Chapter 3

Radiation

Units of Chapter 3

- Types of radiation
- Waves
- Waves in What?
  - The Wave Nature of Radiation
- The Electromagnetic Spectrum
- Thermal Radiation
  - The Kelvin Temperature Scale
  - More about the Radiation Laws
- The Doppler Effect

Learning Outcomes:

1) Understand the basic properties of waves (wavelength, period, speed, etc.)

2) Describe the major regions of the electromagnetic spectrum.

3) Distinguish between particle-like and wave-like phenomena of light.

4) Explain what is meant by blackbody radiation and how it pertains to real thermal radiation.

5) Describe how relative motion influences perceived frequencies through the Doppler Effect.

In short: LEARN THE PHYSICS OF LIGHT AND WAVES!

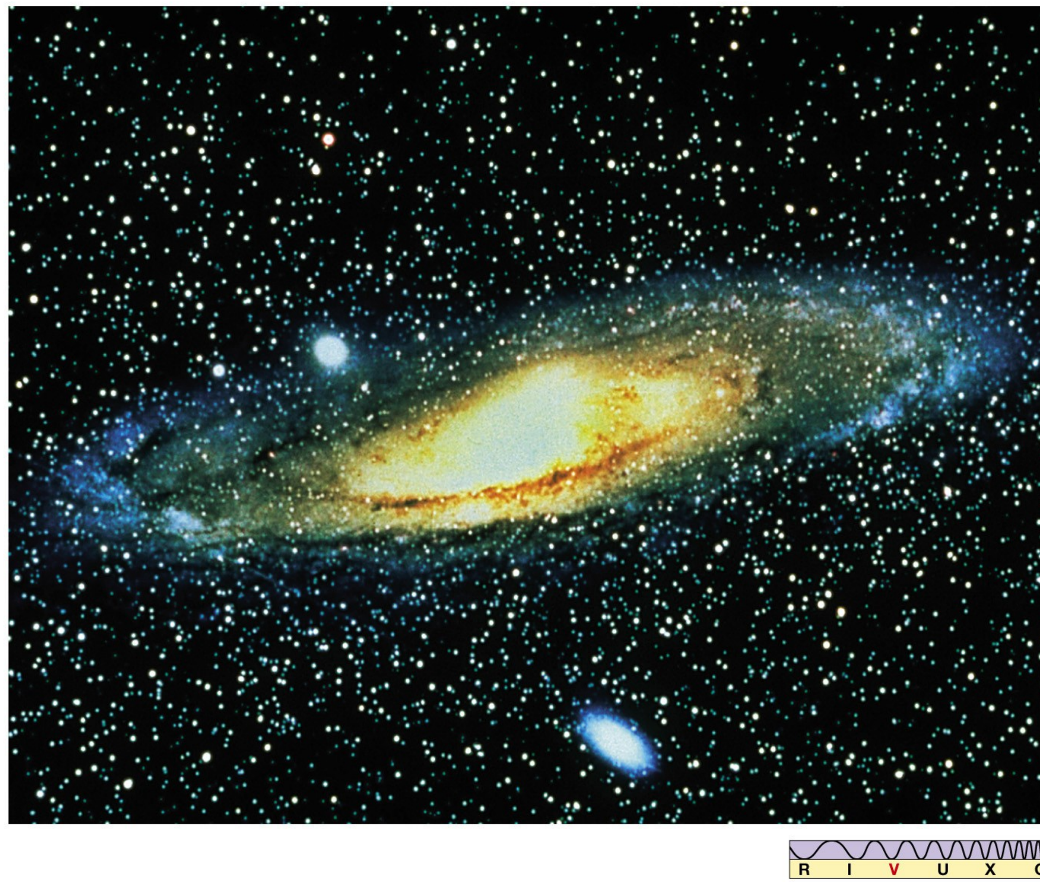
Types of Radiation

Electromagnetic Radiation: energy transmitted through space as varying electric and magnetic fields

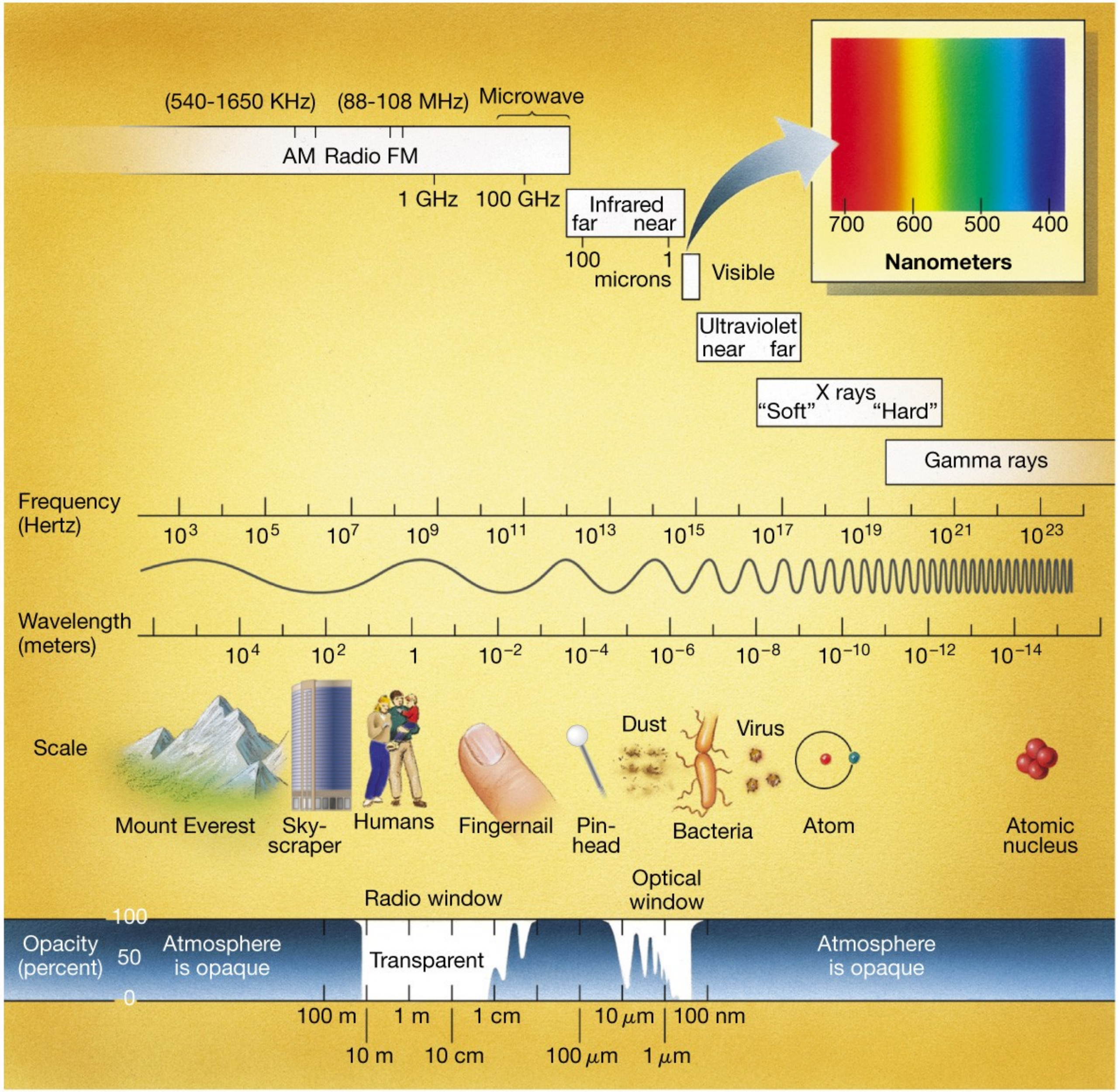
Light, x-rays, radio waves, infrared, etc.

Particulate radiation

beta rays (e-), alpha rays (He) [Not covered here!]



Types of E-M radiation



Electromagnetic radiation

Different ranges have different names

Types of radiation

Electromagnetic Radiation interacts differently with different materials. It may be absorbed, emitted, transmitted, reflected, or scattered.

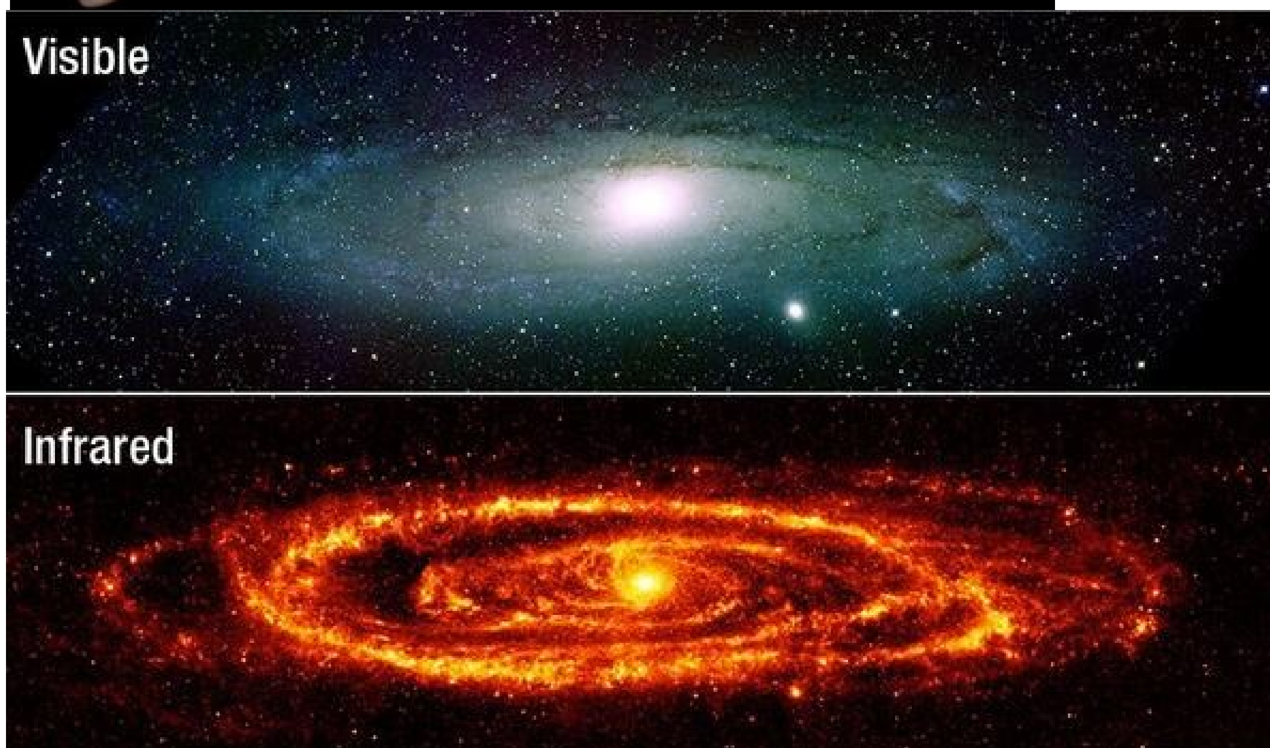
How it interacts depends on 1) the type of radiation (radio, IR, etc), 2) the composition.

Visible

Infrared

Types of radiation

Astronomical objects in different wavelengths.



Waves

Wave: a travelling disturbance or variation in a medium or field which carries energy.

Types:

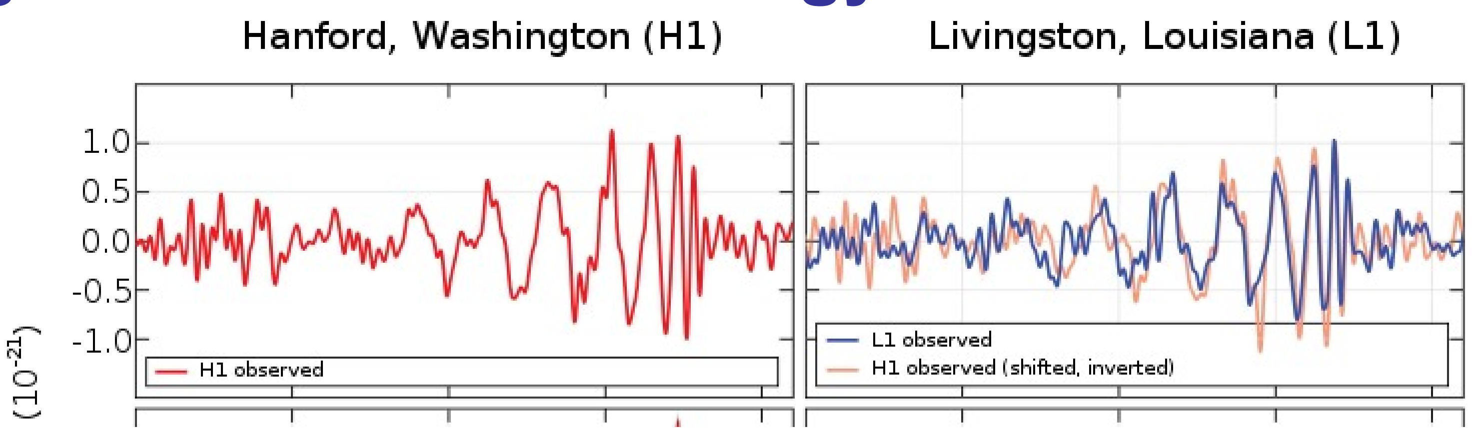
Mechanical	Electromagnetic	Gravitational(!)
sound	visible light	inspiralling BHs
seismic	microwaves	
water	x-rays, gamma rays	
string		

What do they have in common?

The first gravitational wave detection: by the LIGO consortium on Feb 11, 2016.

Source: inspiralling binary black holes. One 29 $M_\odot$ and one 36 $M_\odot$.$1.3x10^9$ LY away. Produced one 62 $M_\odot$ BH.

Power: momentarily greater than all of the stars in the observable universe. 3 $M_\odot$ converted into gravitational wave energy in ~0.2 seconds.



The "chirp"

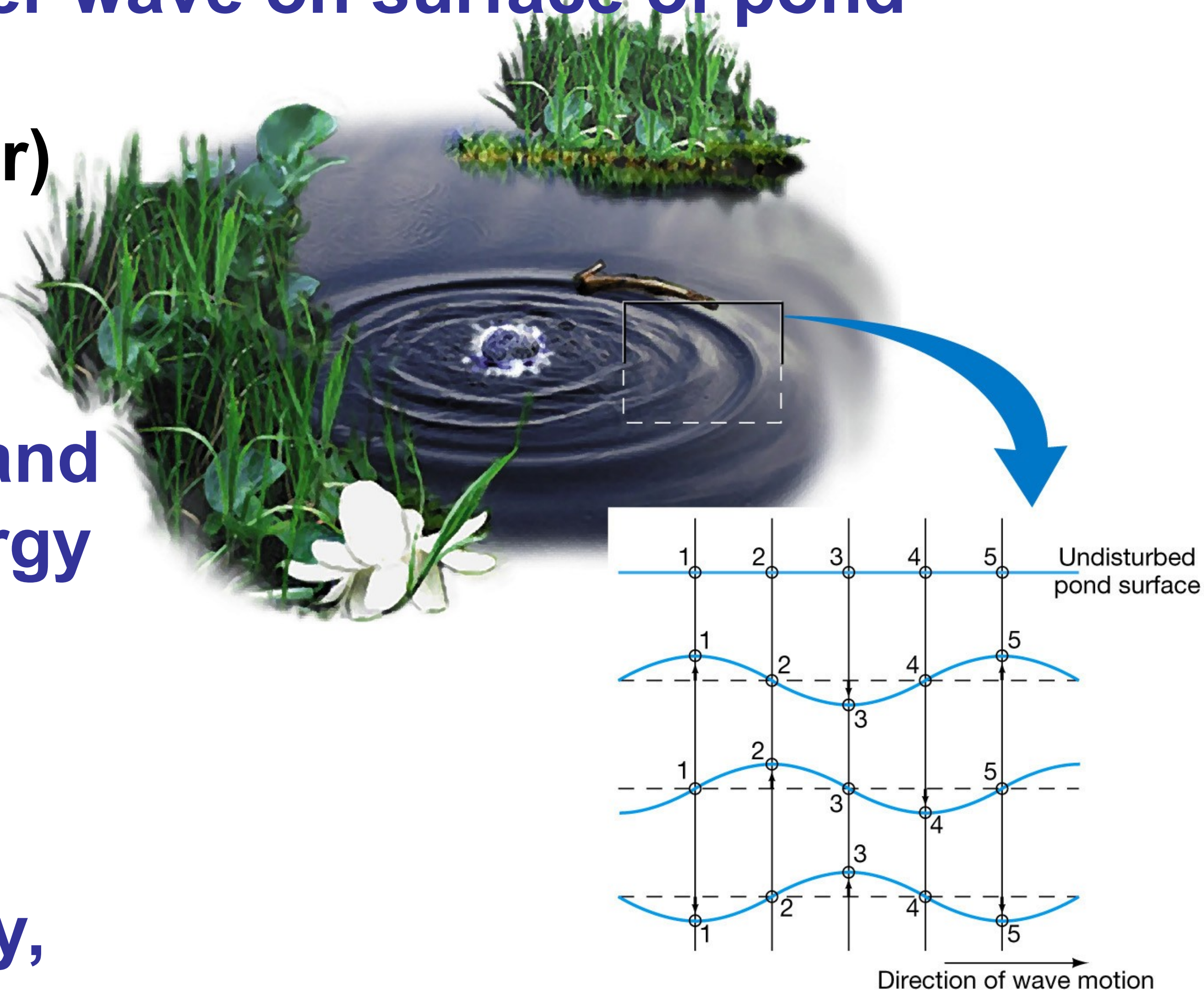
Waves - terminology

Example: water wave on surface of pond

Medium (Water) just moves up and down

Wave travels and transmits energy (Kinetic and potential)

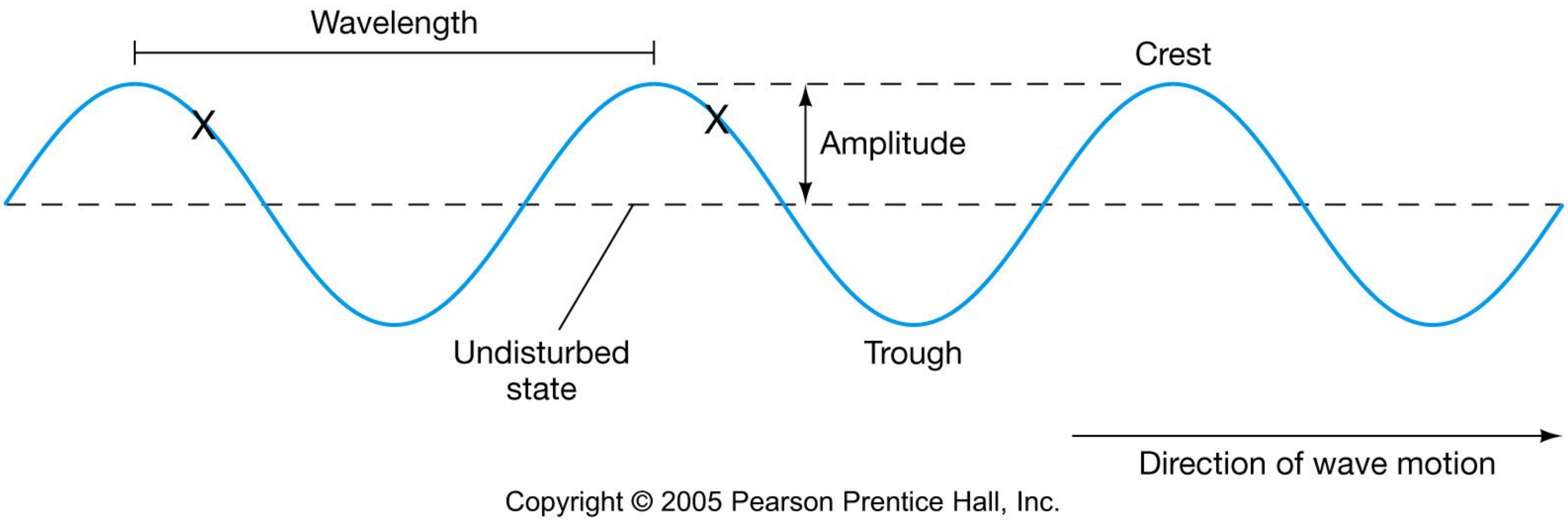
Restoring Forces: gravity, pressure



Waves - terminology

Waveforms: can have many shapes, but usually are …

Sinusoidal: described by a sine or cosine function.



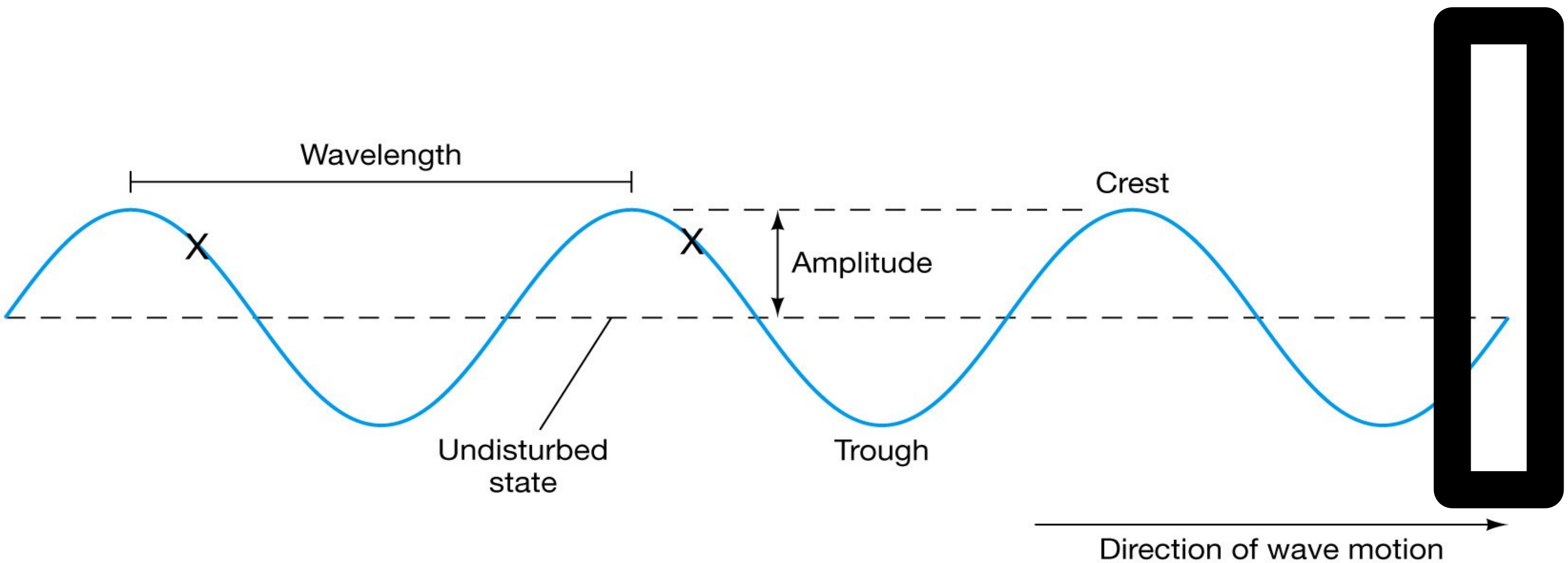
This graph shows amplitude versus position, but amplitude versus time is ALSO a sinusoidal graph!

Waves - terminology

Frequency: number of wave crests that pass a given point per second

Period: time between passage of successive crests

Relationship: **Frequency = 1 / Period**



Waves - terminology

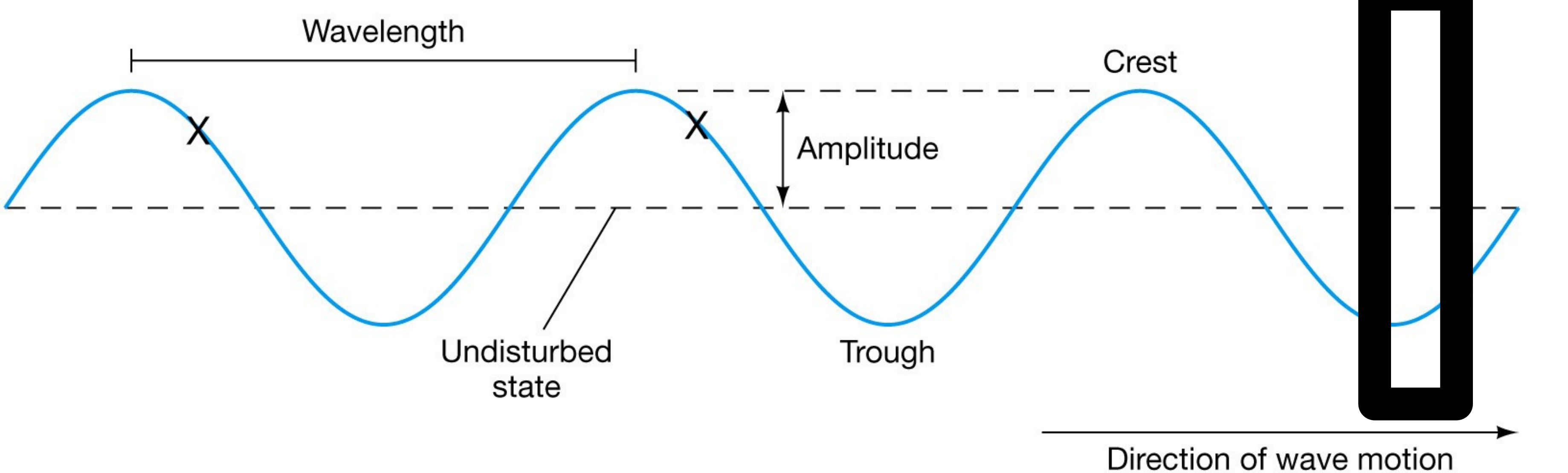
Wavelength: distance between successive crests

Velocity: speed at which crests move

Velocity = Wavelength/Period

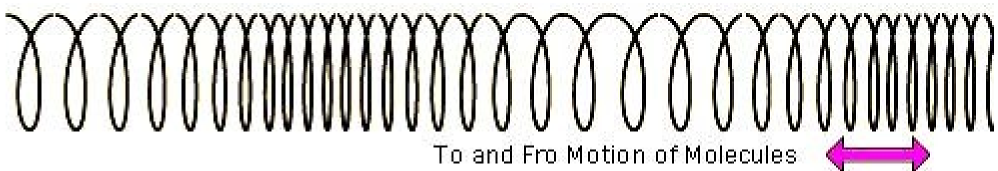
Velocity = Wavelength * frequency

Golden Rule!
$V = \lambda f$

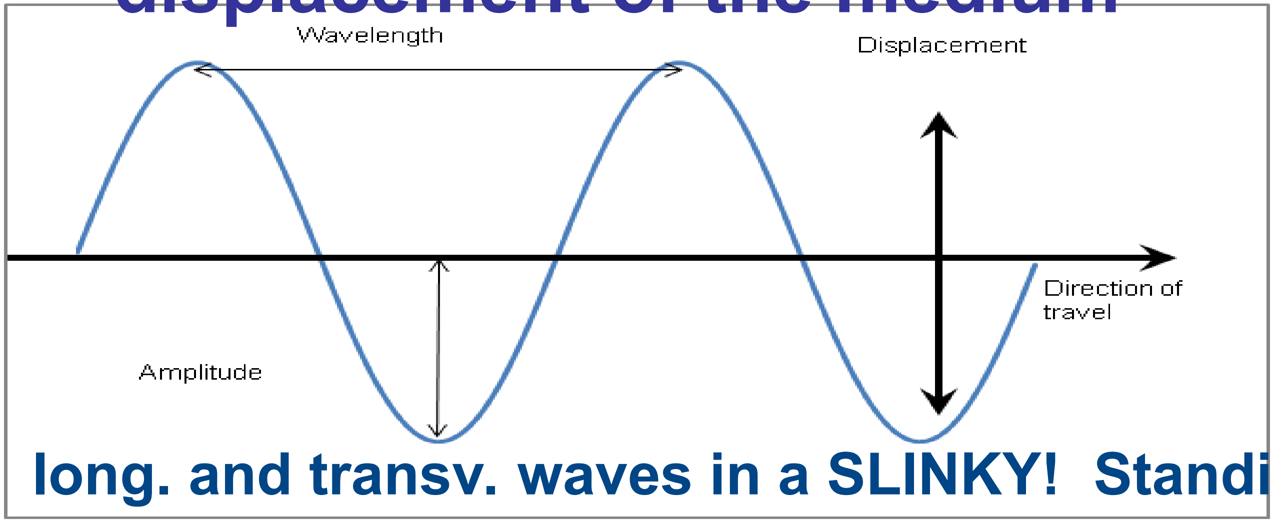


Waves - terminology

Longitudinal wave: propagates in a direction parallel to the displacement of the medium

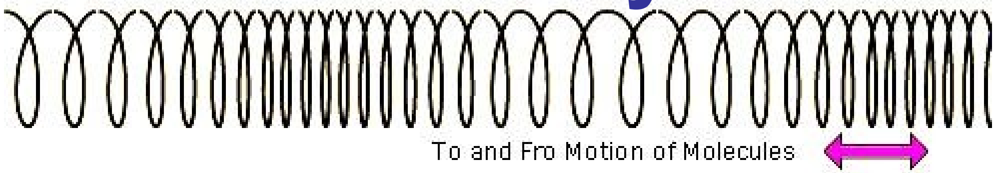


Transverse wave: propagates in a direction perpendicular (or transverse) to the displacement of the medium



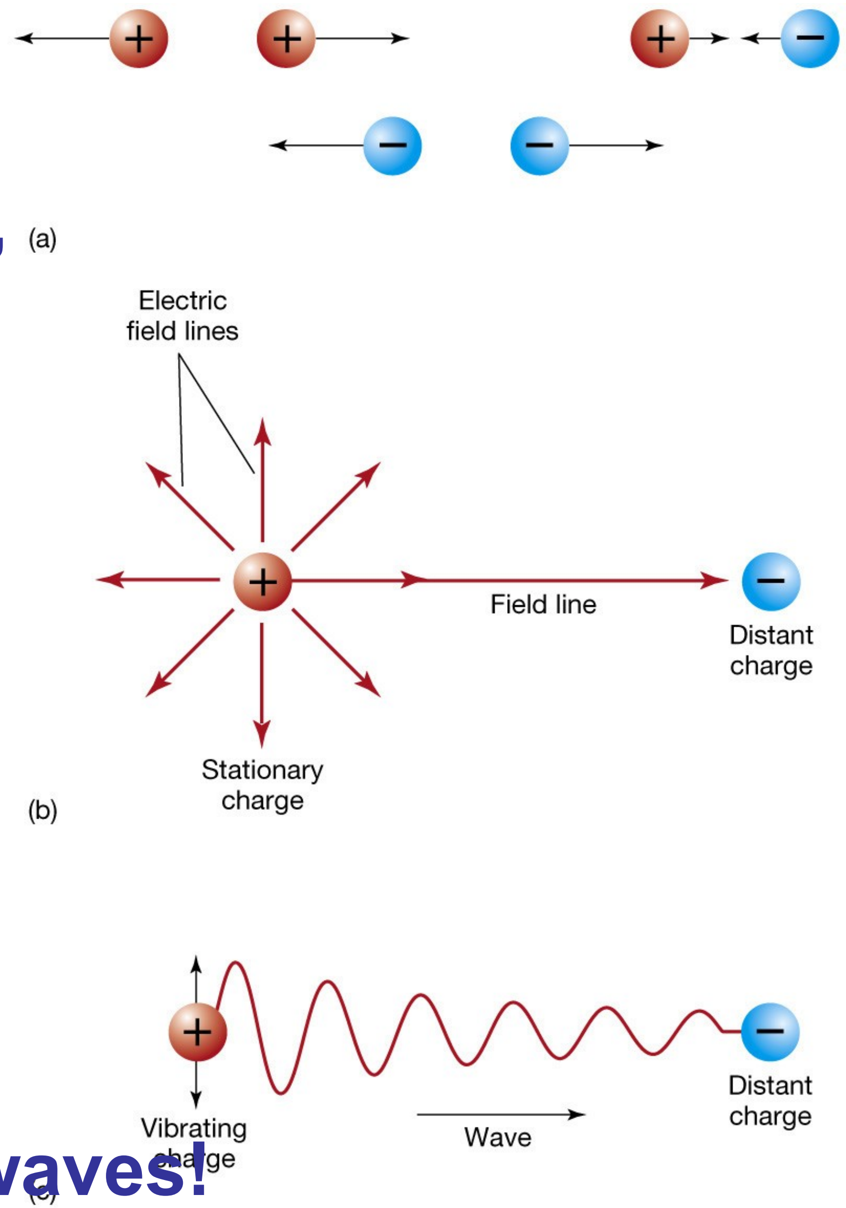
DEMO: long. and transv. waves in a SLINKY! Standing waves!

Waves – Slinky Demo



1. Longitudinal pulses
2. Transverse pulses - note reflected pulse
3. Speed of pulse – increases with tension
4. Superposition of pulses
5. Standing waves (superposition with reflected waves)
6. Harmonics (N=number of antinodes)
7. Polarization

E-M waves: waves in what?



Water waves, sound waves, and so on, travel in a medium (water, air, …)

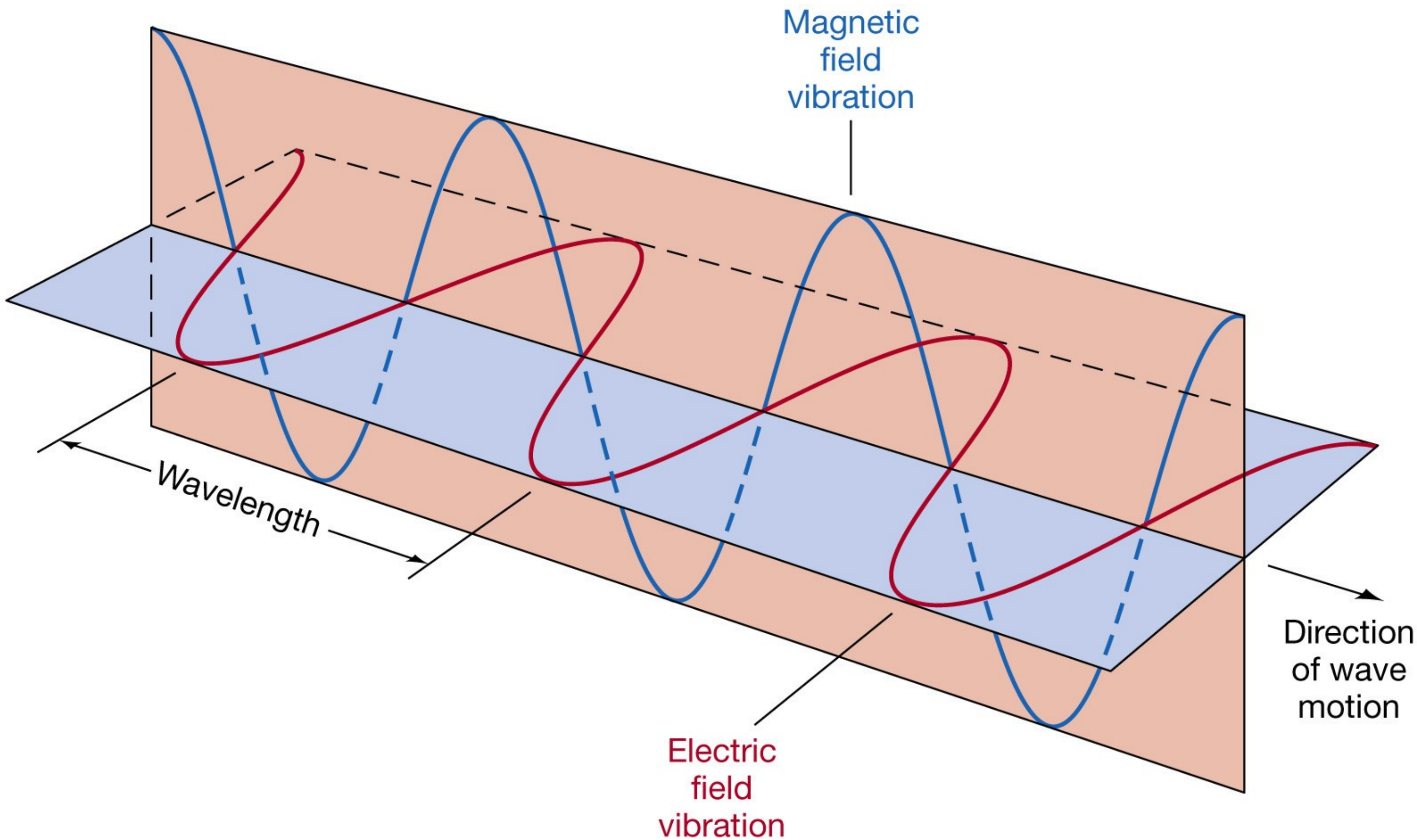
Electromagnetic waves need no medium

Created by accelerating charged particles:

Demo: spark makes radio waves!

Waves in What?

Electromagnetic waves: Oscillating electric and magnetic fields. Changing electric field creates magnetic field, and vice versa



Waves in What?

What is the **wave speed** of electromagnetic waves?

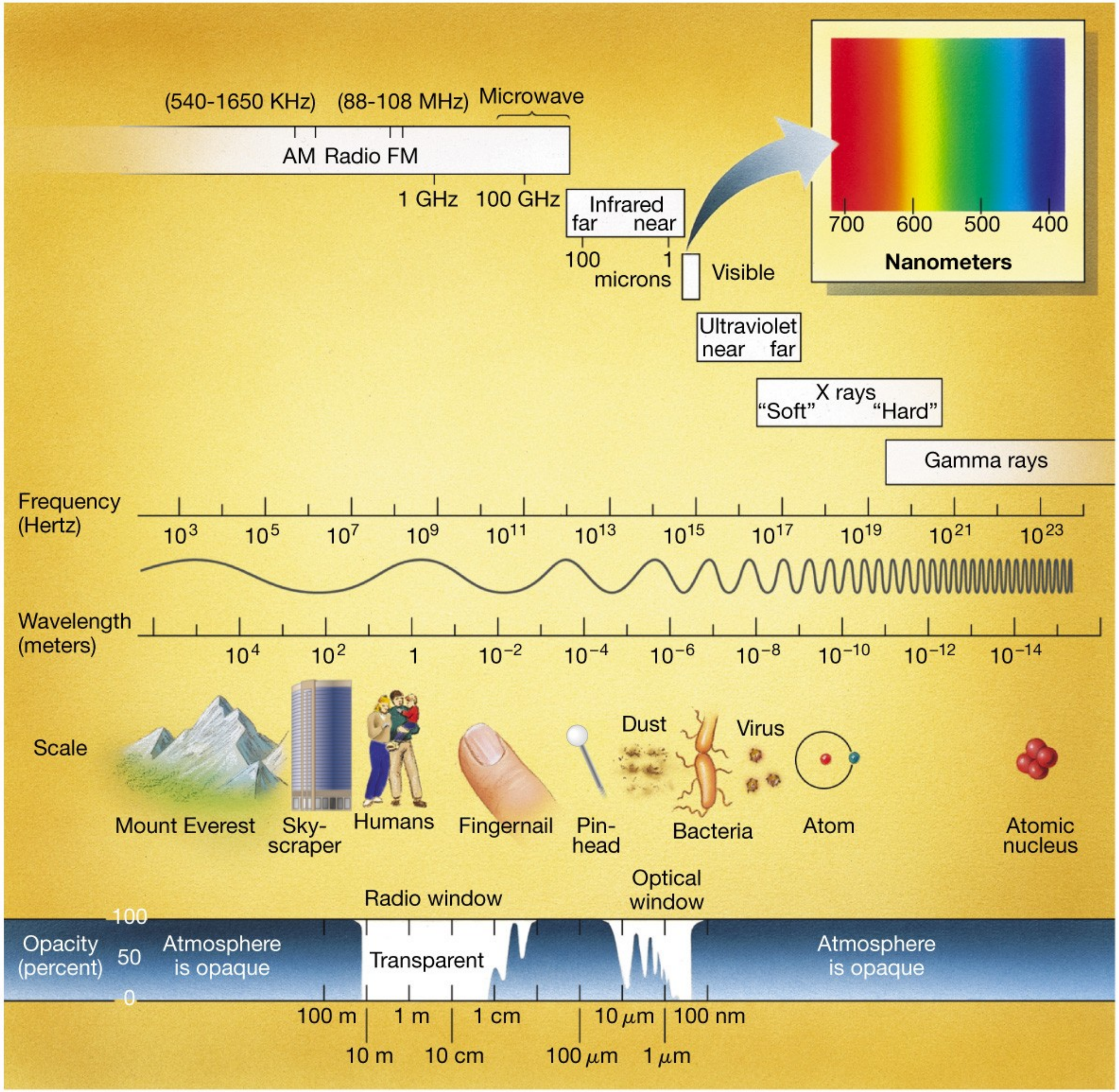
$$c = 3.0 \times 10^8 \text{ m/s}$$

This speed is very large, but still finite; it can take light millions or even billions of years to traverse astronomical distances.

Why special?

1) Nature's speed limit. 2) A beam of light appears to move at the same speed through a vacuum to any observer.

The Electromagnetic Spectrum



No upper limit on wavelength

High frequency radiation has small wavelength.

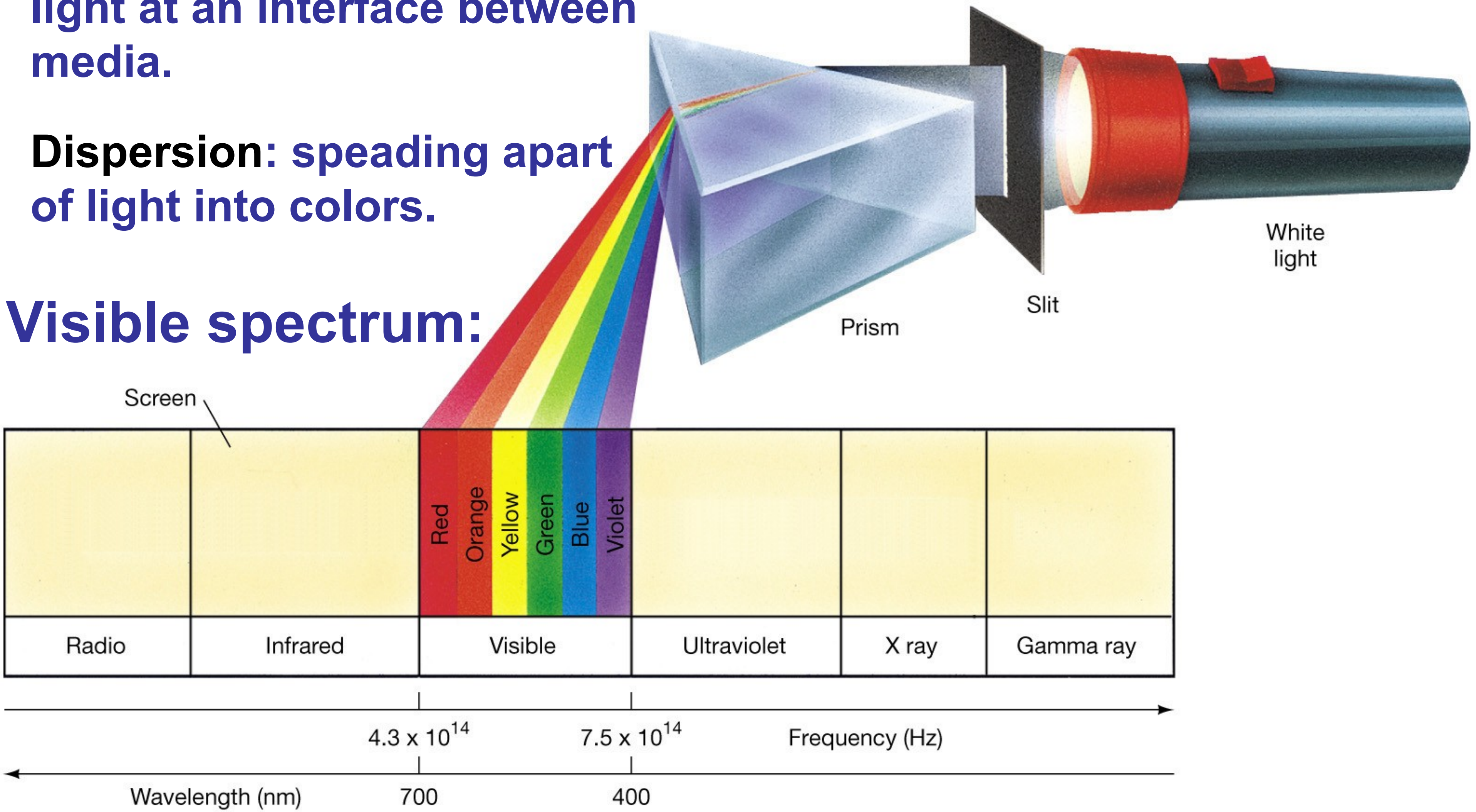
High opacity means low transparency.

Electromagnetic spectrum

Refraction: the bending of light at an interface between media.

Dispersion: speading apart of light into colors.

Visible spectrum:



Light as wave or particle

Light can behave like a wave or like a particle depending on the situation.

An example of a phenomenon which is best described with the particle model is …

The Photoelectric Effect

*** Light with a freq above some limit can dislodge e- from the surface of a metal. Just below that limit, no e- dislodged even if the intensity of the light is great!**

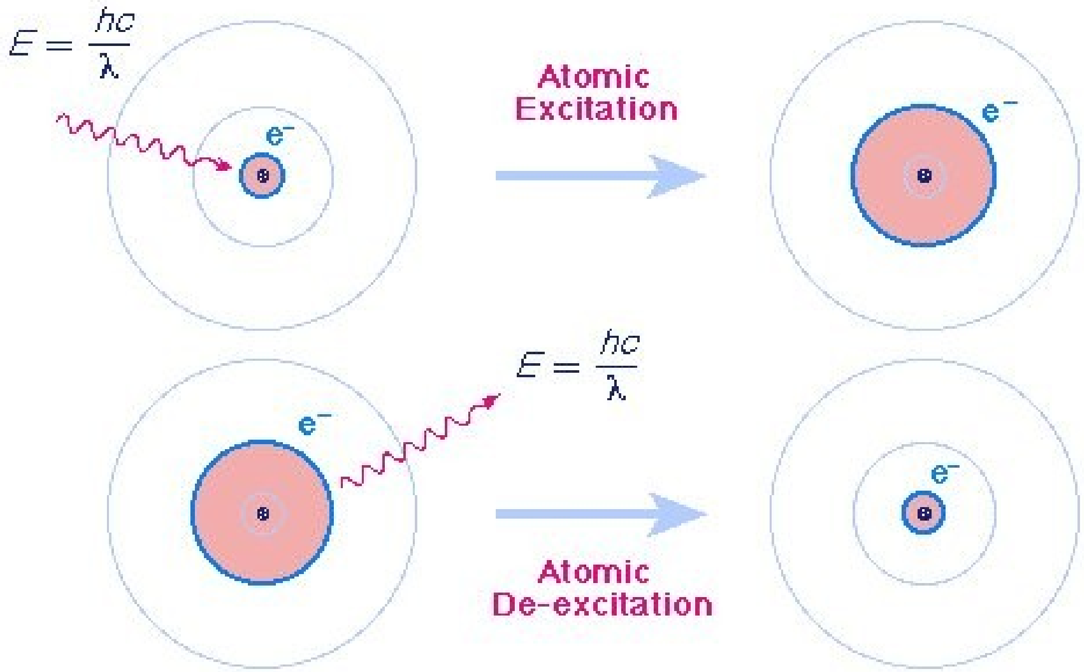
*** Conclusion: light comes in particles called photons with Ephot = hf. ($h=6.626\times10^{-34}$ Js)**

See [phet.colorado.edu/en/simulation/photoelectric]

Light as wave or particle

Another phenomenon which is best described with the particle model is …

The emission and absorption of light by atoms



*** Light must have just the right photon energy (or frequency) to be absorbed by an atom.**

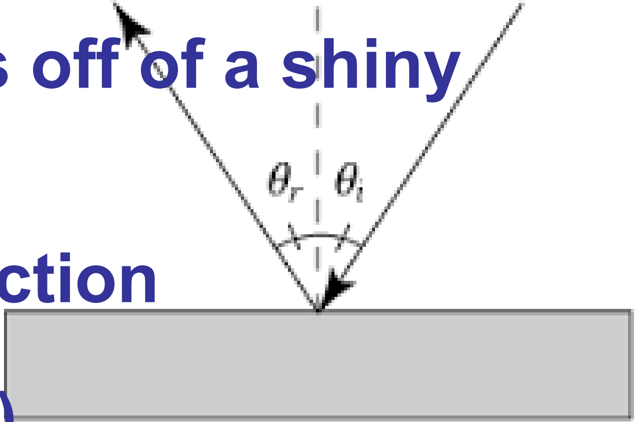
Light as wave or particle

Phenomena which could be described with the particle <u>and</u> wave models are …

Reflection

* the bouncing of photons or waves off of a shiny surface such that …

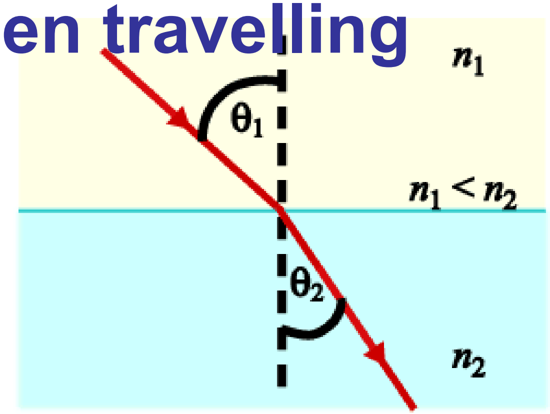
* angle of incidence = angle of reflection



Refraction (wave model is preferred)

* the slowing and bending of light when travelling from one medium to another

* Snell's law: $n_1 \sin\Theta_1 = n_2 \sin\Theta_2$



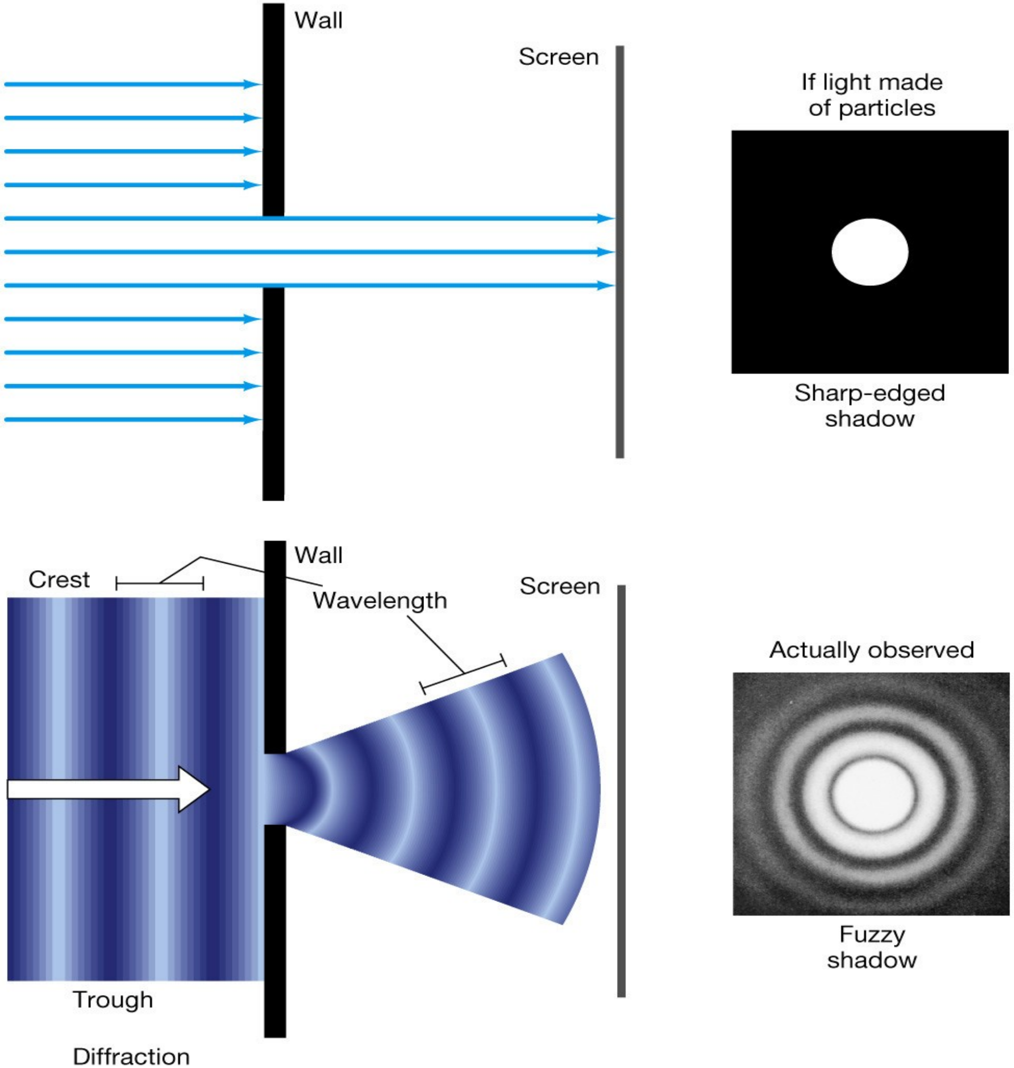
Light as wave or particle

Phenomena best described with waves:

Diffraction **= bending of light around corners and slits.**

Top: no diffraction

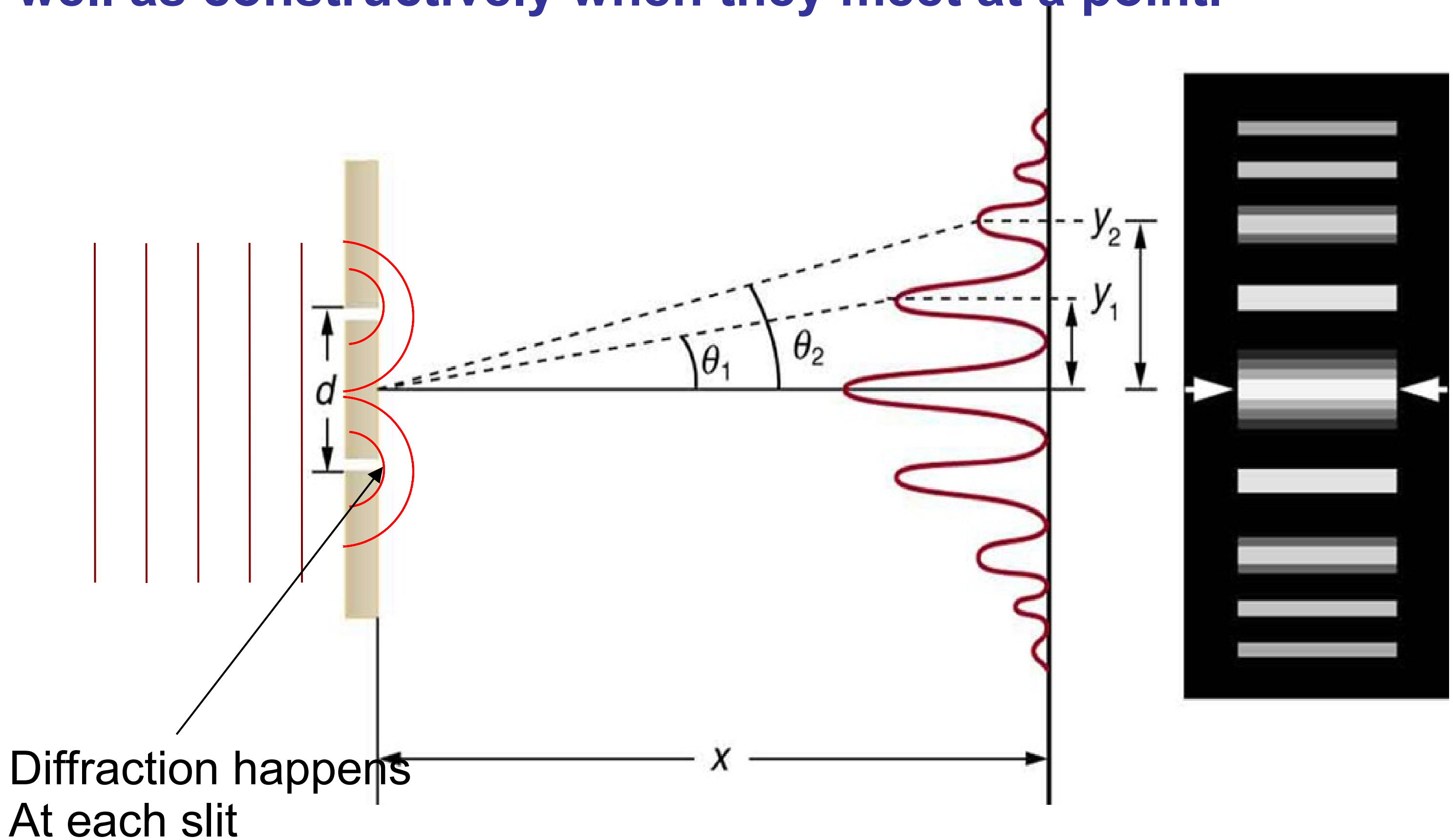
Bottom: diffraction



Light as wave or particle

Phenomena best described with waves

Interference **= two or more waves can combine destructively as well as constructively when they meet at a point.**



Light as wave or particle

Phenomena best described with <u>waves</u>

Polarization **= certain processes (like reflection off of plastic, or scattering off of air molecules) can produce light that has its E-field oriented in only certain directions.**

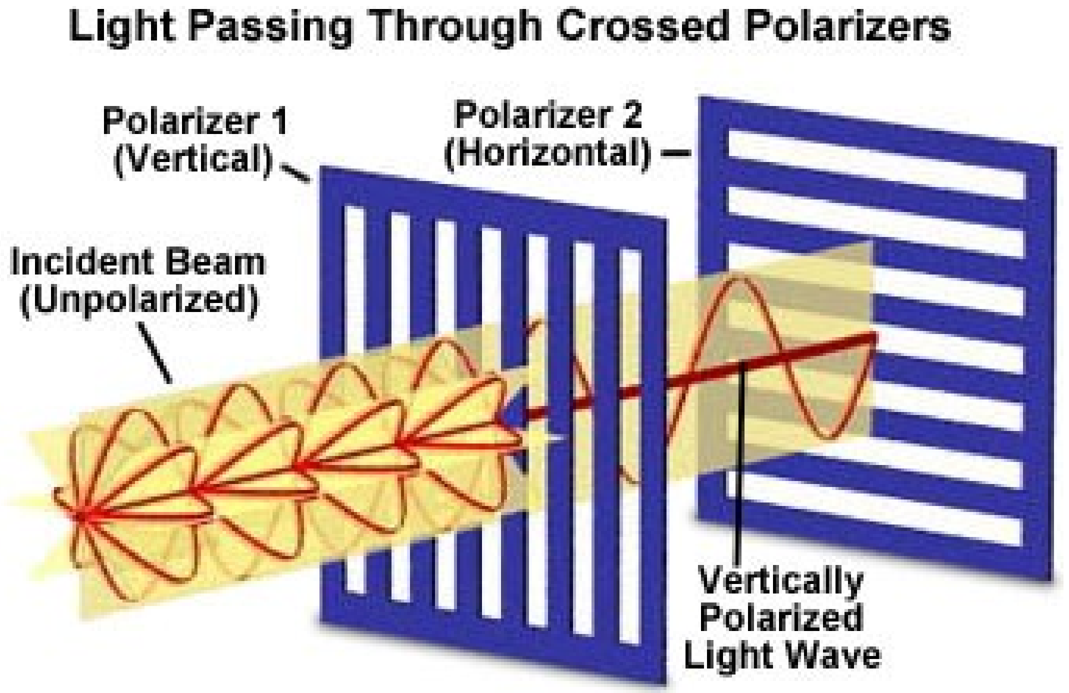


Figure 1

=

Thermal Radiation

Thermal radiation: **the light produced (not reflected) by real objects which depends on the object's temperature and emissivity.**
--> Closely approximates *blackbody radiation*.

Blackbody: *absorbs* 100% of incident light, and *emits* light with a *blackbody spectrum* (continuous with single peak).

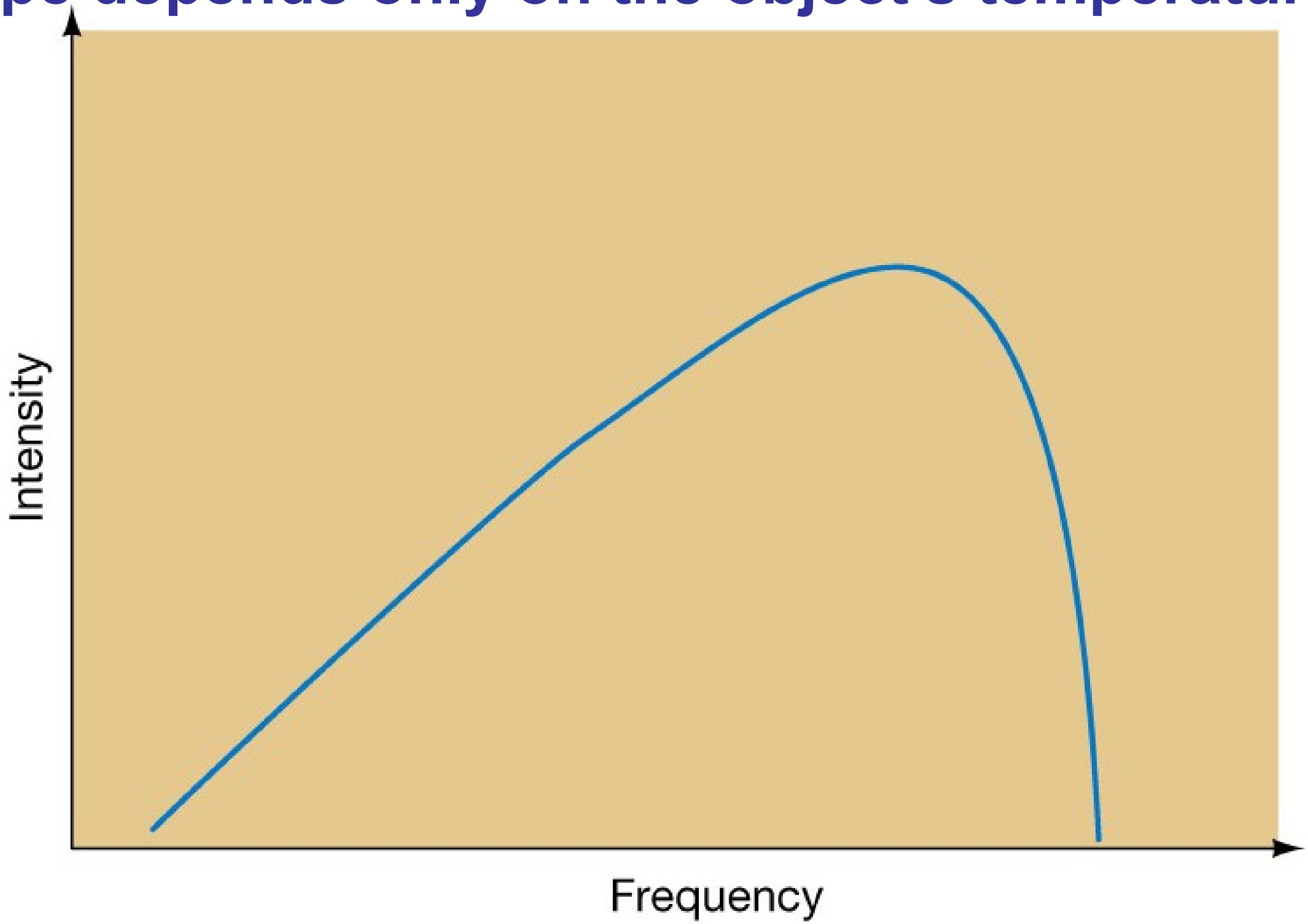
Coal is a good approximation of a black body.

See also "Vantablack" online.

Thermal Radiation

Blackbody Spectrum: radiation emitted by a blackbody, or perfect absorber. The spectrum's shape depends only on the object's temperature.

(Log)

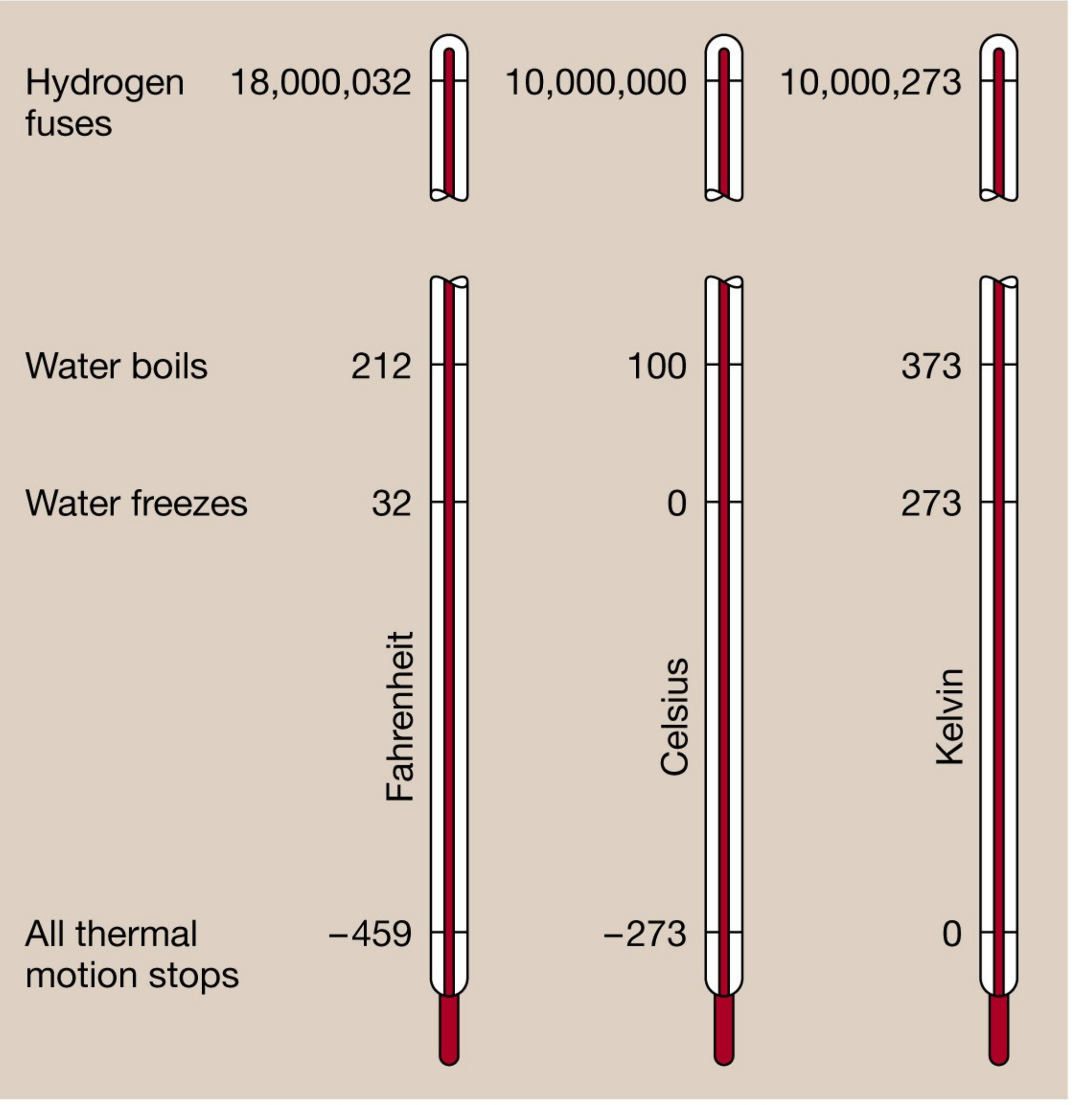


Thermal Radiation *Review: Temperature*

Temperature: a measure of the energy stored in the random motions of atoms and molecules

Kelvin – an absolute temperature scale:

- **All thermal motion** ceases at 0 K
- Water freezes at 273 K and boils at 373 K



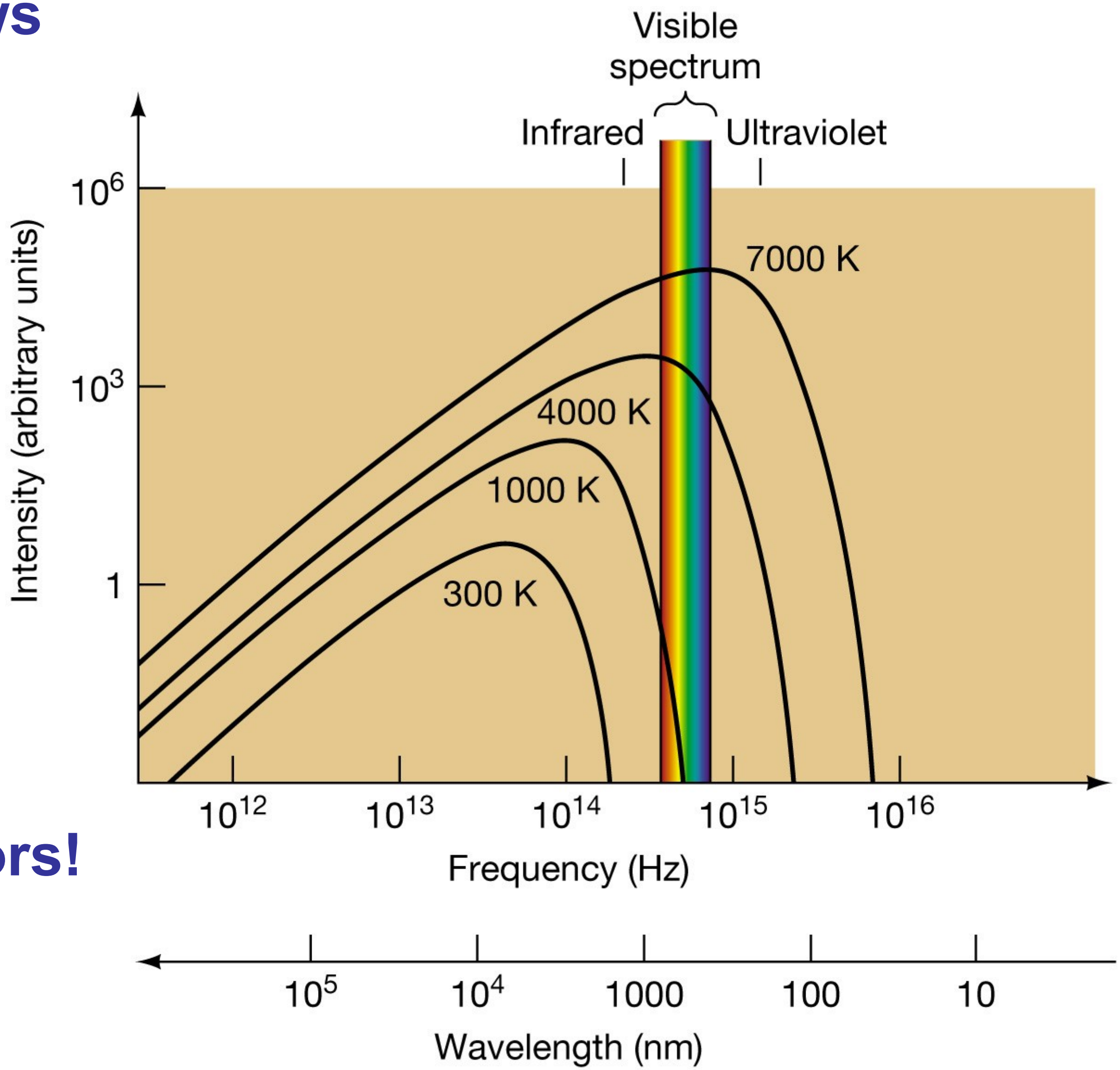
Thermal Radiation

Thermal Radiation Laws

1. Wien's Law:
Peak wavelength is inversely proportional to temperature.

$$\lambda_{max} \sim 1/T$$

This gives us a way to estimate temperatures of stars from their colors!



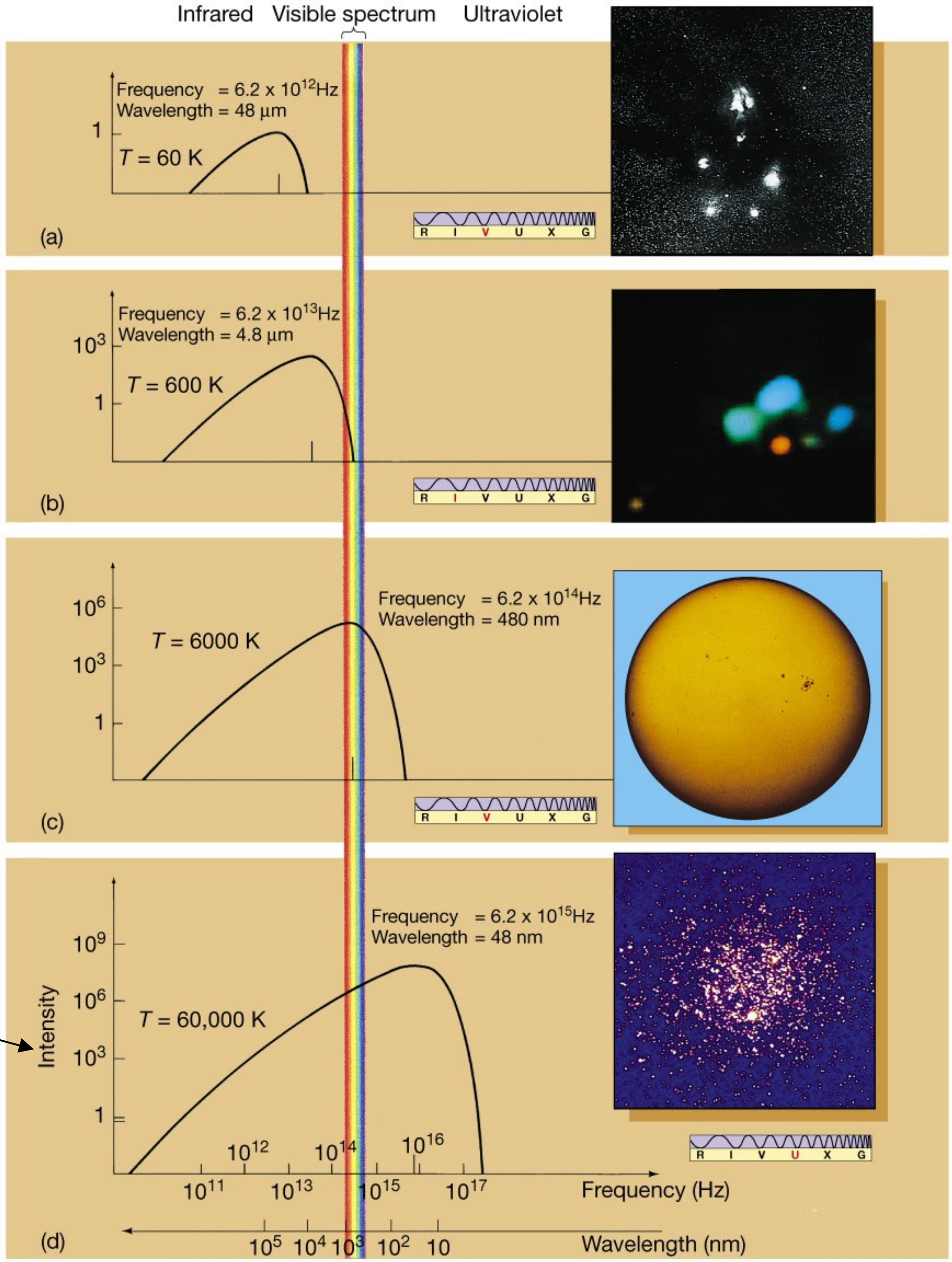
Thermal Radiation

Radiation Laws

2. Stefan's Law:

light energy emitted is proportional to the fourth power of temperature; $I \propto T^4$.

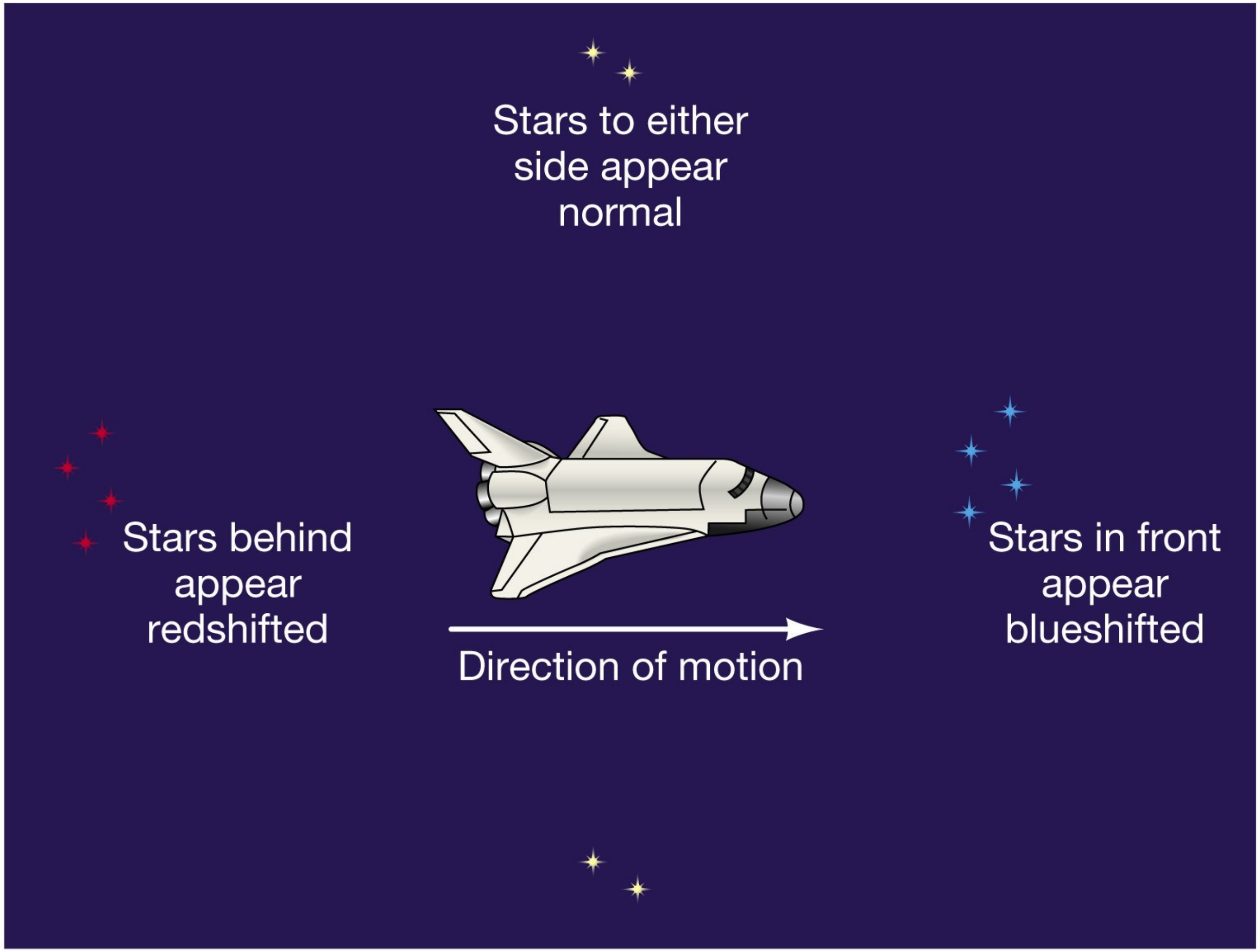
Note: intensity scale of curves is logarithmic!



DEMO: lightbulb filament with varying current

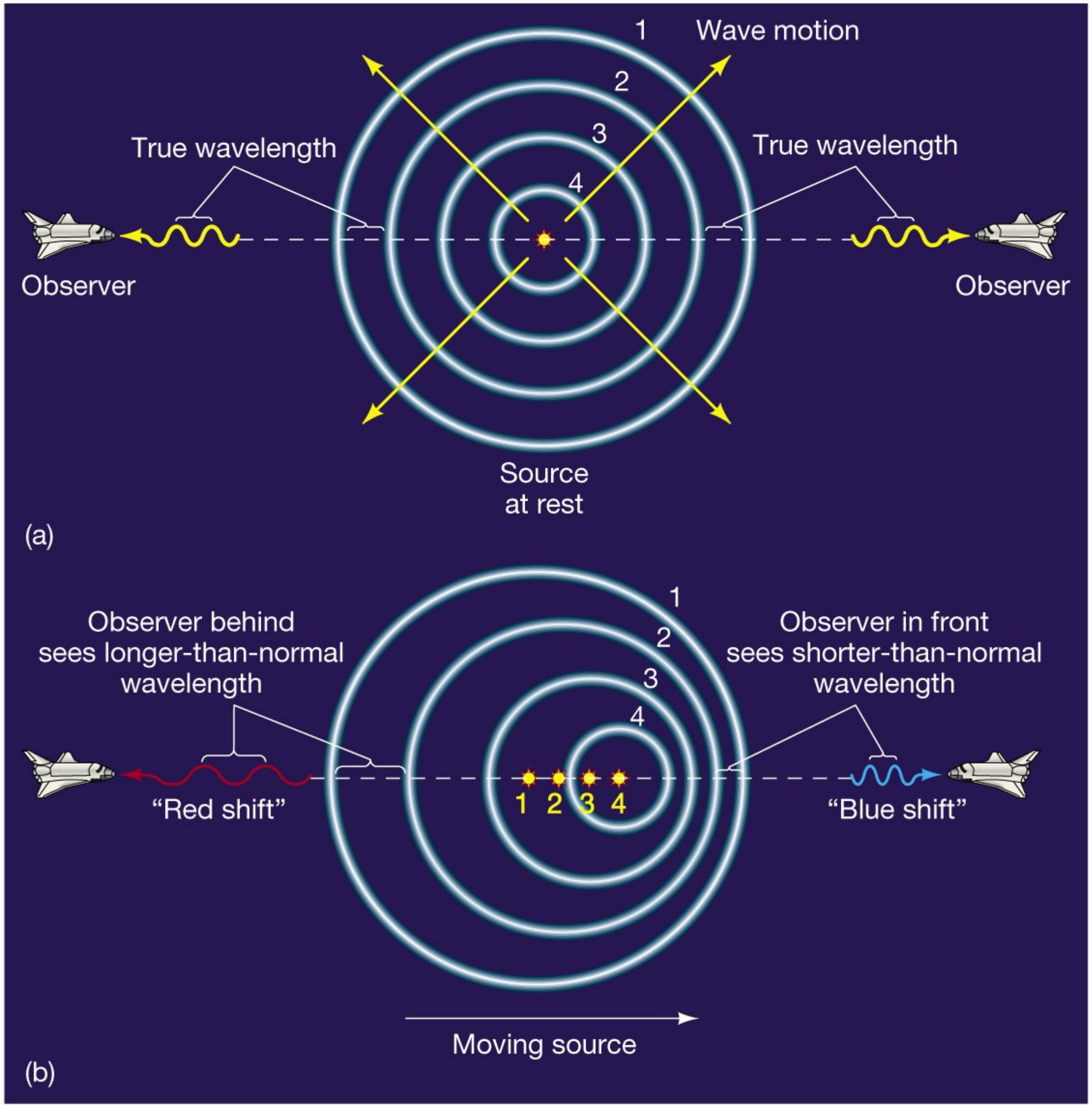
3.5 The Doppler Effect

If one is moving toward a source of waves, the wavelengths seem shorter; if moving away, they seem longer.



3.5 The Doppler Effect

Doppler effect also happens if source moves relative to the observer:



Summary of Chapter 3

- Wave: period, wavelength, amplitude
- Electromagnetic waves created by accelerating charges
- Visible spectrum has about an octave range of frequency and wavelength (ROYGBIV)
- Entire electromagnetic spectrum:

  radio waves, infrared, visible light, ultraviolet, X rays, gamma rays

Summary of Chapter 3, cont.

- Can tell the temperature of an object by measuring its thermal radiation
- Doppler effect can change perceived frequency of radiation
- Doppler effect depends on relative speed of source and observer