Maxwell's Equations

James Clerk Maxwell – Scottish physicist who showed that ______________ and ______________ together create ________________ waves

Maxwell's Equations

1. ____________________________
2. ____________________________
3. ____________________________
4. ____________________________

Maxwell predicted that the __________ of electromagnetic waves would be

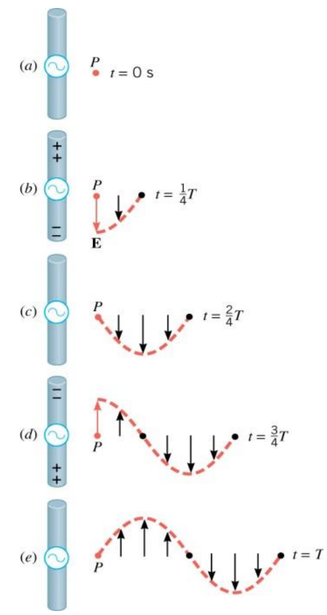
$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.00 \times 10^8 \frac{m}{s}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

$$\mu_0 = 4\pi \times 10^{-7} \frac{T}{Nm}$$

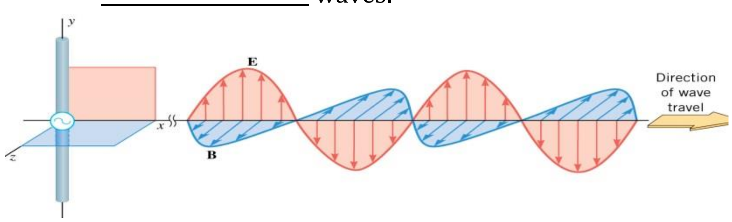
Heinrich Hertz was the first scientist to __________ and __________ EM waves.

Production of EM Waves

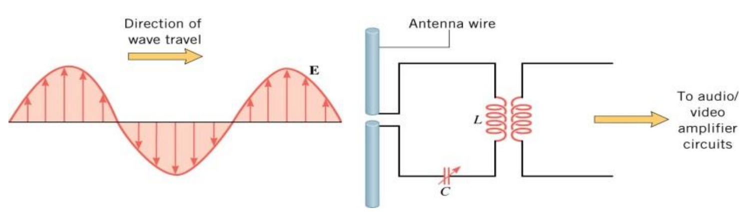


Creation of electromagnetic waves

- Two __________ are connected to either side of an __________ generator to form an __________.
- As the __________ of the generator changes a __________ __________ between the __________ of the wires is created.
- The potential difference makes an __________ field.
- As the AC generator changes __________, the electric field direction is __________.
- Also, as the potential difference changes __________, the __________ in the antenna __________ to the other ends creating a __________.
- Current __________ a __________ ________________ to the wire.
- Electromagnetic waves are both __________ and __________.
- Field are ______________ to each __________ and the __________ of travel.
- ______________ waves.

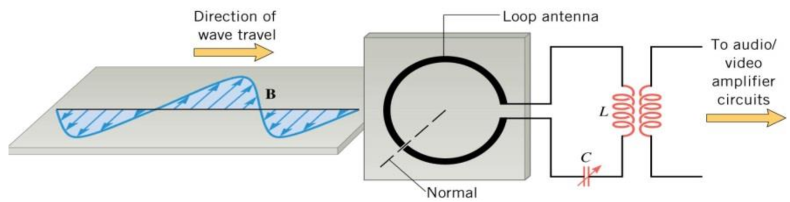


To detect EM waves



- Need __________ to receive either __________ or __________.
- E-field – __________ antenna
  - The E-field causes __________ to flow in the opposite direction creating __________ that changes with time as the E-field changes.
  - The __________ attached to the antenna let you pick the frequency (LC-circuit) and __________ it for speakers.

 Name: ______________________



- B-field – ____________ antenna
  - The B-field flowing through the loop ____________ a ____________ that changes as the B-field changes.

Relating the E-field and B-field strengths

- Stronger ____________ creates greater ____________ which makes greater ____________

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

EM waves can travel through a ____________ or material because E- and B-fields can exist in both.

- All EM waves travel the same ____________ in a vacuum.

$$c = \text{\_\_\_\_\_\_\_\_\_\_} \frac{m}{s}$$

- Frequency of the wave is determined by the ____________.

Homework

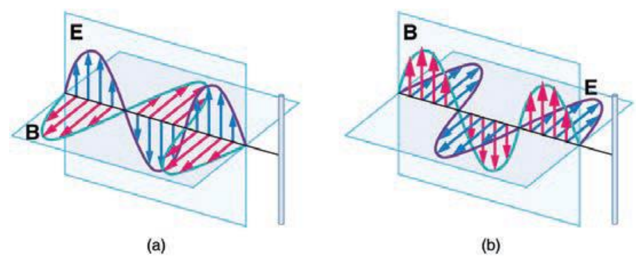


Figure 1

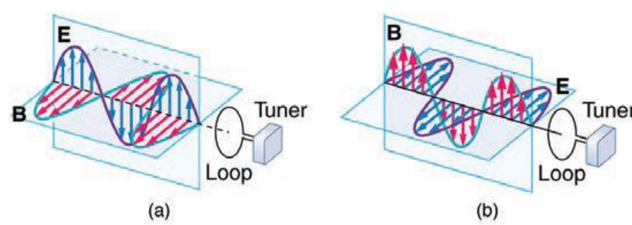
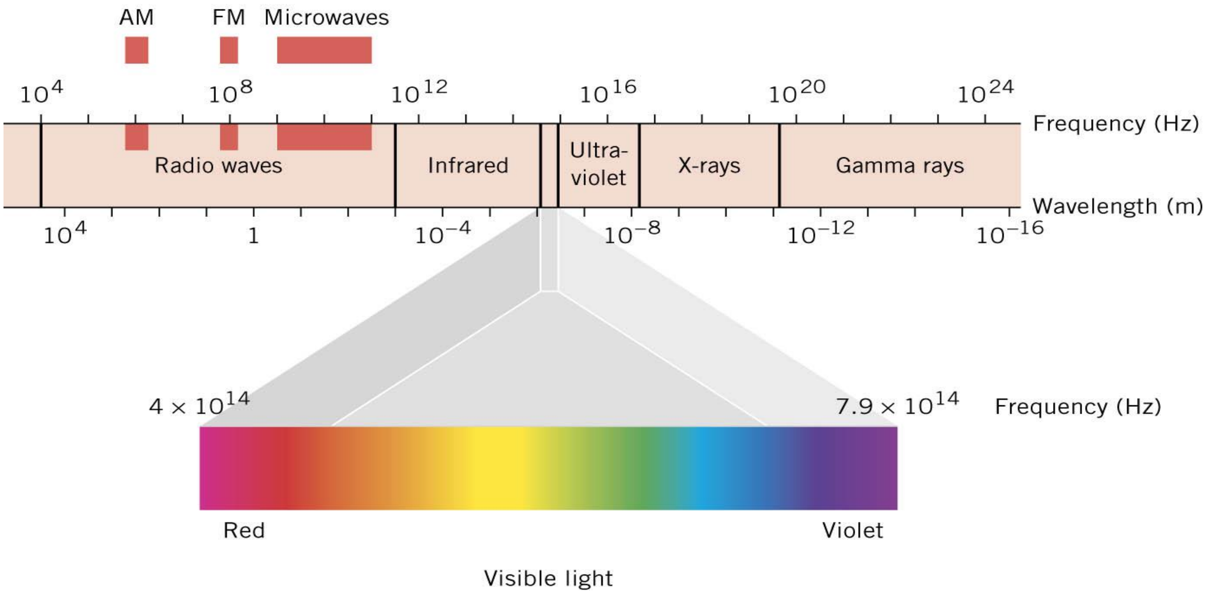


Figure 2

1. In which situation shown in Figure 1 will the electromagnetic wave be more successful in inducing a current in the wire? Explain.
2. In which situation shown in Figure 2 will the electromagnetic wave be more successful in inducing a current in the loop? Explain.
3. Should the straight wire antenna of a radio be vertical or horizontal to best receive radio waves broadcast by a vertical transmitter antenna? How should a loop antenna be aligned to best receive the signals? (Note that the direction of the loop that produces the best reception can be used to determine the location of the source. It is used for that purpose in tracking tagged animals in nature studies, for example.)
4. Verify that the correct value for the speed of light c is obtained when numerical values for the permeability and permittivity of free space (μ_0 and ε_0) are entered into the equation $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$. (OpenStax 24.1) $\mathbf{3.00 \times 10^8\ m/s}$
5. What is the maximum electric field strength in an electromagnetic wave that has a maximum magnetic field strength of 5.00×10^{-4} T (about 10 times the Earth's)? (OpenStax 24.3) **150 kV/m**
6. The maximum magnetic field strength of an electromagnetic field is 5×10^{-6} T. Calculate the maximum electric field strength if the wave is traveling in a medium in which the speed of the wave is 0.75c. (OpenStax 24.4) **1 kV/m**
7. (a) Neil Armstrong was the first person to walk on the moon. The distance between the earth and the moon is 3.85×10^8 m. Find the time it took for his voice to reach earth via radio waves. (b) Someday a person will walk on Mars, which is 5.6×10^{10} m from earth at the point of closest approach. Determine the minimum time that will be required for that person's voice to reach earth. (Cutnell 24.2) **1.28 s, 190 s**

The EM Spectrum



For EM waves in ______________ $v = c =$ ______________ m/s

- This is ______________ and is used to define the ______________
- As EM waves travel ______________ other substances, like plastic, it travels ______________.

Remember ______________ for all waves

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

Wave's ______________ is proportional to the ______________ squared

- Wave's ______________

$$I_{ave} = \frac{c\epsilon_0 E_0^2}{2} = \frac{cB_0^2}{2\mu_0} = \frac{E_0 B_0}{2\mu_0}$$

$$I_0 = 2I_{ave} \, and \; I_{ave} = \frac{P}{A}$$

- Remember $\epsilon_0 = 8.85 \times 10^{-12} \frac{C}{Vm}$ and $\mu_0 = 4\pi \times 10^{-7} \frac{Tm}{A}$

A certain microwave oven can produce 1500 W of microwave radiation over an area that is 30 cm by 30 cm. What is the intensity in W/m^2?

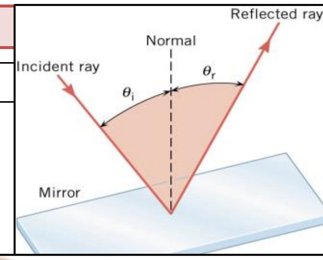
Calculate the peak electric field strength, E_0, in these waves.

What is the peak magnetic field strength, B_0?

Homework

1. Why don't buildings block radio waves as completely as they do visible light?
2. Give an example of energy carried by an electromagnetic wave.
3. (a) Two microwave frequencies are authorized for use in microwave ovens: 900 and 2560 MHz. Calculate the wavelength of each. (b) Which frequency would produce smaller hot spots in foods due to interference effects? (OpenStax 24.6) **11.7 cm**
4. A radio station utilizes frequencies between commercial AM and FM. What is the frequency of a 11.12-m-wavelength channel? (OpenStax 24.8) **26.96 MHz**
5. Combing your hair leads to excess electrons on the comb. How fast would you have to move the comb up and down to produce red light? (OpenStax 24.10) $\mathbf{5.0 \times 10^{14}}$ **Hz**
6. Some radar systems detect the size and shape of objects such as aircraft and geological terrain. Approximately what is the smallest observable detail utilizing 500-MHz radar? (OpenStax 24.14) **0.600 m**
7. Determine the amount of time it takes for X-rays of frequency 3×10^{18} Hz to travel (a) 1 mm and (b) 1 cm. (OpenStax 24.15) $\mathbf{3.3 \times 10^{-12}}$ **s,** $\mathbf{3.3 \times 10^{-11}}$ **s**
8. If you wish to detect details of the size of atoms (about 1×10^{-10} m) with electromagnetic radiation, it must have a wavelength of about this size. (a) What is its frequency? (b) What type of electromagnetic radiation might this be? (OpenStax 24.16) $\mathbf{3 \times 10^{18}}$ **Hz, X-rays**
9. If the Sun suddenly turned off, we would not know it until its light stopped coming. How long would that be, given that the Sun is 1.50×10^{11} m away? (OpenStax 24.17) **500 s**
10. Conversations with astronauts on lunar walks had an echo that was used to estimate the distance to the Moon. The sound spoken by the person on Earth was transformed into a radio signal sent to the Moon, and transformed back into sound on a speaker inside the astronaut's space suit. This sound was picked up by the microphone in the space suit (intended for the astronaut's voice) and sent back to Earth as a radio echo of sorts. If the round-trip time was 2.60 s, what was the approximate distance to the Moon, neglecting any delays in the electronics? (OpenStax 24.25) $\mathbf{3.90 \times 10^{8}}$ **m**
11. Lunar astronauts placed a reflector on the Moon's surface, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. (a) To what accuracy in meters can the distance to the Moon be determined, if this time can be measured to 0.100 ns? (b) What percent accuracy is this, given the average distance to the Moon is 3.84×10^{8} m? (OpenStax 24.26) $\mathbf{1.50 \times 10^{-2}}$ **m,** $\mathbf{3.91 \times 10^{-9}}$ **%**
12. What is the intensity of an electromagnetic wave with a peak electric field strength of 125 V/m? (OpenStax 24.30) **20.7 W/m²**
13. Assume the helium-neon lasers commonly used in student physics laboratories have power outputs of 0.250 mW. (a) If such a laser beam is projected onto a circular spot 1.00 mm in diameter, what is its intensity? (b) Find the peak magnetic field strength. (c) Find the peak electric field strength. (OpenStax 24.32) **318 W/m²,** $\mathbf{1.63 \times 10^{-6}}$ **T, 490 V/m**
14. An AM radio transmitter broadcasts 50.0 kW of power uniformly in all directions. (a) Assuming all of the radio waves that strike the ground are completely absorbed, and that there is no absorption by the atmosphere or other objects, what is the intensity 30.0 km away? (Hint: Half the power will be spread over the area of a hemisphere.) (b) What is the maximum electric field strength at this distance? (OpenStax 24.33) $\mathbf{4.42 \times 10^{-6}}$ **W/m²,** $\mathbf{5.77 \times 10^{-2}}$ **V/m**
15. A 2.50-m-diameter university communications satellite dish receives TV signals that have a maximum electric field strength (for one channel) of 7.50 μV/m. (a) What is the intensity of this wave? (b) What is the power received by the antenna? (c) If the orbiting satellite broadcasts uniformly over an area of 1.50×10^{13} m² (a large fraction of North America), how much power does it radiate? (OpenStax 24.35) $\mathbf{7.47 \times 10^{-14}}$ **W/m²,** $\mathbf{3.67 \times 10^{-13}}$ **W, 1.12 W**

Reflection



Law of Reflection: $\theta_r = \theta_i$

- ____________ Reflection
    - ____________ light rays are reflected ____________
- ____________ Reflection
    - ____________ light rays are ____________ by irregularities in the surface.
- Plane Mirror
    - Image is ____________
    - Image is ____________ size
    - Image is __________ as far ________ the mirror as you are in ________ of it

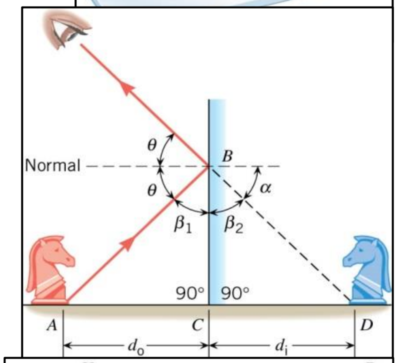
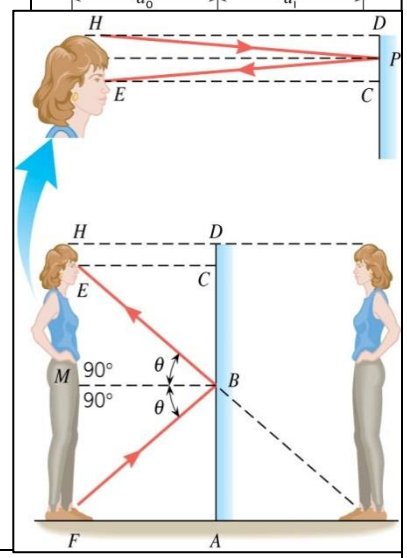


Table 25.1 Index of Refraction in Various Media

Medium	n
Gases at 0°C , 1 atm	
Air	1.000293
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Liquids at 20°C	
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethanol	1.361
Glycerine	1.473
Water, fresh	1.333
Solids at 20°C	
Diamond	2.419
Fluorite	1.434
Glass, crown	1.52
Glass, flint	1.66
Ice at 20°C	1.309
Polystyrene	1.49
Plexiglas	1.51
Quartz, crystalline	1.544
Quartz, fused	1.458
Sodium chloride	1.544
Zircon	1.923

- Since light rays appear to come from ____________ mirror, the image is called a ____________ image.
- If light rays ____________ to come from a ____________ location, the image is called a ____________ image.
- Real images can be ____________ on a screen, virtual images ____________.
- ___________ mirrors only produce __________ images.

How long must a plane mirror be to see your whole reflection?



Refraction

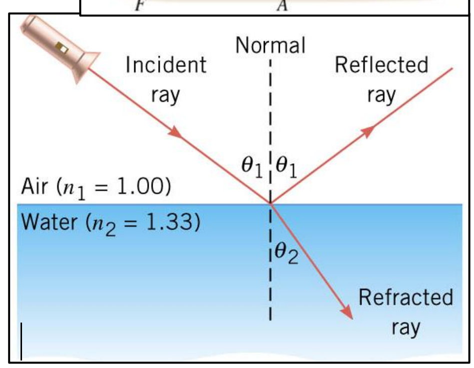
- Speed of light in a vacuum: $c = 3.00 \times 10^8\,\frac{m}{s}$
- Light travels _________ through materials due to light _________, absorbed by, emitted by, and scattered by _________.

Index of Refraction

- ____________to indicate relative ____________ of light in a ____________

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

- When light hits the surface of a material part of it is ____________
- The other part goes into the ____________
- The transmitted part is ________ (____________)



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)

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?

What is the speed of light in the material?

Homework

1. Using the law of reflection, explain how powder takes the shine off of a person's nose. What is the name of the optical effect?
2. Diffusion by reflection from a rough surface is described in this chapter. Light can also be diffused by refraction. Describe how this occurs in a specific situation, such as light interacting with crushed ice.
3. Will light change direction toward or away from the perpendicular when it goes from air to water? Water to glass? Glass to air?
4. Explain why an object in water always appears to be at a depth shallower than it actually is? Why do people sometimes sustain neck and spinal injuries when diving into unfamiliar ponds or waters?
5. Suppose a man stands in front of a mirror. His eyes are 1.65 m above the floor, and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man's height? (OpenStax 25.1) **bottom 0.825 m, top 1.715 m; not related**
6. Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated in figure 1. (OpenStax 25.2) **See below**

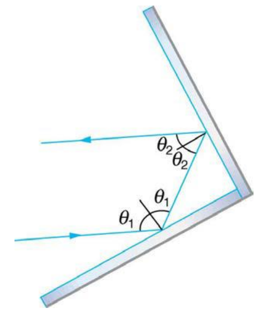


Figure 1

7. Light shows staged with lasers use moving mirrors to swing beams and create colorful effects. Show that a light ray reflected from a mirror changes direction by 2θ when the mirror is rotated by an angle θ. (OpenStax 25.3) **See below**
8. What is the speed of light in water? In glycerine? (OpenStax 25.5) $\mathbf{2.25 \times 10^8\ m/s, 2.04 \times 10^8\ m/s}$
9. Calculate the index of refraction for a medium in which the speed of light is 2.012×10^8 m/s, and identify the most likely substance based on Table 25.1. (OpenStax 25.7) **1.490, polystyrene**
10. In what substance in Table 25.1 is the speed of light 2.290×10^8 m/s? (OpenStax 25.8) **ice at 0° C**
11. Components of some computers communicate with each other through optical fibers having an index of refraction n = 1.55. What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber? (OpenStax 25.11) **1.03 ns**
12. (a) Using information in Figure 2, find the height of the instructor's head above the water, noting that you will first have to calculate the angle of incidence. (b) Find the apparent depth of the diver's head below water as seen by the instructor. (OpenStax 25.12) **2.93 m, 1.37 m**
13. Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of 45.0°, and you observe the angle of refraction to be 40.3°. What is the index of refraction of the substance and its likely identity? (OpenStax 25.13) **1.46, fused quartz**

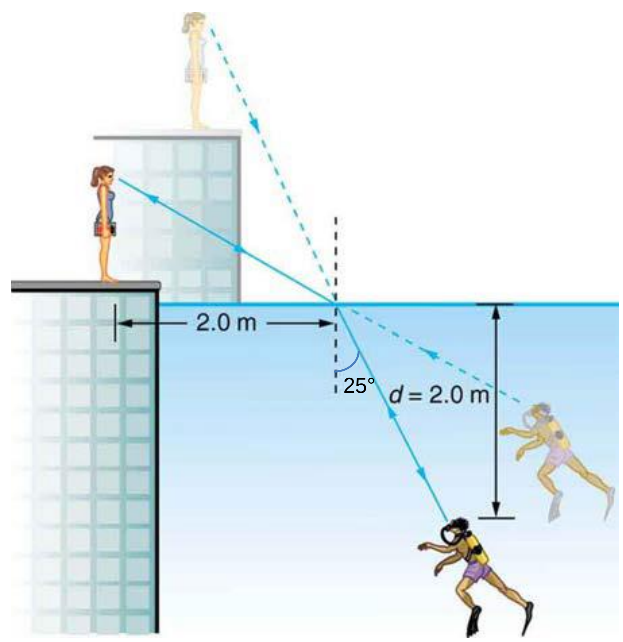


Figure 2

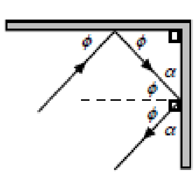


Figure 3 Answer to #6

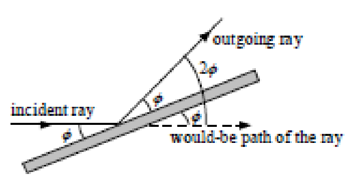
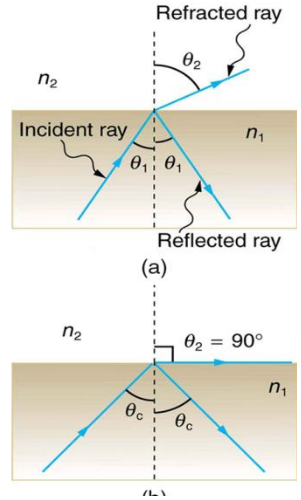


Figure 4 Answer to #7

Total Internal Reflection

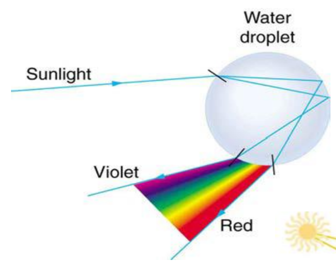


- When light hits an ____________ between two types of ____________ with different indices of ____________
  - Some is ____________
  - Some is ____________
- Critical angle
  - Angle of ____________ where ____________ angle is ____________
  - Angles of incidence ____________ than this cause the ____________ angle to be ____________ the material. This can't happen, so ____________ refraction occurs.
  - $\theta_c = \sin^{-1}\frac{n_2}{n_1}$
    - Where $n_1 > n_2$

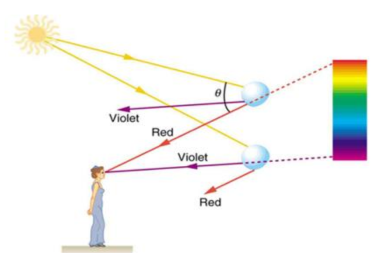
What is the critical angle from cubic zirconia (n=2.16) to air? Will an angle of 25° produce total internal reflection?

Uses of total internal reflection

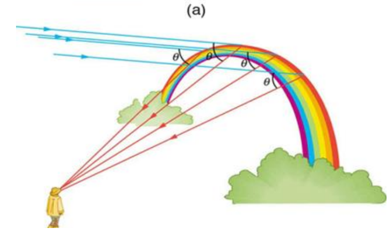
- ____________ ____________ for
  - Endoscopes
  - Telecommunications
  - Decorations
- ____________ /telescopes
  - Makes them shorter
- Reflectors
- Gemstones
  - Cut so that light only ____________ at certain ____________



Dispersion



(a)



- Each ______________ of light has a different ____________ of refraction
  - Red — ____________
  - Violet — ____________
  - When light is refracted, the violet bends more than red, which ____________ the colors
- Rainbows
  - ______________ by ____________ with internal ____________
  - Rainbows are always the ____________ direction from the sun

Table 25.2 Index of Refraction n in Selected Media at Various Wavelengths

Medium	Red (660 nm)	Orange (610 nm)	Yellow (580 nm)	Green (550 nm)	Blue (470 nm)	Violet (410 nm)
Water	1.331	1.332	1.333	1.335	1.338	1.342
Diamond	2.410	2.415	2.417	2.426	2.444	2.458
Glass, crown	1.512	1.514	1.518	1.519	1.524	1.530
Glass, flint	1.662	1.665	1.667	1.674	1.684	1.698
Polystyrene	1.488	1.490	1.492	1.493	1.499	1.506
Quartz, fused	1.455	1.456	1.458	1.459	1.462	1.468

"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

Homework

1. A high-quality diamond may be quite clear and colorless, transmitting all visible wavelengths with little absorption. Explain how it can sparkle with flashes of brilliant color when illuminated by white light.
2. The most common type of mirage is an illusion that light from faraway objects is reflected by a pool of water that is not really there. Mirages are generally observed in deserts, when there is a hot layer of air near the ground. Given that the refractive index of air is lower for air at higher temperatures, explain how mirages can be formed.
3. Verify that the critical angle for light going from water to air is 48.6°. (OpenStax 25.20) **48.6°**
4. (a) Verify that the critical angle for light going from diamond to air is 24.4°. (b) What is the critical angle for light going from zircon to air? (OpenStax 25.21) $\mathbf{24.4°, 31.3°}$
5. An optical fiber uses flint glass clad with crown glass. What is the critical angle? (OpenStax 25.22) $\mathbf{66.3°}$
6. At what minimum angle will you get total internal reflection of light traveling in water and reflected from ice? (OpenStax 25.23) $\mathbf{79.11°}$
7. You can determine the index of refraction of a substance by determining its critical angle. (a) What is the index of refraction of a substance that has a critical angle of 68.4° when submerged in water? What is the substance, based on Table 25.1? (b) What would the critical angle be for this substance in air? (OpenStax 25.25) **Fluorite,** $\mathbf{44.2°}$
8. A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown in Figure 1. What is the index of refraction for the liquid and its likely identification? (OpenStax 25.26) **1.50, Benzene**
9. (a) What is the ratio of the speed of red light to violet light in diamond, based on Table 25.2? (b) What is this ratio in polystyrene? (c) Which is more dispersive? (OpenStax 25.28) **1.020, 1.012, diamond**
10. A beam of white light goes from air into water at an incident angle of 75.0°. At what angles are the red (660 nm) and violet (410 nm) parts of the light refracted? (OpenStax 25.29) $\mathbf{46.5°}$, $\mathbf{46.0°}$
11. By how much do the critical angles for red (660 nm) and violet (410 nm) light differ in a diamond surrounded by air? (OpenStax 25.30) $\mathbf{0.51°}$

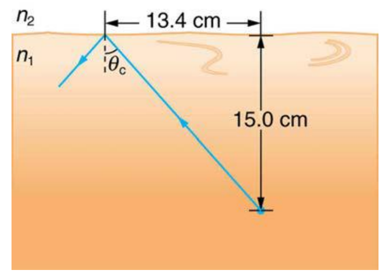
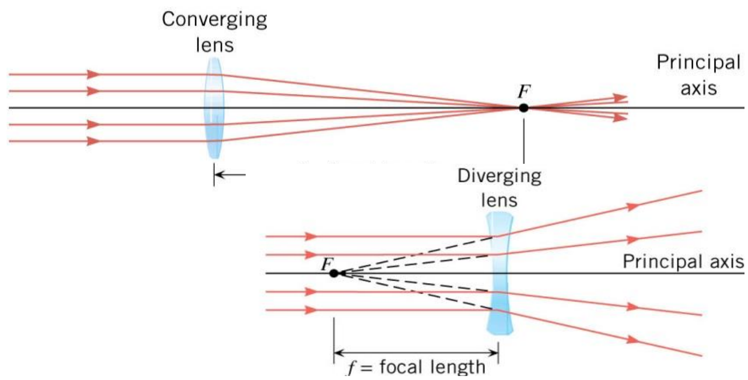


Figure 1

 Name: ____________________

Lenses

- Lens - Made from ______________ material, usually with a __________ edge.
- Converging Lens – __________ middle, __________ edge (__________)
- Diverging Lens – __________ middle, __________ edge (__________)
- Power of lens
  - $P = \frac{1}{f}$
  - Unit: __________ (D)

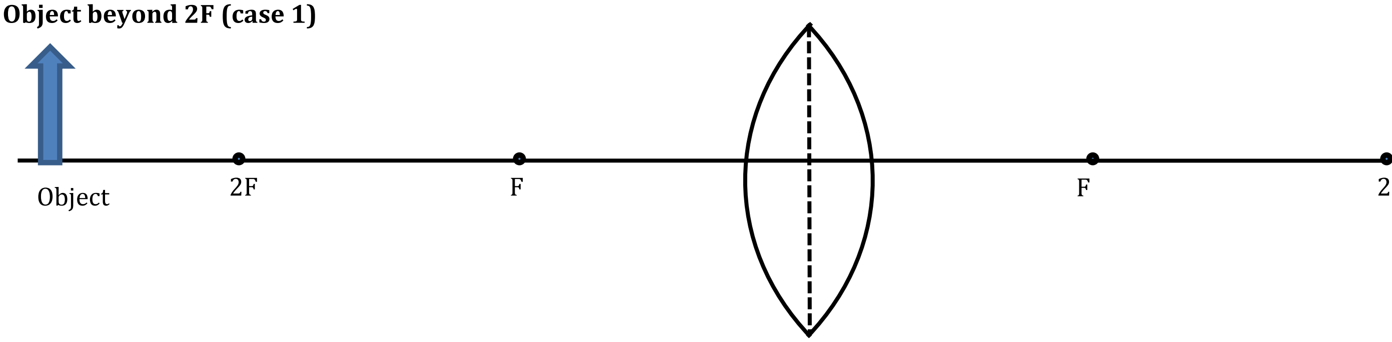


Ray Diagrams

Converging Lenses

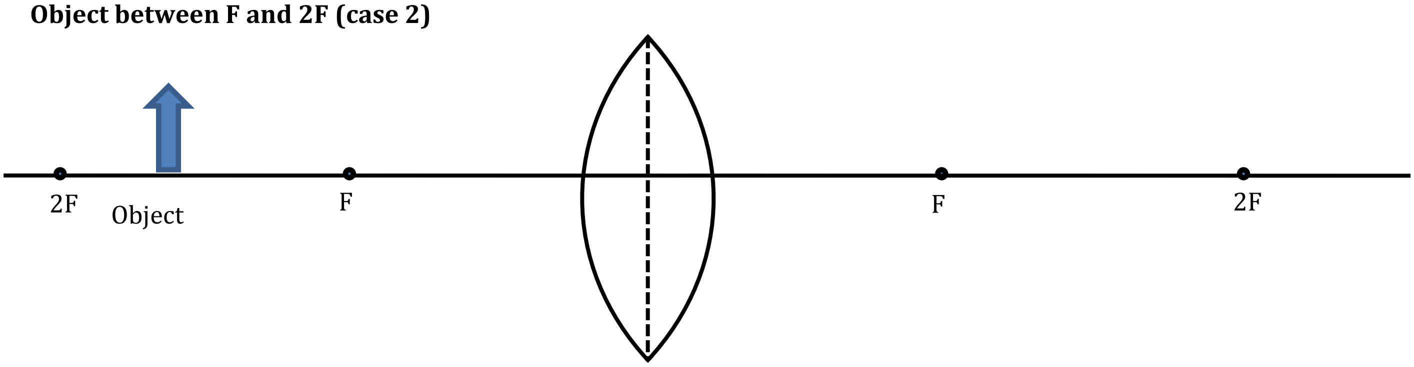
- Ray 1 – __________ to principal __________, bends through __________
- Ray 2 – Through __________, bends __________ to principal axis
- Ray 3 – Goes through __________ of lens, does __________ bend

Object beyond 2F (case 1)



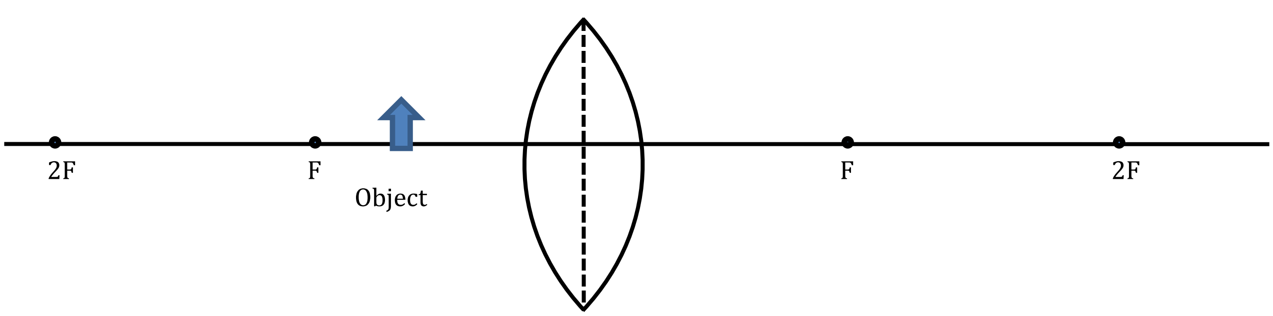
- Image __________, __________, __________, between __________ and __________

Object between F and 2F (case 2)



- Image __________, __________, __________, beyond __________

Object between F and lens (case 3)

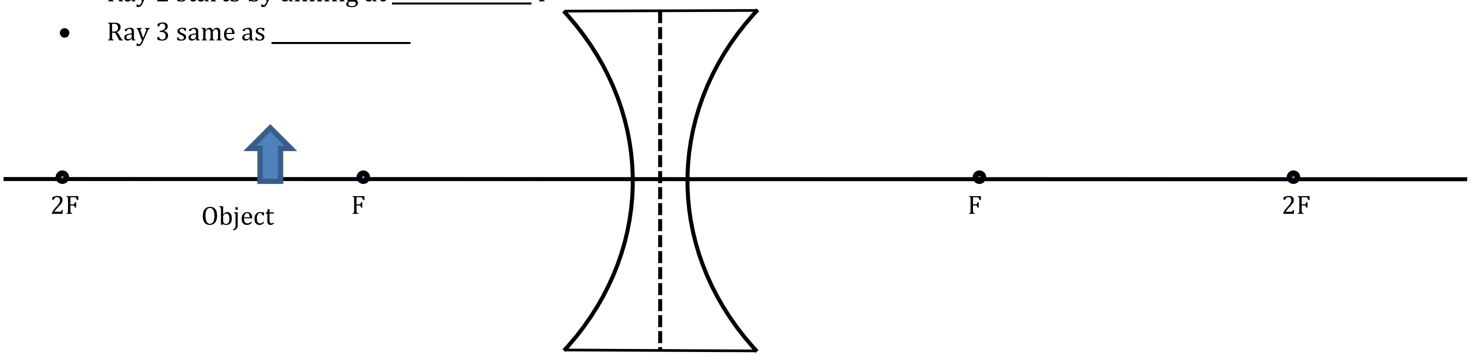


- Image __________, __________, between __________ and __________ on side with __________

Physics 11-05 Image Formation by Lenses Name: ________________________

Diverging Lens

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



- Image ____________, ____________, ____________, between ____________ and ____________

Thin-lens equation

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

- Where f = focal length, d_o = object distance, and d_i = image distance
- 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)

Magnification equation

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

Lens Reasoning Strategy

1. Examine the situation to determine that ____________ formation by a lens is ____________.
2. Determine whether ________ tracing, the ________ lens equations, or ________ are to be employed. A sketch is very ____________ 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 ______________ in the problem (identify the ______________).
4. Make a list of what is ____________ or can be ____________ from the problem as stated (identify the ____________). It is helpful to determine whether the situation involves a case ____________, ____________, or ____________ image. While these are just names for types of images, they have certain characteristics that can be of great use in solving problems.
5. If ray tracing is ____________, use the ray tracing ____________ listed near the beginning of this section.
6. Most _______________ problems require the use of the ____________ lens equations.
7. Check to see if the answer is ______________: Does it make ____________? If you have identified the type of image (case 1, 2, or 3), you should assess whether your answer is ______________ with the type of image, magnification, and so on.

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?

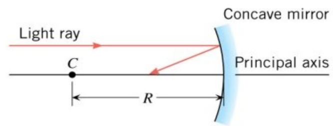
If his eye is really 3 cm across, how big does it appear?

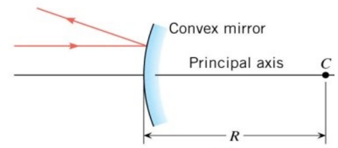
Homework

1. When you focus a camera, you adjust the distance of the lens from the film. If the camera lens acts like a thin lens, why can it not be a fixed distance from the film for both near and distant objects?
2. A thin lens has two focal points, one on either side, at equal distances from its center, and should behave the same for light entering from either side. Look through your eyeglasses (or those of a friend) backward and forward and comment on whether they are thin lenses.
3. Will the focal length of a lens change when it is submerged in water? Explain.
4. Your camera's zoom lens has an adjustable focal length ranging from 80.0 to 200 mm. What is its range of powers? (OpenStax 25.37) **12.5 D, 5.00 D**
5. What is the focal length of 1.75 D reading glasses found on the rack in a pharmacy? (OpenStax 25.38) **57.1 cm**
6. How far from the lens must the film in a camera be, if the lens has a 35.0 mm focal length and is being used to photograph a flower 75.0 cm away? Solve using both a ray diagram and the thin lens equation. (OpenStax 25.40) **36.7 mm**
7. A certain slide projector has a 100 mm focal length lens. (a) How far away is the screen, if a slide is placed 103 mm from the lens and produces a sharp image? (b) If the slide is 24.0 by 36.0 mm, what are the dimensions of the image? (OpenStax 25.41) **3.43 m, 80.0 cm × 120 cm**
8. A doctor examines a mole with a 15.0 cm focal length magnifying glass held 13.5 cm from the mole (a) Where is the image? (b) What is its magnification? (c) How big is the image of a 5.00 mm diameter mole? (OpenStax 25.42) **-1.35 m, +10.0, 50.0 mm**
9. A camera lens used for taking close-up photographs has a focal length of 22.0 mm. The farthest it can be placed from the film is 33.0 mm. (a) What is the closest object that can be photographed? (b) What is the magnification of this closest object? (OpenStax 25.45) **6.60 cm, -0.5**
10. Suppose your 50.0 mm focal length camera lens is 51.0 mm away from the film in the camera. (a) How far away is an object that is in focus? (b) What is the height of the object if its image is 2.00 cm high? (OpenStax 25.46) **2.55 m, 1.00 m**
11. (a) What is the focal length of a magnifying glass that produces a magnification of 3.00 when held 5.00 cm from an object, such as a rare coin? (b) Calculate the power of the magnifier in diopters. (c) Discuss how this power compares to those for store-bought reading glasses (typically 1.0 to 4.0 D). Is the magnifier's power greater, and should it be? (OpenStax 25.47) **7.50 cm, 13.3 D, lots stronger**
12. (a) Where is the image that will be produced by a lens of power –4.00 D (such as might be used to correct myopia) if an object is held 25.0 cm away? Solve by using both a ray diagram and the thin lens equation. (b) What is the magnification?(OpenStax 25.48) **-12.5 cm, +0.500**

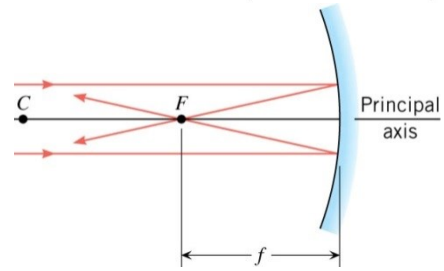
Physics 11-06 Image Formation by Mirrors Name: ____________________

Spherical Mirrors



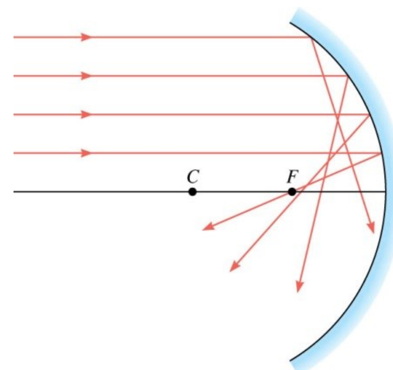


- Concave: bends __________
- Convex: bends __________
- __________are always ______________ to the surface and pass through the __________ of curvature, C.
    - Law of Reflection says that the __________ to the __________ is the same for the __________ and __________ rays
- Principal axis: imaginary line through _______ and the ________ of the mirror.
- Focal point (F): __________ rays strike the mirror and __________ at the focal point.
- Focal length (f): distance between __________ and __________
- Concave mirrors: $f = \frac{1}{2}R$
- Convex mirrors: $f = -\frac{1}{2}R$



Spherical aberration

- Rays ______ from the principle axis actually cross between _____ and the ________.
- Fix this by using a __________ mirror.

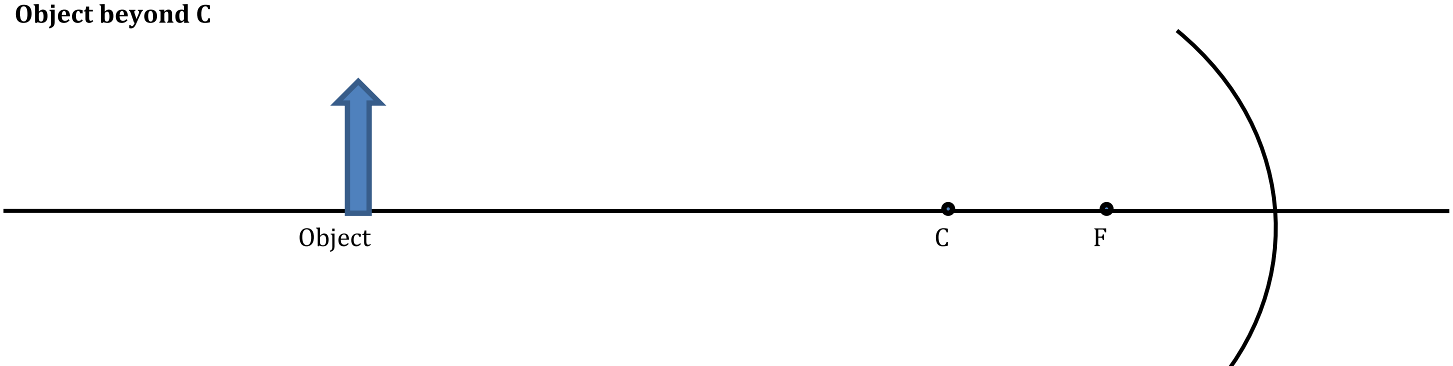


Ray Diagrams

Concave Mirror

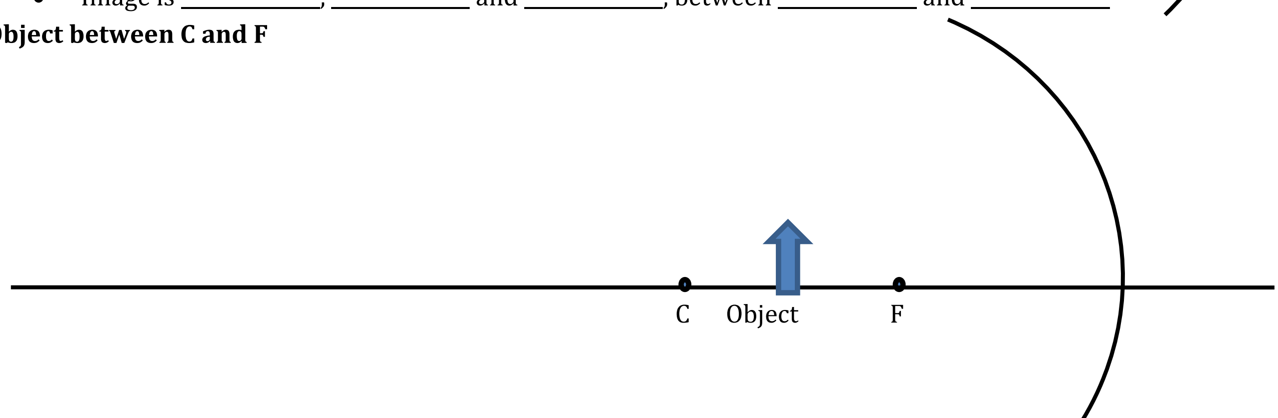
- Ray 1 – __________ to principal axis, strikes mirror and reflects through _________
- Ray 2 – Through ________, strikes mirror and reflects __________ to principal axis
- Ray 3 – Through ________, strikes mirror and reflects back through __________

Object beyond C



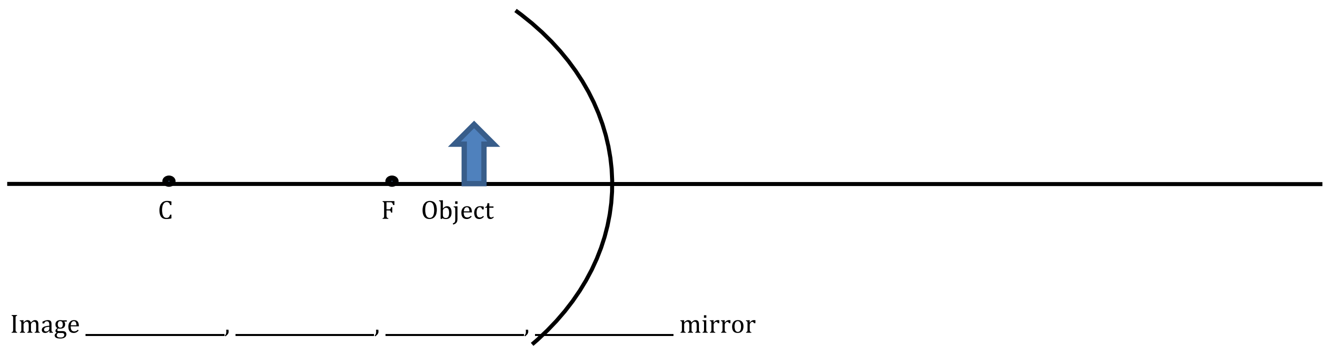
- Image is __________, __________ and __________, between __________ and __________

Object between C and F



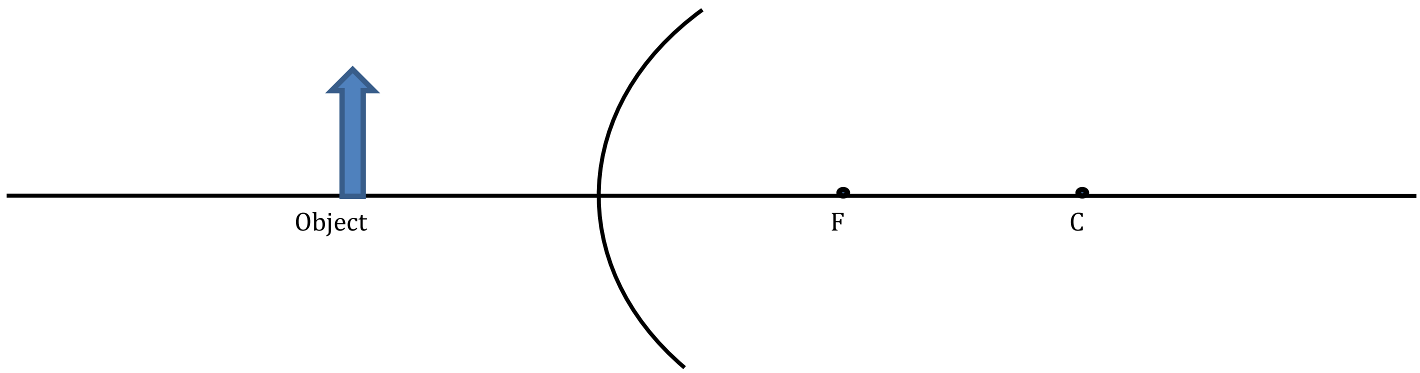
- Image __________, __________, and __________, beyond __________

Object between F and mirror



- Image __________, __________, __________, __________ mirror

Convex Mirrors



- Image __________, __________, __________, __________ mirror between F and __________

Mirror Equation

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

- Where f = focal length (negative if __________), d_0 = object distance, d_i = image distance (negative if __________)

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 __________), d_o = object distance, d_i = image distance (negative if __________)

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?

What is the height of his image?

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?

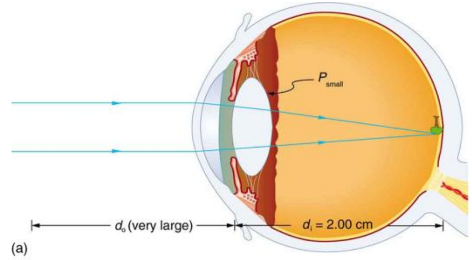
What is the height of his image?

Homework

1. What are the differences between real and virtual images? How can you tell (by looking) whether an image formed by a single lens or mirror is real or virtual?
2. Can you see a virtual image? Can you photograph one? Can one be projected onto a screen with additional lenses or mirrors? Explain your responses.
3. Is it necessary to project a real image onto a screen for it to exist?
4. Under what circumstances will an image be located at the focal point of a lens or mirror?
5. What is meant by a negative magnification? What is meant by a magnification that is less than 1 in magnitude?
6. What is the focal length of a makeup mirror that has a power of 1.50 D? (OpenStax 25.53) **+0.667 m**
7. Some telephoto cameras use a mirror rather than a lens. What radius of curvature mirror is needed to replace a 800 mm focal length telephoto lens? (OpenStax 25.54) **+1.60 m**
8. (a) Calculate the focal length of the mirror formed by the shiny back of a spoon that has a 3.00 cm radius of curvature. (b) What is its power in diopters? (OpenStax 25.55) $\mathbf{-1.50 \times 10^{-2}}$ **m, -66.7 D**
9. Electric room heaters use a concave mirror to reflect infrared (IR) radiation from hot coils. Note that IR follows the same law of reflection as visible light. Given that the mirror has a radius of curvature of 50.0 cm and produces an image of the coils 3.00 m away from the mirror, what is the magnification of the heater element. Note that its large magnitude helps spread out the reflected energy. (OpenStax 25.56) **-11.0**
10. What is the focal length of a makeup mirror that produces a magnification of 1.50 when a person’s face is 12.0 cm away? (OpenStax 25.57) **0.360 m**
11. A shopper standing 3.00 m from a convex security mirror sees his image with a magnification of 0.250. (a) Where is his image? (b) What is the focal length of the mirror? (c) What is its radius of curvature? (OpenStax 25.58) **-0.750 m, -1.00 m, 2.00 m**
12. An object 1.50 cm high is held 3.00 cm from a person’s cornea, and its reflected image is measured to be 0.167 cm high. (a) What is the magnification? (b) Where is the image? (c) Find the radius of curvature of the convex mirror formed by the cornea. (Note that this technique is used by optometrists to measure the curvature of the cornea for contact lens fitting. The instrument used is called a keratometer, or curve measurer.) (OpenStax 25.59) **+0.111, -0.334 cm, -0.752 cm**

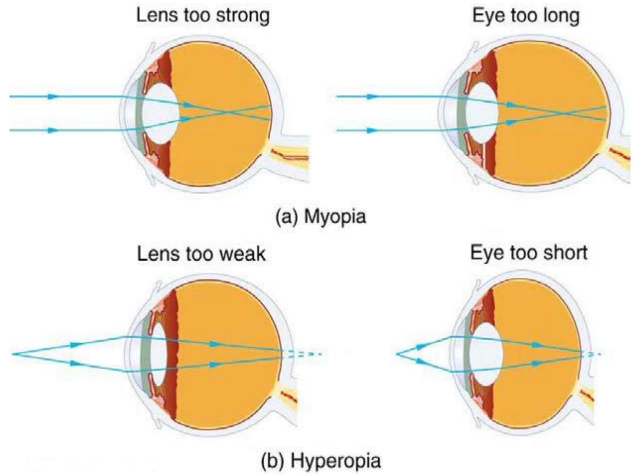
 Name: ____________________

Physics of the Eye



- Cornea/Lens act as __________ thin __________
- To see something in focus the __________ must be on the __________ at __________ of eye
- Lens can change ________ to focus objects from different object ________

Vision Correction

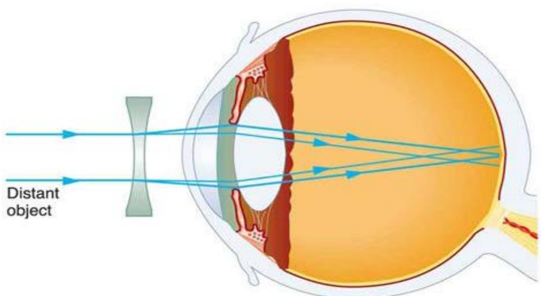


Near-sightedness

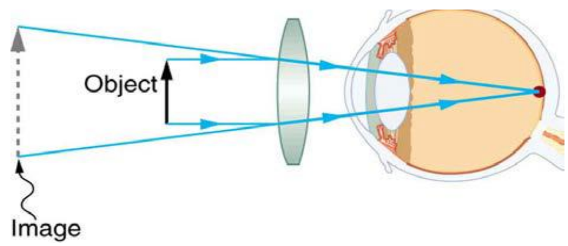
- __________
- Image in __________ of retina
- Correct with __________ lens

Far-sightedness

- __________
- Image __________ retina
- Correct with _____________ lens



Myopia



Hyperopia

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.

Color Vision and Color

Photoreceptors in Eye

- Rods
  - ____________ sensitive (see in ____________)
  - No ____________ info
  - ________________ vision
- Cones
  - Centered in ____________ of retina
  - Work in ____________ in ____________ light
  - Give ____________ info
  - Essentially ____________ types each picking up one ____________ color

Color

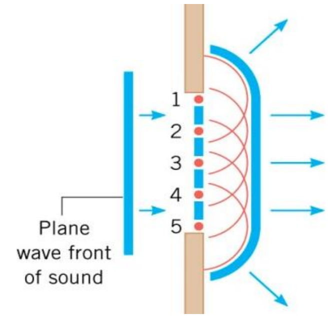
- Non-light producing objects
  - The ____________ we see is the color that ____________ off the object
  - The object ____________ all the other ____________
- Light-producing
  - The color we ____________ is the color ____________

Homework

1. A cataract is cloudiness in the lens of the eye. Is light dispersed or diffused by it?
2. When laser light is shone into a relaxed normal-vision eye to repair a tear by spot-welding the retina to the back of the eye, the rays entering the eye must be parallel. Why?
3. If the cornea is to be reshaped (this can be done surgically or with contact lenses) to correct myopia, should its curvature be made greater or smaller? Explain. Also explain how hyperopia can be corrected.
4. If there is a fixed percent uncertainty in LASIK reshaping of the cornea, why would you expect those people with the greatest correction to have a poorer chance of normal distant vision after the procedure?
5. A pure red object on a black background seems to disappear when illuminated with pure green light. Explain why.
6. What is the power of the eye when viewing an object 50.0 cm away? (OpenStax 26.1) **52.0 D**
7. Calculate the power of the eye when viewing an object 3.00 m away. (OpenStax 26.2) **50.3 D**
8. (a) The print in many books averages 3.50 mm in height. How high is the image of the print on the retina when the book is held 30.0 cm from the eye? (OpenStax 26.3a) **-0.233 mm**
9. Suppose a certain person's visual acuity is such that he can see objects clearly that form an image 4.00 μm high on his retina. What is the maximum distance at which he can read the 75.0 cm high letters on the side of an airplane? (OpenStax 26.4) **3.75 km**
10. What is the far point of a person whose eyes have a relaxed power of 50.5 D? (OpenStax 26.6) **2.00 m**
11. What is the near point of a person whose eyes have an accommodated power of 53.5 D? (OpenStax 26.7) **28.6 cm**
12. A very myopic man has a far point of 20.0 cm. What power contact lens (when on the eye) will correct his distant vision? (OpenStax 26.16) **-5.00 D**
13. Repeat the previous problem for eyeglasses held 1.50 cm from the eyes. (OpenStax 26.17) **-5.41 D**
14. A myopic person sees that her contact lens prescription is –4.00 D. What is her far point? (OpenStax 26.18) **25 cm**
15. Repeat the previous problem for glasses that are 1.75 cm from the eyes. (OpenStax 26.19) **26.8 cm**

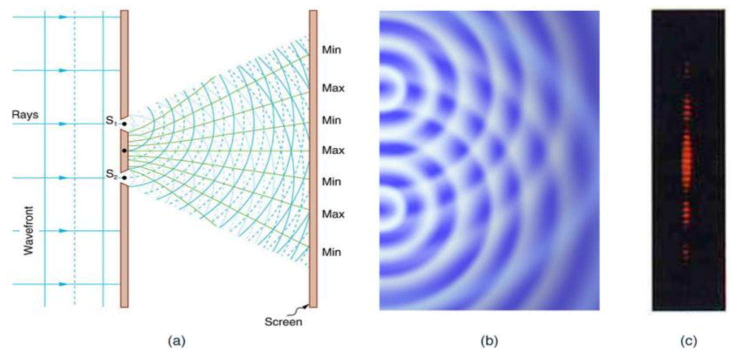
Wave Character of Light

- When __________ interacts with object several __________ it's ______________, it acts like a __________
- When __________ interacts with __________ objects, it acts like a __________
- When light hits __________ from a __________, it __________ down
  - ______________ stays the same
  - $c = f\lambda$
  - $v = \frac{c}{n} = f\frac{\lambda}{n}$
  - $\lambda_n = \frac{\lambda}{n}$
  - Where λ_n = wavelength in medium, n = index of refraction



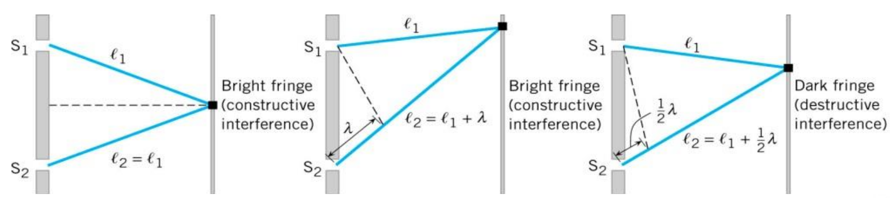
Huygens' Principle

- Every point on a __________ front acts as a __________ of tiny __________ that move forward with the same __________ as the __________; the wave __________ at a later instant is the __________ that is __________ to the wavelets.

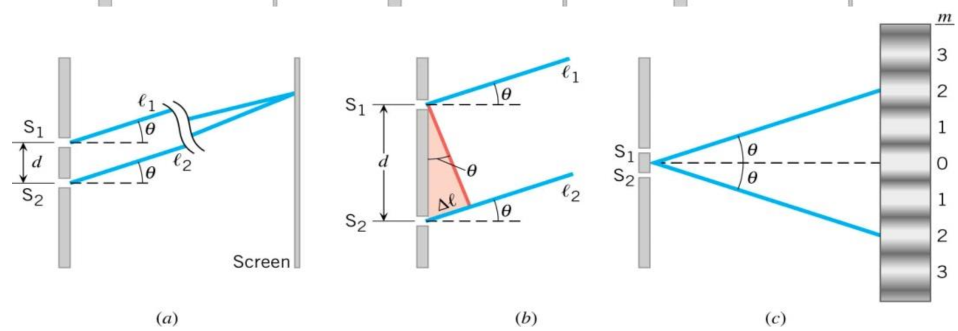


Young's Double Slit Experiment

- Thomas Young showed that two overlapping __________ waves ____________ and was able to calculate _____________.
- Bright fringe where $\ell_1 - \ell_2 = m\lambda$
- Dark fringe where $\ell_1 - \ell_2 = \left(m + \frac{1}{2}\right)\lambda$
- Brightness of fringes __________
  - Center fringe the __________ and ____________ on either side



- (a) Rays from slits S_1 and S_2, which make approximately the same __________ θ with the horizontal, strike a distant __________ at the __________ spot.
- (b) The difference in the __________ lengths of the __________ rays is $\Delta\ell = d \sin\theta$.



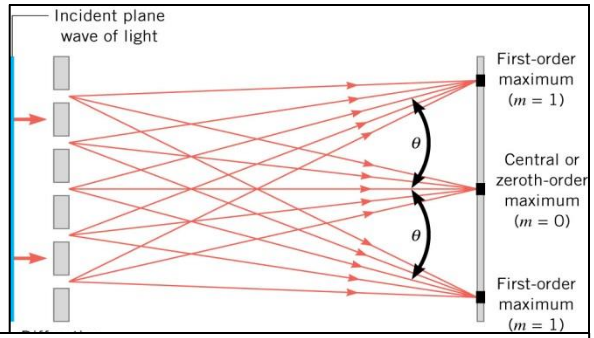
- (c) The angle θ is the angle at which a __________ fringe (m = 2, here) occurs on either side of the __________ bright fringe (m = 0)
- __________ fringe: $\sin\theta = m\frac{\lambda}{d}$
- __________ fringe: $\sin\theta = \left(m + \frac{1}{2}\right)\frac{\lambda}{d}$

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?

Homework

1. What type of experimental evidence indicates that light is a wave?
2. Why does the wavelength of light decrease when it passes from vacuum into a medium? State which attributes change and which stay the same and, thus, require the wavelength to decrease.
3. Does Huygens's principle apply to all types of waves?
4. Young's double slit experiment breaks a single light beam into two sources. Would the same pattern be obtained for two independent sources of light, such as the headlights of a distant car? Explain.
5. Find the range of visible wavelengths of light in crown glass. (OpenStax 27.2) **250 nm to 500 nm**
6. What is the index of refraction of a material for which the wavelength of light is 0.671 times its value in a vacuum? Identify the likely substance. (OpenStax 27.3) **1.49, Polystyrene**
7. Analysis of an interference effect in a clear solid shows that the wavelength of light in the solid is 329 nm. Knowing this light comes from a He-Ne laser and has a wavelength of 633 nm in air, is the substance zircon or diamond? (OpenStax 27.4) **1.92, Zircon**
8. At what angle is the first-order maximum for 450-nm wavelength blue light falling on double slits separated by 0.0500 mm? (OpenStax 27.6) $\mathbf{0.516°}$
9. Calculate the angle for the third-order maximum of 580-nm wavelength yellow light falling on double slits separated by 0.100 mm. (OpenStax 27.7) $\mathbf{0.997°}$
10. What is the separation between two slits for which 610-nm orange light has its first maximum at an angle of 30.0°? (OpenStax 27.8) $\mathbf{1.22 \times 10^{-6}\ m}$
11. Find the distance between two slits that produces the first minimum for 410-nm violet light at an angle of 45.0°. (OpenStax 27.9) $\mathbf{0.290\ \mu m}$
12. Calculate the wavelength of light that has its third minimum at an angle of 30.0° when falling on double slits separated by 3.00 μm. (OpenStax 27.10) **600 nm**
13. What is the wavelength of light falling on double slits separated by 2.00 μm if the third-order maximum is at an angle of 60.0°? (OpenStax 27.11) **577 nm**

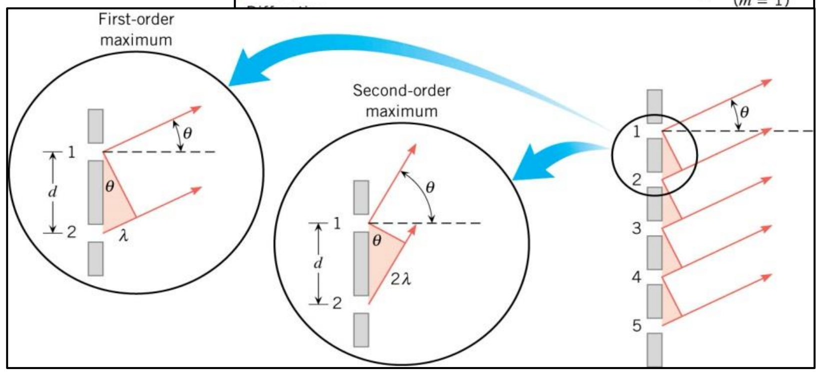
Diffraction Grating



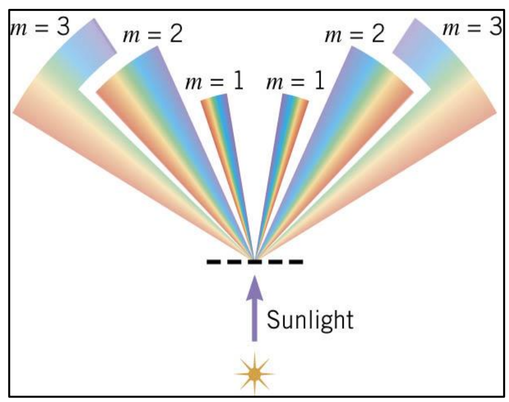
- Arrangement of many ________ spaced ________
- As many as ________ slits per cm
- Produces ____________ patterns

- The light ________ are essentially ________.
- The principal ________ occur when light from one slit travels ________ more to meet light from a ________slit producing ____________ interference.
- Principal ________

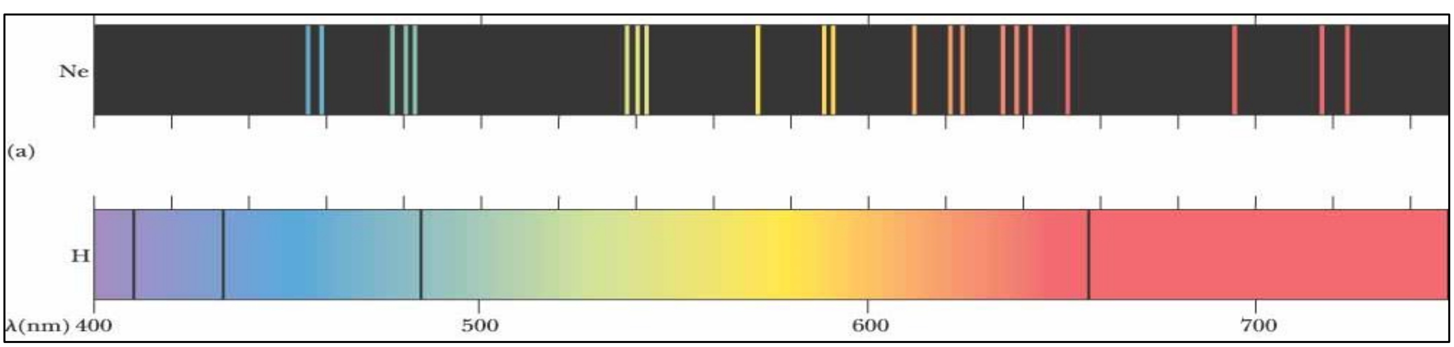
$$\sin\theta = m\frac{\lambda}{d}$$



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?



- Diffraction gratings produce __________, more ________ maxima, but have small ___________ maxima in ________.
- Splitting colors
  - Each ________ of light is a different ___________, so each color bends a different ________.
  - Which color bends the most? ________
  - Which color bends the least? ________
- Application - Determining Elements in Stars
  - Each ________ in a hot gas ________ or ________ certain ____________ of light.
  - By using a diffraction ________ the light can be ________ and the wavelengths ___________.



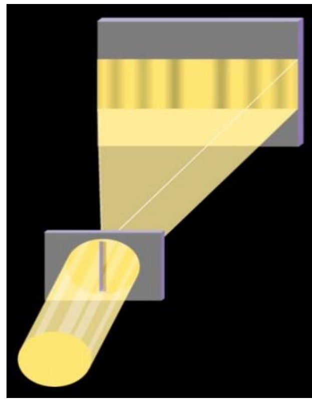
Homework

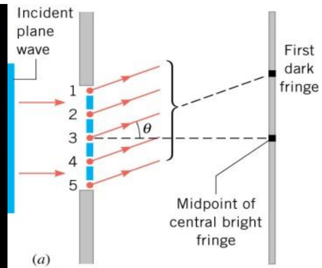
1. What is the advantage of a diffraction grating over a double slit in dispersing light into a spectrum?
2. What are the advantages of a diffraction grating over a prism in dispersing light for spectral analysis?
3. A diffraction grating has 2000 lines per centimeter. At what angle will the first-order maximum be for 520-nmwavelength green light? (OpenStax 27.21) $\mathbf{5.97°}$
4. Find the angle for the third-order maximum for 580-nmwavelength yellow light falling on a diffraction grating having 1500 lines per centimeter. (OpenStax 27.22) $\mathbf{15.1°}$
5. How many lines per centimeter are there on a diffraction grating that gives a first-order maximum for 470-nm blue light at an angle of 25.0°? (OpenStax 27.23) $\mathbf{8.99 \times 10^3}$
6. What is the distance between lines on a diffraction grating that produces a second-order maximum for 760-nm red light at an angle of 60.0°? (OpenStax 27.24) $\mathbf{1.76 \times 10^{-6}\ m}$
7. Calculate the wavelength of light that has its second-order maximum at 45.0° when falling on a diffraction grating that has 5000 lines per centimeter. (OpenStax 27.25) **707 nm**
8. What is the maximum number of lines per centimeter a diffraction grating can have and produce a complete firstorder spectrum for visible light? (OpenStax 27.28) **12800**
9. What is the spacing between structures in a feather that acts as a reflection grating, given that they produce a firstorder maximum for 525-nm light at a 30.0° angle? (OpenStax 27.30) $\mathbf{1.05 \times 10^{-6}\ m}$
10. A He–Ne laser beam is reflected from the surface of a CD onto a wall. The brightest spot is the reflected beam at an angle equal to the angle of incidence. However, fringes are also observed. If the wall is 1.50 m from the CD, and the first fringe is 0.600 m from the central maximum, what is the spacing of grooves on the CD? (OpenStax 27.38) $\mathbf{1.70 \times 10^{-6}\ m}$

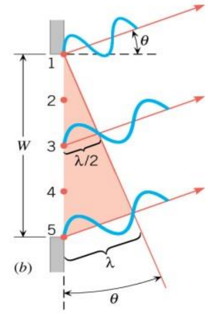
Physics 11-10 Single Slit Diffraction, Limits of Resolution, Thin Film Interference

Name: ___________________________

Single Slit Diffraction







- Large opening → ___________ bend
- Small opening → ___________ bend
- ___________ slit produces a _________________ pattern
- The ___________ wavelets ____________ with each ___________
- The center ___________ band is ________ width of the other _________.

- First order ___________ band occurs when ___________ edge and ___________ edge ___________ lengths differ by 1 wavelength.
- The ___________ wave path length ___________ by ___________ wavelength leading to the _________________ interference.
- The wavelet slightly ___________#1 will cancel with wavelet slightly below ___________ and so on.

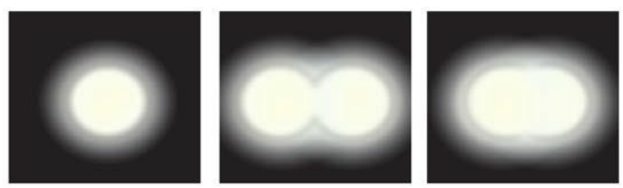
For multiple dark fringes

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

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

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?

Limits of Resolution

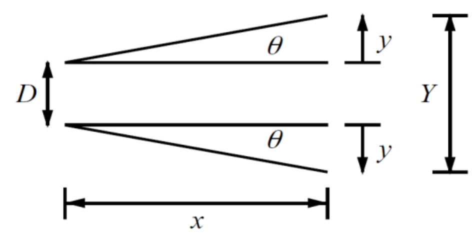


- Light going through a ___________ aperture has ________________
  - Also true for light from ___________ and ___________
- 1st minimum at

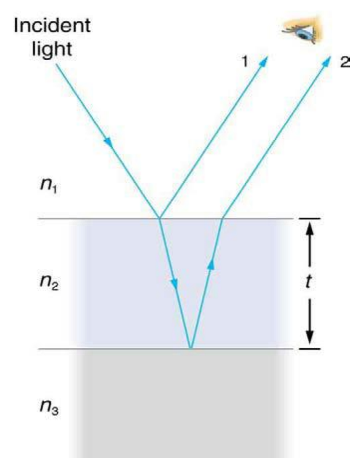
$$\theta = 1.22\frac{\lambda}{D}$$

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

(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?



Thin Film Interference



- Light interference depends on the ___________ of its ________________ and the ___________ size
- If the object is ___________ the size of the wavelength, there will be _________________
- Since each _______ of light is a different ________________, light can be split using thin _________
- When light ___________ from a medium having an ___________ of refraction ___________ than that of the medium in which it is ______________, a ________ phase change (or a λ/2 shift) occurs
- The light hits the ___________ surface.
  - Is it ___________ shifted? Only if $n_2 > n_1$
- The transmitted light ___________ off the ___________ surface.
  - Is it ___________ shifted? Only if $n_3 > n_2$
- ________________ interference when
  - $\boldsymbol{2t = \frac{\lambda_n}{2}}$ if both rays 1 and 2 phase shift or $\boldsymbol{2t = \lambda_n}$ if only one ray phase shifts

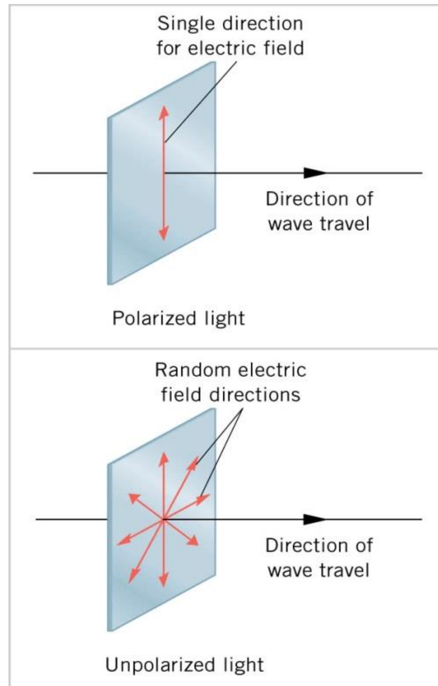
  - Where $\lambda_n = \frac{\lambda}{n_2}$
- ____________________ interference when
  - $\mathbf{2t = \lambda_n}$ if both rays 1 and 2 phase shift or $\mathbf{2t} = \frac{\lambda_n}{2}$ if only one ray phase shifts

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?

Homework

1. As the width of the slit producing a single-slit diffraction pattern is reduced, how will the diffraction pattern produced change?
2. A beam of light always spreads out. Why can a beam not be created with parallel rays to prevent spreading? Why can lenses, mirrors, or apertures not be used to correct the spreading?
3. Is there a phase change in the light reflected from either surface of a contact lens floating on a person's tear layer? The index of refraction of the lens is about 1.5, and its top surface is dry.
4. In placing a sample on a microscope slide, a glass cover is placed over a water drop on the glass slide. Light incident from above can reflect from the top and bottom of the glass cover and from the glass slide below the water drop. At which surfaces will there be a phase change in the reflected light?
5. (a) At what angle is the first minimum for 550-nm light falling on a single slit of width 1.00 µm? (b) Will there be a second minimum? (OpenStax 27.43) $\mathbf{33.4°}$**, No**
6. (a) Calculate the angle at which a 2.00-µm-wide slit produces its first minimum for 410-nm violet light. (b) Where is the first minimum for 700-nm red light? (OpenStax 27.44) $\mathbf{11.8°, 20.5°}$
7. (a) How wide is a single slit that produces its first minimum for 633-nm light at an angle of 28.0°? (b) At what angle will the second minimum be? (OpenStax 27.45) $\mathbf{1.35 \times 10^{-6}}$ **m,** $\mathbf{69.9°}$
8. (a) What is the width of a single slit that produces its first minimum at 60.0° for 600-nm light? (b) Find the wavelength of light that has its first minimum at 62.0°. (OpenStax 27.46) **693 nm, 612 nm**
9. Find the wavelength of light that has its third minimum at an angle of 48.6° when it falls on a single slit of width 3.00 µm. (OpenStax 27.47) **750 nm**
10. Calculate the wavelength of light that produces its first minimum at an angle of 36.9° when falling on a single slit of width 1.00 µm. (OpenStax 27.48) **600 nm**
11. The 300-m-diameter Arecibo radio telescope detects radio waves with a 4.00 cm average wavelength. (a) What is the angle between two just-resolvable point sources for this telescope? (b) How close together could these point sources be at the 2 million light year distance of the Andromeda galaxy? (OpenStax 27.57) $\mathbf{1.63 \times 10^{-4}}$ **rad, 325 ly**
12. Diffraction spreading for a flashlight is insignificant compared with other limitations in its optics, such as spherical aberrations in its mirror. To show this, calculate the minimum angular spreading of a flashlight beam that is originally 5.00 cm in diameter with an average wavelength of 600 nm. (OpenStax 27.59) $\mathbf{1.46 \times 10^{-5}}$ **rad**
13. A telescope can be used to enlarge the diameter of a laser beam and limit diffraction spreading. The laser beam is sent through the telescope in opposite the normal direction and can then be projected onto a satellite or the Moon. (a) If this is done with the Mount Wilson telescope, producing a 2.54-m-diameter beam of 633-nm light, what is the minimum angular spread of the beam? (b) Neglecting atmospheric effects, what is the size of the spot this beam would make on the Moon, assuming a lunar distance of 3.84×10^8 m? (OpenStax 27.61) $\mathbf{3.04 \times 10^{-7}}$ **rad, 235 m**
14. A soap bubble is 100 nm thick and illuminated by white light incident perpendicular to its surface. What wavelength and color of visible light is most constructively reflected, assuming the same index of refraction as water? (OpenStax 27.70) **532 nm, Green**
15. Calculate the minimum thickness of an oil slick on water that appears blue when illuminated by white light perpendicular to its surface. Take the blue wavelength to be 470 nm and the index of refraction of oil to be 1.40. (OpenStax 27.72) **83.9 nm**
16. A film of soapy water (*n* = 1.33) on top of a plastic cutting board has a thickness of 233 nm. What color is most strongly reflected if it is illuminated perpendicular to its surface? (OpenStax 27.74) **620 nm, Orange**

Polarization



- Linearly ________ light ________in only ________ direction
- Common non-________ light vibrates in ________ directions perpendicular to the ________ of travel.

How to make EM waves polarized

- Straight wire ________
- __________ of ________ surfaces
- Passing through a polarizing ________

Polarizing materials

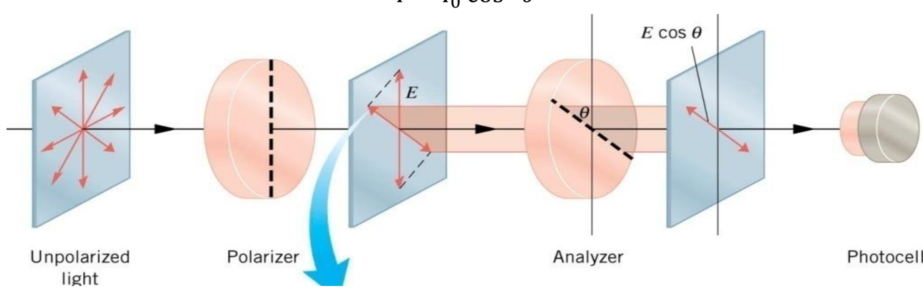
- Light is ________ along the transmission ________
- All __________ of the wave are ________ except the components ________ to the __________ axis
- Since unpolarized light vibrates ________ in ________ directions, the polarizing material absorbs ________ the light.

$$I = \frac{1}{2} I_0$$

Malus's Law

- After light has been polarized a ________ polarizer can be used to ______ the ________ of the transmitted light.
- Polarizer ________ the light. The analyzer ________ the polarized light along another ________. It only transmits the component ________ to the transmission axis of the ________.

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



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?

If the light intensity at the film is 3 W/m^2, what is angle between the transmission axes of the polarizers?

Polarization by Reflection

- Light polarized perpendicular to ____________ is more likely ____________
- Light ______________ to surface is more likely ____________
- Light is ______________ polarized at ______________ Angle

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

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

Homework

1. Can a sound wave in air be polarized? Explain.
2. No light passes through two perfect polarizing filters with perpendicular axes. However, if a third polarizing filter is placed between the original two, some light can pass. Why is this? Under what circumstances does most of the light pass?
3. The angle between the axes of two polarizing filters is 45.0°. By how much does the second filter reduce the intensity of the light coming through the first? (OpenStax 27.85) **0.500**
4. If you have completely polarized light of intensity 150 W/m^2, what will its intensity be after passing through a polarizing filter with its axis at an 89.0° angle to the light's polarization direction? (OpenStax 27.86) $\mathbf{4.57 \times 10^{-2}\ W/m^2}$
5. What angle would the axis of a polarizing filter need to make with the direction of polarized light of intensity 1.00 kW/m^2 to reduce the intensity to 10.0 W/m^2? (OpenStax 27.87) $\mathbf{84.3°}$
6. Verify that the intensity of polarized light is reduced to 90.0% of its original value by passing through a polarizing filter with its axis at an angle of 18.4° to the direction of polarization. (OpenStax 27.88) **90.0%**
7. At what angle will light reflected from diamond be completely polarized? (OpenStax 27.91) $\mathbf{67.6°}$
8. What is Brewster's angle for light traveling in water that is reflected from crown glass? (OpenStax 27.92) $\mathbf{48.8°}$
9. A scuba diver sees light reflected from the water's surface. At what angle will this light be completely polarized? (OpenStax 27.93) $\mathbf{53.1°}$

Physics

Unit 11: Electromagnetic Waves

1. *Know about the spectrum of light including the complete spectrum and visible light.*
2. *Know about the eye, vision correction, and color vision*
3. *Know how to make ray diagrams for mirrors and lenses.*
4. *What type of images to the various mirrors and lenses make? (real or virtual) (upright or inverted) (enlarged or reduced)*
5. *Why does refraction happen?*
6. *A spy satellite is in orbit at a distance of* 1.0×10^5 *m above the ground. It carries a telescope that can resolve the two rails of a railroad track that are 1.4 m apart using light of wavelength 500 nm. What is the size of the mirror in the telescope?*
7. *WAUS has a frequency of 90.7 MHz. What is it's wavelength?*
8. *An electromagnetic wave has a magnetic field with peak value 0.500 T. What is the average intensity of the wave?*
9. *If the index of refraction is 12.5, what is the speed of light in the material?*
10. *A beam of light in a material of index of refraction of 1.5 hits a boundary with air (n = 1.00). If the angle of incidence is 25°, what is the angle of refraction?*
11. *A 2 cm object is placed 15 cm from a lens. The resulting image height has a magnitude of 0.5 cm and the image is inverted. What is the focal length of the lens?*
12. *What is the image distance if an object is placed 10 cm in front of a concave mirror with radius of curvature of 12 cm?*
13. *Light with a 700nm wavelength is shown through a double slit. If the m = 0 and m = 1 bright fringes are separated by 10°, what is the separation of the slits?*
14. *Light with a700nm wavelength is shown through a single slit onto a screen 3 m away. What is the width of the slit if the* 2^{nd}*-order dark fringe is located 50 cm from the center of the central bright region?*
15. *A diffraction grating has 2000 lines/cm and has monochromatic light shown on it. If the* 3^{rd}*-order maximum is at 20°, what is the wavelength of the light?*
16. *A portion of a soap bubble appears to have λ = 500.0 nm in a vacuum when viewed at normal incidence in white light. Determine the smallest, non-zero thickness for the soap film if its index of refraction is 2.0.*
17. *Unpolarized light with an average intensity of 1000* W/m^2 *enters a polarizer with a vertical transmission axis.*
    a. *What is the intensity of the light after the polarizer?*
    b. *Then the light hits a second polarizer. The light that exits the second polarizer has an intensity of 300* W/m^2*. What is the orientation angle of the second polarizer?*

4. *Mirrors*
Concave: $d_o > R$ *image real, inverted, reduced, between C and F*
$f < d_o < R$ *image real, inverted, enlarged, beyond C*
$d_o < f$ *image virtual, upright, enlarged, behind mirror*
Convex: image virtual, upright, reduced, behind mirror

Lenses
Converging: $d_o > 2f$ *image real, inverted, reduced, between 2F and F*
$f < d_o < 2f$ *image real, inverted, enlarged, beyond 2F*
$d_o < f$ *image virtual, upright, enlarged, behind lens*
Diverging: image virtual, upright, reduced, behind lens

5. ***Speed of light changes***

6. $\theta = 1.22\frac{\lambda}{D}$
$$\tan\theta = \frac{1.4\ m}{1 \times 10^5\ m}$$
$\theta = 0.000014$
$$\theta = 1.22\frac{\lambda}{D}$$
$$0.000014 = 1.22\frac{500 \times 10^{-9}\ m}{D}$$
$D = \mathbf{0.044\ m}$

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

8. $I_{ave} = \frac{cB_0^2}{2\mu_0}$
$$I_{ave} = \frac{\left(3.00 \times 10^8 \frac{m}{s}\right)(0.500\ T)^2}{2\left(4\pi \times 10^{-7}\frac{T}{Nm}\right)}$$
$I_{ave} = \mathbf{2.98 \times 10^{13}\ W/m^2}$

9. $n = 12.5$
$n = \frac{c}{v}$
$12.5 = \frac{3.00 \times 10^8 \frac{m}{s}}{v}$
$\boldsymbol{v = 2.4 \times 10^7\ \frac{m}{s}}$

10. $n_1 = 1.5, \theta_1 = 25°, n_2 = 1.0, \theta_2 = ?$
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
$1.5 \sin 25° = 1.0 \sin\theta$
$0.6339 = \sin\theta$
$\theta = \sin^{-1} 0.6339 = \mathbf{39.3°}$

11. $h_0 = 2\ cm, d_o = 15\ cm, h_i = -0.5\ cm, f = ?$
$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$
$\frac{-0.5}{2} = \frac{-d_i}{15}$
$-2d_i = -7.5$
$d_i = 3.75\ cm$
$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$
$\frac{1}{f} = \frac{1}{15} + \frac{1}{3.75}$
$\boldsymbol{f = 3\ cm}$

12. $R = 12\ cm, f = 6\ cm, d_o = 10\ cm$
$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$
$\frac{1}{6} = \frac{1}{10} + \frac{1}{d_i}$
$\frac{1}{6} - \frac{1}{10} = \frac{1}{d_i}$
$\boldsymbol{d_i = 15\ cm}$

13. $\sin\theta = \frac{m\lambda}{d}$
$\sin 10° = \frac{1(700 \times 10^{-9}\ m)}{d}$
$d = 4.03\ \mu m = \mathbf{4.03 \times 10^{-6} m}$

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

$\tan\theta = \frac{0.5}{3}$
$\theta = 9.46°$
$\sin 9.46° = \frac{2(700 \times 10^{-9}\ m)}{W}$
$\boldsymbol{W = 8.52 \times 10^{-6}\ m}$

15. $\sin\theta = \frac{m\lambda}{d}$
$d = \frac{1}{2000\frac{lines}{cm}} = 0.0005\ cm = 0.000005\ m$
$\sin 20° = \frac{3\lambda}{0.000005\ m}$
$\boldsymbol{\lambda = 5.7 \times 10^{-7}\ m}$

16. *Only ray 1 phase shifts so to get constructive interference,* $2t = \frac{\lambda_n}{2}$
$$\lambda_n = \frac{\lambda}{n} = \frac{500 \times 10^{-9}\ m}{2.0} = 250 \times 10^{-9}\ m$$
$$2t = \frac{250 \times 10^{-9}\ m}{2}$$
$t = \mathbf{6.25 \times 10^{-8}\ m}$

17. a. $\mathbf{500 \frac{W}{m^2}}$ *(halved)*
b. $S = S_0 \cos^2\theta$
$300\frac{W}{m^2} = 500\frac{W}{m^2}\cos^2\theta$
$0.6 = \cos^2\theta$
$0.7746 = \cos\theta$
$\theta = \cos^{-1} 0.7746 = \mathbf{39.2°}$