **distance, d, between the slits**, we can form two similar triangles.

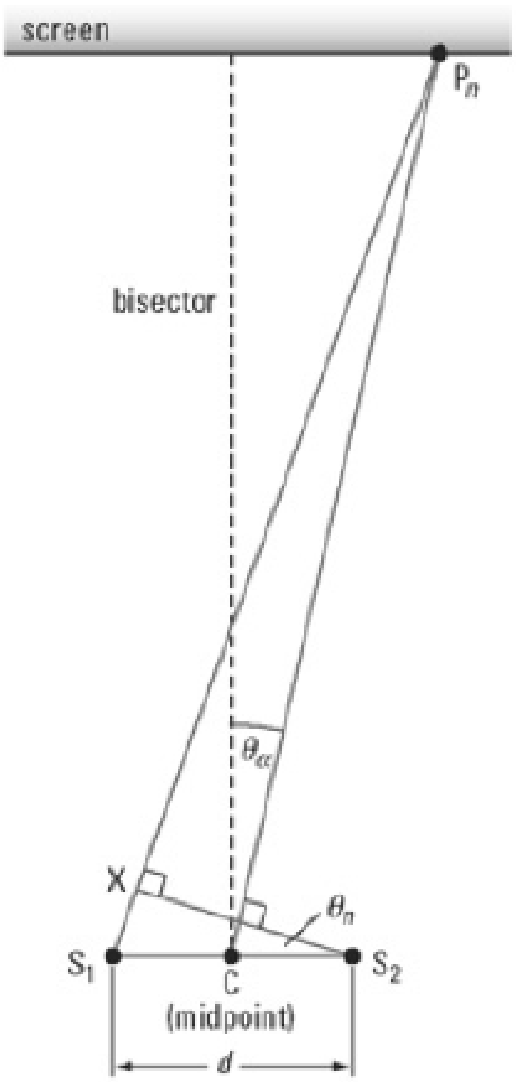
The angle between a perpendicular bisector to the screen and the node is the angle of diffraction.

These values are related by the equation:

$$\sin\theta = \frac{n\lambda}{d}$$

Where:

- θ = angle of diffraction
- λ = wavelength of light
- n = # of the node/antinode
- d = distance b/t slits



▲ **Figure 13.77** When P_n is far away, line S_1P_n is approximately parallel to CP_n, making θ_n and θ_α equal. θ_α is the angle of diffraction.

ex) Calculate the angle of diffraction of the 1 maximum produced by directing light of λ = 410 nm through a diffraction grating in which the slits are 6.00 x 10^{-6} m apart.

Using the Formula

- **When using diffraction gratings, the distance between the slits (d) is not given, rather the density of lines is given (#lines/length).**
- **3. Example: A diffraction grating has 4000 lines/cm. Calculate the distance between adjacent lines (d).**

ex) How many slits per meter does a diffraction grating have if the 2 maximum occurs at an angle of diffraction of 16.0° when light with a wavelength of 530 nm is used?

Examples

- 4. A diffraction grating has 5000 lines/cm and red light (700 nm) passes through it. Find the angle of deviation for the second order maximum (second antinode).
- 5. Find the maximum order number for the above grating. The maximum n corresponds to a turning angle of 90º.

Dark Spots

As discussed earlier, to produce dark spots (nodes), the difference in wavelength must be 1/2. Equations for darks spots (rarely used) are:

$$\sin\theta = \frac{(n - 1/2)\lambda}{d}$$

$$\lambda = \frac{xd}{(n - 1/2)L}$$

- For nodes (dark spots).

Diffraction in Nature

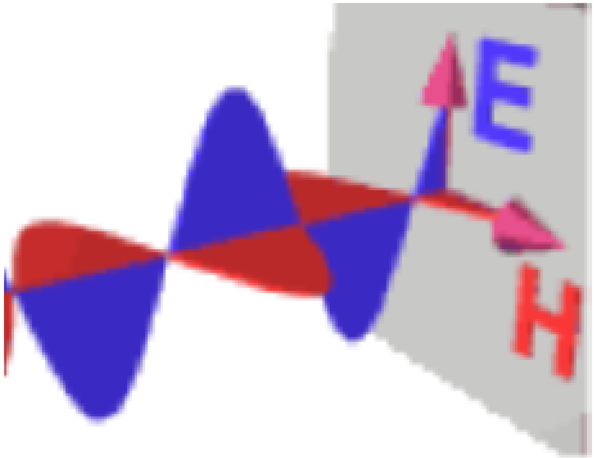
- **When sunlight or moonlight passes through water droplets of nearly uniform size, it is diffracted in a circular pattern.**

"Glory"

Polarization

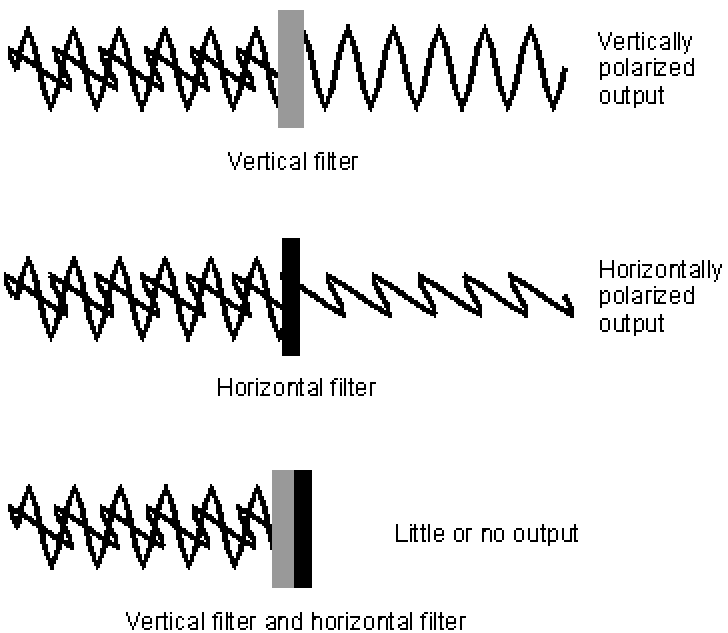
Further evidence that light behaves like a wave comes from the principle of polarization.

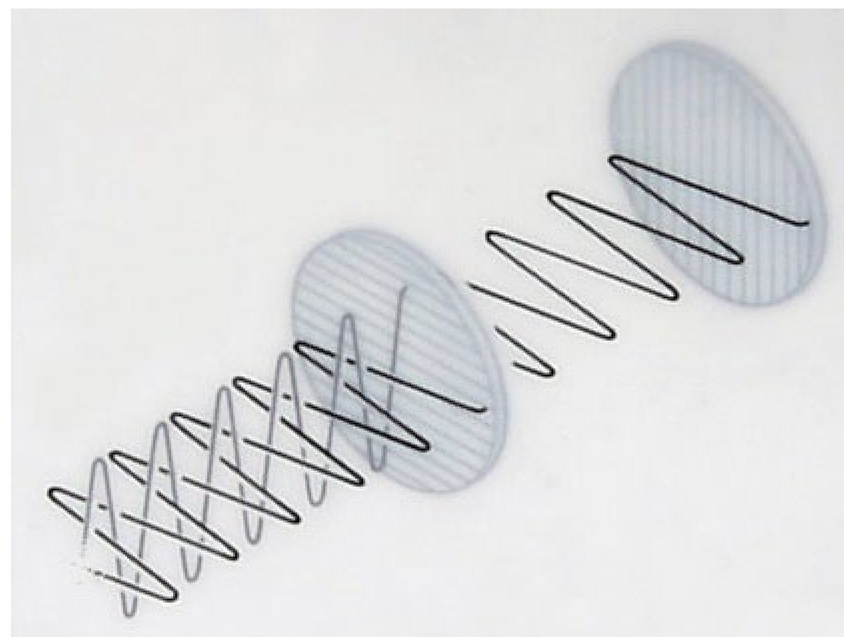
Recall Maxwell said light was made up of perpendicular electric and magnetic waves:



In polarization, we filter out these perpendicular field.

- **Light is said to be polarized if it vibrates in only one plane. Only transverse waves can be polarized.**
- **A polarization disk is nothing more than a barrier with a slit (or series of slits) in it.**





Polarization is often used in sunglasses to filter out some light, making it easier to see on sunny days.

3D Photography with color

- Other 3D pictures offset colors. Usually red and blue.
- http://www.nasa.gov/mission_pages/stereo/news/stereo3D_press.html