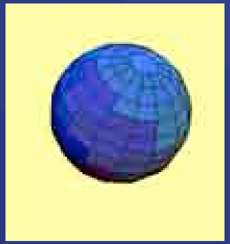
How Things Work II
(Lecture #27)



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Course web site available through COD and Toolkit
or at http://people.virginia.edu/~gdc4k/phys106/spring08

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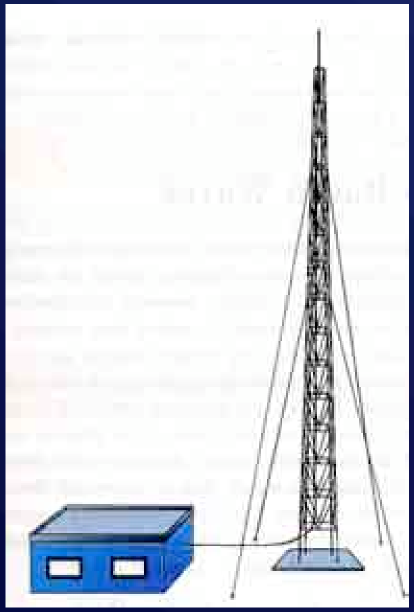
Announcements

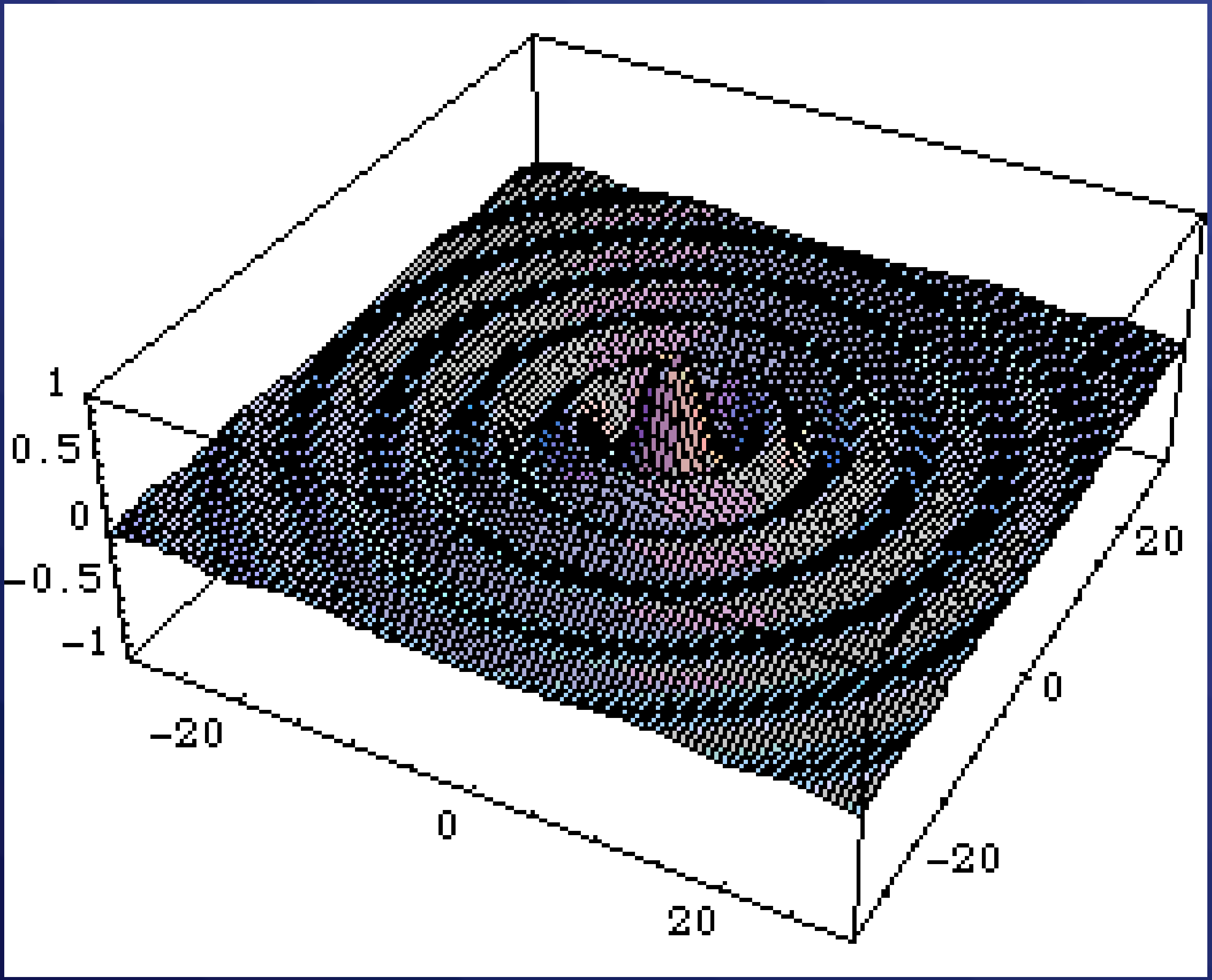
- Problem Set #4 will be posted some time tomorrow, Tuesday, April 1st.
- Midterms will be returned this coming Friday.
- Read Chapter 13 through the end of Section 13.1.
  - Read but do not worry too much about the subsection on "Antennas and Tank Circuits".
- Read Chapter 14 through the end of Section 14.1.

Electromagnetic Waves and Light

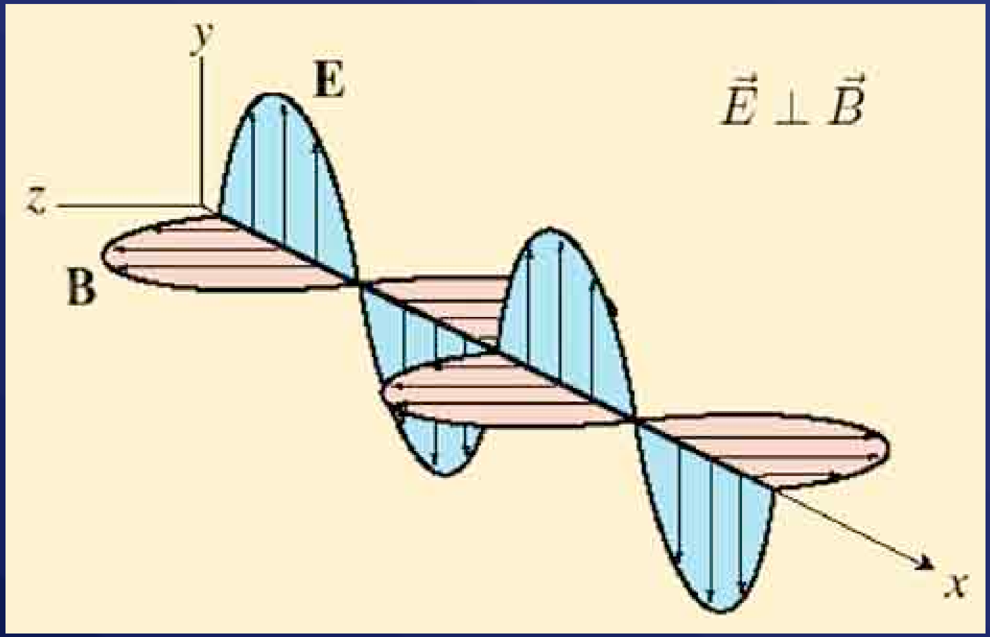
Radio waves are generated when charges accelerate back and forth

A radio transmitter works by pushing charges back and forth in an antenna.





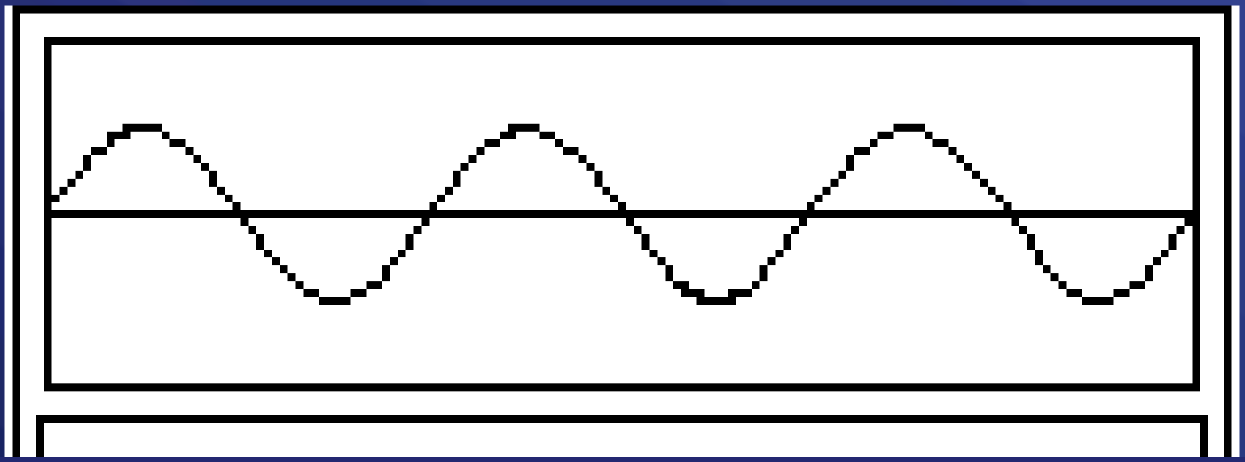
The anatomy of electromagnetic waves



Remember that the thing at left is a PLOT electric and magnetic field as a function of z. It is not just a funny shaped thing that moves through space!

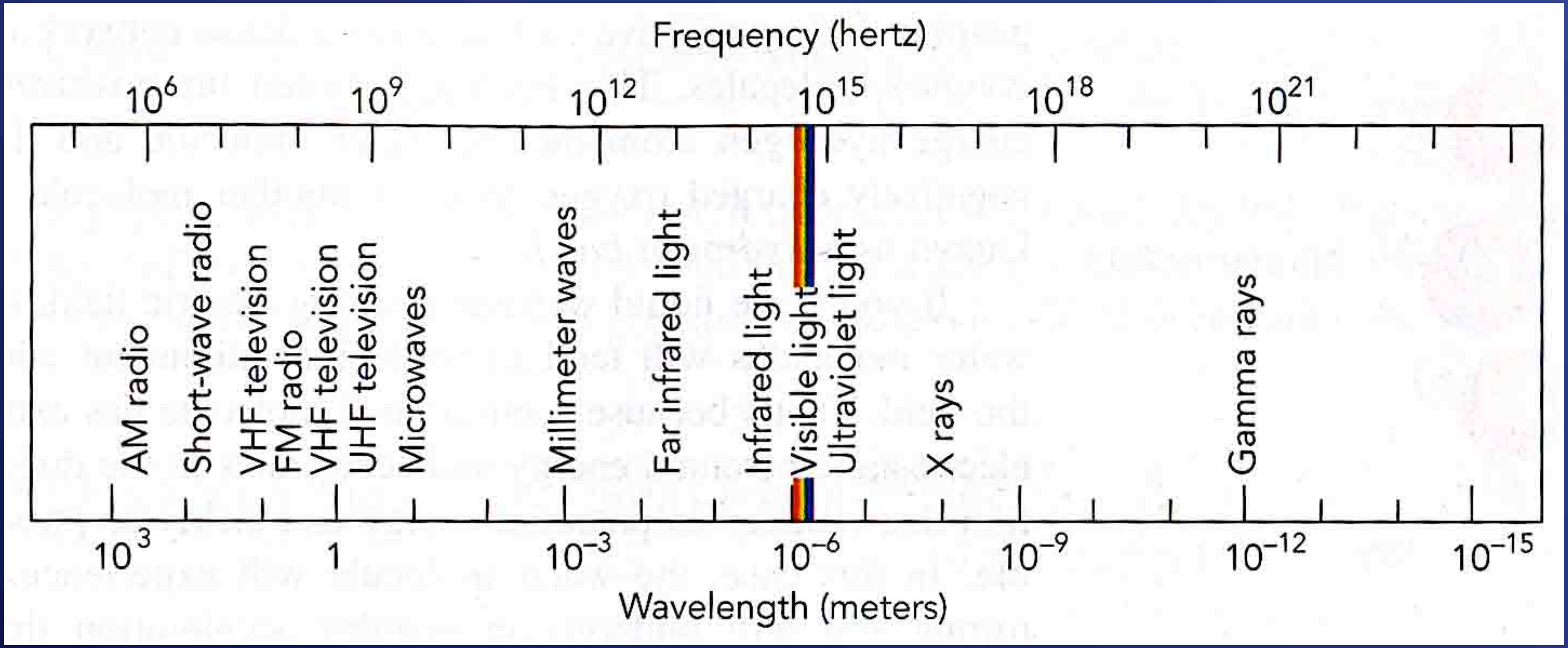
- The wave is perpetuated because of a cycle:
  - The changing magnetic field produces an electric field ...
  - and the changing electric field produces a magnetic field.
- At a snapshot in time, an electromagnetic wave has
  - a sinusoidally varying electric field in one direction,
  - and a corresponding sinusoidally varying magnetic field in the other direction.
- The whole thing propagates along at the speed of light.

Frequency and wavelength



- Wavelength is the distance over which the wave repeats itself. For example, the distance between two adjacent peaks.
- Frequency is the number of times per second that, for instance, a peak passes a particular point.
- Wavelength, frequency, and the velocity of the wave c are related by the formula: c = frequency · wavelength

The electromagnetic spectrum

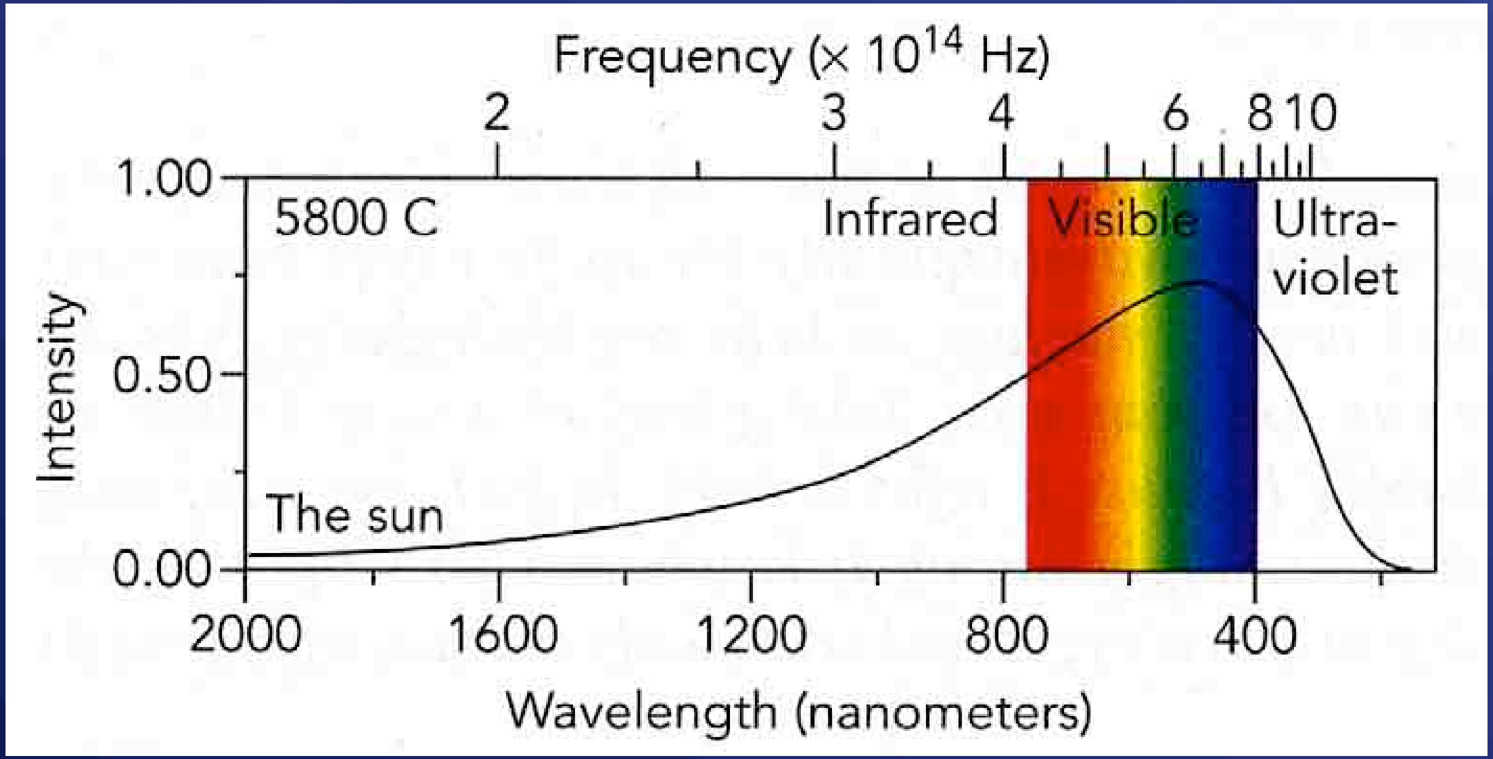


The range of wavelengths of electromagnetic waves associated with phenomena that are important to us is huge.

Observations about sunlight

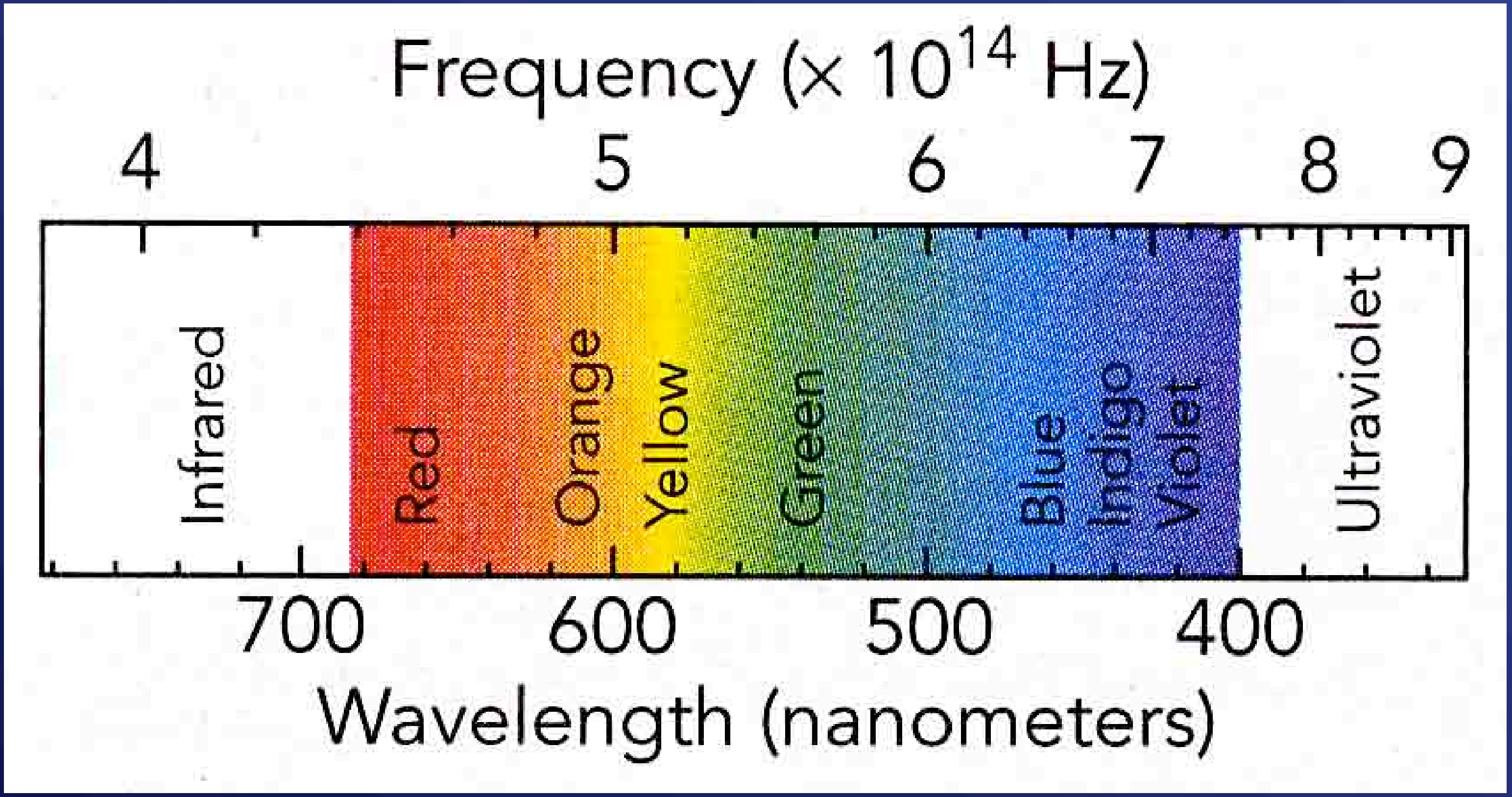
- Sunlight is bright white.
- The sun can appear orange or red particularly at sunrise or sunset, and the effect is enhanced in polluted air.
- You can see clear reflections of yourself and surroundings from “transparent” glass windows.
- On special rainy days we see all the sun’s colors brilliantly displayed in rainbows.
- We also see beautiful “rainbow-like” color patterns in soap bubbles or in oil slicks on a wet road.
- “Polaroid” sunglasses reduce glare better than regular sunglasses.

Sunlight has a "blackbody spectrum"



- All objects emit electromagnetic radiation that is associated with their temperature.
- The spectrum of their thermal radiation is called "blackbody radiation".
- The surface of the sun is about 5800 C, and the associated light peaks in the visible range.
- To our eyes, this mixture of wavelengths appears essentially white.

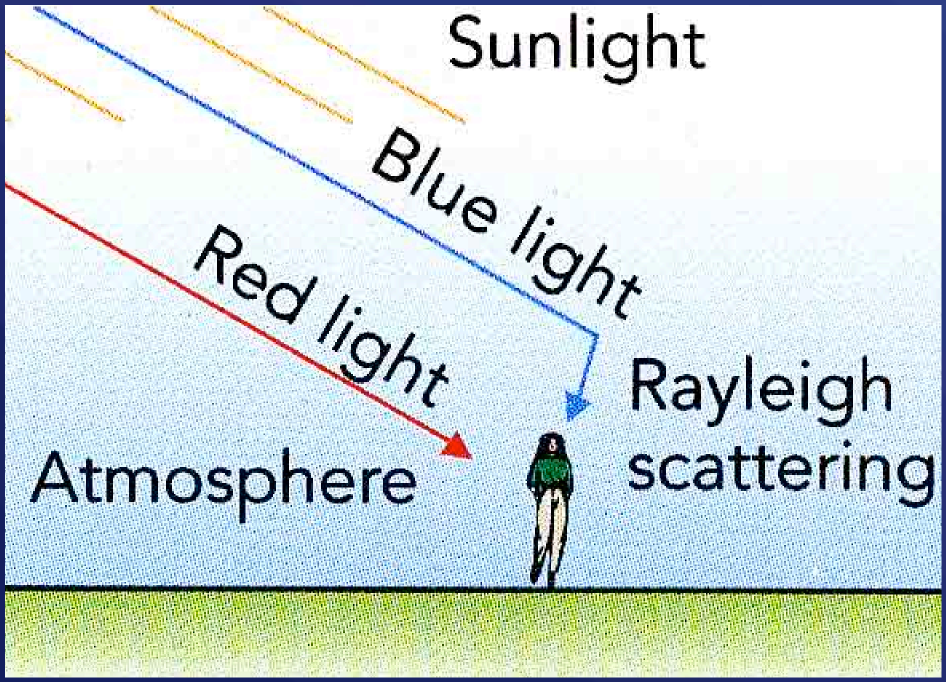
A closer look at the visible spectrum



When we separate light into its different components, as happens if we send it through a prism, or when sunlight hits rain droplets and forms a rainbow, you can see the different colors.

Why is the sky blue?

- Rayleigh scattering is the scattering of light from very small objects, such as molecules of air or very small particles of dust.
- If the size of the particles is much smaller than the wavelength of light, the amount of scattering is very small.
- The molecules of gas in air are much smaller (around 10^{-9} m) than the wavelengths of visible light (around 5×10^{-7} m).
- Light doesn't scatter well off of any of the molecules in air, but in relative terms, blue light scatters much better than red light (which has longer wavelengths).



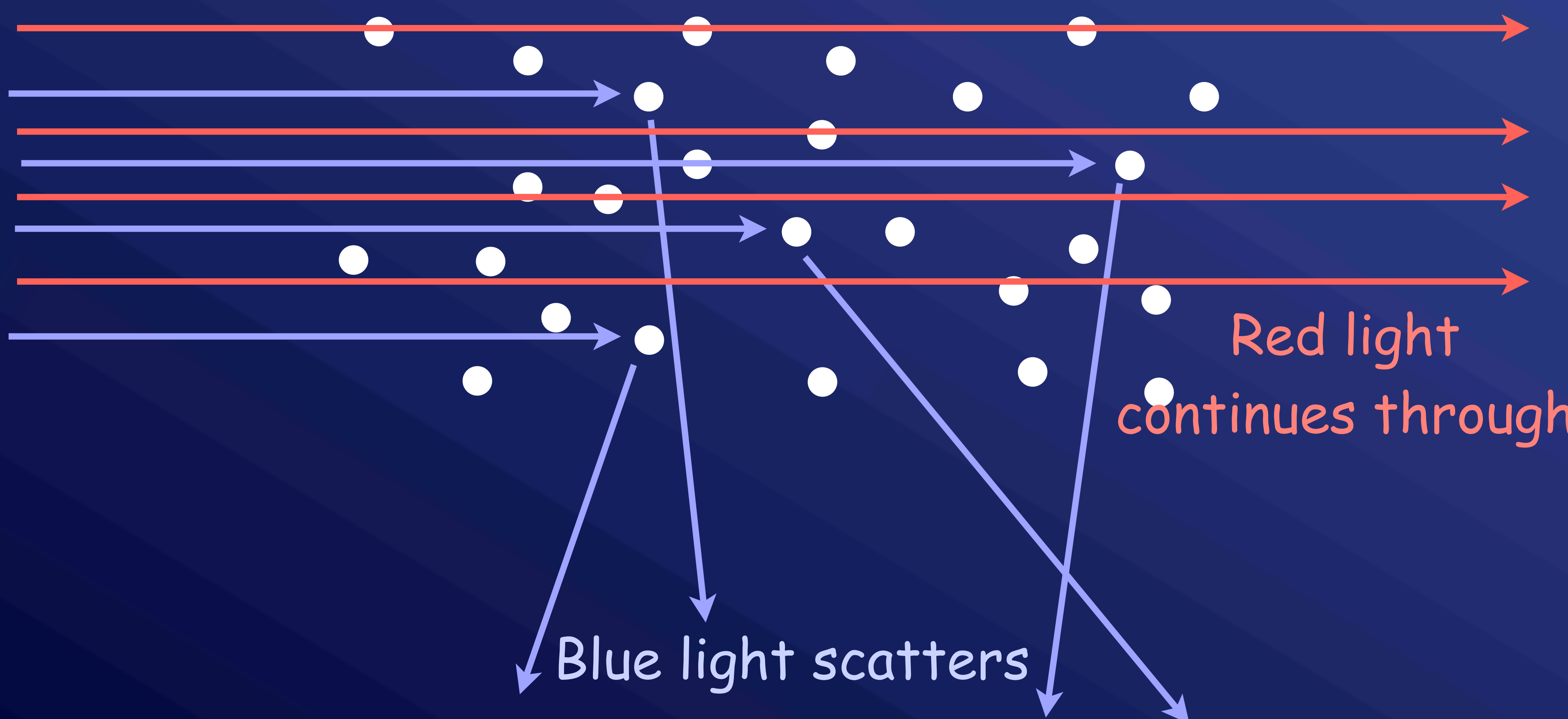
What is Rayleigh scattering?

- In Rayleigh scattering, the air molecules act like little antennas, absorbing electromagnetic waves and reemitting them.
- The fact that the light is absorbed and reemitted slows it down a bit. More on this later.
- The amount of Rayleigh scattering depends in an important manner on the wavelength of light and the size of the particles that are doing the scattering.

How Rayleigh scattering affects the sunlight hitting the Earth

Scattering probability goes like $1/(\text{wavelength}^{4})$

Scattering probability also goes like $(\text{size of particle})^{6}$



Blue skies, red sunsets

- Light from the sun transmitted through the atmosphere around sunset has shorter wavelengths removed (because they are scattered away) leaving the light to appear red.
- Light transmitted through the atmosphere closer to the middle of the day has some short wavelengths removed, giving perhaps a slightly yellow tint to the light.
- Parts of the sky where the sun is not present still give off light because of Rayleigh scattering. These parts appear blue because these are the wavelengths that are most strongly scattered.

Blue skies, red sunsets

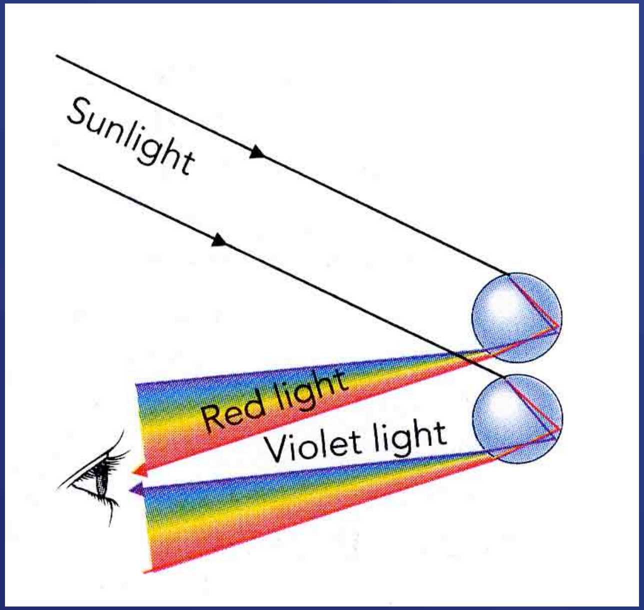
- At left, an excess of blue light is scattered by the atmosphere causing the sky to look blue.
- At right, light from a sunset, scattered off of dust particles and other things, has to travel through a great deal of distance through the atmosphere causing the light to look red.

Question:

When you are looking at a rainbow, is the top of it red or blue?

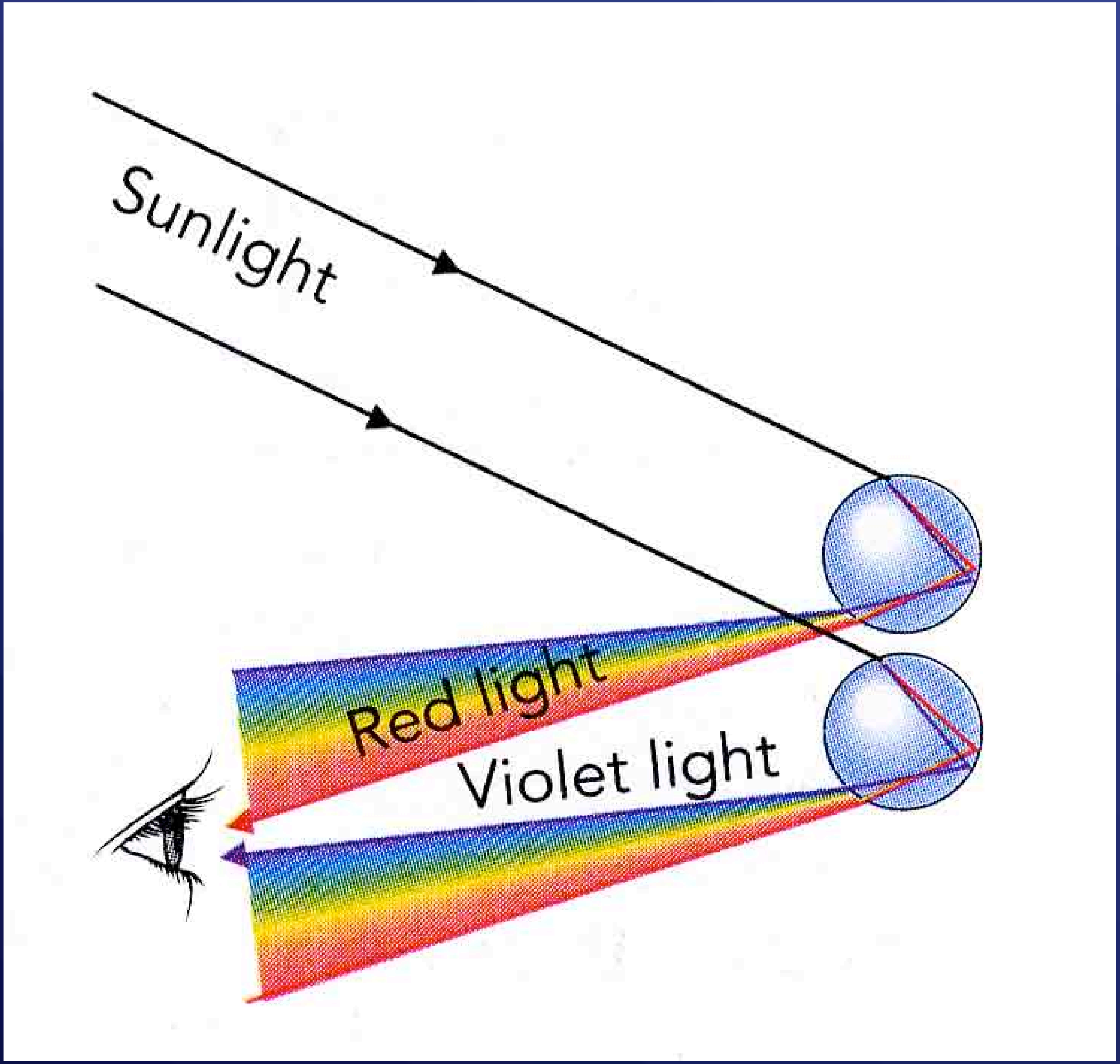
A. Red.
B. Blue

Rainbows - how do they work?

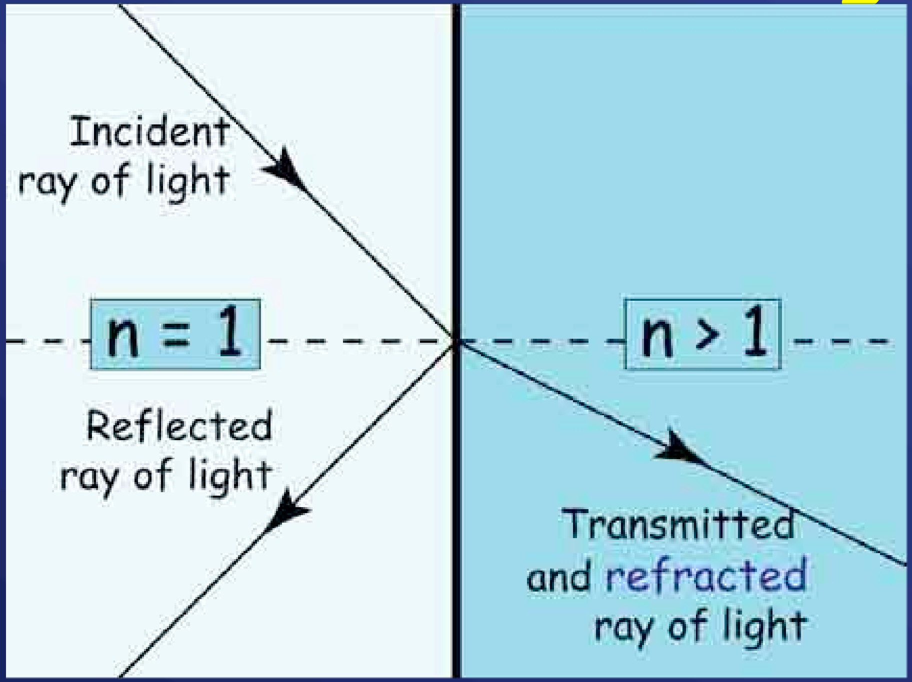


- In a rainbow, droplets of water act both as reflectors and as natural prisms.
- Refraction (bending of light as it enters a new medium) is slightly different for different wavelength. This separates the light into different components.

Rainbows - how do they work?



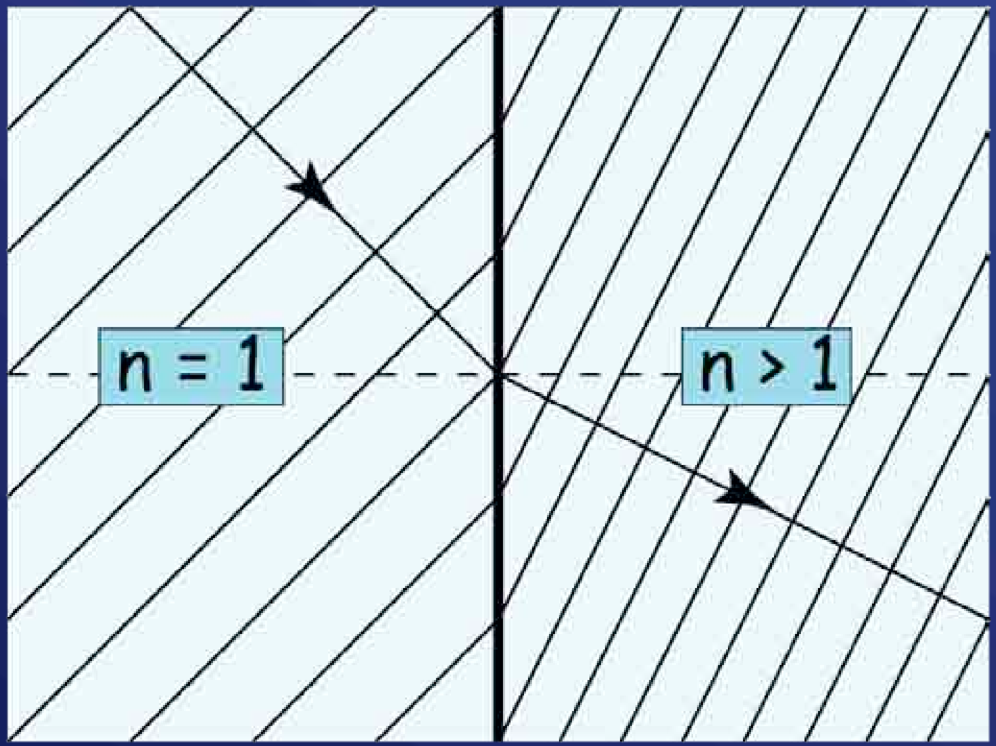
The refraction of light



- Refraction is the phenomenon in which light that is traveling along in one medium and passes into another medium has its direction changed.
- It is governed by the indices of refraction of the two media and the angle with which it hits the interface.
- The index of refraction, n, is the factor by which light travels slower than the speed of light in a vacuum.

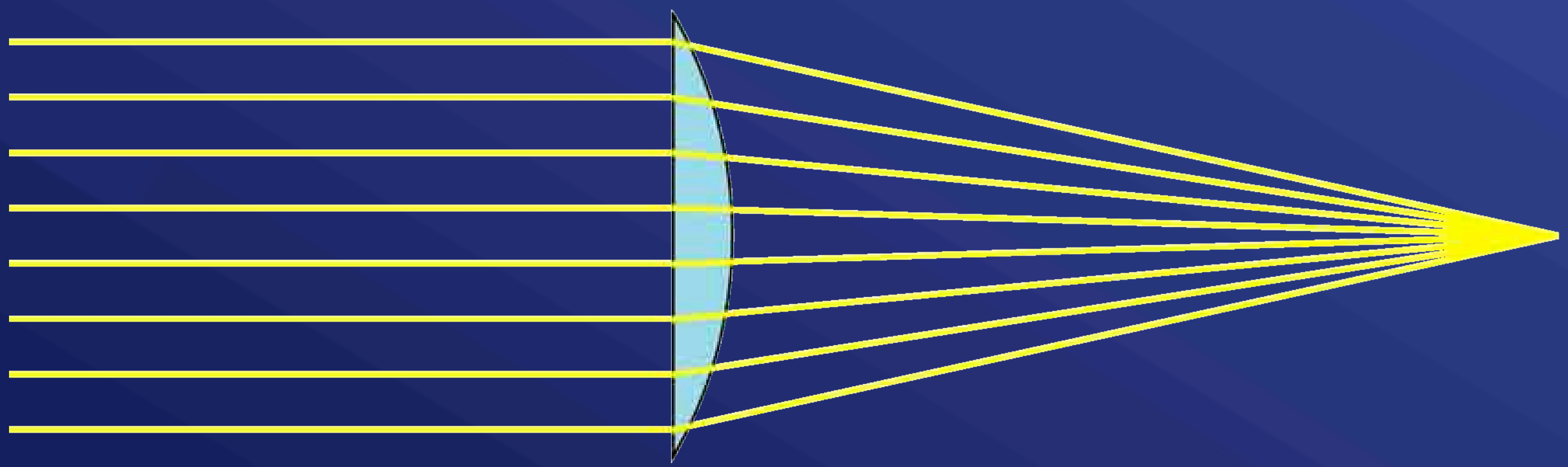
speed of light in medium = c / n

Refraction



- When an electromagnetic wave crosses an interface at an angle between vacuum and a medium with an index of fraction greater than one (n > 1), its direction bends into the medium.
- One way of understanding this is recognizing that even with the shorter wavelength, the “wavefronts” in the two media still need to line up along the interface.

Refraction is also how lenses work



- By sending light through a curved surface, different rays of light are all focused down to a single point.
- This is how light from the sun can be focused down to a small spot to ignite a fire.
- This is also how lenses are used to form images of things, in cameras, etc.