Lecture: October 6, 2010

- Two politicians are in a tight two-person race. A poll says one is ahead by two points. How many people would have to be interviewed to establish that?
- Error drops as square root of number of people interviewed.

Announcements:

Problem Set 3 Due next Monday

Second Exam October 25

Light

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

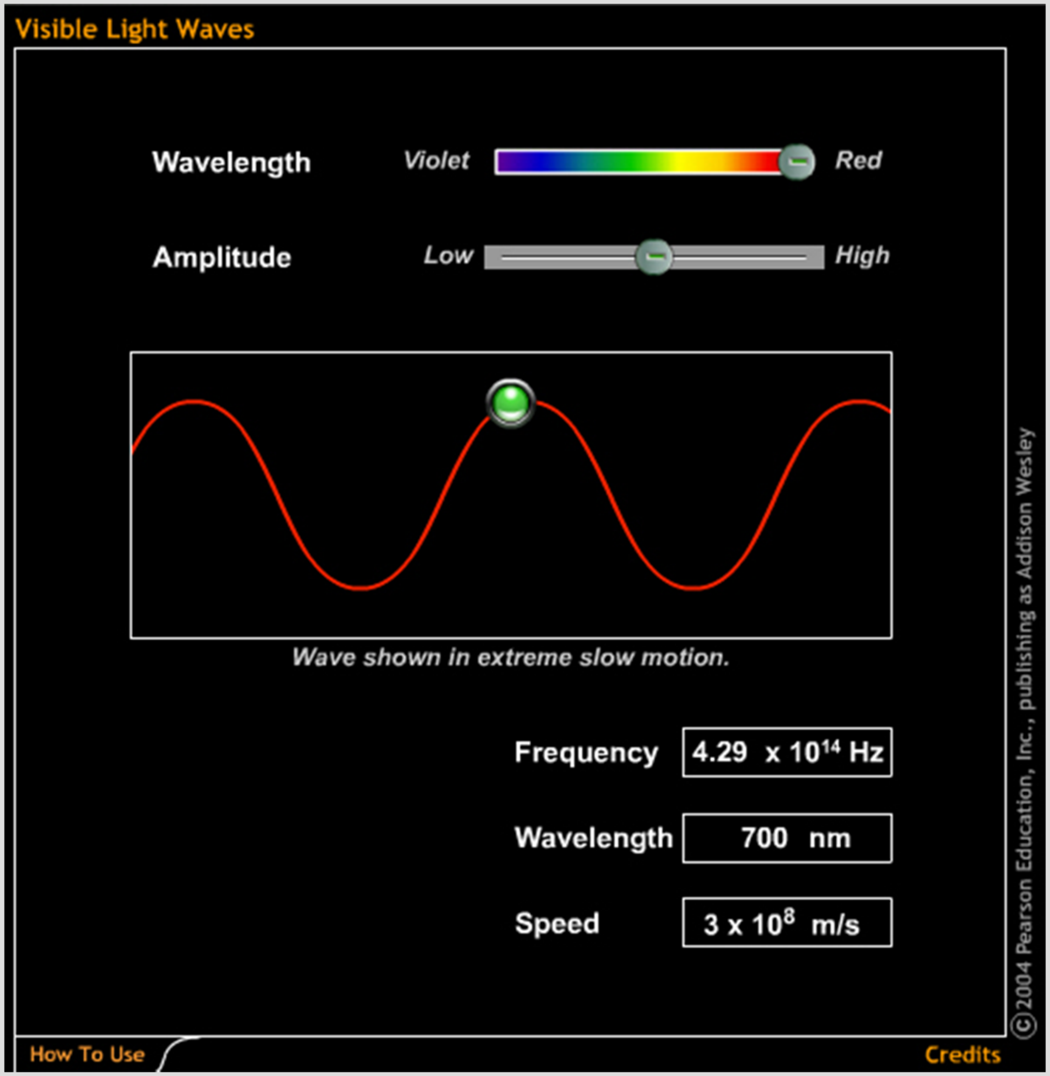
Dual Natures

Light as a wave $f\lambda = c$

Light as a particle $E = hf$ photon

Light as a Wave

- 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*!

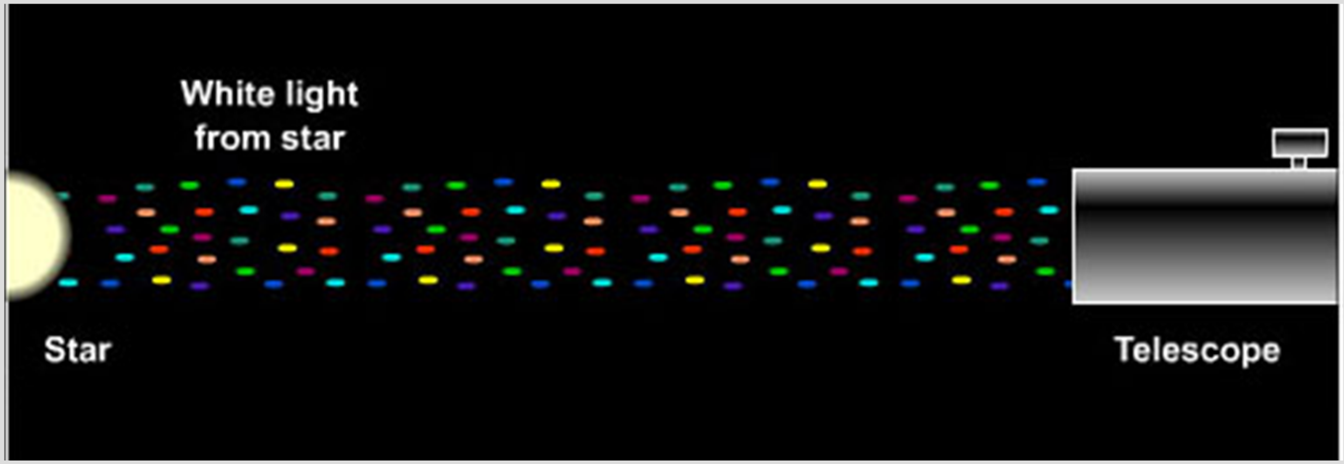


Light as a Particle

- 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.



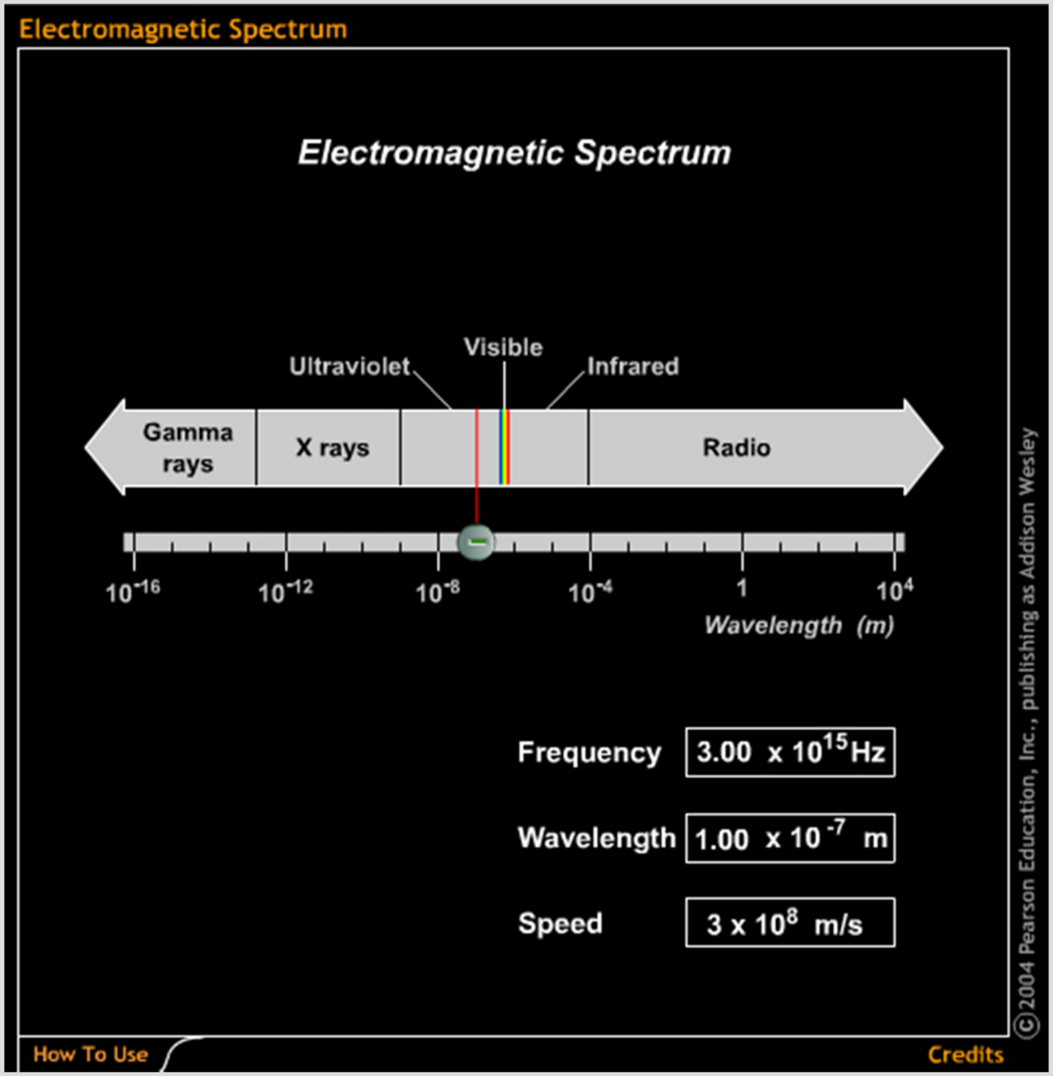
6.3 The Many Forms of Light

Our goals for learning:

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

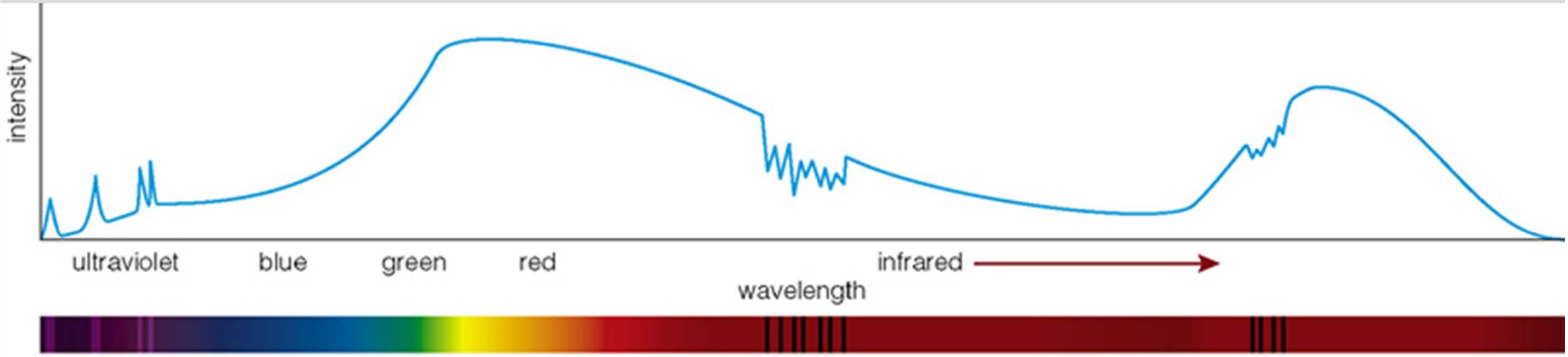
The Electromagnetic Spectrum

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).



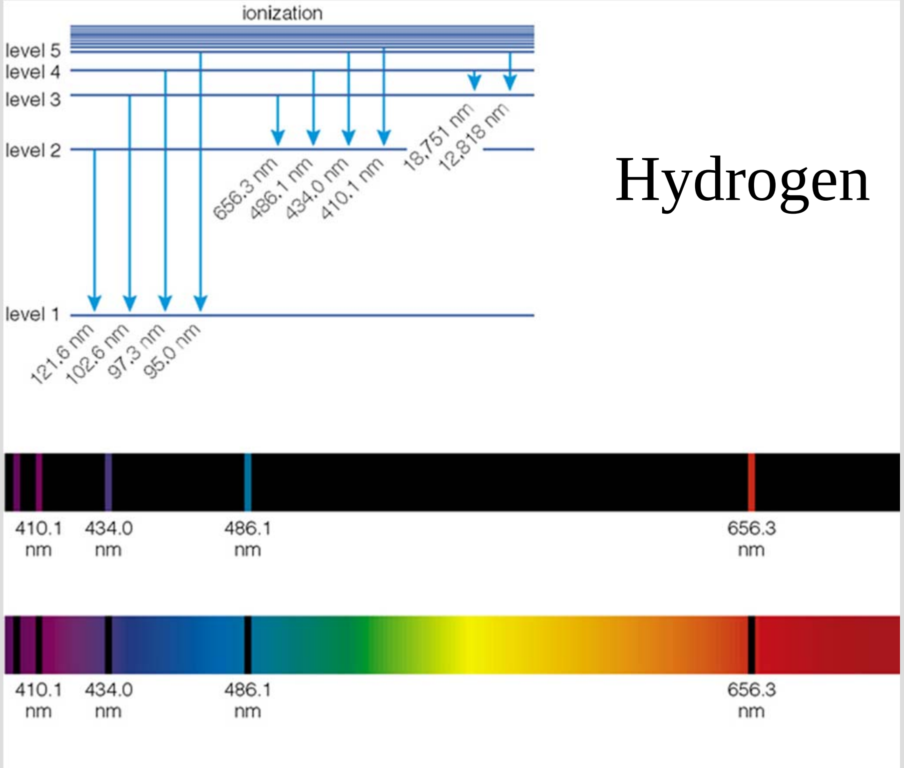
By studying the spectrum of an object, we can learn its:

1 Composition

2 Temperature

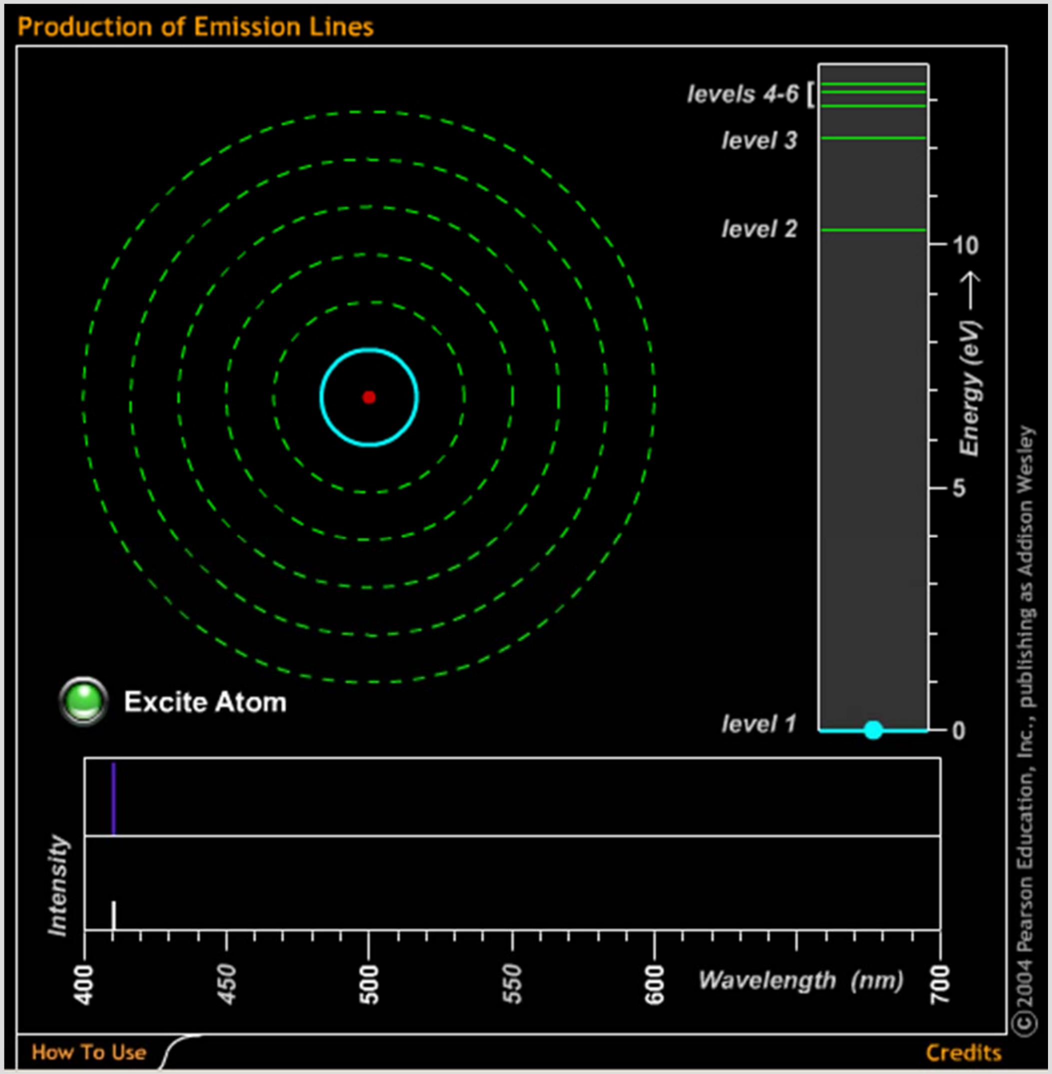
3 Velocity

Interaction of Light with Matter



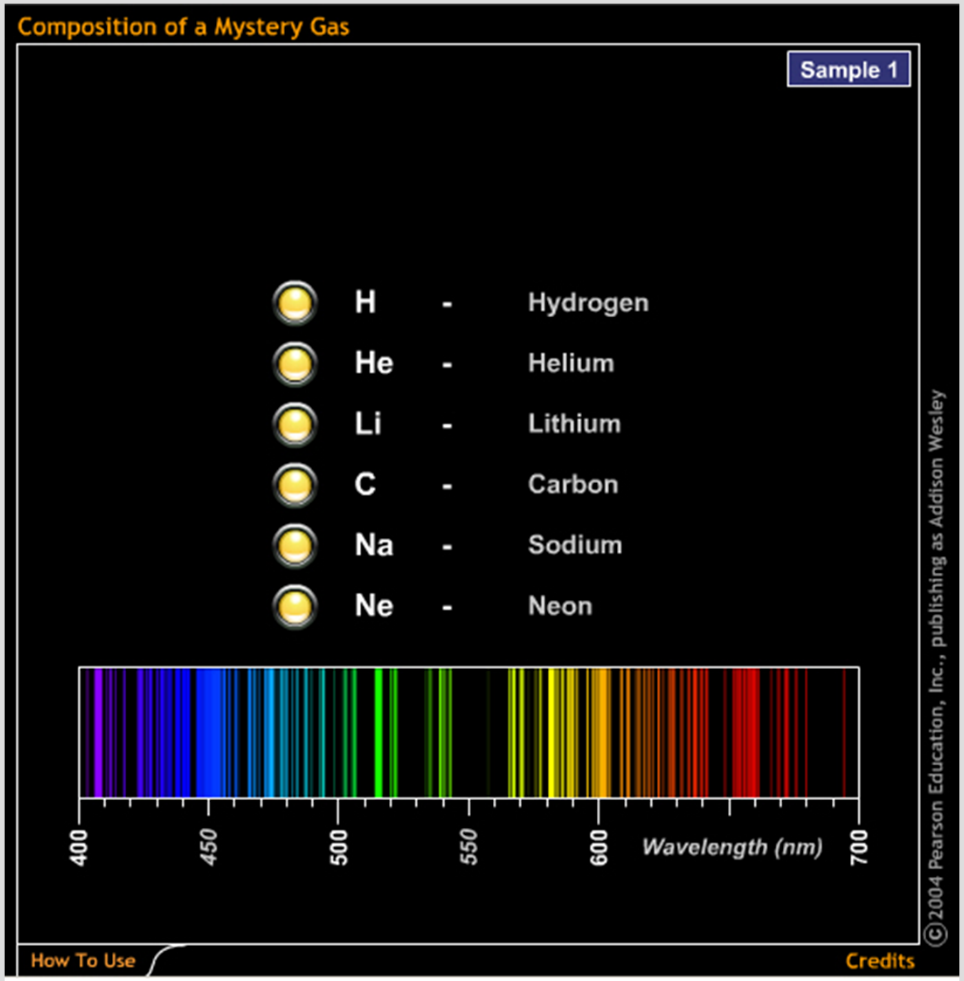
- Remember that each electron is only allowed to have certain energies in an atom.
- Electrons can absorb light and gain energy or emit light when they lose energy.
- It is easiest to think of light as a photon when discussing its interaction with matter.
- Only photons whose energies (colors) match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

Emission of Light

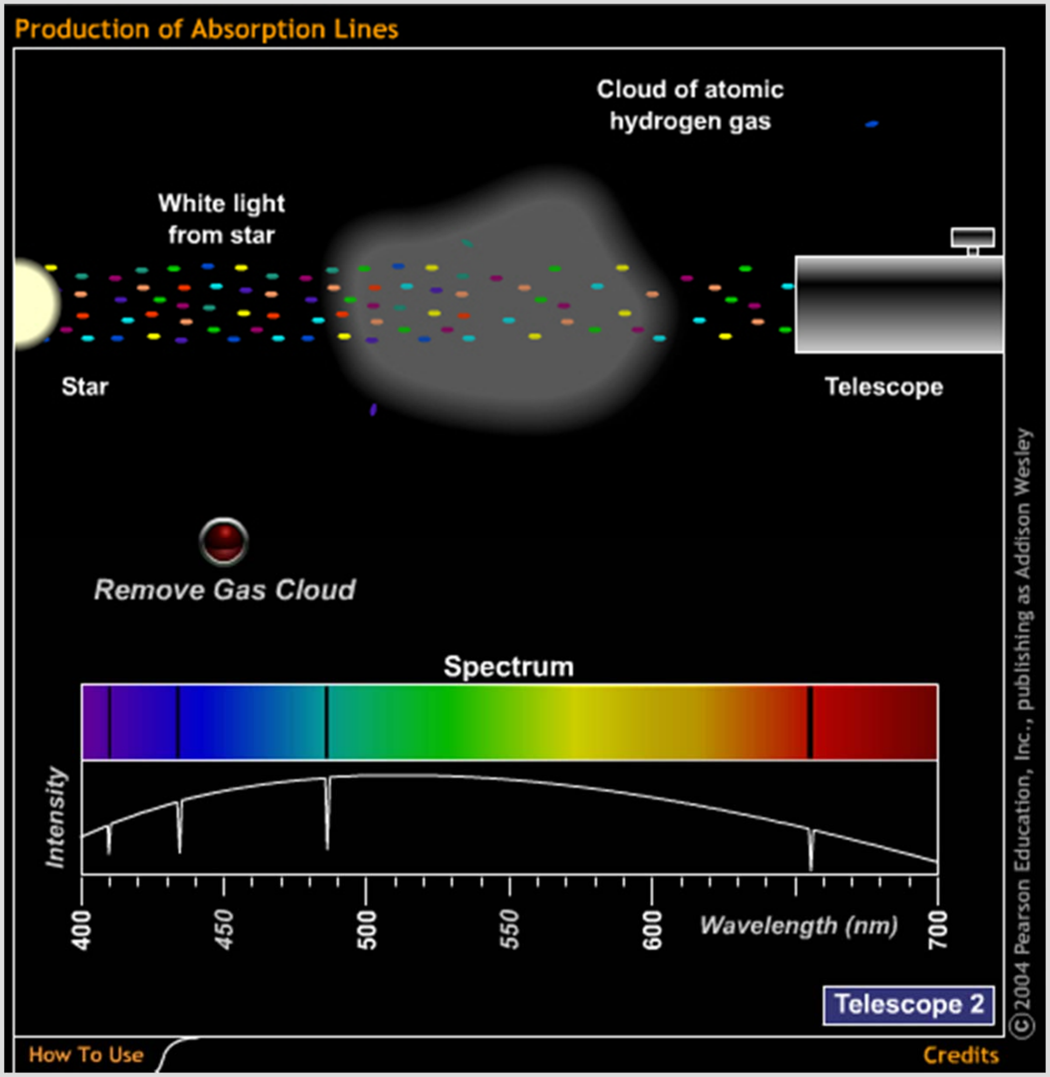


Emission Spectra

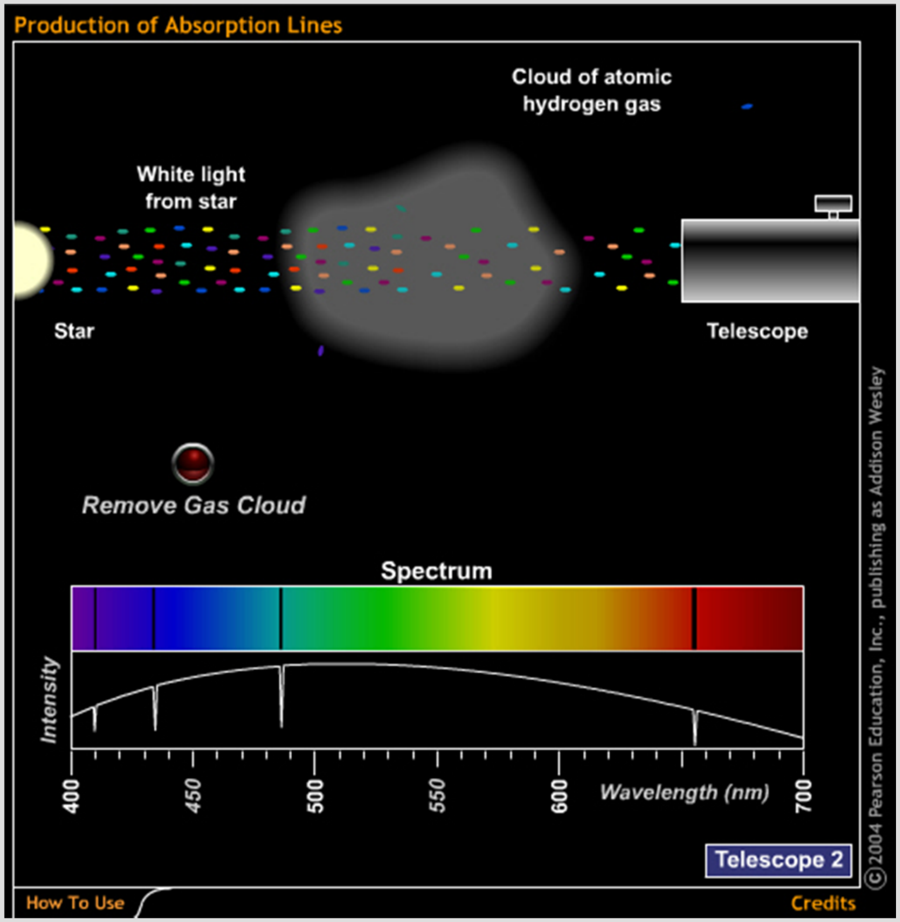
- The atoms of each element have their own distinctive set of electron energy levels.
- Each element emits its own pattern of colors, like fingerprints.
- If it is a hot gas, we see only these colors, called an **emission line spectrum**.



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

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

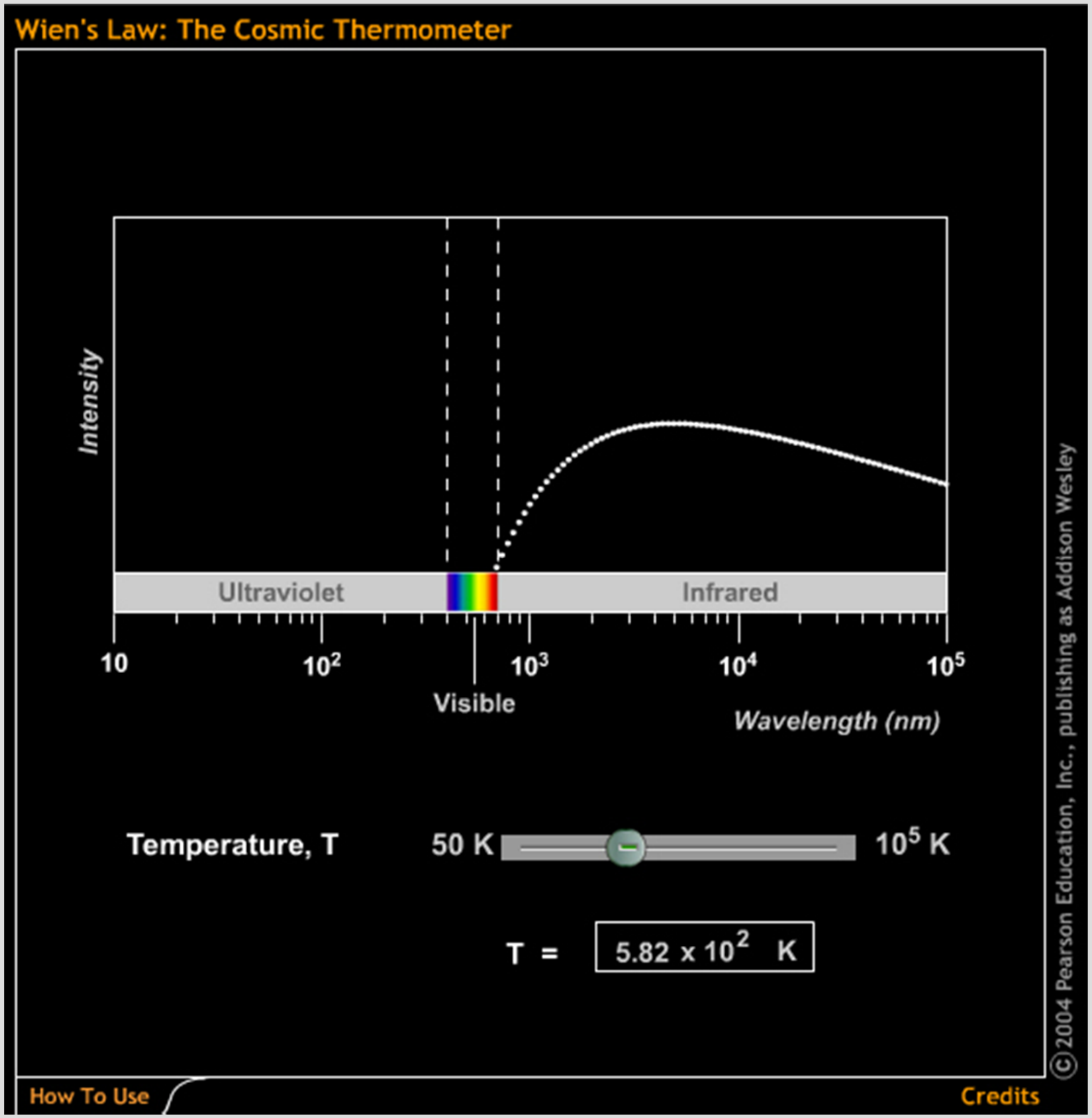
$\sigma = 5.67x10^{-8}$ (mks units)
A is area in square meters -- often $4\pi R^2$
T is temperature in Kelvin

Wien Law

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

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

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 --

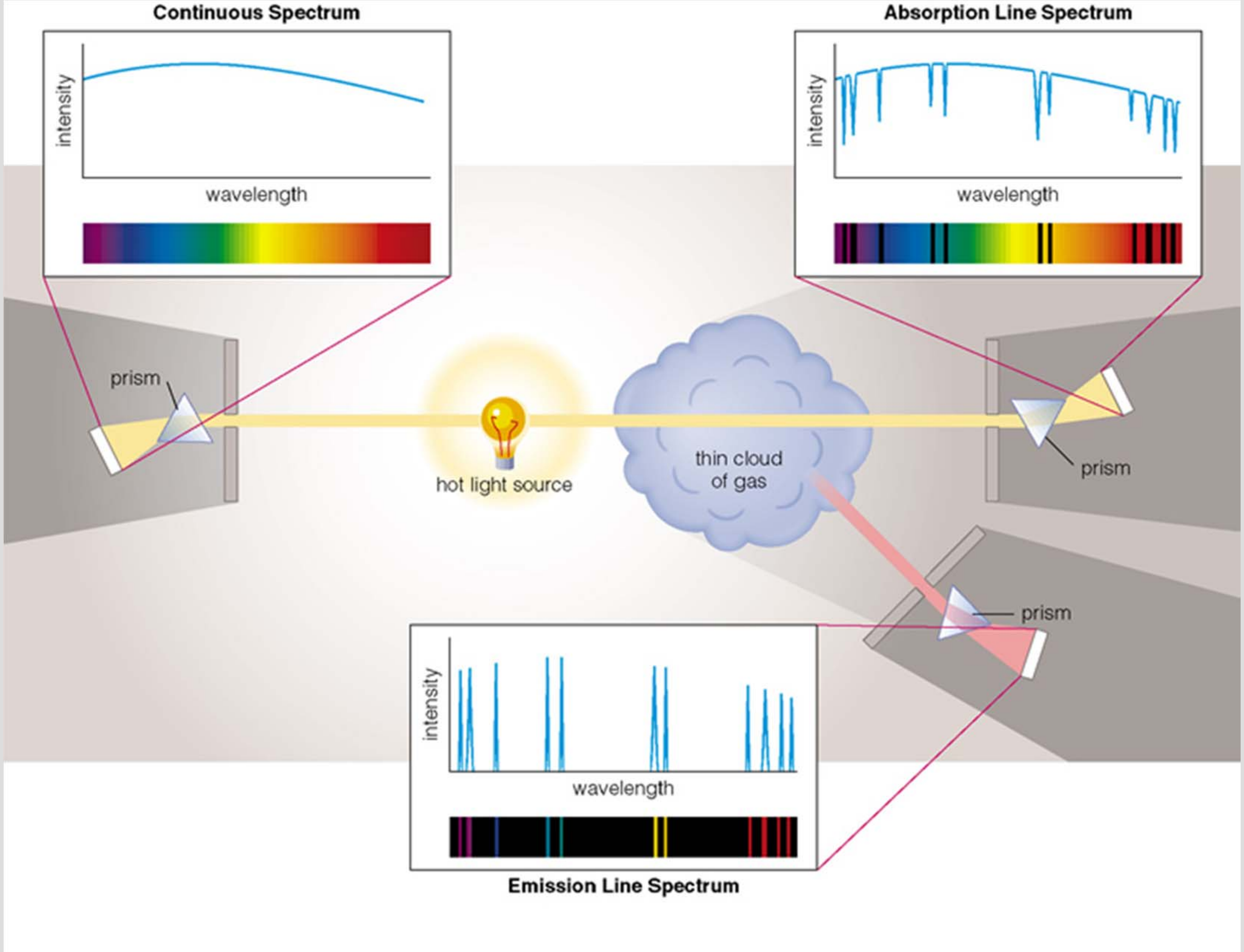
⇨ an emission line spectrum.

Kirchhoff’s Laws

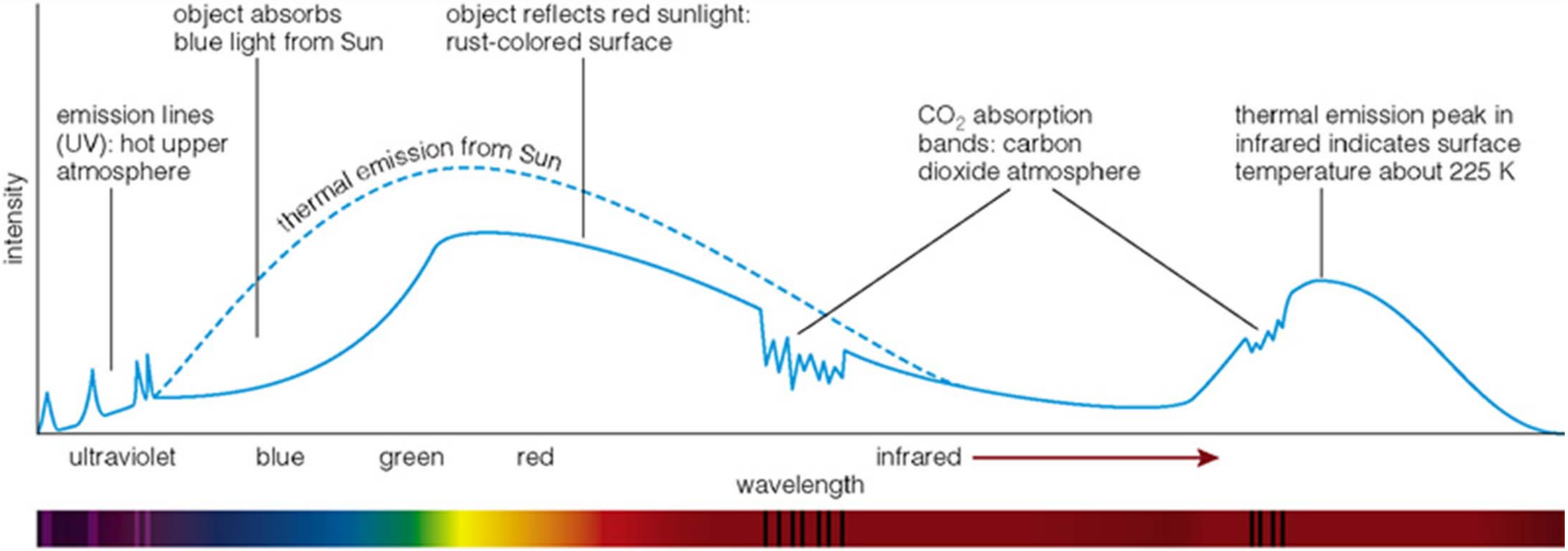
3 When light having a continuous spectrum passes through a cool gas, dark lines appear in the continuous spectrum --

⇨ 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.

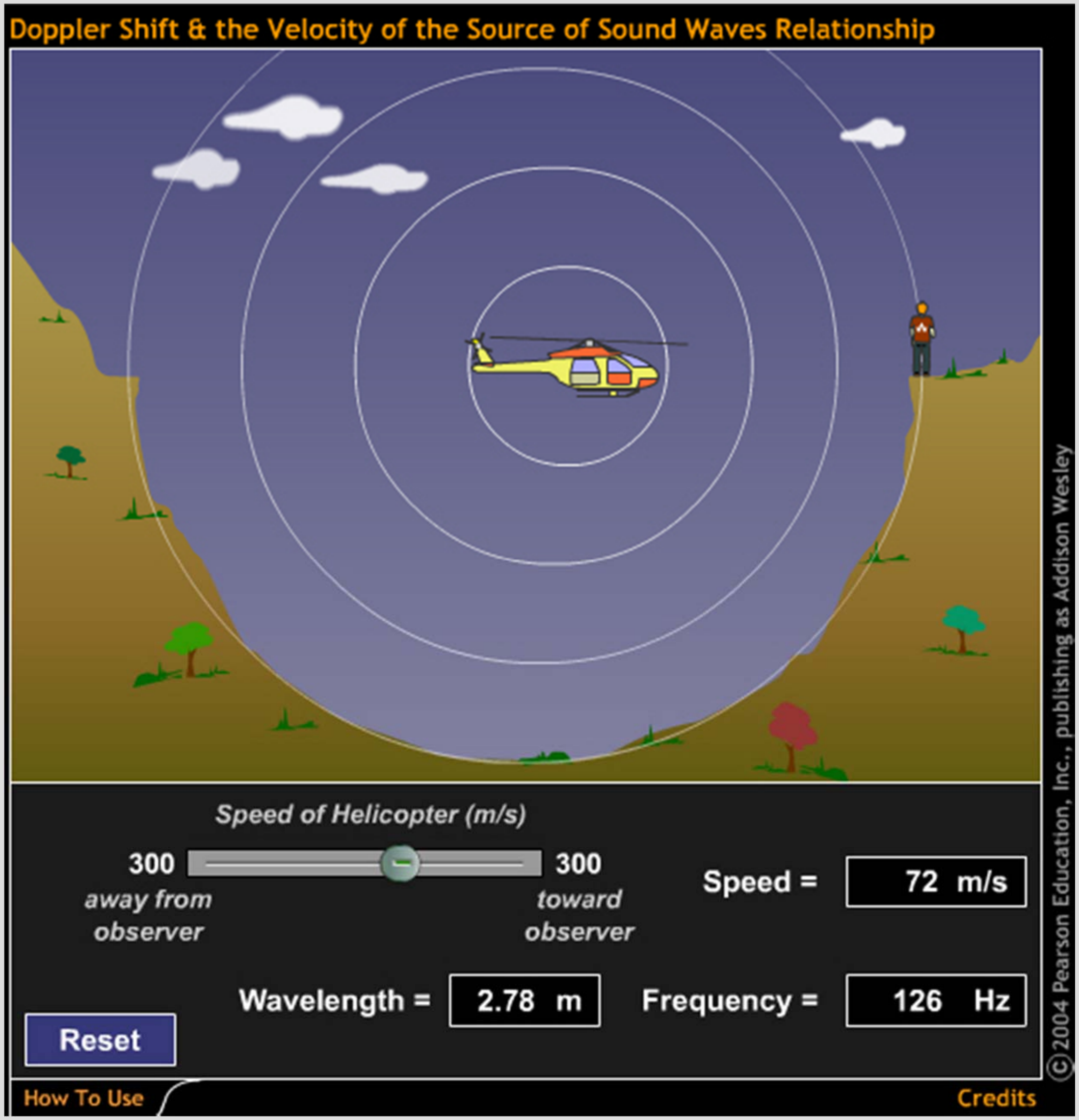
   BLUESHIFT

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

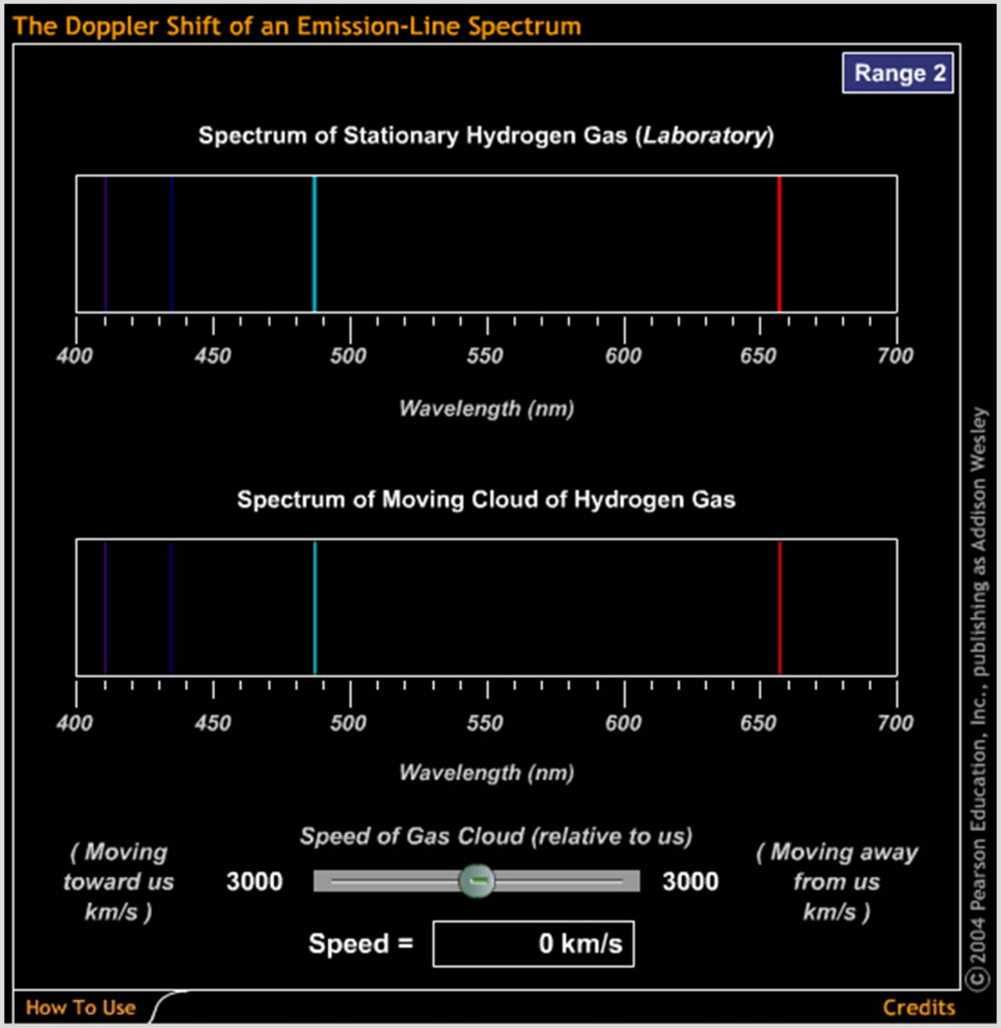


The Doppler Effect

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

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