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# Electromagnetic Waves

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# Table of Contents

*Click on the topic to go to that section*

# An Abridged "History" of Light

Return to Table of Contents

# An Abridged "History" of Light

In 1704, Sir Isaac Newton published "Opticks," which described light as a group of tiny particles that he called corpuscles.

However, certain properties of light, such as diffraction - the bending of light around objects - was better described by thinking of light as a wave.  This theory is credited to Christiaan Huygens with work done by Robert Hooke and Leonhard Euler.

In 1803, Thomas Young's Double Slit Experiment definitively proved that light acted as a wave.

Maxwell then published his four equations of electromagnetism in 1861 where he treated light as a wave.

then came relativity and quantum mechanics......

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# An Abridged "History" of Light

The first dispute with the wave nature of light came in 1900 with Max Planck's explanation of Black Body Radiation where it appeared that light was emitted only in quantized bits of energy - like a particle.

In 1905, Albert Einstein published a paper on the photoelectric effect (for which he later earned his Nobel Prize) which confirmed that light came in discrete packets of energy.

These packets of light energy were named photons by Gilbert Lewis in 1926.

So, light was explained in the classical physics as a wave, and the new field of quantum physics brought back Newton's idea of as a particle.

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# An Abridged "History" of Light

The final word (for now) came with the correct use of relativity and quantum theory that deals with the interaction of electrons with photons.

This branch of physics is called Quantum Electrodynamics and in 1965, Sin-Itiro Tomonaga, Julian Schwinger and Richard Feynamn received the Nobel Prize for this work. Here are Feynman's words on light from his book, QED, the strange theory of light and matter:

"I want to emphasize that light comes in this form - particles. It is very important to know that light behaves like particles, especially for those of you have gone to school, where you were probably told something about light behaving like waves. I'm ...ng you the way it does behave - like particles."

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# An Abridged "History" of Light

You should have a feel now for how light has been the subject of much experimentation and dispute.  Even now, people talk about the "wave-particle" duality of light (and as you go on in physics, you will see a similar behavior of elementary particles such as electrons).

A good way to think about this is that the actual world we observe, with our senses and instruments, is way more complex and it is difficult for us to explain what is really going on.

But, for now, we will start with Newton and his corpuscle theory of light and see how it explains refraction and reflection of light.

1 The original wave theory of light is attributed to:

- A Christian Huygens
- B Isaac Newton
- C Max Planck
- D Albert Einstein

Answer

2 The original particle theory of light is attributed to:

- A Christian Huygens
- B Isaac Newton
- C Max Planck
- D Albert Einstein

Answer

3 The interaction of light with matter (such as electrons) is explained by which theory?

- A Law of Gravitation
- B Coulomb's Law
- C Special Relativity
- D Quantum Electrodynamics

Answer

http://njc.tl/iu

# Reflection, Refraction and Dispersion of Light

Return to Table of Contents

# Isaac Newton's Opticks

Light is made up of tiny particles called corpuscles.

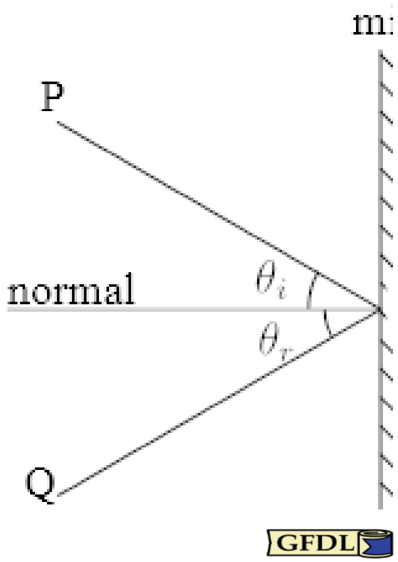
Light is reflected by some surfaces, and the angle of return equals the angle of incidence.

Light can be refracted - bent - as it passes from one medium to another.

White light can be separated by a prism into many colors. But each specific color cannot be separated.

All of these properties are explained nicely by the particle theory of light.

# Reflection




Light originating from Point P is incident on the vertical surface, m, and reflects with the same angle as the incident angle.


The Matterhorn reflected in a lake.

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# Refraction

When light transits from one media to another (air to water), the light bends.

GFDL

Stick in a glass of air.

Stick in glass half filled with water.

The first two pictures superimposed. The image under water is shifted.

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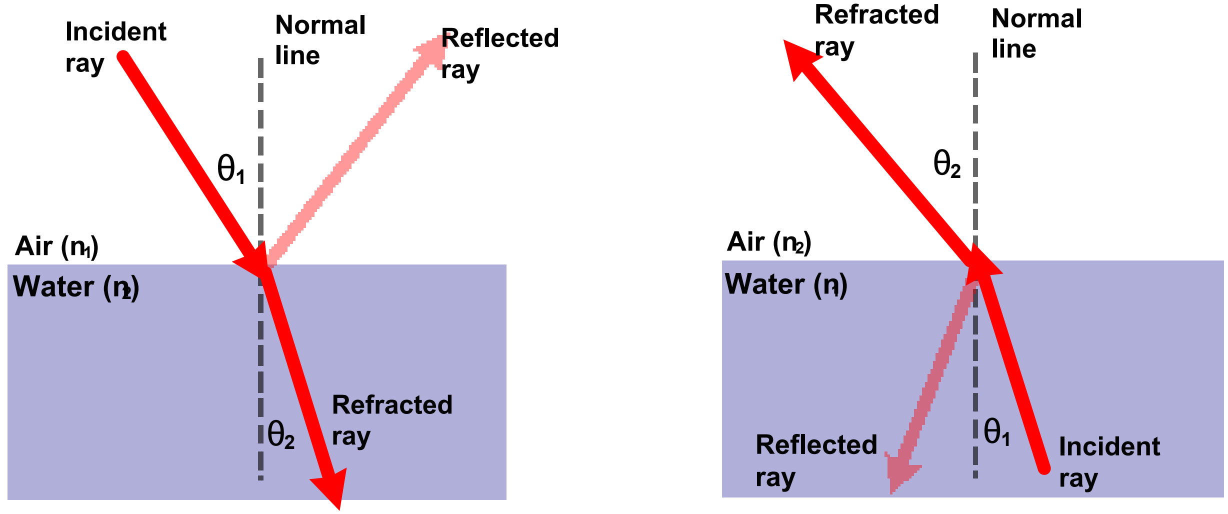
# Refraction

Some light is reflected at the interface between two different media. Some is refracted and the angle the refracted ray makes with the normal is called the angle of refraction.




n is the Index of Refraction and will be discussed next.

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# Index of Refraction

The Index of Refraction, n, is a measure of how the speed and the wavelength of light changes when it passes from one medium to another.  The frequency of the light wave stays constant.

The frequency needs to stay constant so that the waves do not pile up at the interface between the two media.

The Index of Refraction is defined as the ratio of the speed of light in a vacuum (c) to the speed of light in the medium (v).

$$n = \frac{c}{v}$$

# Index of Refraction

Given that the frequency of a light wave ( $f$) is a ratio of its speed to its wavelength ($\lambda$), we have:

$$f = \frac{c}{\lambda}$$

In a medium where the speed of light is $v_1$ and the wavelength is $\lambda_1$:

$$f = \frac{v_1}{\lambda_1}$$

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# Index of Refraction

Dividing these equations by each other, and recognizing that the frequency stays constant, we obtain:

$$\frac{c}{v_1} = \frac{\lambda}{\lambda_1}$$

The left term is the index of refraction of the medium, so we have:

$$n_1 = \frac{\lambda}{\lambda_1}$$

# Index of Refraction Summary

The frequency of the light ray stays constant in all media.

The effective speed of light in a medium other than the vacuum is slower than the vacuum speed to the absorption and reemission of the light by the molecules in the medium.

In materials other than a vacuum, the wavelength of the light ray increases.

The Index of Refraction is equal to 1 in a vacuum, and is always greater than 1 in other media.

As light enters a new medium, it will bend towards the normal to the surface in the medium with a higher Index of Refraction.

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# Indices of Refraction

Here are some sample Indices of Refraction. As n increases, the speed of light in that medium decreases and the wavelength increases.

The Index of Refraction also depends on the wavelength of the incident light - and that contributes to the separation of colors in a prism.

| Indices of Refraction ($\lambda$ = 589 nm) | |
|---|---|
| **Medium** | **N = c / v** |
| Vacuum | 1.0000 |
| Air (at STP) | 1.0003 |
| Water | 1.33 |
| Ethyl alcohol | 1.36 |
| Glass | |
| Fused quartz | 1.46 |
| Crown glass | 1.52 |
| Light flint | 1.58 |
| Lucite or Plexiglas | 1.51 |
| Sodium chloride | 1.53 |
| Diamond | 2.42 |

4 Light travels fastest:

- A In a vacuum.
- B Through water.
- C Through glass.
- D Through diamond.

Indices of Refraction
($\lambda$ = 589 nm)

| **Medium** | **N = c / v** |
|---|---|
| Vacuum | 1.0000 |
| Air (at STP) | 1.0003 |
| Water | 1.33 |
| Ethyl alcohol | 1.36 |
| Glass | |
| Fused quartz | 1.46 |
| Crown glass | 1.52 |
| Light flint | 1.58 |
| Lucite or Plexiglas | 1.51 |
| Sodium chloride | 1.53 |
| Diamond | 2.42 |

Answer

http://njc.tl/iw

5 For all transparent materials, the index of refraction is:

- A less than 1.
- B greater than 1.
- C equal to 1.
- D depends on the material density.

Answer

6 The Index of Refraction of diamond is 2.42. This means that light travels:

- A 2.42 times faster in air than it does in diamond.
- B 2.42 times faster in diamond than it does in air.
- C 2.42 times faster in the vacuum than it does in diamond.
- D 2.42 times faster in diamond than it does in the vacuum.

Answer

http://njc.tl/iy

7 Given that the speed of light in a vacuum is $3x10^8$ m/s and n=1.33 for water; what is the speed of light in water?

Answer

8 The speed of light in an unknown medium is .99 x $10^8$ m/s. The speed of light in the vacuum is 3 x $10^8$ m/s. What is the medium?

| Indices of Refraction ($\lambda$ = 589 nm) | |
|---|---|
| **Medium** | **N = c / v** |
| Vacuum | 1.0000 |
| Air (at STP) | 1.0003 |
| Water | 1.33 |
| Ethyl alcohol | 1.36 |
| Glass | |
| Fused quartz | 1.46 |
| Crown glass | 1.52 |
| Light flint | 1.58 |
| Lucite or Plexiglas | 1.51 |
| Sodium chloride | 1.53 |
| Diamond | 2.42 |

Answer

9 When a light ray enters into a medium with a different Index of Refraction,

- A its speed and frequency change.
- B its speed and wavelength change.
- C its frequency and wavelength change.
- D its speed, frequency and wavelength change.

Answer

# Fermat's Principle of Least Time

Refraction was explained earlier by assuming the frequency of the light ray had to stay constant at the media interfaces - and this led to the statement that the wavelength increased and the speed of the light ray decreased in a medium with a higher Index of Refraction.

The way the ray bends can be understood by using Fermat's Principle of Least Time, which states that light follows a path through different media that takes the least time.

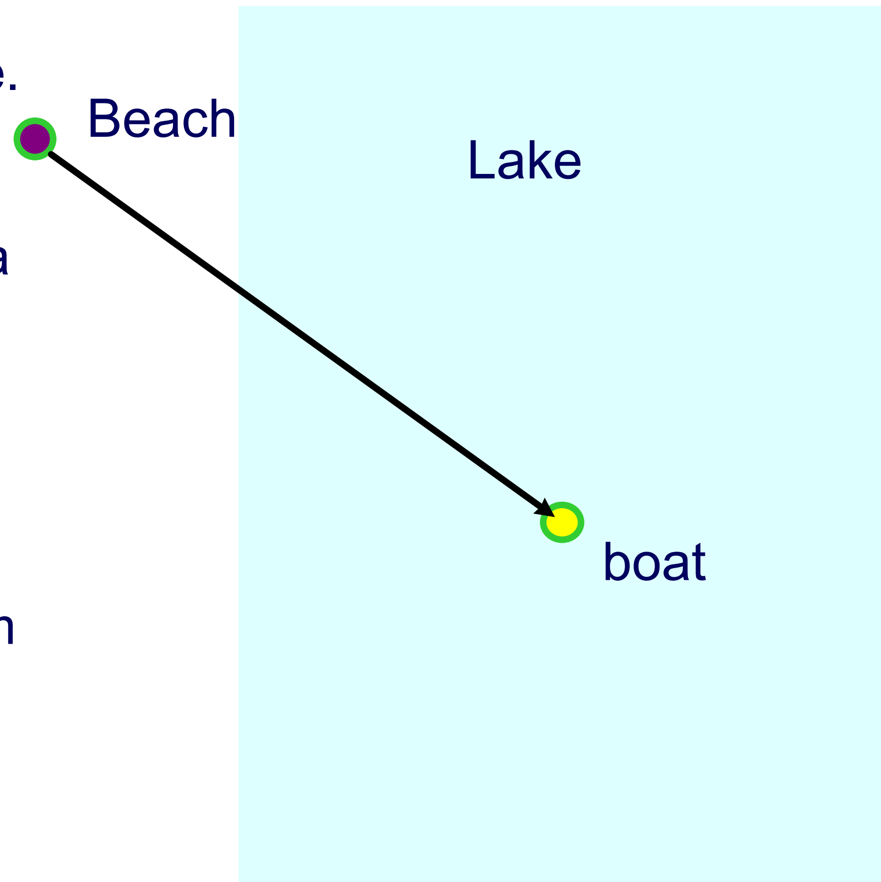
This principle is based upon Huygen's wave theory of light (which will be covered in the next section), and even though it was postulated in 1662, a similar formalism was used in the Quantum Electrodynamics description of light and matter in the 20th century.

# Fermat's Principle of Least Time

Let's use a run/swim analogy to illustrate Fermat's Principle.

Assume you can run a mile in 10 minutes and can swim a mile in 30 minutes. This is analogous to a light ray passing from a vacuum into glass.

What path would get you from the beach to the boat in the shortest time?

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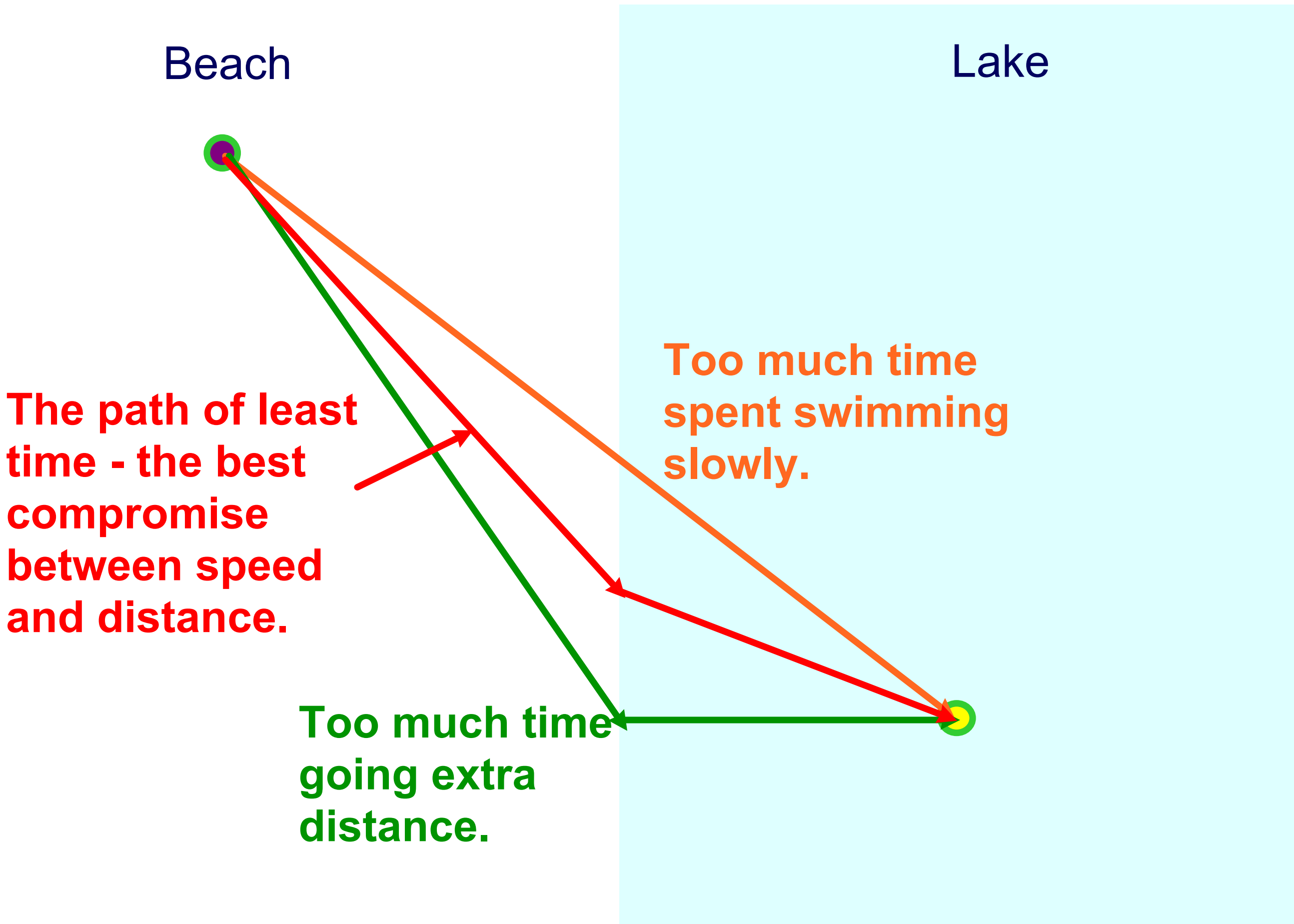
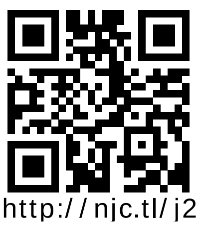
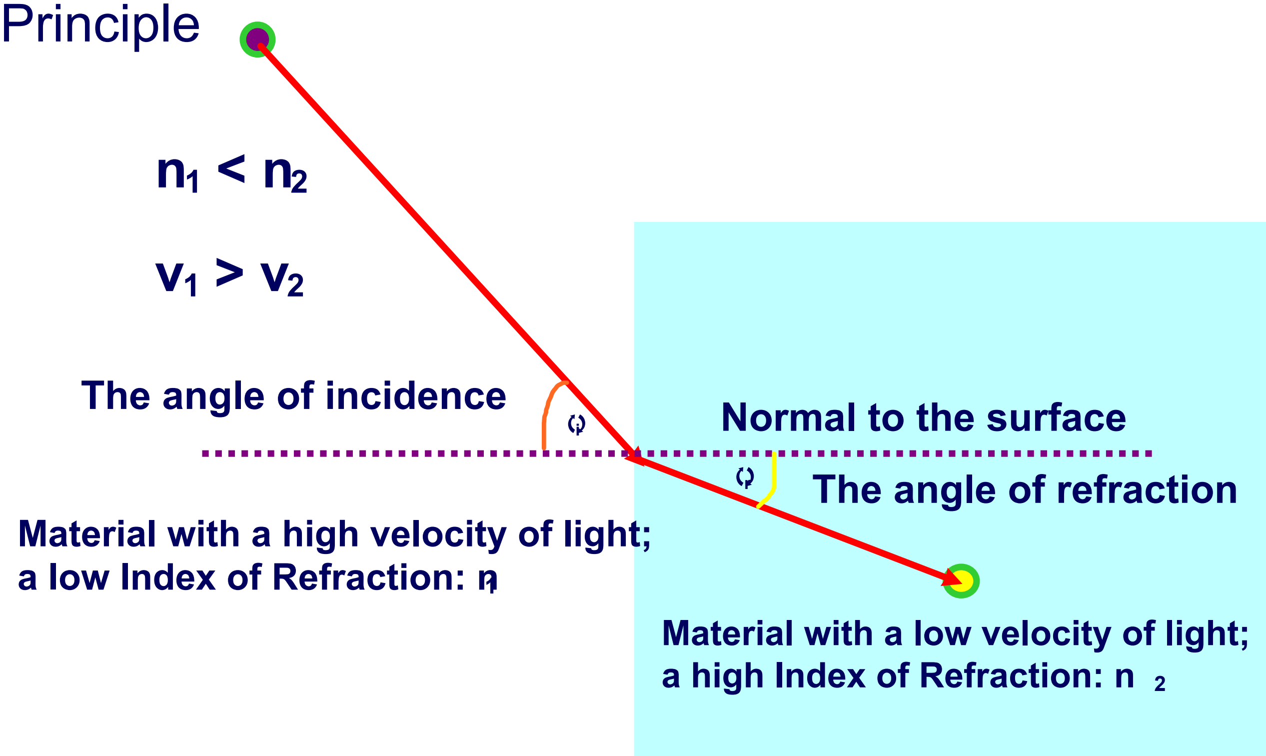
# Fermat's Principle of Least Time



# Fermat's Principle of Least Time

Here is how light behaves when it goes from a medium where the velocity of light is greater than in the second medium. Note how only the red line from the previous slide remains - this is the path of light that Fermat's Principle explains.



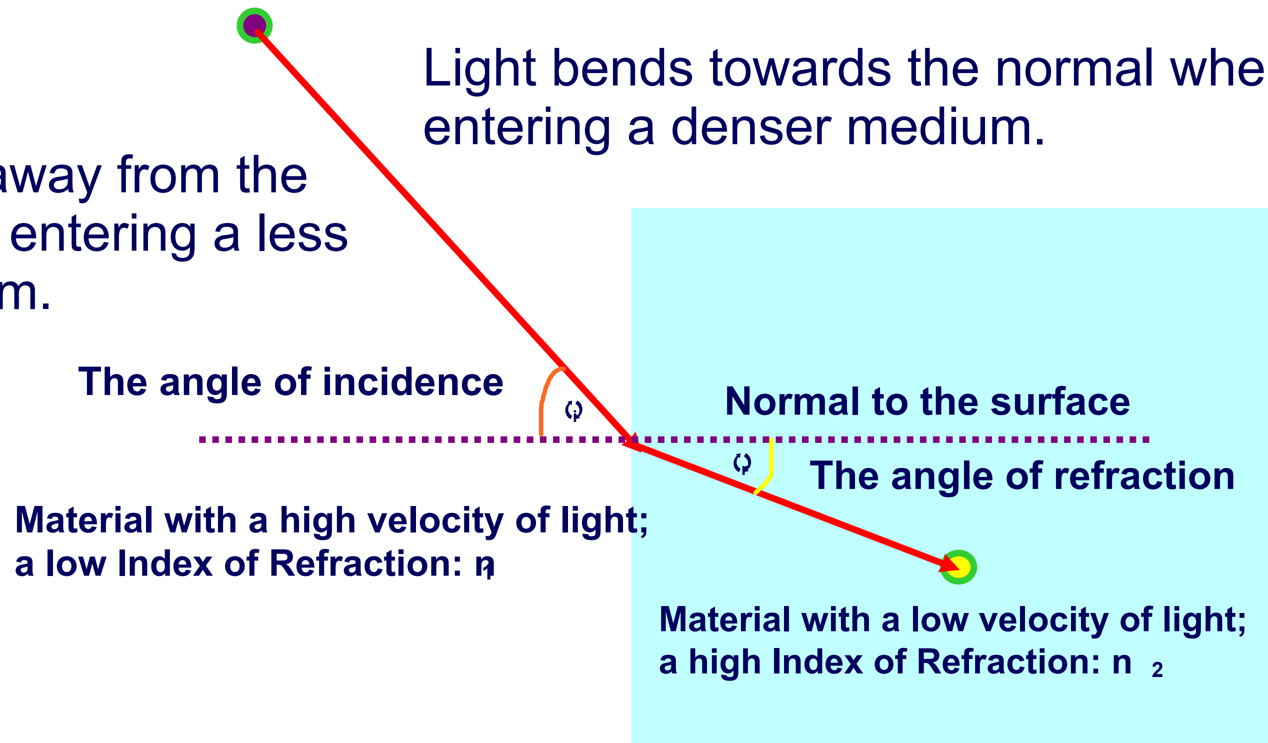

http://njc.tl/j2

# Snell's Law

The relationship between the angle of incidence, and the angle of refraction is given by Snell's Law: $n_1\sin\theta_1 = n_2\sin\theta_2$

Light bends towards the normal when entering a denser medium.

Light bends away from the normal when entering a less dense medium.




http://njc.tl/j2

10 Light traveling at an angle into a medium with a higher Index of Refraction is refracted:

- A towards the Normal.
- B away from the Normal.
- C parallel to the Normal.
- D equally.

Answer

11 Light traveling at an angle into a medium with a smaller Index of Refraction is refracted:

- A towards the Normal.
- B away from the Normal.
- C parallel to the Normal.
- D equally.

Answer

http://njc.tl/j3

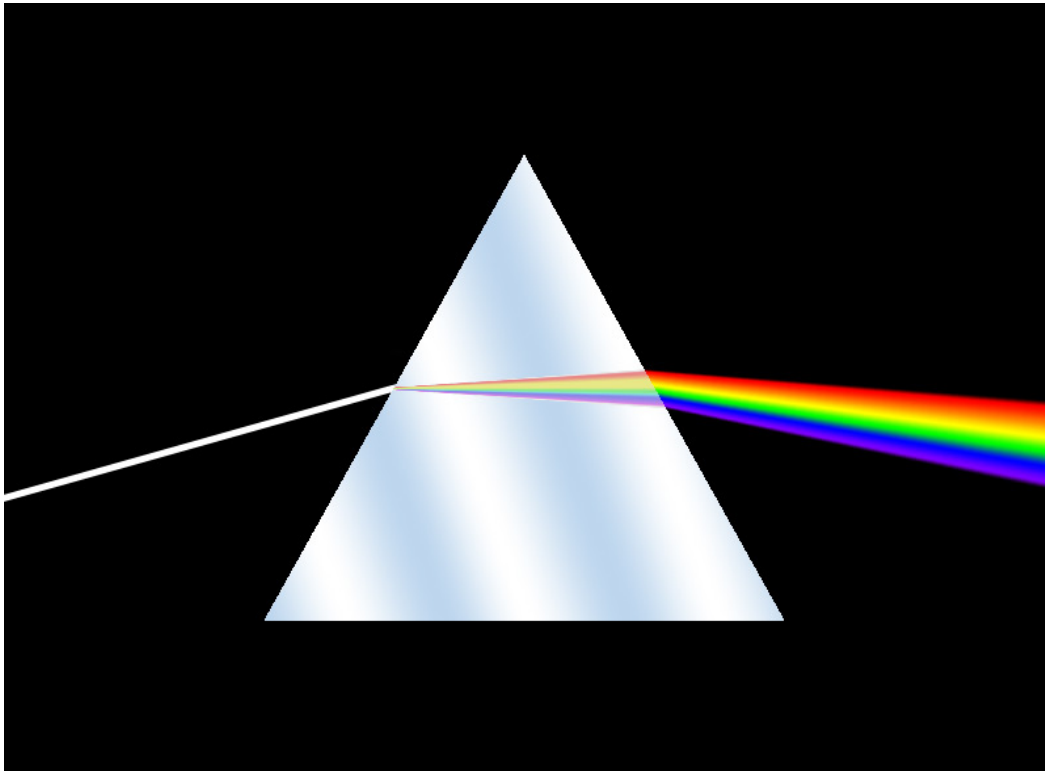
12 Light enters air (n=1) from water (n=1.3). The angle of refraction will be

- A greater than the angle of incidence.
- B less than the angle of incidence.
- C equal to the angle of incidence.

Answer

http://njc.tl/j4

# Dispersion
# Light is made up of colors

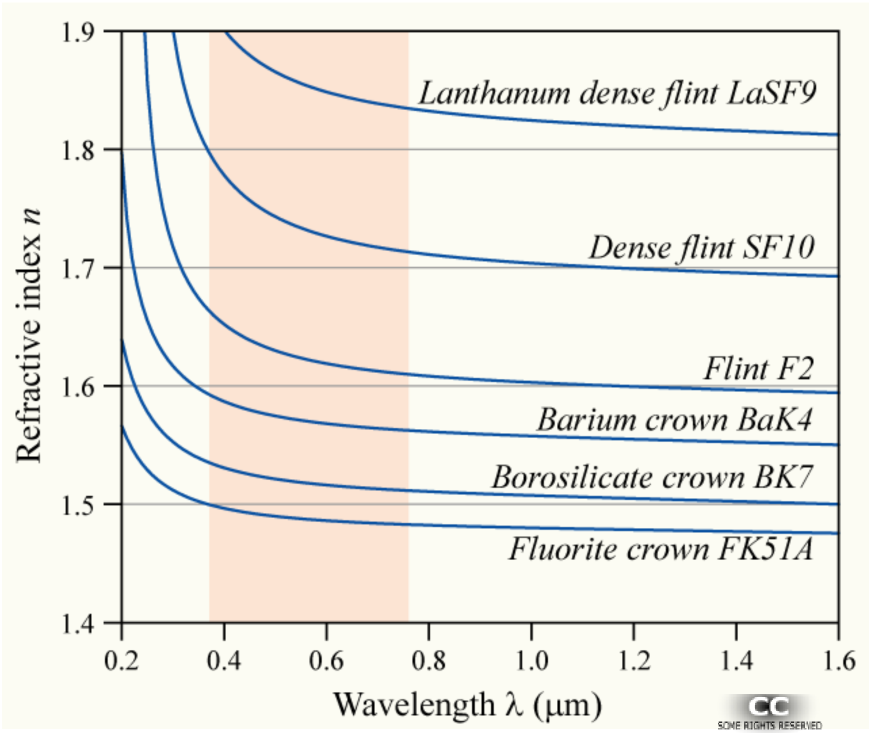


A prism refracts white light twice - at the front and back edges. The index of refraction is wavelength dependent - as wavelength increases, n decreases, so there is less deflection from the normal line to the surface.  This color separation is called dispersion.

http://njc.tl/j5

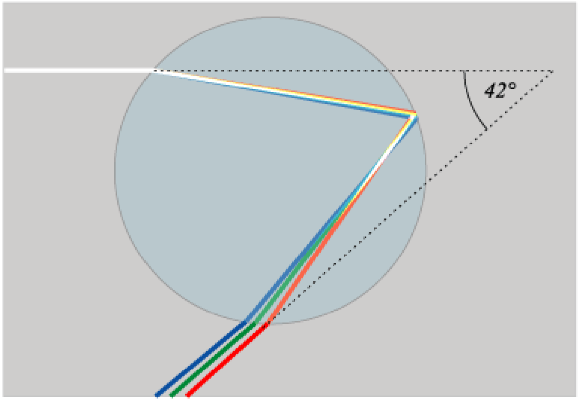
# Dispersion

The index of refraction of a material varies somewhat with the wavelength of the light (each color has a different wavelength).




http://njc.tl/j5

# Dispersion and Rainbows




Dispersion also accounts for the way we see rainbows - with the droplets of water in the air acting as prisms

This sums up what Newton's Opticks explain treating light as a particle. The next section will focus on light's wave behavior.

http://njc.tl/j5

13 White light is composed of:

- A Light of wavelength equal to 550 nm in the middle of the visible spectrum.
- B Electromagnetic radiation of all frequencies.
- C A mixture of colors from red through violet.
- D Very bright light.
- E The opposite of black light.

Answer

http://njc.tl/j6

14 The principle that explains why a prism separates whitelight into its constituent colors is:

- A Interference.
- B Polarization.
- C Dispersion.
- D Total Internal Reflection.

Answer

http://njc.tl/j7

15 Which color of light undergoes the smallest refraction going from air to glass?

- A Red.
- B Yellow.
- C Green.
- D Violet.

Answer

http://njc.tl/j8

16 Which color of light undergoes the greatest refraction going from air to glass?

- A Red.
- B Yellow.
- C Green.
- D Violet.

Answer

# Diffraction and Interference of Light

Return to Table of Contents

# Diffraction

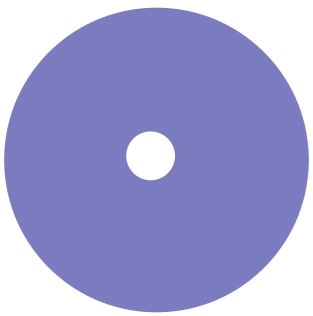
When sound waves and water waves meet an obstacle, they bend around it. This phenomenon is called Diffraction, and explains why you can hear a person around a corner, even though you can't see her (sound waves bend - diffract).

When waves meet a small opening,the opening generates a new wave on the other side. The picture shows a wave moving from right to left.

# Interference

It was also observed that light bends around objects, and when it "meets" the light from the other side, it creates a bright spot where it would be least expected.

Light that is shown on a coin would create a shadow behind the coin, but in certain cases, depending on the light wavelength and the coin size, a bright spot would show in the middle of the shadow.



The diffracted light from one part of the disc "interferes" with the diffracted light from the other part and produces the bright spot in the middle.

# Diffraction and Interference



Let's put these two observations together.

What if we have two or more wave sources bending around an obstacle and then running into each other?

You would get a picture like we have on the left of water waves.

# Young's Double Slit Experiment

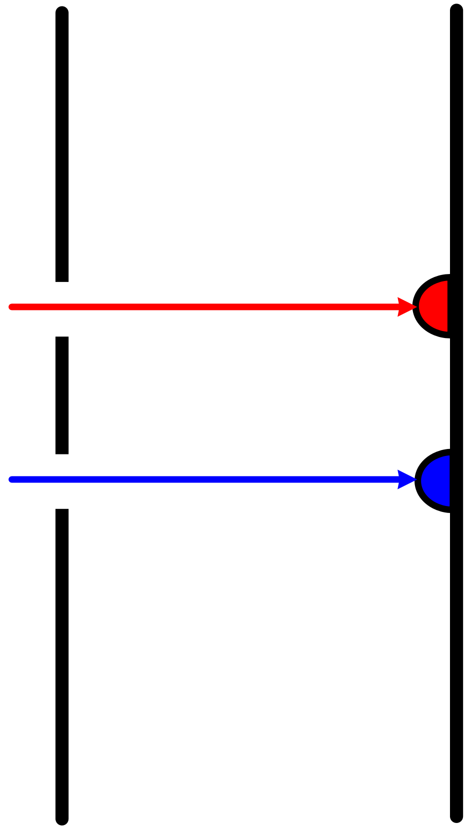
In 1801, Thomas Young put together an experiment to see if light behaved like water waves - forming "ripples" after it passed through two openings - the Double Slit Experiment.

In the case of water waves, the interference effect becomes more pronounced as the wavelength of the water wave is closer to the width of the opening.  So, if we were to see this in light, the openings would have to be very small, as light's wavelength is much smaller than water waves.

But first, let's assume that light is acting like a particle, and predict what would happen if a beam of light particles was incident on a wall with two holes in it - and we'll use a baseball pitcher analogy.

# Light as a Particle (or baseball)

If Cy Young were to be cloned and would throw a great number of baseballs through an opening a little bigger than the size of the ball at a wall, the top baseballs would be concentrated at the red baseball collection basket, and the bottom ones would collect in the blue basket.

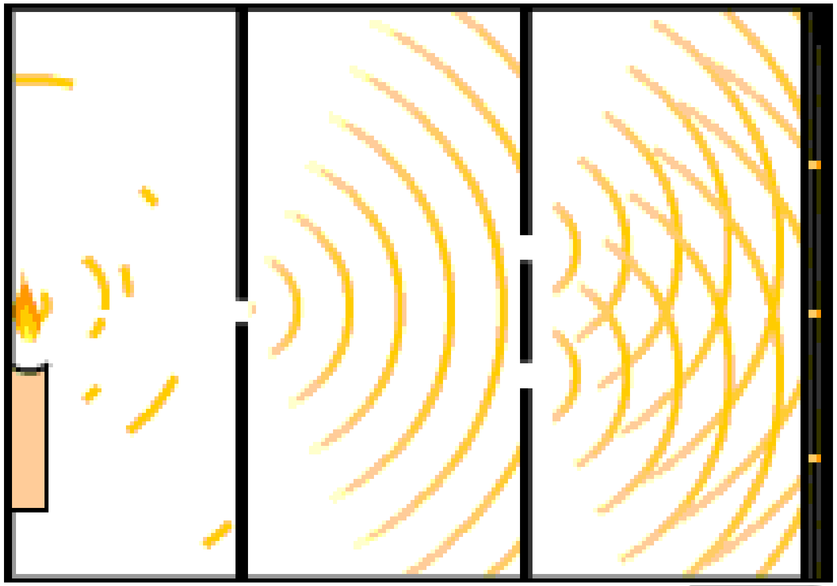


If light was considered merely as a great number of particles, one could expect a similar pattern on the far wall if, instead of baskets, photoelectric detectors would be there, counting the particles.

http://njc.tl/ja

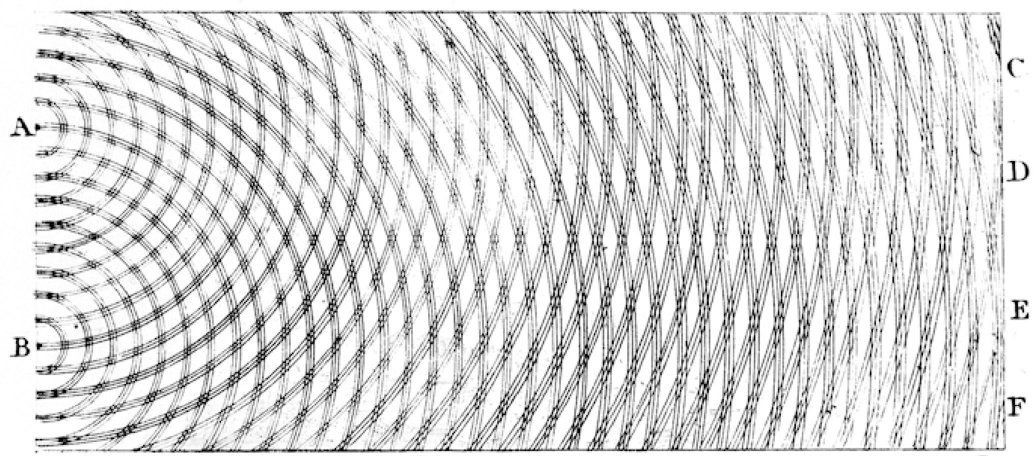
# Young's Double Slit Experiment

But, when Thomas Young set up his experiment with a single color of light, he did not see two patterns of bright light opposite the slits. In fact, he saw an interference pattern, consisting of alternating bright and dark patches of light, which decreased slowly in intensity from a peak brightness right in the middle - not in line with either slit.



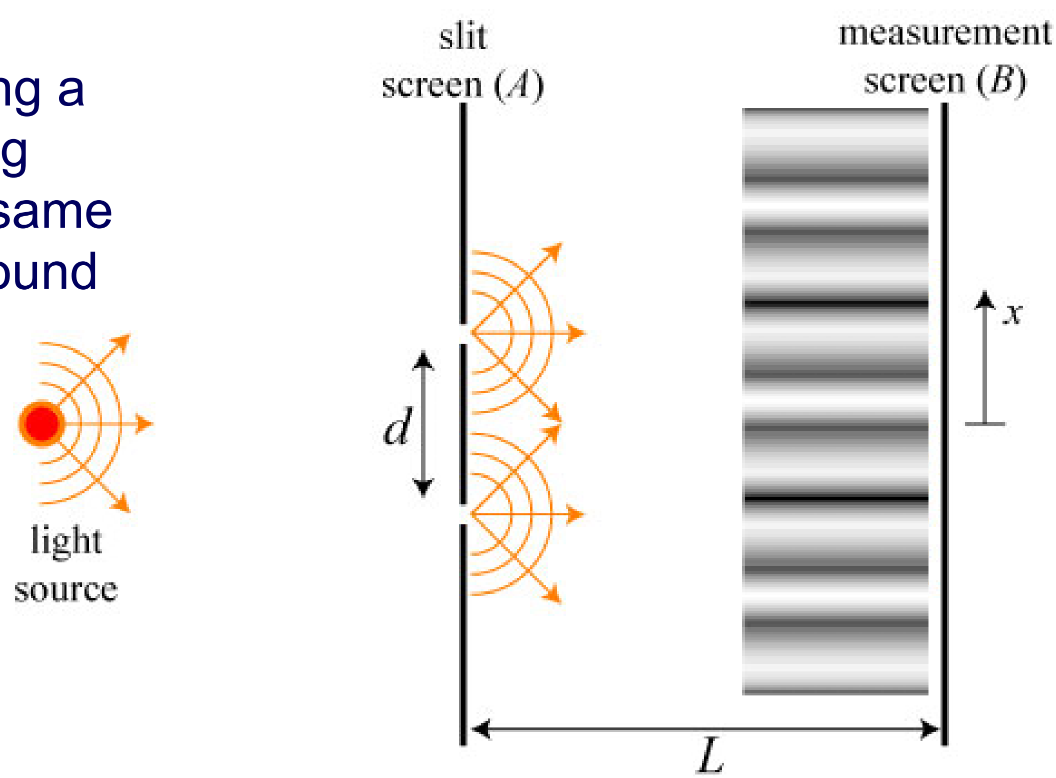
# Young's Double Slit Experiment

Here's Young's actual sketch of his results - with points A and B acting as the sources of the monochromatic light and C, D, E and F showing various stages of interference.



# Young's Double Slit Experiment

This is a photo is of the monochromatic light striking a distant screen after passing through 2 slits, and is the same pattern that results from sound or water waves.

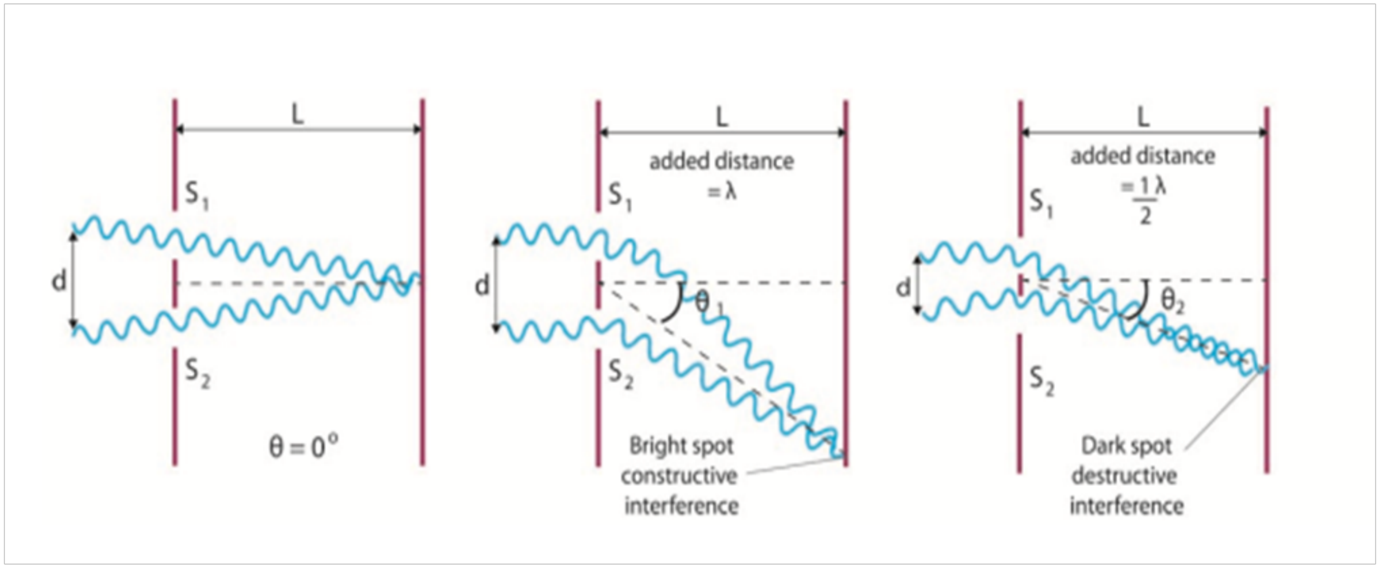



Hence, Thomas Young made the conclusion that light, like sound and water, traveled as a wave.

http://njc.tl/ja

# Double-Slit Maxima and Minima

Interference occurs because each point on the screen is not the same distance from both slits. Depending on the path length difference, the wave can interfere constructively (bright spot) or destructively (dark spot).



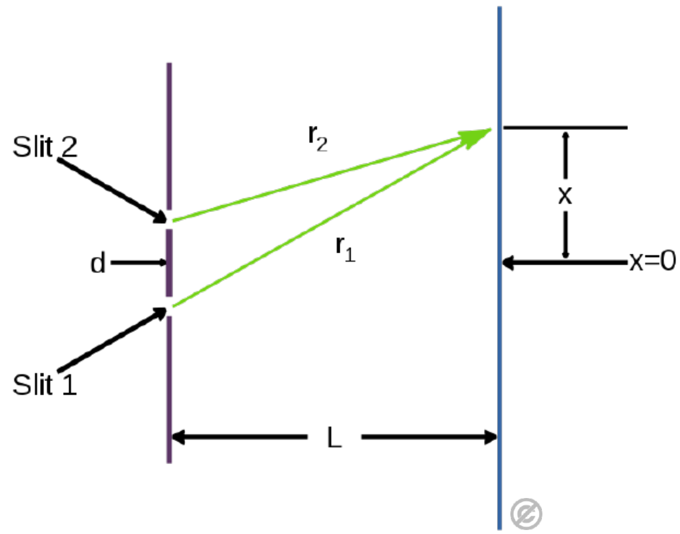
# Double-Slit Maxima and Minima

As shown earlier in the Wave chapter, waves will constructively interfere if they reach a point when they are both at a maximum amplitude.

This occurs when the distance they travel differs by an integral number of wavelengths.

This constructive interference results in a bright spot, or fringe of light.  Dark fringes will occur between the bright fringes.

# Double-Slit Maxima and Minima




Using a little algebra and geometry, the position of the bright fringes is determined to be approximately:

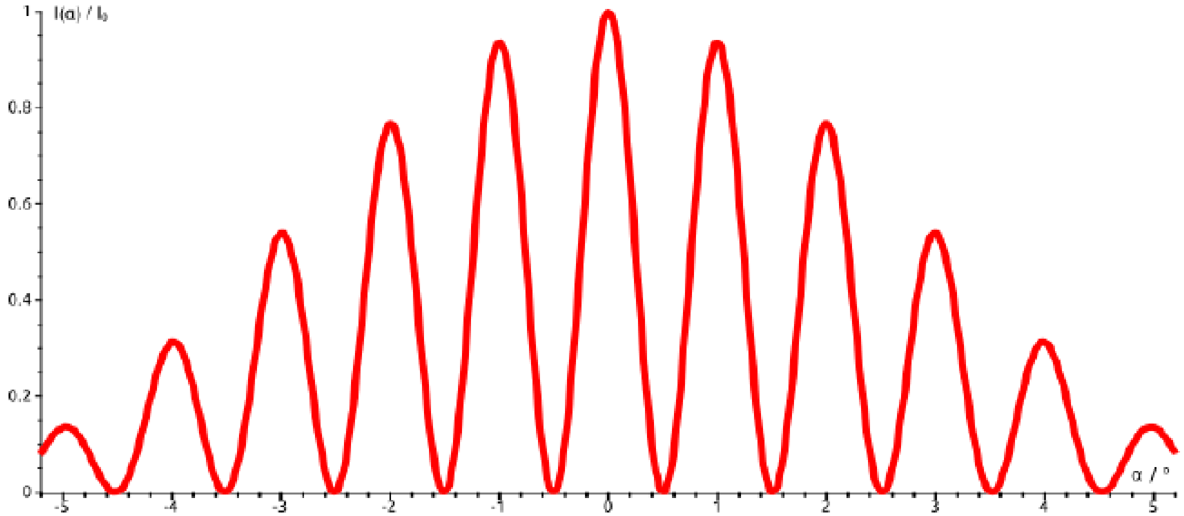
$$x_m = \frac{m\lambda L}{d} \quad \text{where } m = 0, \pm 1, \pm 2, \pm 3....$$

Positive values of m refer to bright fringes above the x=0 position and negative values refer to fringes below x=0.

http://njc.tl/ja

# Double-Slit Maxima and Minima

This equation and the experimental results in a Brightness versus distance (x) from the central maximum plot. The intensity of the light (y axis) decreases smoothly for the higher order interference fringes.





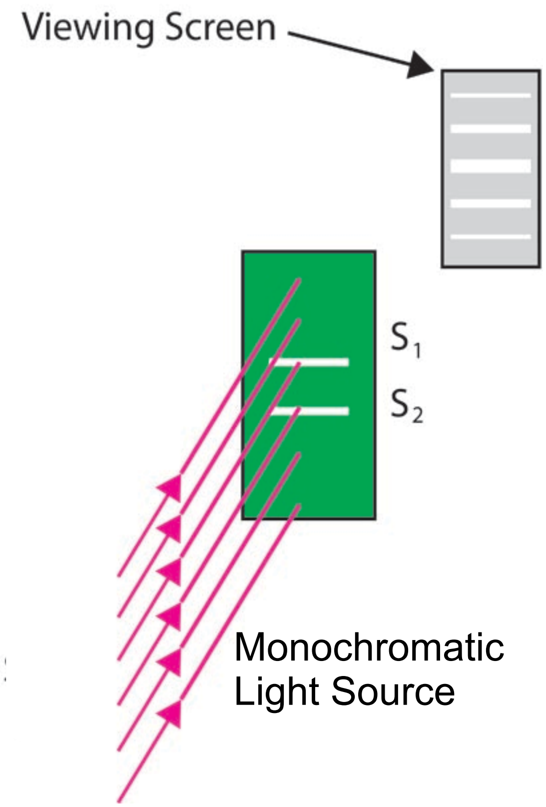

http://njc.tl/ja

# Summary

The double slit experiment relies on two properties of waves - diffraction and interference - which enabled Young to claim that light is a wave.

Each slit generates a new wave due to diffraction.

Those waves then either constructively or destructively interfere on a screen which is at a distance much greater than the distance between the slits.




http://njc.tl/ja

17 What principle is responsible for light spreading as it passes through a narrow slit?

- A Refraction.
- B Polarization.
- C Diffraction.
- D Interference.

Answer

http://njc.tl/jb

18 What principle is responsible for alternating light and dark bands when light passes through two or more narrow slits?

- A Refraction.
- B Polarization.
- C Diffraction.
- D Interference.

Answer

19 If a wave from one slit of a Young's double slit experiment arrives at a point, one-half wavelength behind the wave from the other slit, what is observed at that point?

- A Bright fringe.
- B Gray fringe.
- C Multi-colored fringe.
- D Dark fringe.

Answer

http://njc.tl/jd

20 In a Young's double slit experiment, where the slitseparation is 0.15 mm and the distance to the detection screen is 1.4 m; light of wavelength 550 nm is incident on the two slits.  How far from the midpoint of the detection screen is the 2nd maximum (bright fringe)?

Answer

http://njc.tl/je

21 In a Young's double slit experiment, where the slitseparation is 0.080 mm and the distance to the detection screen is 3.0 m; the first maximum (bright fringe) is found at 2.0 cm. What is the wavelength of the light?

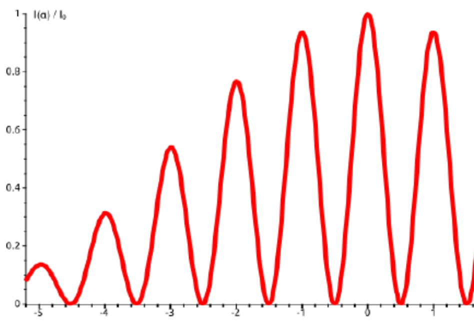
Answer

http://njc.tl/jf

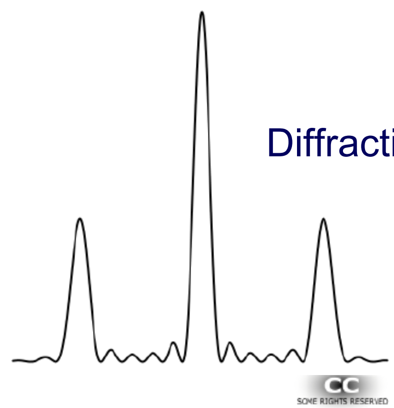
# Diffraction Grating

A diffraction grating consists of a large number of equally spaced narrow slits and are created by etching thousands of thin lines on to a glass slide.  They produce maxima and minima, just like in the Double Slit experiment, but the pattern is much sharper because there are thousands of slits, not just two. The more lines or slits there are, the narrower the peaks.

Also, shining white light on the grating produces  a spectra of all the colors since the location of maxima depends on wavelength, and the colors in white light ate out (just like dispersion).



Double Slit



Diffraction Grating

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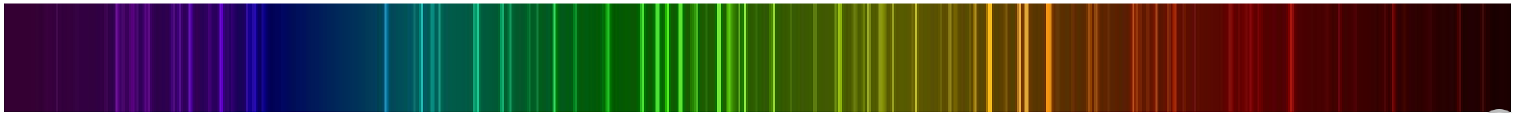
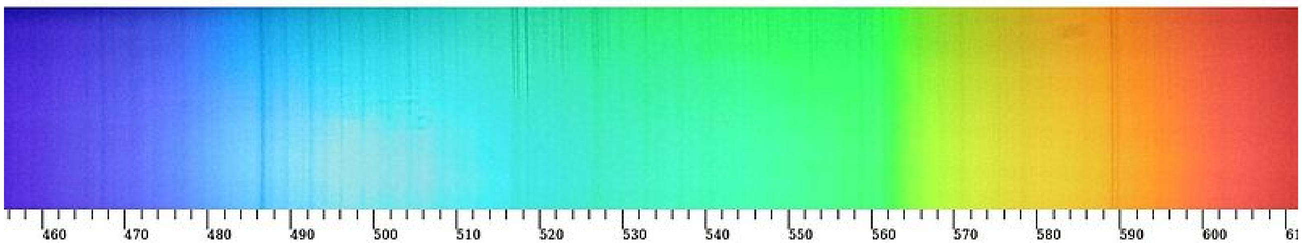
# Diffraction Grating



This is the pattern shown by excited Xenon gas. Note the discrete lines in the spectrum.

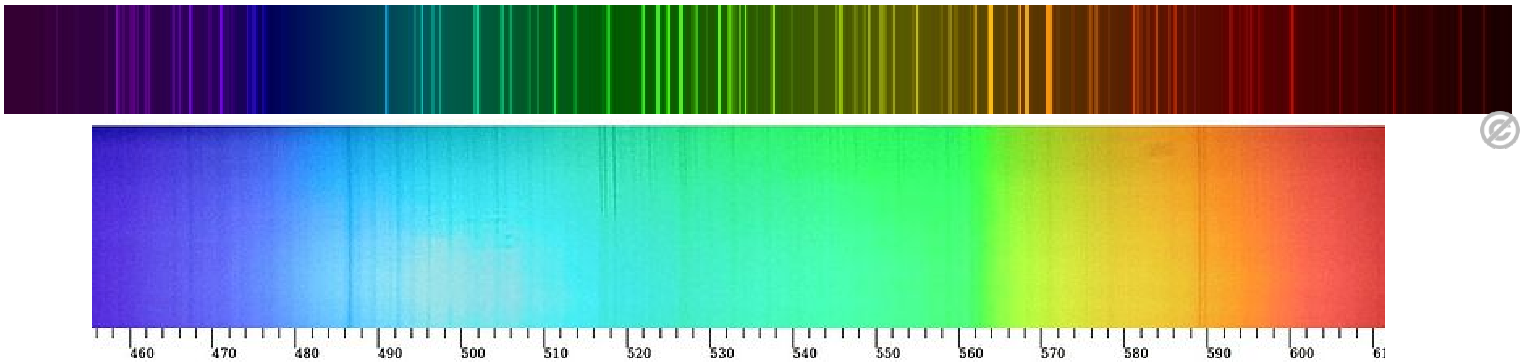





This is the pattern shown by solar light. All of the colors are visible and smeared together. This can also seen by looking at a CD or DVD at an angle - as they are created by etching cuts into a polycarbonate plastic disc.

http://njc.tl/jg

# Diffraction Grating






The equation for the maxima is the same as for the double slit experiment, where d is the distance between the etchings on the diffraction grating.

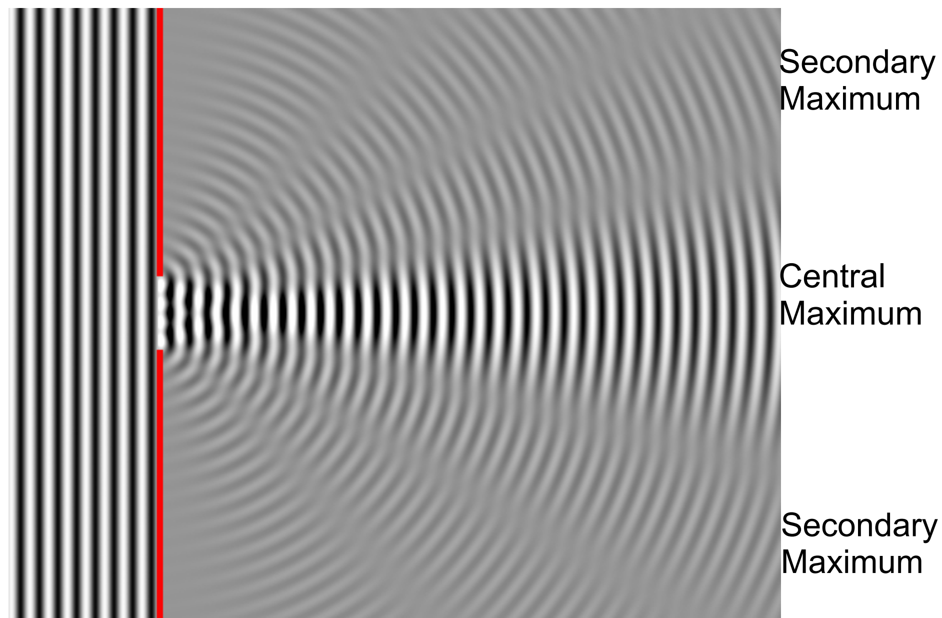
$$x_m = \frac{m\lambda L}{d} \quad \text{where } m = 0, \pm 1, \pm 2, \pm 3....$$

http://njc.tl/jg

# Single Slit Interference

When light strikes a single slit, interference occurs between the individual waves, that together, make up the wavefront. Light wave fronts are incident on the single slit on the red line.  Each individual wave then spreads out as it passes through the slit - and creates the below interference pattern.

This creates a wide bright central maximum, and secondary, dimmer maxima.




http://njc.tl/jg

# Single Slit Interference

In this case, the geometry allows us to calculate the locations of the minima - as opposed to the Double Slit case, where the maxima locations were calculated.

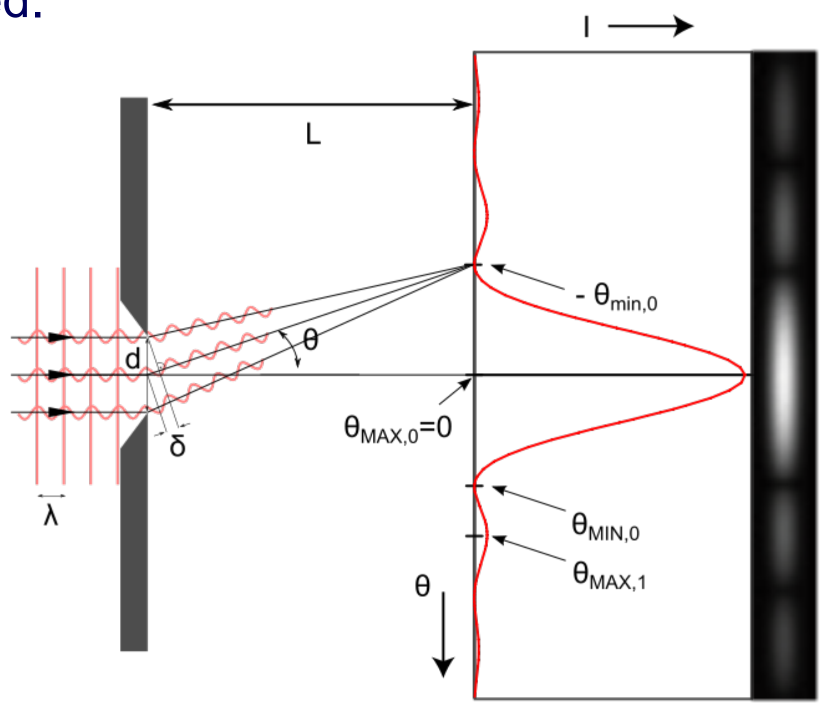
The minima are located at

$$x_m = \frac{m\lambda L}{d}$$

$$m = \pm 1, \pm 2, \pm 3 \ldots\ldots$$

Because of the symmetry, the first maximum is located at x=0, and its width is equal to:

$$w = 2x_1 = \frac{2\lambda L}{d}$$



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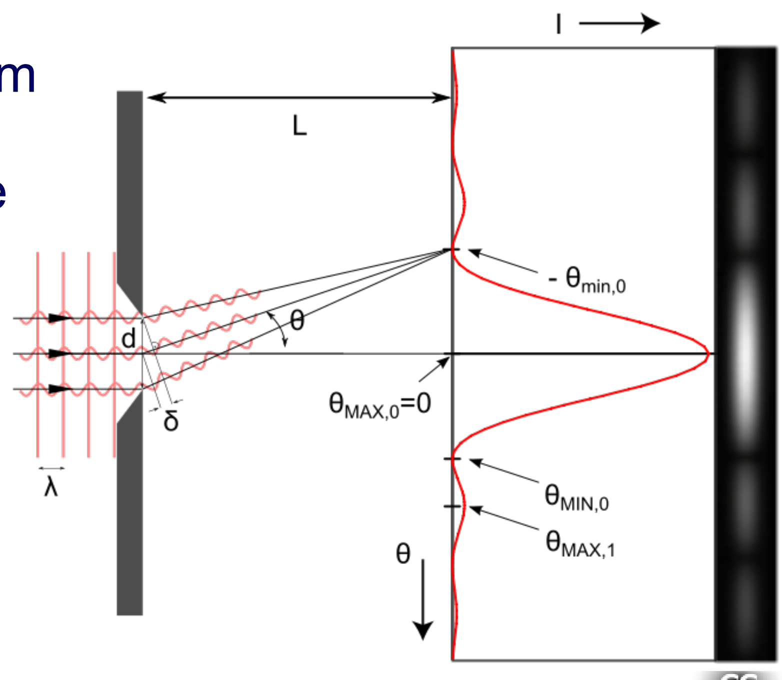
# Single Slit Interference

The intensity pattern is the plot on the right side of the experimental setup shown below. As the width of the slit, becomes smaller, the width of the central maximum increases.

$$w = \frac{2\lambda L}{d}$$

As the width of the central maximum becomes wider, the image is more "smeared out" and images become more difficult to resolve.

That is why an eagle's eye is so large and why telescope lenses are so wide - this narrows the width of the central maximum and makes it possible to see er image detail.



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22 The distance between etchings on a Diffraction Grating is 1.5 μm and the distance between the grating and the observation screen is 0.75 m. What is the distance from the midpoint of the screen to the 1st order maxima for light with a wavelength of 450 nm?

Answer

23 The distance between etchings on a Diffraction Grating is 1.5 μm and the distance between the grating and the observation screen is 0.75 m. The first order maxima resulting from a monochromatic light source is at a distance of 0.33m from the midpoint of the screen. What is the wavelength of the light?

Answer

http://njc.tl/ji

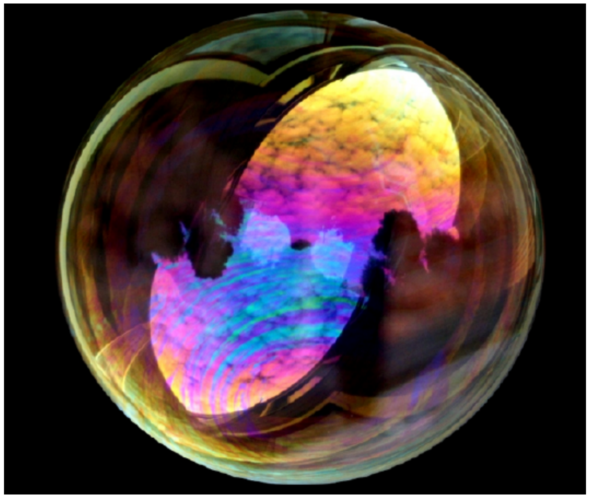
24 In a Single Slit experiment, the width of the slit is 1.2 mm wide, and light of wavelength 400.0 nm passes through and strikes an observation screen 35 cm away. What is the distance of the second minimum (dark fringe) from the center of the screen?

Answer

http://njc.tl/jj

# Interference by Thin Films

One more interesting effect - and this is caused by light's properties of refraction, reflection and interference. It occurs when you have light passing through two media, and the refracted light then interferes with the partially reflected light to produce wonderful colors.



Soap bubble



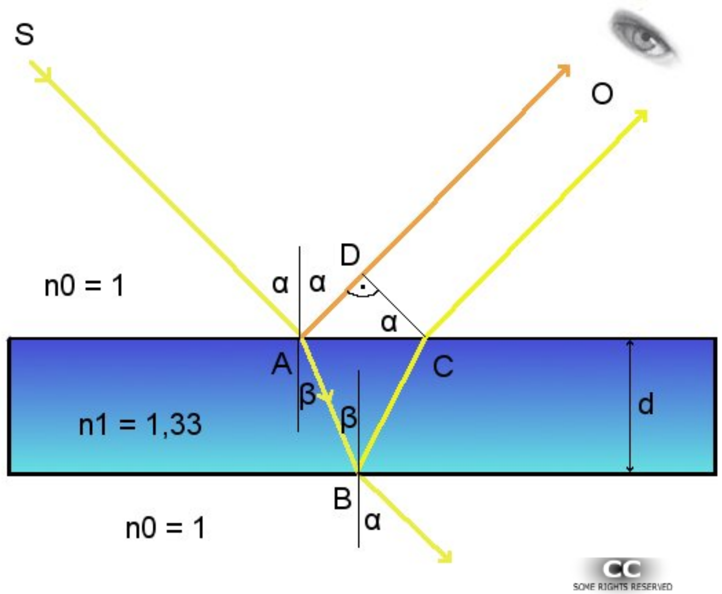
Oil on asphalt

# Interference by Thin Films

Here is a diagram of the soap bubble. The blue area is the soap bubble with an index of refraction of 1.33. It is surrounded by air, with n=1. Let's follow the path of sunlight originating from S.

At point A, some of the light is reflected and passes through point D, and then into the observers eye, point O.

Most of the light refracts, and passes through the water to point B, where a small portion reflects to point C, where it refracts again and reaches the observer.




It is these two rays that will interfere with each other.

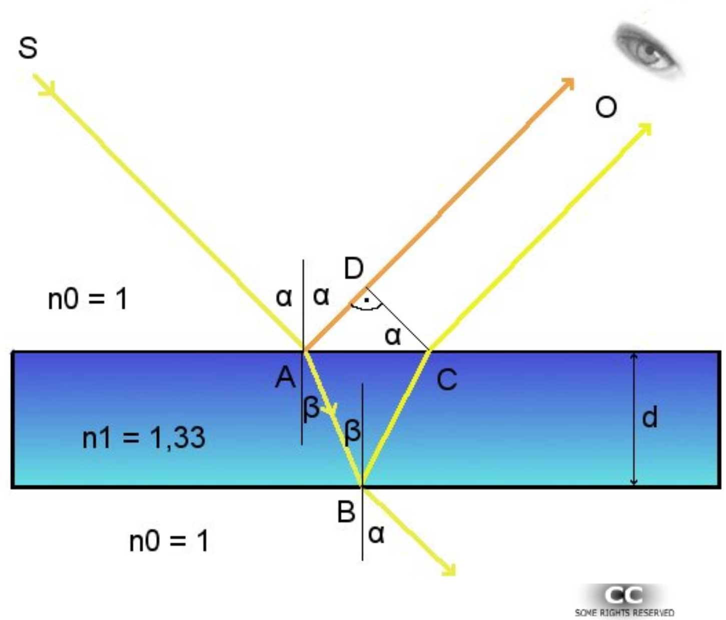
http://njc.tl/jk

# Interference by Thin Films

What the observer sees will depend on the thickness of the film and the angle at which the light is observed.

Since this is white light, all of the colors will be separated out and the film thickness and the observation angle will determine what colors are seen.

If this is a very thin film, the rays coming from points A and B will travel almost the same distance, but the ray reflecting from the front surface is inverted. Hence, destructive interference will result and the observer will see a dark

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# Interference by Thin Films

The equations for Thin Film Interference are determined using the same mathematical techniques for the Diffraction experiments.

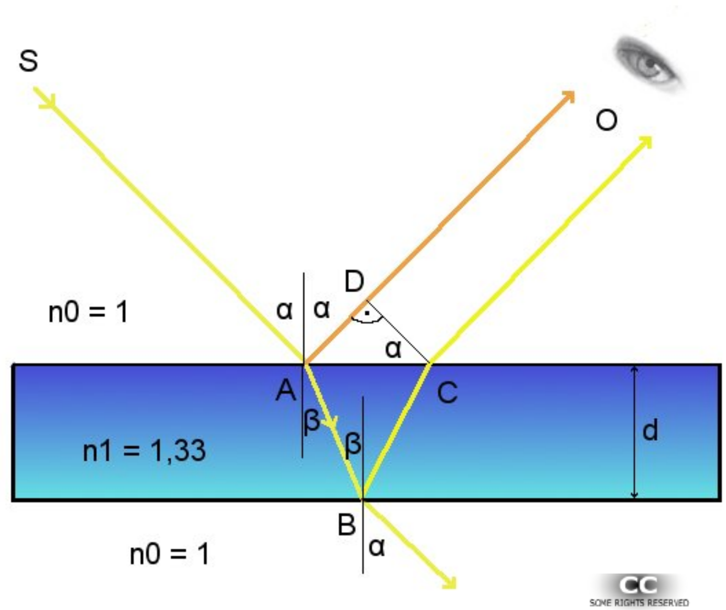
Where t = thickness of the film and $m = 0, \pm 1, \pm 2 ....$

Constructive Interference

$$\lambda_c = \frac{2nt}{m + \frac{1}{2}}$$

Destructive Interference

$$\lambda_d = \frac{2nt}{m}$$

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# Interference by Lens Coating

The Thin Film Interference covered so far involves cases where the index of refraction of the "middle" media (soap bubble or oil) is greater than the index of refraction in the media from where the light ray comes, and where it goes.

Let's consider the case where the index refraction of a thin film (like an anti-glare coating on a pair of glasses), is greater than the incident light's media, but less than the index of the material on the bottom.

Special coatings are painted onto a pair of glasses.  The index of refraction for air is 1.0, approximately 1.3 for the coating and 1.5 for the glass.

The purpose of this is to maximize transmission of the light through
ses and minimize the reflection (glare).

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# Interference by Lens Coating

The physics is slightly different because light behaves differently when it travels from a medium with a higher n to a lower n than it does when going from a lower n medium to a higher n medium.

So, the equations for constructive and destructive interference are changed as follows:

Where t = thickness and n is the index of refraction of the lens coating and $m = 0, \pm 1, \pm 2....$

Constructive Interference

$$\lambda_c = \frac{2nt}{m}$$

Destructive Interference

$$\lambda_d = \frac{2nt}{m - \frac{1}{2}}$$

# Interference by Lens Coating

The glasses on the top do not have the anti glare coating and the reflection of the person standing above the glasses is seen.

With the anti glare coating, the light is transmitted mostly through the lens and there much less reflection.

This helps make photographs of people with glasses look better, and enables you to see the person's eyes behind the glasses!



http://njc.tl/jk

25 The colors on an oil slick are caused by reflection, refraction and ________

- A diffraction.
- B interference.
- C polarization.

Answer

http://njc.tl/jl

26 Light with a wavelength of 550 nm (center of the visible spectrum) shines on a soap bubble (n = 1.33). What is the minimum thickness of the soap bubble to minimize the intensity of the reflected light?

Answer

27 Light with a wavelength of 550 nm (center of the visible spectrum) shines on a soap bubble (n = 1.33). What is the minimum thickness of the soap bubble to maximize the intensity of the reflected light?

Answer

http://njc.tl/jn

# Maxwell's Equations

Return to Table
of Contents

http://njc.tl/jo

# Maxwell's Equations

James Clerk Maxwell put together the major concepts of Electricity and Magnetism in 1861, provided a mathematical formalism, and added the last term to Ampere's Law.  Nobel Laureate, Richard Feynman stated:

> “From a long view of the history of mankind, seen from, say, ten thousand years from now, there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics. The American Civil War will pale into provincial insignificance in comparison with this important scientific event of the same decade.”

# Maxwell's Equations

Here are the equations.  You don't need to know them in this form (until AP Physics), but they're very nice to look at, and you can maybe see the equations you've already learned in this course in a slightly different notation.

| | |
|---|---|
| Gauss's Law | $\oint E \cdot dA = \frac{q_{inc}}{\varepsilon_0}$ |
| Gauss's Law for Magnetism | $\oint B \cdot dA = 0$ |
| Faraday's Law of Induction | $\oint E \cdot ds = -\frac{d\Phi_B}{dt}$ |
| Ampere's Law (plus Maxwell's term at the end) | $\oint B \cdot ds = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{inc}$ |

# Electromagnetic Wave

This chapter has dealt with light and the various ways of interpreting what it is, but we haven't addressed the fundamental nature of light.

We already know from Ampere's Law that a current (which arises from an Electric Field pushing charges) generates a Magnetic Field. And, from Faraday's Law, a changing Magnetic Field will generate an Electric Field.

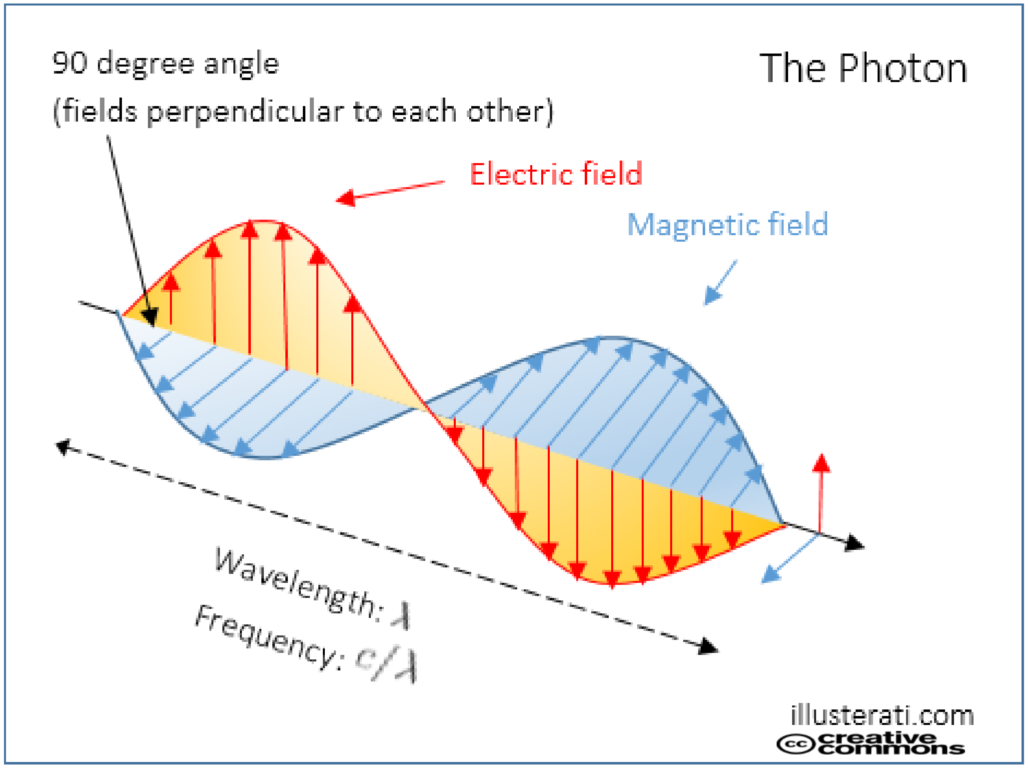
So, if we could create a changing Electric Field, it would create a changing Magnetic Field, which would create a changing Electric Field which would create a changing Magnetic Field ad infinitum - and these traveling fields are called an Electromagnetic Wave.

# Electromagnetic Waves

The electric and magnetic wave segments of an Electromagnetic Wave are perpendicular to each other, and to the direction of propagation.

The Electromagnetic waves are made of discrete packets of energy; Photons.

Each photon has an energy of E=hf, where h is Planck's Constant and is equal to $6.63 \times 10^{-34}$ J-s. Not a very big number - but we're dealing with individual photons.

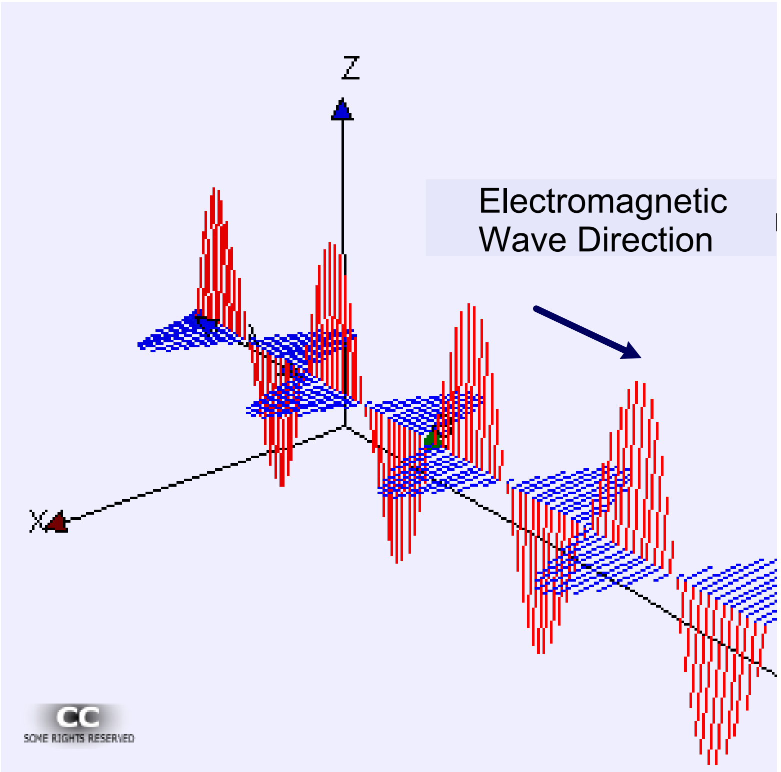



http://njc.tl/jo

# Accelerating Charges create Electromagnetic waves

This is an example of how an Electromagnetic Wave can be created.

In a broadcast radio or TV antenna oriented on the vertical (z) axis, electrons are accelerated up and down by a changing voltage from an amplifier. As they accelerate they create a changing Electric Field in the z direction. This creates a changing magnetic n the x-y plane.



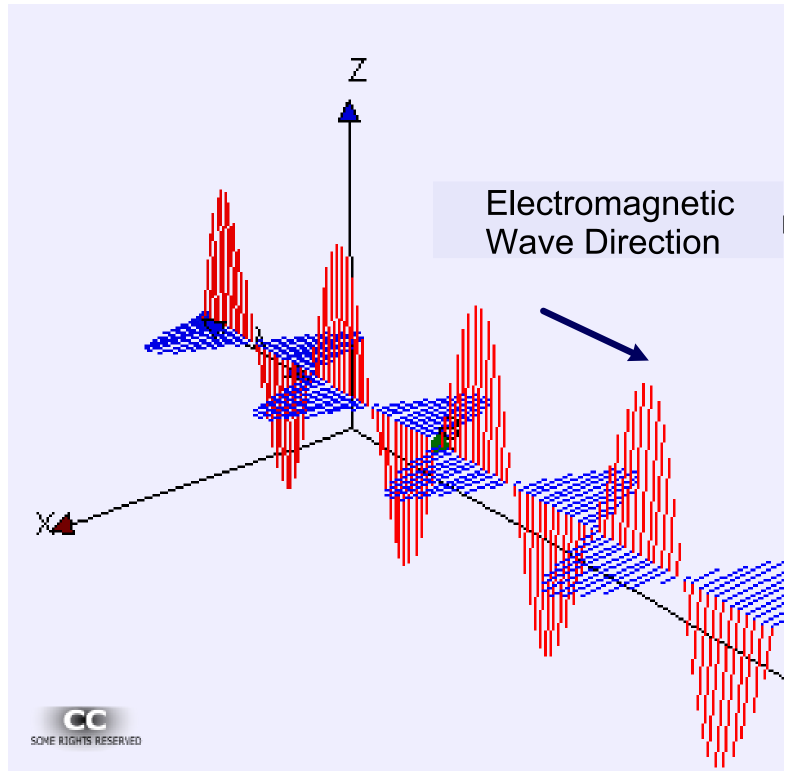

http://njc.tl/jo

# Accelerating Charges create Electromagnetic waves

These initial magnetic and electric fields propagate to the right (along the y axis) and would get really small very quickly due to their $1/r^2$ and $1/r$ dependence.

But because these are changing fields, they keep creating their partner field.

Which creates an Electromagnetic wave which will keep going until absorbed by another material.

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# Light is an Electromagnetic Wave

The solutions to Maxwell's Equations showed that the speed of an Electromagnetic Wave is 3.00 x$10^8$ m/s. This was also measured to be the speed of light. Hence, light is an Electromagnetic Wave.

There is also a very interesting relationship between the electrical permittivity and magnetic permeability constants:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = \frac{1}{\sqrt{(8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2})(4\pi \times 10^{-7}\,\mathrm{N \cdot s^2/C^2})}}$$
$$= 3.00 \times 10^8\,\mathrm{m/s}$$

3.00 x $10^8$ m/s is the speed of light in a vacuum.

http://njc.tl/jo

28 An Electric Field is produced by a separation of charges or by a:

A Changing Magnetic Field.

B Constant Magnetic Field.

C A changing or constant Magnetic Field.

D None of the above.

Answer

29 A changing Electric Field will produce a:

- A Changing Electric Field.
- B Changing Magnetic Field.
- C Gravitational Field.
- D None of the above.

Answer

http://njc.tl/jq

# Properties of Electromagnetic Waves

Return to Table of Contents

# Properties of Electromagnetic Waves

The last section showed how light is an Electromagnetic Wave, consisting of discrete packets of energy called photons, travelling at $3.00 \times 10^8$ m/s in a vacuum. And its velocity is equal to its wavelength times the frequency.

This isn't the whole story of Electromagnetic Waves.

Light is but a small segment of the Electromagnetic Spectrum which consists of Electromagnetic Radiation that has smaller and larger frequencies than the visible light we're used to.

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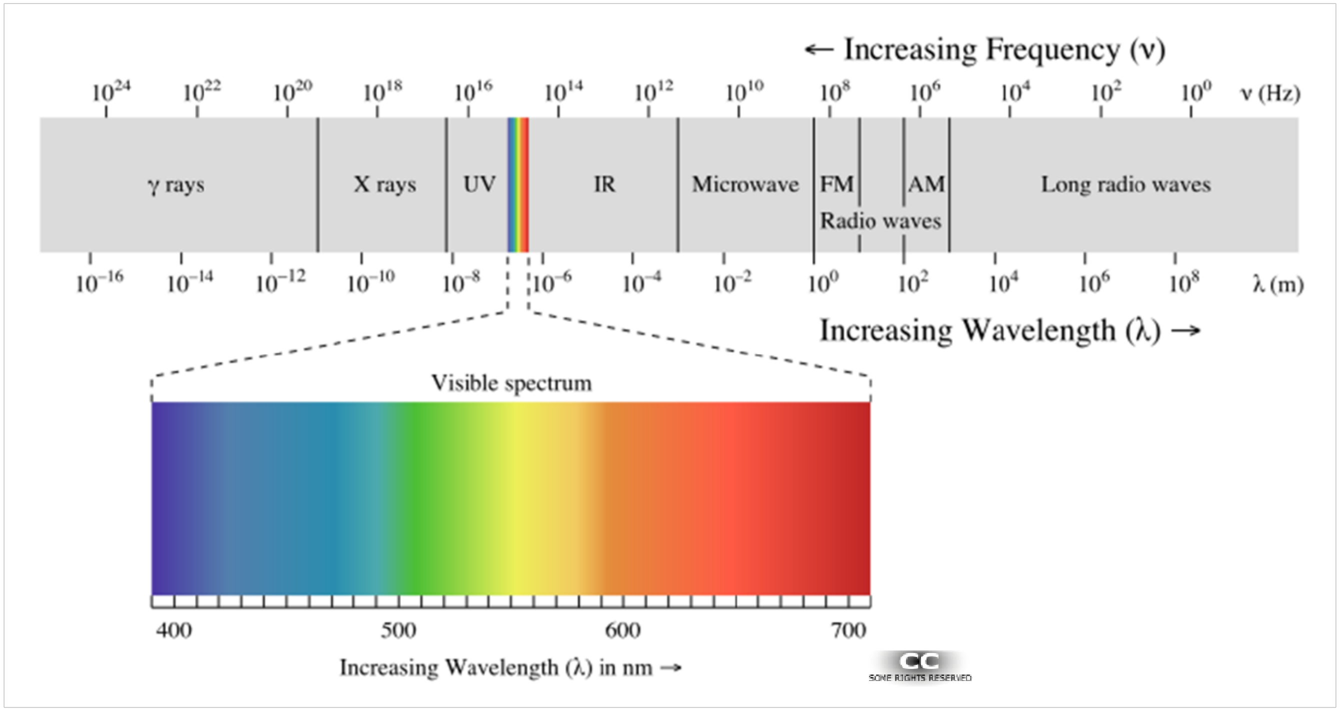
# Electromagnetic Spectrum




This is the spectrum of all Electromagnetic Radiation presented in increasing wavelength, and decreasing photon energy from left to right. Visible light is a very small component - it has been highlighted and expanded so the individual colors can be seen.

http://njc.tl/jr

30 Light with a wavelength slightly shorter than 400 nm is called:

- A Ultraviolet light.
- B Visible light.
- C Infrared light.
- D None of the above.

Answer

http://njc.tl/js

31 All electromagnetic waves travel through a vacuum with:

- A A speed that depends on their wavelength.
- B A speed that is proportional to their frequency.
- C A speed that is inversely proportional to their frequency.
- D The same speed, $3.00 \times 10^8$ m/s.

Answer

http://njc.tl/ju

32 Of the following, which is not electromagnetic in nature?

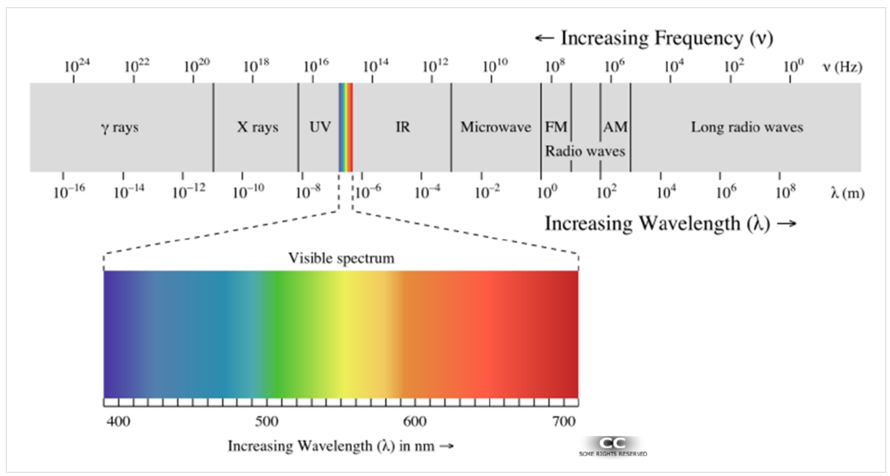
- A Microwaves.
- B Gamma rays.
- C Sound waves.
- D Radio waves.

Answer

http://njc.tl/jv

33 Which of the following lists Electromagnetic Waves in order from longest to shortest wavelength?

- A Gamma rays, Ultraviolet, Infrared, Microwaves.
- B Microwaves, Ultraviolet, Visible Light, Gamma rays.
- C Radio waves, Infrared, Gamma rays, Ultraviolet.
- D Radio waves, Infrared, Visible Light, X-rays.




Answer

http://njc.tl/jw

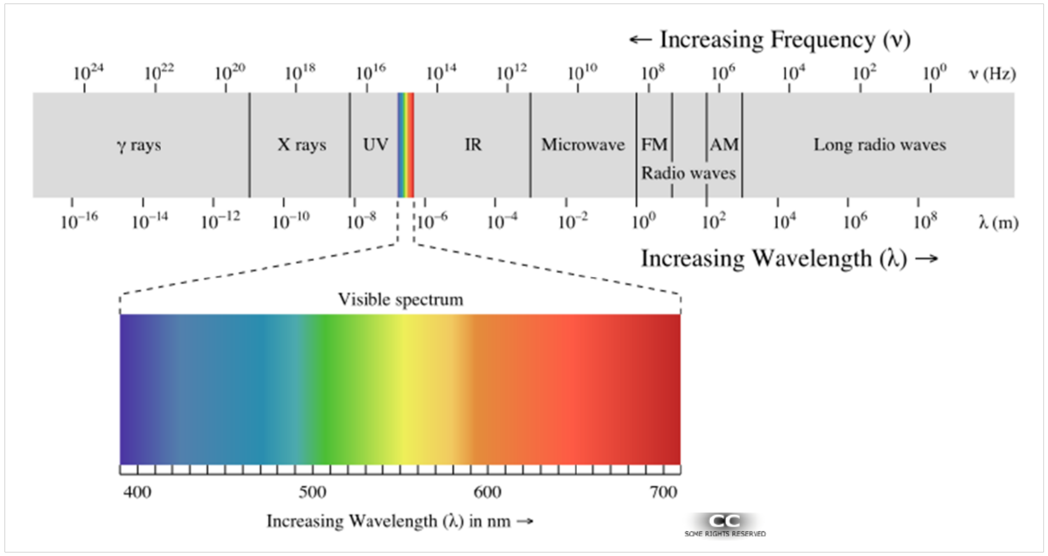
34 For an Electromagnetic wave, its frequency multiplied by its wavelength is the wave's:

- A Speed.
- B Amplitude.
- C Intensity.
- D Power.

Answer

35 What color of light has the highest frequency?

- A Green.
- B Red.
- C Yellow.
- D Blue.

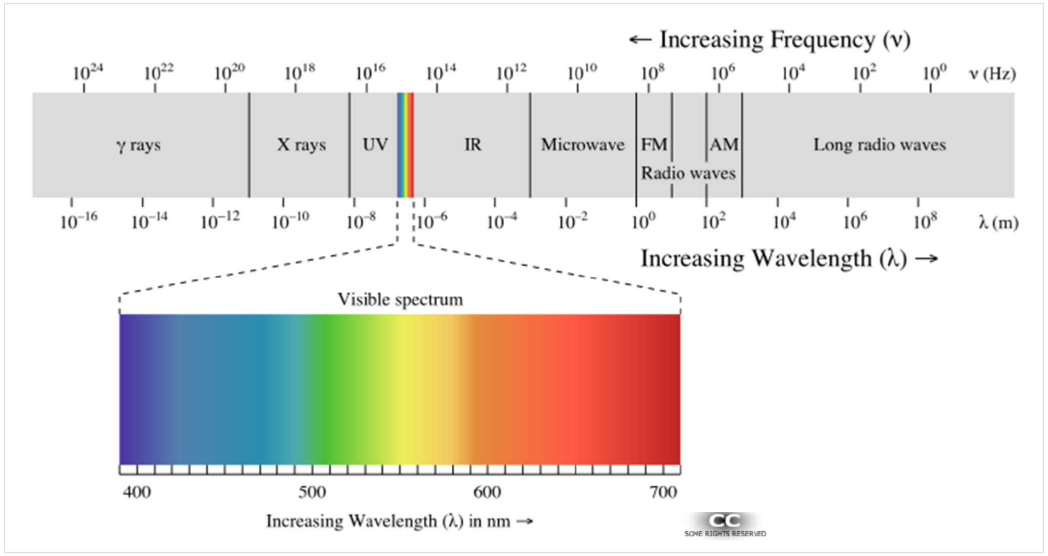



Answer

http://njc.tl/jy

36 What color of light has the longest wavelength?

- A Green.
- B Red.
- C Yellow.
- D Blue.




Answer

http://njc.tl/jz

37 The wavelength of light that has a frequency of $6.20 \times 10^{14}$ Hz is:

Answer

38 What is the frequency of light whose wavelength is600.0 nm?

Answer

http://njc.tl/k1

# Polarization

The Electric Field vectors of an Electromagnetic Wave are in a plane perpendicular to the direction of motion of the wave, called the Plane of Polarization.

Light from the sun is emitted independently from its atoms, so the Electromagnetic Wave's planes of polarization are in random directions - this is unpolarized light.

Most of light's interaction with matter is due to the Electric Field vector.

# Polarization

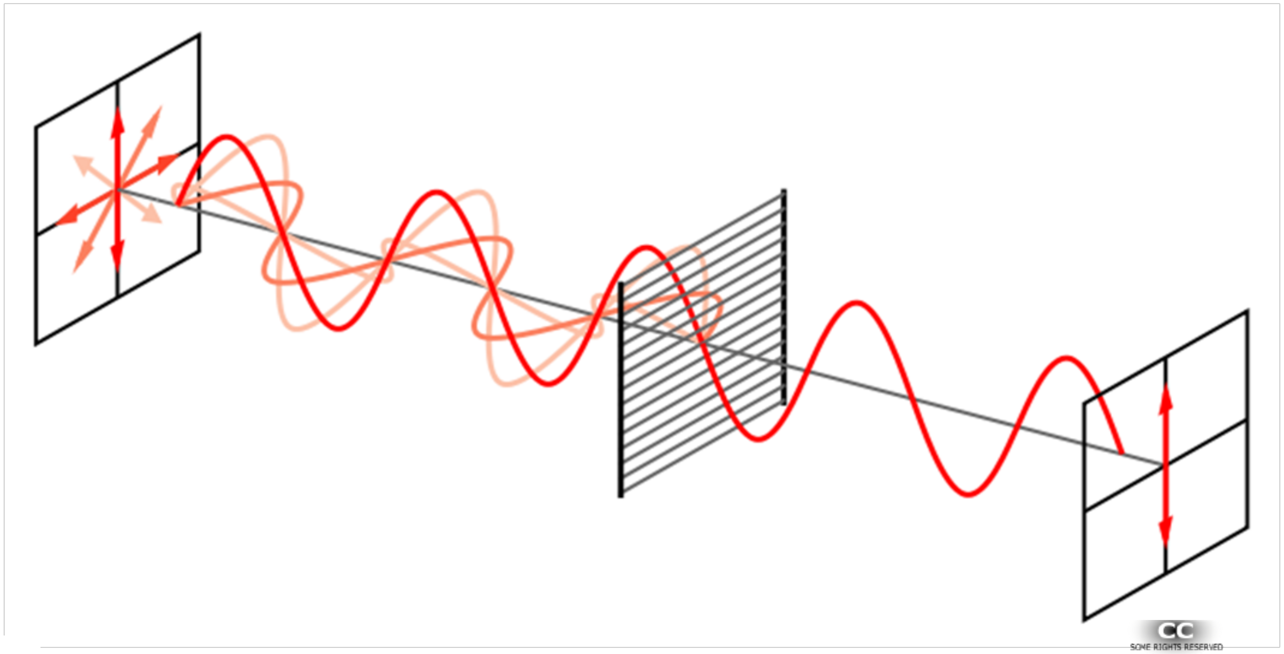
There are long organic molecules, polymers, that conduct electrons up and down their lengths. When the Electric Field of an Electromagnetic Wave is parallel to the polymer's length, it accelerates the electrons in the polymer, thereby losing energy, which decreases the magnitude of the Electric Field in that direction.

Electric Field vectors that are perpendicular to this axis are unaffected - since the electrons in the polymer can't vibrate in this direction, so the Electric Field component of the wave loses no energy as it passes through.

There is a practical application of this - sunglasses and light filters.

# Polarization

Unpolarized light enters from the left.  The sheet of polymers only allows light through that is perpendicular to its molecular chain - polarizing the light in the vertical direction.



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# Polarization

Polarizing sunglasses contain a polarizing filter that blocks the horizontally polarized light. Since light that reflects off of water and other horizontal surfaces is mainly horizontally polarized, this light is blocked, thus reducing the intensity of the light without losing any of the details.



http://njc.tl/k2

39 What principle is responsible for the fact that certain sunglasses can reduce glare from reflected surfaces?

- A Refraction.
- B Polarization.
- C Diffraction.
- D Total internal reflection.

Answer

http://njc.tl/k3

40 Which component of an Electromagnetic Wave interacts most strongly with matter?

- A Electric Field and Magnetic field, equally.
- B Gravitational Field.
- C Electric Field.
- D Magnetic Field.

Answer

http://njc.tl/k4