Chapter 8: Light Basics

Dual Nature of Light

Light is said to have a dual nature. This means that we can consider light to be a wave and we can consider it to be a particle. Light has the properties of both a WAVE and a PARTICLE.

Light as a Particle

A light particle is called a photon. Although it doesn't have mass, it does have momentum!

The speed of light, *c*, is 3.0×10^8 m/s.

Light as a Wave

If we consider light to be a wave, then the wave propagates at the speed of light (3.0×10^8 m/s).

Amplitude (A): 1/2 of total height of wave (related to intensity of light)

Frequency (*f*): # of oscillations per second
units: 1/s = Hertz (Hz)

Wavelength (λ): distance between 2 peaks
(related to colour of light)
units: nm → nanometer 1nm = 10^{-9} m

Remember that for all colours of light, $c = f\lambda$.

$\frac{m}{s} \times \frac{1}{m}$

Examples:

1. What is the frequency of yellow light if it has a wavelength of 570 nm?

$\lambda = 570 \times 10^{-9}$ m
$c = 3 \times 10^8$ m/s
$f = ?$

$f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{570 \times 10^{-9} \text{ m}} = 5.26 \times 10^{14} \frac{1}{s} = 5.26 \times 10^{14}$ Hz

2. What is the wavelength of x-rays if they have a frequency of 6×10^{16} Hz?

$\lambda = ?$
$c = 3 \times 10^8$ m/s
$f = 6 \times 10^{16}$ Hz

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

$\lambda = \frac{3.0 \times 10^8 \text{ m/s}}{6 \times 10^{16} \text{ Hz}} = 5 \times 10^{-9}$ m $= 5$ nm

Types of Objects and Materials:

Luminous: emits light (ex: sun, light bulb, tv screen)

Non-luminous: only reflect light (ex: moon, bike reflector, shirt)

Types of Light Sources (Luminous Objects)

Incandescent: light is produced by heating a material
ex: light bulb, toaster element

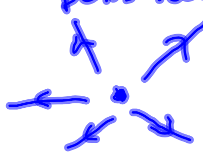
Luminescent: light is produced by chemical reaction
ex: glow sticks, fireworks, fireflies, angler fish

Fluorescent: light is produced by exciting electrons with current (ex: CFL, fluorescent lights)

Phosphorescent: Stores energy and releases it later
ex: glow in the dark

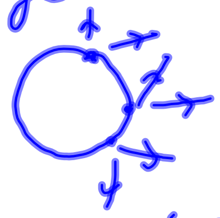
Size of Light Sources

point source



all light comes from single point

large source



collection of 2 or more point sources

Some Light Phenomena:

Reflection: When light bounces of a surface.
ex: mirrors, pencil, table

Refraction: When light changes direction as a result of going from one medium to another.
ex: "broken" pencil in water

Diffusion: When light is scattered after hitting a rough surface or going through a translucent material
ex: frosted glass

Dispersion: When white light is separated into light of different colours.
ex: rainbow, prism

Diffraction: When light « bends » as it travels around obstacles or through openings that are of (→ very small) dimensions similar to those of the wavelength of the light

Absorption: When the light energy is absorbed (→ as opposed to reflected) by a material.
ex: dark objects absorb more light

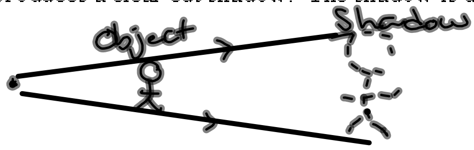
Scattering: When light goes in all directions after hitting small particles.
ex: dust in air

Some Properties of Light

- Light travels in a straight line.
- A ray of light is the path along which the light energy is carried.
  We use an arrow to represent a ray of light.

Shadows, Umbra, Penumbra

A **point source** produces a clear cut shadow. The shadow is upright (not upside down).

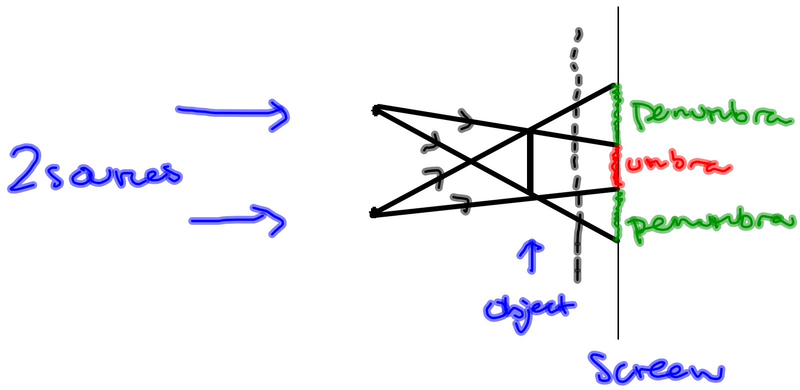


A **large source** (or **two point sources**) produces a shadow where some areas of partially lit.

- **Umbra**: Area that does not receive any light. (intersection of shadows)
- **Penumbra**: Area that receives some light.

Examples:

1. Determine the regions of umbra and penumbra produced on the screen.



2. What happens to the region of umbra on the screen as the screen gets closer to the object causing the shadow?

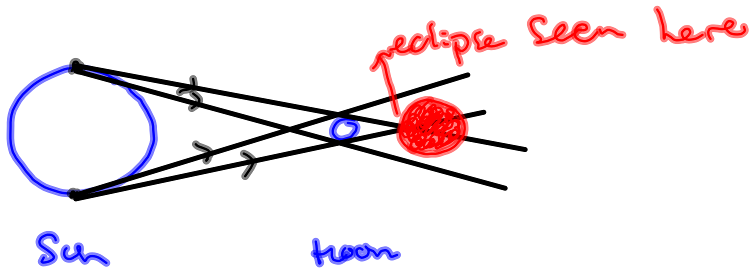
larger on the screen

3. What happens to the region of umbra on the screen as the object causing the shadow gets closer to the light source?

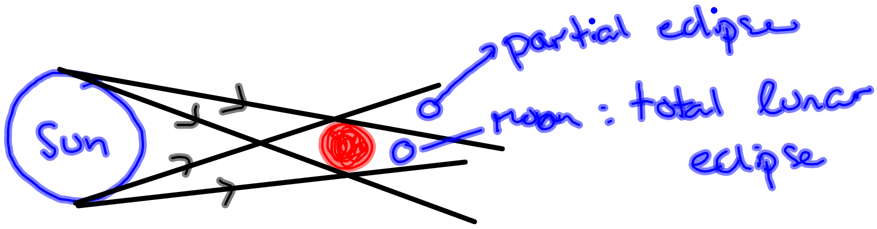
smaller on the screen

Application of Shadows: Eclipses

Solar eclipse: Sun can't be seen. Moon is between Sun and earth

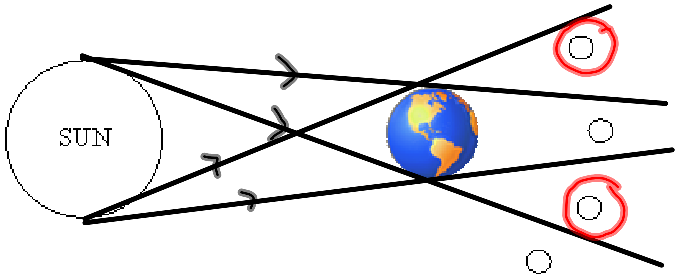


Lunar eclipse: Moon can't be seen. Earth is between the Sun and moon

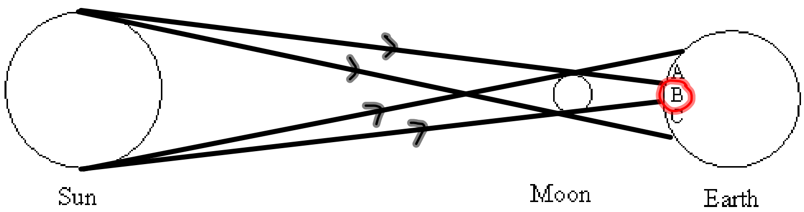


A few more examples:

1. In which position(s) is the moon in the Earth's penumbra?



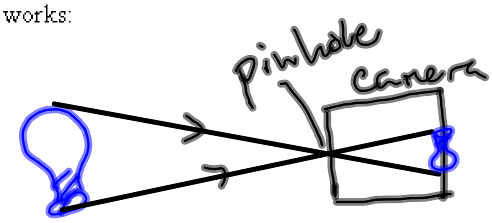
2. In which region(s) of the Earth can a total solar eclipse be seen?



The Pinhole Camera

The pinhole camera (aka camera obscura) illustrates the fact that **light travels in a straight line**.

This is how it works:



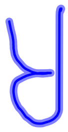
The images produced by a pinhole camera are inverted.

↳ upside down
→ flipped L↔R

Example: Consider the object below, which is looked at through a pinhole camera

R

1. What would the image look like on the screen of the pinhole camera?



2. What happens to the image seen on the pinhole camera screen when the pinhole camera gets closer to the object? When it gets further?

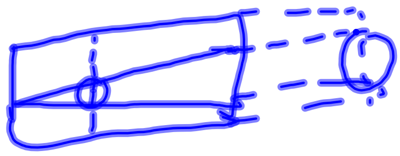
closer → bigger image (great angles of light entering camera)

further → smaller image (smaller angle of light entering camera)

3. What happens to the image seen on the pinhole camera screen when the screen within the pinhole camera gets closer to the pinhole? When is gets further?

closer → smaller image

further → larger image



Some Vocabulary and Symbols

Object: actual, physical thing you look at

Image: representation of object that we see

d_o: distance from the pinhole to the object
d_i: distance from the pinhole to the image

** Always measure distances from the pinhole! Beware of signs!!!

h_o: height of object
h_i: height of image (always ⊖ for pinhole camera)

Beware of signs!

*Images in pinhole cameras are always inverted, so M is always ⊖ and hi is always ⊖.

Magnification with the Pinhole Camera

Magnification (M): factor by which the height of the object is reduced/enlarged in order to obtain the image

$$M = \frac{h_i}{h_o} \qquad M = -\frac{d_i}{d_o} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

M always ⊖ for pin. cam.
|M| < 1 image smaller
|M| > 1 " bigger
|M| = 1 image same size

Examples

1. Using a pinhole camera, you look at a tree that is 4 m high. On the screen of the pinhole camera, the tree appears to be only 2 cm high. What is the magnification?

$h_i = -2\text{ cm}$
$h_o = 4\text{ m} = 400\text{ cm}$
$M = ?$

$$M = \frac{h_i}{h_o} = \frac{-2\text{ cm}}{400\text{ cm}} = -0.005$$

2. You are observing a firefly that is 1.5 cm long. The image of the firefly measures 4.5 cm. What is the magnification?

$h_i = -4.5\text{ cm}$
$h_o = 1.5\text{ cm}$
$M = ?$

$$M = \frac{h_i}{h_o} = \frac{-4.5\text{ cm}}{1.5\text{ cm}} = -3$$

3. When you look at a candle through a pinhole camera, the image you see is 4 times smaller than the actual candle. What is the magnification of this pinhole camera?

$$M = -\frac{1}{4} = -0.25$$

4. Using a pinhole camera, you wish to produce an image of a house that would be 100 times smaller that the actual house. The screen of your pinhole camera is located 30 cm away from the pinhole. How far from the house should you position the pinhole of your camera in order to obtain the desired image?

$M = -\frac{1}{100} = -0.01$
$d_i = 30\text{ cm}$
$d_o = ?$

$$M = -\frac{d_i}{d_o}$$

$$d_o = -\frac{d_i}{M} = -\frac{(30\text{ cm})}{-0.01} = 3000\text{ cm} = 30\text{ m}$$

Colours

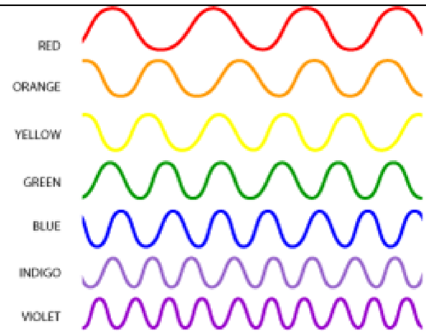
White light is composed of : all the colours of light combine

Different colours of light have different wavelength

Wavelengths of Different Colours of Light

Roy G. Biv

R	- red	650 nm
O	- orange	590 nm
Y	- yellow	570 nm
G	- green	510 nm
B	- blue	475 nm
I	- indigo	445 nm
V	- violet	400 nm



Colour theory

Primary Colour of Light: Red Green Blue

Primary Colour of Pigment (Paint): Yellow Cyan Magenta

ADDING LIGHT

Blue Light + Red Light: Magenta

Blue Light + Green Light: Cyan

Red Light + Green Light: yellow

ADDING PIGMENT

Magenta + Yellow: Red

Magenta + Cyan: blue

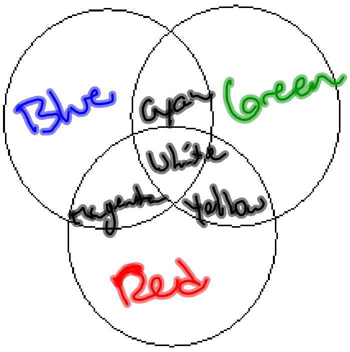
Cyan + Yellow: green

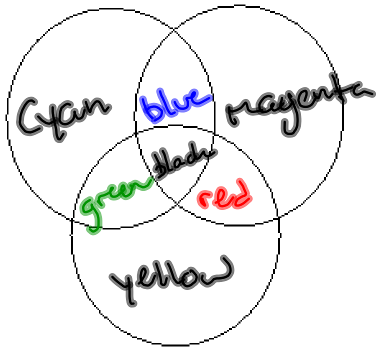
Adding light: tv, cell phone, computers

Adding pigment: paint, ink (printer)

Summary

Colour theory (Additive)	Colour theory (Subtractive)
Adding light of different colours	Adding pigment of different colours (ex: paint)





Coloured Items:

Object that appear GREEN reflects: green light
absorbs: absorb all other colours

Object that appear RED reflects: red light
absorbs: absorb all other colours

Object that appear BLUE reflects: blue light
absorb: absorb all other colours

Looking at coloured items in different colours of light

* Remember that object only appear to be a certain colour because they REFLECT light of a certain colour. So an apple does not look red because it IS red, it looks red because it REFLECTS red light.

* Object that DON'T reflect any light are BLACK.

\Examples:

1. What is the colour of a red apple in → in white light
   - a. Red light red
   - b. White light red
   - c. Blue light black
   - d. Green light black

2. Lisa is wearing a blue shirt. She goes to a party where to a ~~party where there~~ is a “light show”. The dance floor is successively lit by a red light, by a blue light and by a white light. What is the colour of Lisa’s shirt as viewed in the different lights?

red light → black
blue light → blue
white " → blue

3. A singer is giving a show. She is wearing a white shirt and red pair of pants. A green light is lighting the stage. What colour do her shirt and pants appear on stage?

Shirt = green
pants = black

Colour Filters

Remember that light of different colours has different wavelengths. This is called the visible spectrum

Colour filters are substances that only allow specific wavelengths of lights (specific colours) through. Filters absorb other colours of light.

Ex: A red filter: lets red light through

Absorbs: all other colors of light

In reality, filters are not pure. They don't let only ONE colour through, they also allow adjacent colours through. (See ROYGBIV.)

Ex:

1. A composed (not pure) yellow filter lets orange, yellow, green light through

2. Two filters are place in front of the same white light source. The light from the source first goes through the orange filter, then through the green filter. What is the colour of the light that passes through the second filter?

→ W
orange: → R, → O, → Y
green: → Y, → G, → B
→ Yellow