Lecture: October 6, 2010

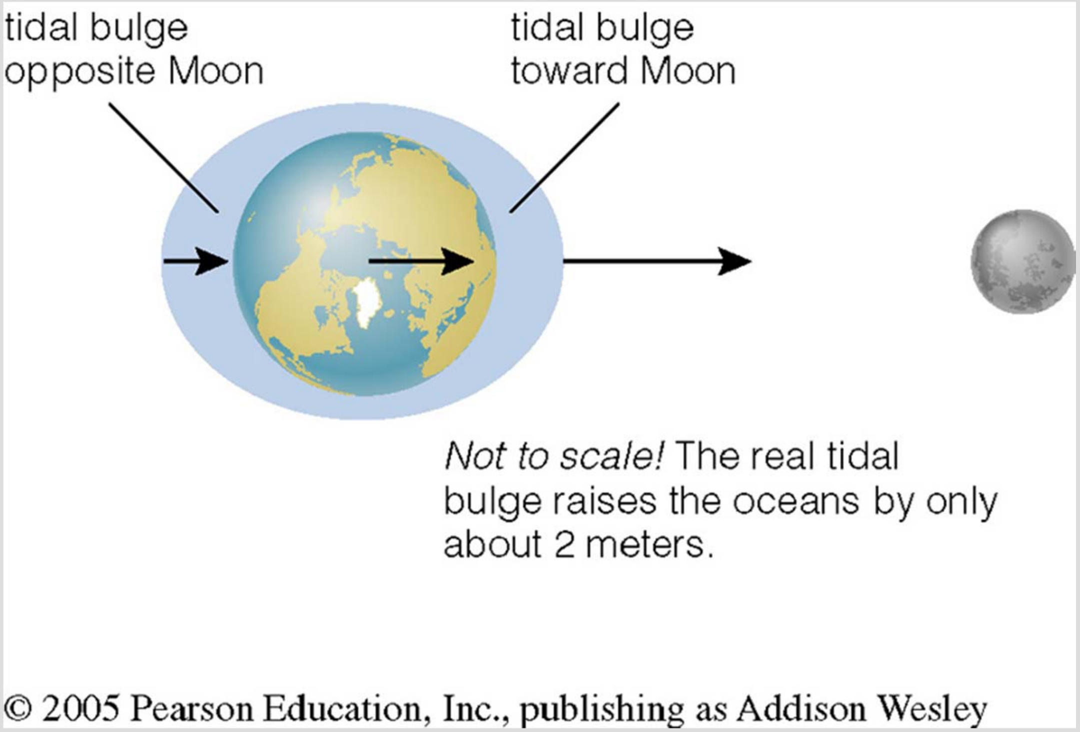
Announcements:

Next Observatory Opportunity: Tonight at 7:30

Problem Set 3 Due next Monday

Second Exam October 25

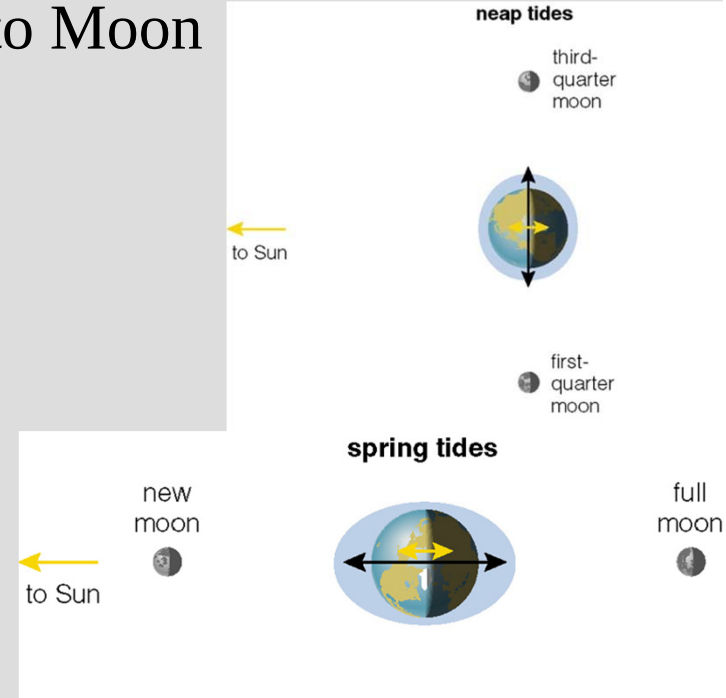
Tides



- Since gravitational force decreases with $(\text{distance})^2$, the Moon’s pull on Earth is strongest on the side facing the Moon, and weakest on the opposite side.
- The Earth gets stretched along the Earth-Moon line.
- The oceans rise relative to land at these points.

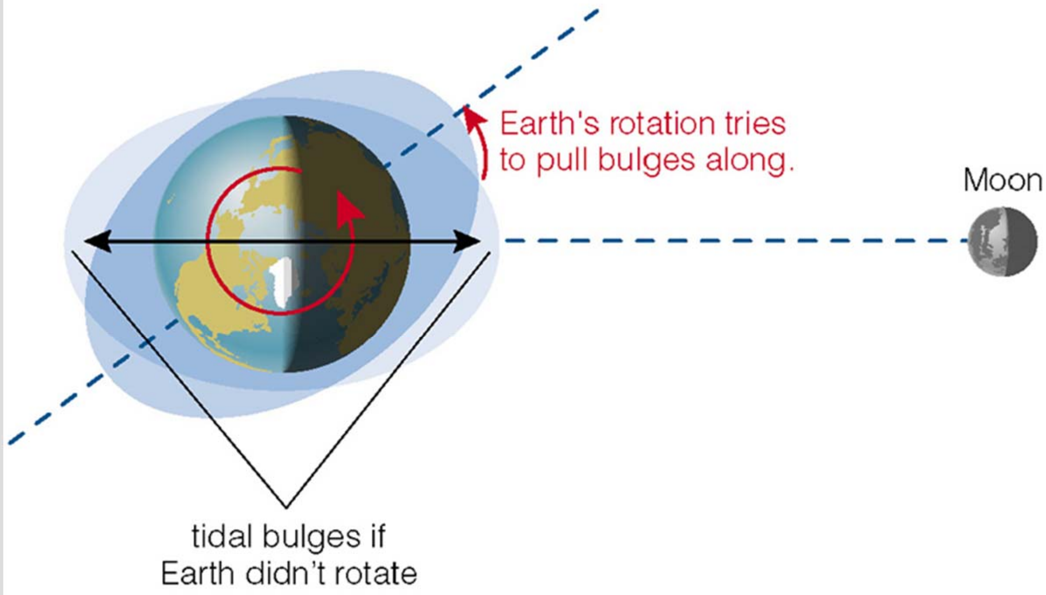
Tides

- Every place on Earth passes through these points, called **high tides**, twice per day as the Earth rotates.
- High tides occur every 12 hours 25minutes
  - remember, the Moon moves!
- The Sun's tidal effect on Earth is not as strong.
  - the ratio Earth's diameter : distance to Sun is much less than ratio Earth's diameter : distance to Moon
- When the Sun & Moon pull in the same direction (new & full phases)
  - high tide is higher than usual (**spring**)
- When the Sun & Moon pull at right angles (first & last quarter phases)
  - high tide is lower than usual (**neap**)



Tidal Friction

- This fight between Moon's pull & Earth's rotation causes friction.
- Earth's rotation slows down (1 sec every 50,000 yrs.)



- Conservation of angular momentum causes the Moon to move farther away from Earth.

Synchronous Rotation

- …is when the rotation period of a moon, planet, or star equals its orbital period about another object.
- Tidal friction on the Moon (caused by Earth) has slowed its rotation down to a period of one month.
- The Moon now rotates synchronously.
  - We always see the same side of the Moon.
- Tidal friction on the Moon has ceased since its tidal bulges are always aligned with Earth.

Changing Orbits

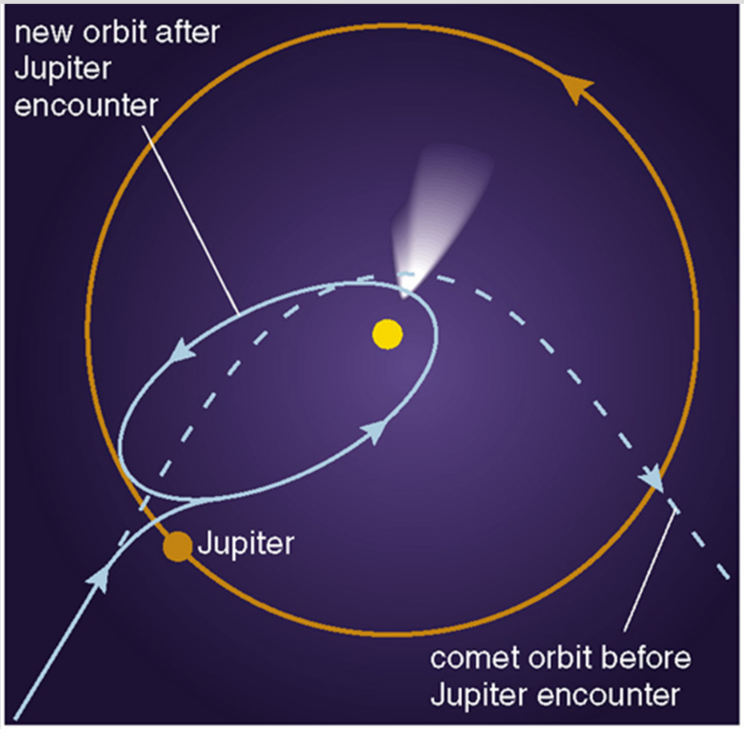
orbital energy = kinetic energy + gravitational potential energy

conservation of energy implies:

orbits can't change spontaneously

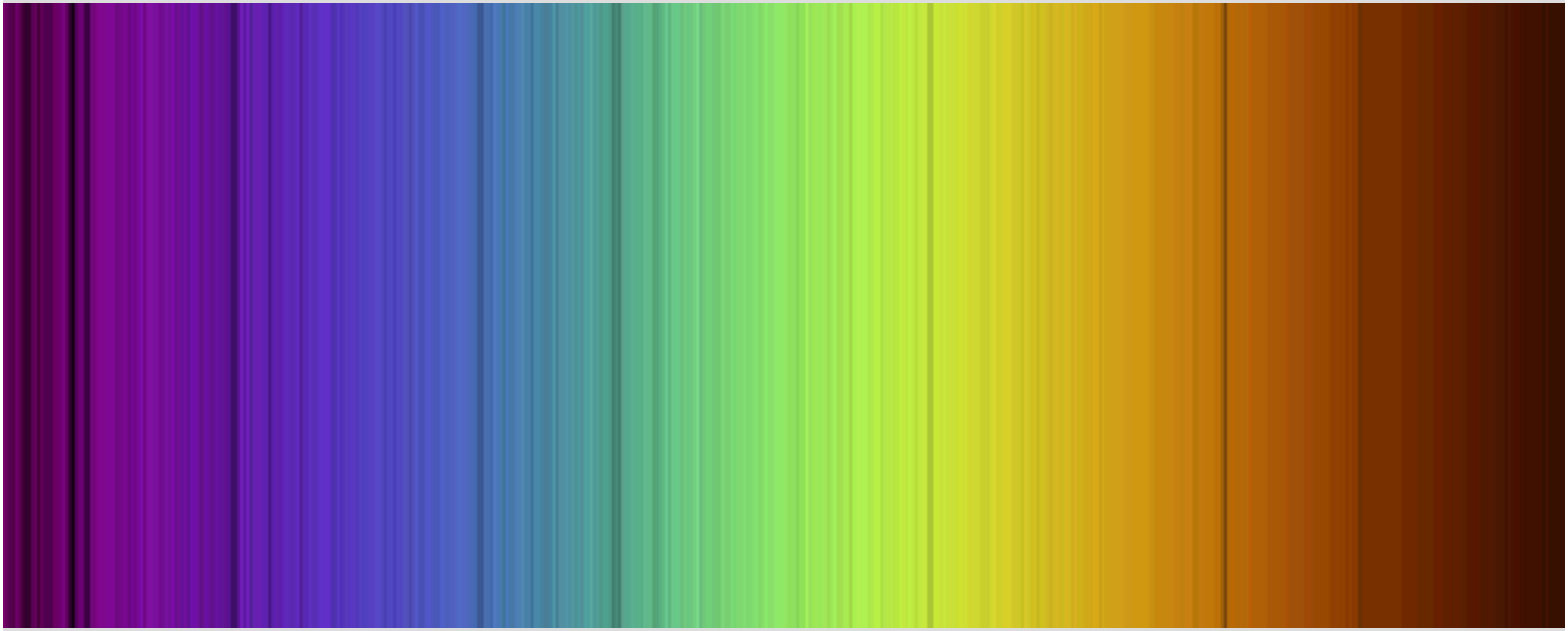
An object can't crash into a planet unless its orbit takes it there.

An orbit can only change if it gains/loses energy from another object, such as a gravitational encounter:



If an object gains enough energy so that its new orbit is unbound, we say that it has reached **escape velocity**.

6. Light: The Cosmic Messenger



Virtually all of our information about the Universe
Comes to us through light.

Power

- **power**: the rate at which energy is used/emitted
- It is measured in units called **watts**.

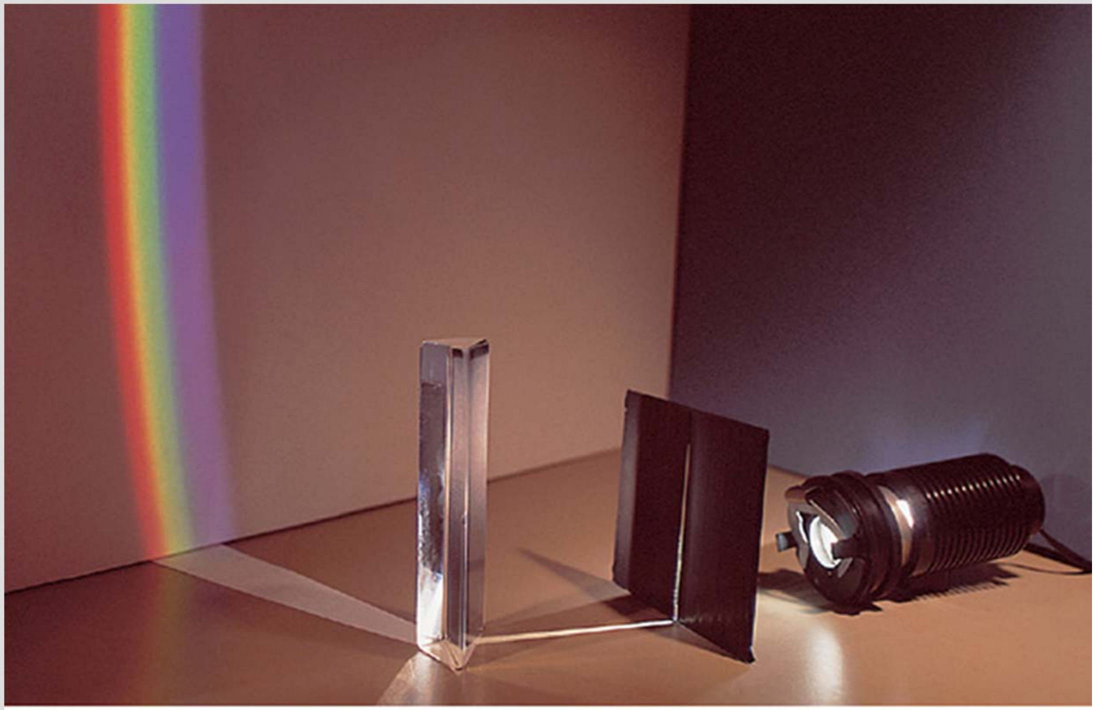
  1 watt = 1 joule per second

- A 100 watt light bulb radiates 100 joules of energy every second.

Spectrum

- When light is broken up into its constituent wavelengths

- Produced by a prism or by a diffraction grating



Four Ways in Which Light can Interact with Matter

1. **emission** – matter releases energy as light
2. **absorption** – matter takes energy from light
3. **transmission** – matter allows light to pass through it
4. **reflection** – matter repels light in another direction

Light

A vibration in an electromagnetic field through which energy is transported.

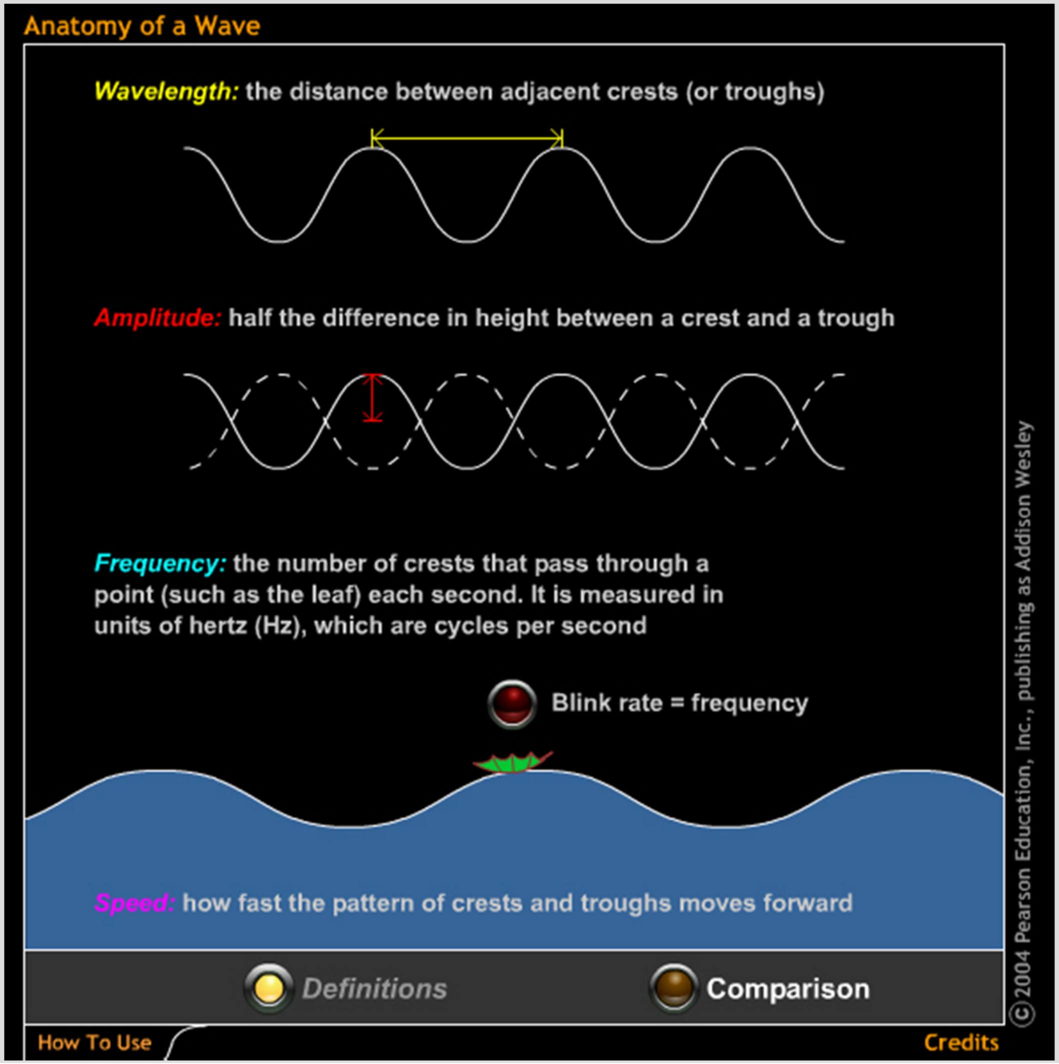
Dual Natures

Light as a wave $f\lambda = c$

Light as a particle $E = hf$ photon

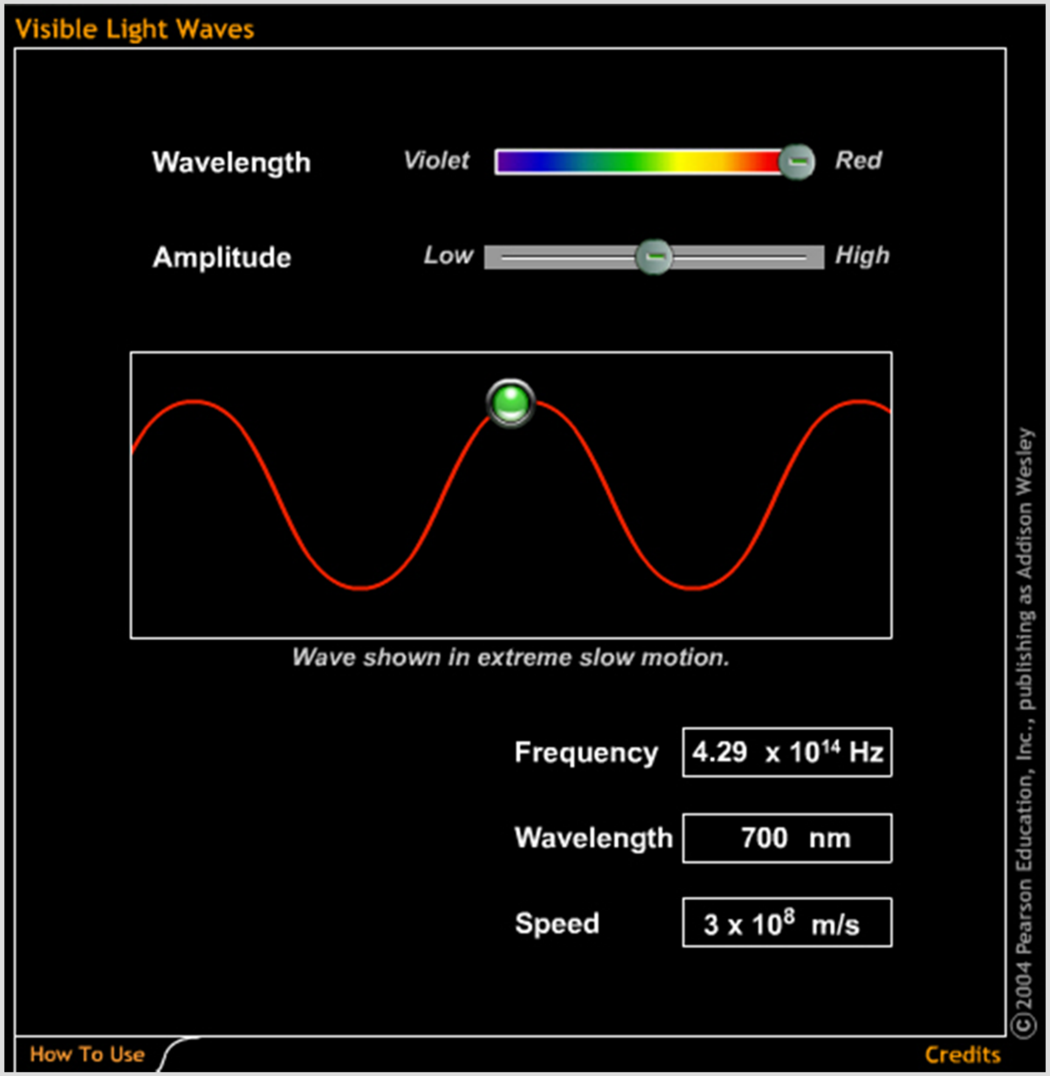
Light as a Wave

A *wave* is a pattern which is revealed by its interaction with particles.



Light as a Wave

- For a wave, its speed: $s = f\lambda$
- But the speed of light is a constant, c.
- For light: $f\lambda = c$
- The higher f is, the smaller λ is, and vice versa.
- Our eyes recognize f (or λ) as *color*!

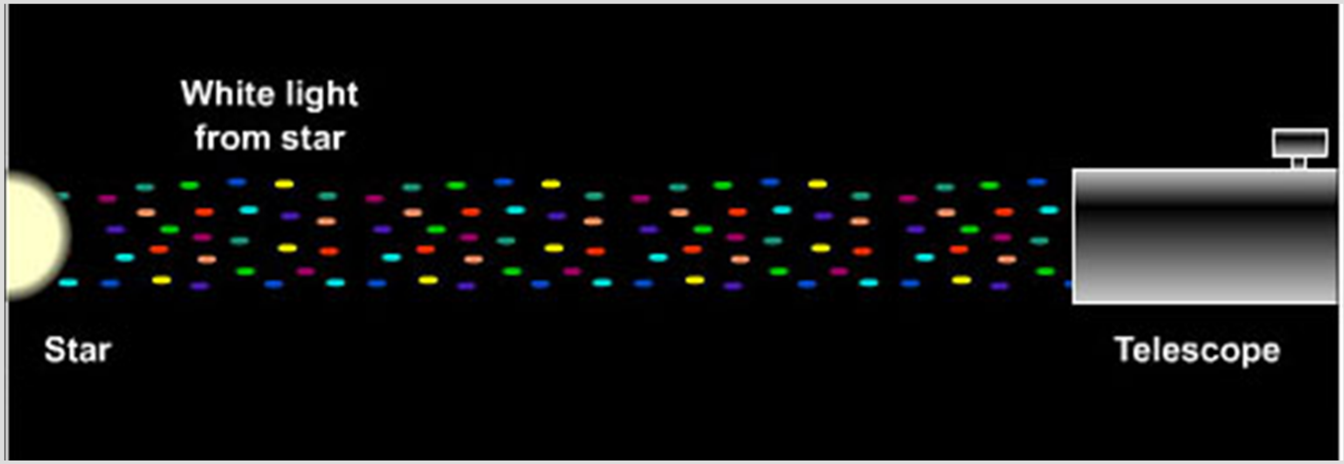


Light as a Particle

- Light can also be treated as *photons* – packets of energy.
- The energy carried by each photon depends on its frequency (color)

  $E = hf = hc / \lambda$ [“h” is called Planck’s Constant]

- Bluer light carries more energy per photon.



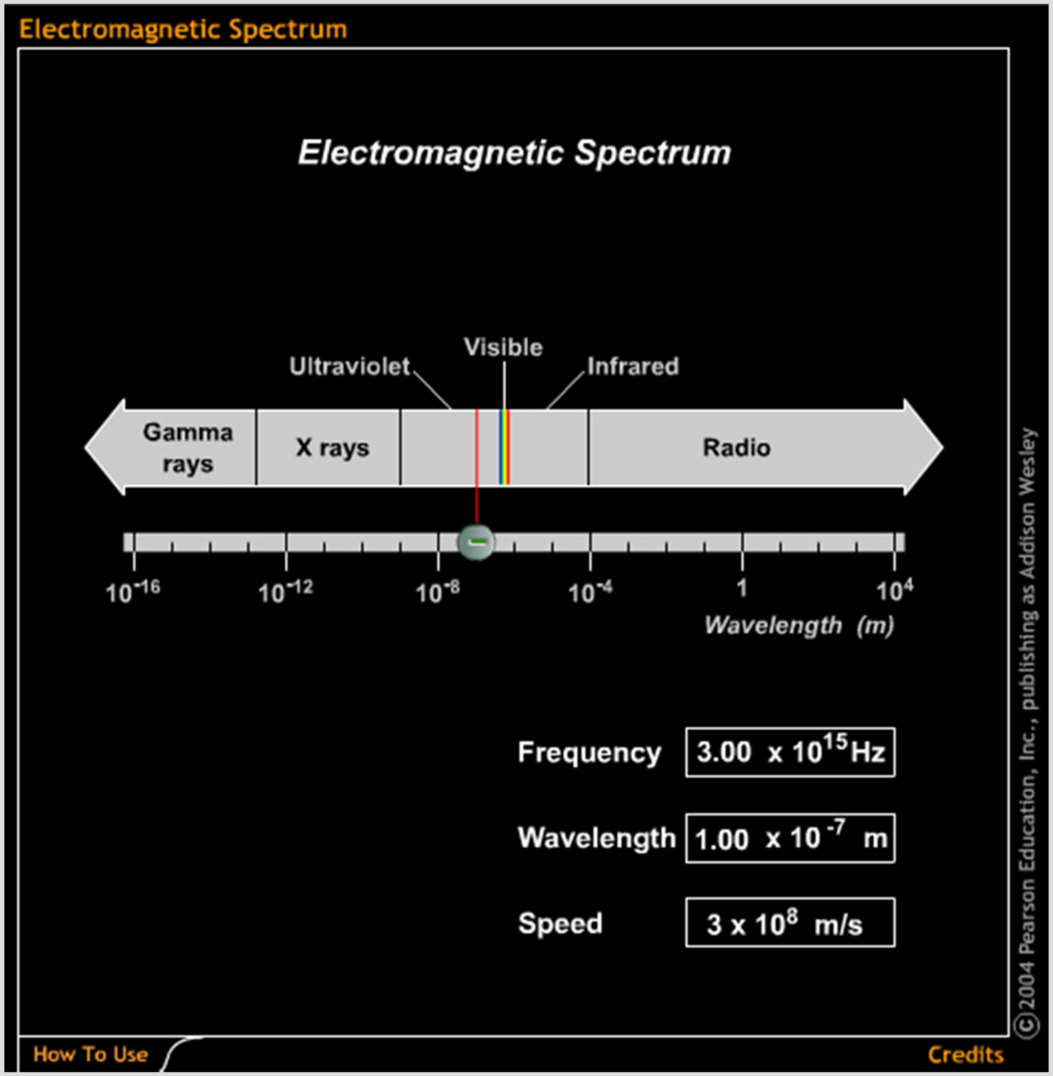
6.3 The Many Forms of Light

Our goals for learning:

- List the various forms of light that make up the electromagnetic spectrum.

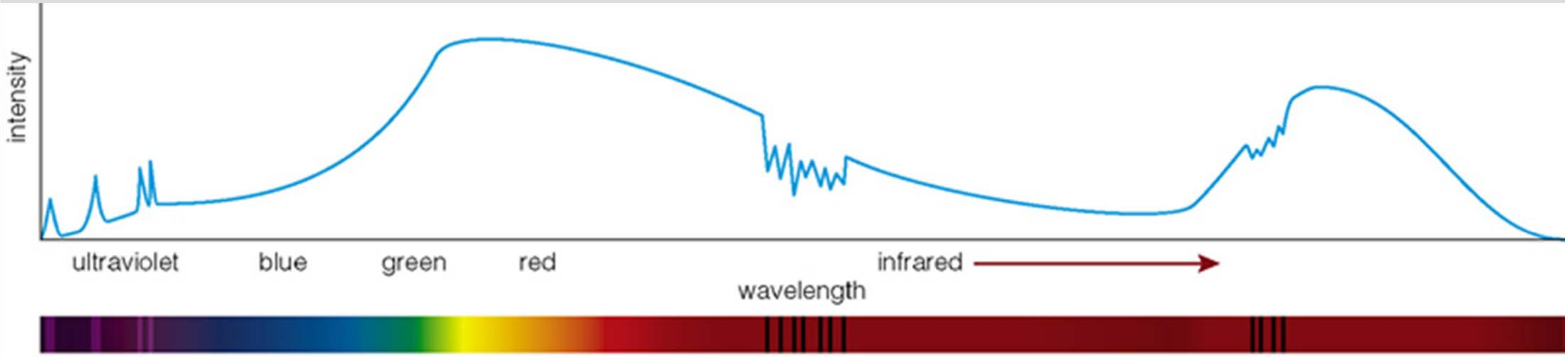
The Electromagnetic Spectrum

Most wavelengths of light can not be seen by the human eye.



Light as Information Bearer

We can separate light into its different wavelengths (spectrum).



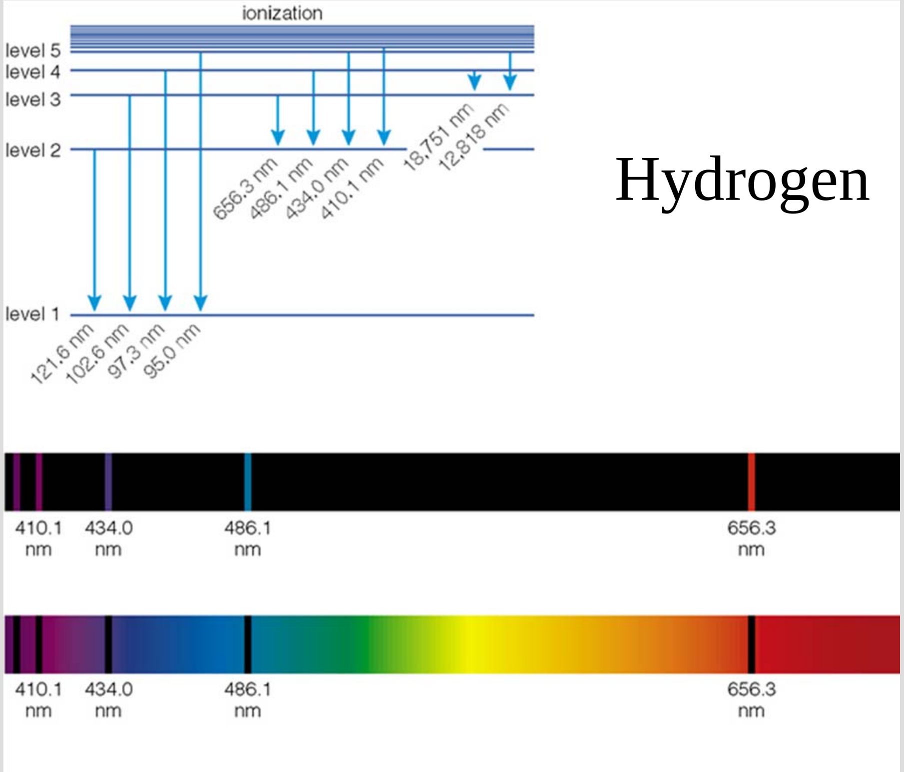
By studying the spectrum of an object, we can learn its:

1 Composition

2 Temperature

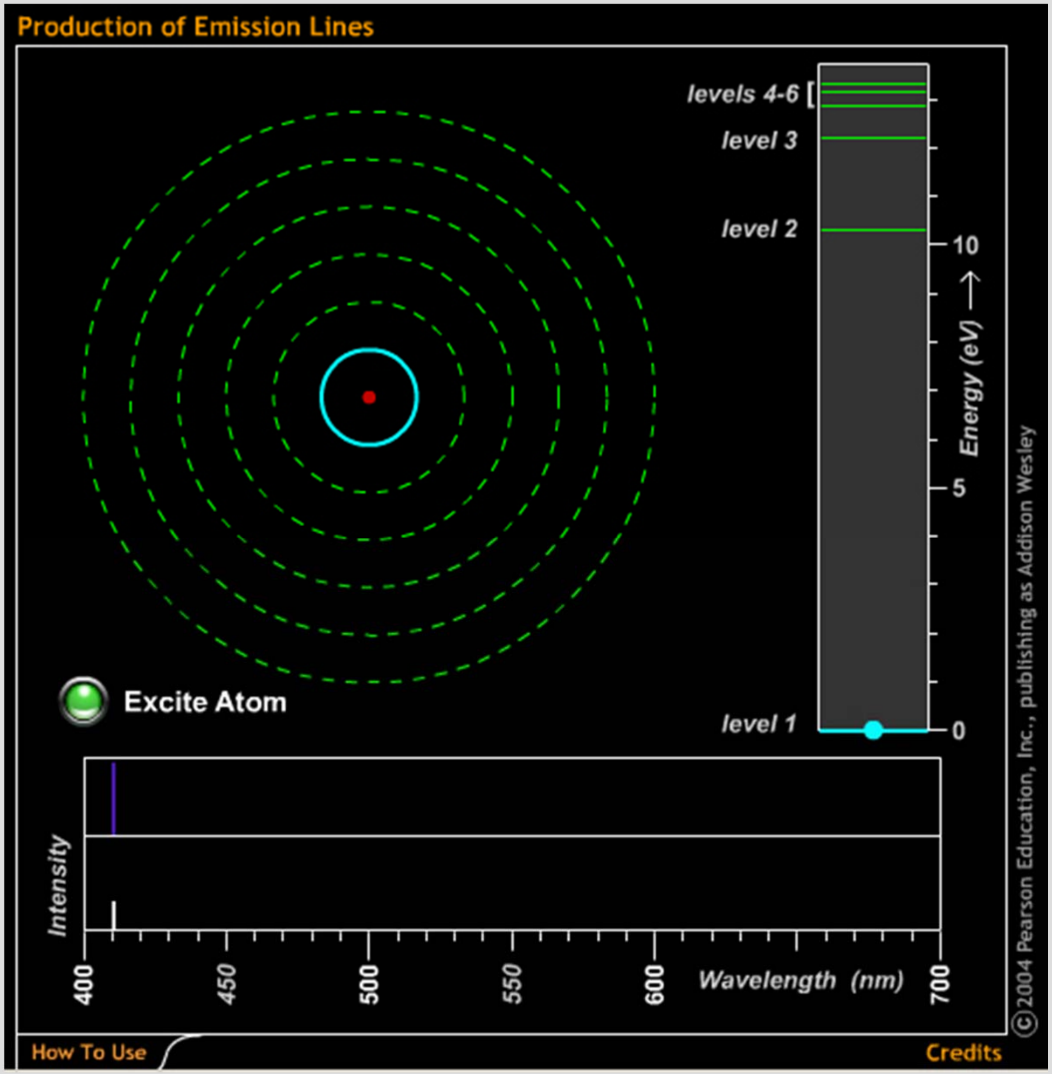
3 Velocity

Interaction of Light with Matter



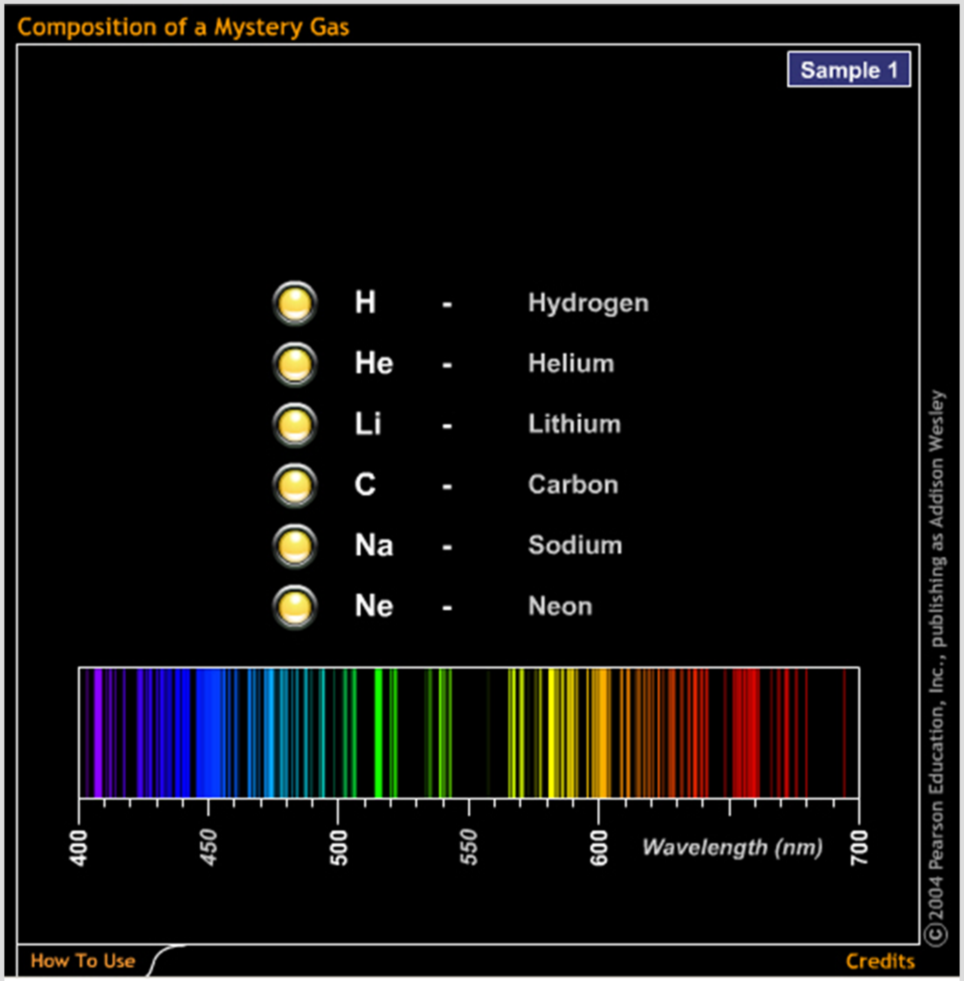
- Remember that each electron is only allowed to have certain energies in an atom.
- Electrons can absorb light and gain energy or emit light when they lose energy.
- It is easiest to think of light as a photon when discussing its interaction with matter.
- Only photons whose energies (colors) match the “jump” in electron energy levels can be emitted or absorbed.

Emission of Light

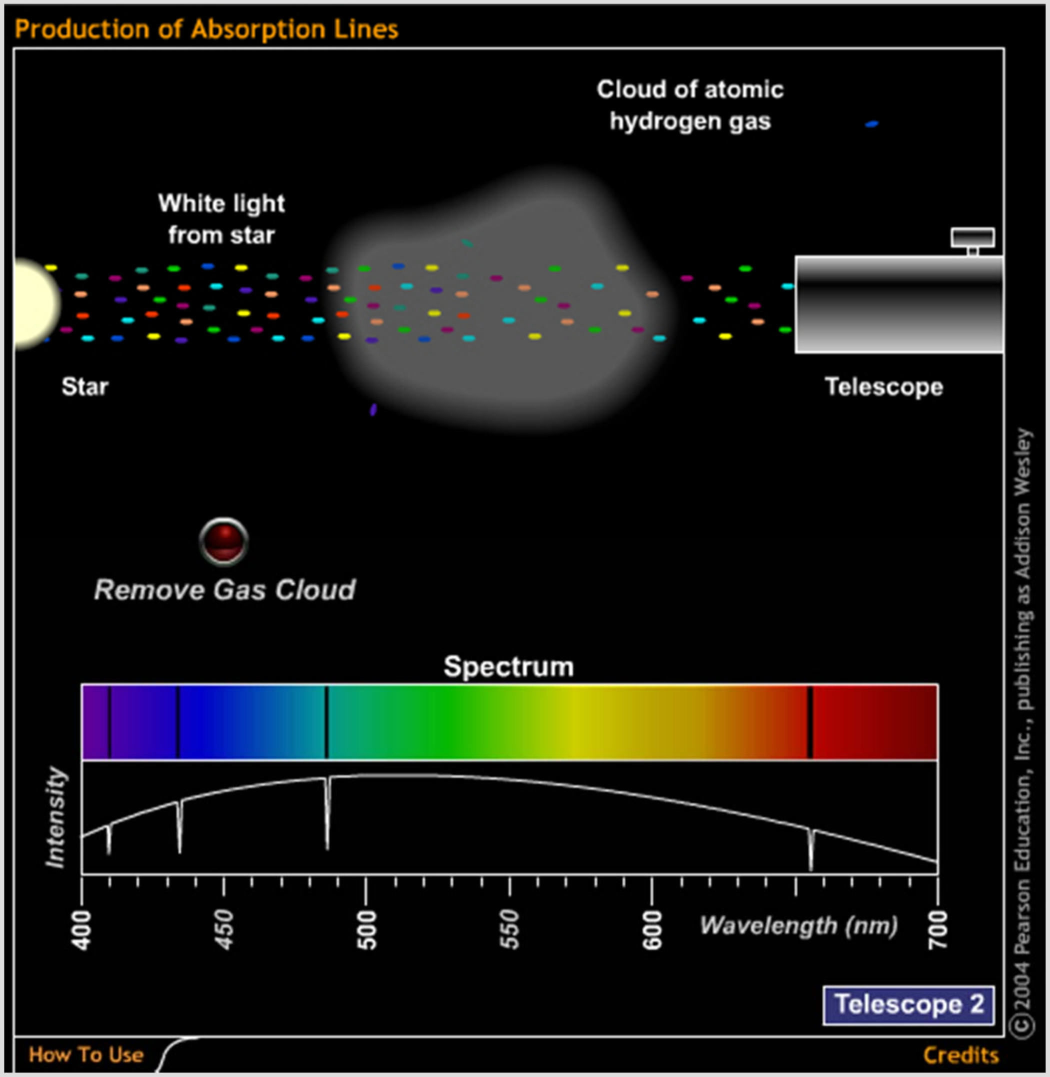


Emission Spectra

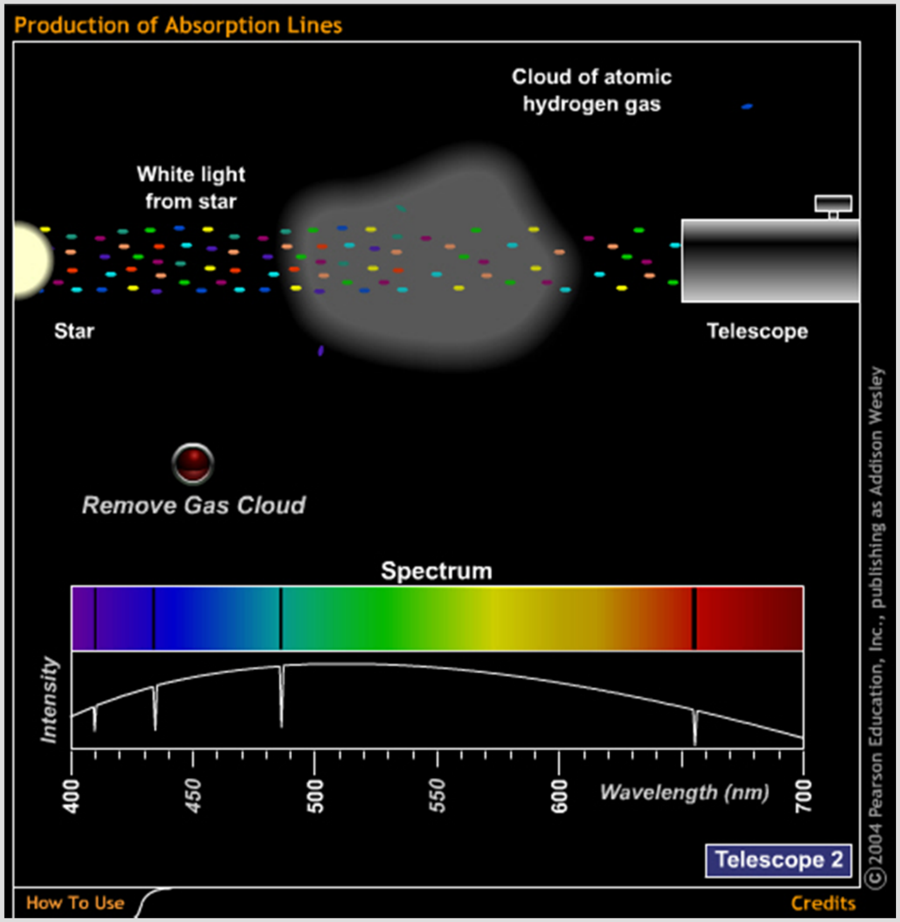
- The atoms of each element have their own distinctive set of electron energy levels.
- Each element emits its own pattern of colors, like fingerprints.
- If it is a hot gas, we see only these colors, called an **emission line spectrum**.



Absorption of Light



Absorption Spectra



- If light shines through a gas, each element will absorb those photons whose colors match their electron energy levels.
- The resulting **absorption line spectrum** has all colors minus those that were absorbed.
- We can determine which elements are present in an object by identifying emission & absorption lines.

Rules for Emission by Opaque Objects

1. Hotter objects emit more total radiation per unit surface area.
   - Stefan-Boltzmann Law
   - $E = \sigma T^4$
2. Hotter objects emit *bluer* photons (with a higher average energy.)
   - Wien Law
   - $\lambda_{max} = 2.9 \times 10^6 / T(K)$ [nm]

Stefan-Boltzman Law

$$L = \sigma A T^4$$

$\sigma = 5.67x10^{-8}$ (mks units)

A is area in square meters -- often $4\pi R^2$

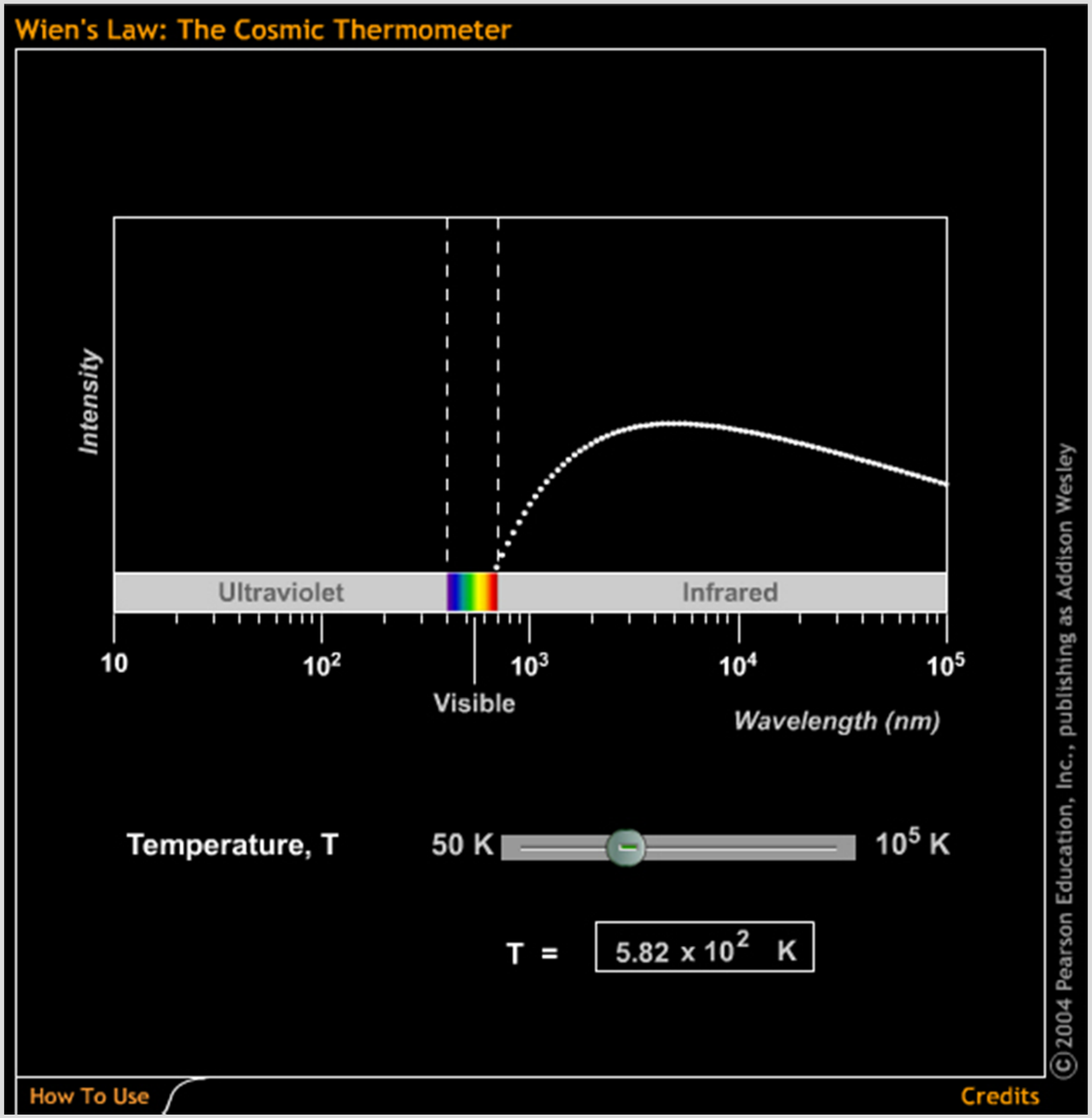
T is temperature in Kelvin

Wien Law

$$\lambda_{max} = 2.9 \times 10^6 / T(K) \quad [nm]$$

$$\lambda_{max} = 2.9 \times 10^7 / T(K) \quad [Å]$$

Thermal Radiation



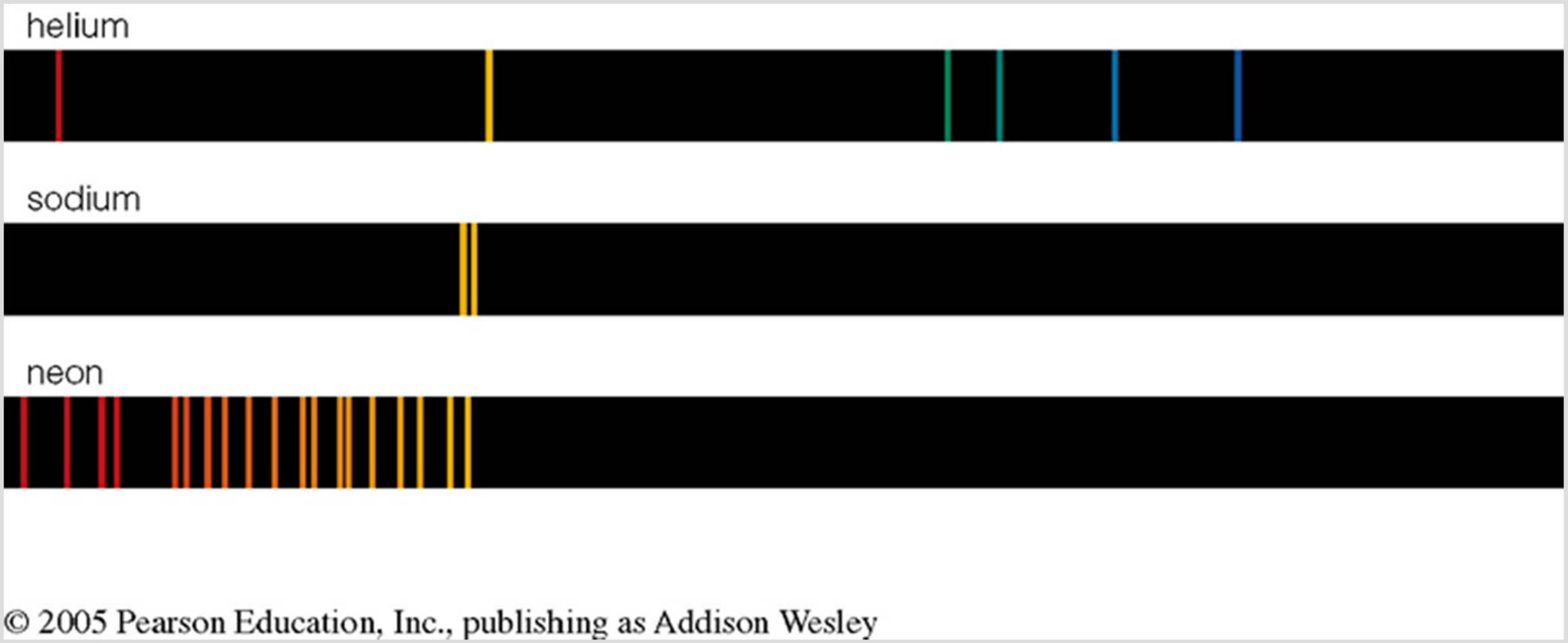
Kirchhoff’s Laws

1 A hot, dense glowing object (solid or gas) emits a continuous spectrum.

Kirchhoff’s Laws

2 A hot, low density gas emits light of only certain wavelengths --

⇨ an emission line spectrum.

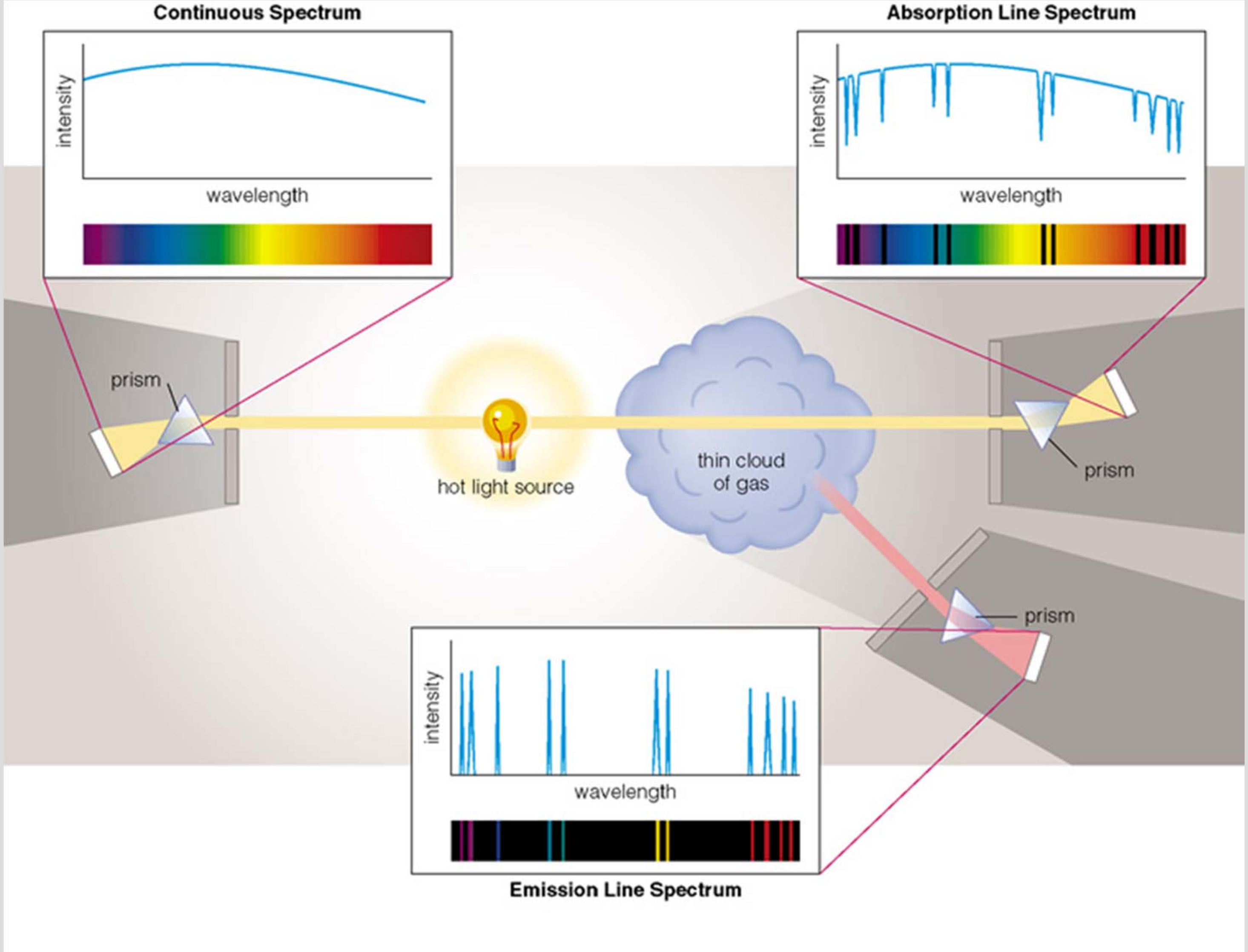


Kirchhoff's Laws

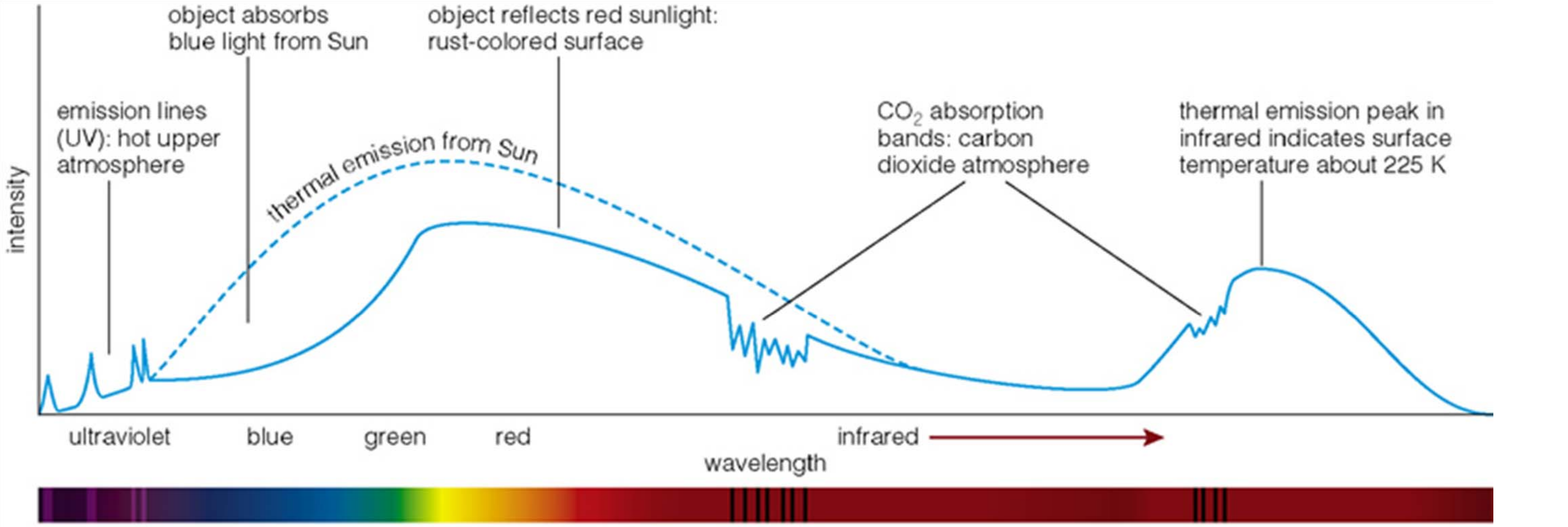
3 When light having a continuous spectrum passes through a cool gas, dark lines appear in the continuous spectrum --

⇨ an absorption line spectrum.

Kirchhoff's Laws



Sum it up



object absorbs
blue light from Sun
object reflects red sunlight:
rust-colored surface
emission lines
(UV): hot upper
atmosphere
thermal emission from Sun
CO_2 absorption
bands: carbon
dioxide atmosphere
thermal emission peak in
infrared indicates surface
temperature about 225 K
intensity
ultraviolet
blue
green
red
infrared
wavelength

The Doppler Effect

1. Light emitted from an object moving towards you will have its wavelength shortened.

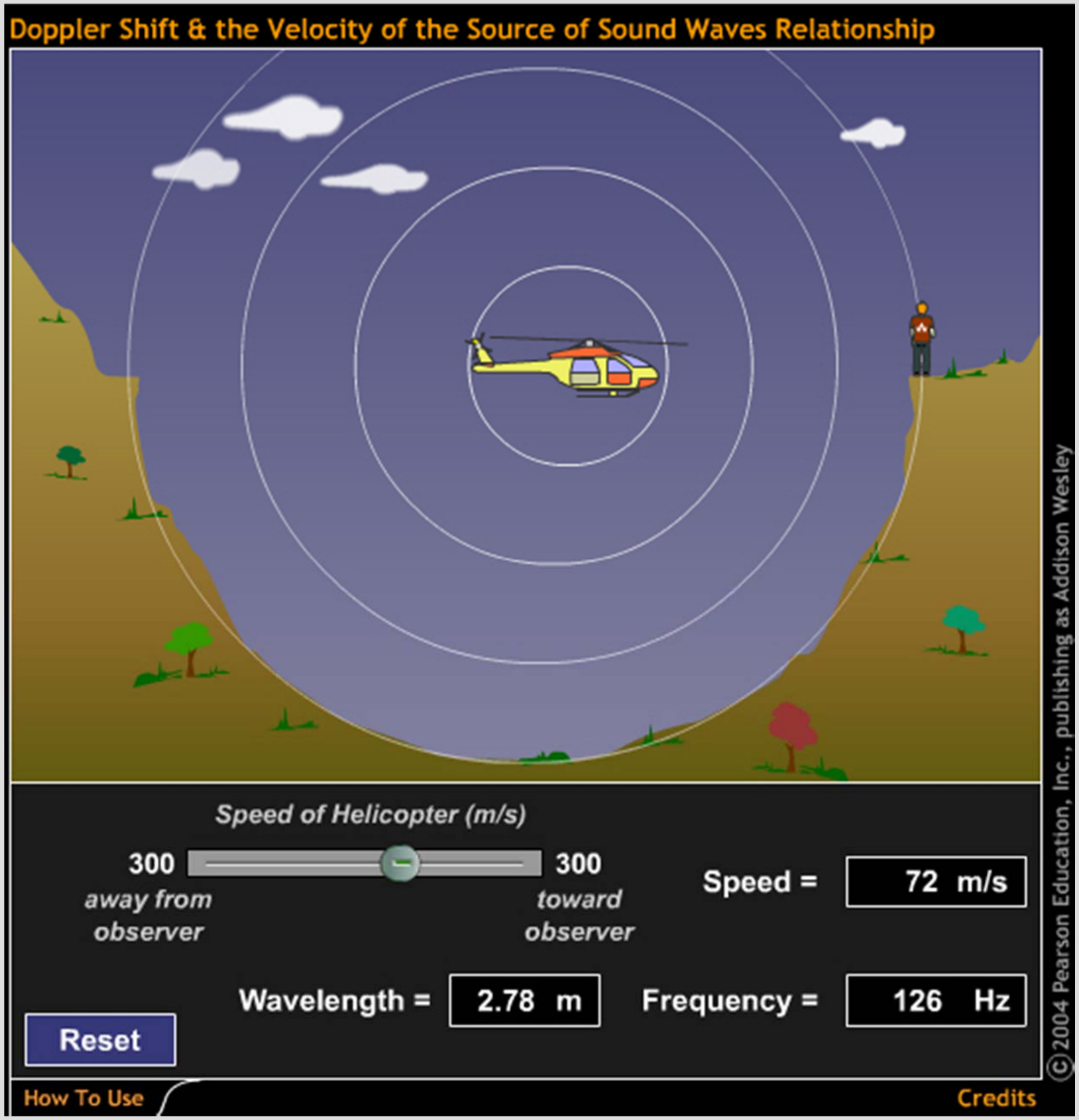
   BLUESHIFT

2. Light emitted from an object moving away from you will have its wavelength lengthened.

   REDSHIFT

3. Light emitted from an object moving perpendicular to your line-of-sight will not change its wavelength.

The Doppler Effect

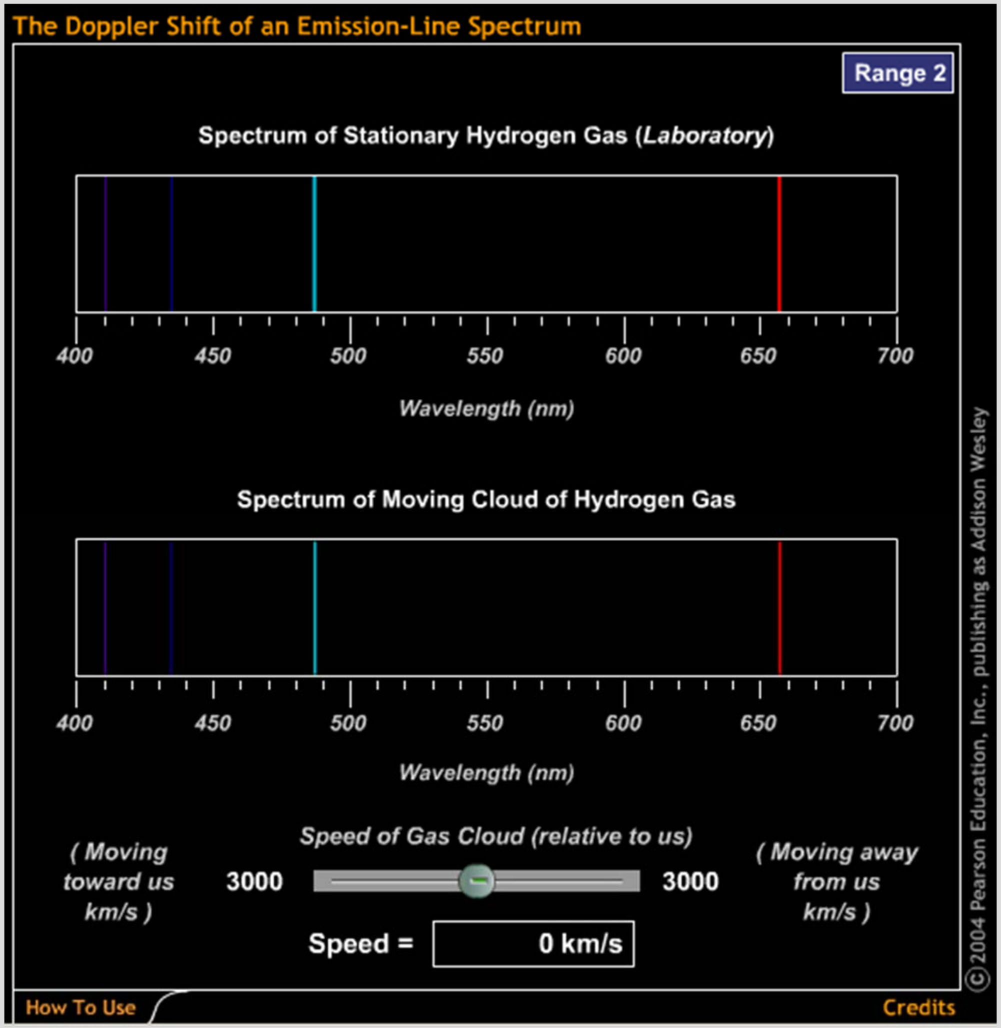


The Doppler Effect

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

Measuring Radial Velocity

- We can measure the Doppler shift of emission or absorption lines in the spectrum of an astronomical object.
- We can then calculate the velocity of the object in the direction either towards or away from Earth. (**radial velocity**)



Measuring Rotational Velocity