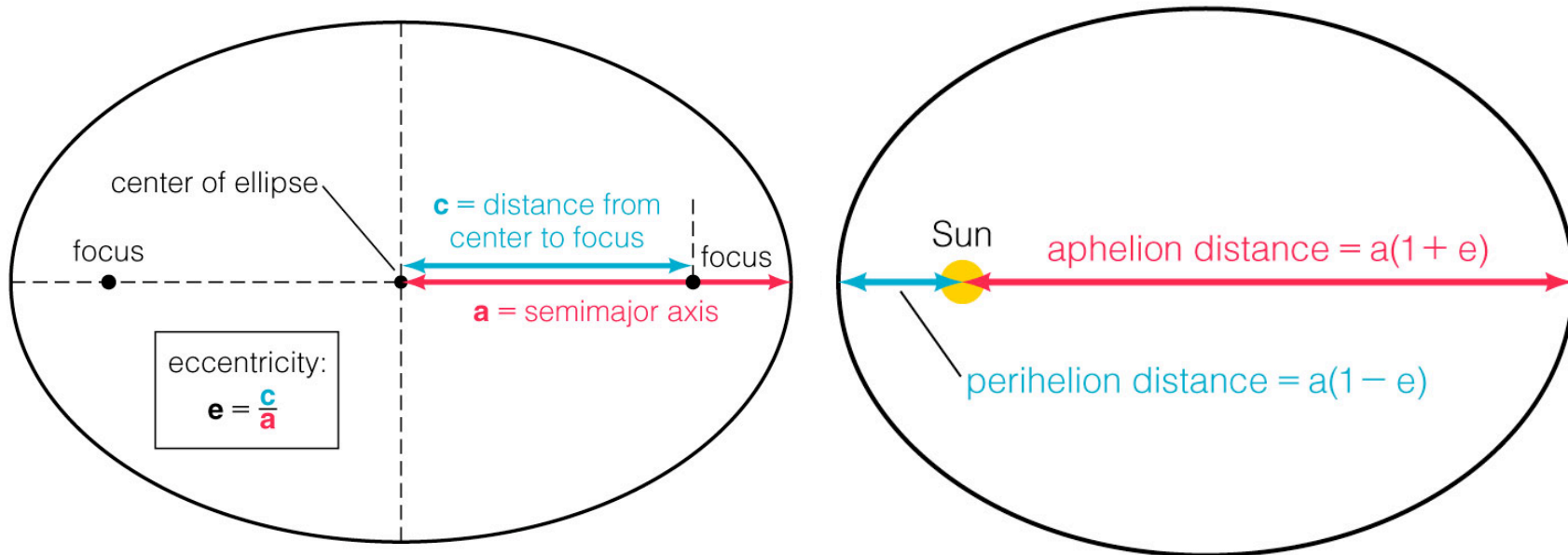


4- Kepler's Laws

1. Observe / Question
2. Hypothesize / Explain
3. Predict
4. Test!

A heliocentric model where planets move on ellipses = excellent predictions

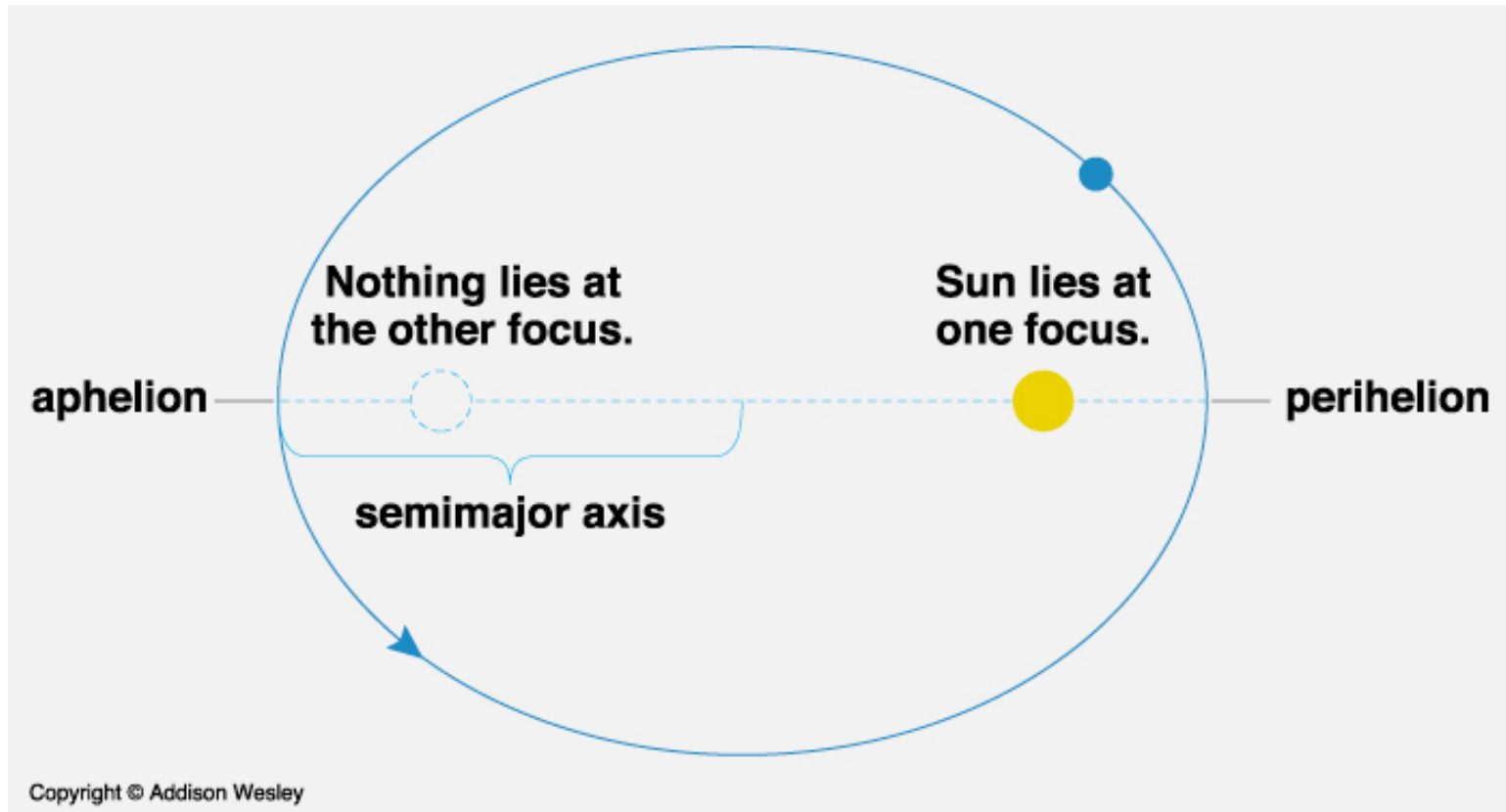


4- Kepler's Laws

Kepler's 1st Law:

All planets have elliptical orbits w/ the sun at one focus.

(Eccentricity of Earth's path = 1.7%... nearly perfect circle.)

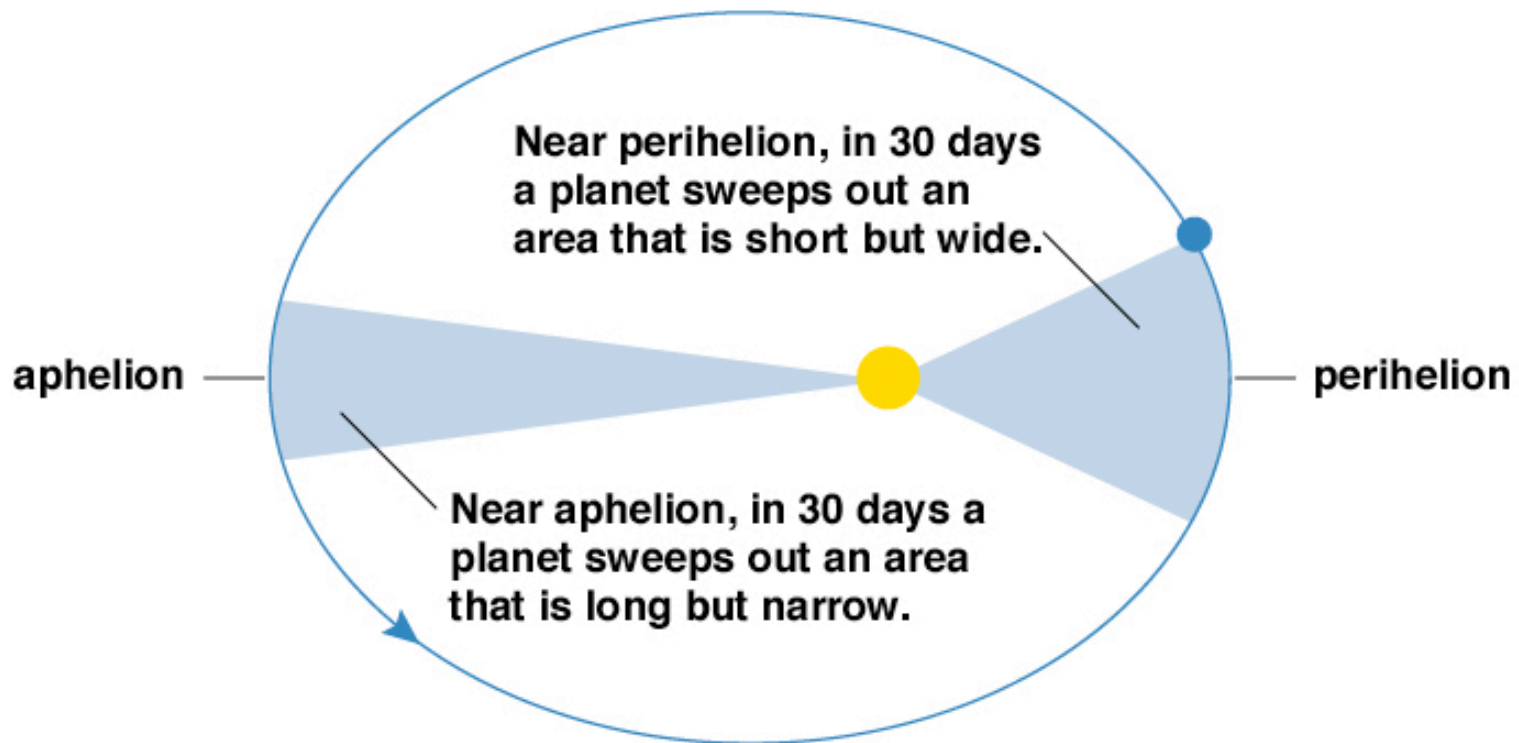


4- Kepler's Laws

Keplers 2nd Law:

A planets sweeps out equal areas in equal times.

i.e. Move fastest at perihelion. Slowest at aphelion.



The areas swept out in 30-day periods are all equal.

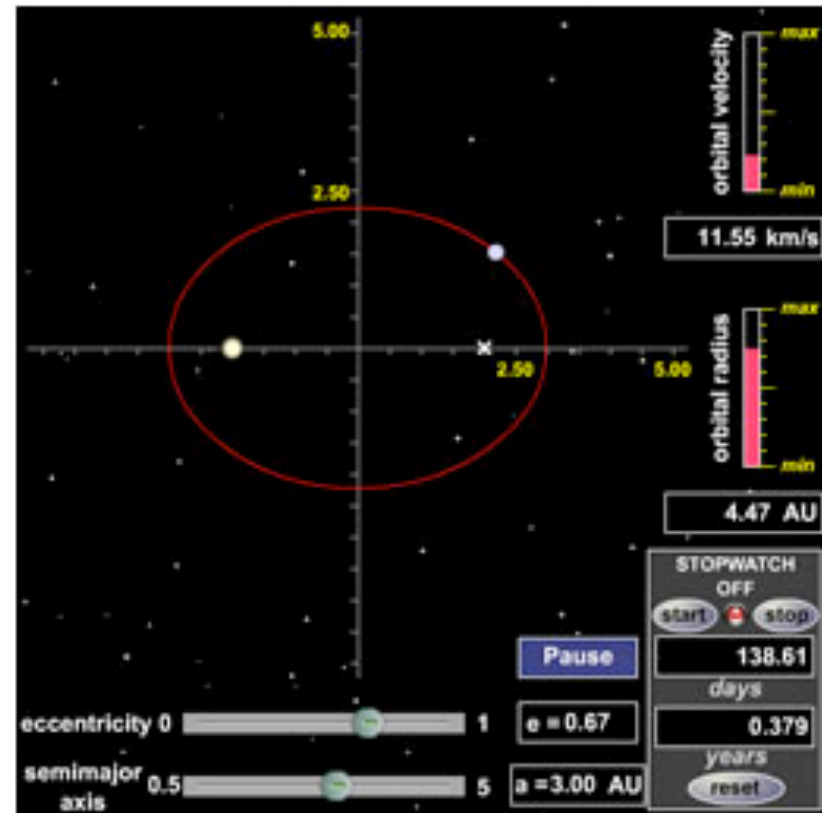
4- Kepler's Laws

Kepler's 3rd Law:

The ratio of

(a planet's average distance from the Sun)³ to (its orbital period)²
is a constant for all the planets.

$$a^3 / P^2 = \text{constant}$$



4- Kepler's Laws

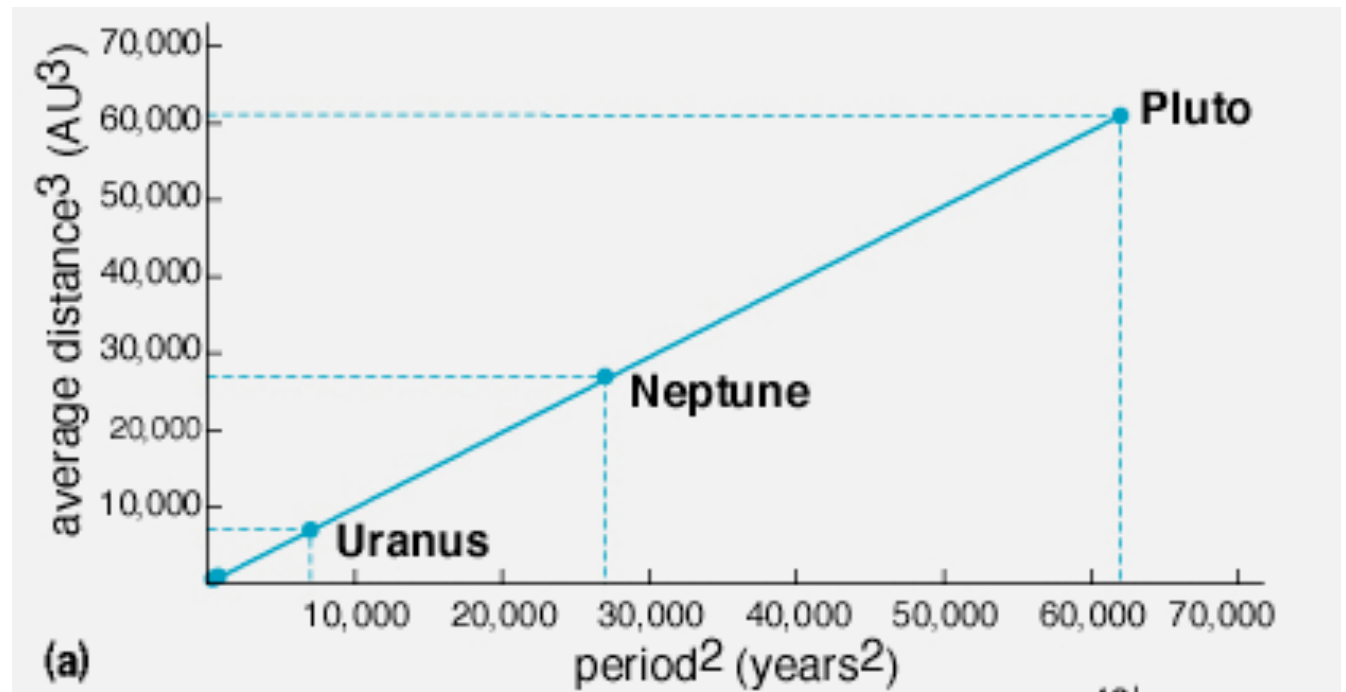
Kepler's 3rd Law:

The ratio of

(a planet's average distance from the Sun)³ to (its orbital period)²
is a constant for all the planets.

$$P^2 = \text{constant} * a^3$$

$$P = \text{constant} * a^{3/2}$$



iClicker Quiz #4: Moon's motion

The moon's spin period and orbital period around the Earth are about the same (both equal to about a month). Which of the following statements is FALSE?

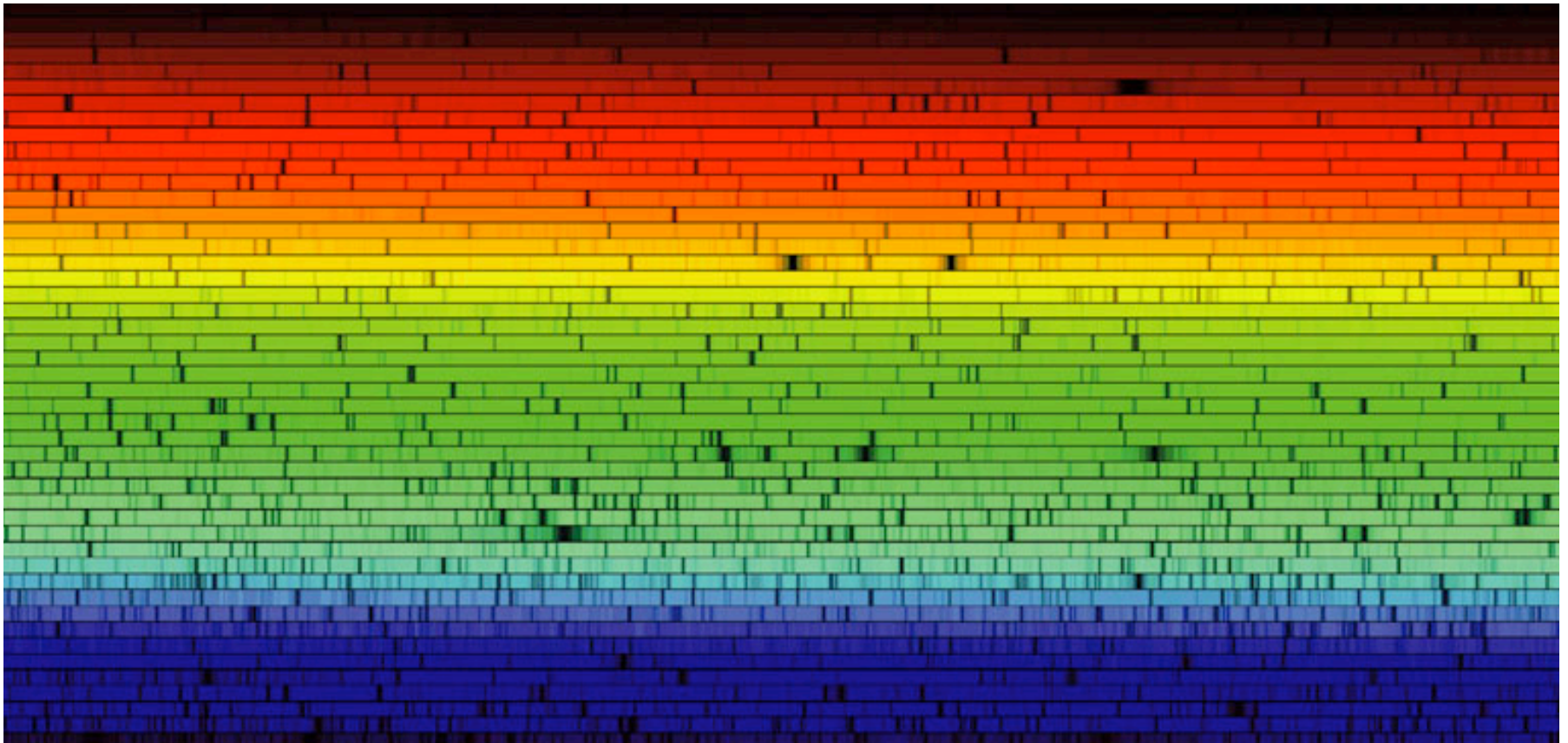
- A.** Only one half of the Moon's surface is sunlit at any given time but all parts of the Moon receive sunlight at one point in time or another
- B.** One half of the Moon is never visible to a person on Earth
- C.** A person on the Moon would see the Earth go through various phases and would see the Earth periodically rise and set
- D.** A person on the Moon would see the Earth at different phases (i.e. different fractions sunlit at different times)
- E.** The reason for the equality of the Moon's spin and orbital periods is because it is tidally locked to the Earth

iClicker Quiz #5: Tidal locking

Venus's spin period and orbital period around the Sun are about the same (analogous situation to the Moon-Earth system). Which of the following statements is TRUE?

- A. We always see the same half of Venus from Earth
- B. The same half of Venus always faces the Sun
- C. It is not possible to observe phases of Venus from the Earth
- D. It is possible to observe phases of Pluto from the Earth

Atoms, Light, and Radiation



A little intro...

Electric charges:

electrons (e ⁻)	-1
protons (p)	+1
neutrons (n)	0 (neutral)

fundamental unit of charge = 1 e⁻ !

In a *neutral* atom: net charge = 0 [# p = # e⁻]

The Electro-Magnetic forces: between CHARGED particles.

Electro-magnetic force: $F = -K (q_1 q_2 / r^2)$

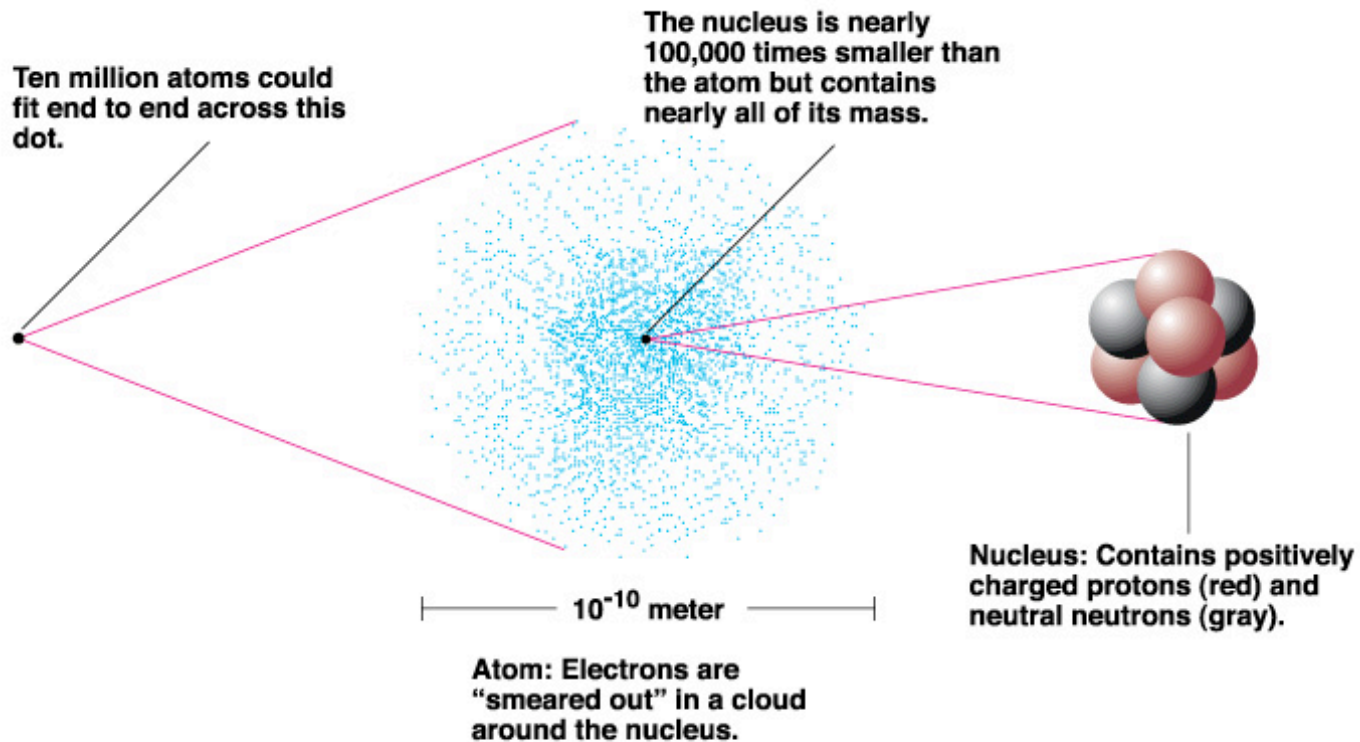
q = charge

r = distance between charges

like charges REPEL, opposite charges ATTRACT

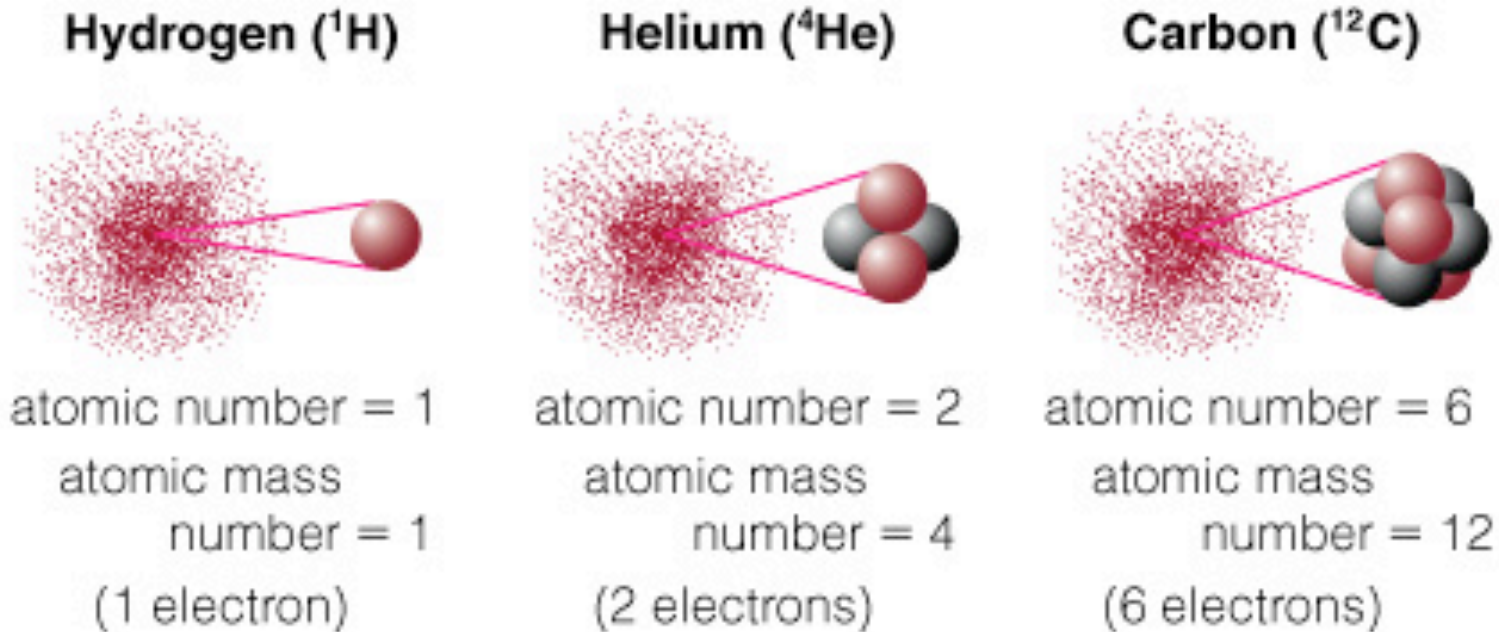
What is the structure of matter?

Atoms = Nucleus + Electron cloud
Nucleus contains protons and neutrons
Electrons sort of “orbit” the nucleus



Terminology

- **Atomic Number** = # of protons in nucleus
- **Atomic Mass Number** = # of protons + neutrons



- **Molecules**: consist of two or more atoms (H_2O , CO_2)

Terminology

- **Isotope:** same # of protons but different # of neutrons. (^4He , ^3He)

Isotopes of Carbon

carbon-12



^{12}C

(6 protons
+ 6 neutrons)

carbon-13



^{13}C

(6 protons
+ 7 neutrons)

carbon-14



(6 protons
+ 8 neutrons)

How is energy stored in atoms?

There is energy in the bonds between the particles.

ELECTRONS store energy that can be released easily.

When they release energy, they move to lower energy states.

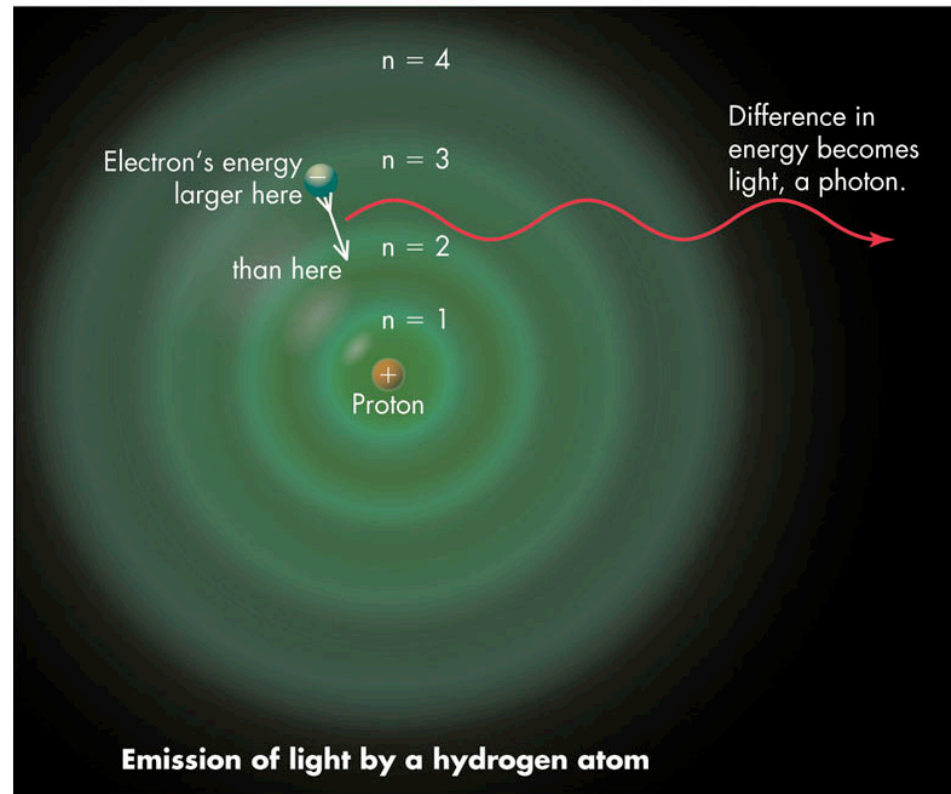
When the GAIN Energy, they move to higher energy states.

Key point is:

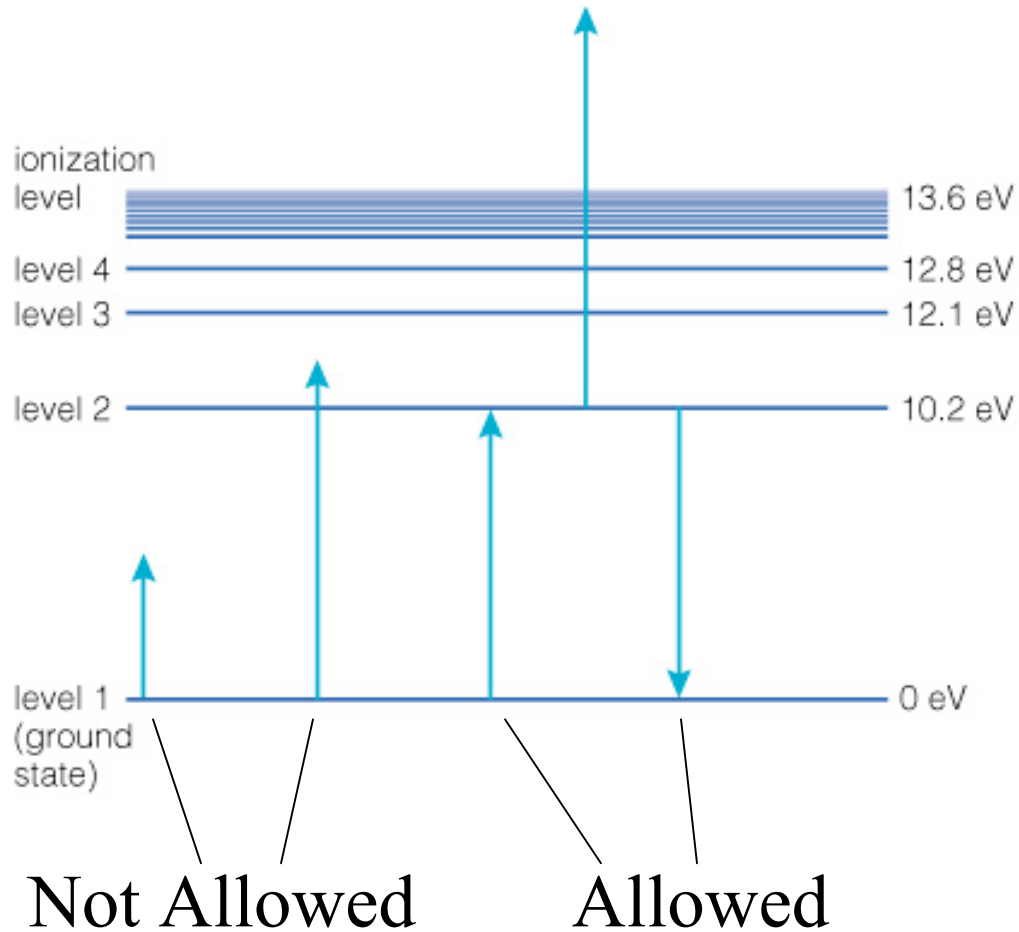
Electrons in atoms can only have QUANTIZED amounts of energy levels.

i.e. they can only be at specific energy levels, where the exact energy of these levels depends on the neutrons, protons, and other electrons in the nucleus..

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



Energy Level Transitions



- The only allowed changes in energy are those corresponding to a transition between energy levels

iClicker Quiz #6

Which of the following pictures properly depicts the crescent moon in the evening sky shortly after sunset?

- A. Neither picture #1 nor picture #2
- B. Picture #1 does, but picture #2 does not
- C. Picture #2 does, but picture #1 does not
- D. Both picture #1 and picture #2



iClicker Quiz #7

Say it's midday for an astronomer on Jupiter and, at the same instant, it is midnight for an astronomer on Earth. The sunlit face of the Earth looks like a full circle (i.e., a “full earth”) to the astronomer on Jupiter. Which of the following statements is **TRUE**:

- A. Jupiter, Earth, and the Sun are in a straight line in that order
- B. Jupiter is visible to the astronomer on Earth at that instant
- C. Jupiter is not visible to the astronomer on Earth at that instant
- D. Jupiter, the Sun, and Earth form a right angle
- E. Earth, Jupiter, and the Sun are in a straight line in that order

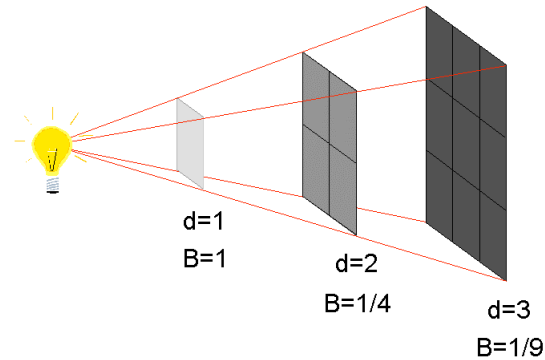
Schroedinger, Erwin! Professor of physics!
Wrote daring equations! Confounded his critics!
(Not bad, eh? Don't worry. This part of the verse
Starts off pretty good, but it gets a lot worse.)
Win saw that the theory that Newton'd invented
By Einstein's discov'ries had been badly dented.
"What now?", wailed his colleagues. Said Erwin, "Don't panic,
No grease monkey I, but a quantum mechanic.
Consider electrons. Now, these teeny articles
Are sometimes like waves, and then sometimes like particles.
If that's not confusing, the nuclear dance
Of electrons and suchlike is governed by chance!
No sweat, though—my theory permits us to judge
Where some of 'em is and the rest of 'em was."
Not everyone bought this. It threatened to wreck
The comforting linkage of cause and effect.
E'en Einstein had doubts, and so Schroedinger tried
To tell him what quantum mechanics implied.
Said Win to Al, "Brother, suppose we've a cat,
And inside a tube we have put that cat at—
Along with a solitaire deck and some Fritos,
A bottle of Night Train, a couple mosquitoes
(Or something else rhyming) and, oh, if you got 'em,
One vial prussic acid, one decaying ottom
Or atom—whatever—but when it emits,
A trigger device blasts the vial into bits
Which snuffs our poor kitty. The odds of this crime
Are 50 to 50 per hour each time.

The cylinder's sealed. The hour's passed away. Is
Our pussy still purring—or pushing up daisies?
Now, you'd say the cat either lives or it don't
But quantum mechanics is stubborn and won't.
Statistically speaking, the cat (goes the joke),
Is half a cat breathing and half a cat croaked.
To some this may seem a ridiculous split,
But quantum mechanics must answer, "Tough @#&!
We may not know much, but one thing's fo' sho':
There's things in the cosmos that we cannot know.
Shine light on electrons—you'll cause them to swerve.
The act of observing disturbs the observed—
Which ruins your test. But then if there's no testing
To see if a particle's moving or resting
Why try to conjecture? Pure useless endeavor!
We know probability—certainty, never."
The effect of this notion? I very much fear
'Twill make doubtful all things that were formerly clear.
Till soon the cat doctors will say in reports,
"We've just flipped a coin and we've learned he's a corpse."
So saith Herr Erwin. Quoth Albert, "You're nuts.
God doesn't play dice with the universe, putz.
I'll prove it!" he said, and the Lord knows he tried—
In vain—until fin'ly he more or less died.
Win spoke at the funeral: "Listen, dear friends,
Sweet Al was my buddy. I must make amends.
Though he doubted my theory, I'll say of this saint:
Ten-to-one he's in heaven—but five bucks says he ain't."

— CECIL ADAMS

Forces of Nature

- Newton's Laws of Motion
- Inverse square law of forces
- Fundamental forces (4)



(1) Gravitational force

Example:
falling
apple



(2) Electromagnetic force

Example:
horseshoe
magnet

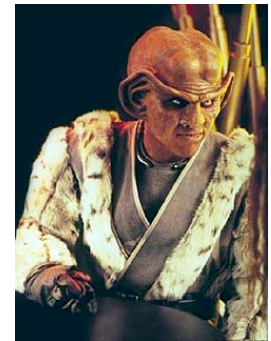


(3) Weak nuclear force

Example:

β -decay or

top \rightarrow bottom quark



(4) Strong nuclear force

Example:

force that binds
protons & neutrons
in atomic nuclei



What is Light?

Light = energy (sunlight feels warm!)

Energy unit: Joules

Flow of energy: Watts = 1 Joule/ second

Light can act either like a wave or a particle ... “wave/particle duality”

It is convenient to think of light as

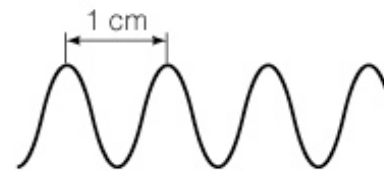
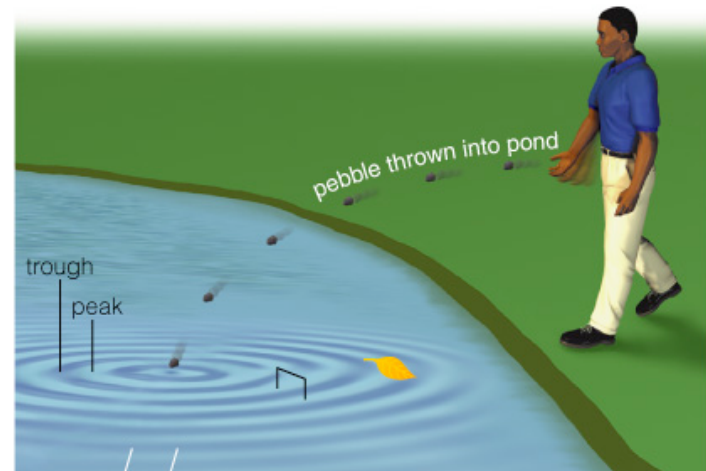
a photon -- because it acts like a packet of energy.

a wave -- because it moves like a wave moves

(this makes the math to describe light easier)

Waves

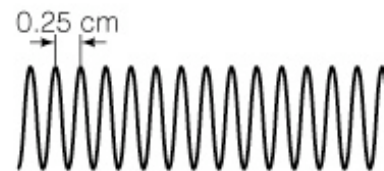
- A **wave** is a pattern of motion that can carry energy without carrying matter along with it
- **Wavelength** = distance between two wave peaks
- **Frequency** = number of times per second that a wave vibrates up and down



wavelength = 1 cm,
frequency = 30 Ghz



wavelength = $\frac{1}{2}$ cm,
frequency = 2×30 Ghz = 60 Ghz



wavelength = $\frac{1}{4}$ cm,
frequency = 4×30 Ghz = 120 Ghz

wave speed = wavelength x
frequency

$$\text{wave speed} = \lambda * f$$

Wavelength, Frequency, and Energy

A particle of light, a photon, is like an energy packet.

The energy carried by the photon is related to its wavelength and frequency.

$$\textit{photon's energy: } E = h * f = h * c/\lambda$$

$$\lambda * f = c = \text{the speed light (in a vacuum)}$$

$$\lambda = \text{wavelength (unit = meters)}$$

$$f = \text{frequency (unit = sec}^{-1}\text{)}$$

$$c = 3.00 \times 10^8 \text{ m/s} = \text{speed of light in vacuum}$$

$$h = 6.626 \times 10^{-34} \text{ joule sec}$$

our eyes are *detectors*:

- molecules in our eyes can absorb photons,
- the photons free electrons,
- and those electrical currents signals go to our brain.

Different energies = different colors!



Prisms bend the path of photons according to their energy.

White light contains a *continuum* of energies (wavelengths).

Electromagnetic Spectrum:

high energy

(break down molecules, damage DNA, release e- in metals)

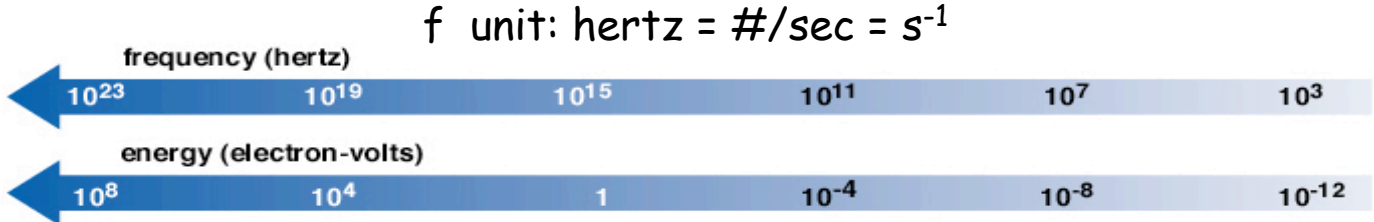
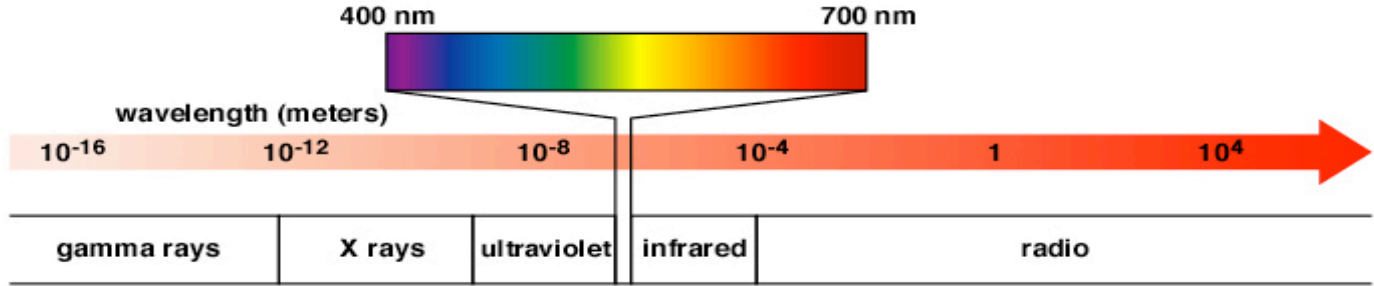
Moderate energies (“visible” bandpass, aka “optical” bandpass)

(the amounts of energy that release electrons from atoms)

low energy

(Can “shake” e-’s in metals, causing current in antennae, receivers, etc)

(“radio waves” are photons, NOT sound!)



iClicker Quiz #8

Which one of the following is **TRUE**:

- A. The Sun and Solar System lie about 1,000 light years from the center of the Milky Way galaxy
- B. The carbon, nitrogen, and oxygen present in the Sun and Earth were synthesized in nuclear fusion reactions in the Sun's core
- C. Mature galaxies tend to look more straggly than infant galaxies
- D. The subtle ripples in the density of the early Universe from which galaxies formed left imprints that are visible in the Big Bang's afterglow

iClicker Quiz #9

Which of the following statements most accurately describes what happens when **I HOLD A PIECE OF CHALK IN MY HAND:**

- A. A gravitational force and an electromagnetic force are canceling each other
- B. Only a gravitational force is acting on the piece of chalk
- C. Only an electromagnetic force is acting on the piece of chalk
- D. A gravitational force and a strong nuclear force are canceling each other

iClicker Quiz #10

Which of the following statements comparing our Sun to another star X located at the outer edge of the Milky Way galaxy is **TRUE**:

- A. They have the same orbital period around the center of our Galaxy
- B. Star X takes a longer time than the Sun to orbit the Galaxy's center
- C. The Sun takes a longer time than Star X to orbit the Galaxy's center
- D. Star X and the Sun are at the same distance from the center of the Milky Way

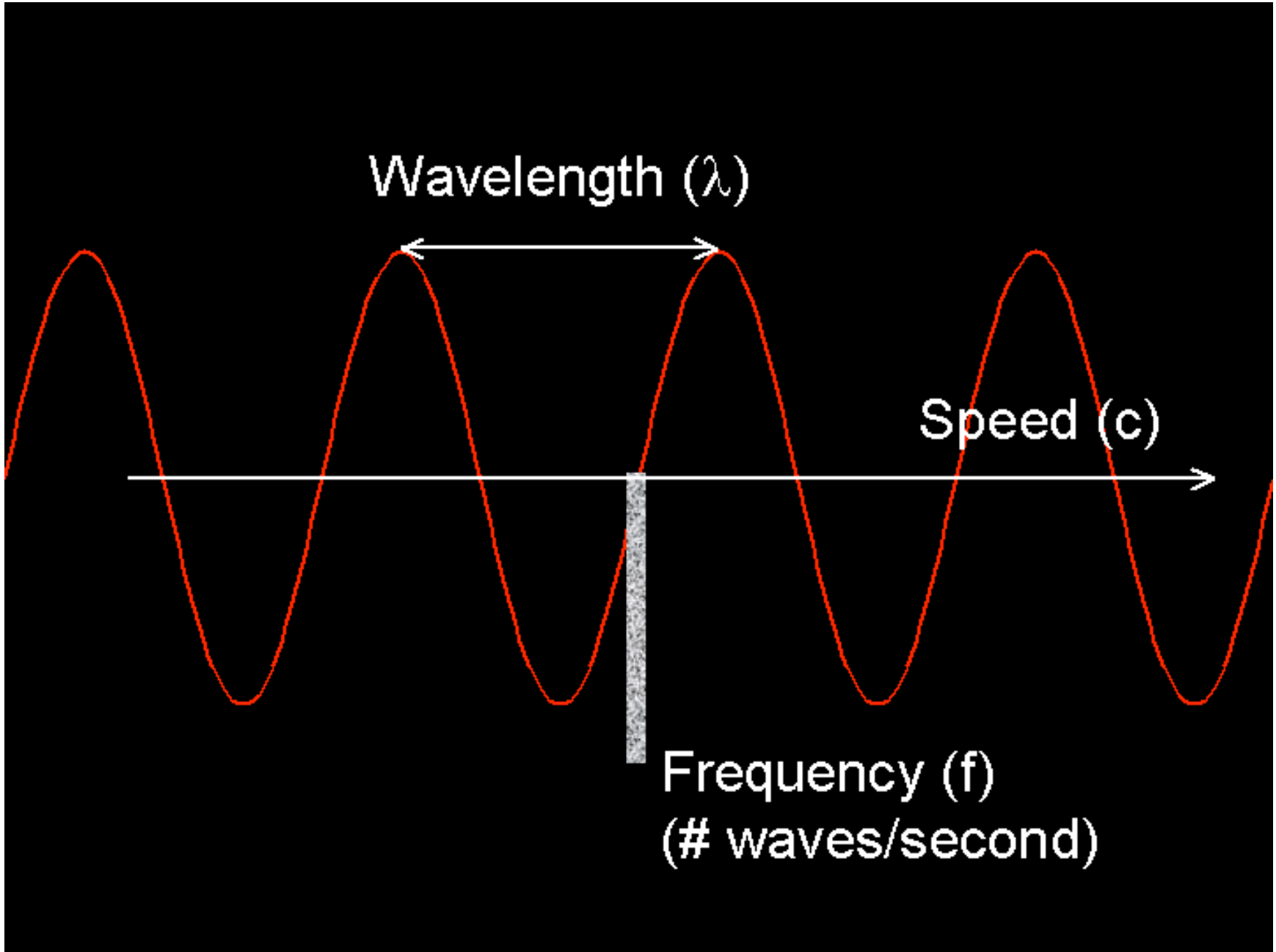
Electromagnetic Radiation

- Propagation of Energy in the Form of Oscillating Electric and Magnetic Fields
- Speed of propagation (in vacuum): $c = 300,000 \text{ km/s}$
- Frequency f : number of oscillations per second
[Unit of frequency: s^{-1} or Hertz (Hz)]
- Wavelength λ : distance traveled during one oscillation
[Unit of wavelength: meter (m), Angstrom ($1 \text{ \AA} = 10^{-10} \text{ m}$)]
- $c = \lambda f$ or $\lambda = c/f$ or $f = c/\lambda$
[f & λ are inversely proportional to each other]

Wavelength (λ)

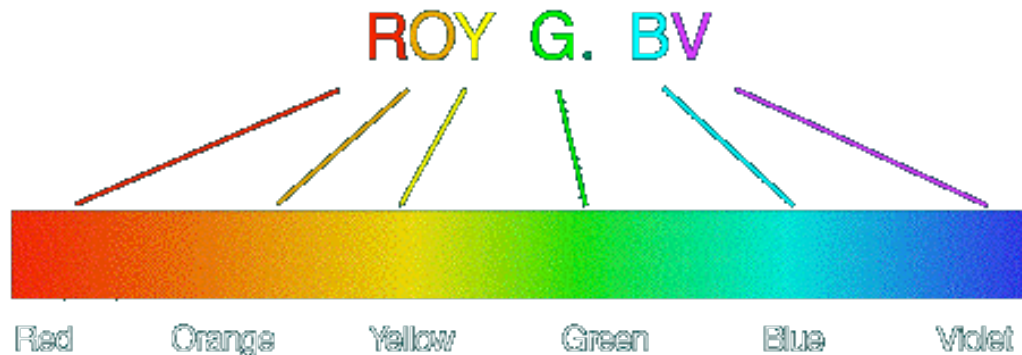
Speed (c)

Frequency (f)
(# waves/second)



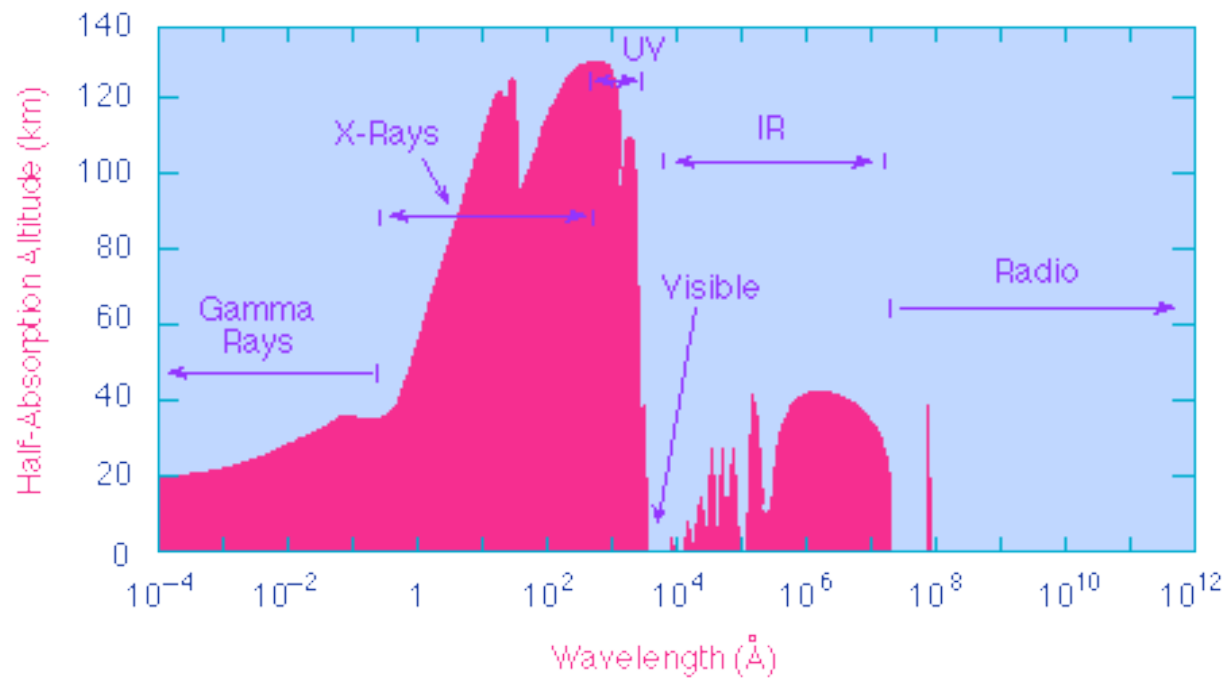
Electromagnetic Spectrum

- Progression of frequency or wavelength
Radio, millimeter, sub-millimeter, microwave, infrared, optical, ultraviolet, X-ray, gamma rays
- Optical/visible white light spectrum (rainbow colors):
Red Orange Yellow Green Blue Indigo Violet
[Order of decreasing wavelength, increasing frequency]



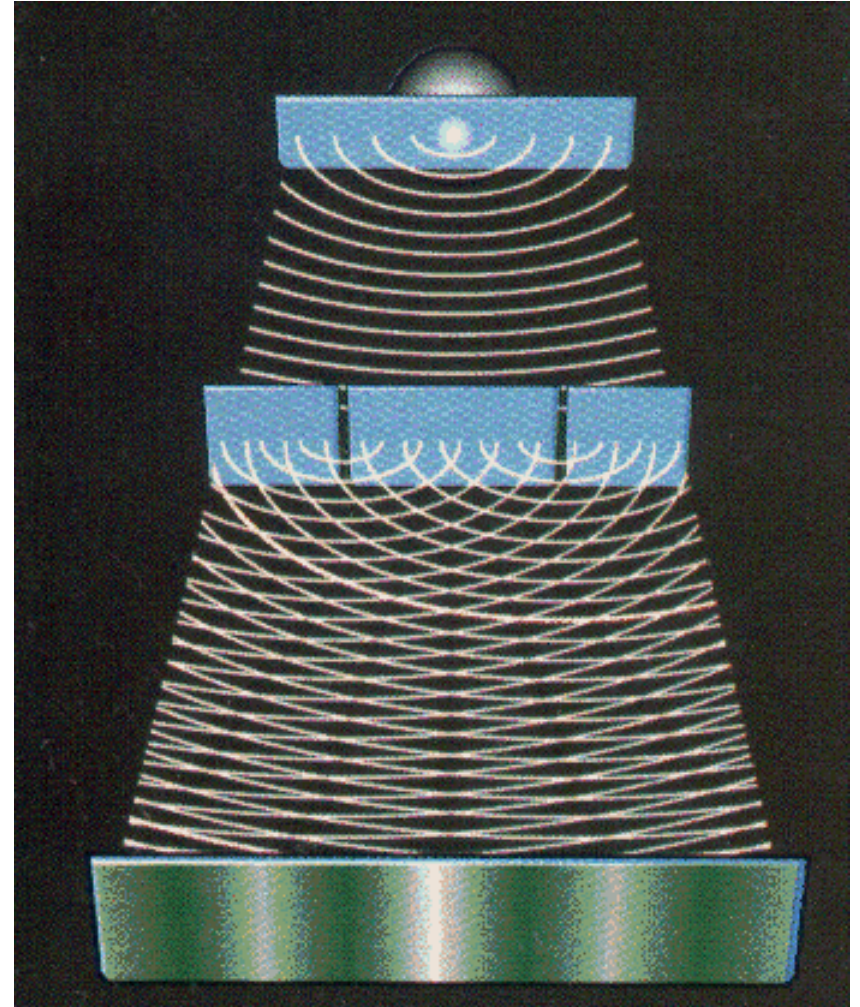
Atmospheric Windows

- Optical, [sub-millimeter], millimeter, and radio wavelengths
- Impact on astronomy (and on human evolution!)



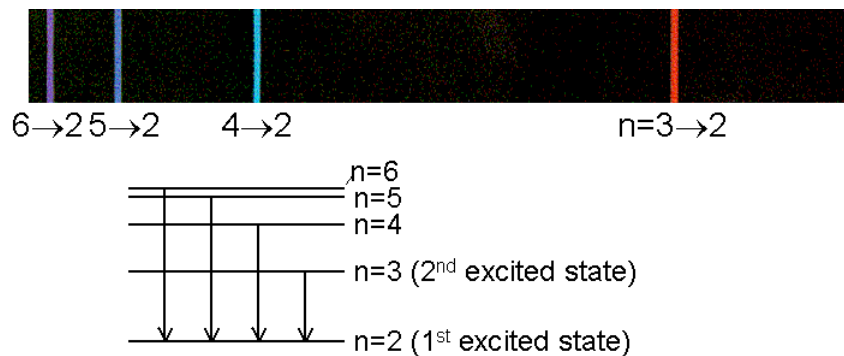
Wave-Particle Duality

- Radiation consists of energy bundles (quanta) called photons
- Energy of each photon: $E = hf$
where: h = Planck's constant, ν = frequency of radiation
[Energy of each photon depends on 'color' (λ , ν) of radiation]
- The more luminous a source of radiation, the more photons it emits per second



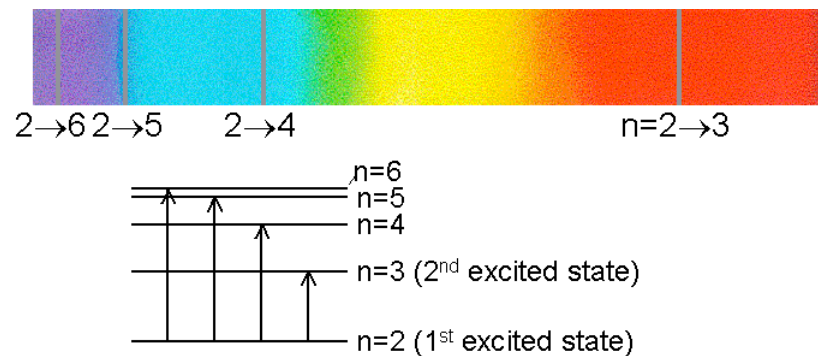
Atomic Energy Levels

- An atom in Quantum Mechanics; discrete energy levels
- Transitions between levels: emission & absorption lines



Larger Jump = More Energy = Bluer Wavelength

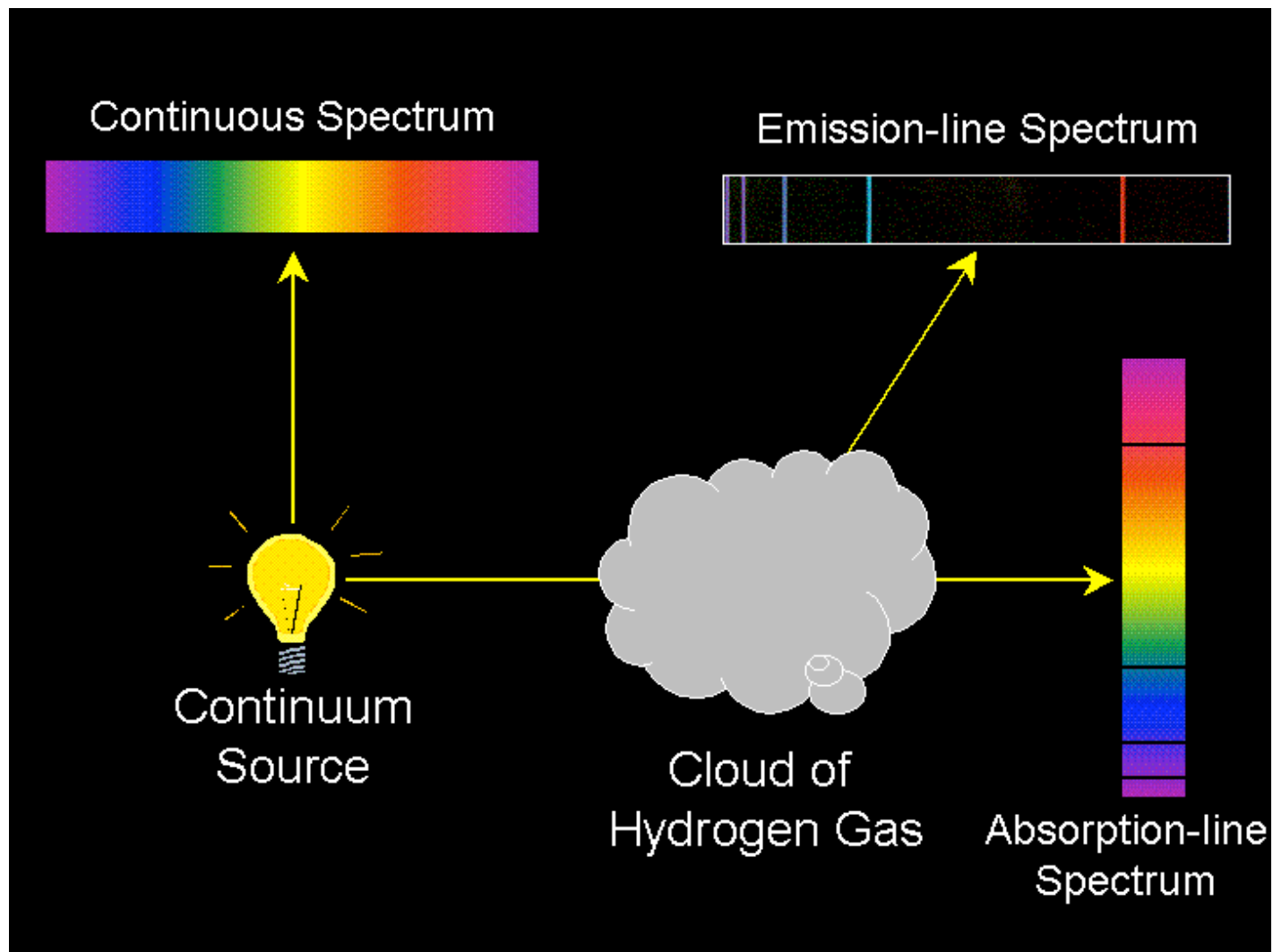
————— $n=1$ (Ground State)



Photons of all other energies (wavelengths) are ignored and pass on by unabsorbed.

————— $n=1$ (Ground State)

Continuum, Emission Line, and Absorption Line Radiation



Animations (week 3)

Eclipse Shadow Simulator

Phase Positions Demonstrator

Phases of Venus

Ptolemaic Phases of Venus

Ptolemaic Orbit of Mars

Epicycles Demo

Retrograde Motion

Kepler's Third Law

Planetary Orbit Simulator (NAAP)

Eccentricity Demonstrator

Hydrogen Atom Simulator (NAAP)

Spectrum Demonstrator

Three Views Spectrum Demonstrator

Doppler Shift Demonstrator

Extrasolar Planet Radial Velocity Demonstrator

Blackbody Curves of Melting