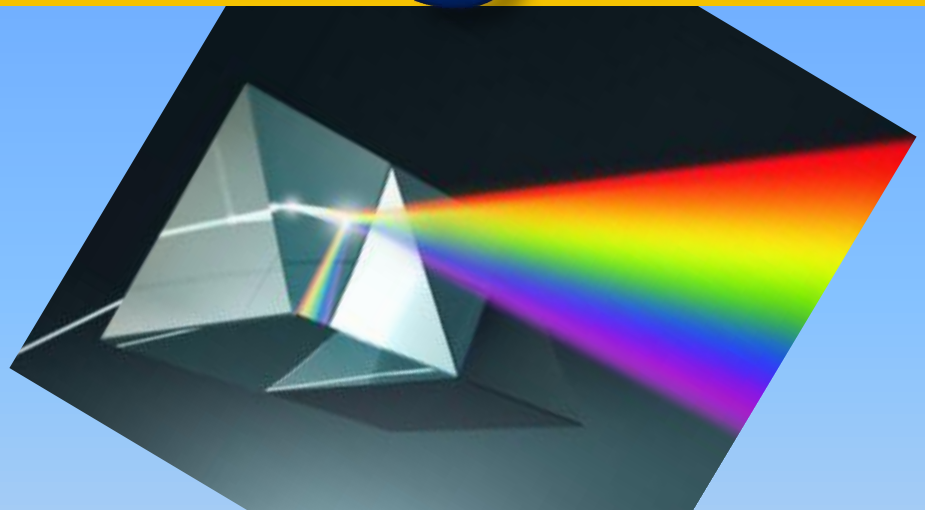
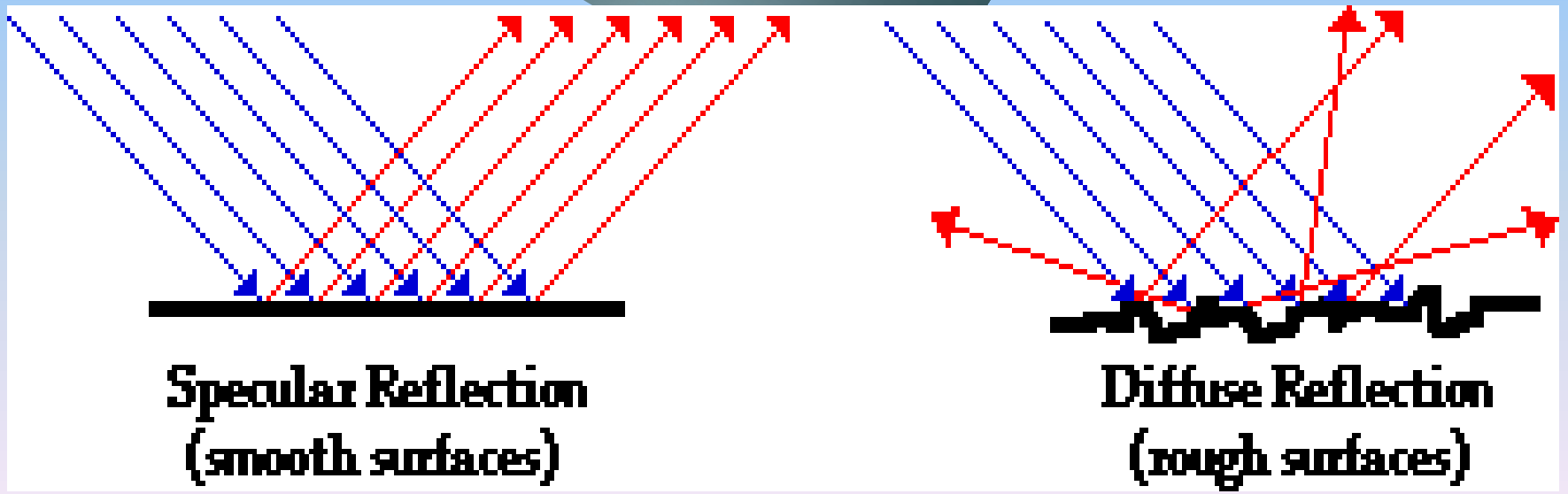
Light




Specular Reflection
(smooth surfaces)
Diffuse Reflection
(rough surfaces)

WARM-UP

Are these images real?
What causes them?

Focus Questions

LESSON QUESTION

1. Define electromagnetic radiation and recognize the relationship between frequency, wavelength, and the speed of light.
2. Describe wave-particle duality and classify associated properties of light (photoelectric effect, reflection, refraction, diffraction, and polarization).
3. Recognize types of reflection of light, the law of reflection.
4. Recognize refraction of light, optical density, index of refraction, identifying all components of light as it refracts while travelling through different media.
5. Identify behaviors of light in materials.

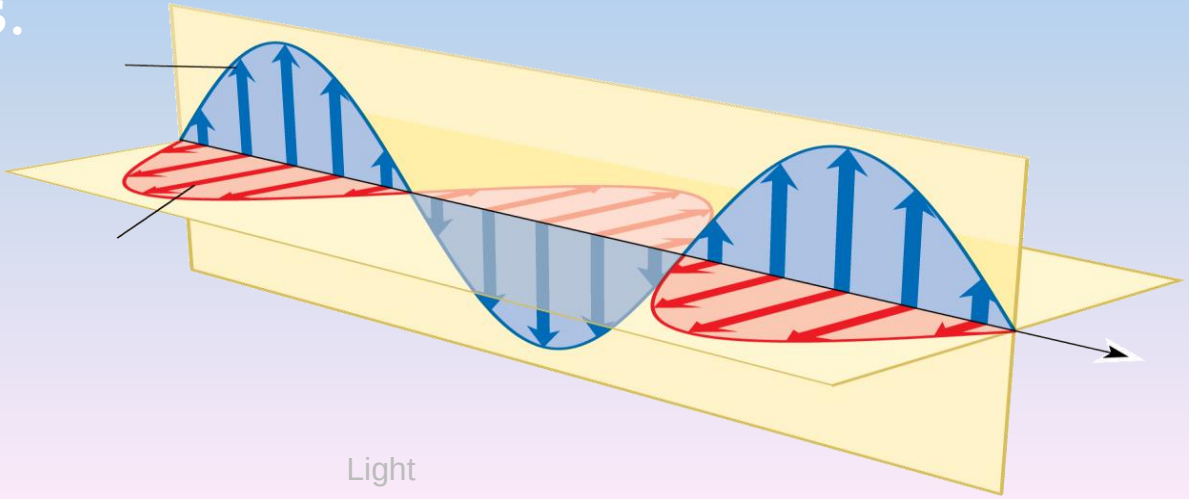
The waves that carry this girl's cell phone conversation are not visible.

Electromagnetic Waves

Electromagnetic waves are transverse waves produced by changing electric fields and changing magnetic fields. Mechanical waves originate by vibration.

Electromagnetic waves do not need a medium to travel through as with mechanical waves.

Electromagnetic waves are transverse waves because the fields are at right angles to the direction in which the wave travels.

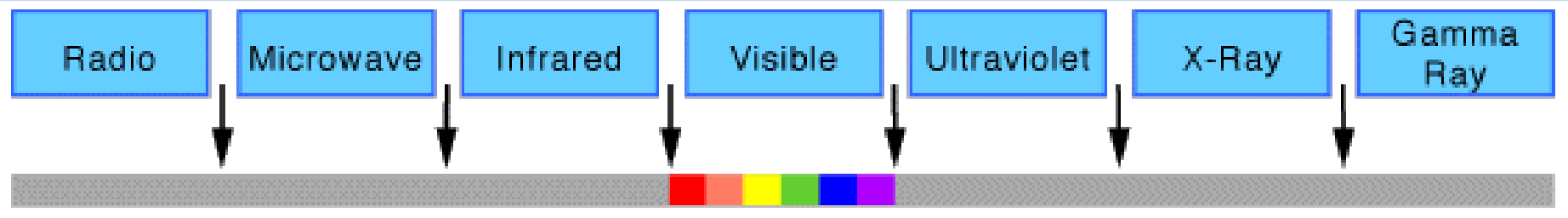


Electromagnetic Radiation

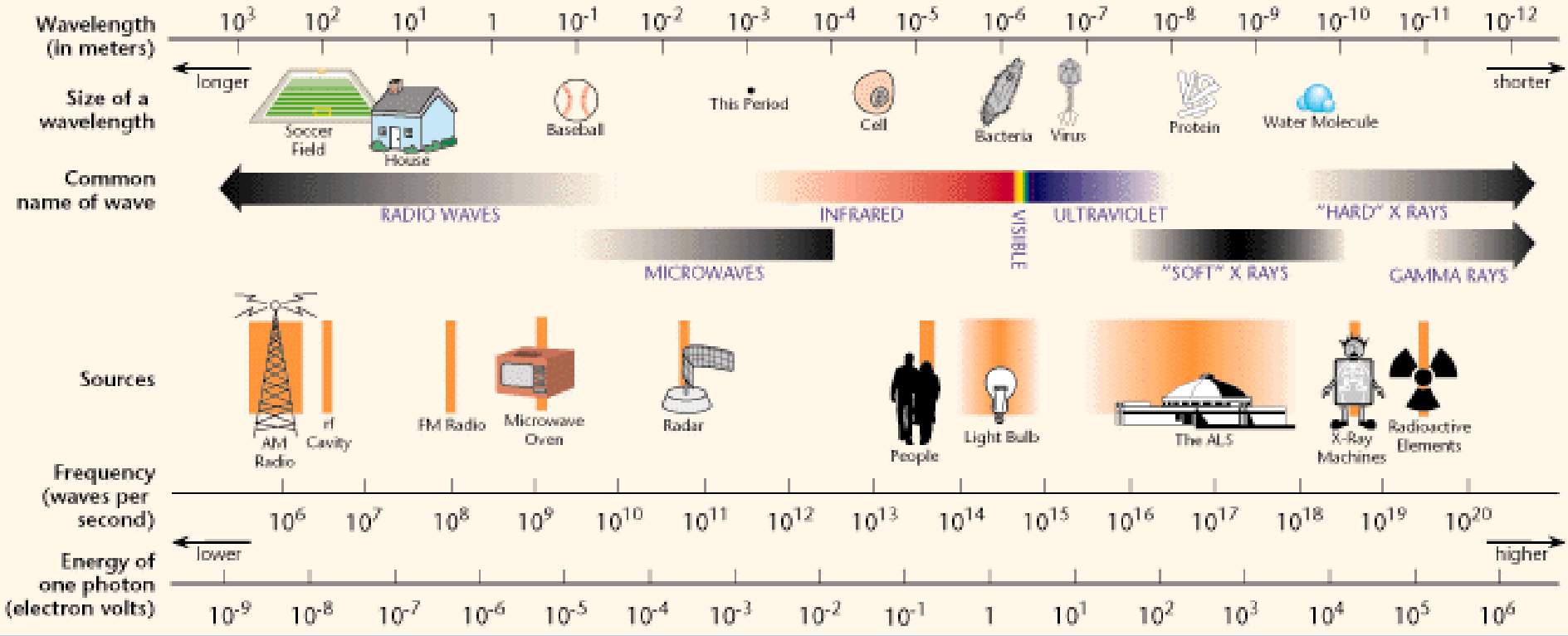
Electromagnetic (EM) radiation is radiant energy consisting of electric & magnetic fields. It needs no particles to travel through (as sound does).

Visible light is one type of EM radiation; the vast majority of EM radiation is invisible.

- EM Radiation is often called "Light".



THE ELECTROMAGNETIC SPECTRUM



$$c = f\lambda$$

Speed of light = frequency x wavelength

f and λ are inversely proportional

QUICK CHECK

$c = f \lambda$

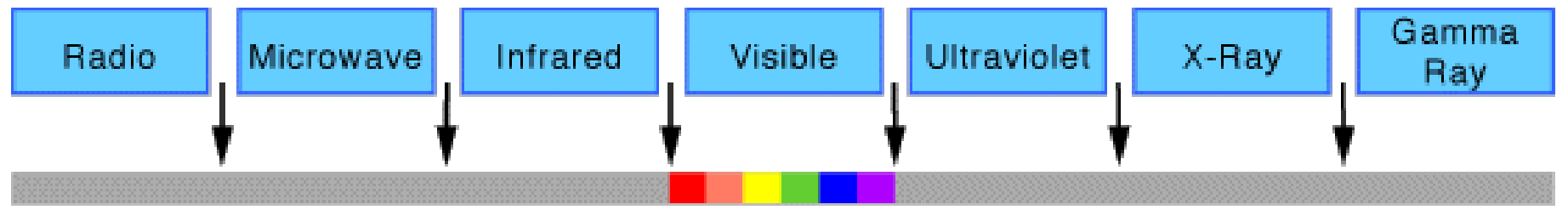
Calculate the wavelength of **green** light when its frequency is 6.02×10^{14} Hertz. [c = *3.00 x 10^8 m/s*.]

A

G

E

S



QUICK CHECK

$c = f \lambda$

Calculate the wavelength of **green** light when its frequency is 6.02×10^{14} Hertz. [$c = 3.00 \times 10^{8}$ *m/s*.]

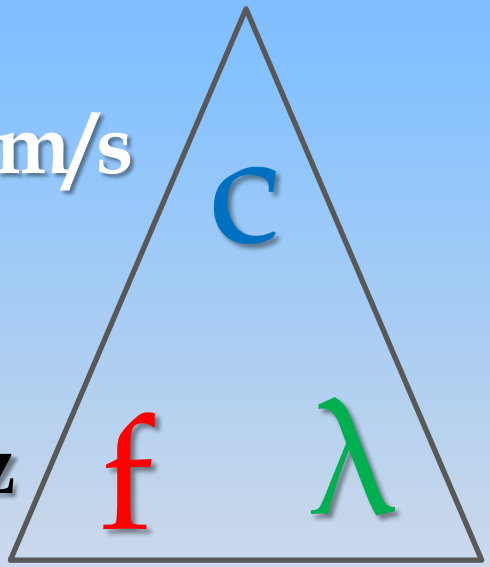
A **wavelength (λ)**

G $f = 6.02 \times 10^{14}$ Hz; $c = 3.00 \times 10^{8}$ m/s

E $c = f \lambda$; rearrange: $\lambda = c/f$

S $\lambda = 3.00 \times 10^{8}$ m/s / 6.02×10^{14} Hz

$\lambda = 4.98 \times 10^{-7}$ m

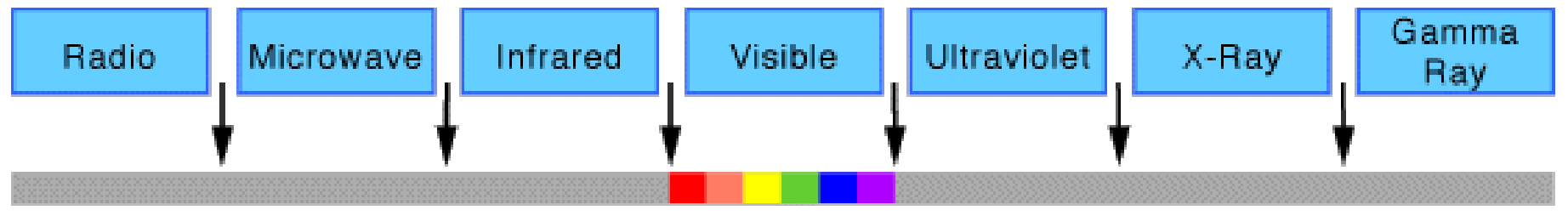


QUICK CHECK

$$c = f \lambda$$

Do radio waves have lower or higher frequency than visible light? What about X-rays compared to visible light?

Order the colors of the rainbow from highest to lowest frequency.



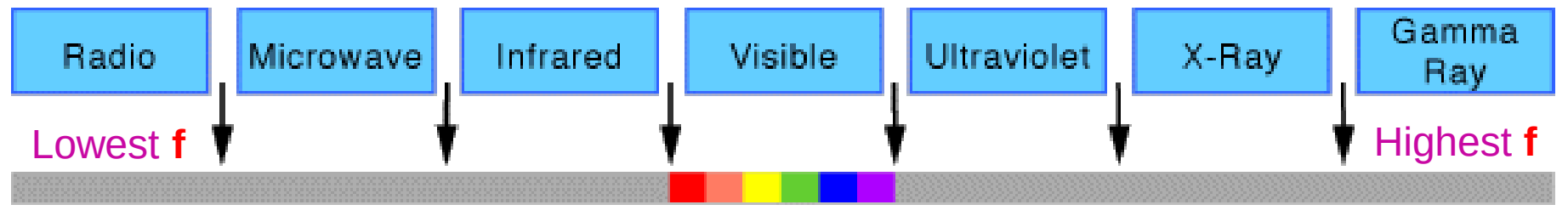
QUICK CHECK

$$c = f\lambda$$

Radio waves have lower frequency than visible light. X-rays have higher frequency than visible light.

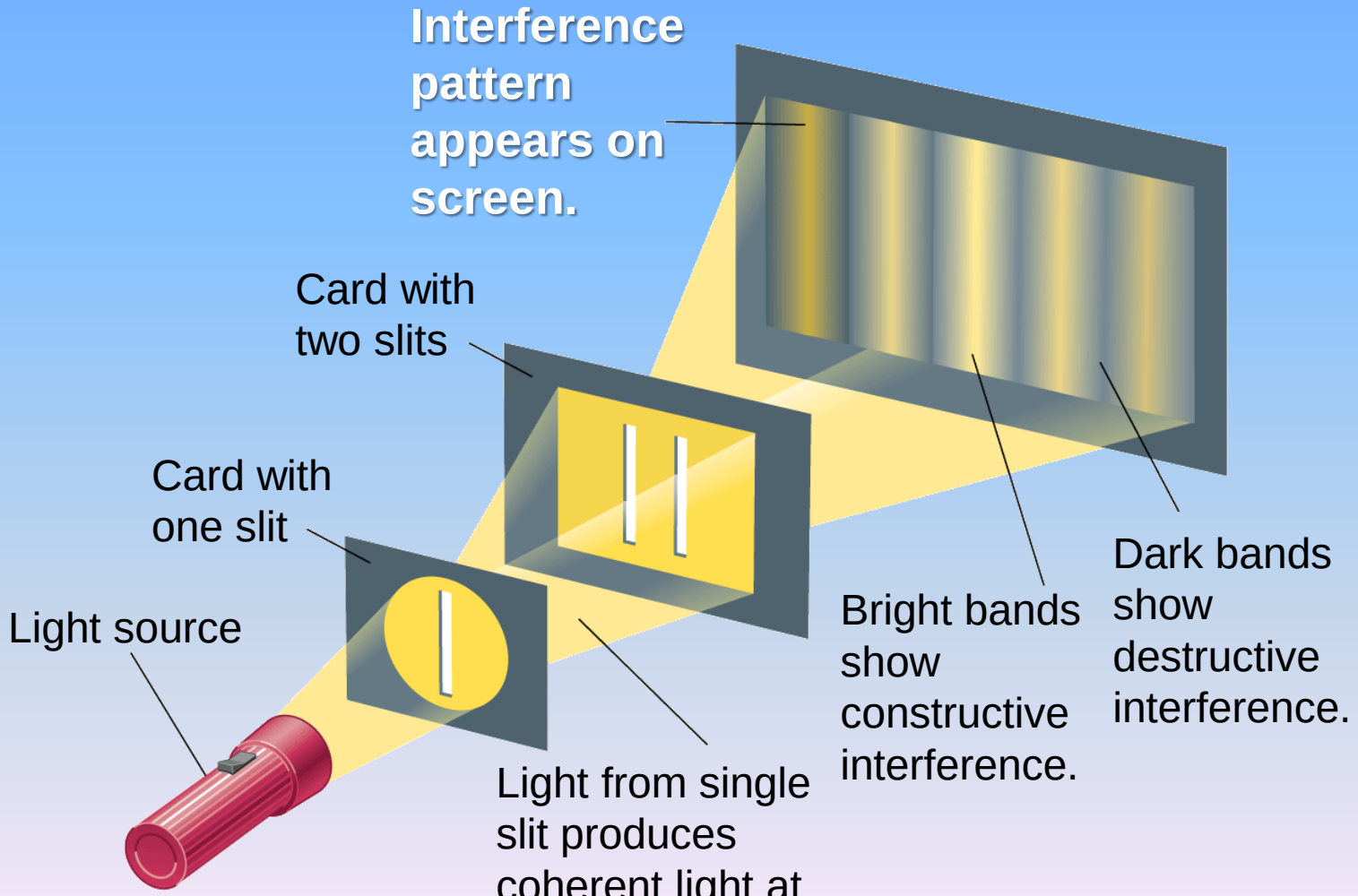
Order the colors of the rainbow from highest to lowest frequency: VIBGYOR

ROYBIV (longest to shortest wavelength)



WAVE – PARTICLE DUALITY

- **Wave or Particle?**



Wave or Particle?

The fact that light casts a shadow has been used as evidence for both the wave model of light and the particle model of light.

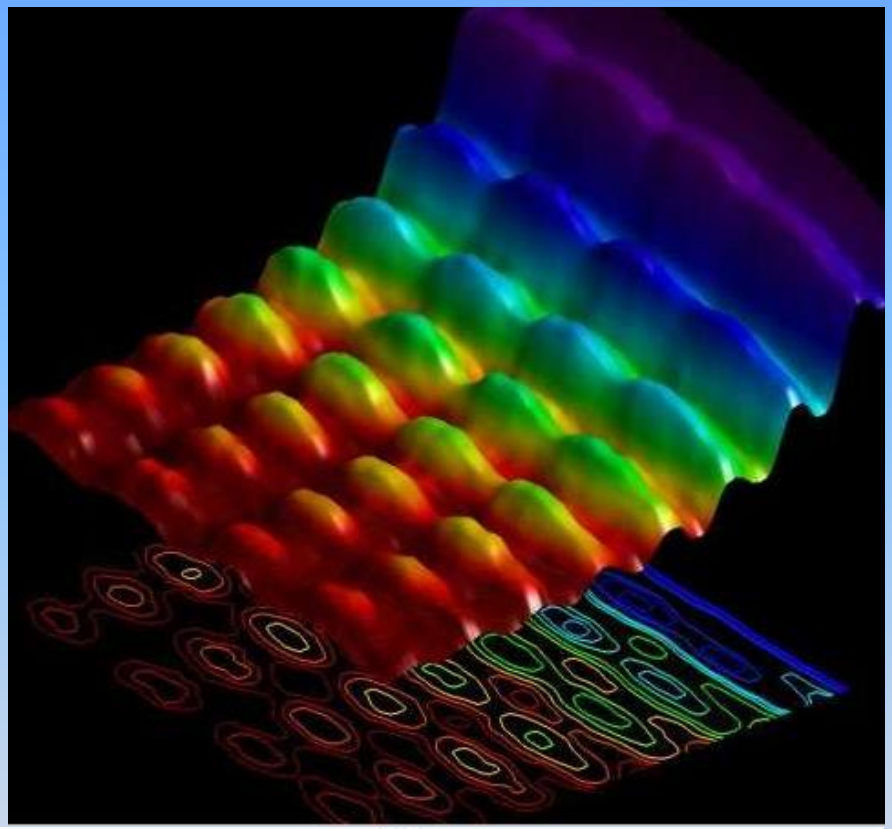
WAVE – PARTICLE DUALITY

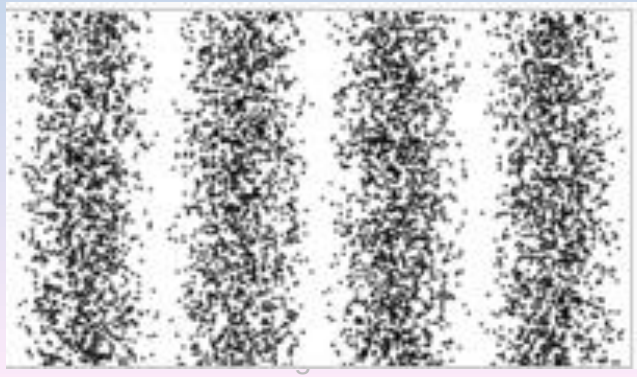
LIGHT or E-M radiation behaves as a particle.

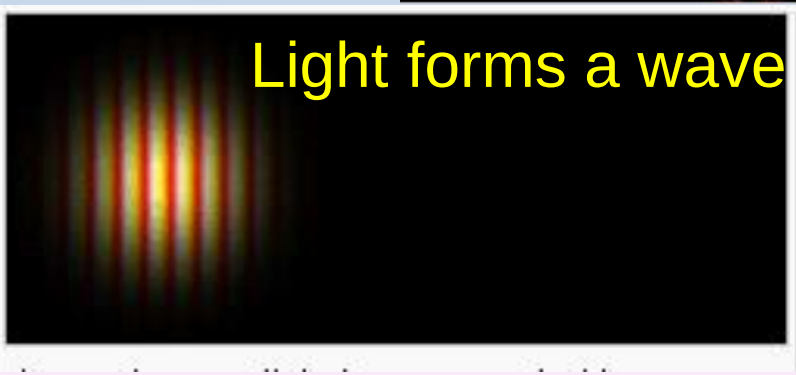
Light has no mass.

Light acts as a "bundle of energy" (photon).

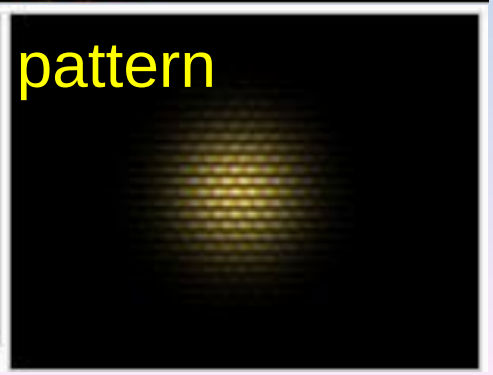
Light "strikes" as a particle.





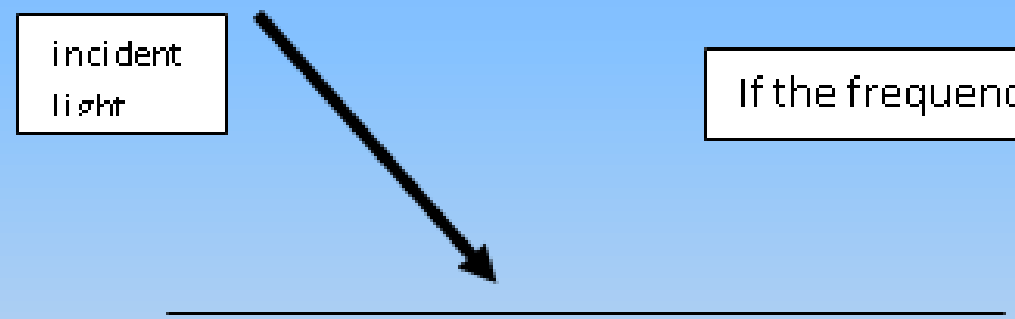


Light forms a wave pattern

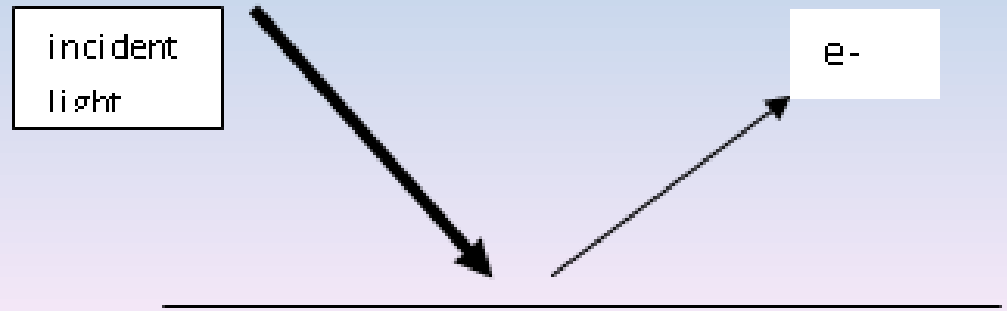


Photoelectric Effect

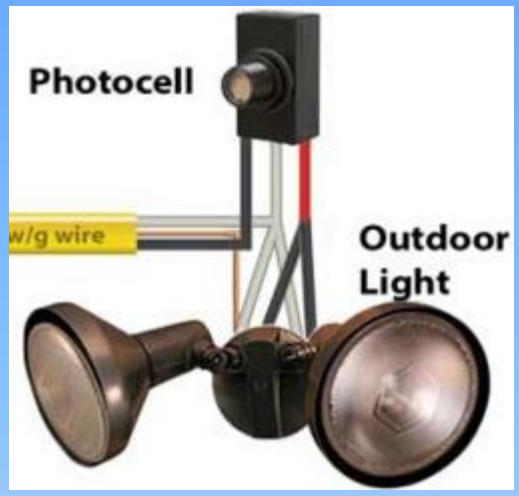
The transfer of energy from the **light** to an **electron** in the metal. E.g. *electric eyes, light meter in photography, sound track in a motion picture, photocells.*

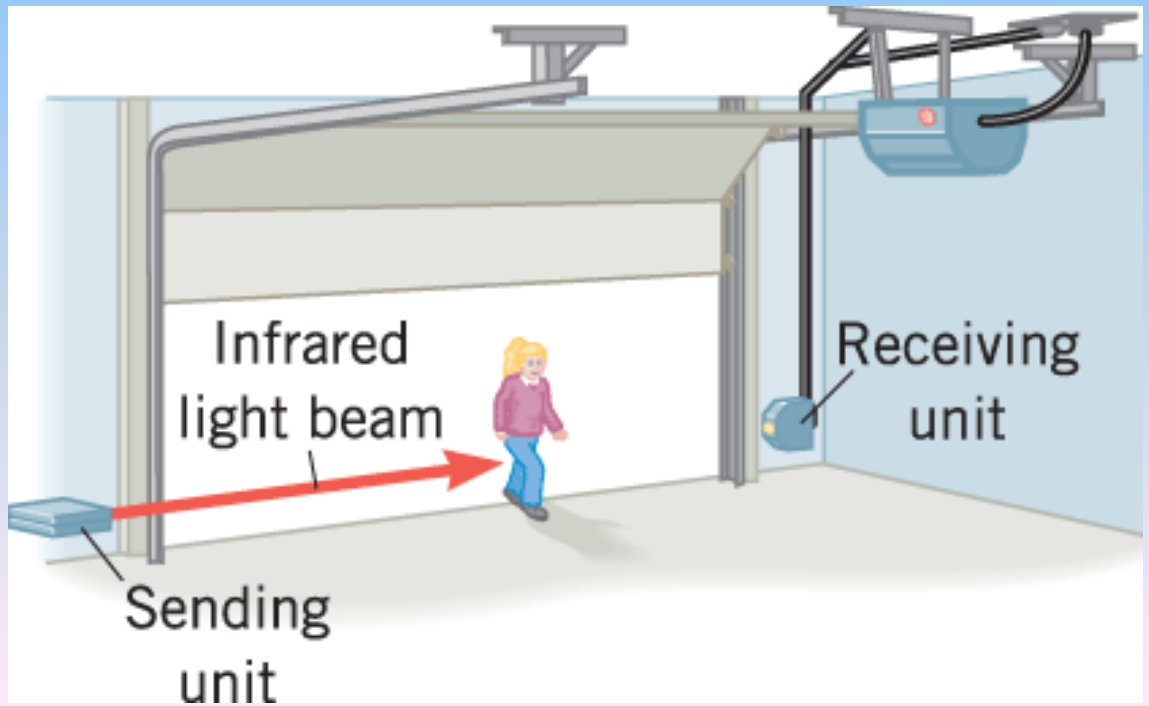


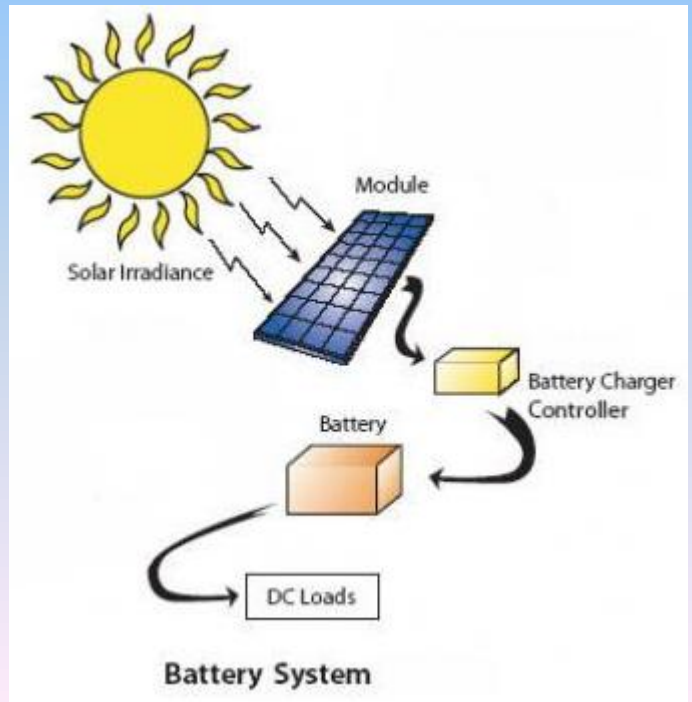
If the frequency is high enough, electrons are emitted from the surface of the substance



Photoelectric Effect - Examples







QUICK CHECK

How are electromagnetic waves different from all mechanical waves?

a. Electromagnetic waves don't carry energy.
b. Electromagnetic waves are invisible.
c. Electromagnetic waves are longitudinal waves.
d. Electromagnetic waves can travel through a vacuum.

The photoelectric effect is evidence that light behaves like

a. a wave.
b. a particle.
c. both a wave and a particle.
d. neither a wave nor a particle.

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b. Electromagnetic waves are invisible.

c. Electromagnetic waves are longitudinal waves.

d. Electromagnetic waves can travel through a vacuum. Mechanical waves need a medium.

The photoelectric effect is evidence that light behaves like

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QUICK CHECK

What type of electromagnetic radiation is used to keep prepared foods warm in a serving area?

a. ultraviolet rays
b. infrared rays
c. X-rays
d. gamma rays

What type of electromagnetic radiation helps the body produce vitamin D, kills microorganisms, helps plants grow, but also can cause damage to skin (cancer) and eyes?

a. ultraviolet rays
b. infrared rays
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QUICK CHECK

What type of electromagnetic radiation is used to keep prepared foods **warm** in a serving area?

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b. **infrared rays**
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What type of electromagnetic radiation helps the body produce vitamin D, kills microorganisms, helps plants grow, but also can cause damage to skin (cancer) and eyes?

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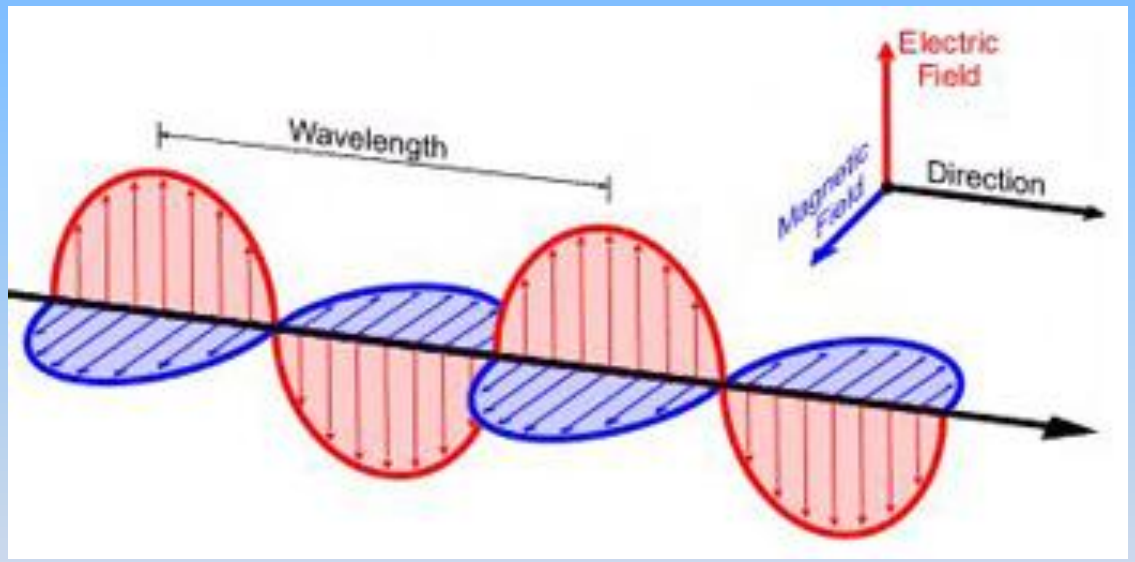
WAVE – PARTICLE DUALITY

LIGHT or E-M radiation behaves as a **wave**.

Reflection Refraction Diffraction / Interference



*[**Electric field** in transverse north south direction*

***Magnetic field** in transverse east west direction]*

Properties of Light Waves

Reflection

Refraction

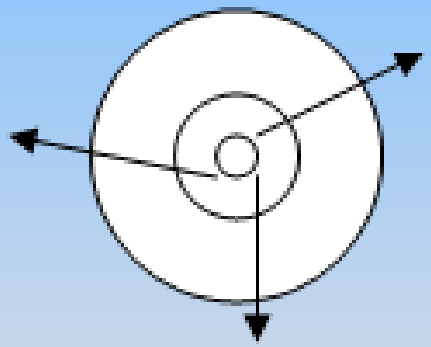
Polarization

Light Waves

Light travels in waves carrying energy from one point to another.

The speed of light is 3.0×10^8 meters per second.

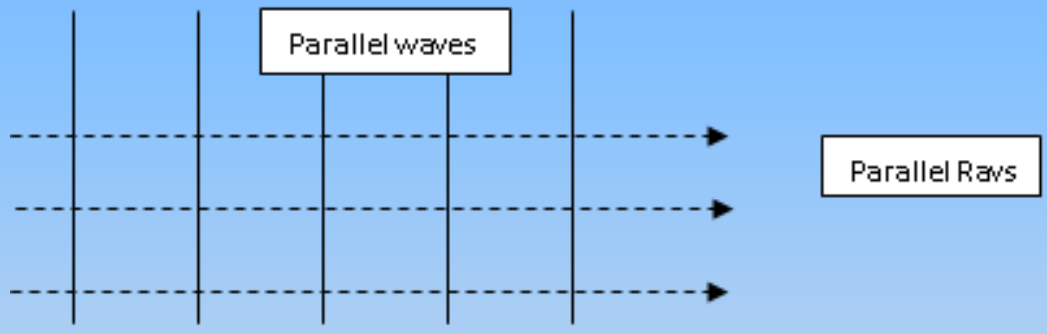
The direction of wave travel is indicated by "**RAYS**" of light.



WAVEFRONT: a set of points with constant phase when all are at "peak" or "crest".

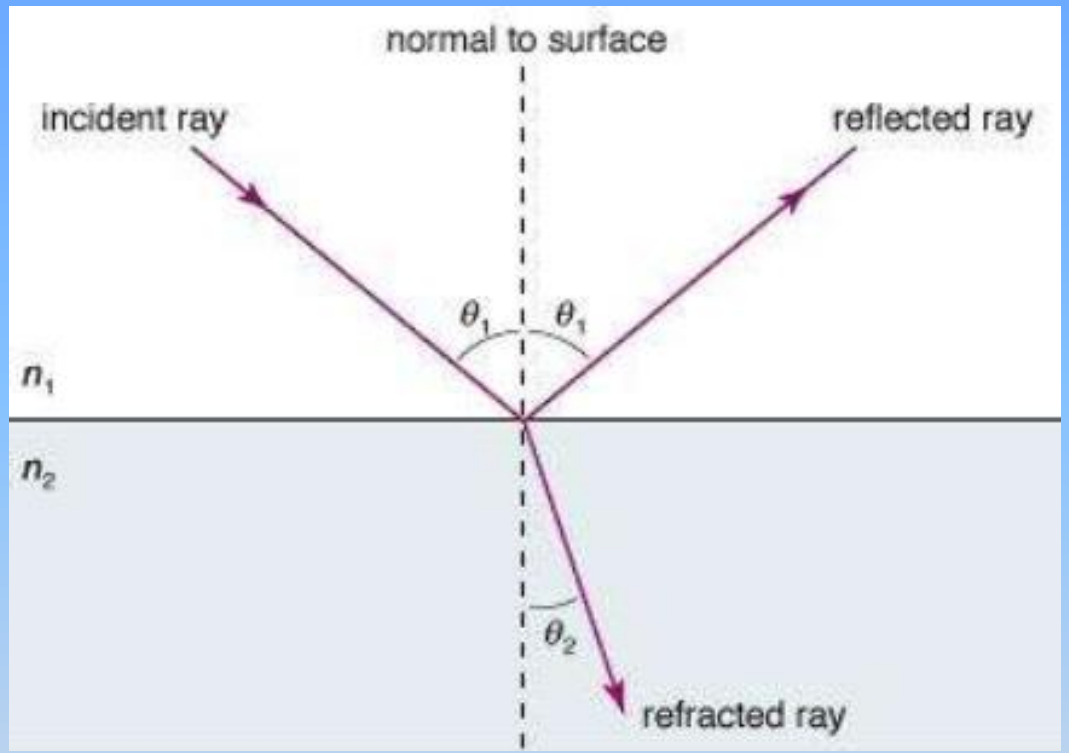
Light Waves
Basic Information & Definitions

The **wave fronts** spread out as they travel or propagate … eventually they are so large they look like straight lines (**Plane waves** or **parallel waves**).



Using rays and wave fronts, we can calculate measurements such as the wave speed, the angle of incoming rays, the angle of outgoing rays for a system.

Light Waves
Basic Information & Definitions



INCIDENT RAY: incoming rays to any surface or medium

REFLECTED RAY: the outgoing rays from a reflective surface

REFRACTED RAY: the outgoing rays from a different medium than the incident ray

MEDIUMS: air, water, glass, metals, earth (e.g. Seismic waves)

Reflection

Specular reflection

Reflection from a "smooth" surface; *i.e. the irregularities are small compared to the wavelength of the radiation.*

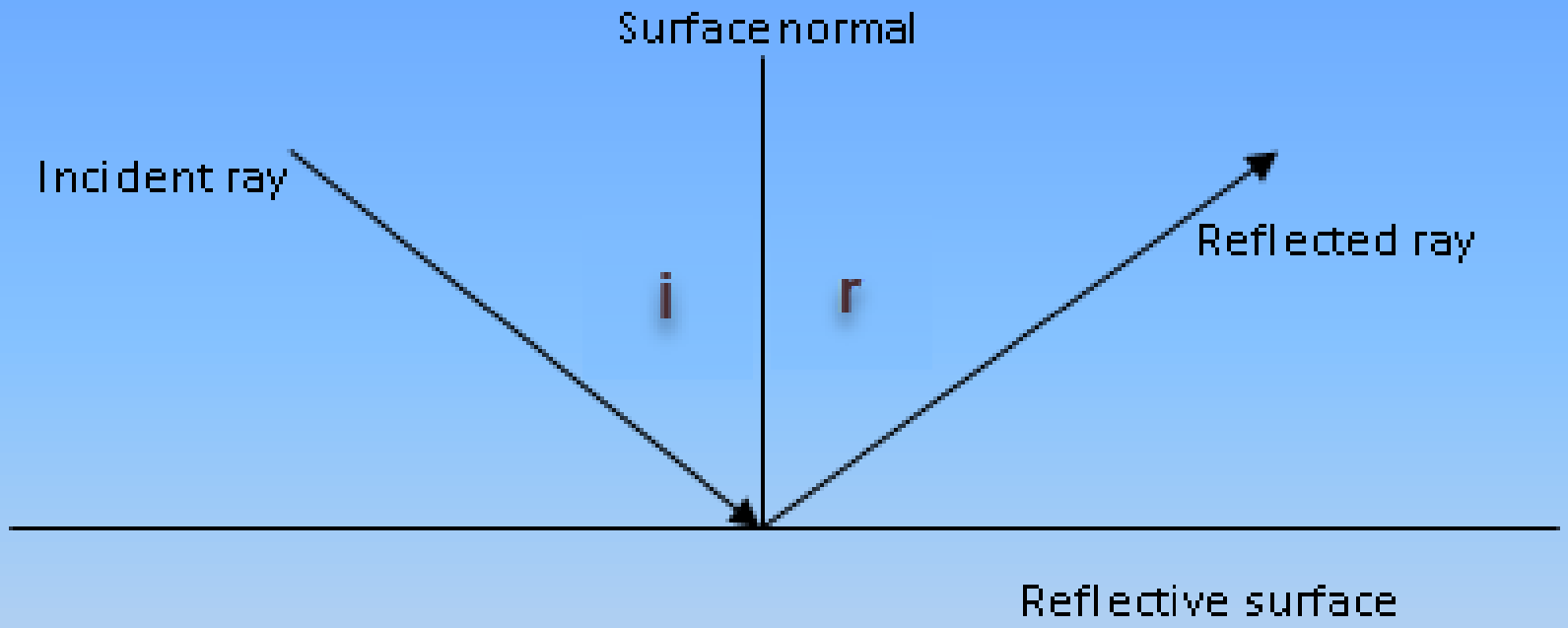
A polished metal surface reflects light because the irregularities are tiny – visible light wavelength is 400-700 nm.

TV satellite dish with mesh – microwaves are larger than the holes in the antennae of the satellite dish.

https://screencast-o-matic.com/watch/cqVDYO3DUJ

Simulation (0:22)

Reflection



i = the angle of incidence (*made in relation to the surface normal*)

r = the angle of reflection (*made in relation to the surface normal*)

surface **normal** = the line perpendicular to the surface

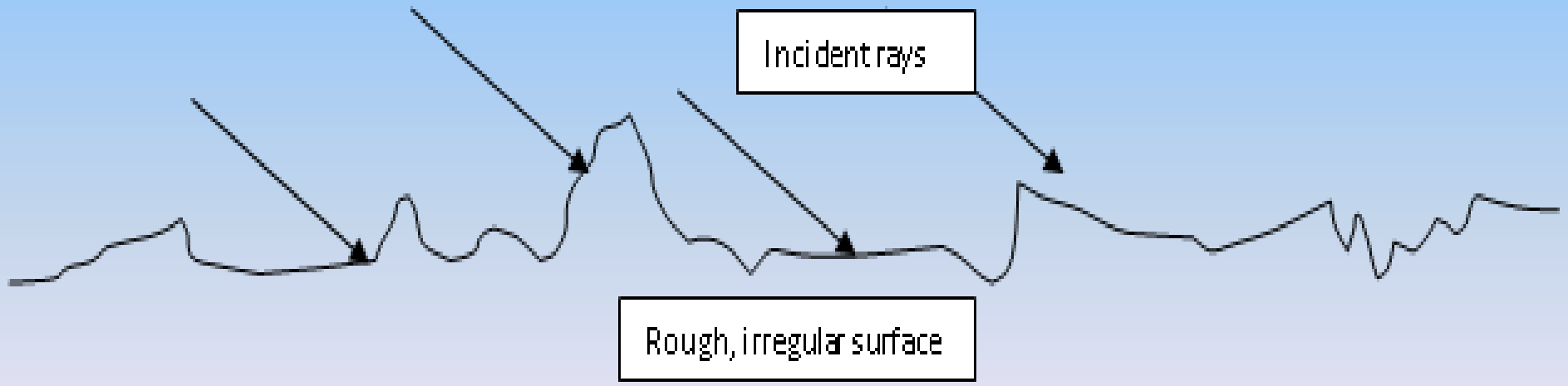
Law of Reflection **i = r**

Reflection

Diffuse Reflection

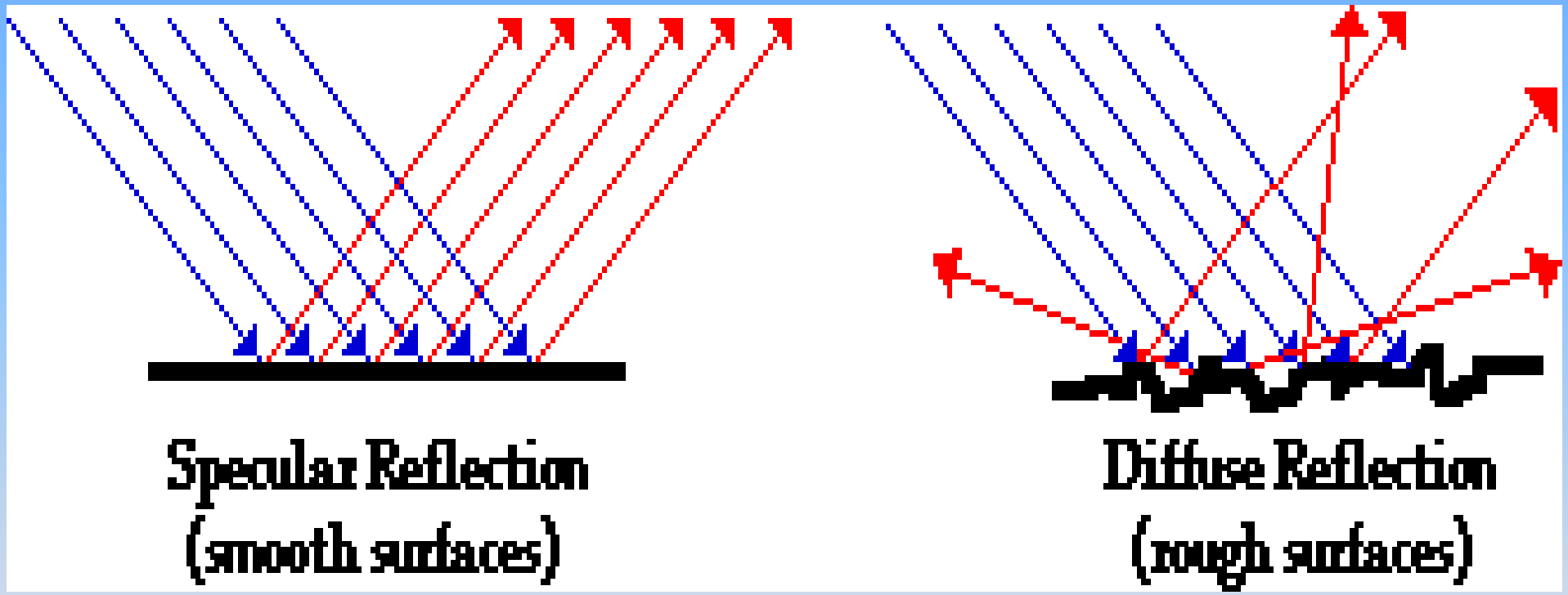
Reflection from a "rough" surface; *i.e. the irregularities are large compared to the wavelength of the radiation.*

Paper, cloth, sand … Rough, irregular surface



Reflection

Specular versus Diffuse Reflection



http://somup.com/cFfeFEVp1h (2:45)

Refraction

The speed of the wave changes as it passes from one "medium" to another "medium."

For **transverse waves like EM radiation**, the more dense the medium ("n"), the more the wave will slow down as it enters the **denser** medium.

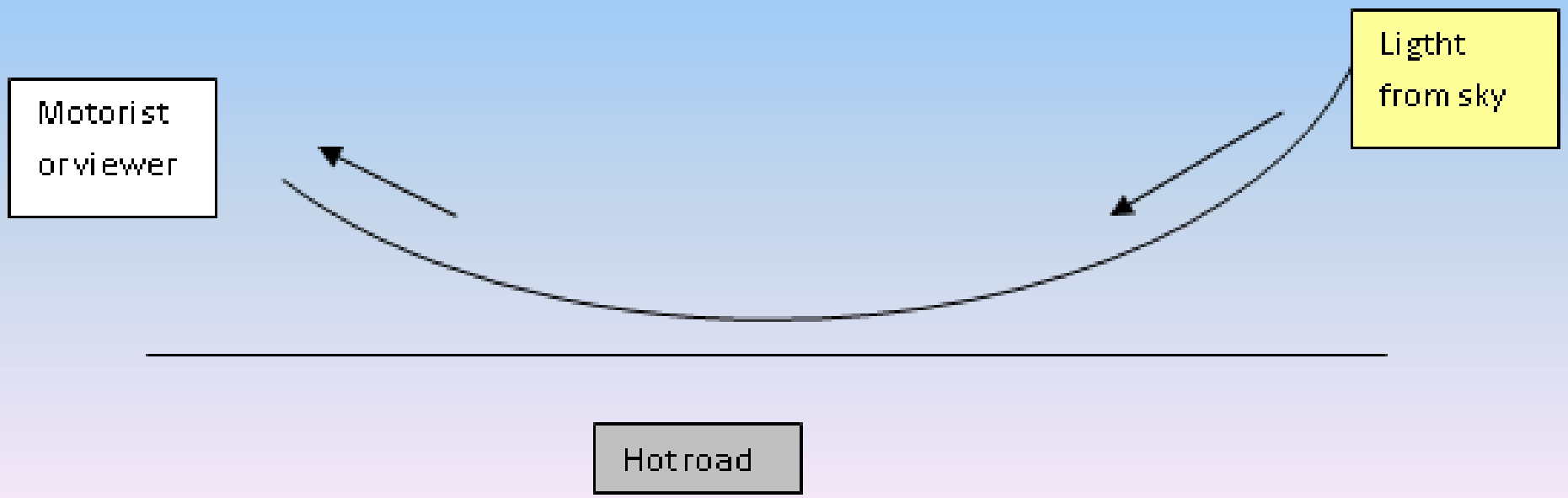
Sound waves actually speed up in more dense mediums. Why?

(They are longitudinal waves & travel by compressions & rarefactions.)

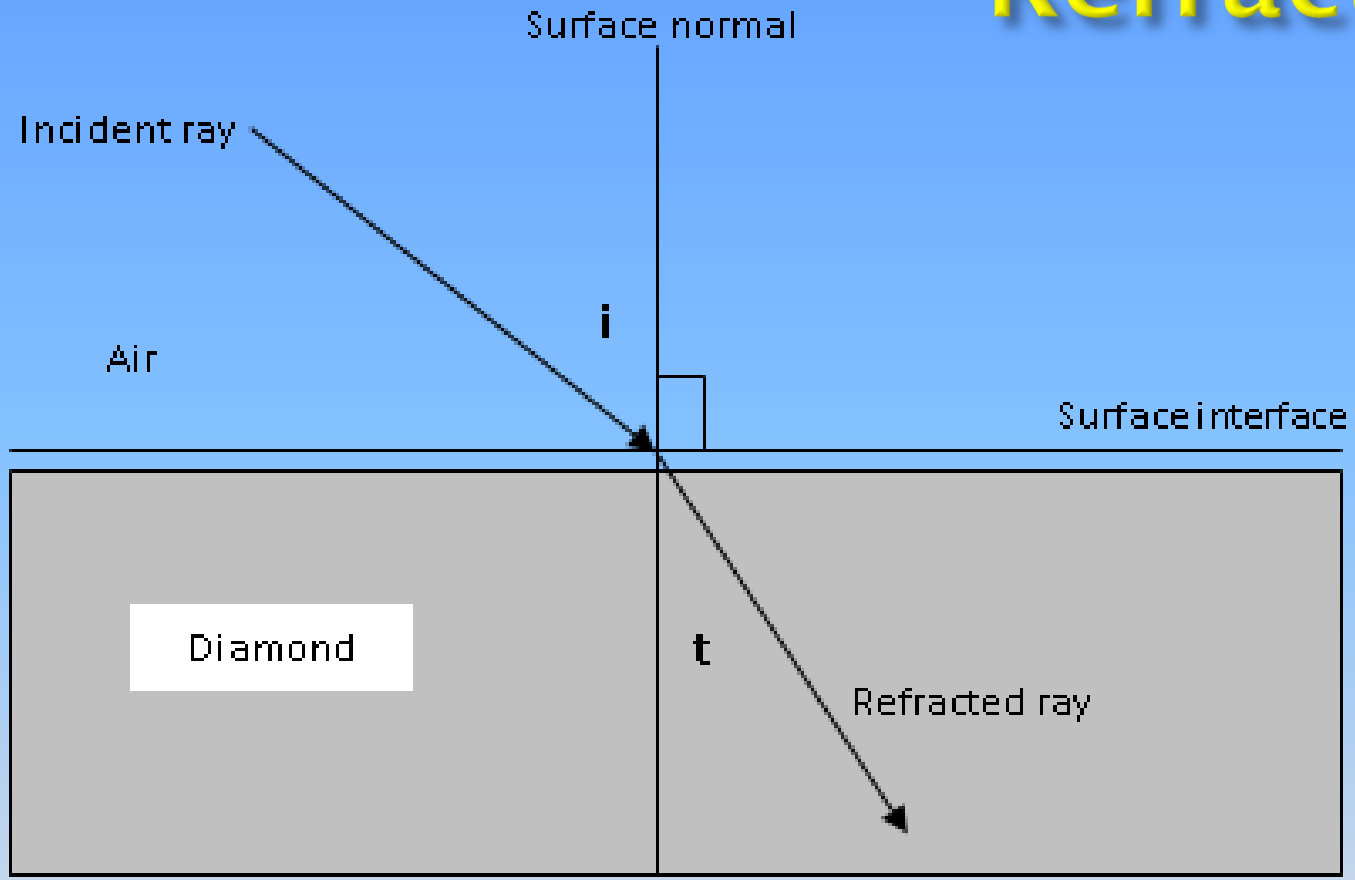
Refraction

Some practical examples of refraction:

- **The sun's shape is distorted along the horizon.**
- **Mirages – Refraction of sky light through warmer and less dense air near the surface of the earth or road** (light travels faster than in cooler, more dense air).



Refraction



i = the angle of incidence (*made in relation to the surface normal*)

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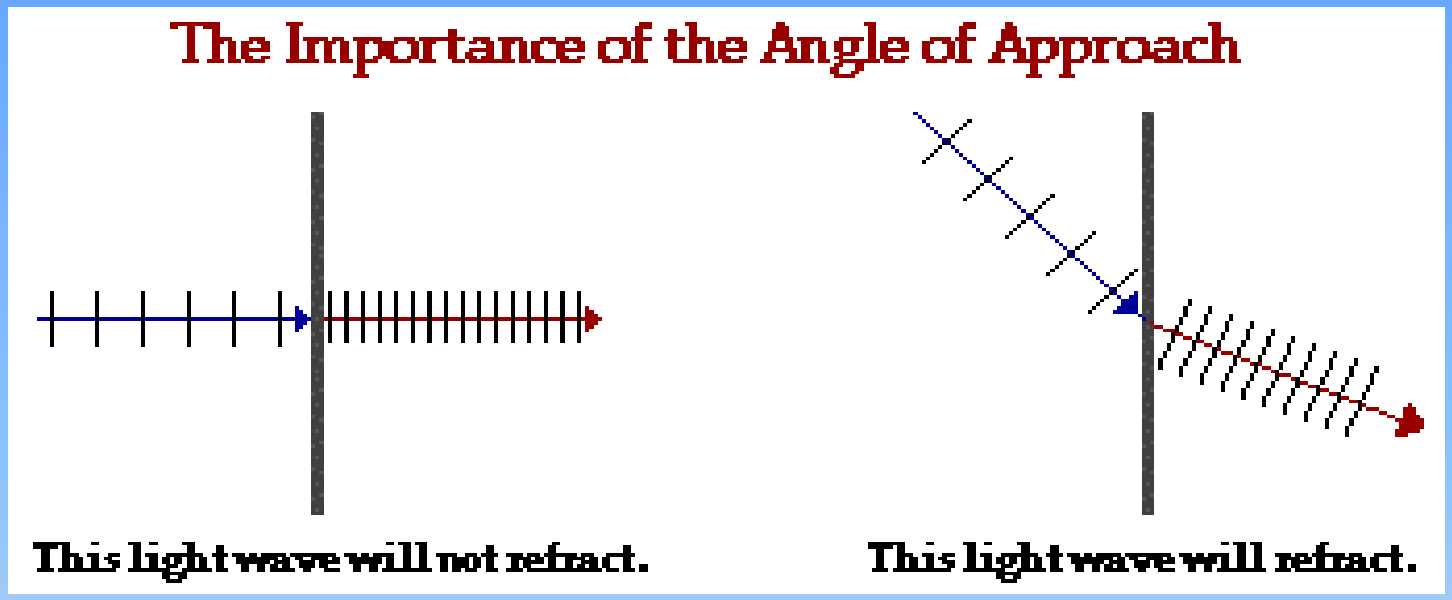
surface **normal** = the line perpendicular to the surface

Refraction



Media that light can pass through are categorized by density and given an index of refraction (n).

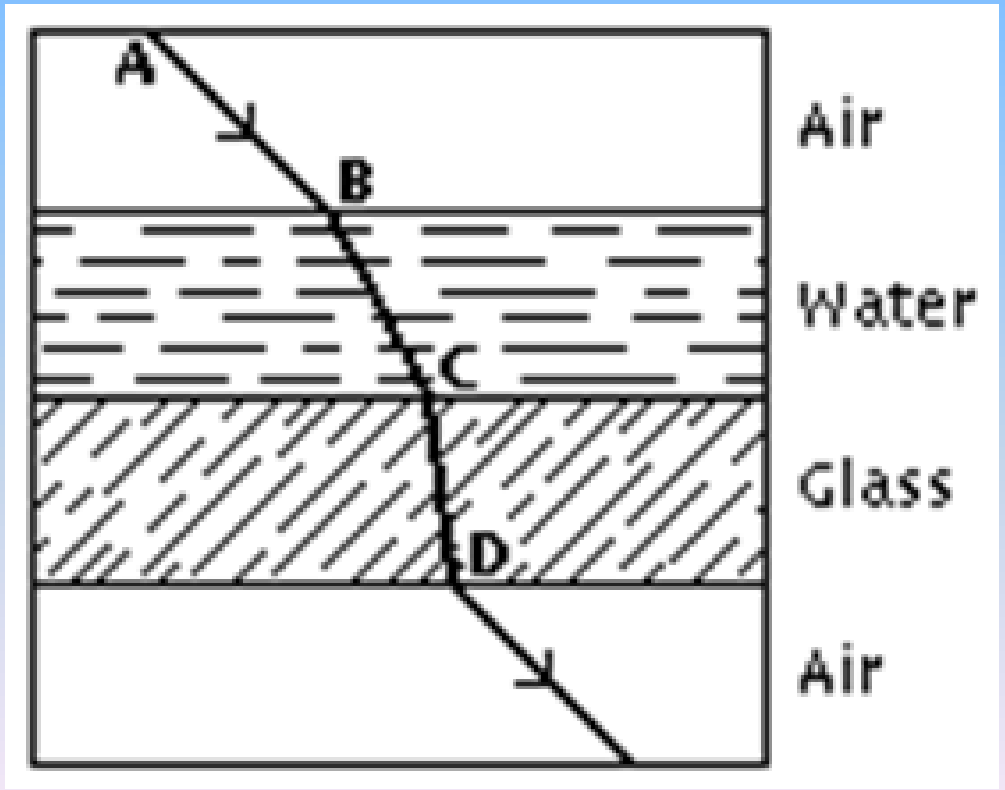
As the index of refraction (n) value increases, the optical density increases, and the speed of light in that material decreases.

Refraction

Light slows down when entering a MORE DENSE medium (higher "n") and it bends toward the normal.

Light speeds up when entering a LESS DENSE medium (lower "n") and it bends away from the normal.

SUBSTANCE	INDEX of Refraction (**n**)
Vacuum	1.0000
Air	1.0003
Ice	1.309
Water	1.33
Ethyl alcohol	1.36
Glass (fused quartz)	1.46
Glass (crown)	1.52
Sodium chloride (salt)	1.54
Zircon	1.92
Diamond	2.42



Refraction

Watch video:

http://somup.com/cqfXD9nU6Z (3:52)

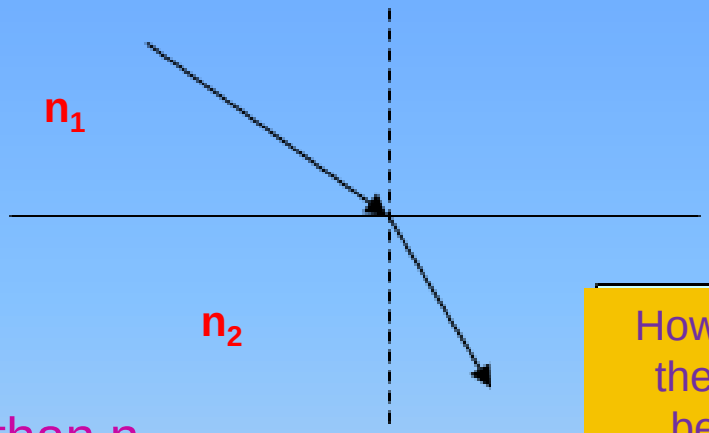
Light "bending". Index of Refraction.

Describe the Refraction

QUICK CHECK

Ray Diagrams of substances going from:

- Air into water
- Water into glass
- Glass into diamond



How does the light bend?

n_2 is (more/less) dense than n_1

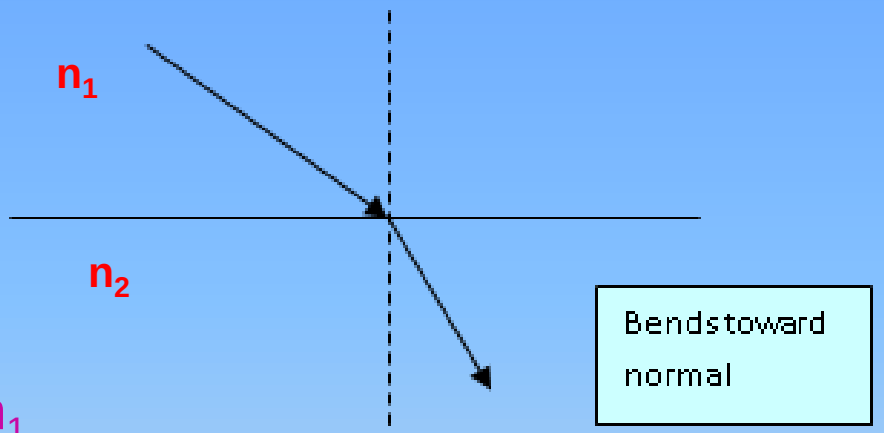
Describe the Refraction

QUICK CHECK

Ray Diagrams of substances going from:

- Air into water
- Water into glass
- Glass into diamond

$n_1 < n_2$



n_2 is **more** dense than n_1

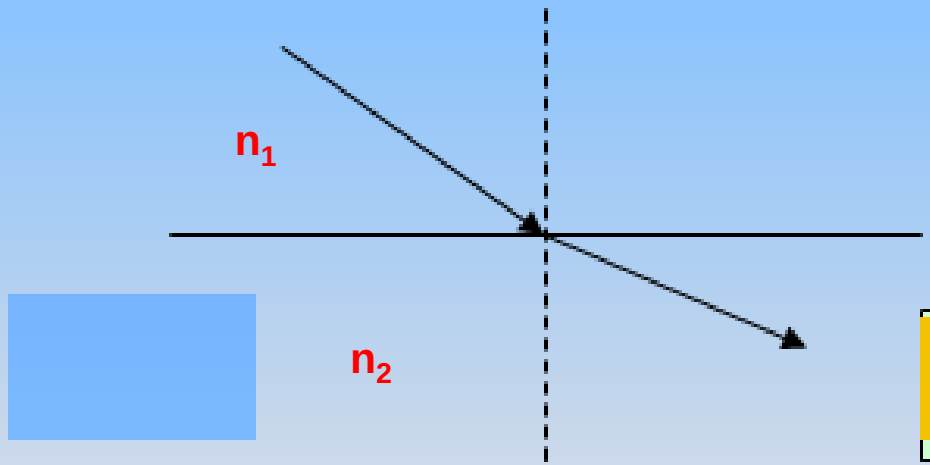
Describe the Refraction

QUICK CHECK

Ray Diagrams of substances going from

- Glass into air
- Diamond into water
- Ice into air

n_1 is (more/less) dense than n_2



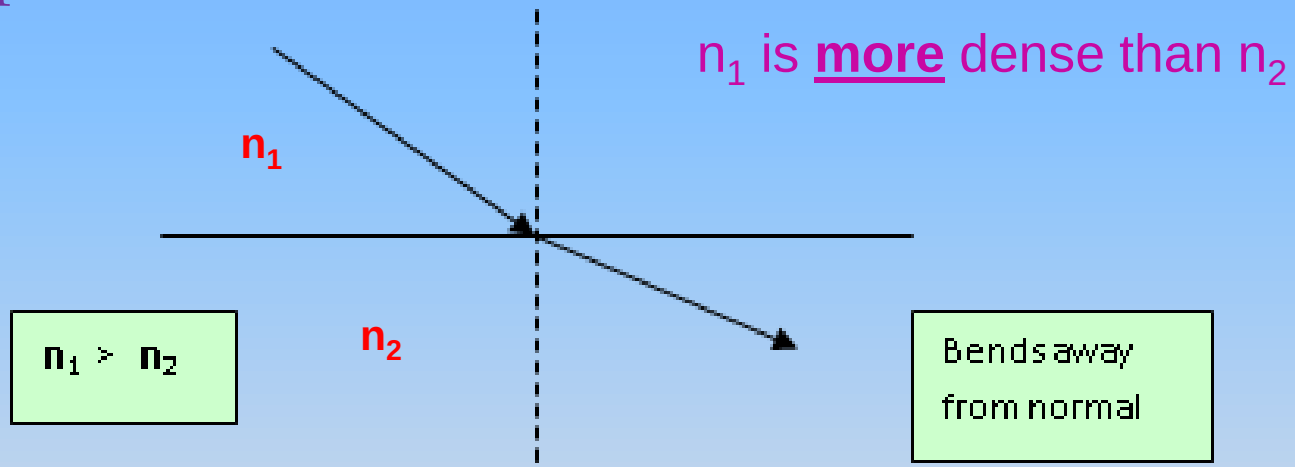
How does the light bend?

Describe the Refraction

QUICK CHECK

Ray Diagrams of substances going from:

- Glass into air
- Diamond into water
- Ice into air



Properties of Refraction

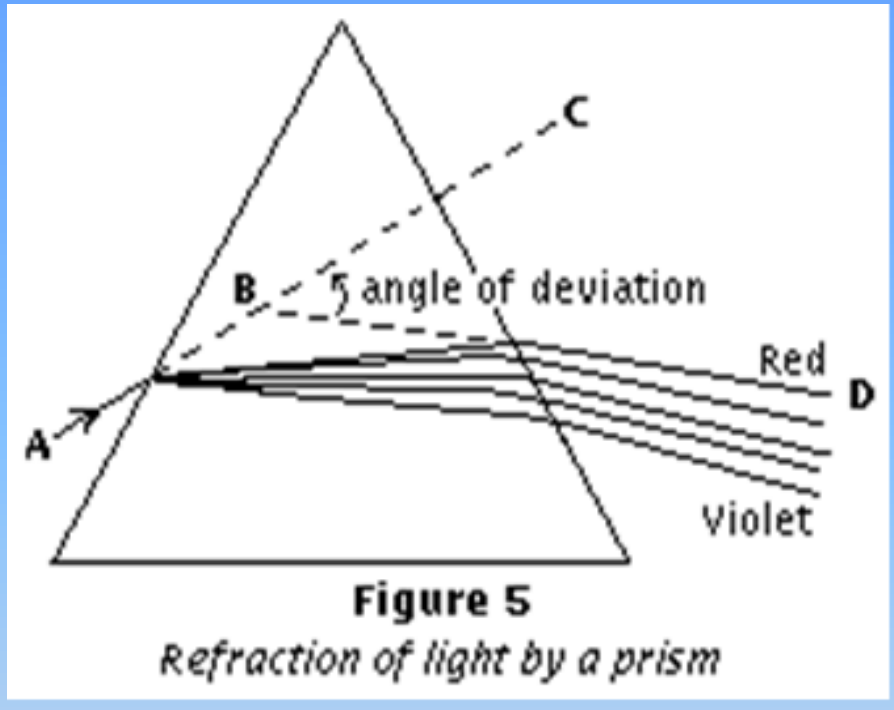


Figure 5

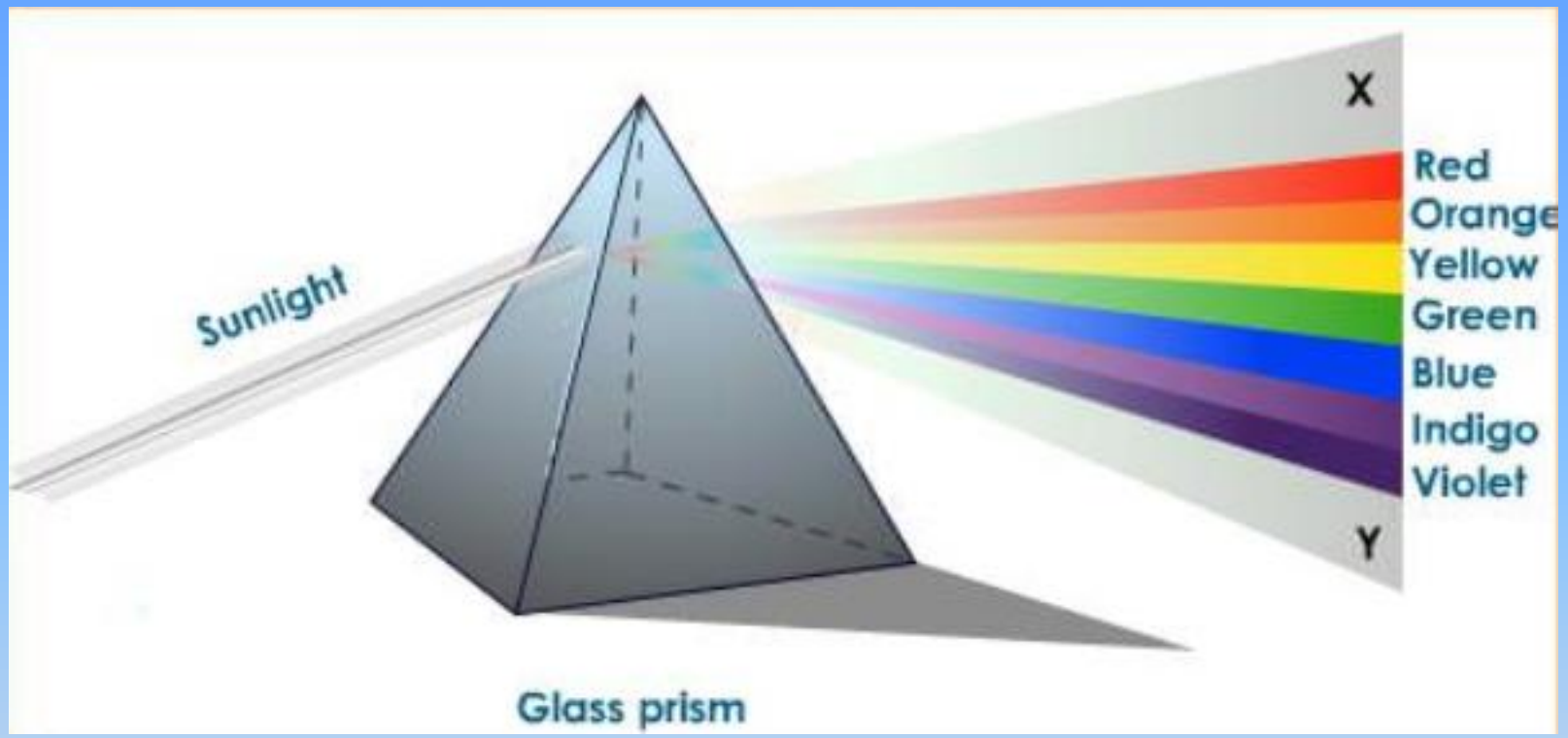
Refraction of light by a prism

DISPERSION

The index of refraction (n) of a prism is greater than that of air, thus slowing light down.

The prism eventually shows the effect of refraction by separating the light by wavelength (color).

Properties of Refraction



Violet is slightly slower and therefore, bends more.

Red is slightly faster and therefore, bends less.

Rainbows are produced as light is refracted by water drops acting as prisms.

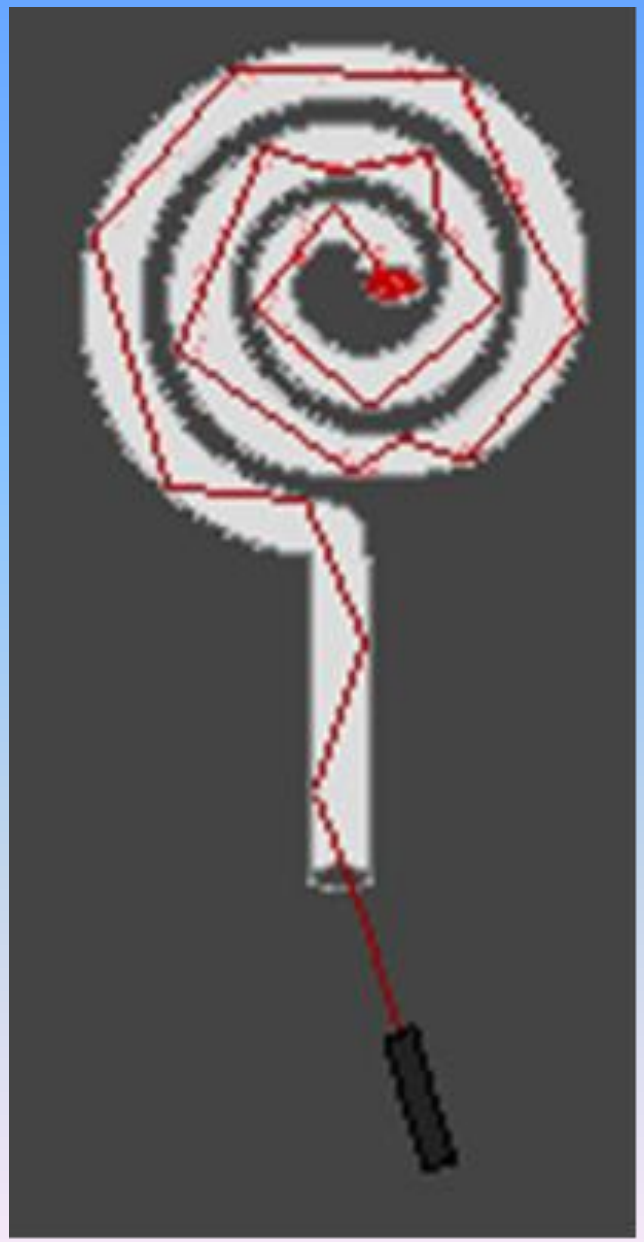
Refraction

Watch video:

http://somup.com/cFfeq2Vp1T (2:40)

Dispersion. Total Internal Reflection.

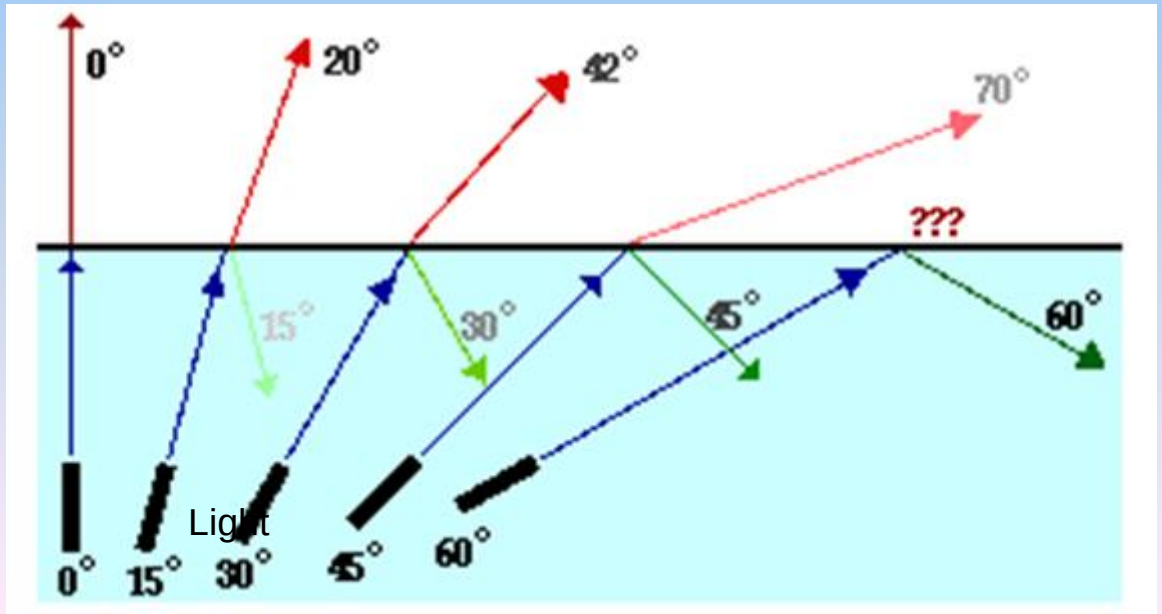
Properties of Refraction



Total Internal Reflection

is a subset of refraction.

- Diamonds sparkle
- Light pipes
- Fiber Optics
- Rainbow (Water drops)



Polarization of Light

Incident light (e.g. from the sun) vibrates in more than one plane. When light passes through "filters" it becomes "Polarized" or aligned in a particular plane.

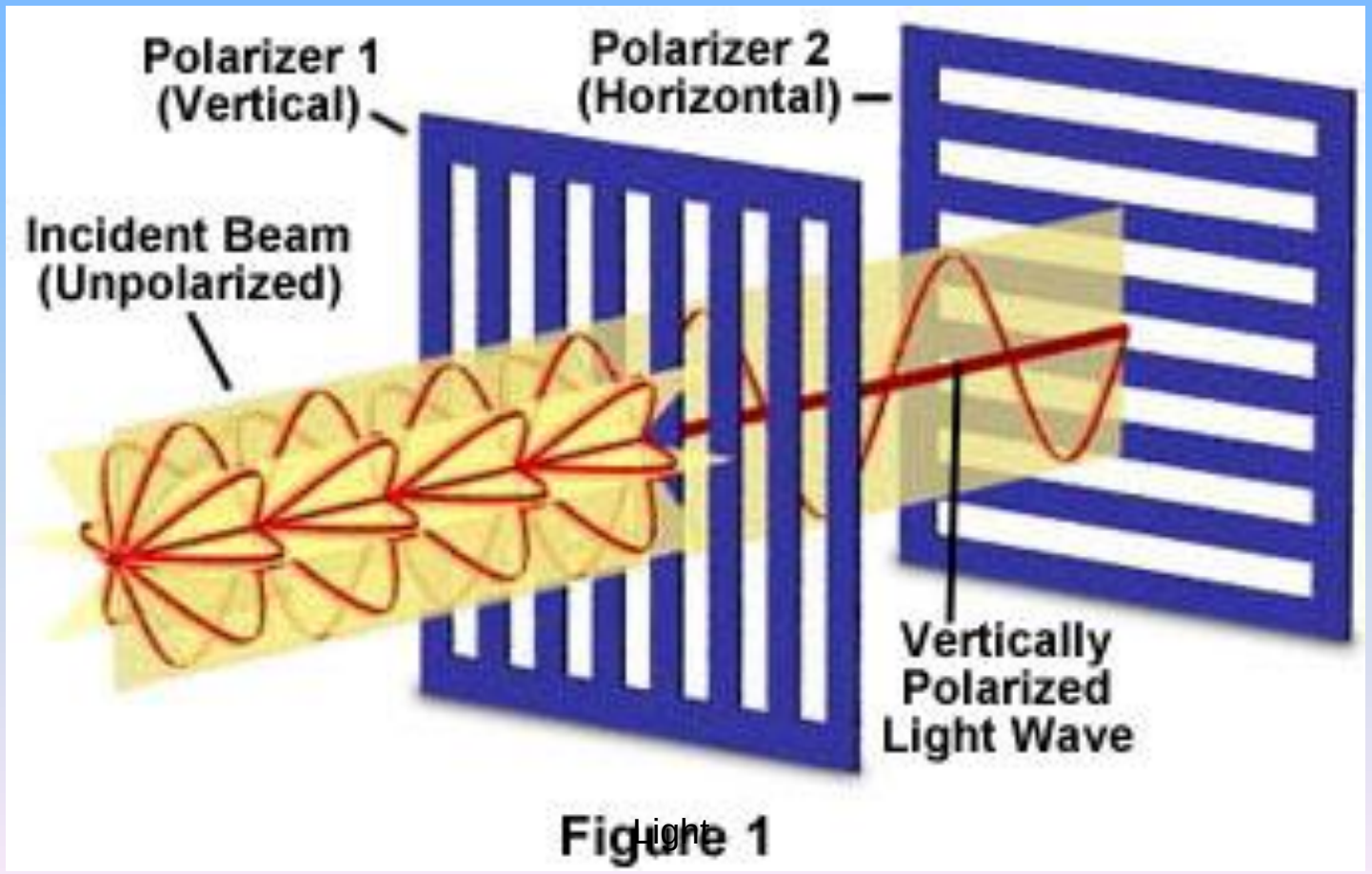
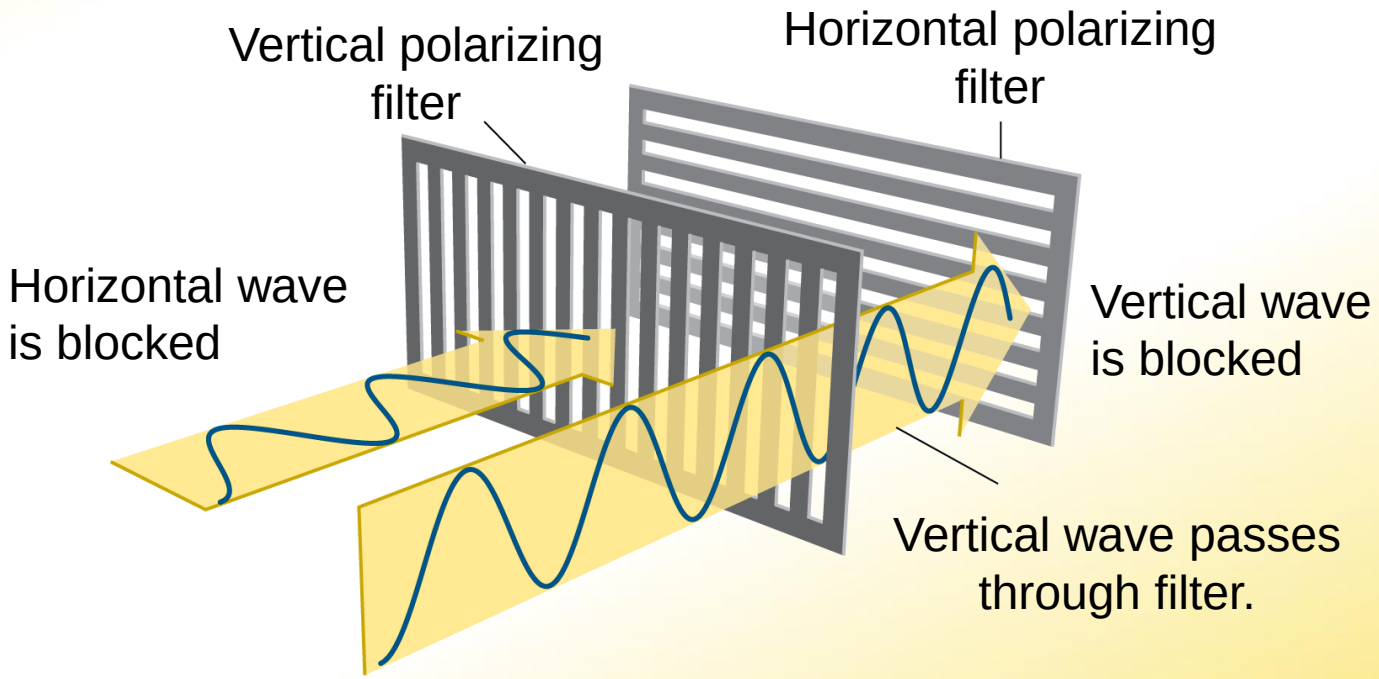


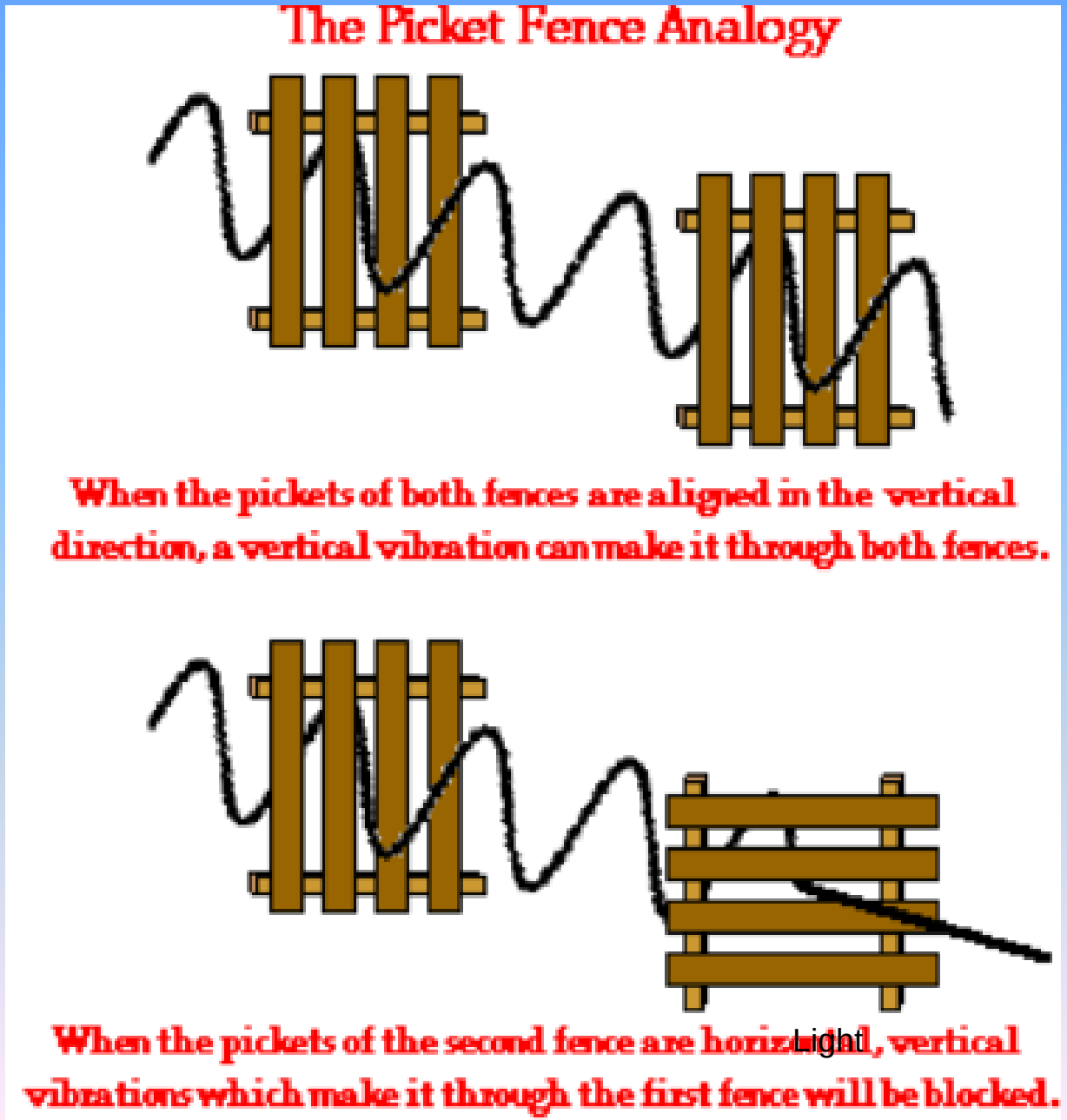
Figure 1

Interactions of Light

This simplified model shows how polarizing filters behave. A vertical polarizing filter blocks light that is horizontally polarized.



Polarization of Light



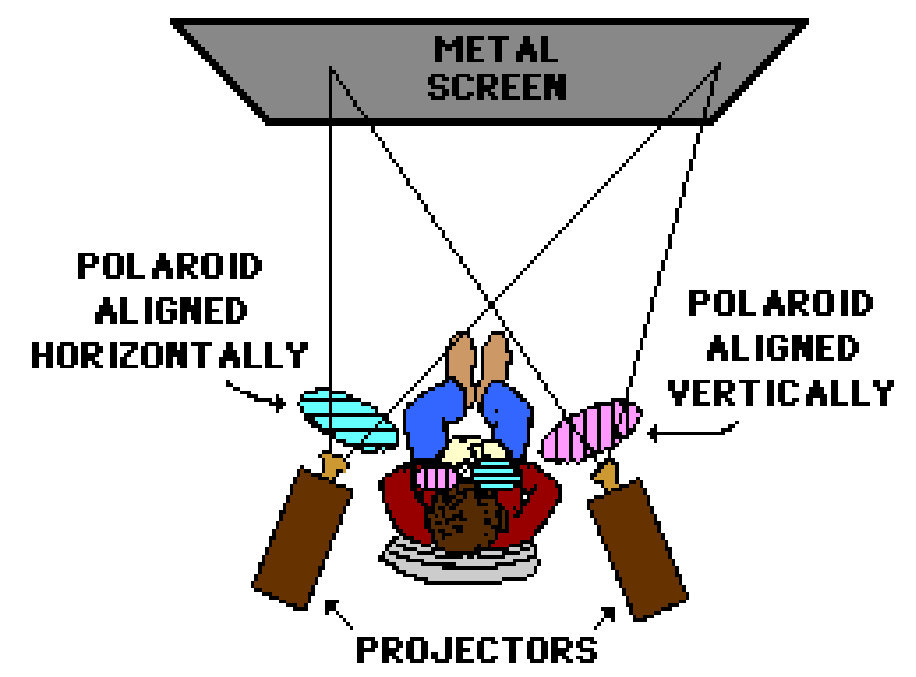
Imagine standing straight up and passing through the first “fence” (filter).

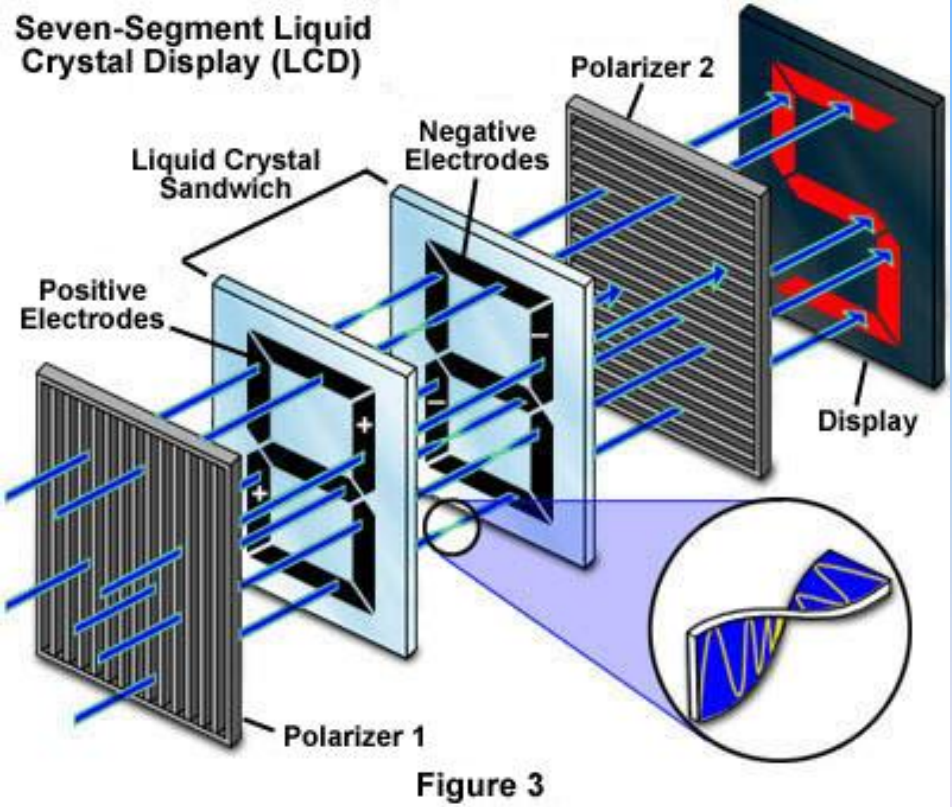
Can you pass through the second fence (filter) standing up?

Polarization of Light

Light is aligned along particular planes by filters, making it more useful to us.

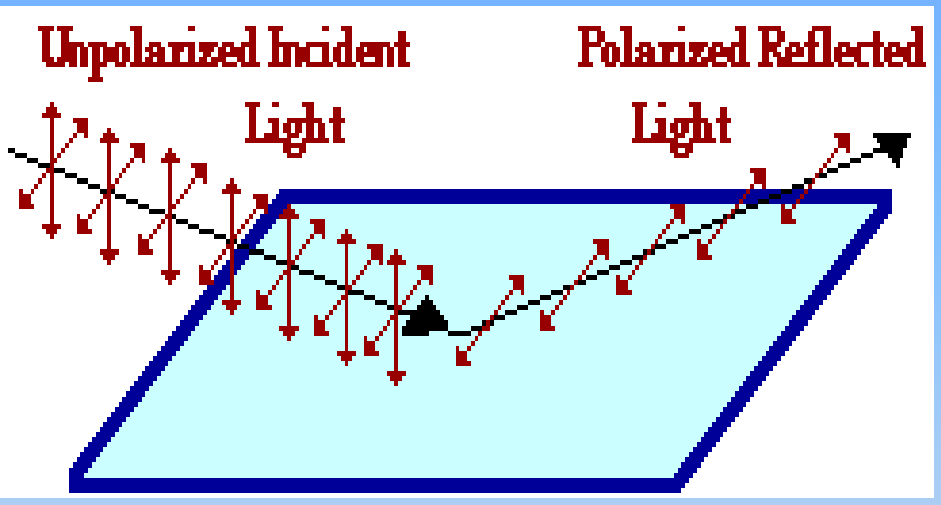
- 3D movie projection, digital clocks, scoreboards

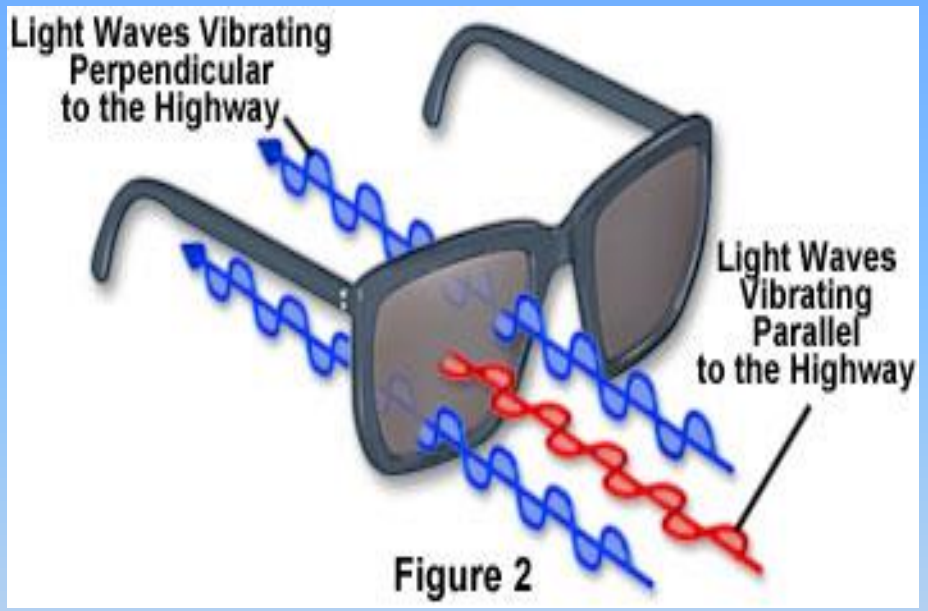




Polarization of Light

How do sunglasses work?





Light from the sun reflects off the road or water (e.g. at a lake), becoming polarized horizontally.

Sunglasses are polarized vertically so the horizontal "glare" from the road or lake will not pass through them.

Behavior of Light

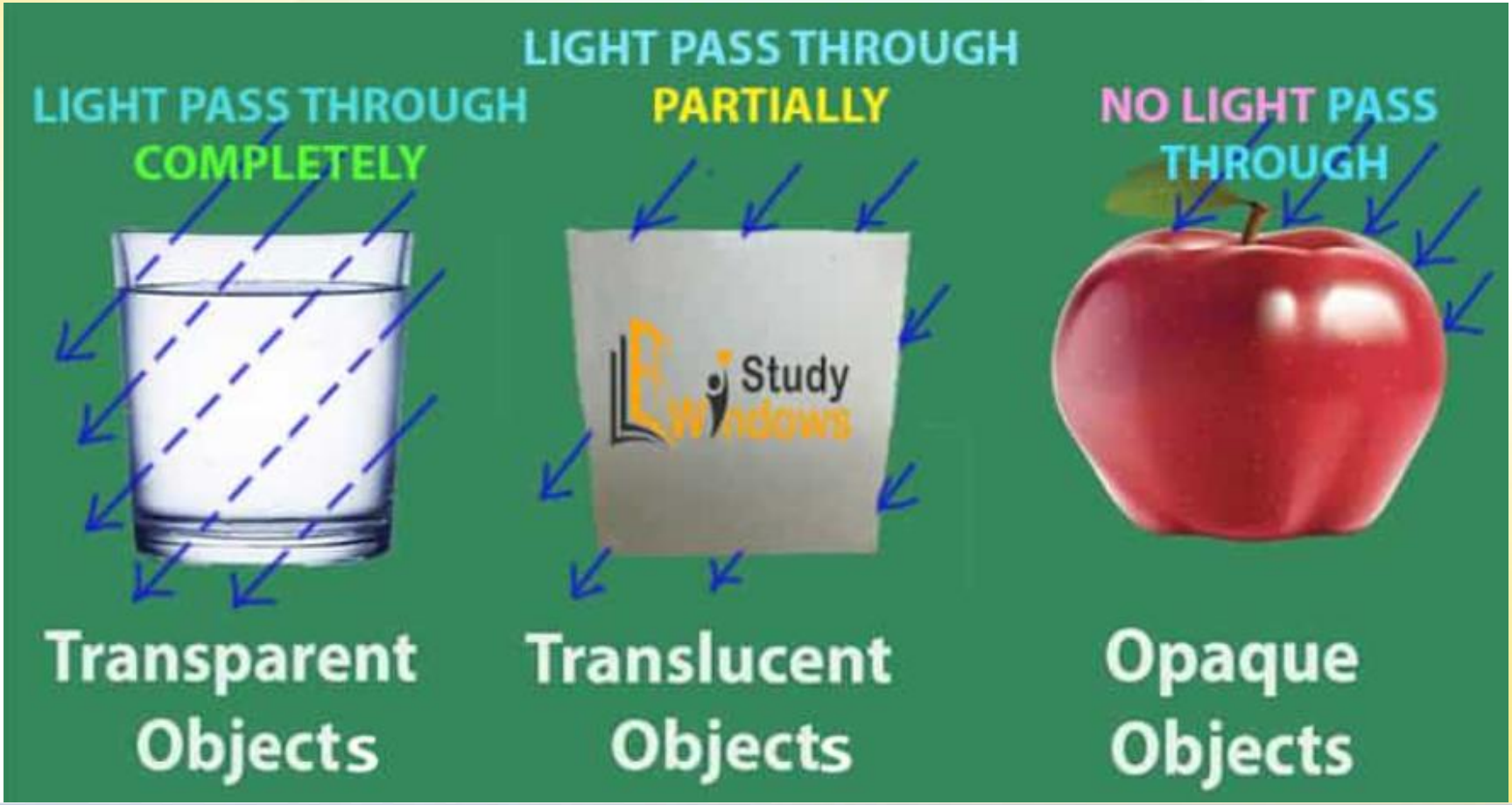
Transparent

Translucent

Opaque

Scattering

Materials can be transparent, translucent, or opaque.

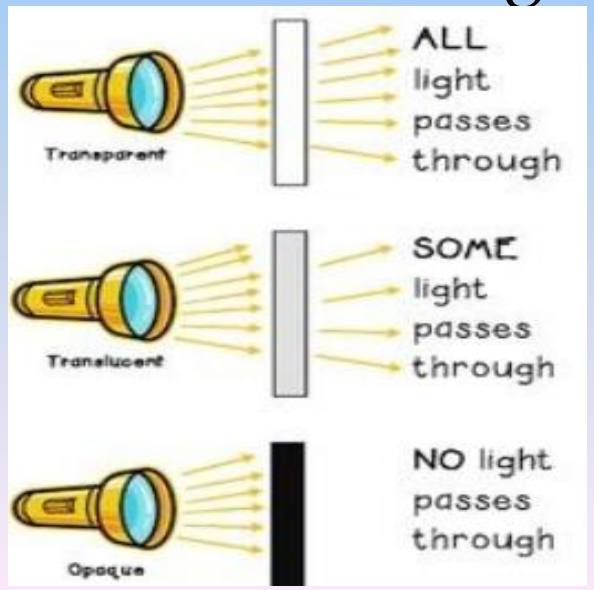


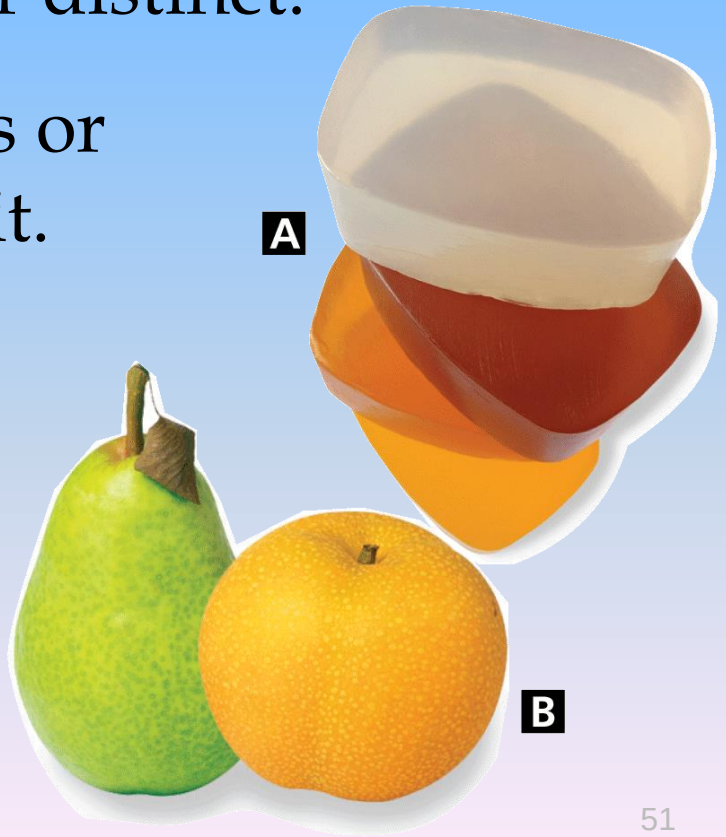
Light in Materials

A **transparent** material transmits light. Light can pass through it mostly or fully unimpeded.

A **translucent** material scatters light. Light passes through but objects are not clear or distinct.

An **opaque** material either absorbs or reflects all of the light that strikes it.





Light in Materials

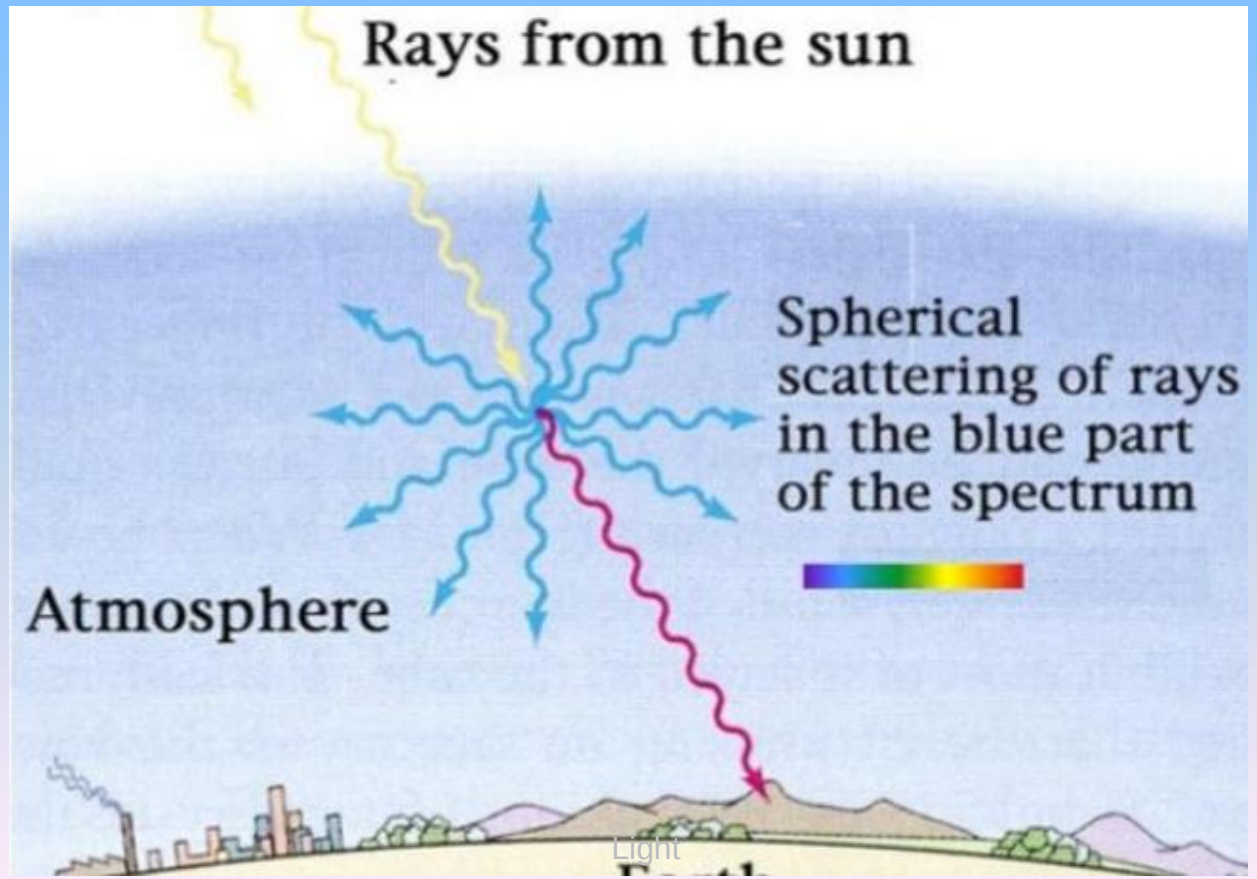
Scattering

Light is redirected as it passes through a medium.

- When the sun is close to the horizon, sunlight travels farther through the atmosphere.
- By the time the sunlight reaches your eyes, most shorter-wavelength light (ROY) has been scattered.

Scattering - Why is the sky blue?

- Small particles scatter shorter-wavelength (**B**IV) light more than light of longer wavelengths (ROYG).
- **Our eyes recognize Blue light (not much violet).**



QUICK CHECK

How do polarized sunglasses reduce glare?

a. by scattering light as it passes through the glasses
b. by providing a smooth surface that light can reflect off
c. by absorbing all light
d. by blocking horizontally polarized light

Glass block windows allow light to pass through, but people can't see clear images of whose inside. This is an example of a ___ material.

The sun appears huge and orange sometimes at sunset. Why?

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Glass block windows allow light to pass through, but people can't see clear images of whose inside. This is an example of a **translucent** material.

The sun appears huge and orange sometimes at sunset. Why? **Refraction (light bends in earth's atmosphere) and scattering of longer wavelengths (ROY) of light.**

Enrichment Videos

What is a mirror?

Misconception that you will see more of yourself if you back up when looking in a mirror.

Misconceptions about complete darkness (as in a cave, thinking that your eyes will never "adjust" when there is no light)

Infrared thermal vision

Black objects vs. invisibility cloaks.

mirror cloak: http://somup.com/cFXoqZnj6U (1:21)

invisibility cloak: http://somup.com/cFXoqbnj6Y (1:00)

laser maze: http://somup.com/cFXoqynj6y (2:26)

Wavelength and Frequency

Math Practice

1. A global positioning satellite transmits a radio wave with a wavelength of 19 cm. What is the frequency of the radio wave? (*Hint:* Convert the wavelength to meters before calculating the frequency.)

Wavelength and Frequency

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Speed = Wavelength × Frequency

$c = f\lambda$; rearrange: $f = c/\lambda$

Frequency = Speed/Wavelength =

$(3.00 \times 10^8 \text{ m/s})/(0.19 \text{ m}) = \mathbf{1.6 \times 10^9 \text{ Hz}}$

Wavelength and Frequency

Math Practice

2. The radio waves of a particular AM radio station vibrate 680,000 times per second. What is the wavelength of the wave?

Wavelength and Frequency

Math Practice

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Wavelength = Speed/Frequency

$\lambda = (3.00 \times 10^8 \text{ m/s})/680{,}000 \text{ Hz} =$ **440 m**