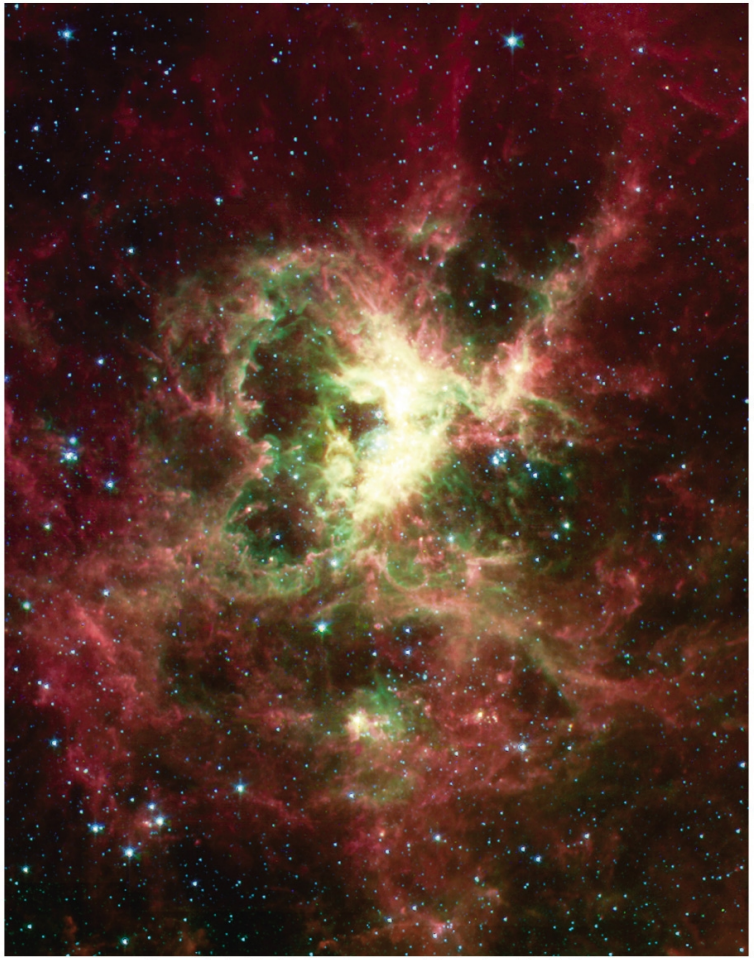
Chapter 3

Radiation



Units of Chapter 3

Types of radiation

Waves

Waves in What?

- The Wave Nature of Radiation

The Electromagnetic Spectrum

Thermal Radiation → "blackbody" radiation

- The Kelvin Temperature Scale
- More about the Radiation Laws

The Doppler Effect

Types of Radiation

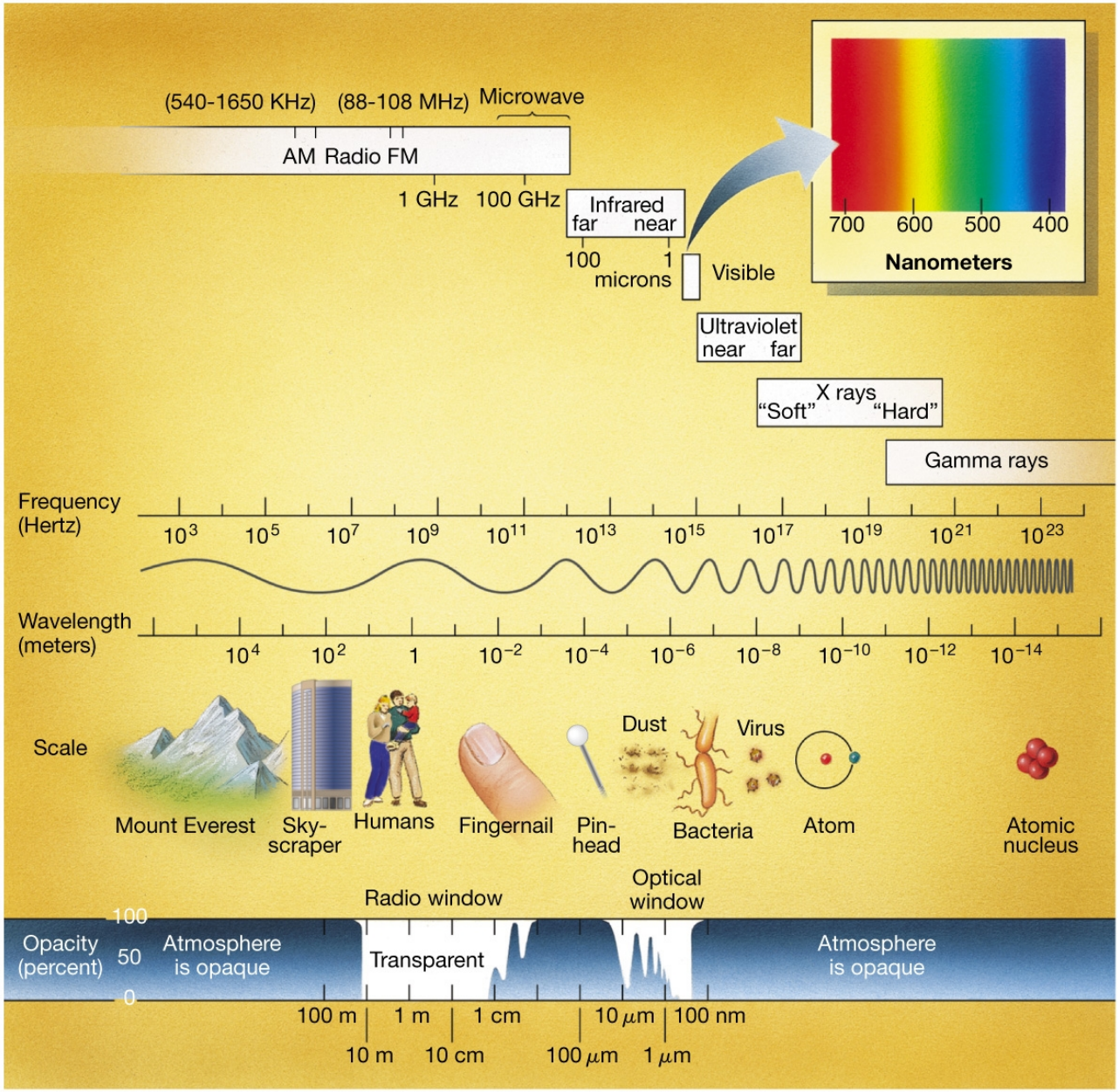
Electromagnetic Radiation: energy transmitted through space as varying electric and magnetic fields

Light, x-rays
radio waves,
infrared

Particulate radiation:

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

Types of 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.

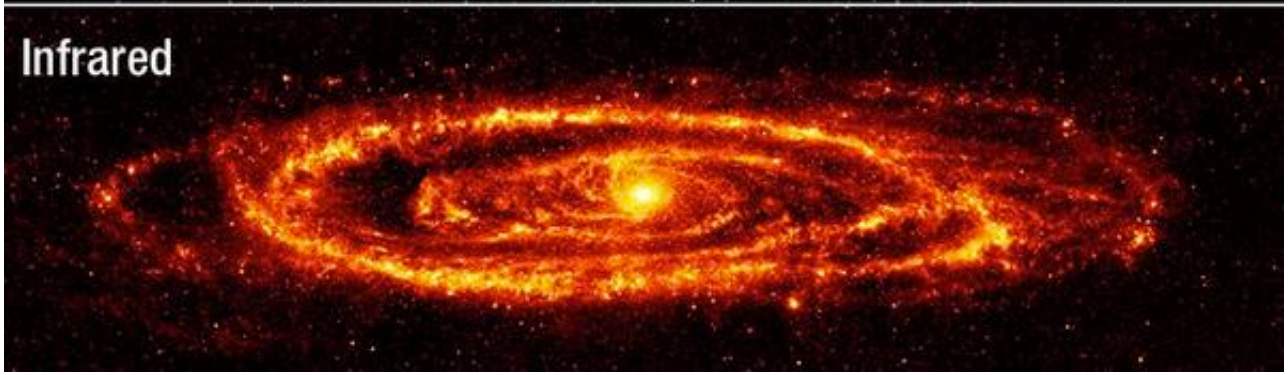
For a given material, E-M radiation can behave differently at different wavelengths.

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	Light	
seismic	microwaves	
water	x-rays, gamma rays	
strings		

What do they have in common?

Mechanical need restoring force & medium, E-M and Grav do not.

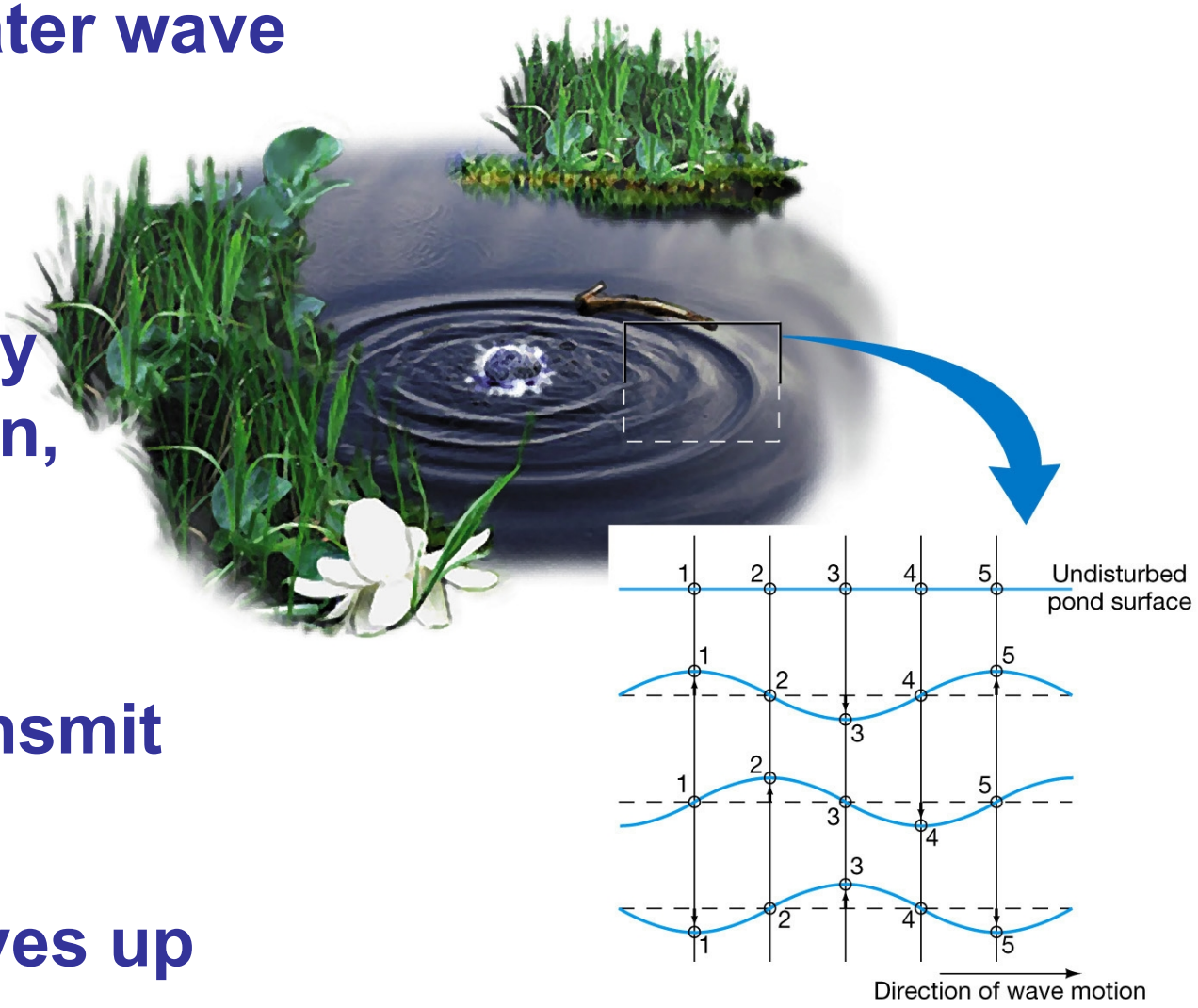
Waves - terminology

Example: water wave

Waves all propagate, transmit energy and information, and have an amplitude.

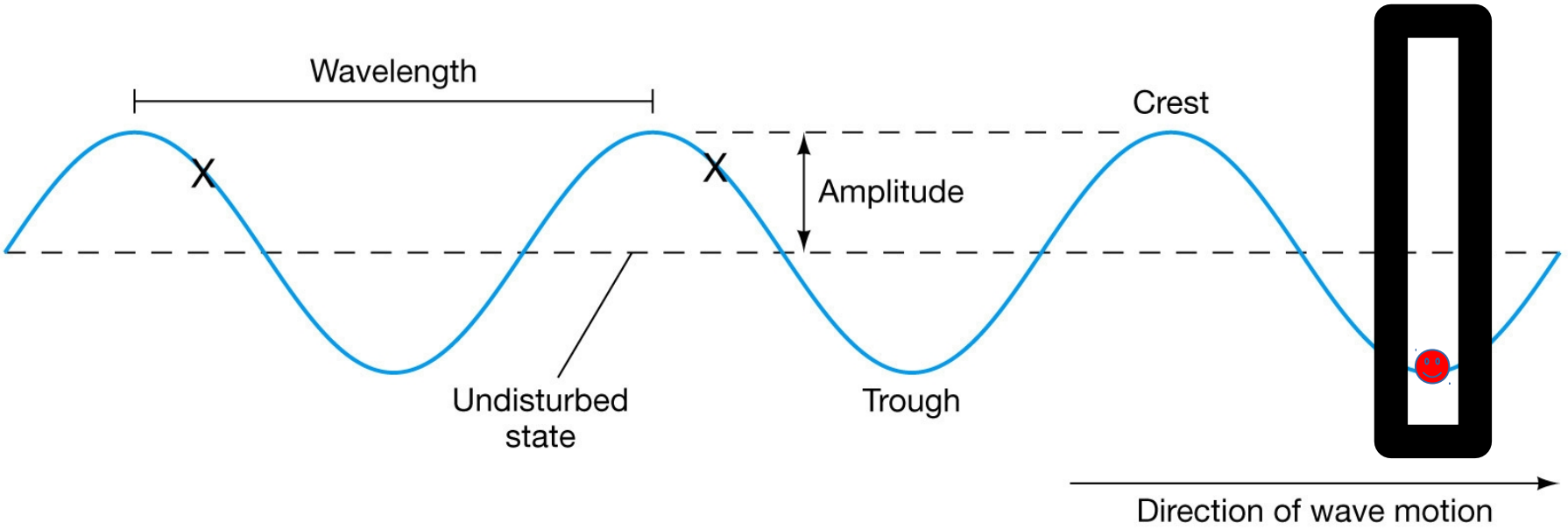
They don't transmit their medium.

Water just moves up and down.



Waves - terminology

Sine waves: **waves described by a sine or cosine function. Also called: *"sinusoidal"***



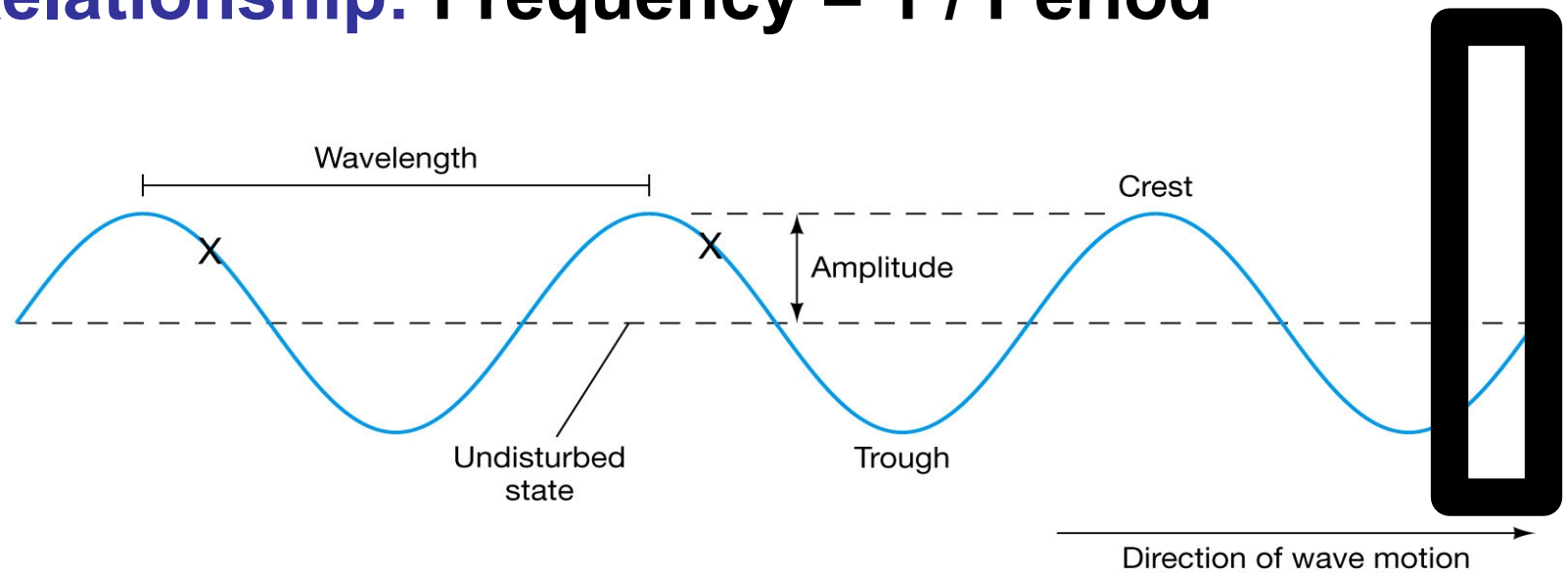
This graph shows <u>amplitude versus position</u>, but <u>amplitude versus time</u> is ALSO a sinusoidal graph!

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



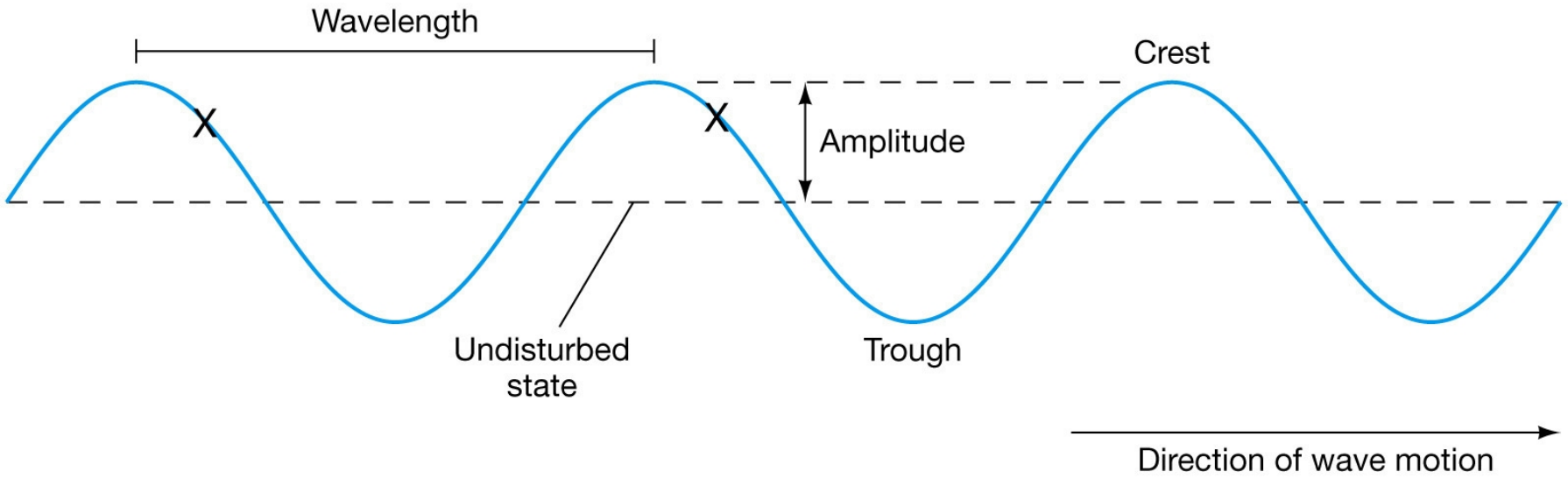
Waves - terminology

Wavelength: distance between successive crests

Velocity: speed at which crests move

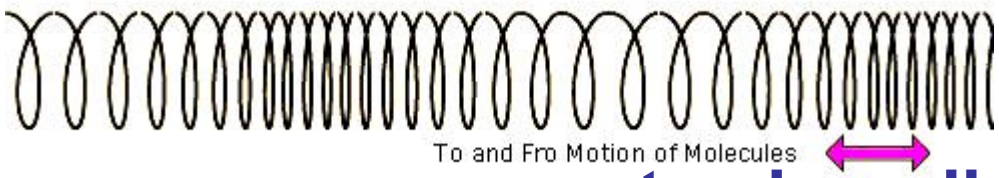
Relationship:

Velocity = Wavelength * frequency

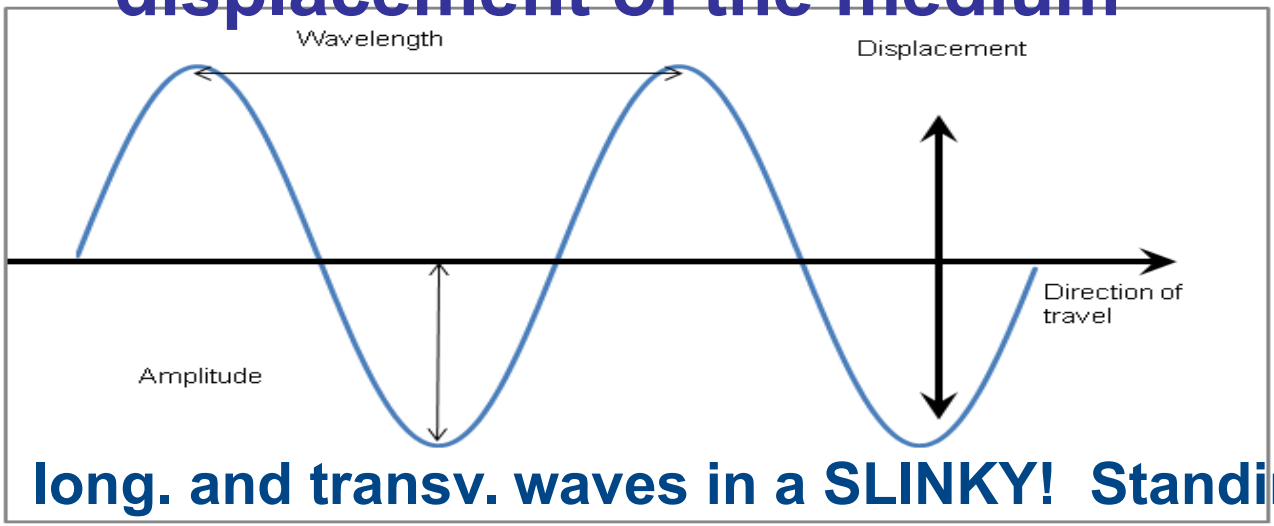


Waves - terminology

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

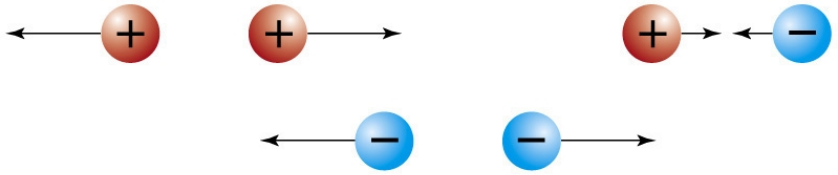


Transverse wave: propogates in a direction perpendicular (or transverse) to the displacement of the medium



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

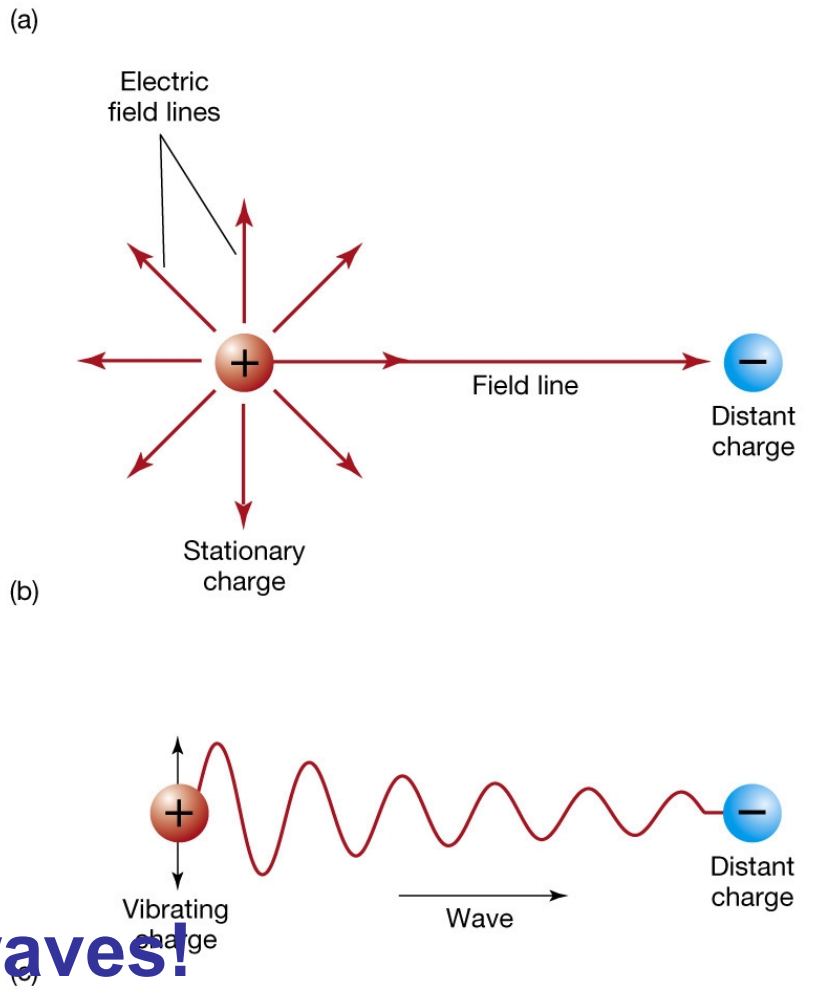
E-M waves: waves in what?



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

Electromagnetic waves need no medium to travel!

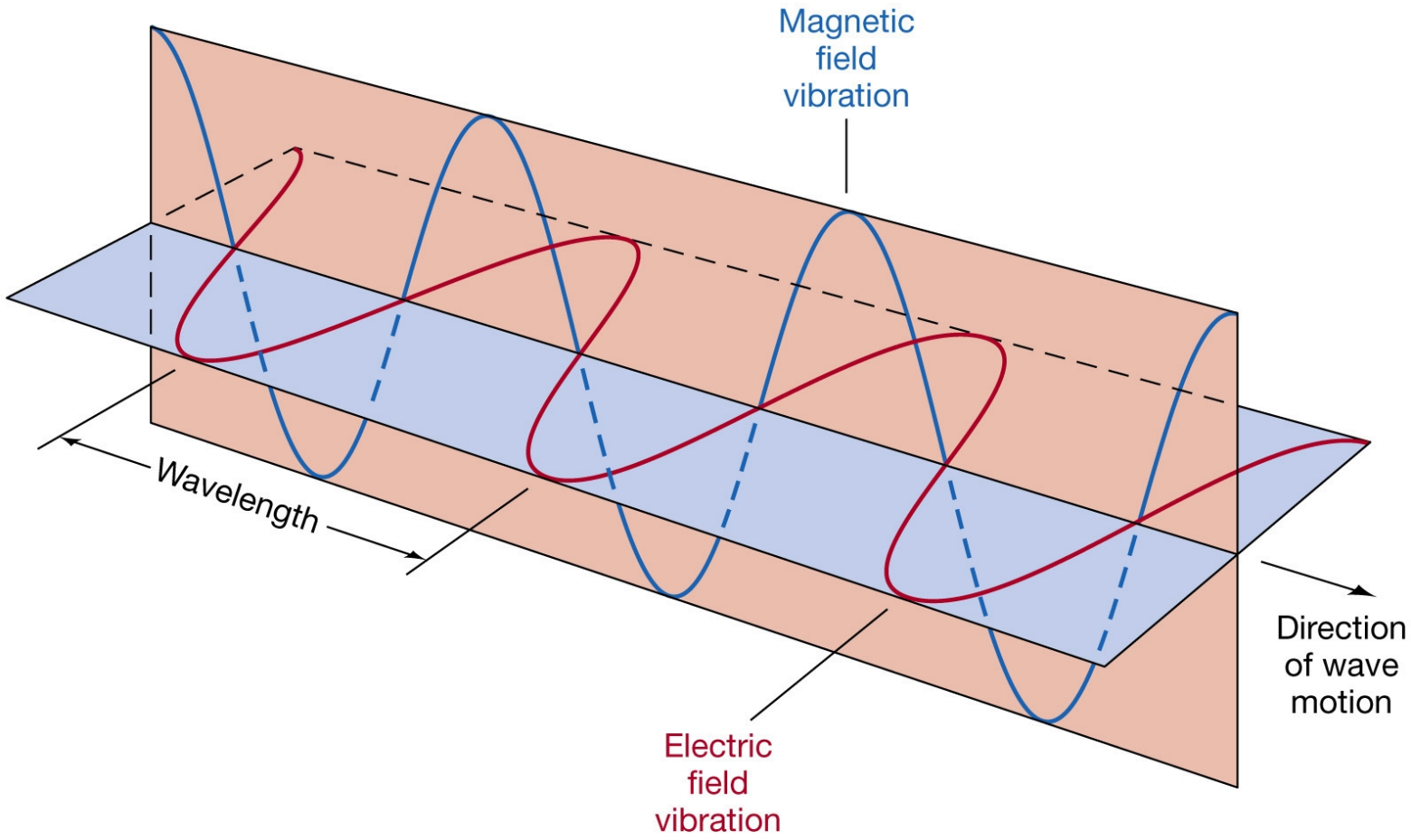
Can be created by accelerating charged particles:



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?

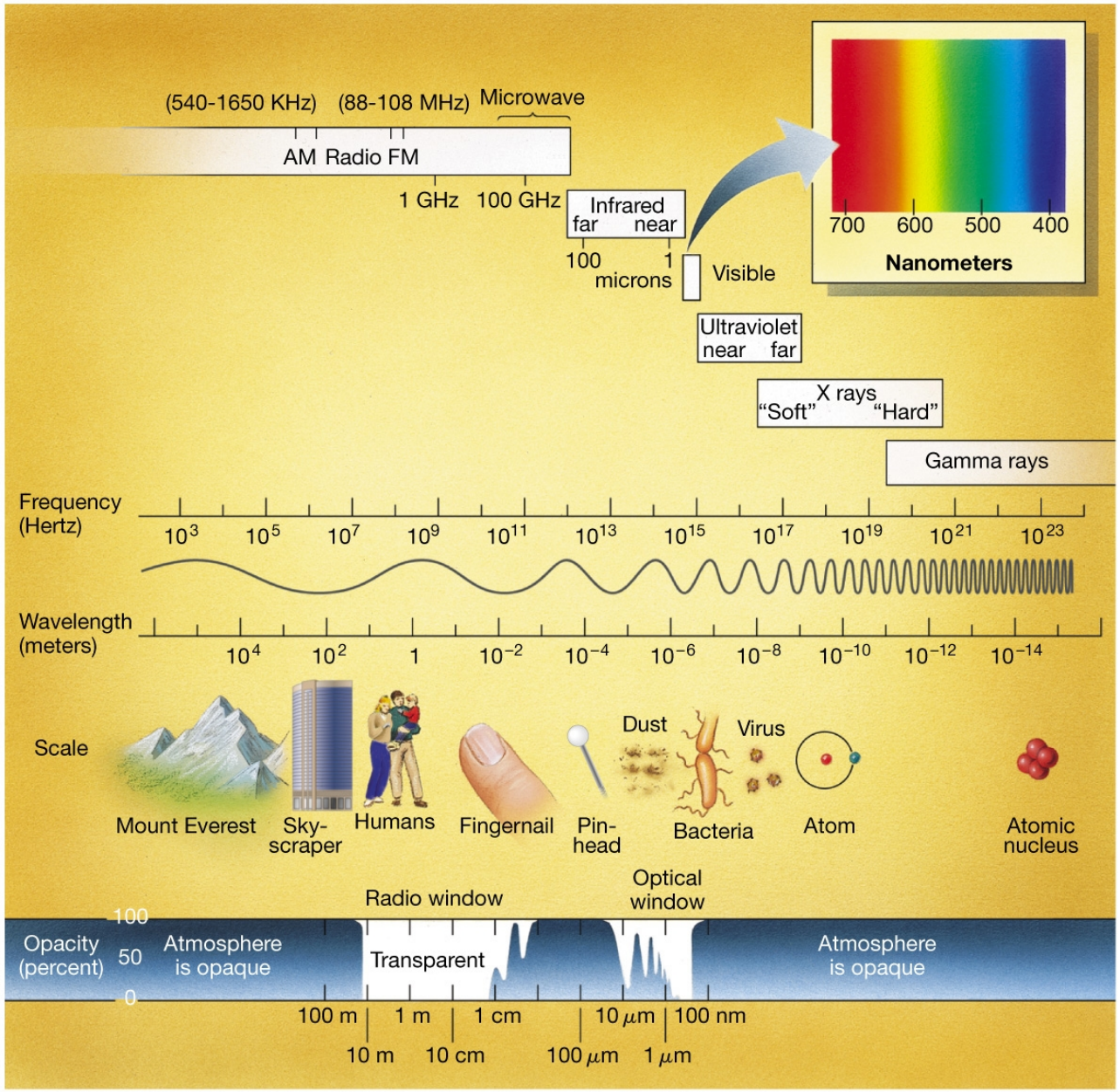
$$c = 3.0 \times 10^8 \text{ m/s}$$

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.

$c=f\lambda$ "golden rule"

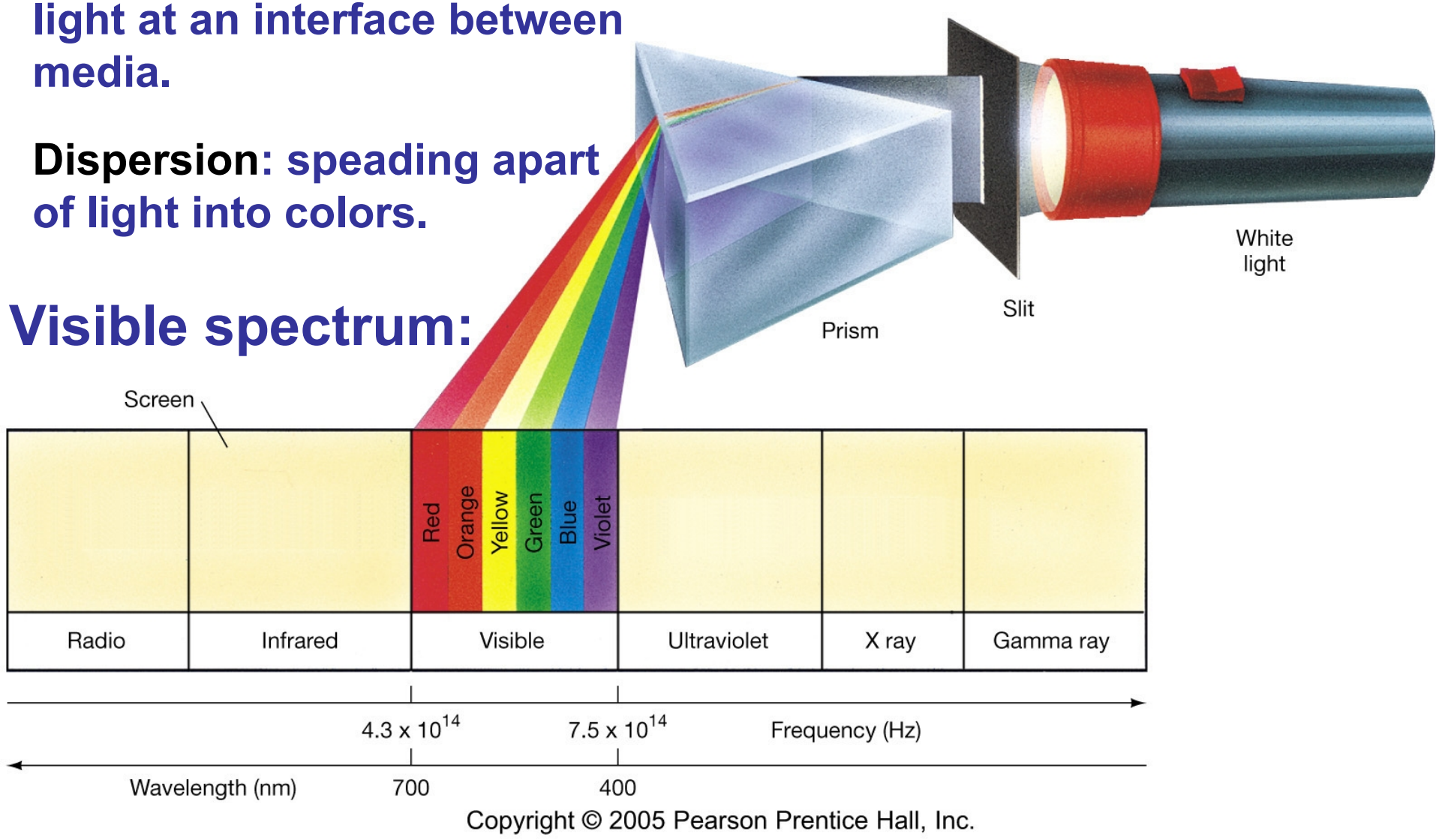
High opacity means low transparency.

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!**

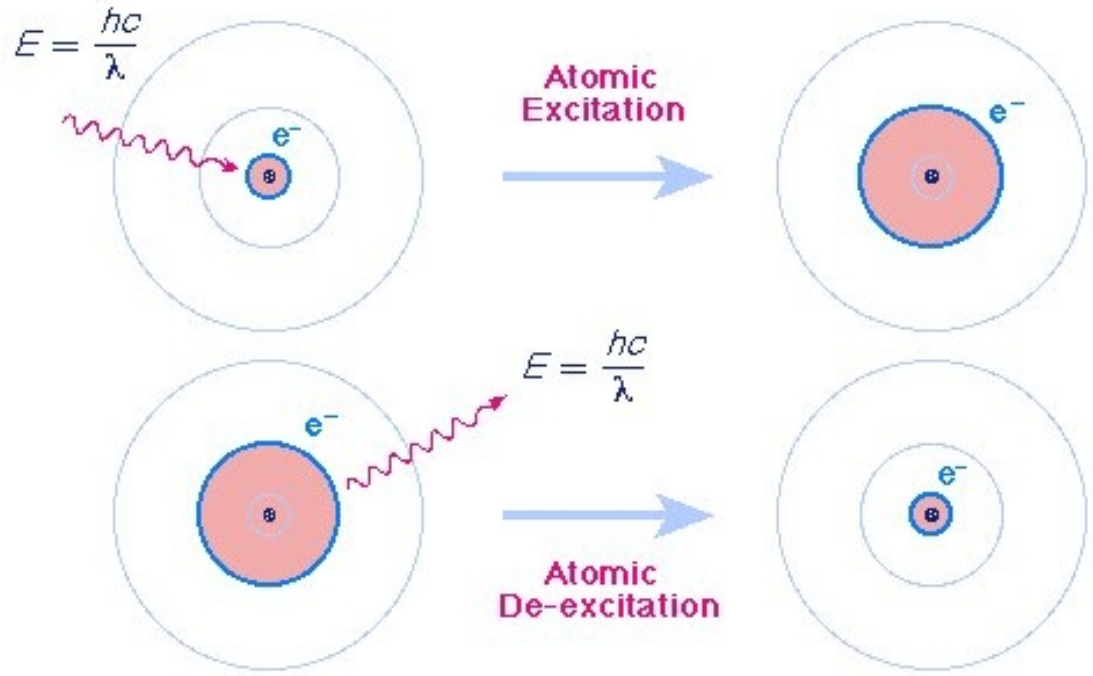
*** Conclusion: light comes in particles called photons with Ephot = hf. ($h=6.626\times10^{-34}$ Js)**

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



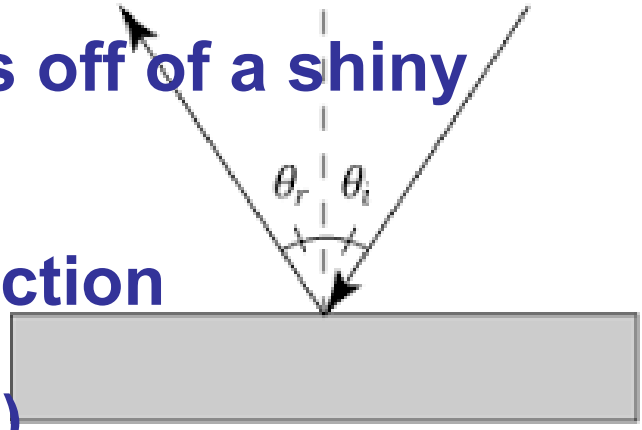
*** Light must have just the right photon energy (or frequency) to be absorbed by an atom.**

Light as wave or particle

Phenomena which could be described with the particle and wave models are …

Reflection

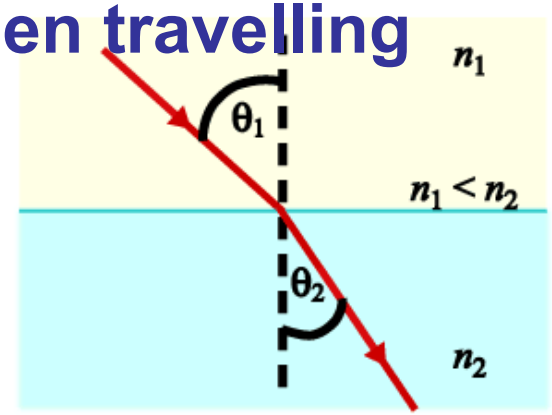
* the bouncing of photons or waves off of a shiny surface such that …



* 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: $n_1 \sin\Theta_1 = n_2 \sin\Theta_2$

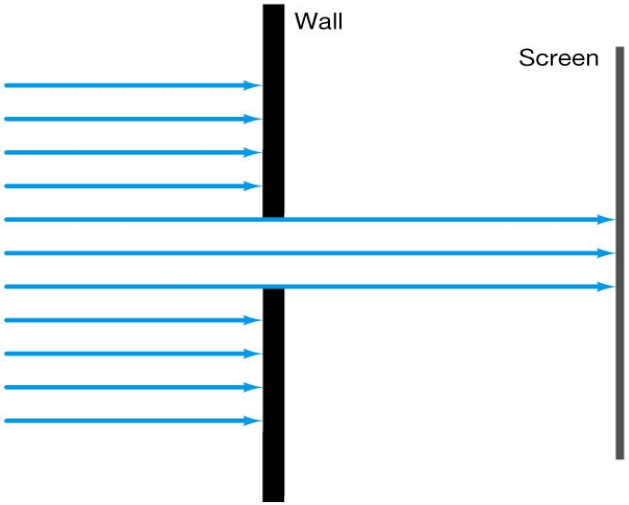
Light as wave or particle

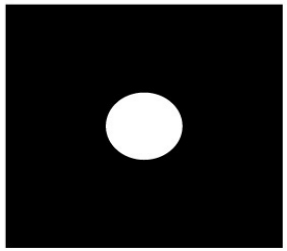
Phenomena best described with waves:

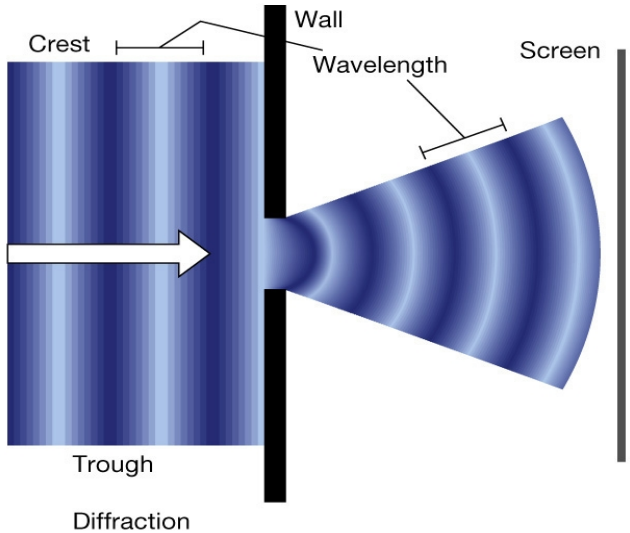
***Diffraction* = bending of light around corners and slits.**

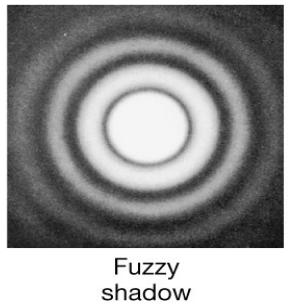
Top: no diffraction

Bottom: diffraction





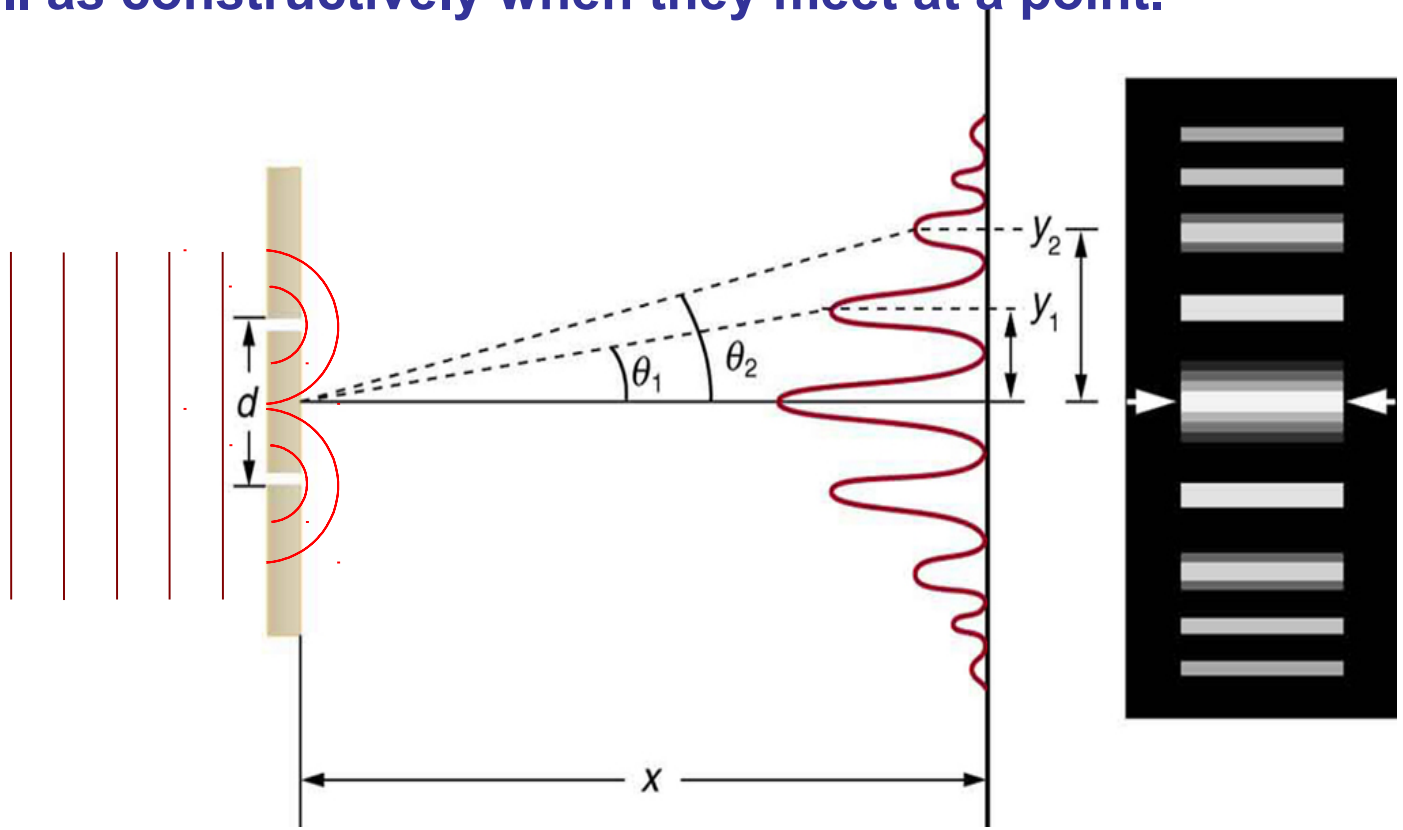




Light as wave or particle

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

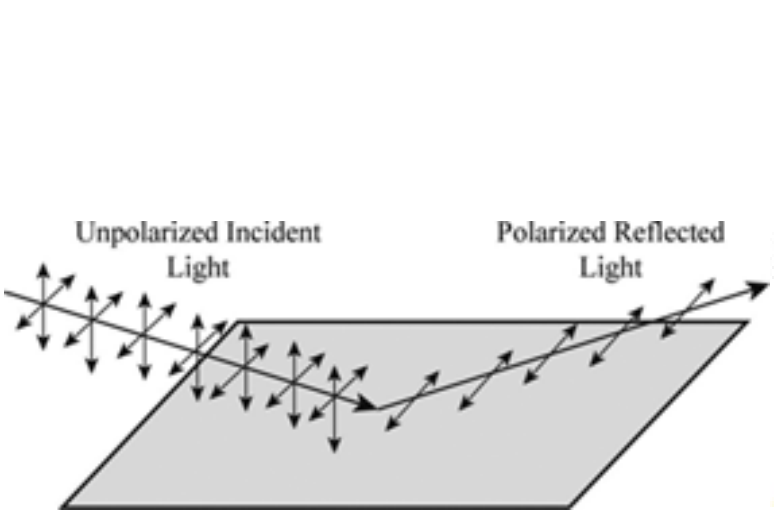
Interference **= two or more waves can combine destructively as well as constructively when they meet at a point.**



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.**



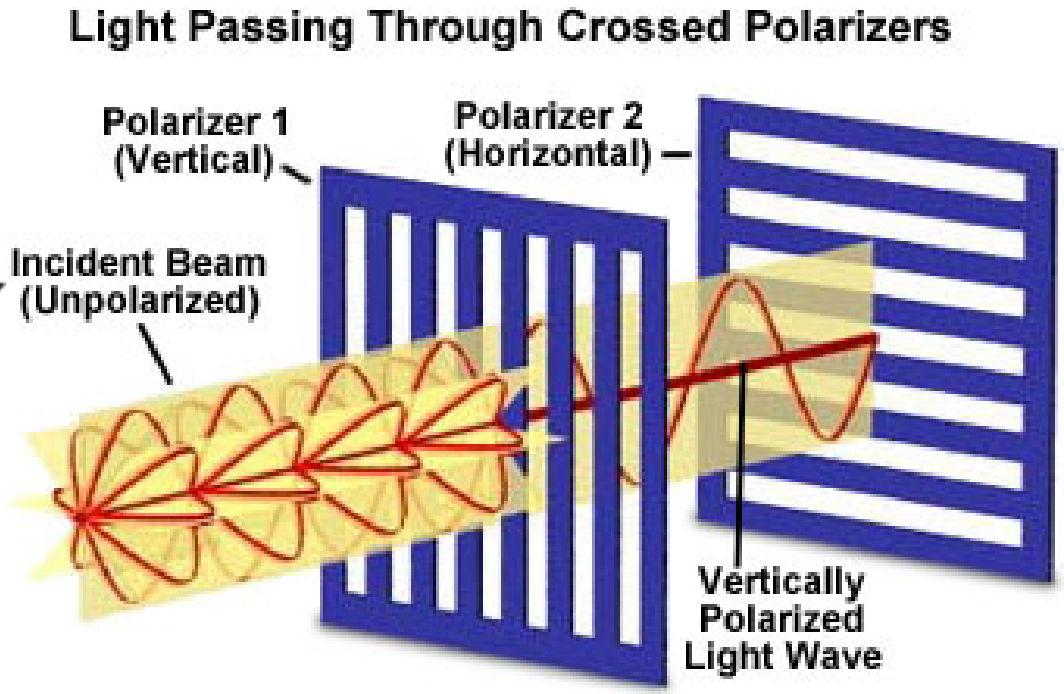


Figure 1

Thermal Radiation

Thermal radiation: the EM radiation produced (not reflected) by real objects which depends on the object's temperature and emissivity.

→ Felt as "heat"

→ Closely approximates *blackbody radiation*.

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

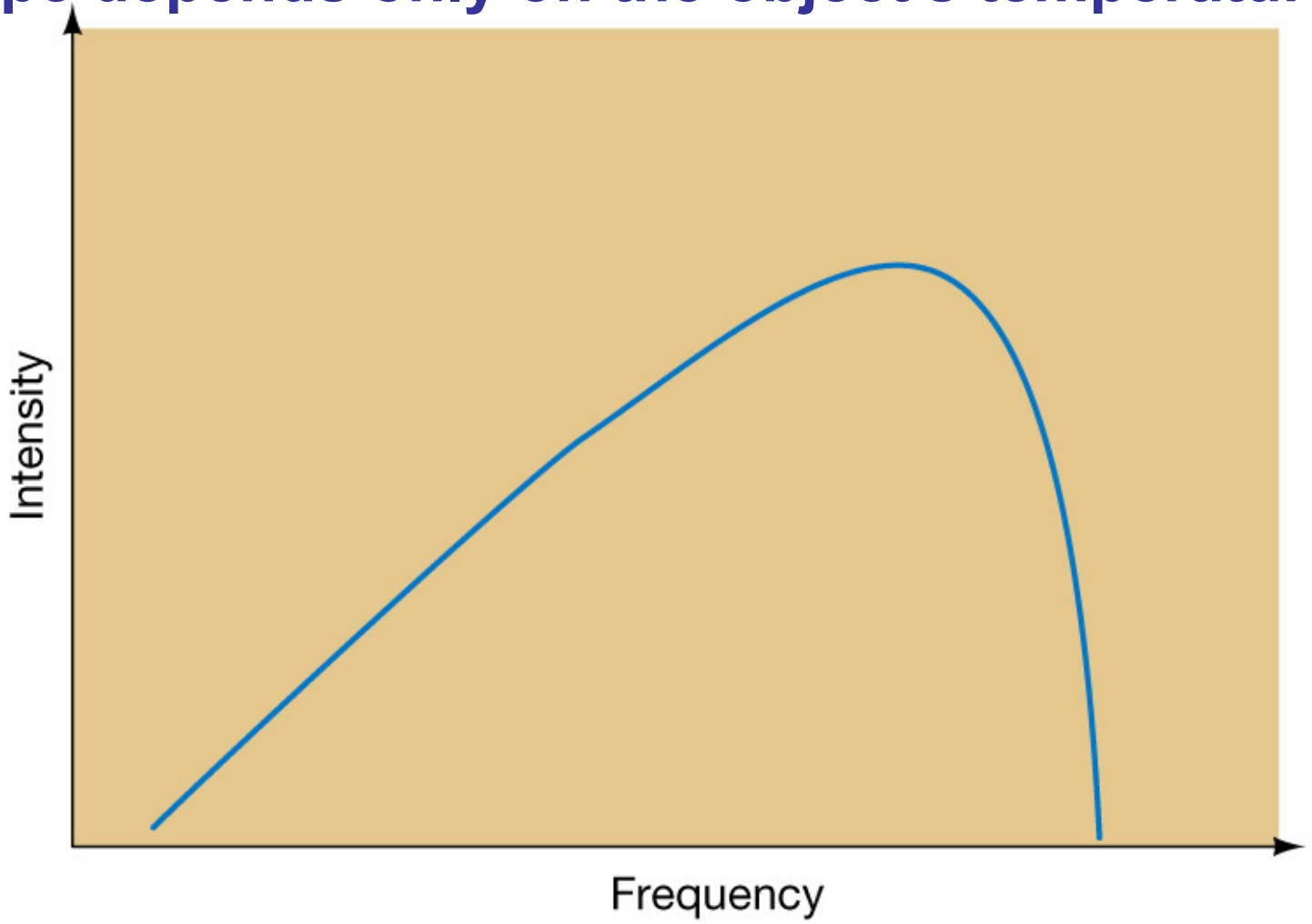
Coal is a good approximation of a black body.

Thermal Radiation

"Ventablack" is a *better* approximation of a black body (99.96% of light absorbed).

Thermal Radiation

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

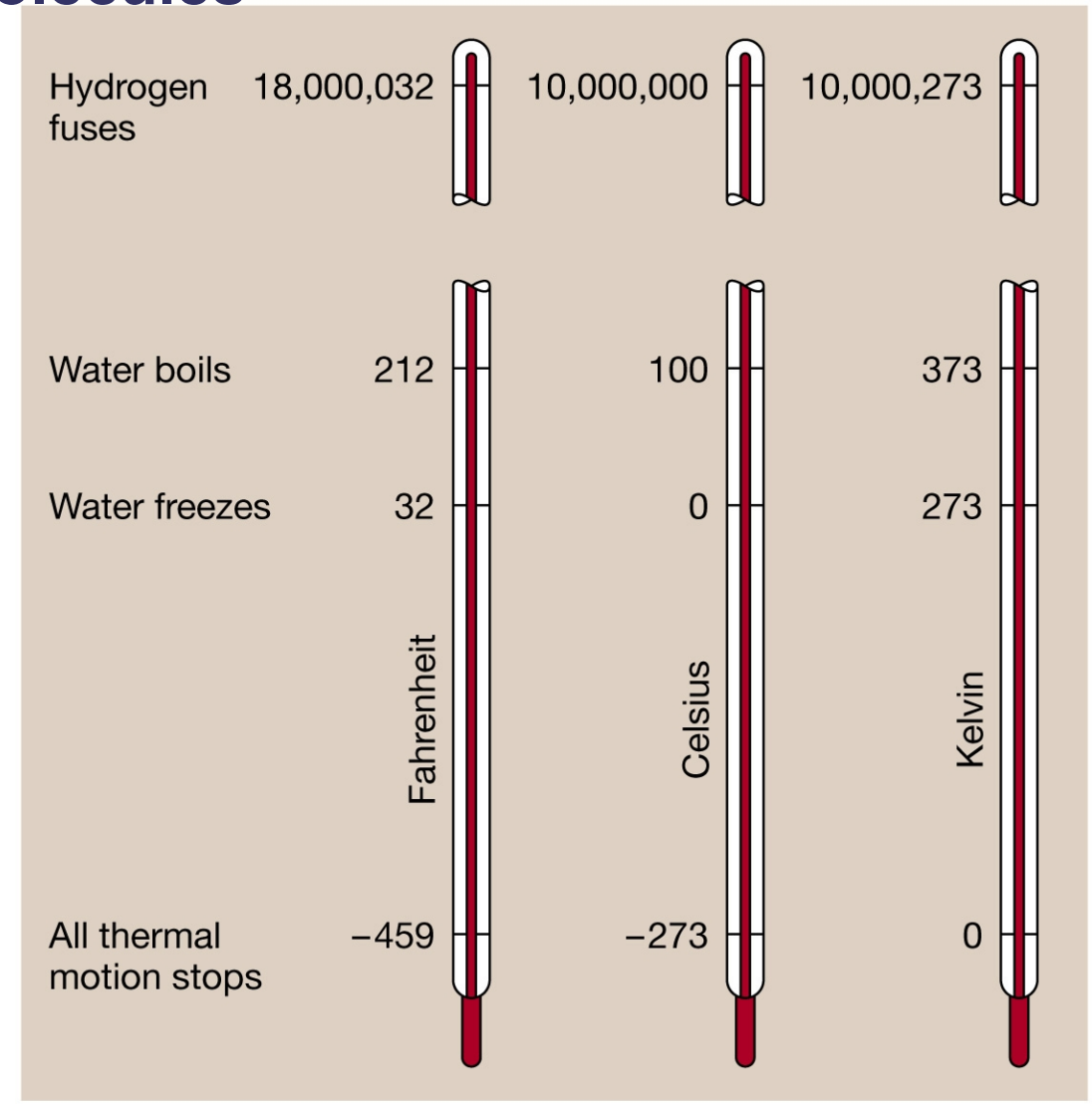


Thermal Radiation *Review: Temperature*

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



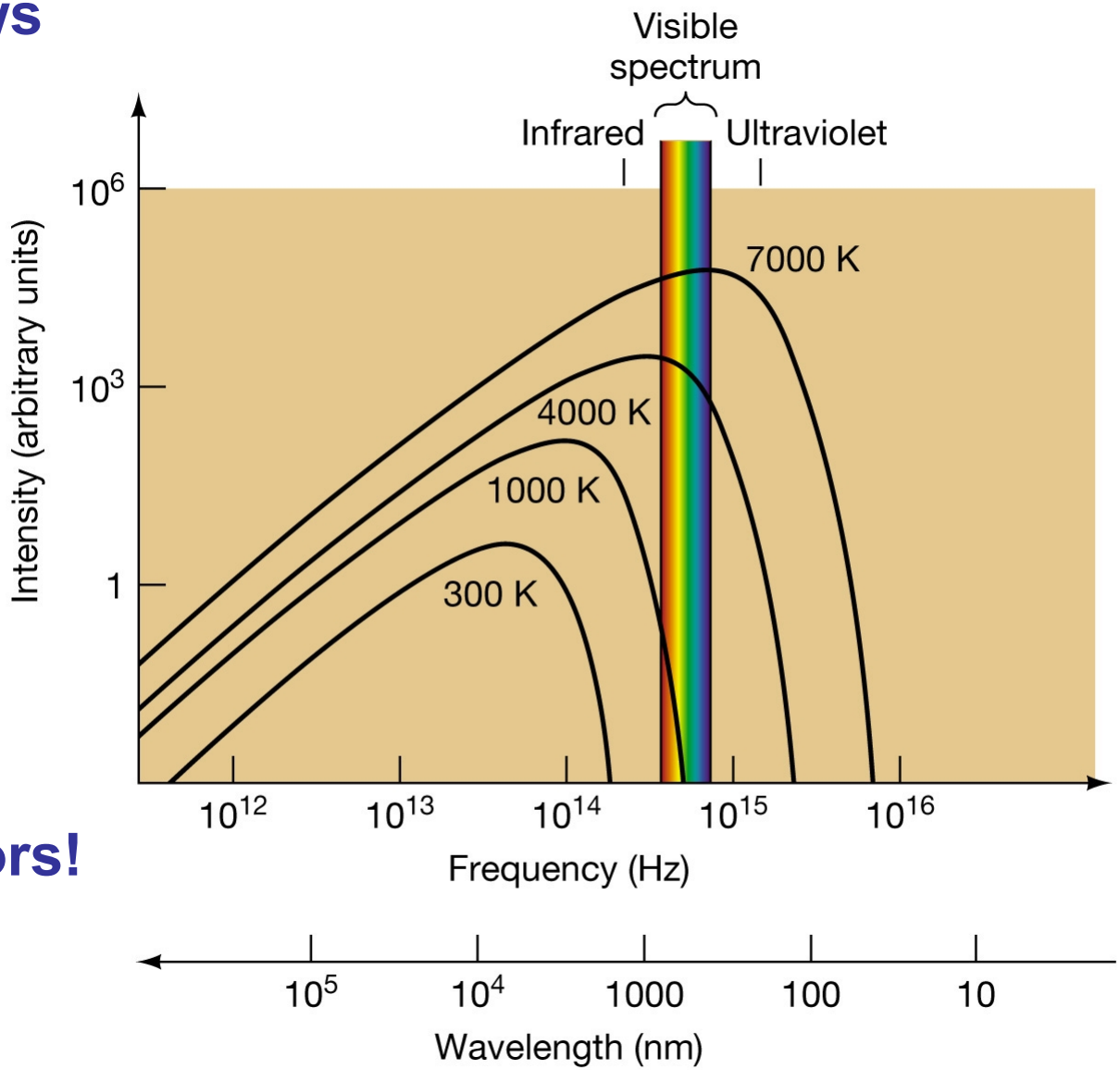
Thermal Radiation

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!



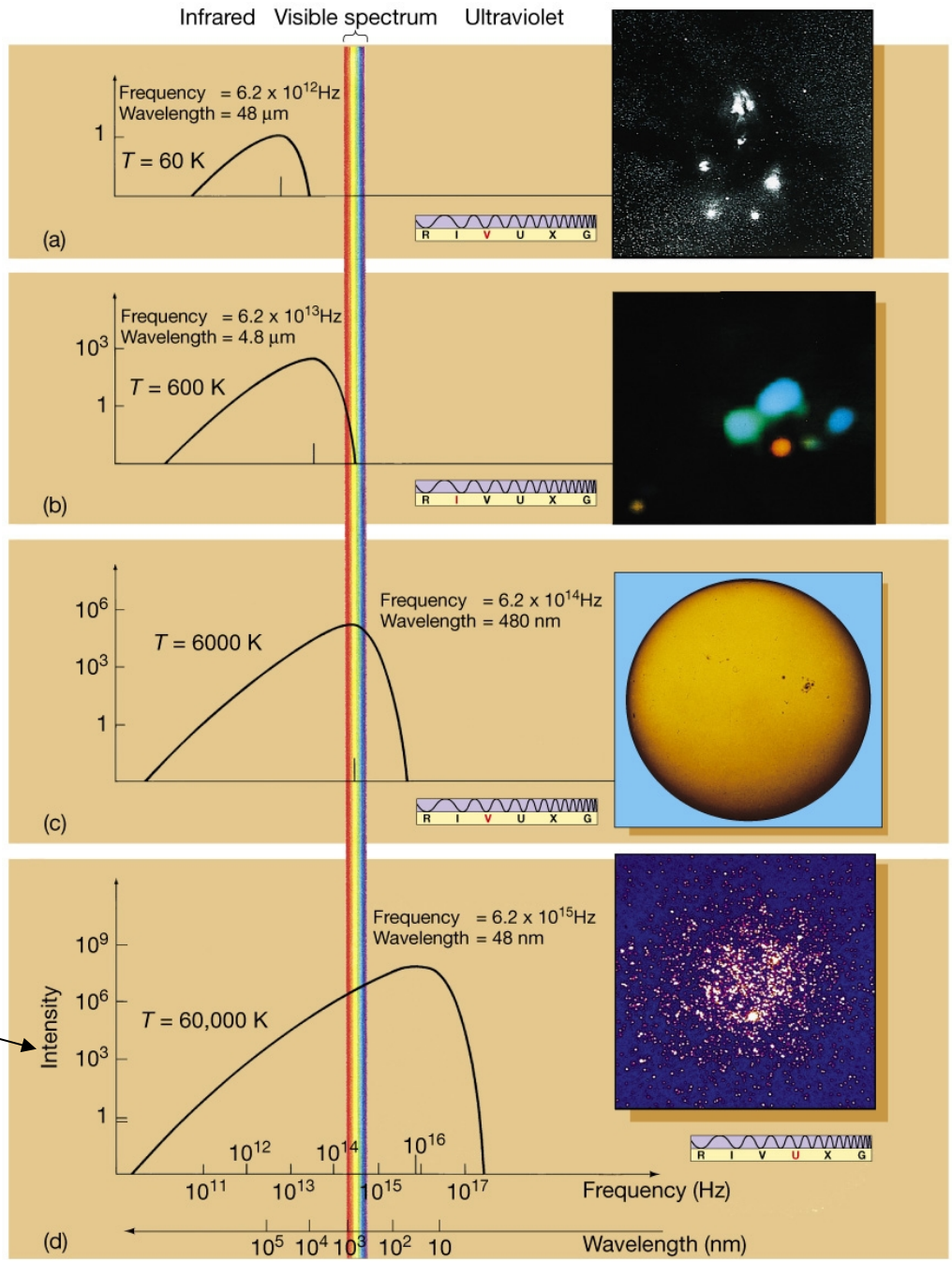
Thermal Radiation

Radiation Laws

2. Stefan's Law: energy emitted by BB is proportional to the fourth power of temperature; $I \propto T^4$.

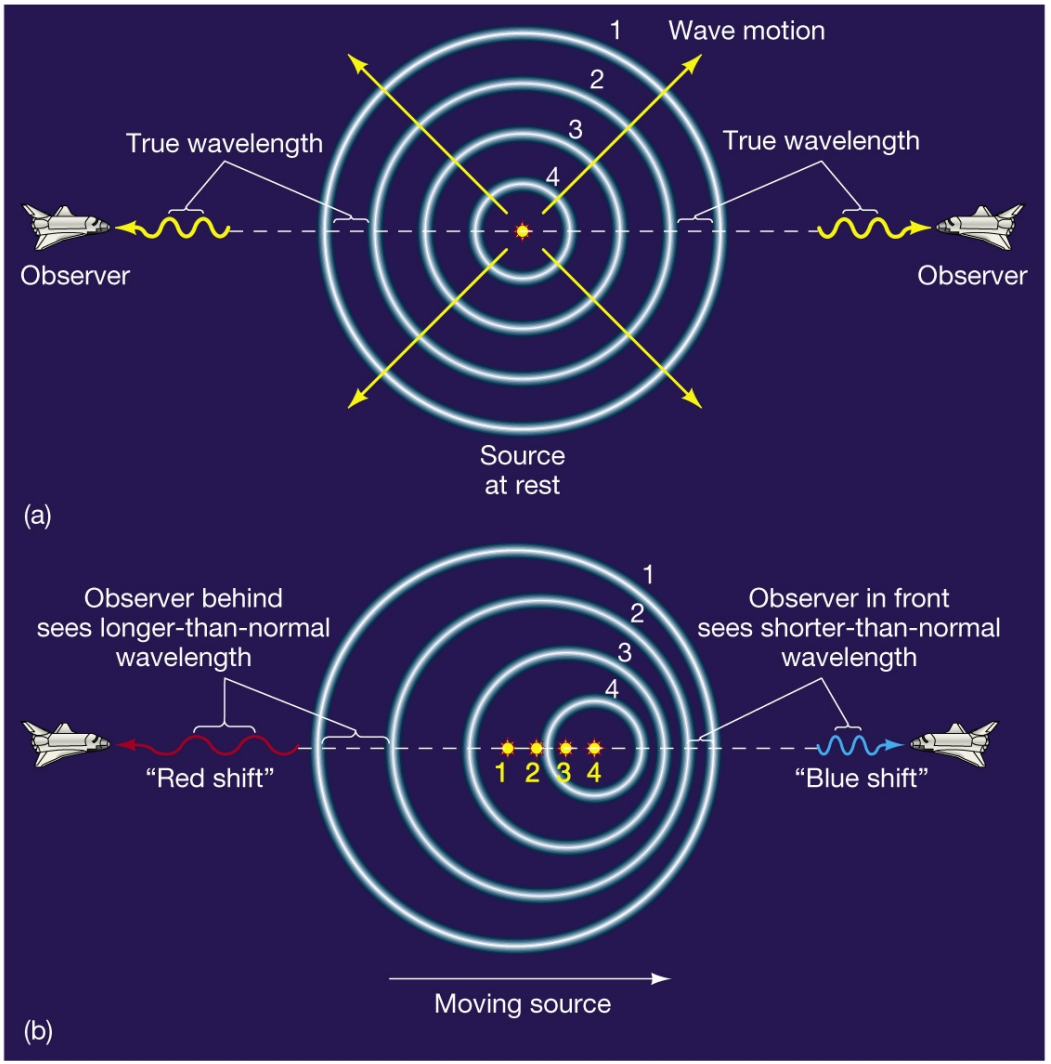
Note: intensity scale of curves is logarithmic!

DEMO: lightbulb filament with varying current!



3.5 The Doppler Effect

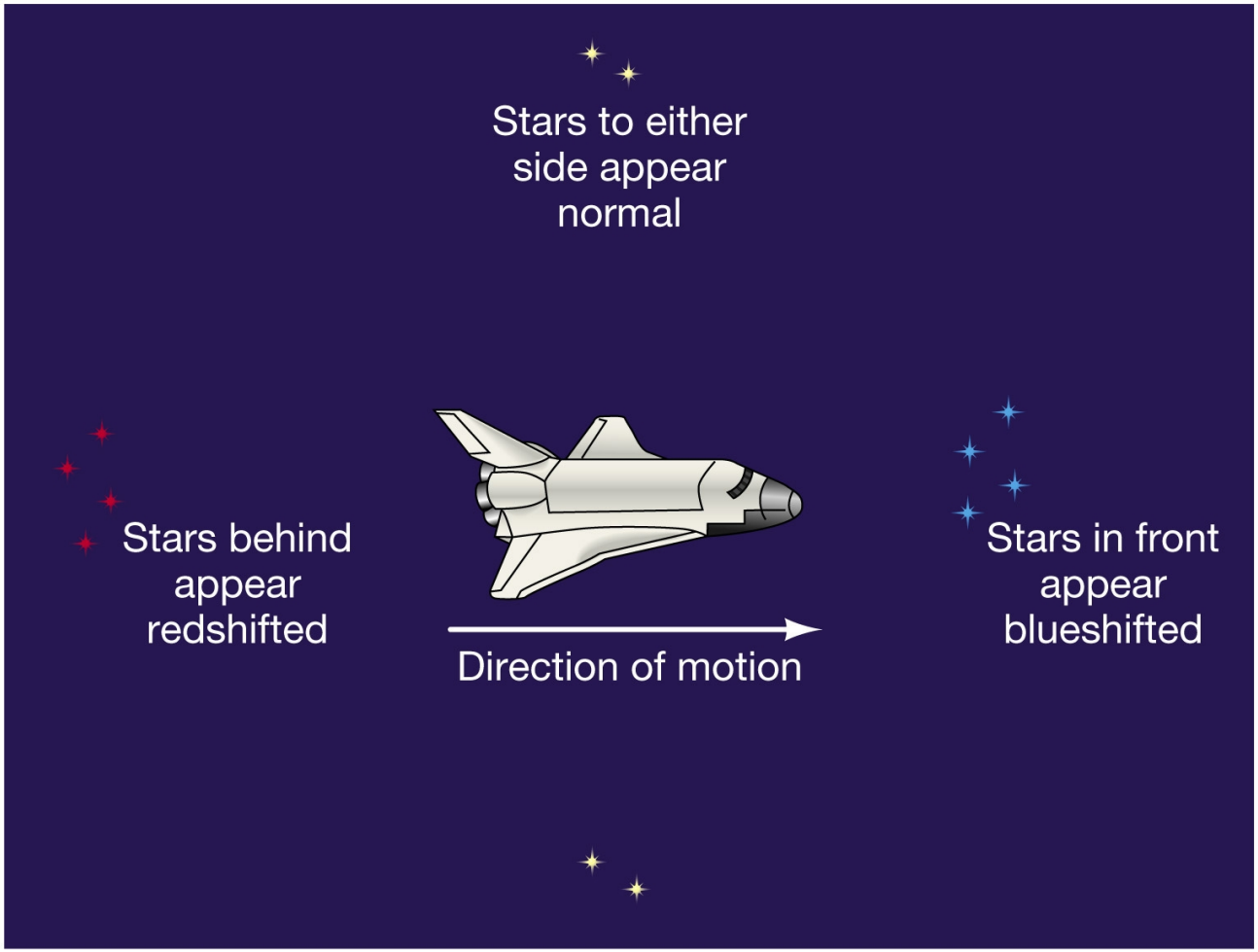
Depends only on the relative motion of source and observer:



See: https://www.youtube.com/watch?v=h4OnBYrbCjY

3.5 The Doppler Effect

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



Summary of Chapter 3

- Wave: period, wavelength, amplitude
- Electromagnetic waves created by accelerating charges
- Visible spectrum is different wavelengths of light
- 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