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

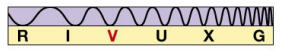
Types of Radiation

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

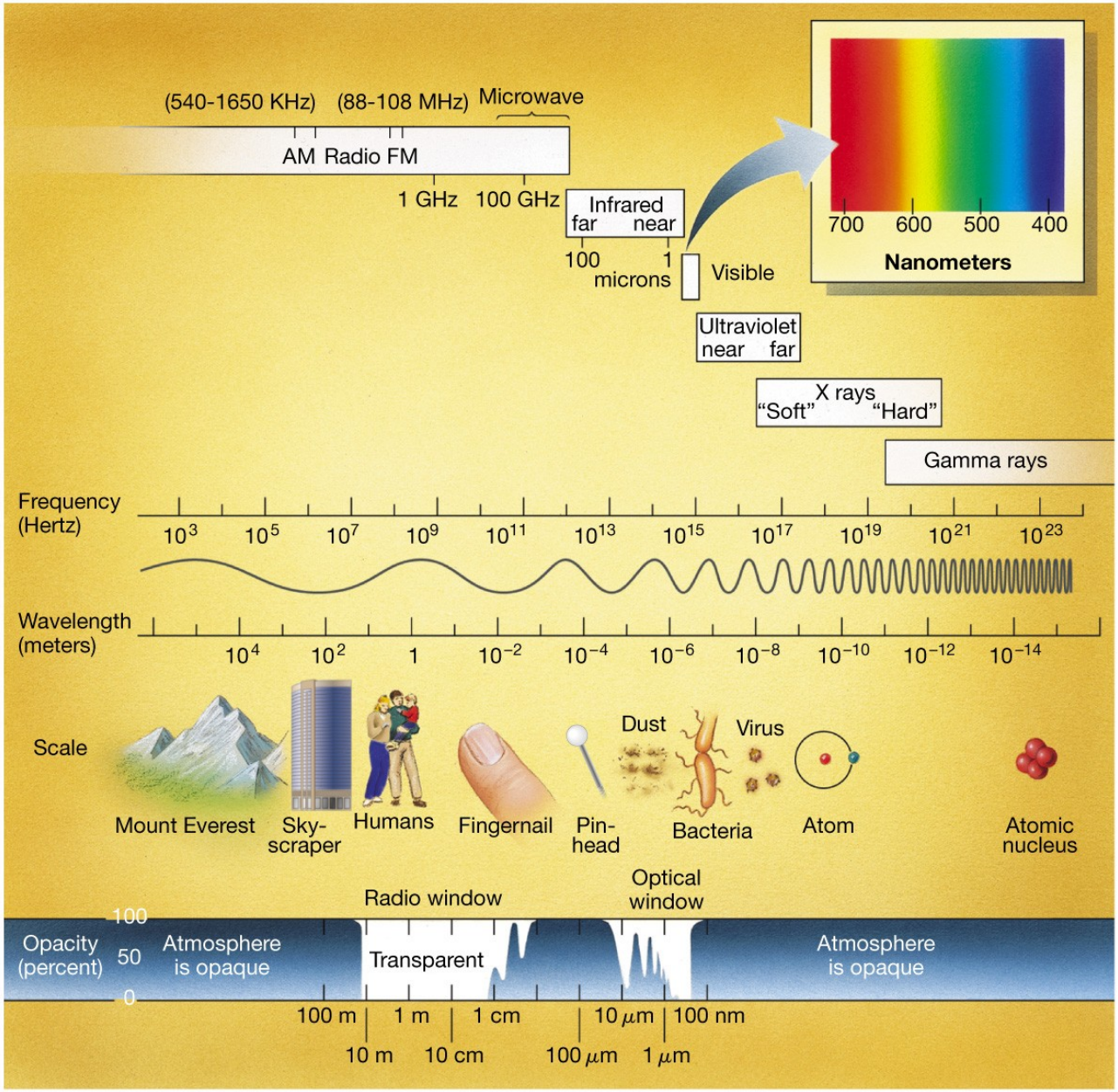
Light, x-rays
radio waves,
infrared

Particulate radiation

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



Types of radiation



Electromagnetic radiation

Different ranges have different names

Types of radiation

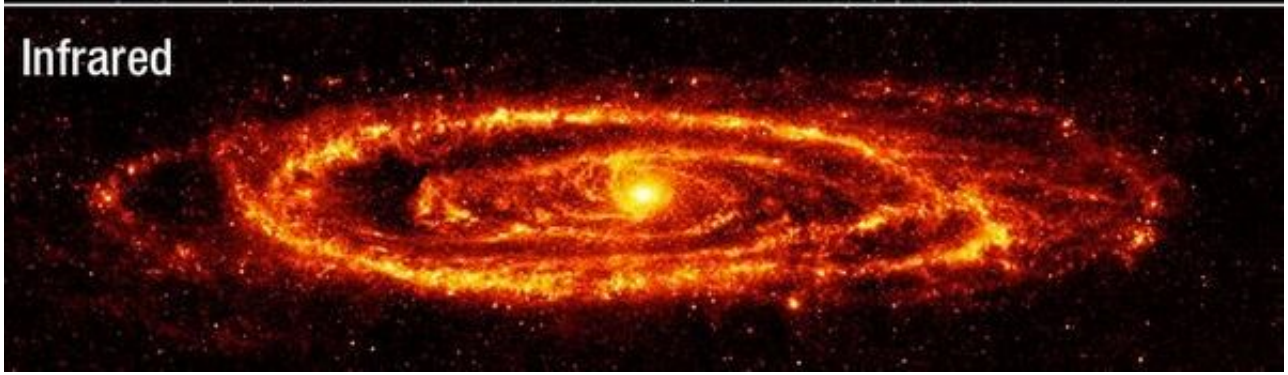
Electromagnetic Radiation may be transmitted, reflected, absorbed, or scattered off of obstructions. How it interacts depends on
1) the type of radiation (radio, IR, etc),
2) the composition.

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	Light	inspiralling BHs
seismic	microwaves	"chirp"
water	x-rays, gamma rays	
"the wave"		

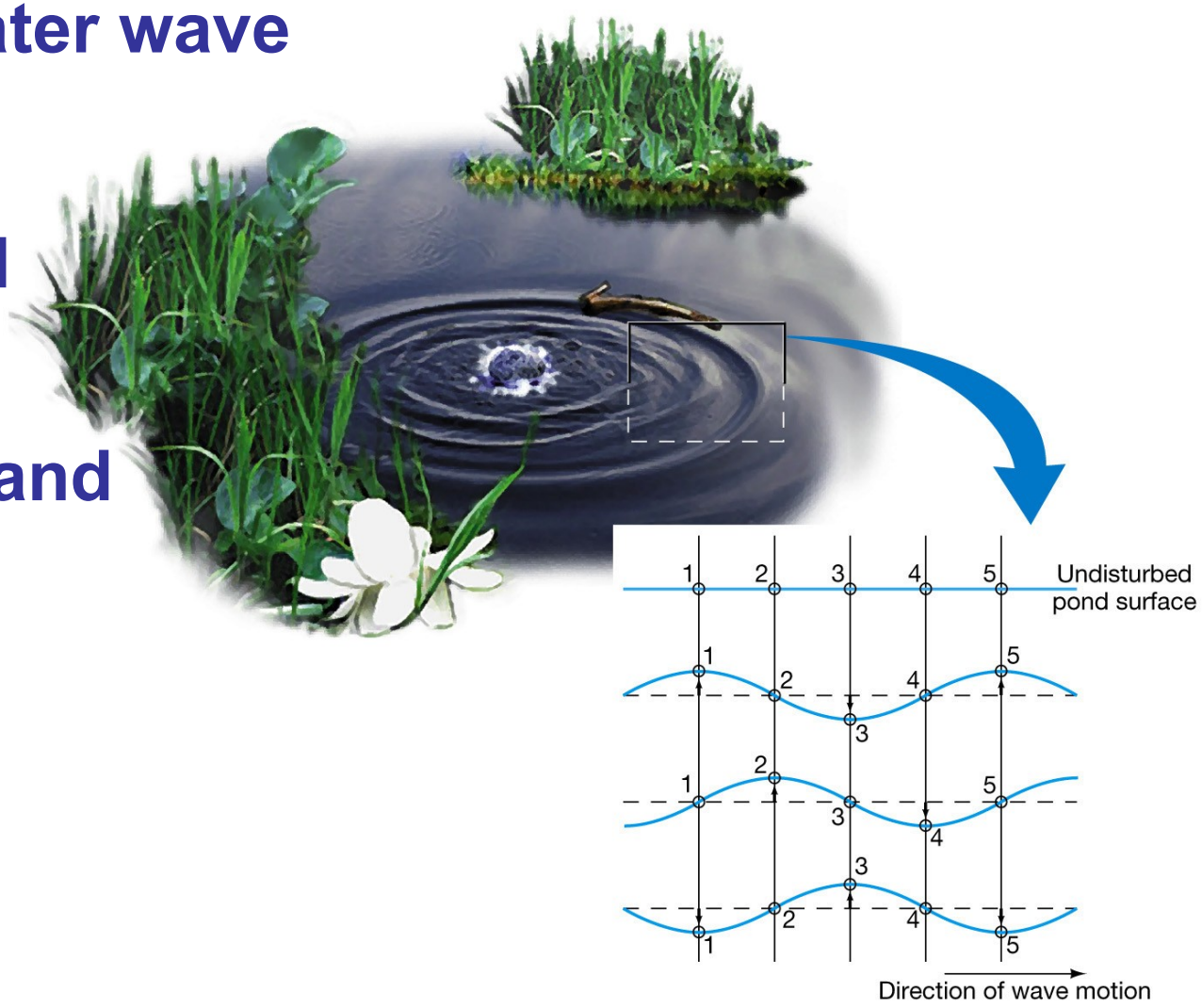
What do they have in common?

Waves - terminology

Example: water wave

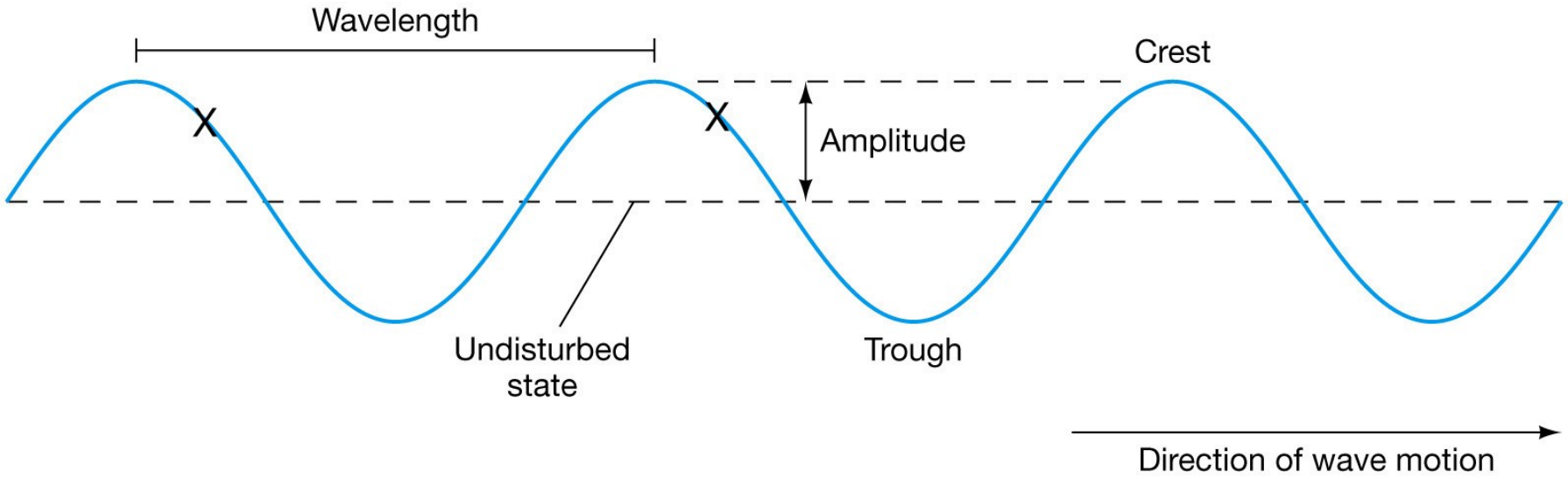
Water just moves up and down

Wave travels and can transmit energy



Waves - terminology

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



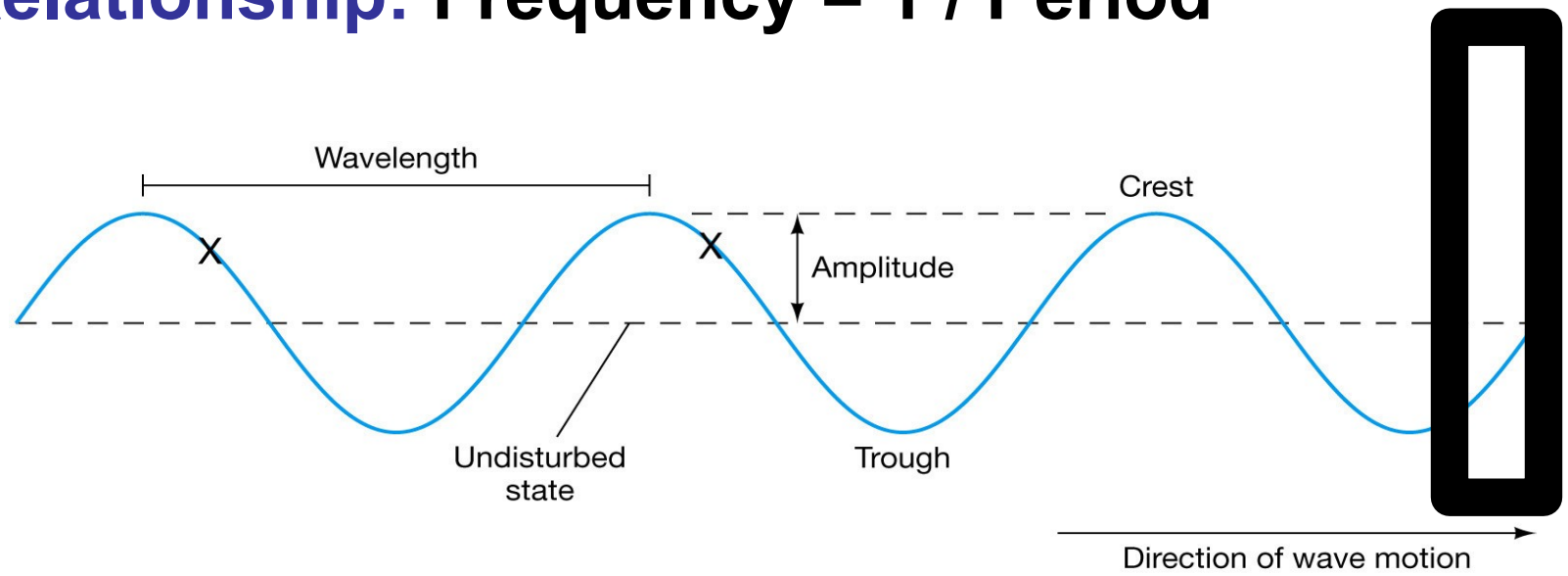
This graph shows amplitude versus position, but amplitude versus time is ALSO a sinusoidal graph!

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

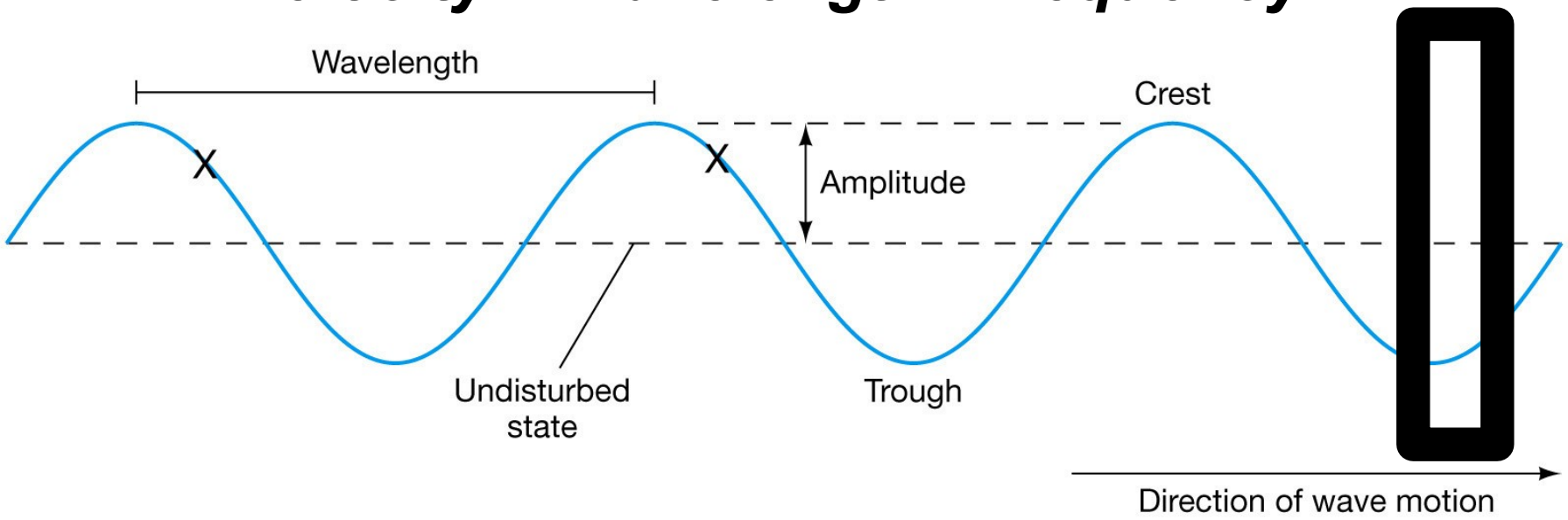
Wavelength: distance between successive crests

Velocity: speed at which crests move

Velocity = Wavelength/Period

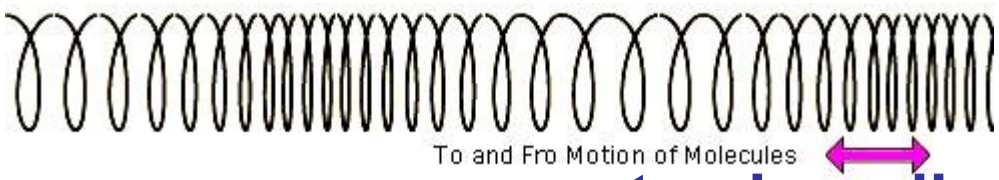
Velocity = Wavelength * frequency

Golden Rule!
$V = \lambda f$

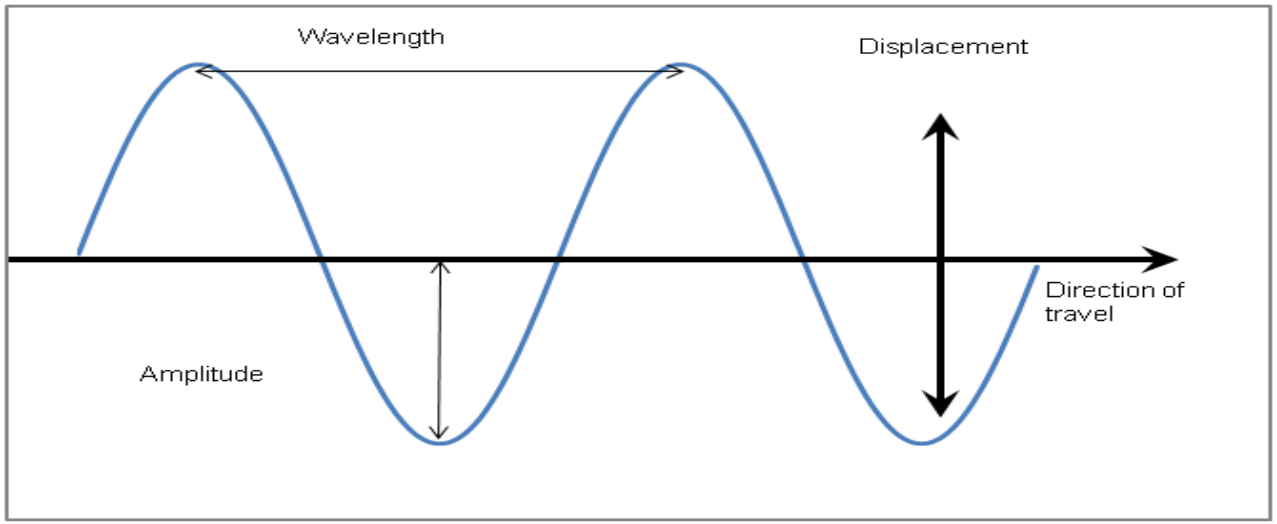


Waves - terminology

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

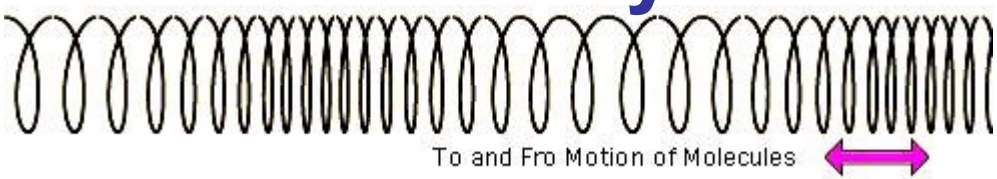


Transverse wave: propogates in a direction perpendicular (or transverse) to the displacement of the medium



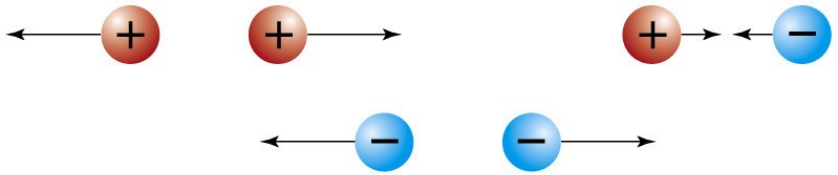
DEMO: long. and transv. waves in a SLINKY! Standing waves

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

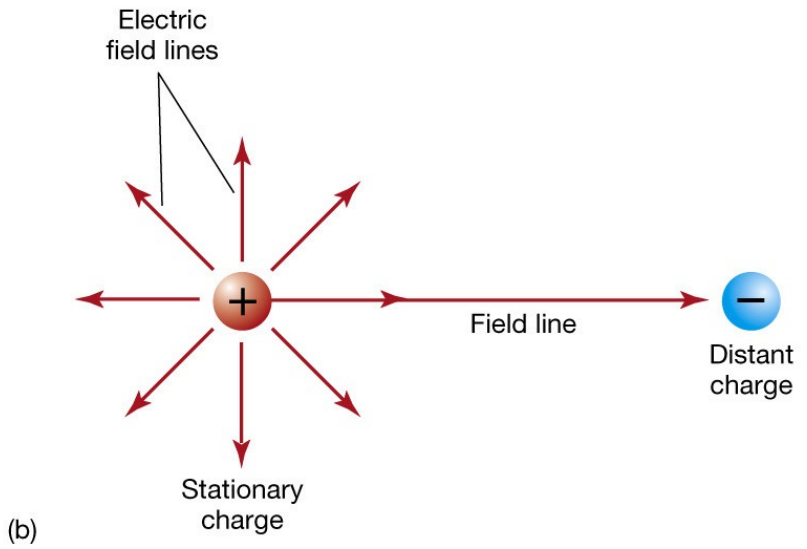
Waves in What?



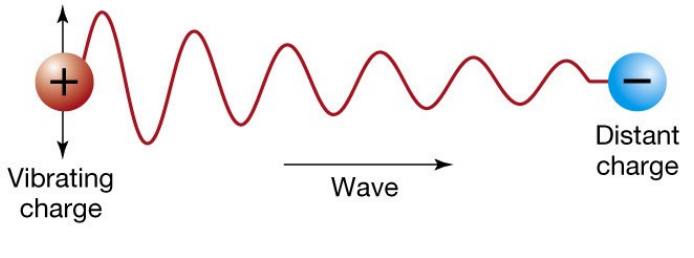
Water waves, sound waves, and so on, travel in a medium (water, air, …)

Electromagnetic waves need no medium

Created by accelerating charged particles:

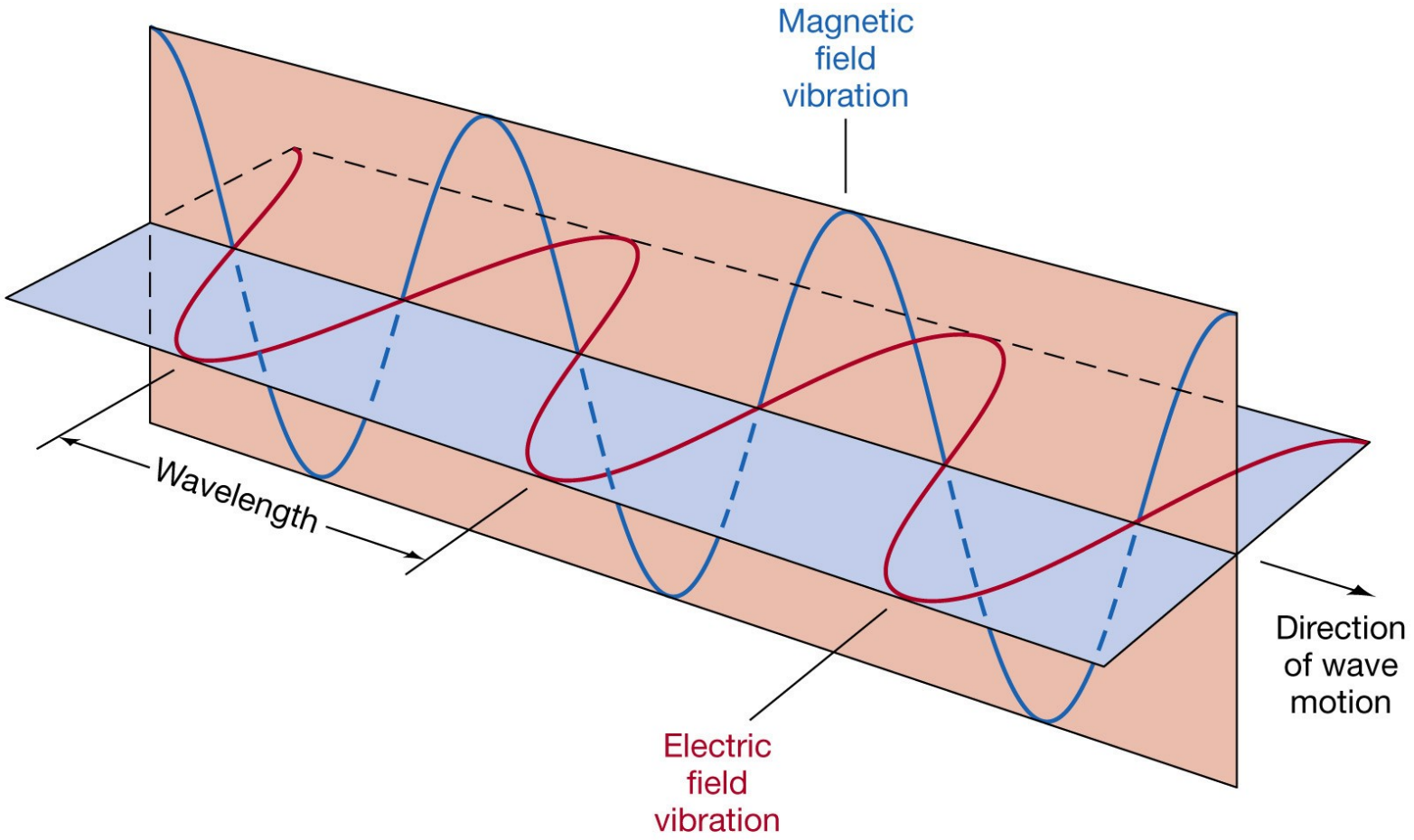


Demo: spark makes radio waves!



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?

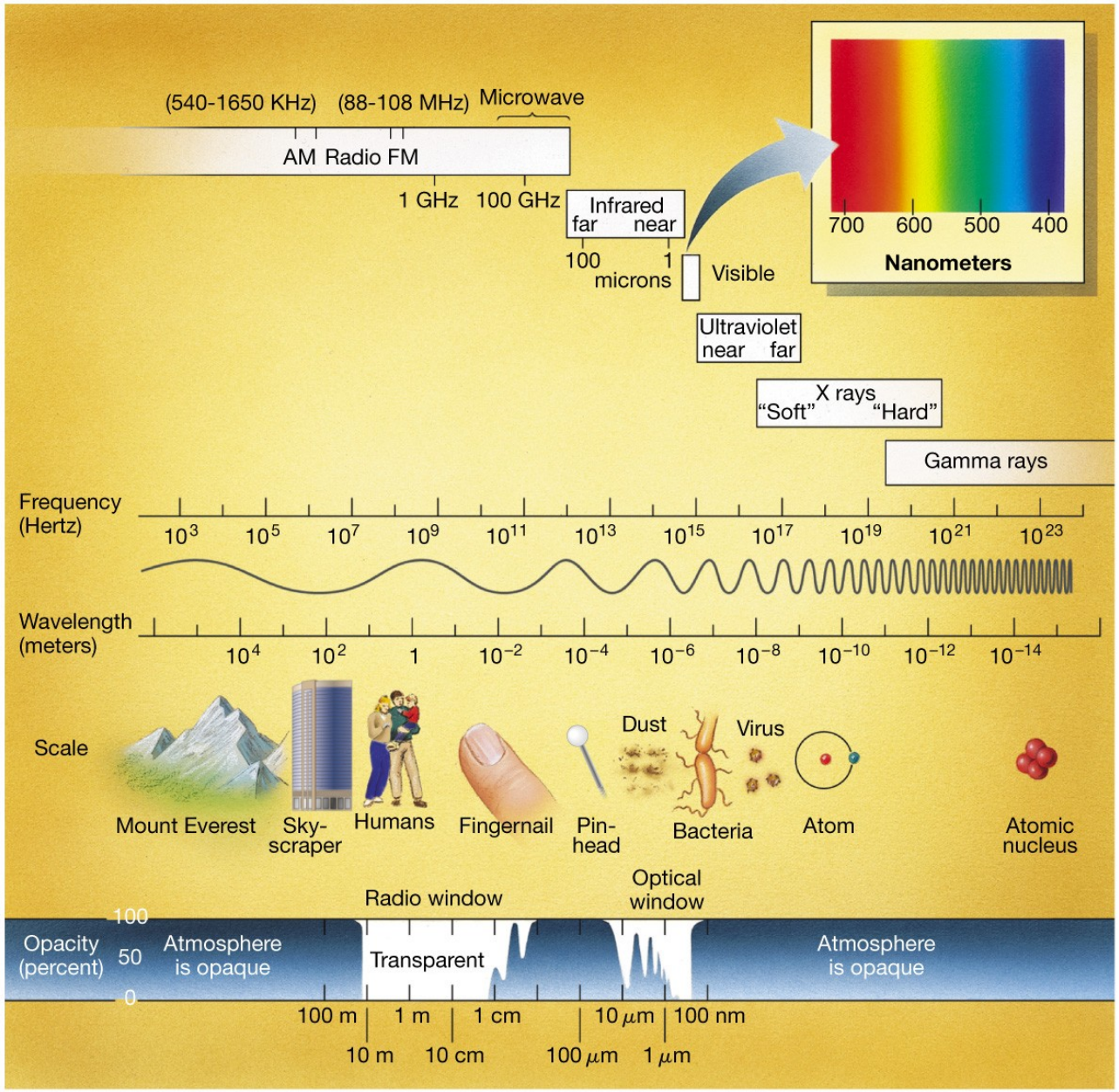
$$c = 3.0 \times 10^8 \text{ m/s}$$

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.

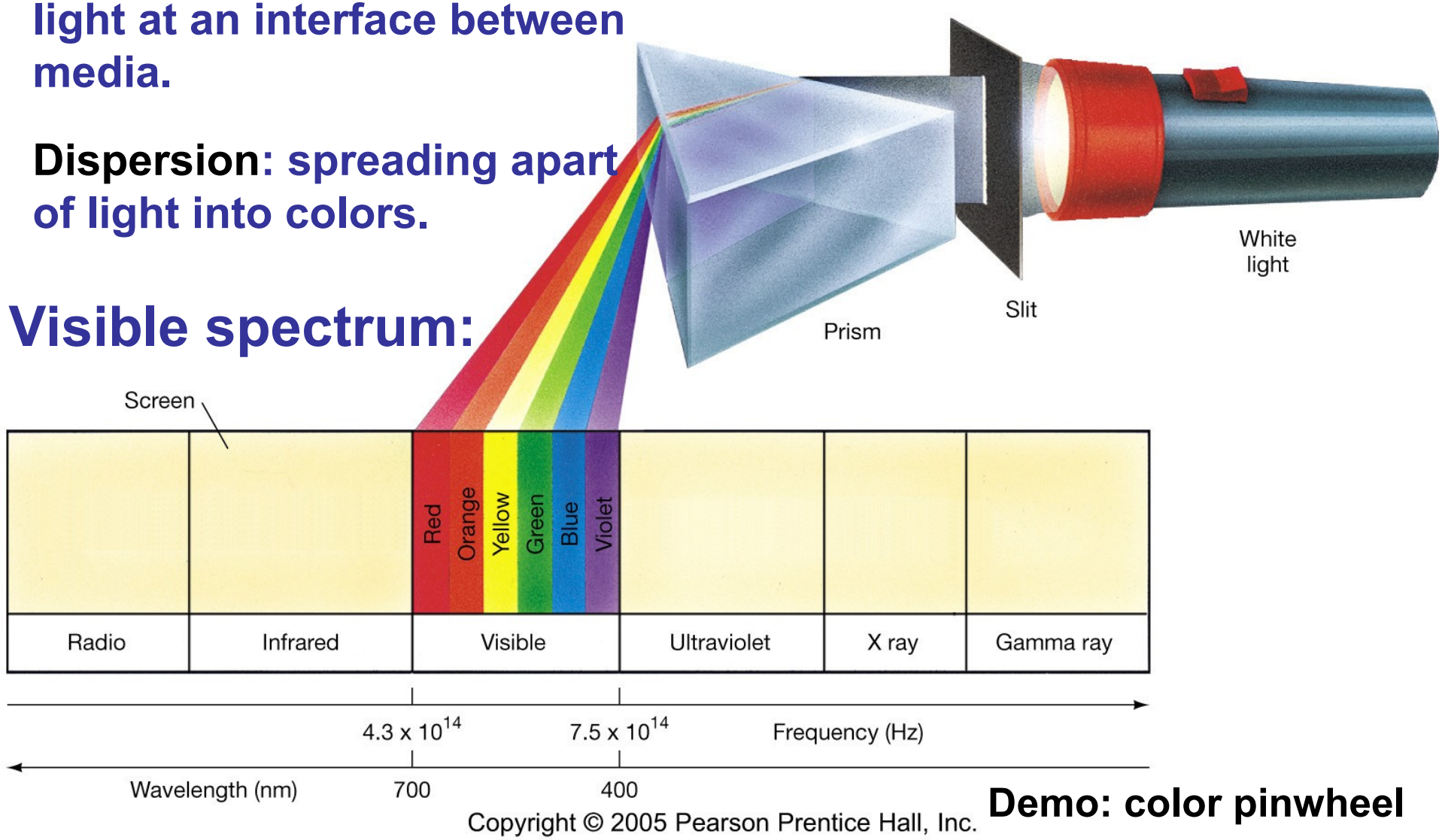
High opacity means low transparency.

Electromagnetic spectrum

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

Dispersion: spreading apart of light into colors.

Visible spectrum:

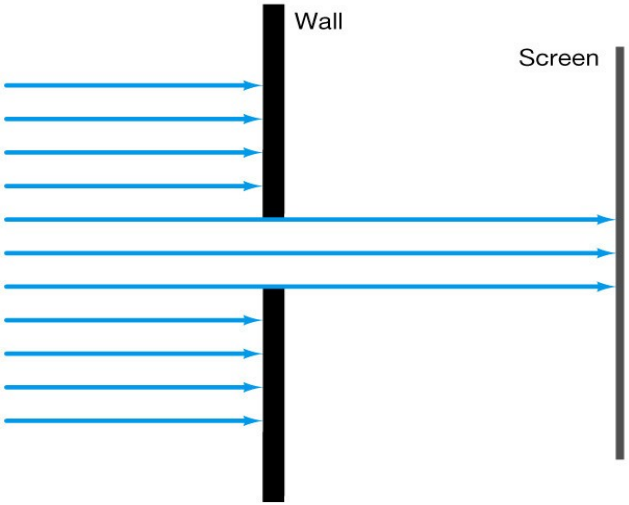


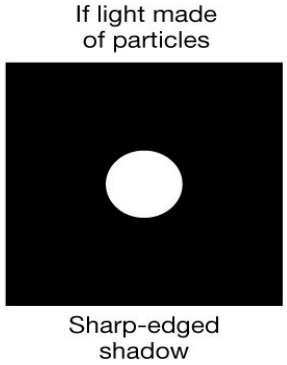
Demo: color pinwheel

Light as wave or particle

Phenomena best described with waves:

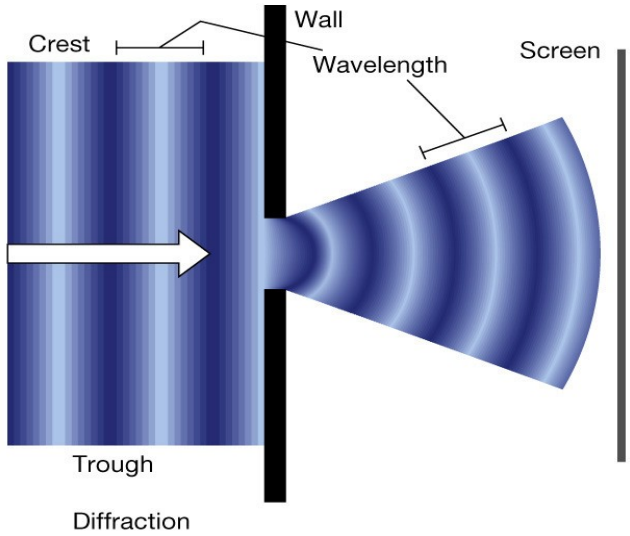
Diffraction **= bending of light around corners and slits.**

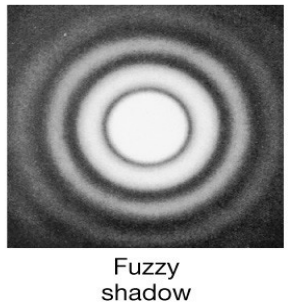




Top: no diffraction

Bottom: diffraction



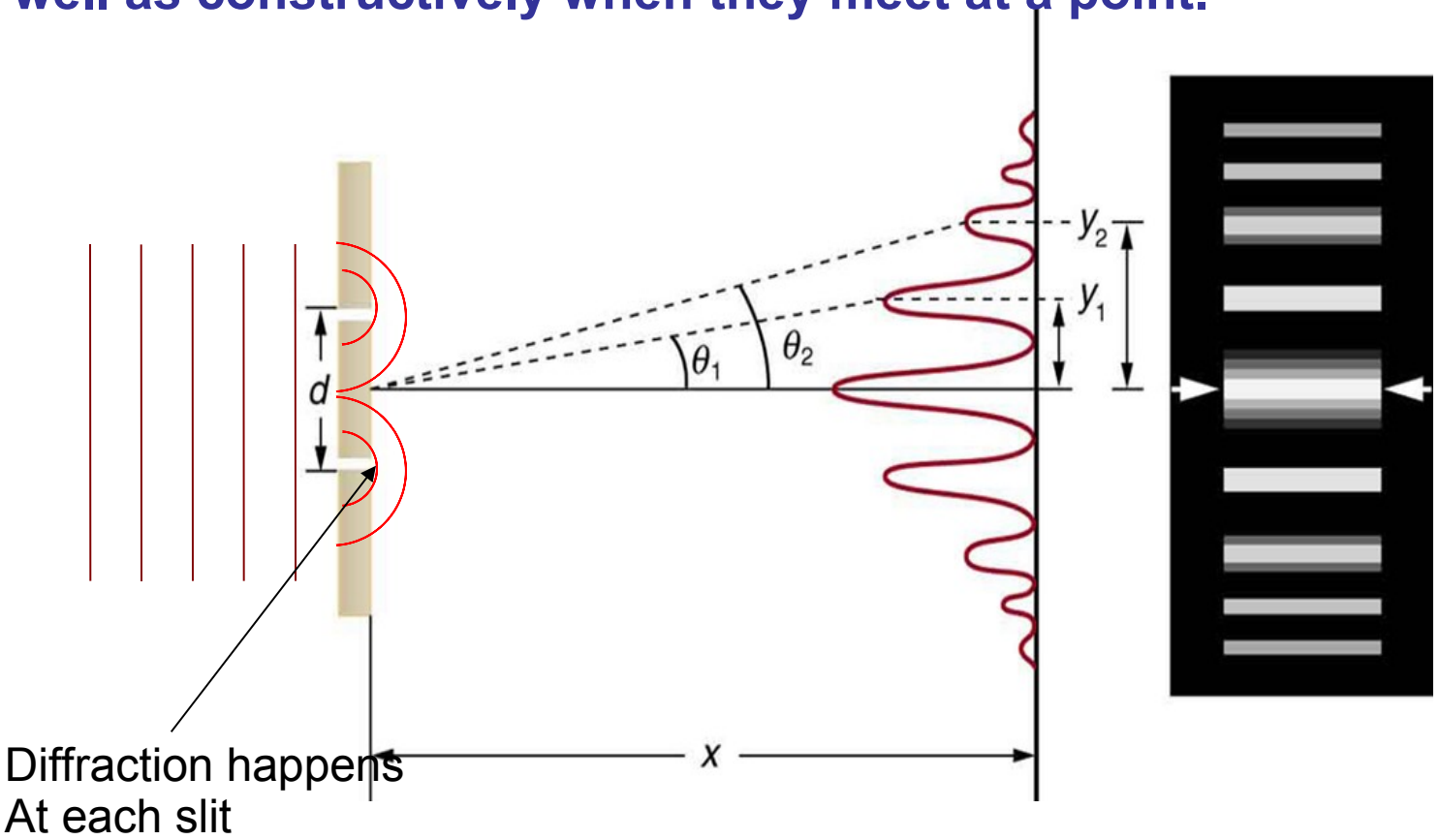


DEMO: laser diff-racted by edges.

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

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]

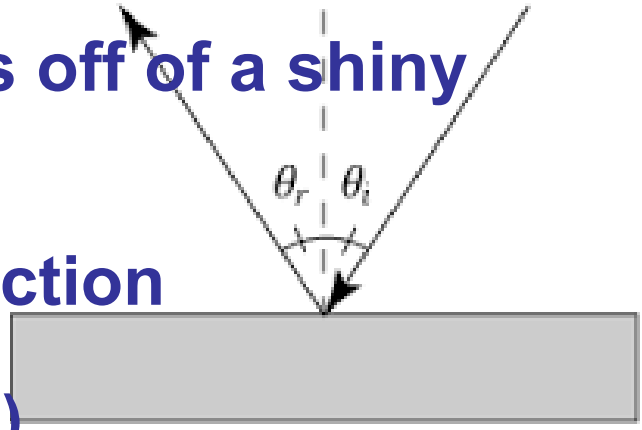
Light as wave or particle

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 …

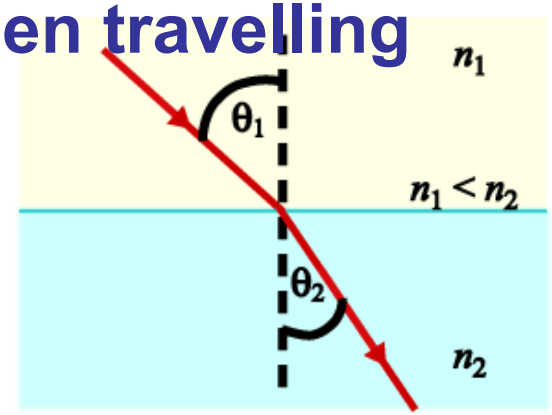
* angle of incidence = angle of reflection



Refraction (wave model is preferred)

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

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



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.

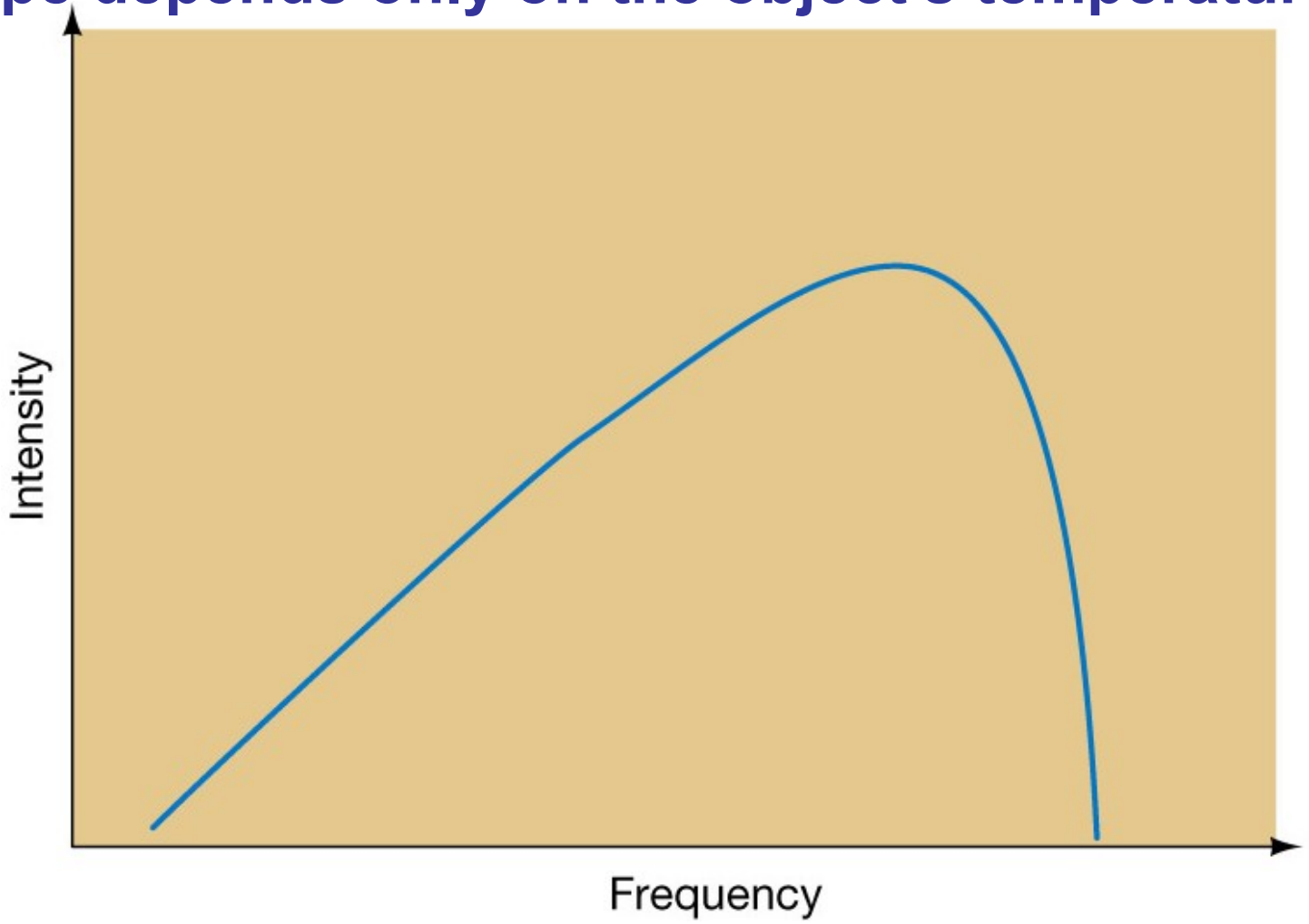
See also "Vantablack" online.

Thermal Radiation

“Vantablack” 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.

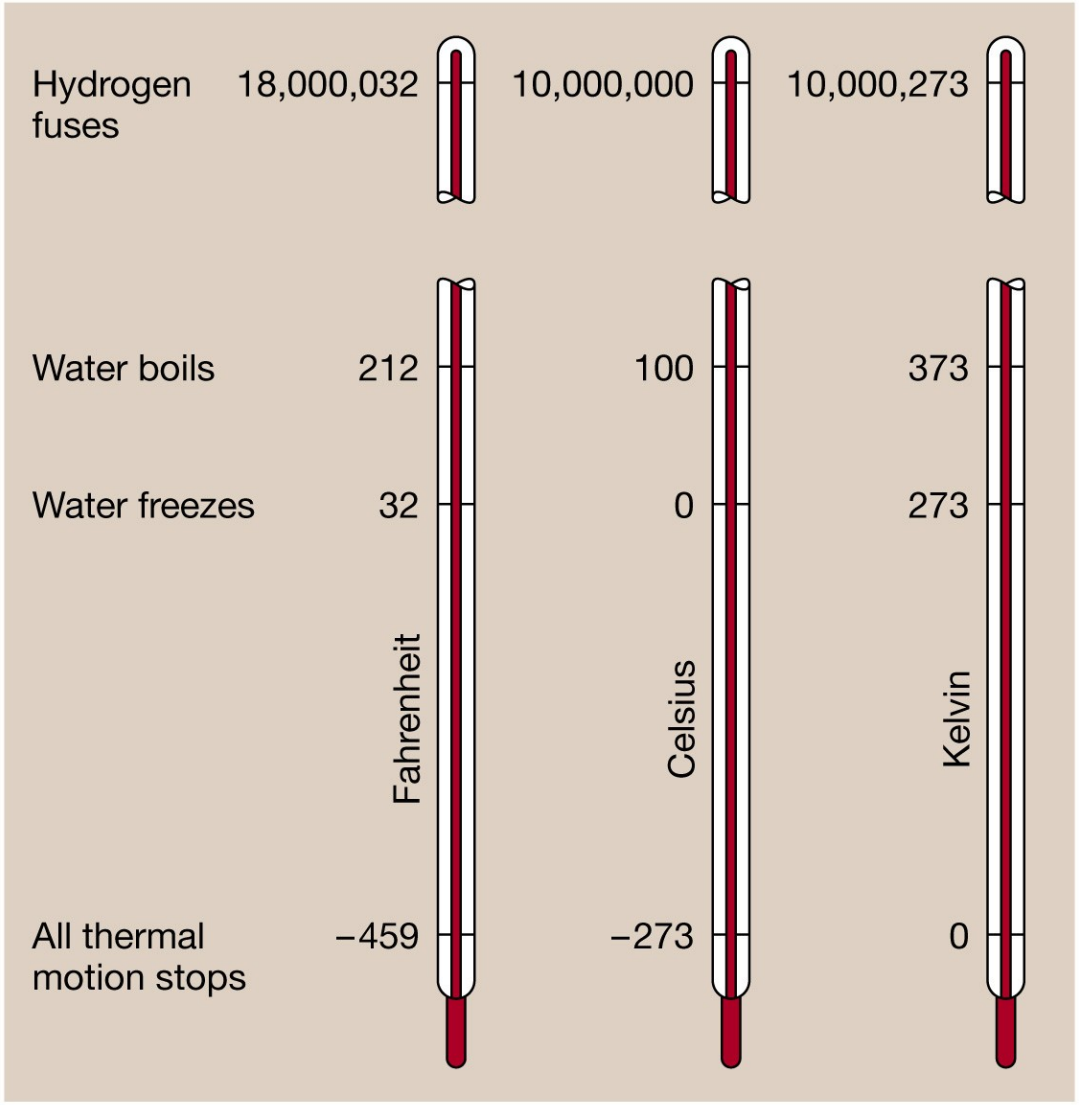


Thermal Radiation *Review: Temperature*

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



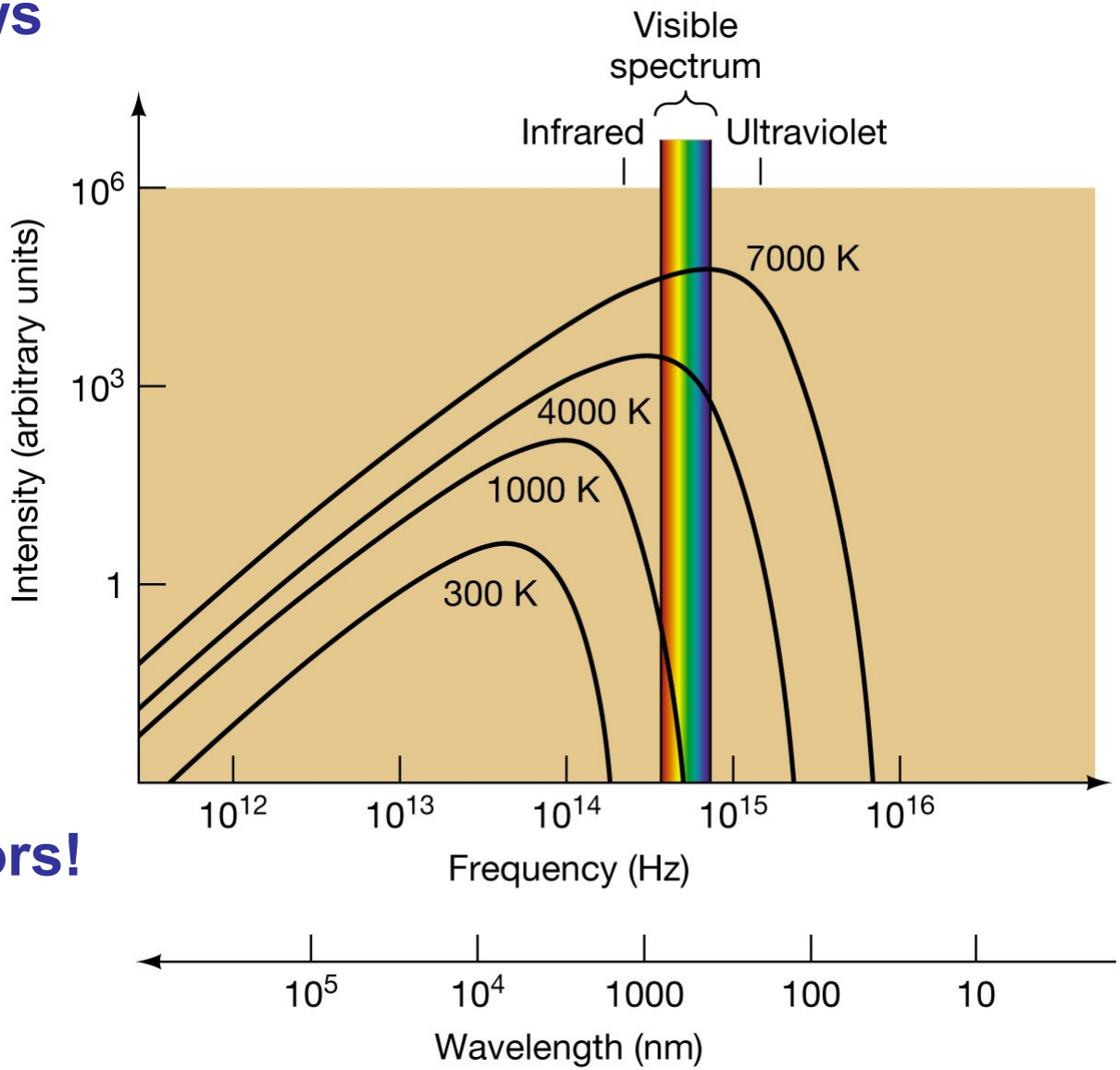
Thermal Radiation

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!



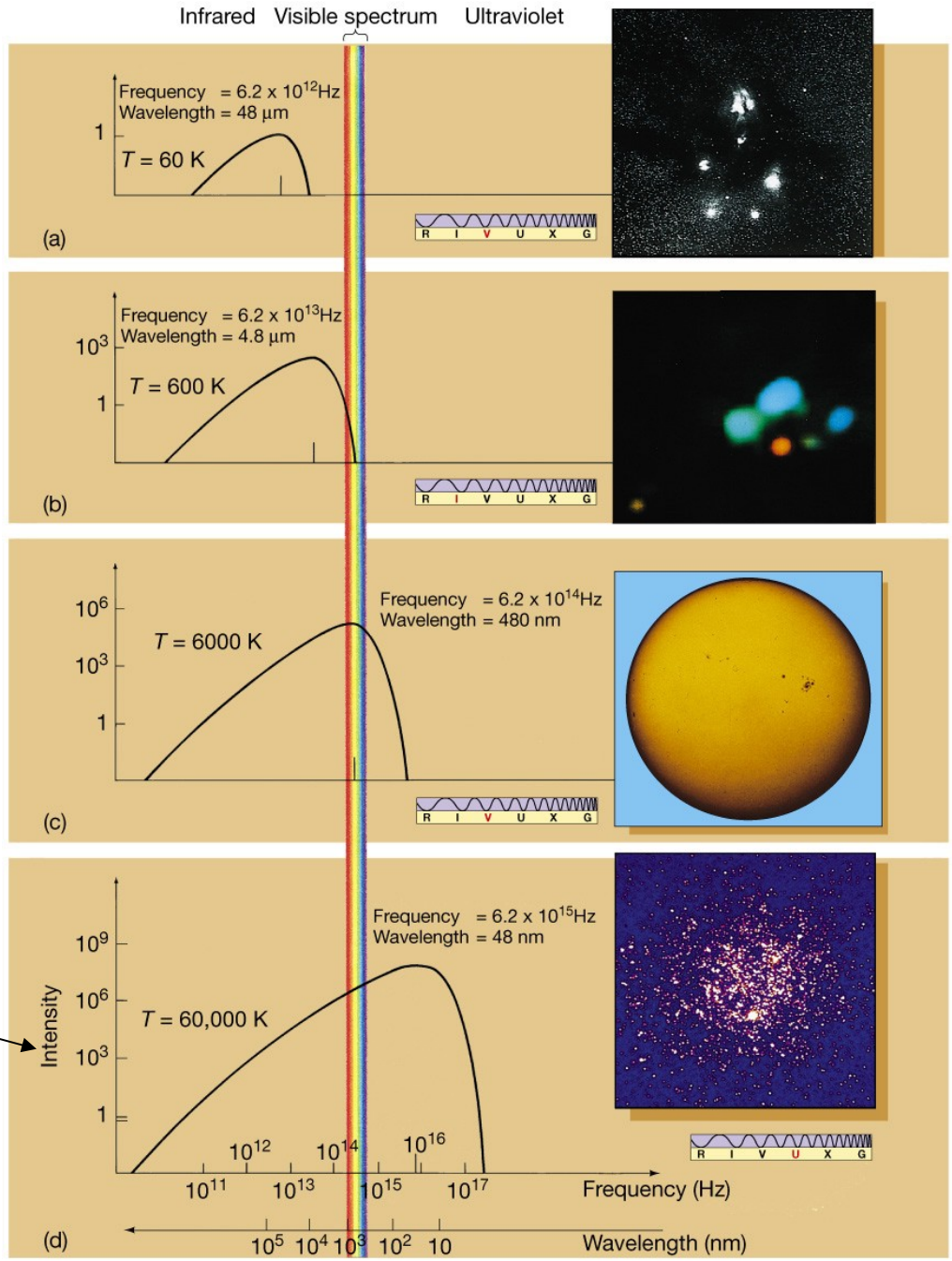
Thermal Radiation

Radiation Laws

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

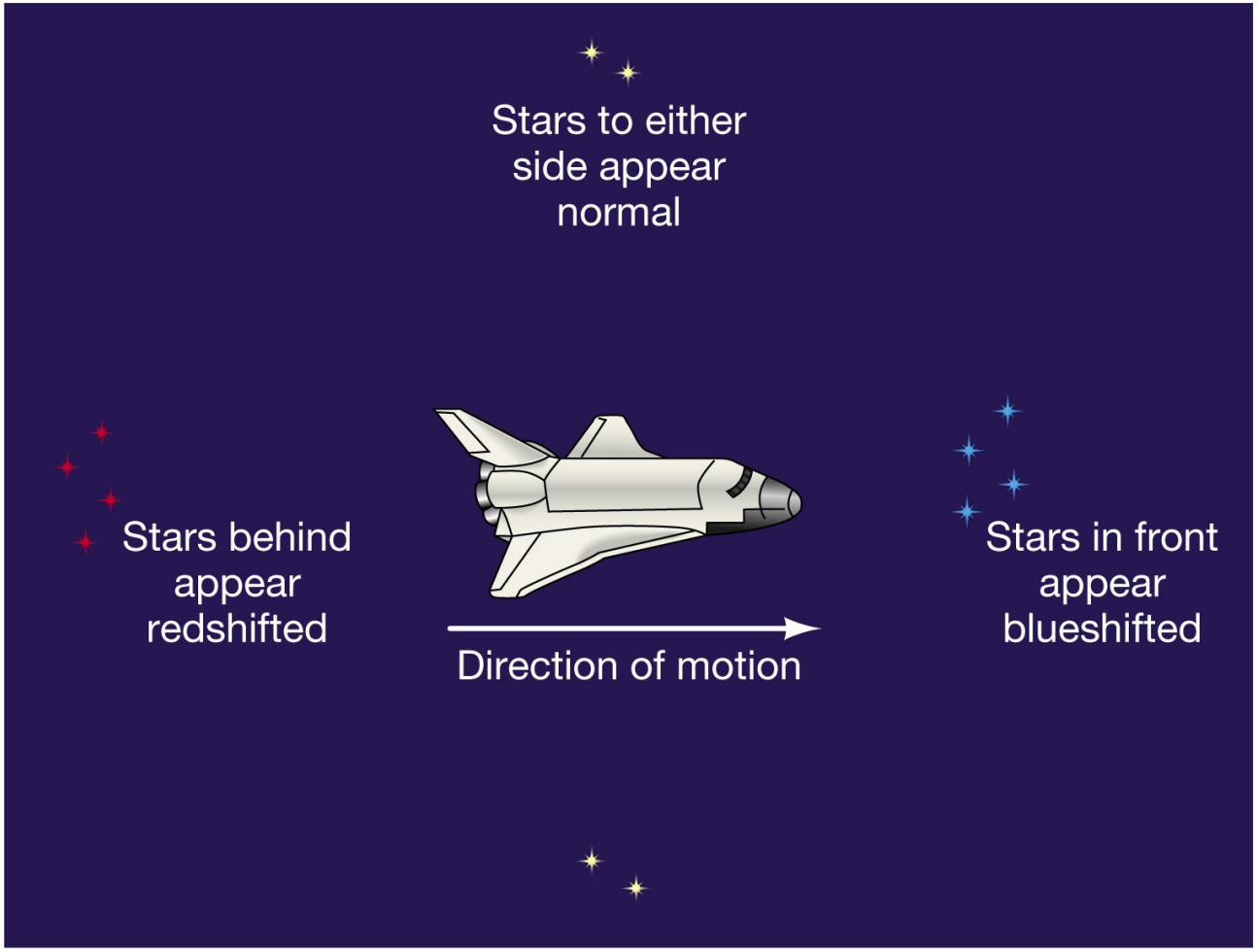
Note: intensity scale of curves is logarithmic!

DEMO: lightbulb filament with varying current



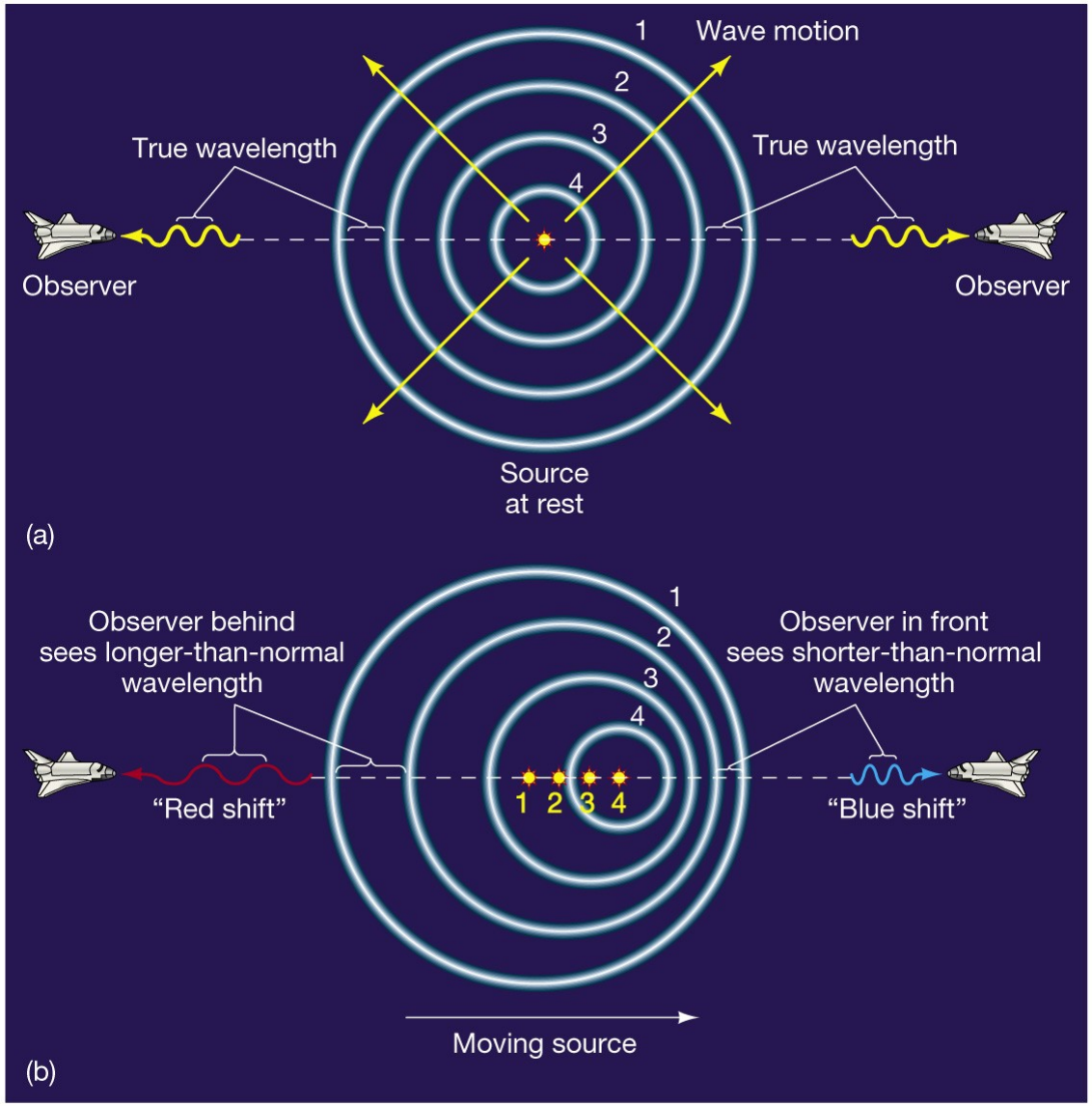
3.5 The Doppler Effect

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



3.5 The Doppler Effect

Depends only on the relative motion of source and observer:



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