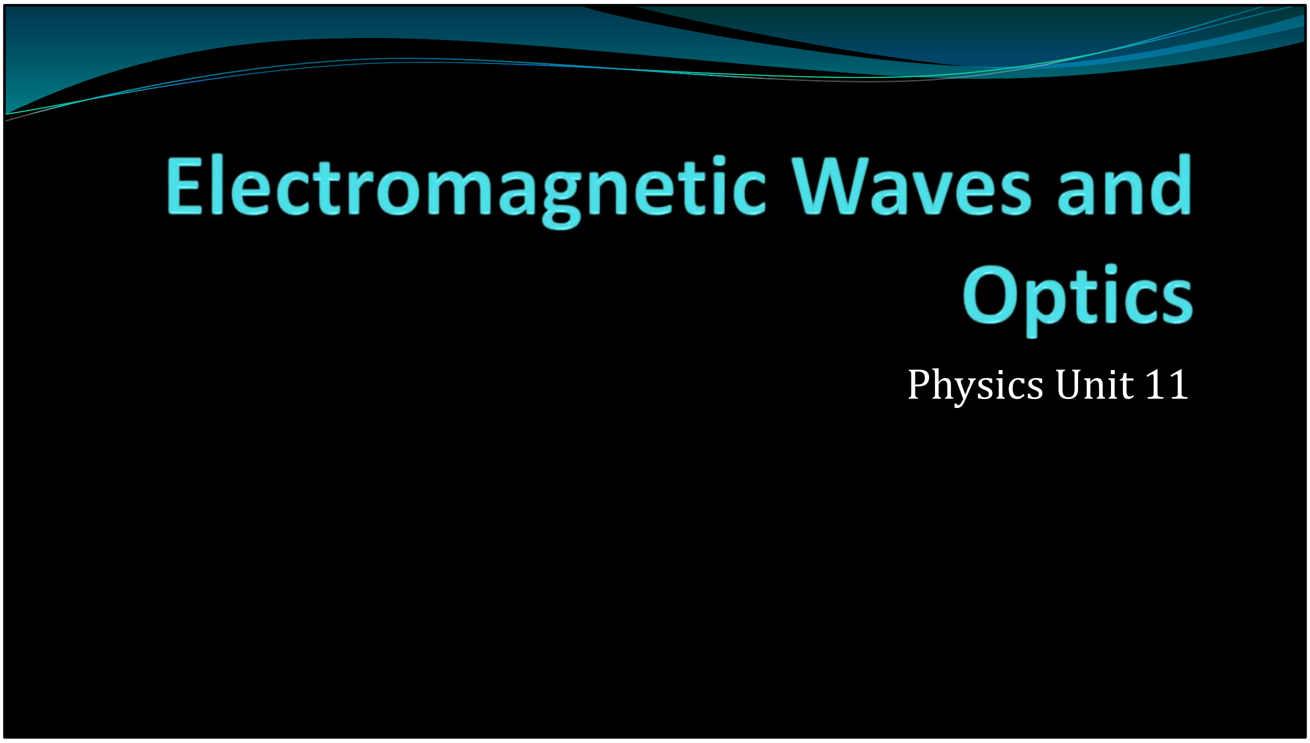


Physics Unit 11

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at* https://openstaxcollege.org/textbooks/college-physics
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

Slides created by
Richard Wright, Andrews Academy
rwright@andrews.edu

11-01 Maxwell's Equations and Production of EM Waves

In this lesson you will…

- Restate Maxwell's equations.
- Describe the electric and magnetic waves as they move out from a source, such as an AC generator.
- Explain the mathematical relationship between the magnetic field strength and the electrical field strength.
- Calculate the maximum strength of the magnetic field in an electromagnetic wave, given the maximum electric field strength.

11-01 Maxwell's Equations and Production of EM Waves

- James Clerk Maxwell – Scottish physicist who showed that electricity and magnetism together create electromagnetic waves
- **Maxwell's Equations**
  - Gauss's Law

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

  - Gauss's Law for Magnetism (no magnetic monopoles)

$$\nabla \cdot B = 0$$

  - Faraday's Law

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

  - Ampere's Circuit Law

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

Operators are divergence (upside down Δ with dot) – how does it spread out
Curl (how does it twist)

11-01 Maxwell's Equations and Production of EM Waves

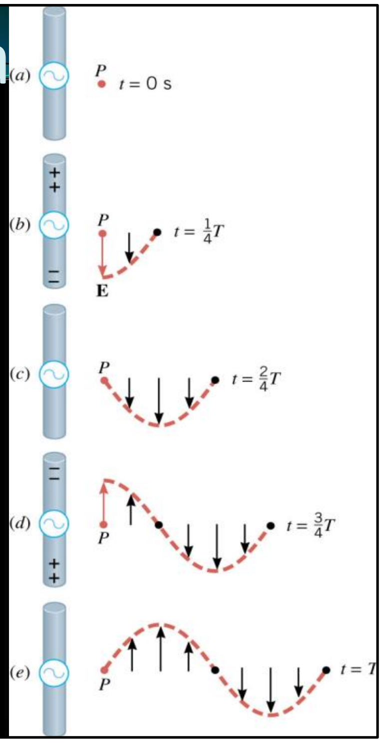
- Maxwell predicted that the speed of electromagnetic waves would be

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.00 \times 10^8 \; m/s$$
$$\epsilon_0 = 8.85 \times 10^{-12} \; C^2/Nm^2$$
$$\mu_0 = 4\pi \times 10^{-7} \; T/Nm$$

- Heinrich Hertz was the first scientist to generate and receive EM waves.

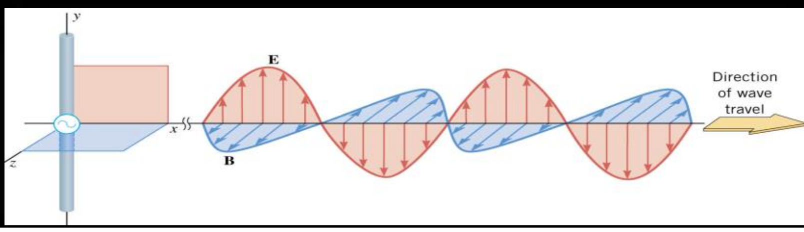
11-01 Maxwell's Equations a Production of EM Waves

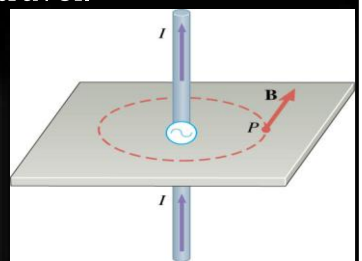
- Creation of electromagnetic waves
  - Two wires are connected to either side of an AC generator to form an antenna.
  - As the emf of the generator changes a potential difference between the ends of the wires is created.
  - The potential difference makes an electric field.
  - As the AC generator changes polarity, the electric field direction is reversed.



11-01 Maxwell's Equations and Production of EM Waves

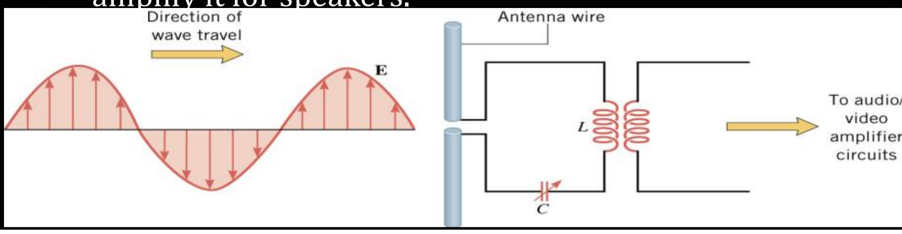
- Also, as the potential difference changes directions, the charges in the antenna run to the other ends creating a current.
- Current creates a B-field perpendicular to the wire.
- Electromagnetic waves are both E-field and B-field.
- Field are perpendicular to each other and the direction of travel.
- Transverse waves.





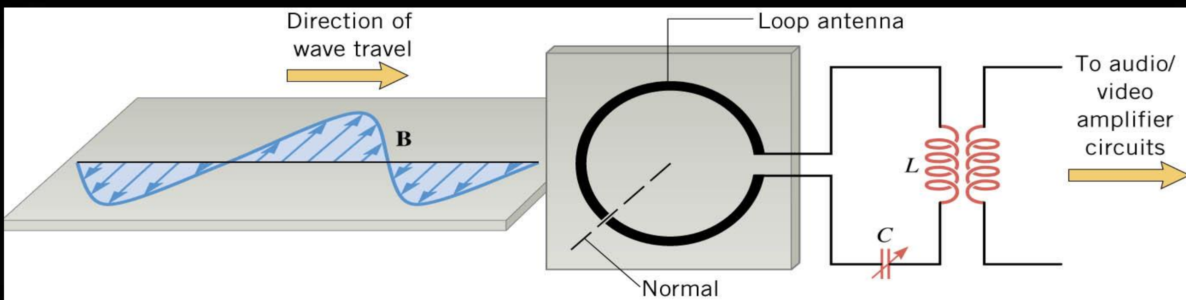
11-01 Maxwell’s Equations and Production of EM Waves

- To detect EM waves
  - Need antenna to receive either E-field or B-field.
  - E-field – Straight antenna
    - The E-field causes electrons to flow in the opposite direction creating current that changes with time as the E-field changes.
    - The circuitry attached to the antenna let you pick the frequency (LC-circuit) and amplify it for speakers.



11-01 Maxwell's Equations and Production of EM Waves

- B-field – Loop antenna
  - The B-field flowing through the loop induces a current that changes as the B-field changes.



11-01 Maxwell’s Equations and Production of EM Waves

- Relating the E-field and B-field strengths
  - Stronger E-field creates greater current which makes greater B-field

$$\frac{E}{B} = c$$

11-01 Maxwell's Equations and Production of EM Waves

- EM waves can travel through a vacuum or material because E- and B-fields can exist in both.
- All EM waves travel the same speed in a vacuum.
  - $c = 3.00 \times 10^{8}\ m/s$
- Frequency of the wave is determined by the source.

11-01 Homework

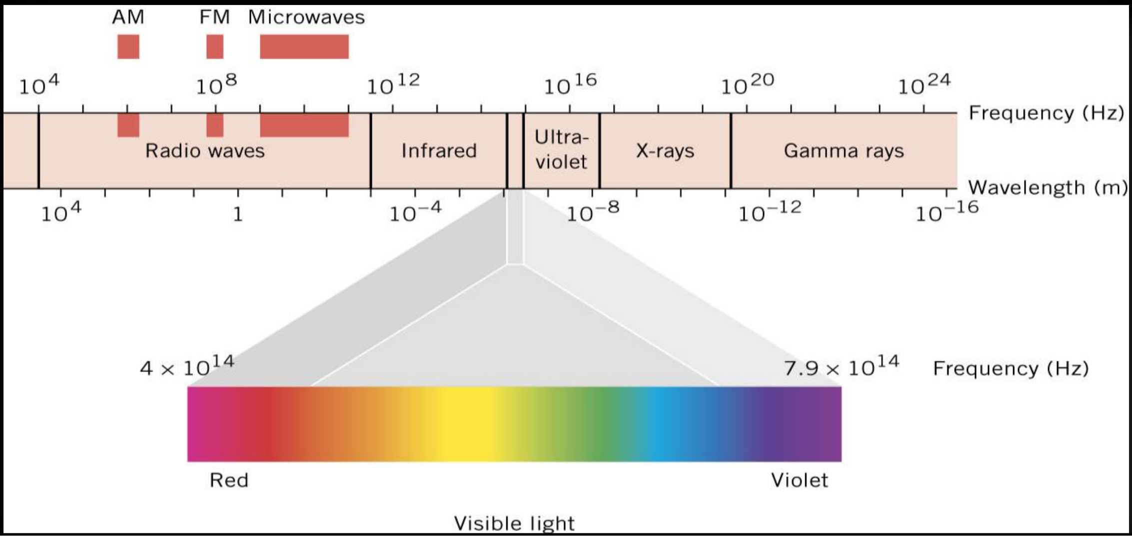
- Produce waves. Do homework.
- Read 24.3, 24.4

11-02 The EM Spectrum and Energy

In this lesson you will…

- Explain why the higher the frequency, the shorter the wavelength of an electromagnetic wave.
- Draw a simplified electromagnetic spectrum, indicating the relative positions, frequencies, and spacing of the different types of radiation bands.
- Explain how the energy and amplitude of an electromagnetic wave are related.

11-02 The EM Spectrum and Energy



The wavelength/frequency determines the type of EM wave

11-02 The EM Spectrum and Energy

- For EM waves in vacuum $v = c = 299792458\ m/s$
  - This is exact and is used to define the meter
  - As EM waves travel through other substances, like plastic, it travels slower.

- For all waves $v = f\lambda$

Use $c = 3.00 \times 10^8$ m/s for most calculations

11-02 The EM Spectrum and Energy

- An EM wave has a frequency of 90.7 MHz. What is the wavelength of this wave? What type of EM wave is it?

- λ = 3.31 m
- Radio wave (FM)

$$c = f\lambda \rightarrow 3.00 \times 10^{8}\,\frac{m}{s} = (90.7 \times 10^{6}\ Hz)\lambda \rightarrow \lambda = 3.31\ m$$

11-02 The EM Spectrum and Energy

- Wave's energy is proportional to the amplitude squared
- Wave's intensity

$$I_{ave} = \frac{c\epsilon_0 E_0^2}{2}$$

$$I_{ave} = \frac{cB_0^2}{2\mu_0}$$

$$I_{ave} = \frac{E_0 B_0}{2\mu_0}$$

$$I_0 = 2I_{ave} \text{ and } I = \frac{P}{A}$$

Third eq from substituting $cB_0 = E_0$ into the 2nd eq

11-02 The EM Spectrum and Energy

- A certain microwave oven can produce 1500 W of microwave radiation over an area that is 30 cm by 30 cm.
  a. What is the intensity in W/m^2?
    - $1.67 \times 10^4 \frac{W}{m^2}$
  b. Calculate the peak electric field strength, E_0, in these waves.
    - $3.55 \times 10^3 \frac{N}{C}$
  c. What is the peak magnetic field strength, B_0?
    - $1.18 \times 10^{-5}\ T$

$$I = \frac{P}{A}$$

$$I = \frac{1500\ W}{0.3\ m \times 0.3\ m} = 1.67 \times 10^4 \frac{W}{m^2}$$

$$I_{ave} = \frac{c\epsilon_0 E_0^2}{2}$$

$$1.67 \times 10^4 \frac{W}{m^2} = \frac{\left(3.00 \times 10^8 \frac{m}{s}\right)\left(8.85 \times 10^{-12} \frac{C^2}{Nm^2}\right) E_0^2}{2}$$

$$E_0^2 = 1.258 \times 10^7 \frac{N^2}{C^2}$$

$$E_0 = 3.55 \times 10^3 \frac{N}{C}$$

$$\frac{E}{B} = c$$

$$\frac{3.55 \times 10^3 \frac{N}{C}}{B} = 3.00 \times 10^8 \frac{m}{s}$$

$$B = 1.18 \times 10^{-5}\ T$$

11-02 Homework

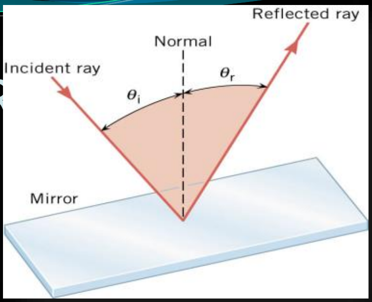
- These are a whole spectrum of problems.
- Read 25.1, 25.2, 25.3

11-03 The Laws of Reflection and Refraction

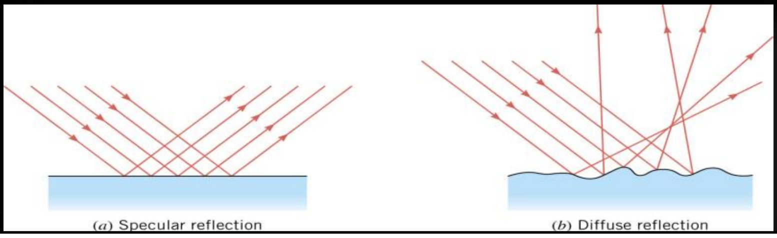
In this lesson you will…

- List the ways by which light travels from a source to another location.
- Explain reflection of light from polished and rough surfaces.
- Determine the index of refraction, given the speed of light in a medium.

11-03 The Laws of Reflection and R



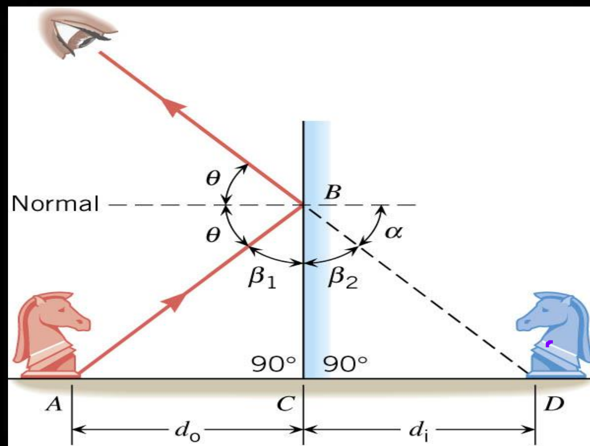
- Law of Reflection: $\theta_r = \theta_i$
- Specular Reflection
  - Parallel light rays are reflected parallelly
- Diffuse Reflection
  - Parallel light rays are scattered by irregularities in the surface.



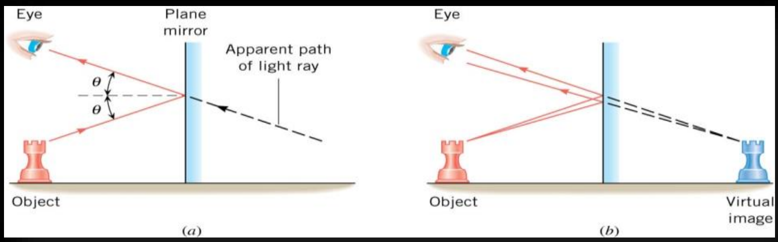
11-03 The Laws of Reflection and Refraction

Plane Mirror

- Image is upright
- Image is same size
- Image is located as far behind the mirror as you are in front of it



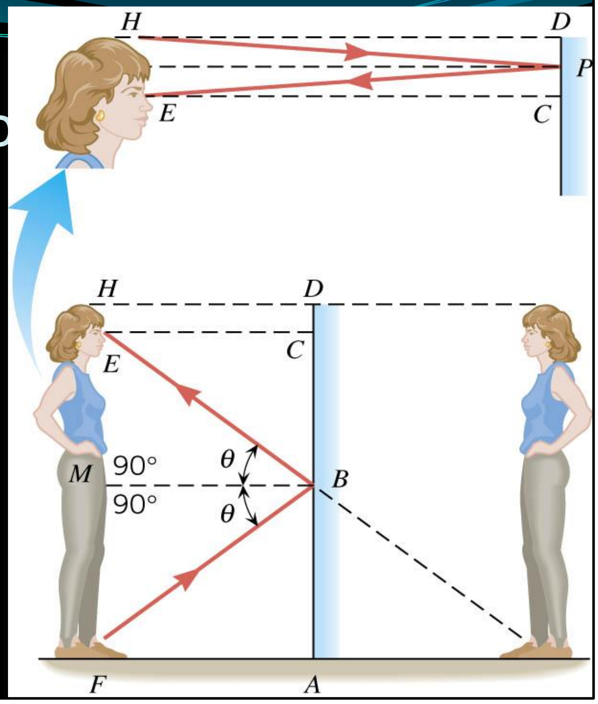
11-03 The Laws of Reflection and Refraction



- Since light rays appear to come from behind mirror, the image is called a **virtual image**.
- If light rays appear to come from a real location, the image is called a **real image**.
  - Real images can be projected on a screen, virtual images cannot.
- Plane mirrors only produce virtual images.

11-03 The Laws of Reflectio

- How long must a plane mirror be to see your whole reflection?
- From half way between your eyes and floor to half way between your eyes and the top of your head.



11-03 The Laws of Reflection and Refraction

- Speed of light in a vacuum:
  - $c = 3.00 \times 10^8$ m/s
- Light travels slower through materials due to light hitting, absorbed by, emitted by, and scattered by atoms.

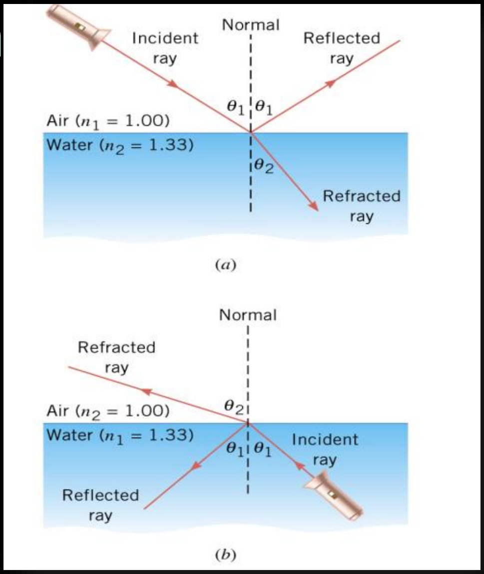
- Index of Refraction
  - Number to indicate relative speed of light in a material

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

n = index of refraction
c = speed of light in vacuum
v = speed of light in material

11-03 The Laws of Reflection a

- When light hits the surface of a material part of it is reflected
- The other part goes into the material
- The transmitted part is bent (***refracted***)

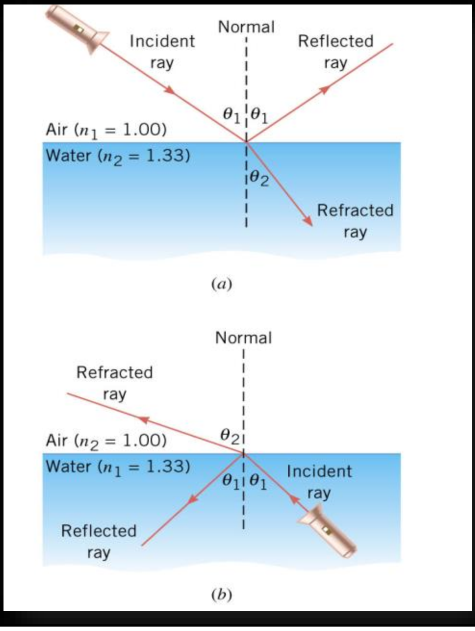


11-03 The Laws of Reflection

- Snell's Law (The Law of Refraction)

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

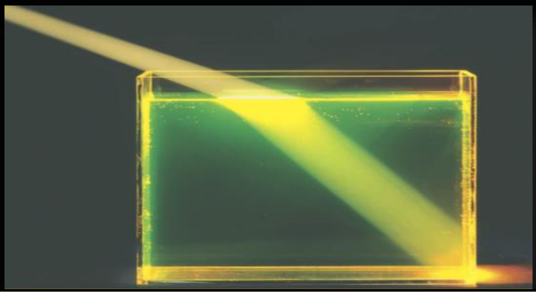
- Where
  - n_1 = index of refraction of incident medium
  - n_2 = index of refraction of second medium
  - θ_1 = angle of incidence (measured to normal)
  - θ_2 = angle of refraction (measured to normal)



To go from less optically dense to more optically dense, the ray is bent towards normal.
To go from more optically dense to less optically dense, the ray is bent away from the normal.
When the light goes from one material to another, it bends towards the slower material.

11-03 The Laws of Reflection and Refraction

- You shine a laser into a piece of clear material. The angle of incidence is 35°. You measure the angle of refraction as 26°. What is the material?
  - Ice
- What is the speed of light in the material?
  - $v = 2.29 \times 10^8$ m/s



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$1.00 \sin 35° = n \sin 26° \rightarrow n = 1.308$$
$$\textit{Table says this should be ice.}$$

$$n = \frac{c}{v} \rightarrow 1.308 = \frac{3.00 \times 10^8 \frac{m}{s}}{v} \rightarrow v = 2.29 \times 10^8\ m/s$$

11-03 Homework

- Let your answers reflect the truth.
- Read 25.4, 25.5

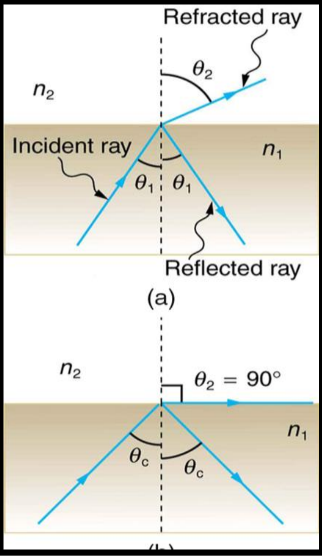
11-04 Total Internal Reflection

In this lesson you will…

- Explain the phenomenon of total internal reflection.
- Describe the workings and uses of fiber optics.
- Analyze the reason for the sparkle of diamonds.
- Explain the phenomenon of dispersion and discuss its advantages and disadvantages.

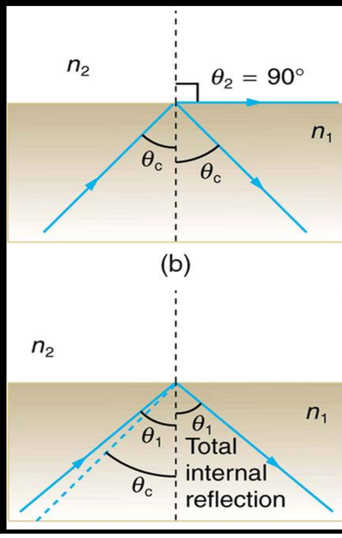
11-04 Total Internal Reflection

- Total Internal Reflection
  - When light hits a interface between two types of media with different indices of refractions
    - Some is reflected
    - Some is refracted
  - Critical angle
    - Angle of incidence where refracted angle is 90°
    - Angles of incidence larger than this cause the refracted angle to be inside the material. This can't happen, so no refraction occurs.



11-04 Total Internal Reflection

- Critical angle
  - $\theta_2 = 90°$
  - $n_1 \sin\theta_1 = n_2 \sin\theta_2$
  - $n_1 \sin\theta_c = n_2 \sin 90°$
  - $\theta_c = \sin^{-1}\frac{n_2}{n_1}$
    - Where $n_1 > n_2$



11-04 Total Internal Reflection

- What is the critical angle from cubic zirconia (n=2.16) to air? Will an angle of 25° produce total internal reflection?
- 27.7°
- No

$$\theta_c = \sin^{-1}\frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\frac{1.000293}{2.15}$$

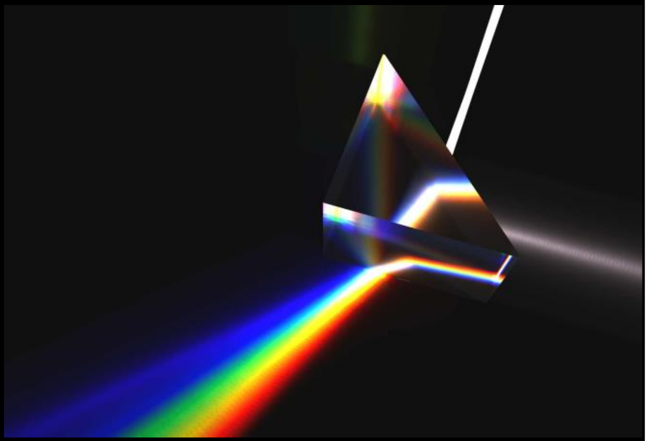
$$\theta_c = 27.7°$$

11-04 Total Internal Reflection

- Uses of total internal reflection
  - Fiber optics for
    - Endoscopes
    - Telecommunications
    - Decorations
  - Binoculars/telescopes
    - Makes them shorter
  - Reflectors
  - Gemstones
    - Cut so that light only exits at certain places

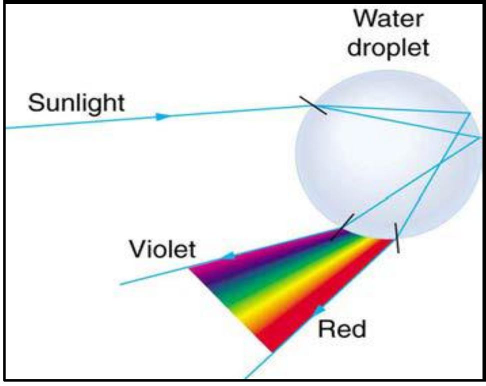
11-04 Total Internal Reflection

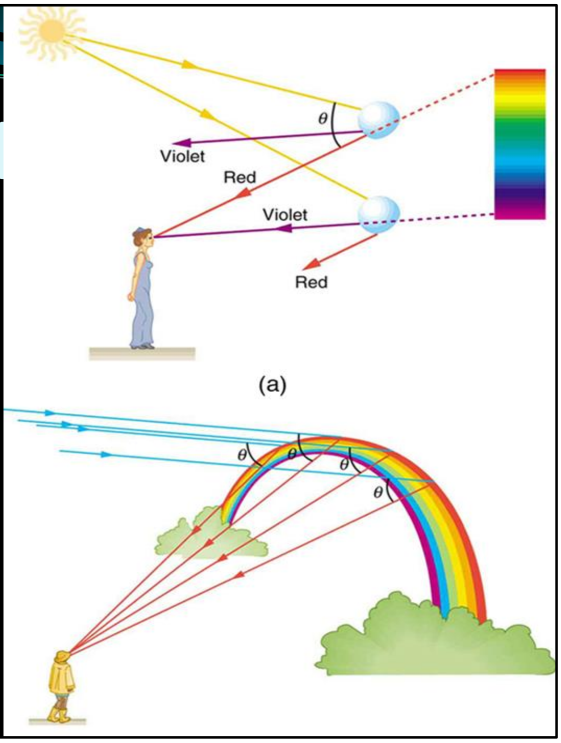
- Dispersion
  - Each wavelength of light has a different index of refraction
  - Red — lowest
  - Violet — highest
  - When light is refracted, the violet bends more than red, which splits the colors



11-04 Total Internal

- Rainbows
  - Dispersion by refraction with internal reflection

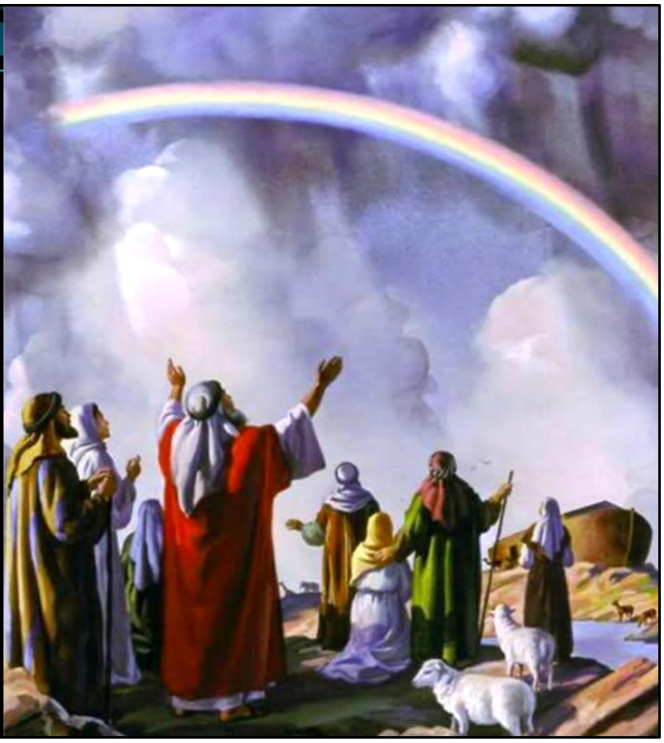




11-04 Homework

- "I have set my rainbow in the clouds, and it will be the sign of the covenant between me and the earth." Genesis 9:13

- Read 25.6



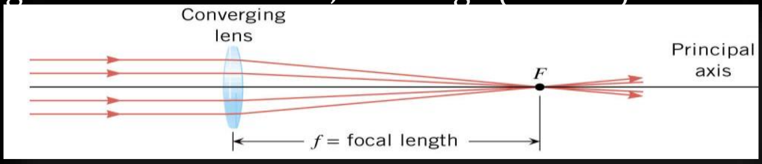
11-05 Image Formation by Lenses

In this lesson you will…

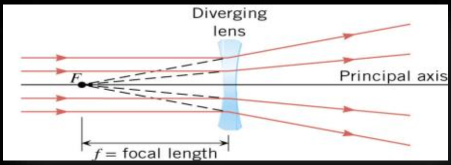
- List the rules for ray tracking for thin lenses.
- Illustrate the formation of images using the technique of ray tracking.
- Determine power of a lens given the focal length.

11-05 Image Formation by Lenses

- Lens - Made from transparent material, usually with a curved edge.
- Converging Lens – thick middle, thin edge (convex)

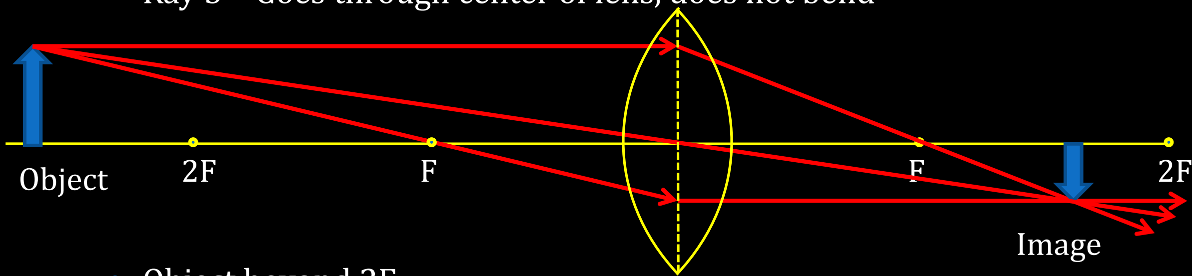


- Diverging Lens – thin middle, thick edge (concave)
- Power of lens
- $P = \frac{1}{f}$
  - Unit: diopters (D)



11-05 Image Formation by Lenses

- Ray Diagrams - Converging Lenses
  - Ray 1 – Parallel to principal axis, bends through F
  - Ray 2 – Through F, bends parallel to principal axis
  - Ray 3 – Goes through center of lens, does not bend

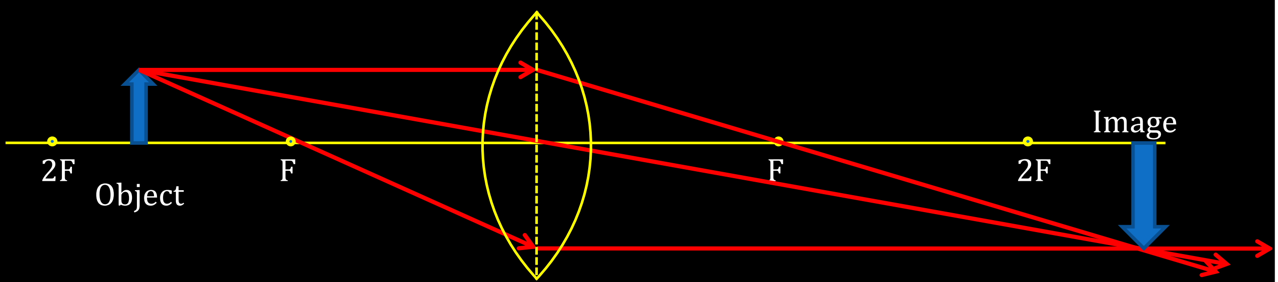


  - Object beyond 2F,
  - Image inverted, real, smaller between F and 2F

Like camera

11-05 Image Formation by Lenses

- Object between 2F and F

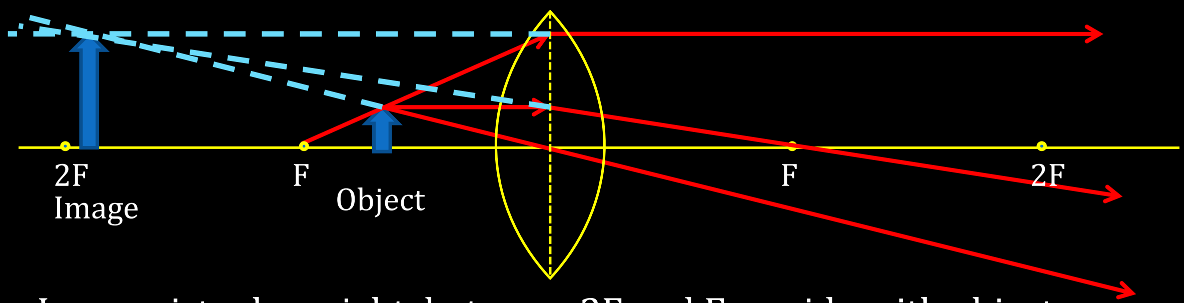


- Image real, inverted, larger beyond 2F

projector

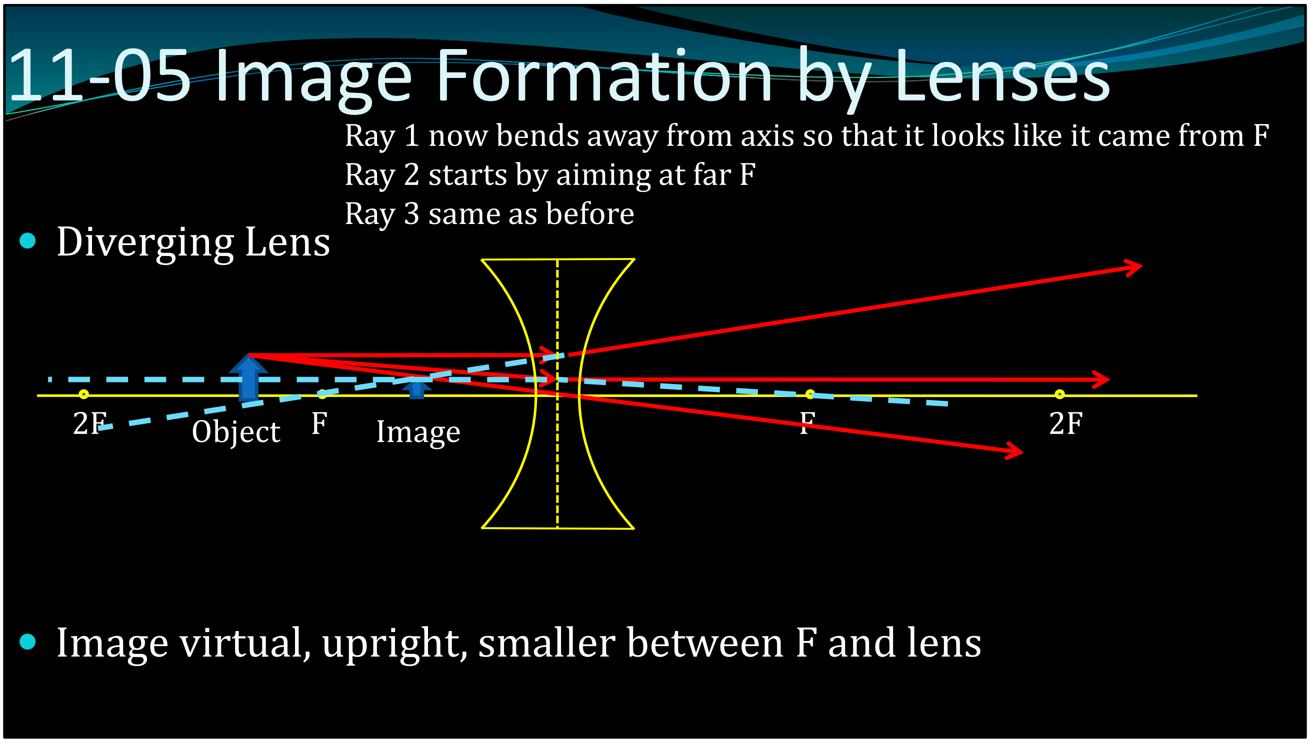
11-05 Image Formation by Lenses

- Object between F and lens



- Image virtual, upright, between 2F and F on side with object

Like magnifying glass



Ray 1 now bends away from axis so that it looks like it came from F
Ray 2 starts by aiming at far F
Ray 3 same as before

Like some glasses

11-05 Image Formation by Lenses

- Thin-lens equation
- $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

- Magnification equation
- $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

- Converging Lens
  - f +
  - d_o + if real (left side)
  - d_i + if real (right side)

- Diverging Lens
  - f -
  - d_o + if real (left side)
  - d_i - if virtual (left side)

Lenses can be put in combination where a real image from the first lens is the object of the second lens. This is done in a microscope and telescope.

Lab idea: make a telescope or microscope on optics bench.

11-05 Image Formation by Lenses

- Lens Reasoning Strategy
  1. Examine the situation to determine that image formation by a lens is involved.
  2. Determine whether ray tracing, the thin lens equations, or both are to be employed. A sketch is very useful even if ray tracing is not specifically required by the problem. Write symbols and values on the sketch.
  3. Identify exactly what needs to be determined in the problem (identify the unknowns).
  4. Make a list of what is given or can be inferred from the problem as stated (identify the knowns). It is helpful to determine whether the situation involves a case 1, 2, or 3 image. While these are just names for types of images, they have certain characteristics (given in **Table 25.3**) that can be of great use in solving problems.
  5. If ray tracing is required, use the ray tracing rules listed near the beginning of this section.
  6. Most quantitative problems require the use of the thin lens equations. These are solved in the usual manner by substituting knowns and solving for unknowns. Several worked examples serve as guides.
  7. Check to see if the answer is reasonable: Does it make sense? If you have identified the type of image (case 1, 2, or 3), you should assess whether your answer is consistent with the type of image, magnification, and so on.

11-05 Image Formation by Lenses

- A child is playing with a pair of glasses with diverging lenses. The focal length is 20 cm from the lens and his eye is 5 cm from the lens. A parent looks at the child's eye in the lens. If the eye is the object, where is the image located?
  - 4 cm behind the lens
- If his eye is really 3 cm across, how big does it appear?
  - h_i = 2.4 cm

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \rightarrow \frac{1}{-20\ cm} = \frac{1}{5\ cm} + \frac{1}{d_i} \rightarrow \frac{1}{-20} - \frac{1}{5} = \frac{1}{d_i} \rightarrow \frac{1}{d_i} = -0.25 \rightarrow -4\ cm$$

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow \frac{h_i}{3\ cm} = -\frac{-4\ cm}{5\ cm} \rightarrow h_i = 2.4\ cm$$

This is like "Coke bottle" lenses.

11-05 Homework

- Form an image in your mind of doing well.
- Read 25.7

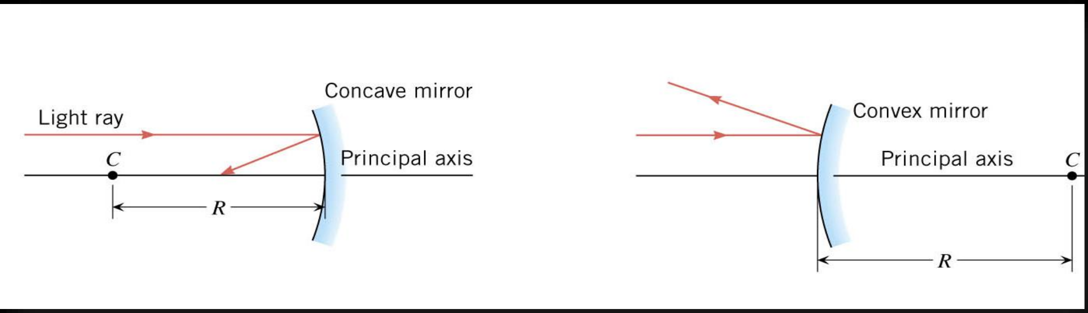
11-06 Image Formation by Mirrors

In this lesson you will…

- Illustrate image formation in a flat mirror.
- Explain with ray diagrams the formation of an image using spherical mirrors.
- Determine focal length and magnification given radius of curvature, distance of object and image.

11-06 Image Formation by Mirrors

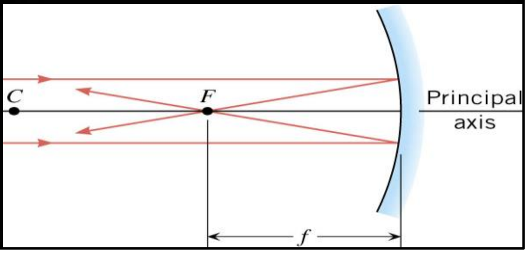
- Concave: bends in
- Convex: bends out



Remember concave because it makes a small cave

11-06 Image Formation by Mirrors

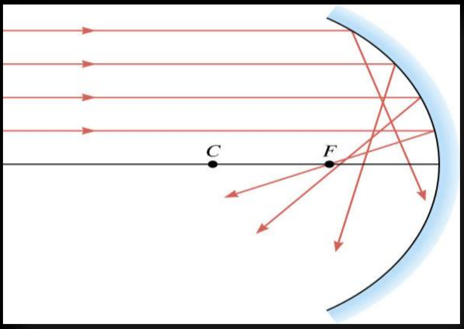
- Normals are always perpendicular to the surface and pass through the center of curvature, C.
  - Law of Reflection says that the angle to the normal is the same for the incident and reflected rays
- Principal axis: imaginary line through C and the center of the mirror.
- Focal point (F): parallel rays strike the mirror and converge at the focal point.
- Focal length (*f*): distance between F and mirror
  - Concave mirrors: $f = \frac{1}{2}R$
  - Convex mirrors: $f = -\frac{1}{2}R$



R = radius of curvature

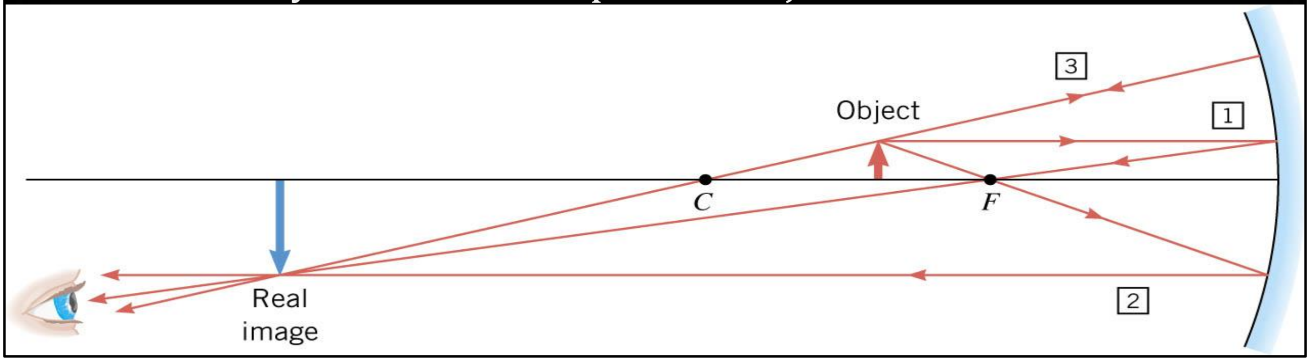
11-06 Image Formation by Mirrors

- Spherical aberration
  - Rays far from the principle axis actually cross between F and the mirror.
  - Fix this by using a parabolic mirror.



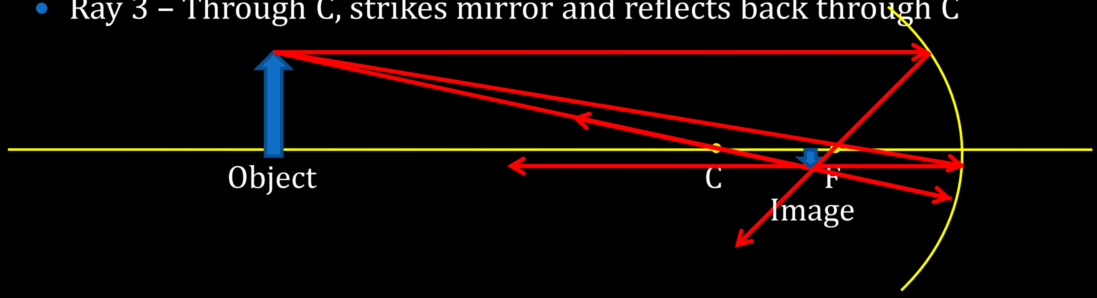
11-06 Image Formation by Mirrors

- Ray tracing diagram: Diagram used to find the location and type of image produced.
- Notice the rays start at the top of the object.



11-06 Image Formation by Mirrors

- Concave Mirror
  - Ray 1 – Parallel to principal axis, strikes mirror and reflects through F
  - Ray 2 – Through F, strikes mirror and reflects parallel to principal axis
  - Ray 3 – Through C, strikes mirror and reflects back through C

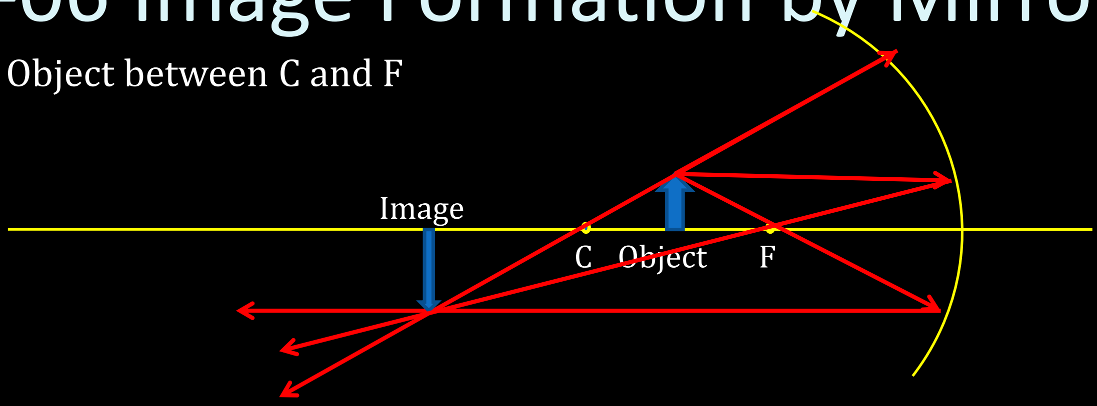


  - Object beyond C – image is real, inverted and smaller between C and F

Like a telescope

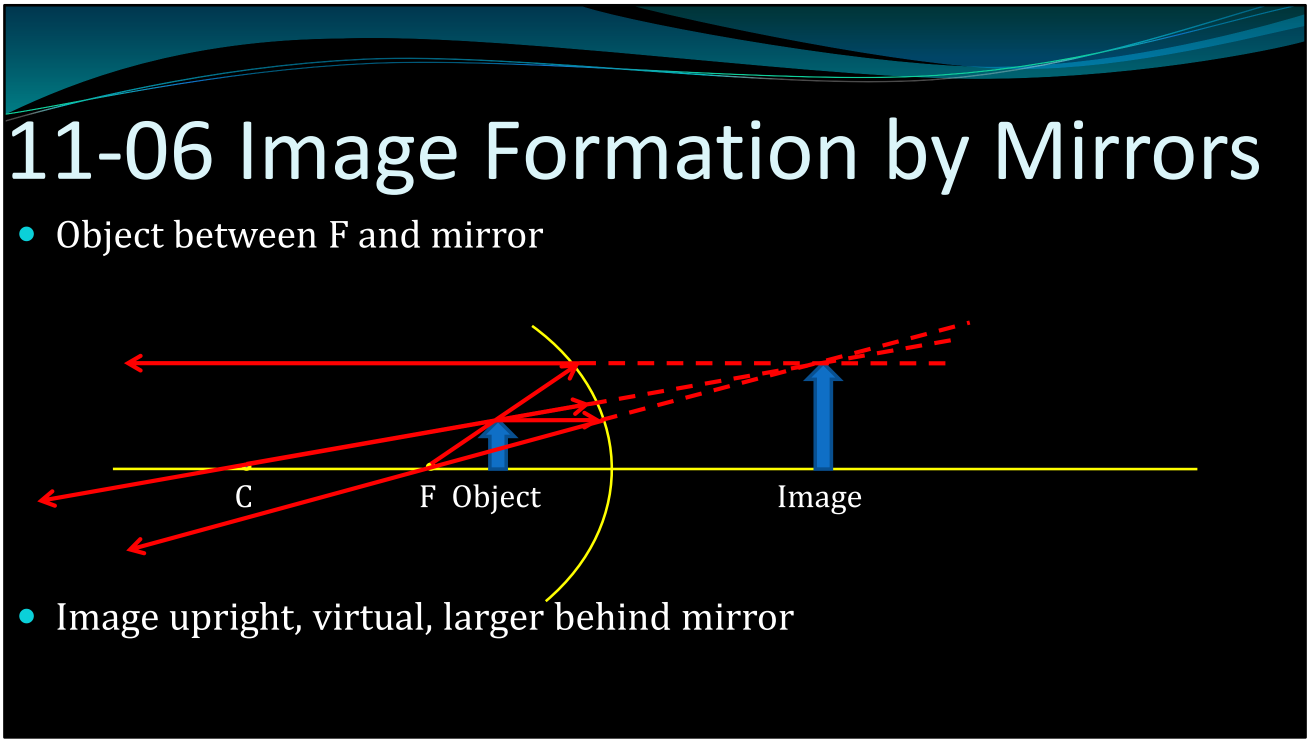
11-06 Image Formation by Mirrors

- Object between C and F



- Image inverted, real, and larger beyond C

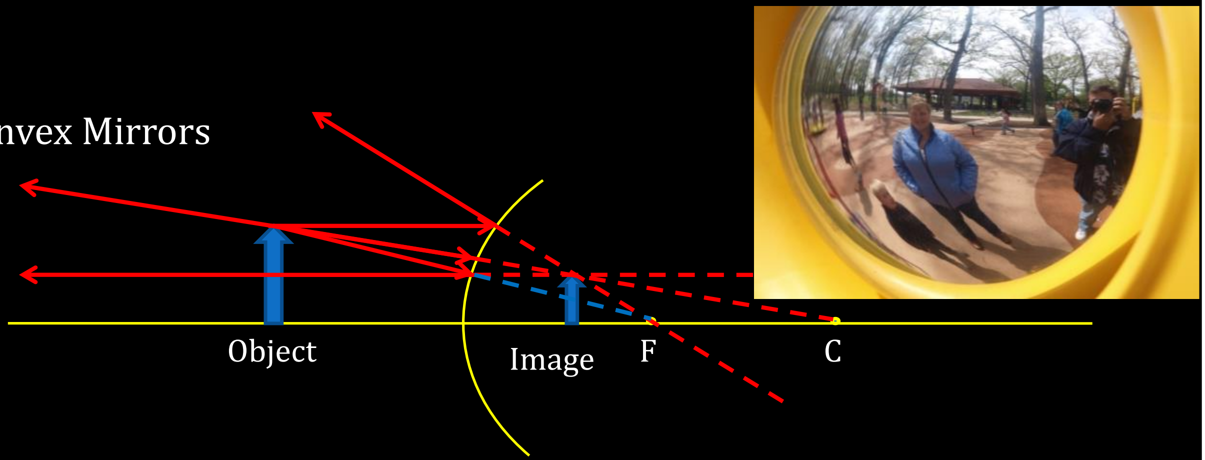
Like a projector



Like a makeup mirror

11-06 Image Formation by Mirrors

- Convex Mirrors



- Image upright, virtual, smaller behind mirror between F and mirror

Like passenger side view mirror

11-06 Image Formation by Mirrors

- Mirror Equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

- Where
  - f = focal length (negative if convex)
  - d_0 = object distance
  - d_i = image distance (negative if virtual)

f= distance between F and mirror
d_0 = distance between object and mirror
d_i = distance between image and mirror

These were discovered through the use of geometry and similar triangles.

11-06 Image Formation by Mirrors

- Magnification Equation:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

- Where
  - m = magnification
  - h_o = object height
  - h_i = image height (negative if inverted)
  - d_0 = object distance
  - d_i = image distance (negative if virtual)

11-06 Image Formation by Mirrors

- A 0.5-m high toddler is playing 10 m in front of a concave mirror with radius of curvature of 7 m.
  - What is the location of his image?
    - d_i = 5.38 m
  - What is the height of his image?
    - h_i = -0.269 m

$$f = \frac{1}{2}R = \frac{1}{2}(7\ m) = 3.5\ m$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \rightarrow \frac{1}{3.5} = \frac{1}{10} + \frac{1}{d_i} \rightarrow \frac{1}{3.5} - \frac{1}{10} = \frac{1}{d_i} \rightarrow \frac{1}{d_i} = 0.1857 \rightarrow d_i = 5.38\ m$$

$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o} \rightarrow -\frac{5.38}{10} = \frac{h_i}{0.5} \rightarrow h_i = -0.269m$$

11-06 Image Formation by Mirrors

- A 0.5-m high toddler is playing 10 m in front of a convex mirror with radius of curvature of 7 m.
  - What is the location of his image?
    - d_i = -2.59 m
  - What is the height of his image?
    - h_i = 0.130 m

$$f = -\frac{1}{2}R = -\frac{1}{2}(7\ m) = -3.5\ m$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \rightarrow \frac{1}{-3.5} = \frac{1}{10} + \frac{1}{d_i} \rightarrow \frac{1}{-3.5} - \frac{1}{10} = \frac{1}{d_i} \rightarrow \frac{1}{d_i} = -0.3857 \rightarrow d_i = -2.59\ m$$

$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o} \rightarrow \frac{2.59}{10} = \frac{h_i}{0.5} \rightarrow h_i = 0.130\ m$$

11-06 Homework

- The homework mirrors the lesson.
- Read 26.1, 26.2, 26.3

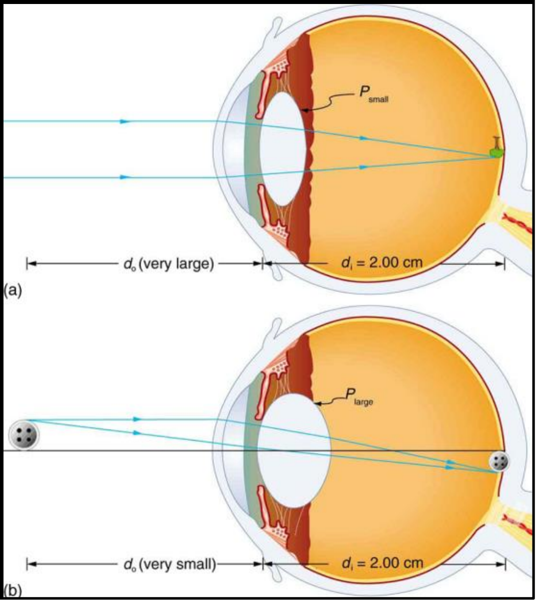
11-07 Vision

In this lesson you will…

- Explain the image formation by the eye.
- Explain why peripheral images lack detail and color.
- Analyze the accommodation of the eye for distant and near vision.
- Identify and discuss common vision defects.
- Explain nearsightedness and farsightedness corrections.
- Explain the simple theory of color vision.
- Outline the coloring properties of light sources.

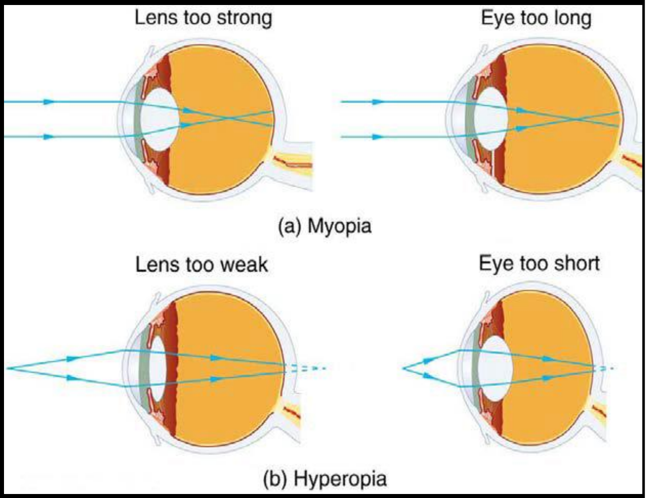
11-07 Vision

- Cornea/Lens act as single thin lens
- To see something in focus the image must be on the retina at back of eye
- Lens can change shape to focus objects from different object lengths



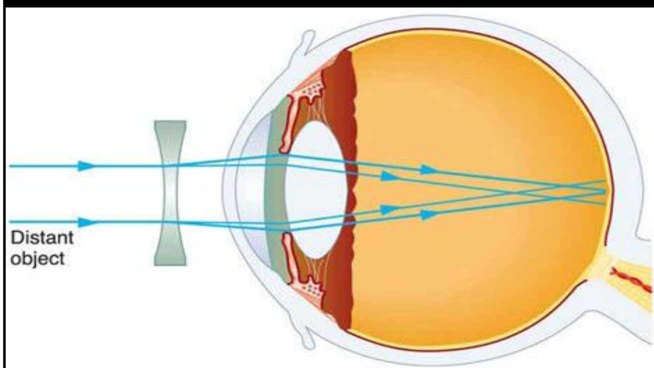
11-07 Vision

- Near-sightedness
  - Myopia
  - Image in front of retina
  - Correct with diverging lens
- Far-sightedness
  - Hyperopia
  - Image behind retina
  - Correct with converging lens

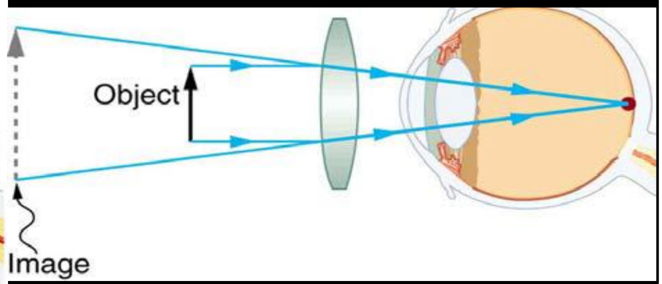


11-07 Vision

Myopia – Near-sighted



Hyperopia – Far-sighted



11-07 Vision

- What power of spectacle lens is needed to correct the vision of a nearsighted person whose far point is 20.0 cm? Assume the spectacle (corrective) lens is held 1.50 cm away from the eye by eyeglass frames.
- -5.41 D

You want this nearsighted person to be able to see very distant objects clearly. That means the spectacle lens must produce an image 20.0 cm
from the eye for an object very far away. An image 20.0 cm from the eye will be 18.5 cm to the left of the spectacle lens (see **Figure 26.6**).
Therefore, we must get $d_i = -18.5$ cm when $d_o \approx \infty$. The image distance is negative, because it is on the same side of the spectacle as the object.

Solution

Since d_i and d_o are known, the power of the spectacle lens can be found using $P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ as written earlier:

$$P = \frac{1}{\infty} + \frac{1}{-0.185}$$

Since $\frac{1}{\infty} = 0$, we obtain:

$$P = 0 - 5.405\ /m = -5.41\ D$$

11-07 Vision

- Color Vision
  - Photoreceptors in Eye
    - Rods
      - Very sensitive (see in dark)
      - No color info
      - Peripheral vision

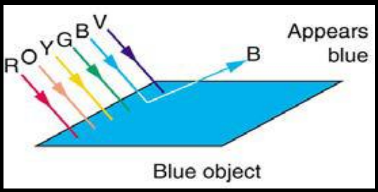
- Cones
  - Centered in center of retina
  - Work in only in bright light
  - Give color info
  - Essentially three types each picking up one primary color

Color vision is actually much more complicated

And they say this just “happened”

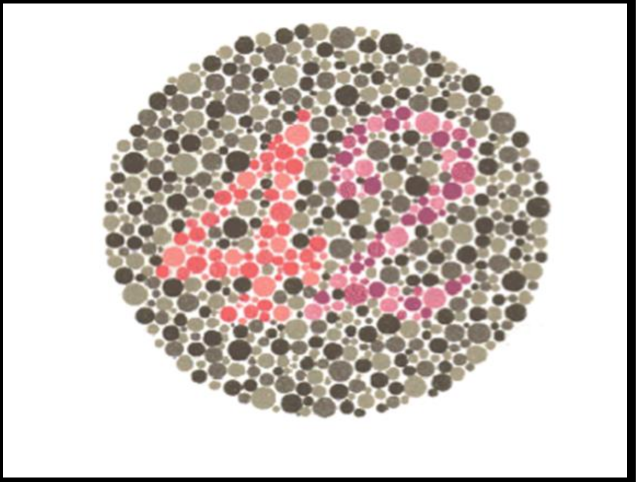
11-07 Vision

- Color
  - Non-light producing
    - The color we see is the color that reflects off the object
    - The object absorbs all the other colors
- Light-producing
  - The color we see is the color produced



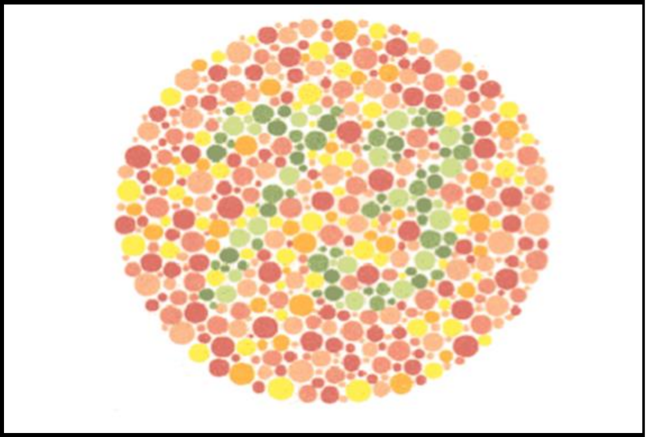
11-07 Vision

- If you have normal color vision, you'll see a **42**.
- Red colorblind people will see a **2**.
- Green colorblind people will only see a **4**.



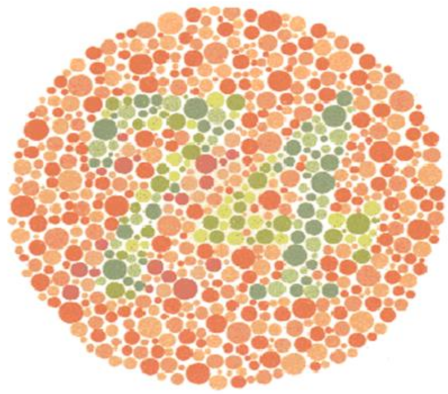
11-07 Vision

- If you have normal color vision, you see a **73** above.
- If you are colorblind you will not see a number above.



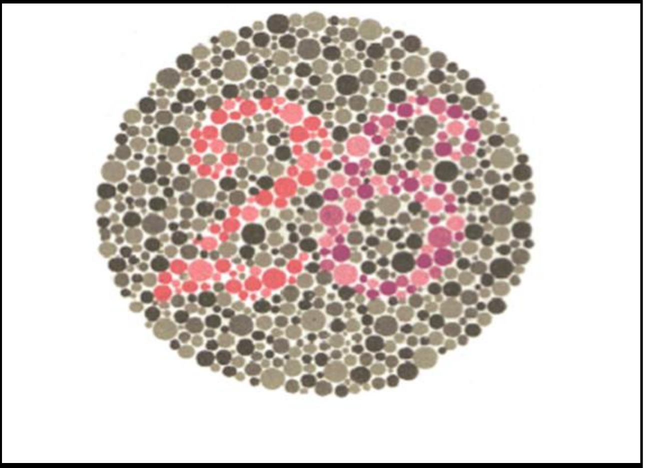
11-07 Vision

- If you have normal color vision you'll see a **74** above.
- If you are red green colorblind, you'll see a **21**.
- If you are totally colorblind you will not see a number above.



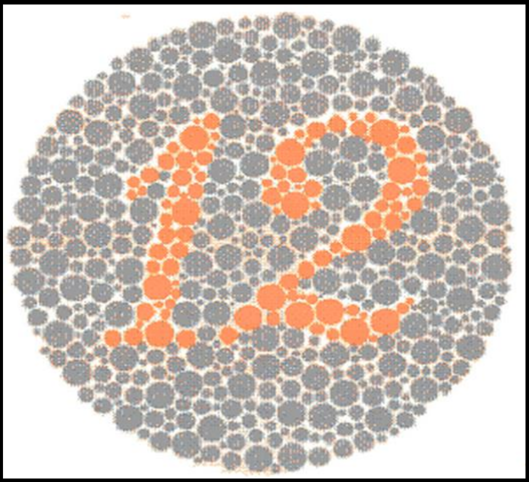
11-07 Vision

- If you have normal color vision you'll see a **26**.
- If you are red colorblind you will see a **6,** if you're mildly red colorblind you'll see a faint **2** as well.
- If you are green colorblind you'll see the a **2**, and if you're mildly green colorblind a faint **6** as well.



11-07 Vision

- If you have normal color vision you'll see a **12**.
- If you do not see **12** you are a liar. Everyone can see this one!



11-07 Homework

- Isn't it amazing how the eye works?

- Read 27.1, 27.2, 27.3

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment

In this lesson you will…

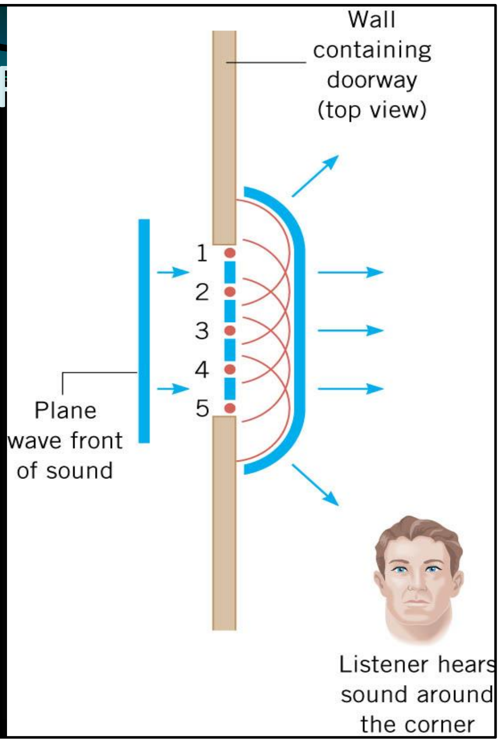
- Discuss the wave character of light.
- Identify the changes when light enters a medium.
- Discuss the propagation of transverse waves.
- Discuss Huygens's principle.
- Explain the bending of light.
- Explain the phenomena of interference.
- Define constructive interference for a double slit and destructive interference for a double slit.

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment

- Wave Character of Light
  - When interacts with object several times it's wavelength, it acts like a ray
  - When interacts with smaller objects, it acts like a wave
- When light hits medium from a vacuum, it slows down
- Frequency stays the same
- $c = f\lambda$
- $v = \frac{c}{n} = f\frac{\lambda}{n}$
- $\lambda_n = \frac{\lambda}{n}$
  - Where λ_n is wavelength in medium
  - n is index of refraction

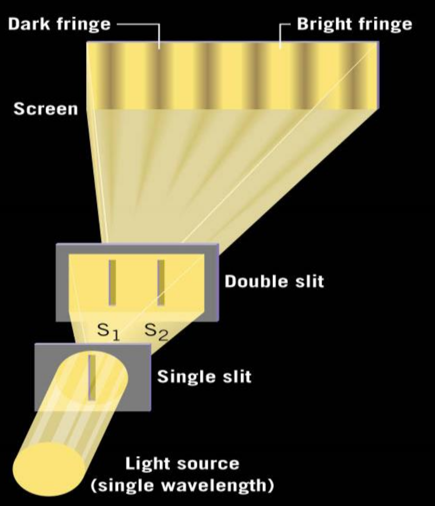
11-08 Interference, Huygens's Principle and Double Slit Experiment

- Huygens' Principle
  - Every point on a wave front acts as a source of tiny wavelets that move forward with the same speed as the wave; the wave front at a later instant is the surface that is tangent to the wavelets.



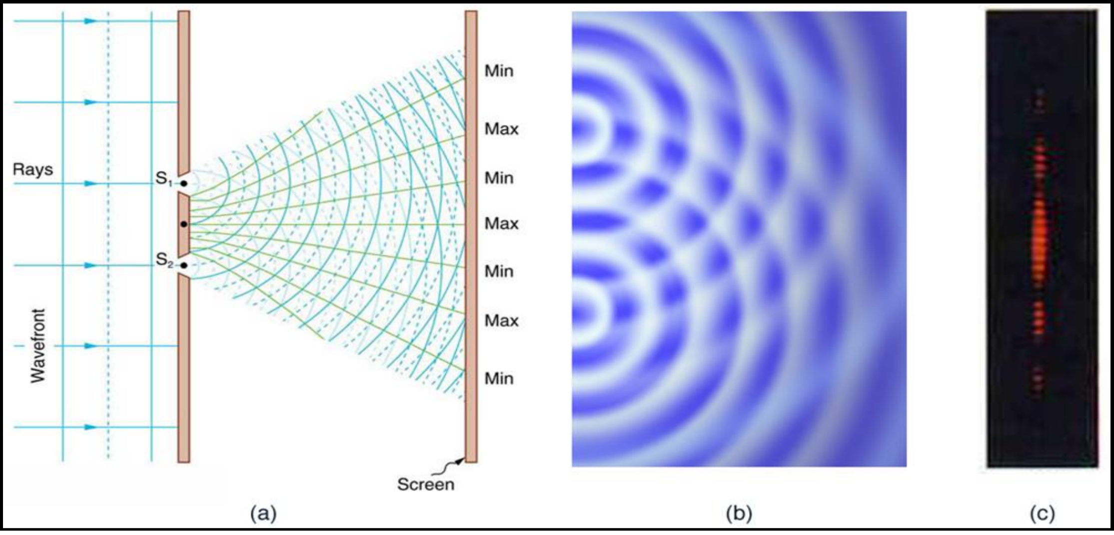
11-08 Interference, Huygens's Principle, Young's Double Slit Experiment

- In 1801, Thomas Young showed that two overlapping light waves interfered and was able to calculate wavelength.

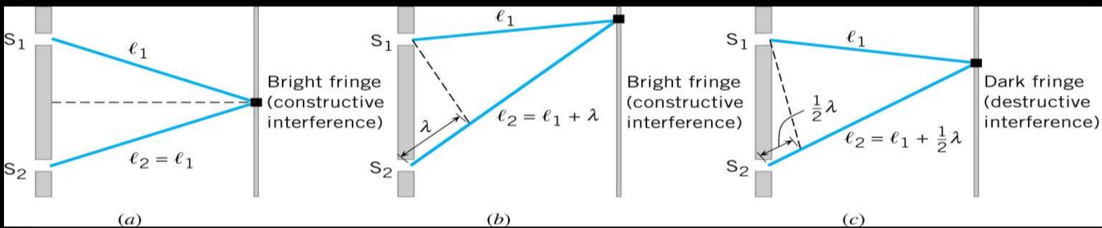


Have laser and double slit for demo (optics bench?)

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment



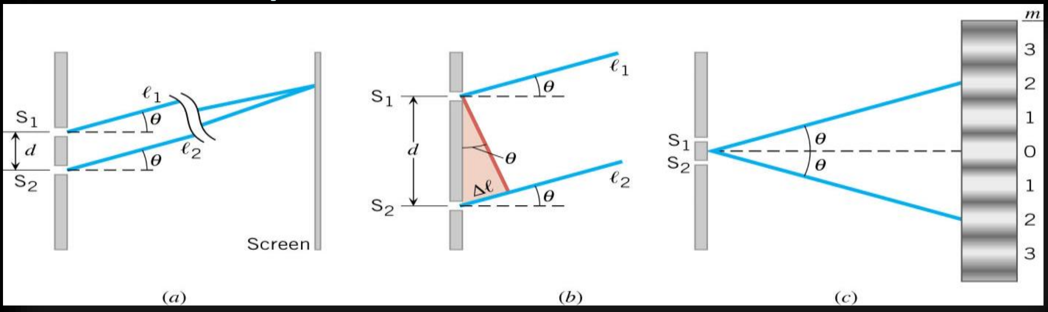
11-08 Interference, Huygens's Principle, Young's Double Slit Experiment



- Bright fringe where $\ell_1 - \ell_2 = m\lambda$
- Dark fringe where $\ell_1 - \ell_2 = (m + ½)\lambda$

- Brightness of fringes varies
  - Center fringe the brightest and decreases on either side

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment



- A) Rays from slits S_1 and S_2, which make approximately the same angle θ with the horizontal, strike a distant screen at the same spot.
- B) The difference in the path lengths of the two rays is $\Delta\ell = d \sin \theta$.
- C) The angle θ is the angle at which a bright fringe (m = 2, here) occurs on either side of the central bright fringe (m = 0)

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment

- $\Delta\ell = d \sin\theta$

- Bright fringe $\Delta\ell = m\lambda$
  - $d \sin\theta = m\lambda$

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

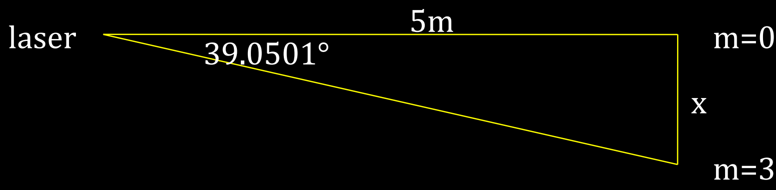
- Dark fringe $\Delta\ell = (m + \frac{1}{2})\lambda$
  - $d \sin\theta = (m + \frac{1}{2})\lambda$

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

θ = angle between fringe and center
m = integer
λ = wavelength
d = distance between slits

11-08 Interference, Huygens's Principle, Young's Double Slit Experiment

- A laser beam (λ = 630 nm) goes through a double slit with separation of 3 μm. If the interference pattern is projected on a screen 5 m away, what is the distance between the third order bright fringe and the central bright fringe?
- 4.06 m



$$\sin\theta = m\frac{\lambda}{d} \rightarrow \sin\theta = 3\frac{630\times10^{-9}\,m}{3\times10^{-6}\,m} \rightarrow \sin\theta = 0.63 \rightarrow \theta = 39.0501°$$

$$\tan 39.0501° = \frac{x}{5\,m} \rightarrow 5\,m\,(\tan 39.0501°) = x = 4.06\,m$$

11-08 Homework

- Don’t let your other work interfere with these problems.
- Read 27.4

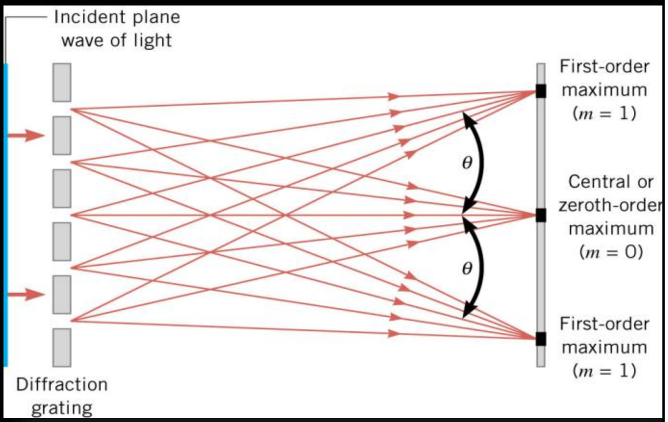
11-09 Multiple Slit Diffraction

In this lesson you will…

- Discuss the pattern obtained from diffraction grating.
- Explain diffraction grating effects.

11-09 Multiple Slit Diffraction

- Arrangement of many closely spaced slits
- As many as 40,000 slits per cm
- Produces interference patterns

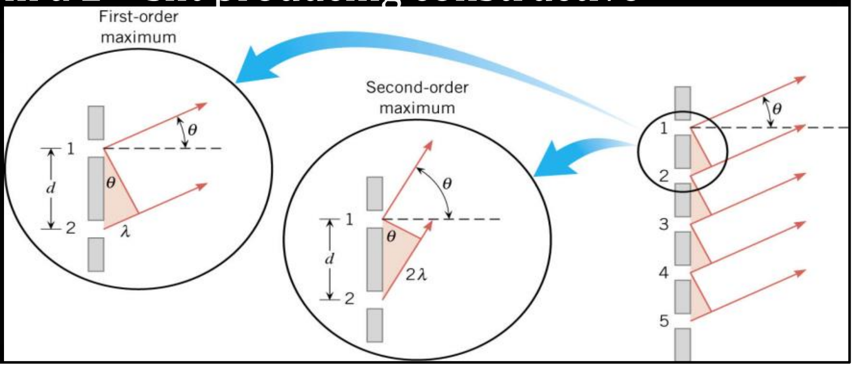


Have a couple diffraction gratings to play with

11-09 Multiple Slit Diffraction

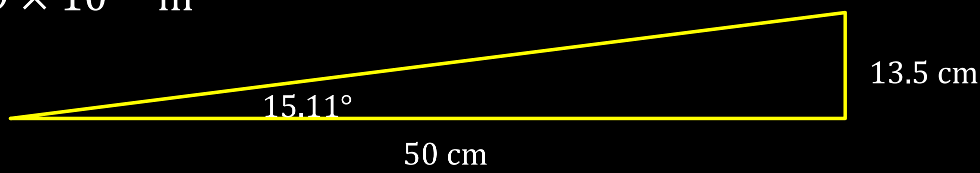
- The light rays are essentially parallel.
- The principal maxima occur when light from one slit travels mλ more to meet light from a 2nd slit producing constructive interference.
- Principal maxima

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



11-09 Multiple Slit Diffraction

- A laser which produces 650 nm light shines through a diffraction grating. An interference pattern is produced on a screen 50 cm away. The distance on the screen between the second order maxima and the center is 13.5 cm. What is the slit separation in the grating?
  - 4.99×10^{-6} m

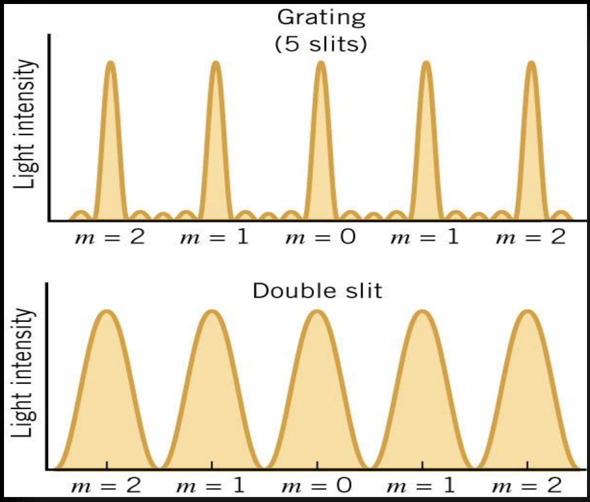


$$\tan\theta = \frac{13.5\ cm}{50\ cm} \rightarrow \theta = \tan^{-1}\frac{13.5}{50} = 15.11°$$

$$\sin\theta = m\frac{\lambda}{d} \rightarrow \sin 15.11° = 2\frac{650 \times 10^{-9}\ m}{d} \rightarrow d = 2\frac{650 \times 10^{-9}\ m}{\sin 15.11°}$$
$$= 4.99 \times 10^{-6}\ m$$

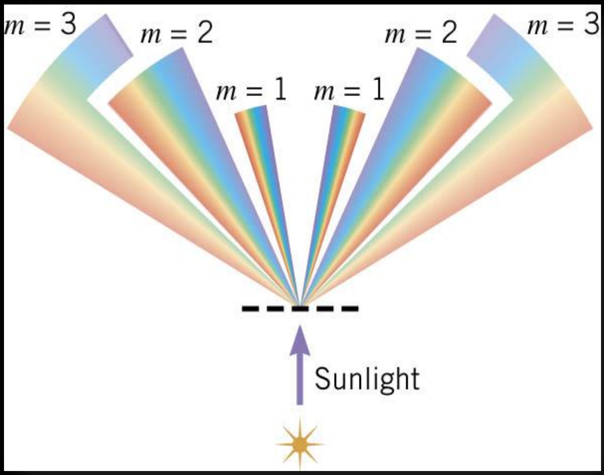
11-09 Multiple Slit Diffraction

- Diffraction gratings produce narrower, more defined maxima, but have small secondary maxima in between.



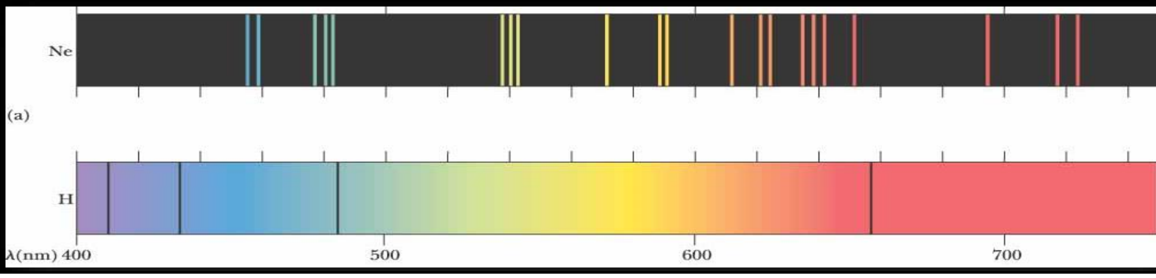
11-09 Multiple Slit Diffraction

- Splitting colors
  - Each color of light is a different wavelength, so each color bends a different angle.
  - Which color bends the most?
    - Red
  - Which color bends the least?
    - Violet



11-09 Multiple Slit Diffraction

- Application - Determining Elements in Stars
  - Each element in a hot gas emits or absorbs certain wavelengths of light.
  - By using a diffraction grating the light can be split and the wavelengths measured.



Top is an emission spectra of Neon
Bottom is an absorption spectra of Hydrogen

11-09 Homework

- I hope you don't find these problems grating.
- Read 27.5, 27.6, 27.7

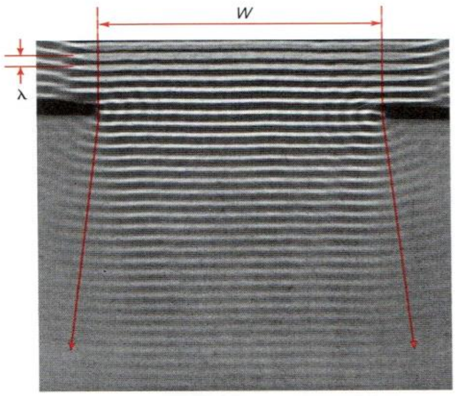
11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

In this lesson you will…

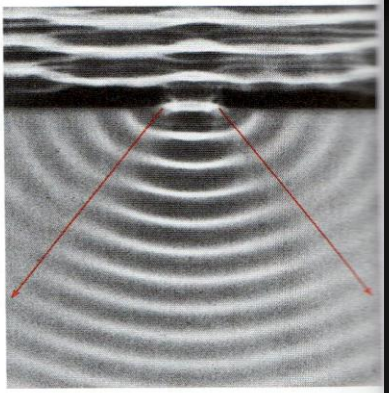
- Discuss the single slit diffraction pattern.
- Discuss the Rayleigh criterion.
- Discuss the rainbow formation by thin films.

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

Large opening → small bend **Small opening → large bend**



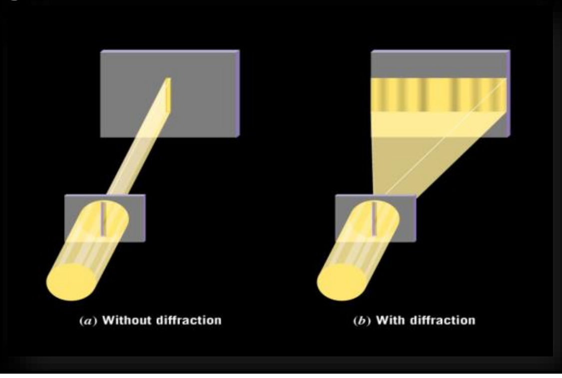
(a) Smaller value for λ/W, less diffraction.



(b) Larger value for λ/W, more diffraction.

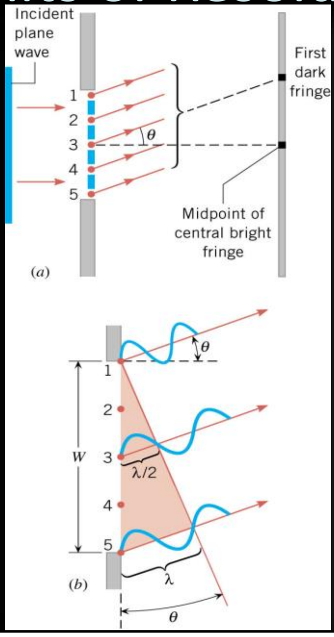
11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- Single slit produces a diffraction pattern
- The Huygens wavelets interfere with each other
- The center bright band is twice width of the other bands.



11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- First order dark band occurs when left edge and right edge path lengths differ by 1 wavelength.
- The center wave path length differs by ½ wavelength leading to the destructive interference.
- The wavelet slightly below #1 will cancel with wavelet slightly below #3 and so on.



The screen is far from the single slit so that wavelets are parallel. We are looking at the part of the wavelets that are traveling at an angle to the normal.

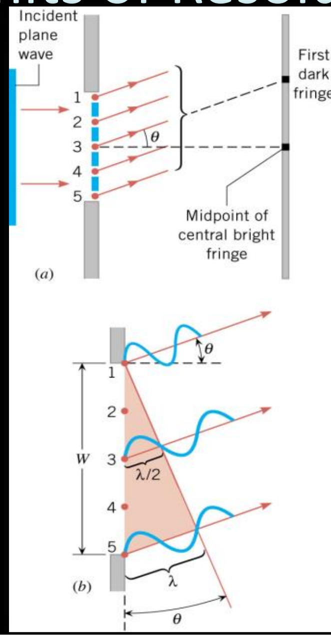
11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

$$\sin\theta = \frac{\lambda}{W}$$

- For multiple dark fringes

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

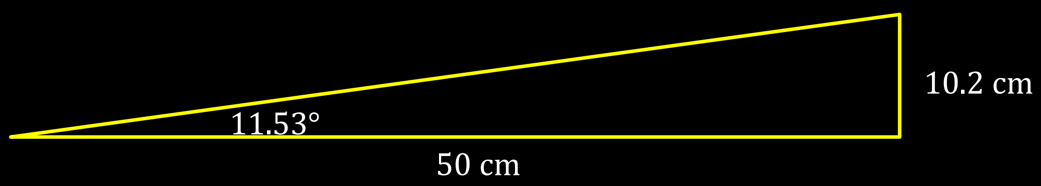
- Where
  - θ = angle between wave and normal to slit
  - m = dark band order
  - λ = wavelength
  - W = width of slit



The screen is far from the single slit so that wavelets are parallel. We are looking at the part of the wavelets that are traveling at an angle to the normal.

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- A laser shines through a single slit of width 3.25×10^{-6} m. The first order dark fringe is 10.2 cm from the center and the slit is 50 cm from the screen. What is the wavelength of the laser?
  - 650 nm



$$\tan\theta = \frac{10.2\ cm}{50\ cm} \rightarrow \theta = \tan\left(\frac{10.2}{50}\right) = 11.53°$$

$$\sin\theta = m\frac{\lambda}{W} \rightarrow \sin 11.53° = 1\frac{\lambda}{3.25 \times 10^{-6}\ m} \rightarrow 6.496 \times 10^{-7}\ m = \lambda$$

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- Application – Microchip Production
  - Very small electrical components are used.
  - Make masks similar to photographic slides.
  - Light shines through the mask onto silicon wafers coated with photosensitive material.
  - The exposed portions are chemically removed later.
  - If too much diffraction occurs, the lines will overlap.
  - Currently UV rays which have smaller wavelengths than visible light is used to minimize λ/W ratio.
  - To improve could use X-rays or Gamma Rays with even smaller wavelengths.

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

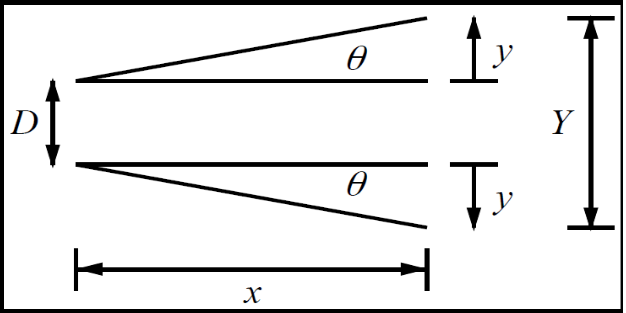
- Light going through a circular aperture has diffraction
  - Also true for light from lens and mirrors
- 1st minimum at

$$\theta = 1.22\frac{\lambda}{D}$$

  - Where
  - θ is in radians
  - λ is the wavelength
  - D is the diameter of aperture, lens, mirror, etc.
- Two light sources are "resolved" when one's center is at the 1st minimum of the other

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- (a) What is the minimum angular spread of a 633-nm wavelength He-Ne laser beam that is originally 1.00 mm in diameter? (b) If this laser is aimed at a mountain cliff 15.0 km away, how big will the illuminated spot be?
- 23.2 m



$(a)\ \theta = 1.22\frac{\lambda}{D} = 1.22\frac{633\times10^{-9}\ m}{1\times10^{-3}\ m} = 7.72\times10^{-4}\ radians$

$(b) \tan\theta = \frac{y}{x} \rightarrow \tan 7.72\times10^{-4}\ rad = \frac{y}{15000\ m} \rightarrow y =$
$(15000\ m)\tan 7.72\times10^{-4}\ rad = 11.58\ m$

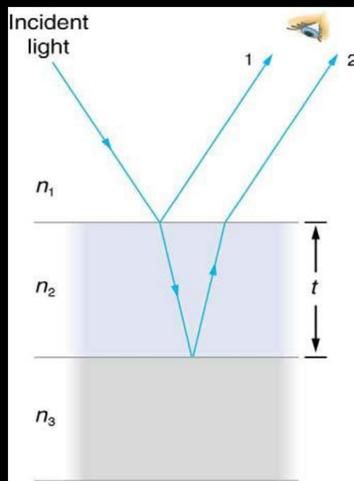
$Y = 2y + D = 2(11.58\ m) + 1\times10^{-3}\ m = 23.2\ m$

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- Light interference depends on the ratio of its wavelength and the object size
- If the object is near the size of the wavelength, there will be interference
- Since each color of light is a different wavelength, light can be split using thin films
- When light reflects from a medium having an index of refraction greater than that of the medium in which it is traveling, a 180° phase change (or a $\lambda / 2$ shift) occurs

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- The light hits the first surface.
  - Is it phase shifted? Only if $n_2 > n_1$
- The transmitted light reflects off the second surface.
  - Is it phase shifted? Only if $n_3 > n_2$



11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- Destructive interference when

$2t = \frac{\lambda_n}{2}$ if both rays 1 and 2 phase shift

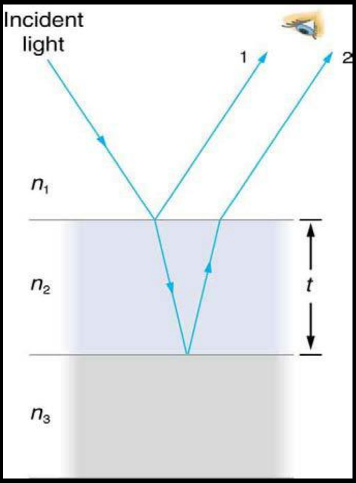
Or $2t = \lambda_n$ if only one ray phase shifts

  - Where $\lambda_n = \frac{\lambda}{n_2}$

- Constructive interference when

$2t = \lambda_n$ if both rays 1 and 2 phase shift

Or $2t = \frac{\lambda_n}{2}$ if only one ray phase shifts

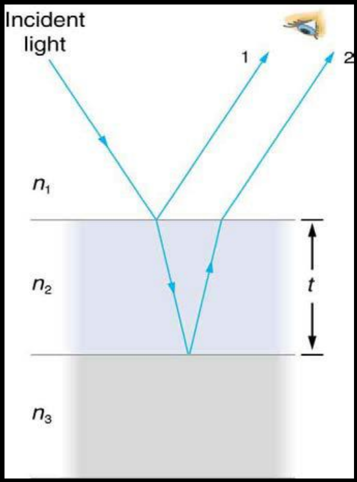


Only if incident light is nearly perpendicular to surface

Difference in path length = ½ wavelength to get destructive interference

11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

- An oil slick on water is 120 nm thick and illuminated by white light incident perpendicular to its surface. What color does the oil appear (what is the most constructively reflected wavelength), given its index of refraction is 1.40?
- $\lambda = 672\ nm$, Red



$$n_1 = 1.00\ air$$
$$n_2 = 1.40\ oil$$
$$n_3 = 1.33\ water$$

Ray 1 phase shifts; Ray 2 no phase shift

We want constructive interference, so want difference of one wavelength

$$2t = \frac{\lambda_n}{2} = \frac{\lambda}{2n}$$
$$2(120 \times 10^{-9}\ m) = \frac{\lambda}{2(1.40)}$$
$$\lambda = 672 \times 10^{-9}\ m = 672\ nm$$

Red

11-10 Homework

- Lets not split this assignment up.
- Read 27.8

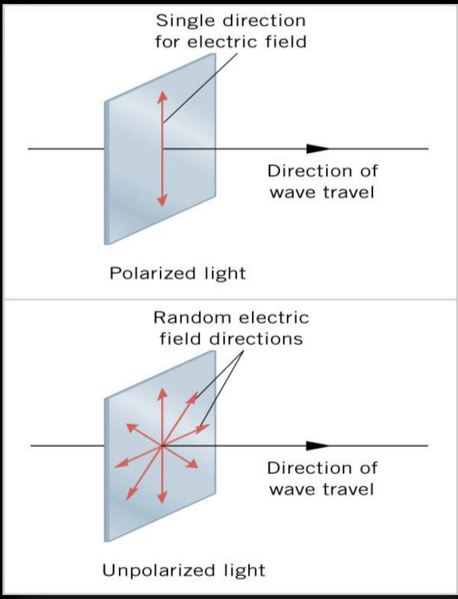
11-11 Polarization

In this lesson you will…

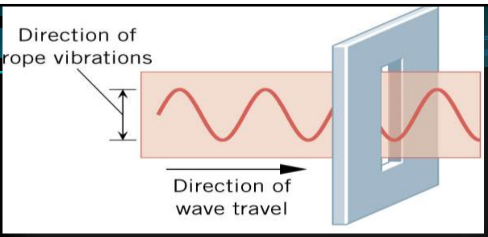
- Discuss the meaning of polarization.

11-11 Polarization

- Linearly polarized light vibrates in only one direction
- Common non-polarized light vibrates in all directions perpendicular to the direction of travel.



11-11 Polarization



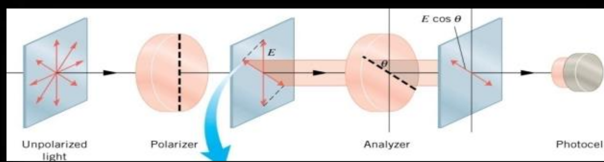
- How to make EM waves polarized
  - Straight wire antenna
  - Reflections of flat surfaces
  - Passing through a polarizing material
- Polarizing materials
  - Light is polarized along the transmission axis
  - All components of the wave are absorbed except the components parallel to the transmission axis
  - Since unpolarized light vibrates equally in all directions, the polarizing material absorbs ½ the light.
  - $I = \frac{1}{2} I_0$

Have some polarizing filters

I = intensity of light

11-11 Polarization

- Malus's Law
  - After light has been polarized a second polarizer can be used to adjust the intensity of the transmitted light.



  - Polarizer polarizes the light. The analyzer polarizes the polarized light along another axis. It only transmits the component parallel to the transmission axis of the analyzer.

$$I = I_0 \cos^2 \theta$$

Us the overhead projector and two polarizing filters to demonstrate.
When polarizers cross at 90 degree no light is transmitted.

Its $\cos^2$ because the intensity is proportional to the energy squared and the angle is found by E cos θ.

11-11 Polarization

- Uses of polarization
  - Sunglasses
    - Automatically cuts light intensity in half
    - Often the sunlight is reflected off of flat surfaces like water, roads, car windshields, etc. With the correct polarization, the sunglasses can eliminate most of those waves.
  - 3-D movies
    - Cameras are side-by-side.
    - The movies is projected by two projectors side by side, but polarized at 90°.
    - The audience wears glasses that have the same polarization so the right eye only sees the right camera and the left eye only sees the left camera.
  - LCD
    - Voltage changes the direction of the LCD polarization. The pixels turned on are transmitted (parallel), the pixel turned off are not transmitted (perpendicular).

11-11 Polarization

- A certain camera lens uses two polarizing filters to decrease the intensity of light entering the camera. If the light intensity in the scene is 20 W/m^2, what is the intensity of the light between the two filters?
  - 10 W/m^2
- If the light intensity at the film is 3 W/m^2, what is angle between the transmission axes of the polarizers?
  - 56.8°

a) $I = \frac{1}{2} I_0 \rightarrow I = \frac{1}{2}\left(20 \frac{W}{m^2}\right) = 10\, W/m^2$

b) $S = S_0 \cos^2\theta \rightarrow 3 = 10 \cos^2 \theta \rightarrow 0.3 = \cos^2 \theta \rightarrow 0.5477 = \cos^2 \theta \rightarrow \theta = 56.8°$

11-11 Polarization

- Polarization by Reflection
  - Light polarized perpendicular to surface is more likely refracted
  - Light horizontal to surface is more likely reflected
  - Light is completely polarized at Brewster's Angle

$$\tan\theta_b = \frac{n_2}{n_1}$$

  - Where
    - θ_b = Brewster's angle
    - n_1 and n_2 are indices of refraction

11-11 Homework

- Don’t let yourself become polarized with these problems.