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Rapid Learning Center Presents …

Teach Yourself AP Physics in 24 Hours

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Physical Optics

Physics Rapid Learning Series

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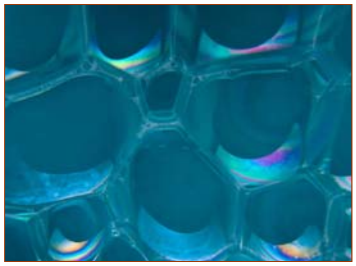
Learning Objectives

By completing this tutorial, you can:



- Describe the electromagnetic spectrum and the nature of light.
- Understand constructive and destructive interference.
- Understand the concept of diffraction and solve related problems.
- Describe the polarization of light.

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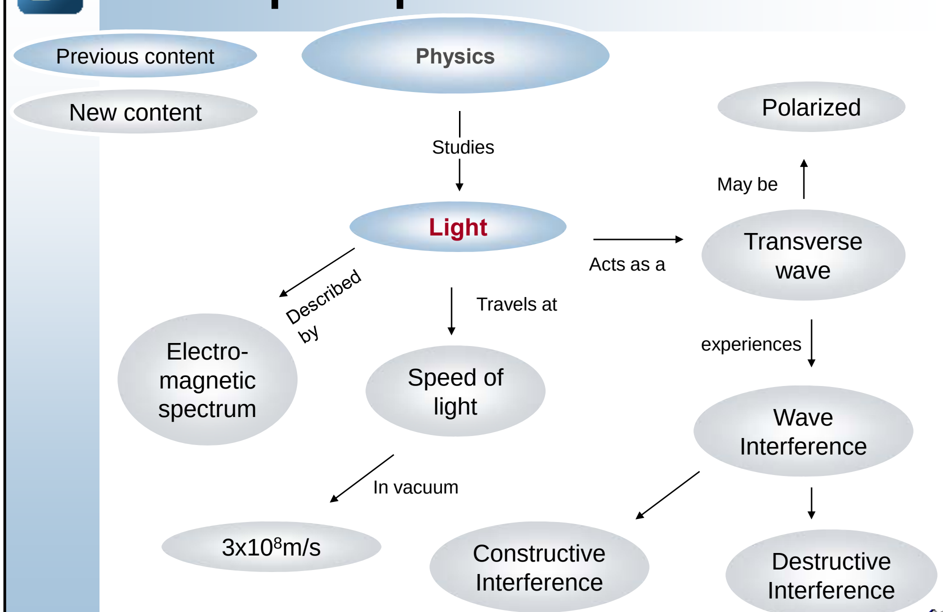
Concept Map



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The Electromagnetic Spectrum

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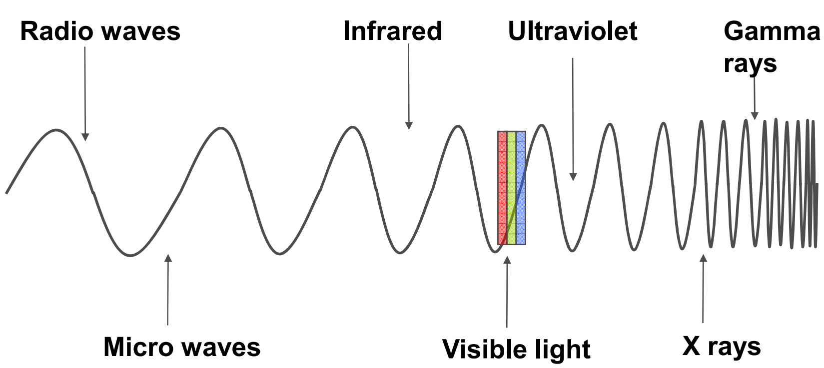
Electromagnetic Spectrum

The electromagnetic spectrum can be considered a catalog or map of all the various frequencies of light.



Obviously our eyes perceive only a small amount of the EM spectrum, visible light.

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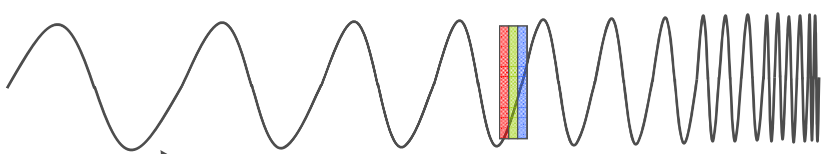
EM Spectrum Observations

Note the highest frequencies/lowest wavelengths are to the right.



Also note the lowest frequencies/highest wavelengths are to the left.

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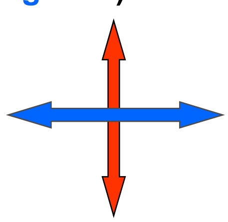
Electromagnetic Waves

An electromagnetic wave is an oscillating combination of a magnetic and an electric field.

It can be visualized as two perpendicular waves (electric and magnetic).



This view shows the light wave coming right at you.

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Speed of Light

In a vacuum, all electromagnetic waves have a velocity of 300,000,000 m/s! ($3x10^8$m/s)

That's 186,000 miles per second!

Later we will see that this speed can vary depending on the medium.

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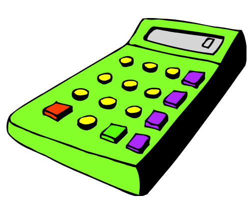
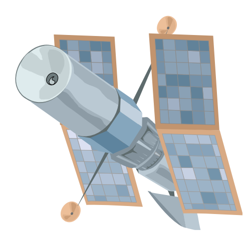
First Calculation of Light Speed

The approximate speed of light was first calculated in 1675 by Danish astronomer Olaus Roemer.

He had no computers, calculators, or other sophisticated instruments...





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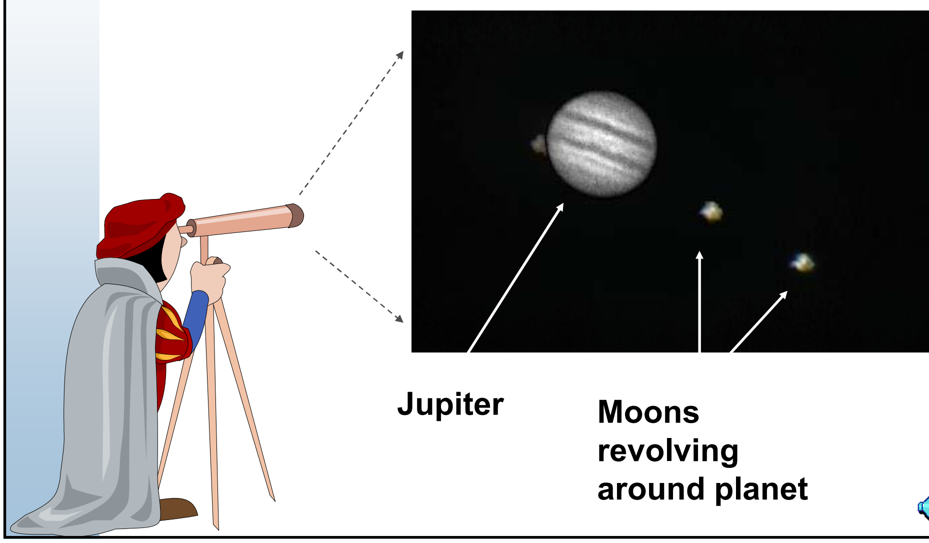
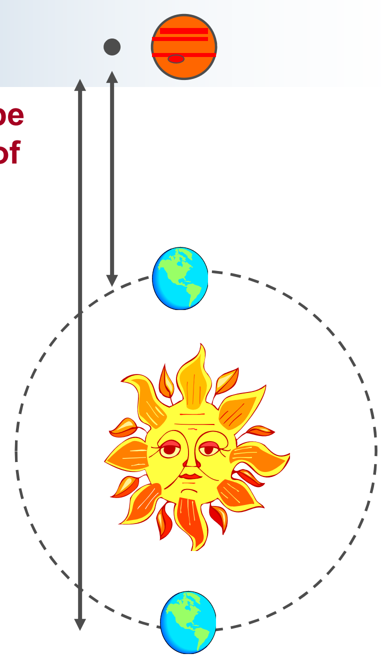
Observations

He used careful telescopic observations of the motions of Jupiter's moons.



Orbital Difference



The Jupiter's moon could be observed from either side of the Earth orbit around the Sun.

This yielded a substantial difference in distance for the light to travel.

Roemer measured a 16.5 minute time difference.

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Calculation of Light Speed

At the time, it was known that the diameter of Earth's orbit was 3 x 10^{11}m.

Roemer used this information, and his time difference, to calculate the speed of light:

$$v = \frac{d}{t} \qquad v = \frac{3x10^{11}m}{990s}$$

16.5 minutes converted into seconds.

$$v = 3.03x10^{8}m/s$$

This is surprisingly accurate for the time period.

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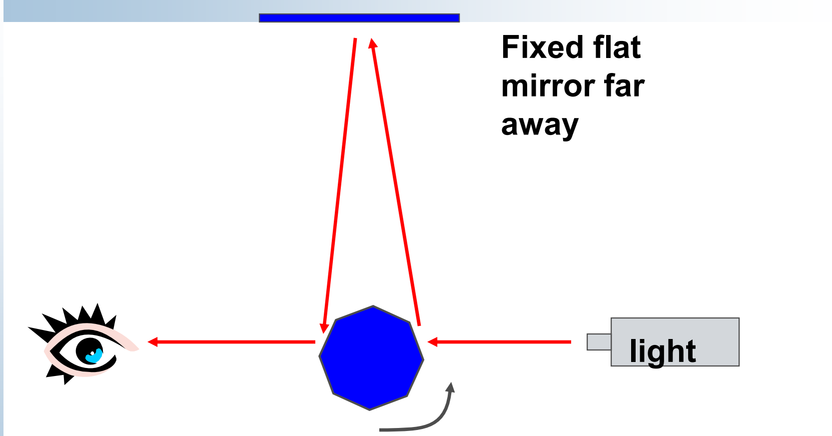
Michelson's Measurement



American physicist Albert Michelson used a rotating mirror with fixed mirror on a distant mountain.

The speed of the mirror was used to "time" the trip that light took to obtain a more accurate value.

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Constructive and Destructive Interference

Waves often superimpose, or interfere with each other when they overlap.

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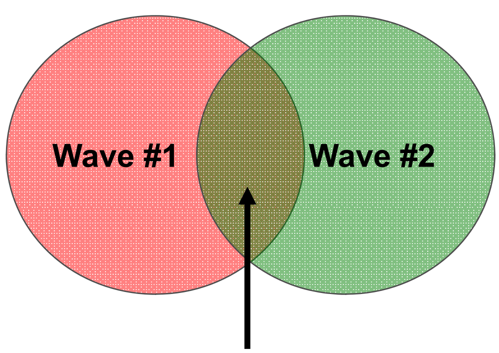
Principle of Superposition

When two or more waves occupy the same region of space simultaneously, the resulting wave disturbance is the sum of separate waves.



Resulting wave due to superposition.

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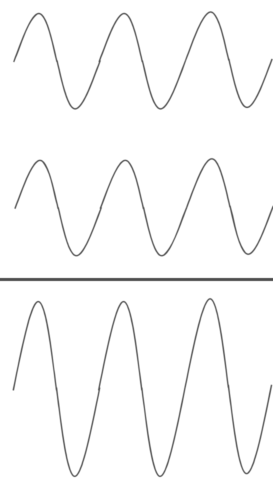
Constructive Interference

When waves overlap or superimpose, they may create a larger amplitude wave as a result.

wave 1

+ wave 2

equals



Notice how the wave crests and troughs line up perfectly.

Greater amplitude wave.

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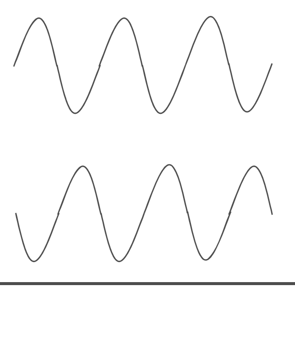
Destructive Interference

When waves overlap or superimpose, they may create a smaller amplitude wave as a result.

wave 1

+ wave 2

equals



Notice how the wave crests and troughs are perfectly out of phase.

A zero amplitude wave.

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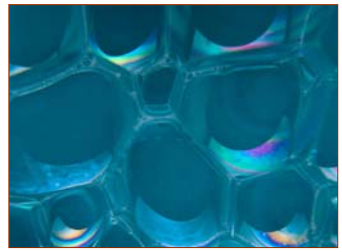
Thin Film Interference

Soap bubbles and thin films of gasoline or oil often produce pretty colored patterns.



This results from some light penetrating the film, then reflecting backwards.

This light interferes with light reflecting off the surface and creates certain colors depending on the thickness of the film.

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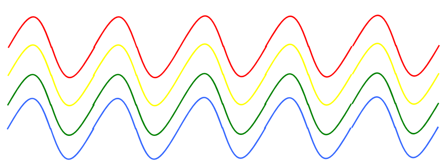
Coherent Light

Light waves that are all in phase, or in step with each other, are called coherent.



This basically means that the waves don't shift with respect to each other as time passes.

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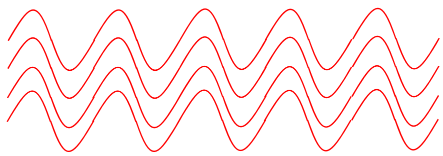
Monochromatic Light

Light waves that have all the same frequency/ wavelength/color are called monochromatic.

Laser light is both monochromatic and coherent.



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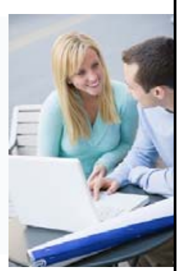
Diffraction



Diffraction is the bending of waves around obstacles, corners, or openings.

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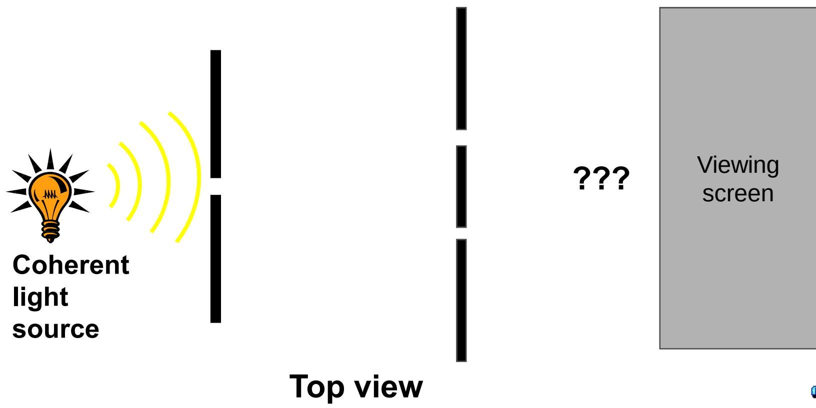
Young's Double Slit Experiment

In 1801 Thomas Young was the first person to measure the wavelength of light.

He sent light originating from one location incident upon a pair of slits in a barrier and observed.



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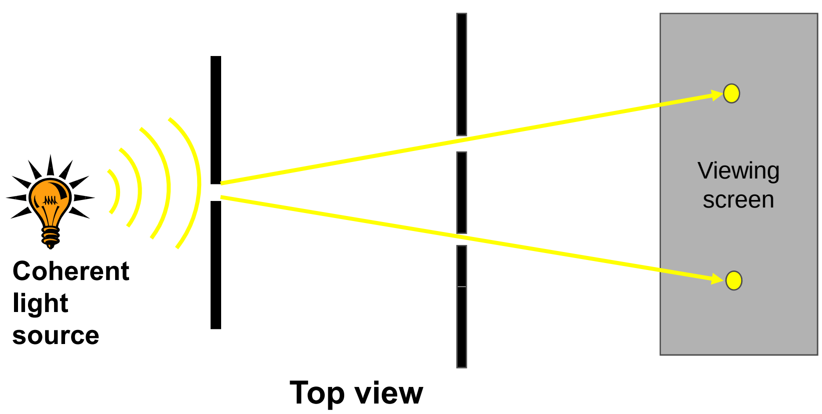
Particle Result

If light had behaved like a particle, two spots of light on the screen would have been observed.



However, in this experiment, this did not happen. In this case, light behaves like a wave!

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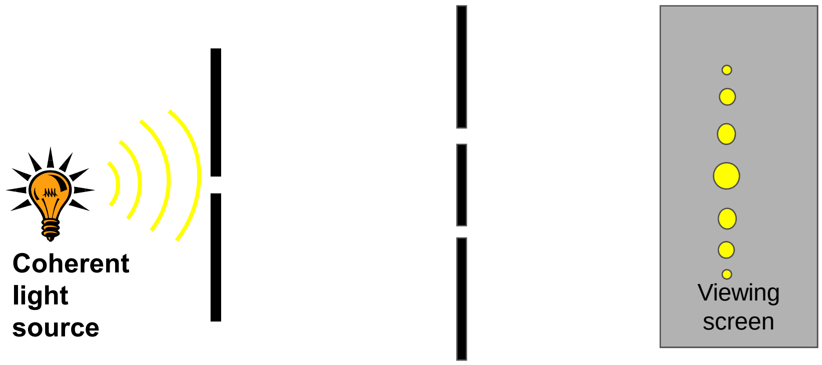
Wave Result

Instead, alternating spots of brightness and darkness occur. This is quite strange!



Top view

An explanation of this depends on the wave behavior of light.

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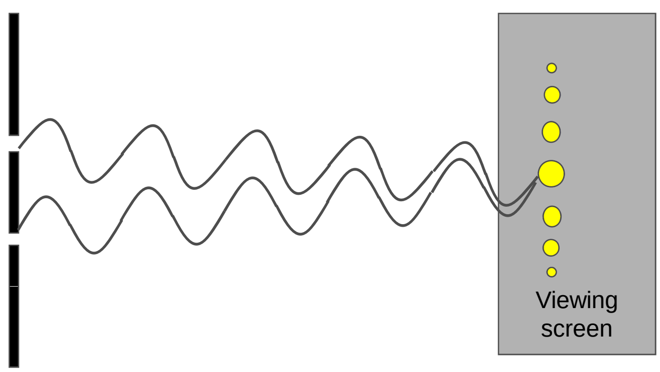
Constructive Interference Spot

A set of light waves each goes through an open slit.



When there are bright spots, the two waves arrive in phase, and constructively interfere, giving a bright central spot.

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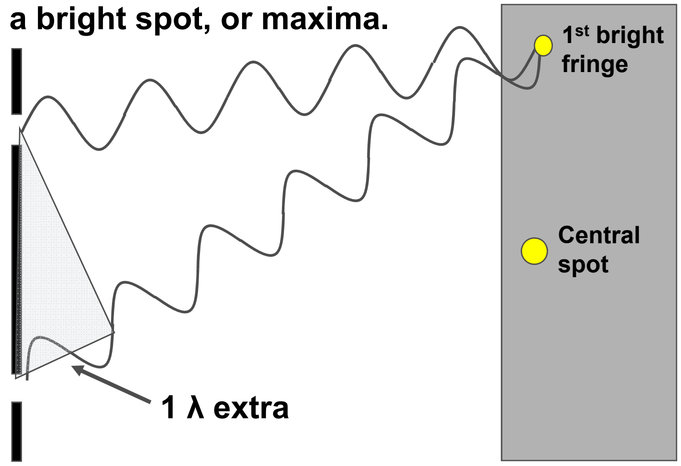
Different Path Lengths

Even if the two sets of wave have different distances to travel, they can still constructively interfere to produce a bright spot, or maxima.

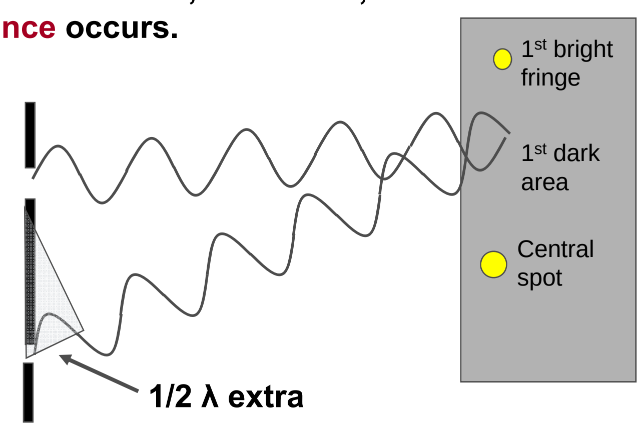


In these spots, the path difference between the two waves is a whole value of wavelength, λ.

27/50

Different Path Lengths Again

For area of darkness, or minima, destructive interference occurs.



In these spots, the path difference between the two waves is a half value of wavelength, λ/2.

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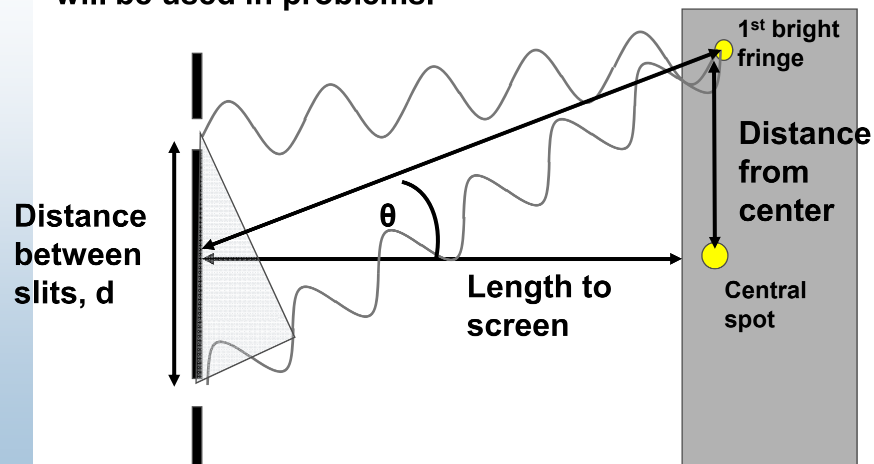
Relevant Variables

Diagramed below are the relevant quantities that will be used in problems.



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Bright Spot Formula

The following formula describes the bright fringes created by constructive interference.

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

- Integer m=0,1,2,3…
- Wavelength, m
- Angle between bright spot and central spot
- Distance between slits, m

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Dark Spot Formula

The following formula describes the dark areas created by destructive interference.

Integer m=0,1,2,3…

Wavelength, m

$$\sin\theta = (m + 1/2)\frac{\lambda}{d}$$

Angle between dark spot and central spot

Distance between slits, m

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Double Slit Example Problem

The second dark area in an interference pattern is noticed to be 2° away from the central bright spot. The slits are $5\text{x}10^{-5}$ m apart. What is the wavelength of the coherent light used?

Use our formula for destructive interference fringes.

$$\sin\theta = (m + 1/2)\frac{\lambda}{d}$$

In this case, since the second dark area is being used, m = 2.

32/50

Double Slit Solution

$$\sin\theta = (m + 1/2)\frac{\lambda}{d} \Rightarrow \frac{d\sin\theta}{(m+1/2)} = \lambda$$

$$\lambda = \frac{5x10^{-5}\,m\,\sin(2^\circ)}{(2 + 1/2)}$$

$$\lambda = 7x10^{-7}\,m$$

Calculate carefully. Be sure to use the correct order of operations. Use degrees for angular units.

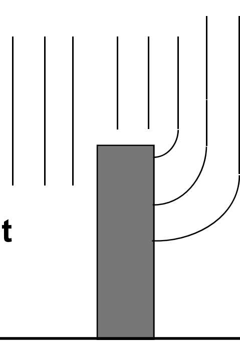
33/50

Diffraction

Diffraction also occurs in places other than a double slit experiment.

If you yell to someone in another room that isn't in a direct path, they still hear you. Your sound waves diffract around the doorways.

Wave front



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Diffraction Gratings

Diffraction also occurs for multiple small openings.

The same formula applies as with Young's double slit experiment.

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

In this case, d is the distance between in individual gratings, or slits.

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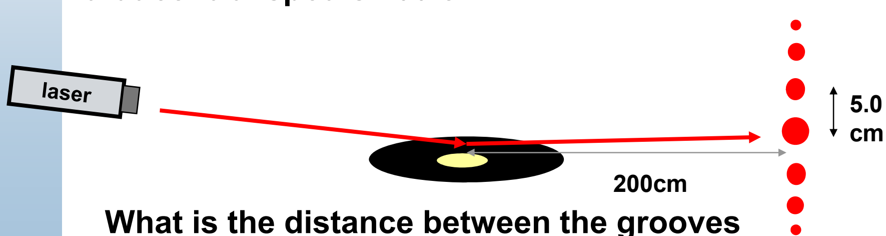
Diffraction Grating Problem

A 570 nm wavelength laser beam is aimed at a vinyl record. The tiny grooves act like a diffraction grating and produce a pattern.

The first maxima is 5.0 cm away from the central spot. The distance from the record to that central spot is 200 cm.



What is the distance between the grooves on the vinyl record?

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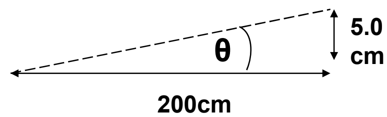
Diffraction Grating Solution

First, find the angle between the central spot and the first fringe.



$$\tan\theta = \frac{opp}{adj}$$

$$\tan\theta = \frac{5.0cm}{200cm} = .025 \qquad \tan^{-1}(.025) = 1.4^\circ$$

Now use this value in our maxima/bright fringe formula.

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

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Diffraction Solution Continued

$$\sin\theta = m\frac{\lambda}{d} \Rightarrow d = m\frac{\lambda}{\sin\theta}$$

In this case, since we're using the first bright fringe, m=1.

The wavelength of 570 nm should be converted.

$$570nm \text{ x } \frac{1m}{1x10^{9}nm} = 570x10^{-9}m$$

$$d = 1\frac{570\,x10^{-9}m}{\sin(1.4^\circ)} \qquad d = 2.3x10^{-5}m$$

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Polarization of Light

Because light is a transverse wave, it can vibrate in a variety of directions compared to its direction of motion.

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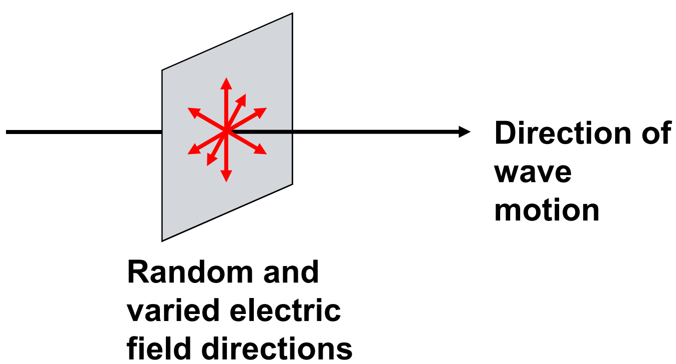
Unpolarized Light

In unpolarized light, the fluctuations in the electric field occur in all directions. It's random.



Most of the light we see is unpolarized.

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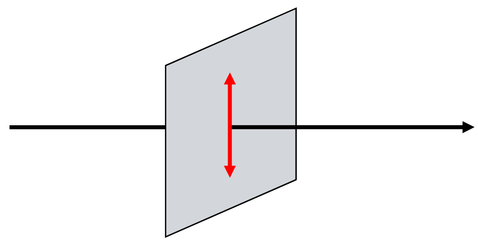
Polarized Light

Because light is a transverse wave, it can be polarized. Longitudinal waves cannot be polarized.

In polarized light, the electric field oscillates in only one direction.



Direction of wave motion

Field varies in only one direction

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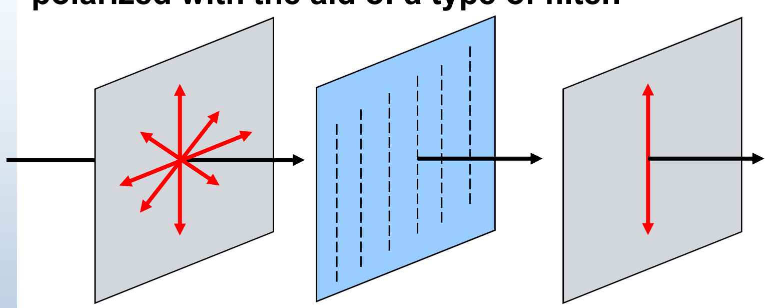
Polarizers

Unpolarized, random light can be made to be polarized with the aid of a type of filter.



Unpolarized light | **Polarizing filter** | **Polarized light**

The polarizing filter acts like a grate or strain that allows only one direction of motion.

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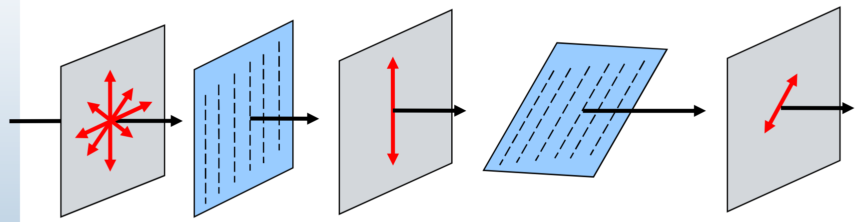
Pairs of Polarizers

A pair of polarizers can be used to precisely adjust the intensity of a light source.



The end result is polarized light of a particular reduced intensity.

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Intensity Adjusting Polarizers

With the pair of polarizing filters at a 0 degree angle with each other, a maximum amount of light emerges.

With the pair of polarizing filters at a 90 degree angle with each other, a minimum amount of light emerges, virtually 0 intensity.

By adjusting the angle between the direction of the two filters, the intensity of the light can be controlled.

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Malus' Law

Malus' law describes how the angle between a pair of polarizers affects the average intensity, or strength, of the light.

Reduced average intensity of light, W/m^2

$$\overline{S} = \overline{S}_o \cos^2\theta$$

Original average intensity of light, W/m^2

Angle between the two polarizing filter axes

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Malus' Law Example

If two polarizing filters were to be used to cut the intensity of light to ½ of its original value, how should they be arranged?

We'll be using Malus' law, but we won't be finding the reduced intensity, that's given in the problem.

$$\overline{S} = \overline{S}_o \cos^2\theta$$

Instead we'll be finding the angle that achieves that reduced intensity.

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Malus' Law Solution

$$\bar{S} = \bar{S}_o \cos^2\theta \quad \Rightarrow \quad \frac{\bar{S}}{\bar{S}_o} = \cos^2\theta$$

$$\sqrt{\frac{\bar{S}}{\bar{S}_o}} = \cos\theta \quad \Rightarrow \quad \cos^{-1}\sqrt{\frac{\bar{S}}{\bar{S}_o}} = \theta$$

$$\theta = \cos^{-1}\sqrt{\frac{\bar{S}}{\bar{S}_o}} = \cos^{-1}\sqrt{\frac{1/2}{1}} = \cos^{-1}\sqrt{.5} = 45^\circ$$

This should seem reasonable since it's the angle that is halfway between maximum and minimum transmission.

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Learning Summary

$\sin\theta = m\frac{\lambda}{d}$ maxima

$\sin\theta = (m + 1/2)\frac{\lambda}{d}$ minima

The electromagnetic, EM, spectrum displays all types of light.

Polarized light oscillates in only one direction.

In constructive interference, a wave of larger amplitude is created by adding waves.

In destructive interference, a wave of smaller amplitude is created by adding waves.

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Congratulations

You have successfully completed the tutorial

Physical Optics

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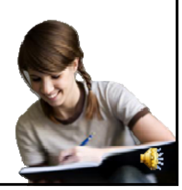
What's Next …

Step 1: Concepts – Core Tutorial (Just Completed)

→ **Step 2: Practice – Interactive Problem Drill**

Step 3: Recap – Super Review Cheat Sheet

Go for it!



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