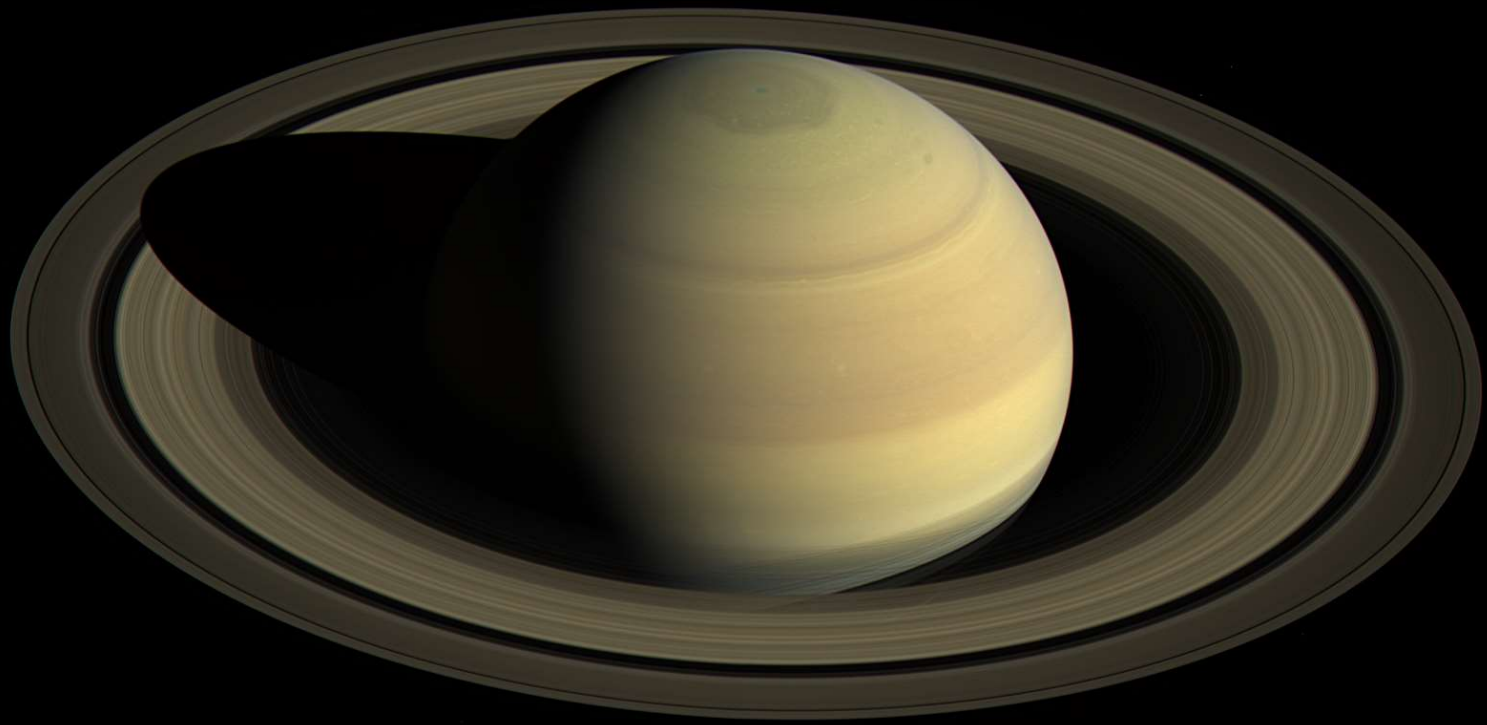
AST 2002
Introduction to Astronomy



A Few Quick Things…

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3pm. PSB 316

My office hours: Mon 3-4pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term is on Friday 9th February.
https://ucfsga.com/services/free-scantrons-and-blue-books/

Exam Tips… Go over lecture slides! … On Wednesday will give a better idea what to expect for exams… material from Today and Monday Will be on the first mid-term!

Knights Under the Stars event on Wednesday – Thank you for coming

Today: Tides &Light

Last Time:

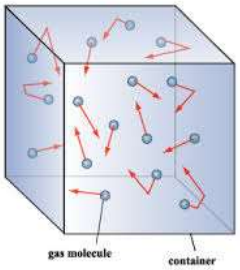
- Conservation Laws
- What determines the strength of gravity?
- How does Newton's law of gravity extend Kepler's laws?
- How do gravity and energy together allow us to understand orbits?

Topics Covered Today:

- How does gravity cause tides?
- What is light and matter, and how do they interact?
- Three types of Spectra
- What can we learn from light (composition, temperatures, and speed/distance)

Law of Conservation of Energy

"energy can neither be created nor destroyed; rather, it can only be transformed from one form to another"



Forms of Energy

Energy

can be

Kinetic Energy

energy of movement

Potential Energy

stored energy

energy comes from moving

energy is stored to be used later

we experience energy in different ways

Thermal Energy

energy of moving particles (heat)

Mechanical Energy

energy of objects in motion

Electrical Energy

energy of particles moving through a wire

Magnetic Energy

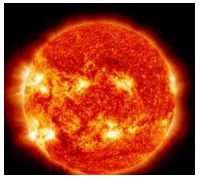
energy causing push or pull

Sound Energy

form of energy we can hear

Light Energy

form of energy our eyes can detect



Chemical Energy

energy stored in food, fuel

Elastic Energy

energy stored in objects that are stretched

Nuclear Energy

energy stored in centre of particles

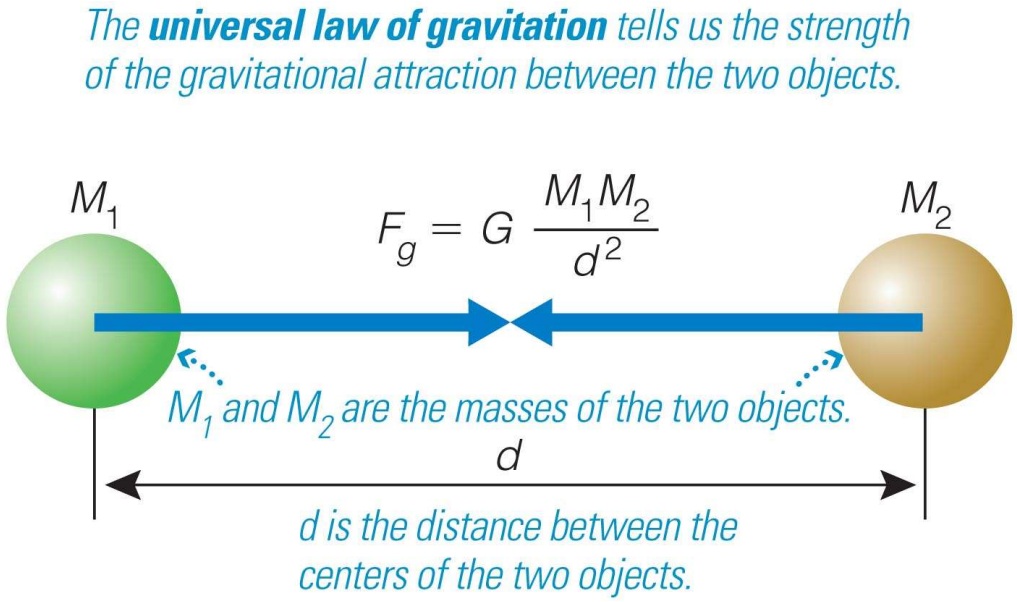
Gravitational Energy

energy stored in an object when it is above the earth's surface

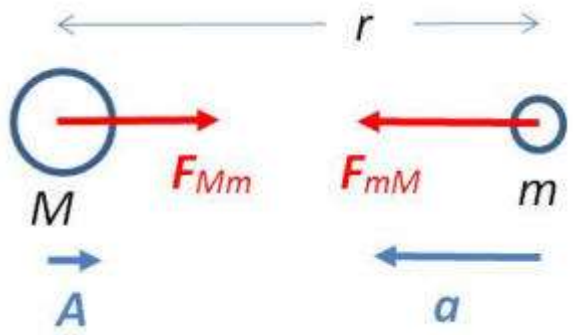
What determines the strength of gravity?

The **Universal Law of Gravitation:**

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



The Force between two objects must be the same



But the acceleration each experiences may be different (F=ma)

Newton's Version of Kepler's 3rd Law

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

p = orbital period, in seconds

a = average orbital distance (between centers), in meters

(M_1 + M_2) = sum of object masses, in kg

G is the gravitational constant, $6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}$

Example: Use the fact that Earth orbits the Sun at an average distance of 1 AU over the period of 1 year to calculate the Sun's mass.

$$p_{Earth}^2 = \frac{4\pi^2}{G(M_{Sun} + M_{Earth})} a_{Earth}^3$$

$M_{Sun} + M_{Earth} \sim M_{Sun}$ (> 3×10^6 M_{Earth})

1 AU = 1.5×10^{11} m

1 year = 3.15×10^7 seconds

Substitute:

$$p_{Earth}^2 \sim \frac{4\pi^2}{G \times M_{Sun}} a_{Earth}^3$$

Rearrange:

$$M_{Sun} \sim \frac{4\pi^2}{G \times p_{Earth}^2} a_{Earth}^3$$

Evaluate:

$$M_{Sun} \sim \frac{4\pi^2}{\left(6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}\right) \times (3.15 \times 10^7\ s)^2} \times (1.5 \times 10^{11} m)^3 \sim 2.0 \times 10^{30}\ kg$$

Newton's version of Kepler's third law & Orbits

If a small object orbits a larger one and you measure the orbiting object's orbital period AND average orbital distance THEN you can calculate the mass of the larger object.

Examples:

- Calculate the mass of the Sun from Earth's orbital period and average distance.
- Calculate the mass of Earth from orbital period and distance of a satellite.
- Calculate the mass of Jupiter from orbital period and distance of one of its moons.

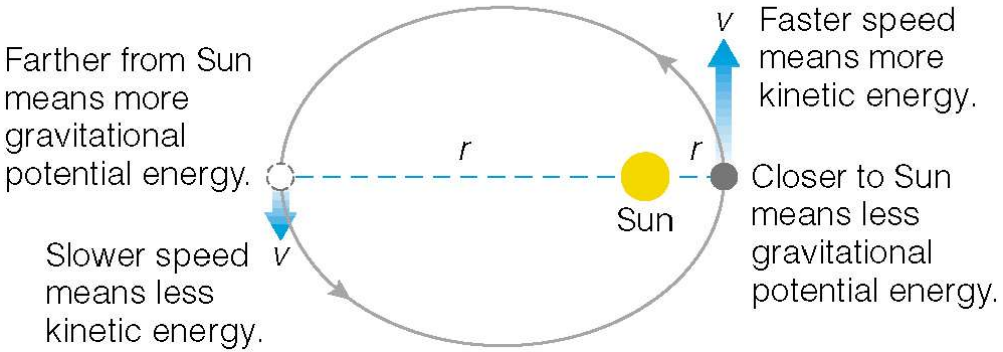
What else can we learn from Conservation Laws?

- Orbits cannot change spontaneously *(would orbit continuously)*

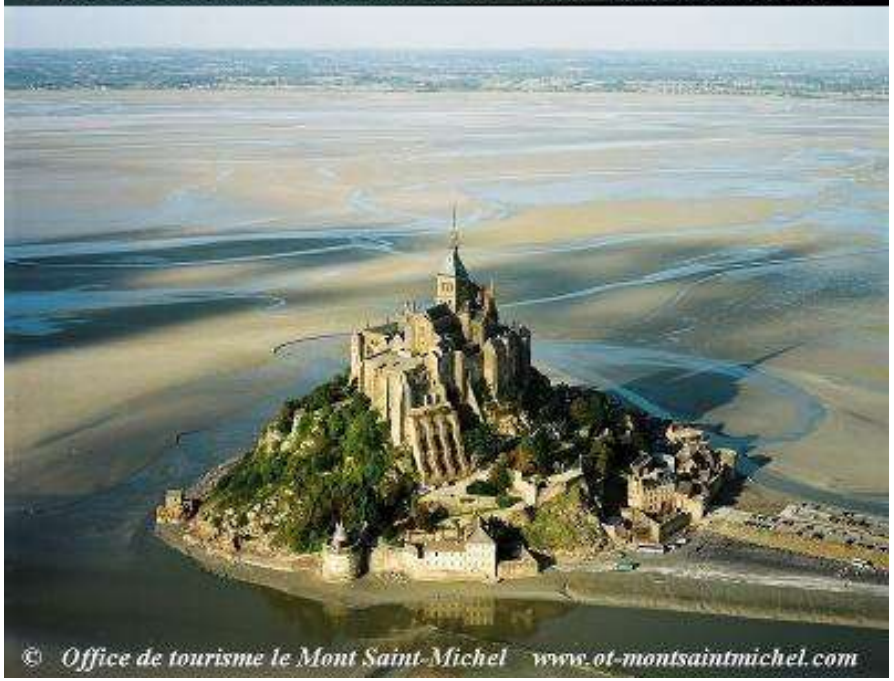
- An object's orbit can only change if it somehow gains or loses orbital energy =

  kinetic energy + gravitational potential energy

Total orbital energy (gravitational potential energy plus kinetic energy) stays constant.

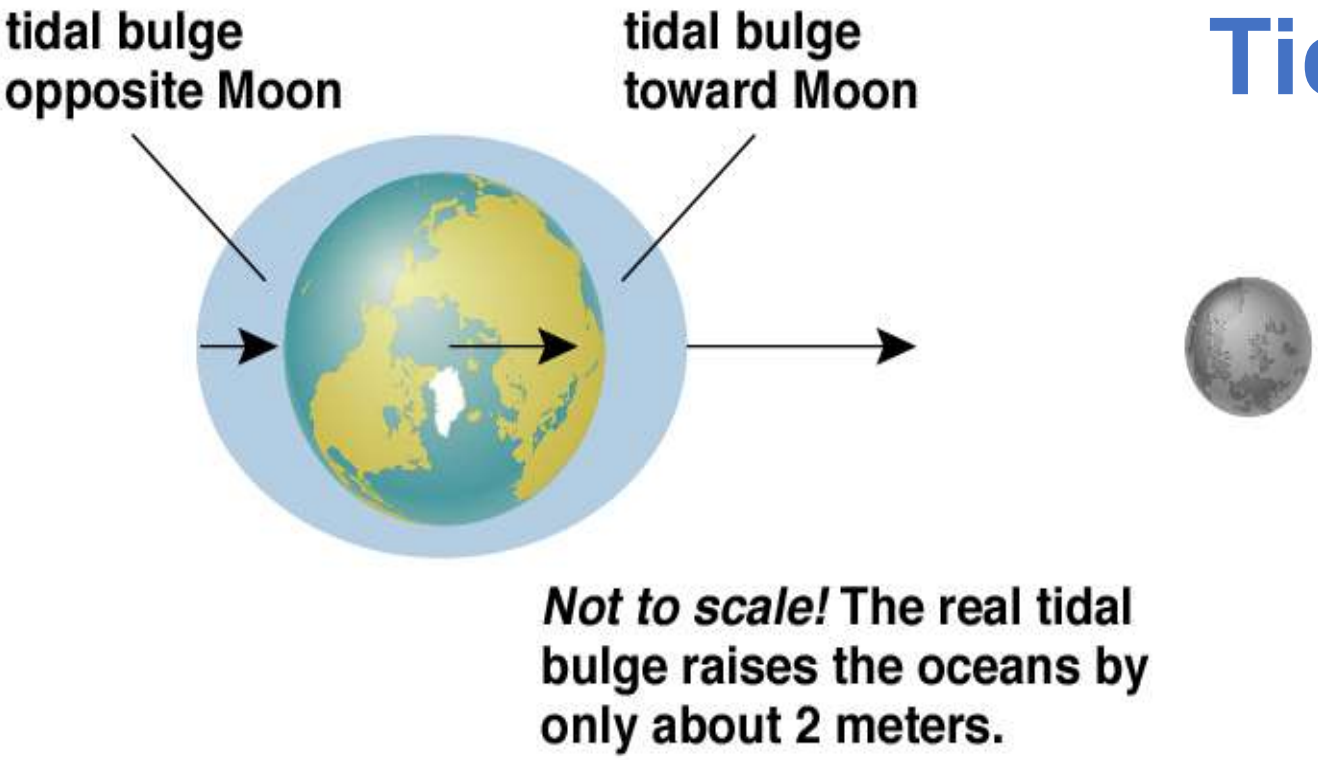


Tides



- Every place on Earth passes through high tides twice per day as the Earth rotates.
- High tides occur every 12 hours 25 minutes
  - remember, the Moon moves!
- The Sun's tidal effect on Earth is not as strong. Remember the inverse square law….the Sun is a long way away.

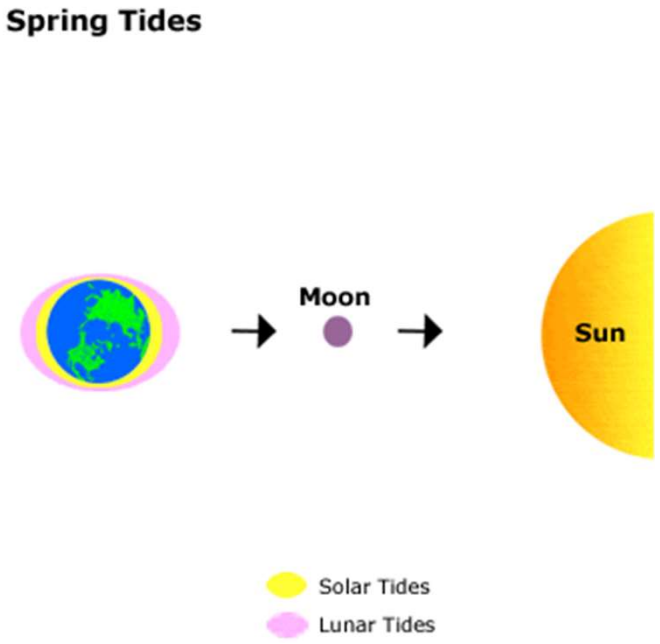
Tides

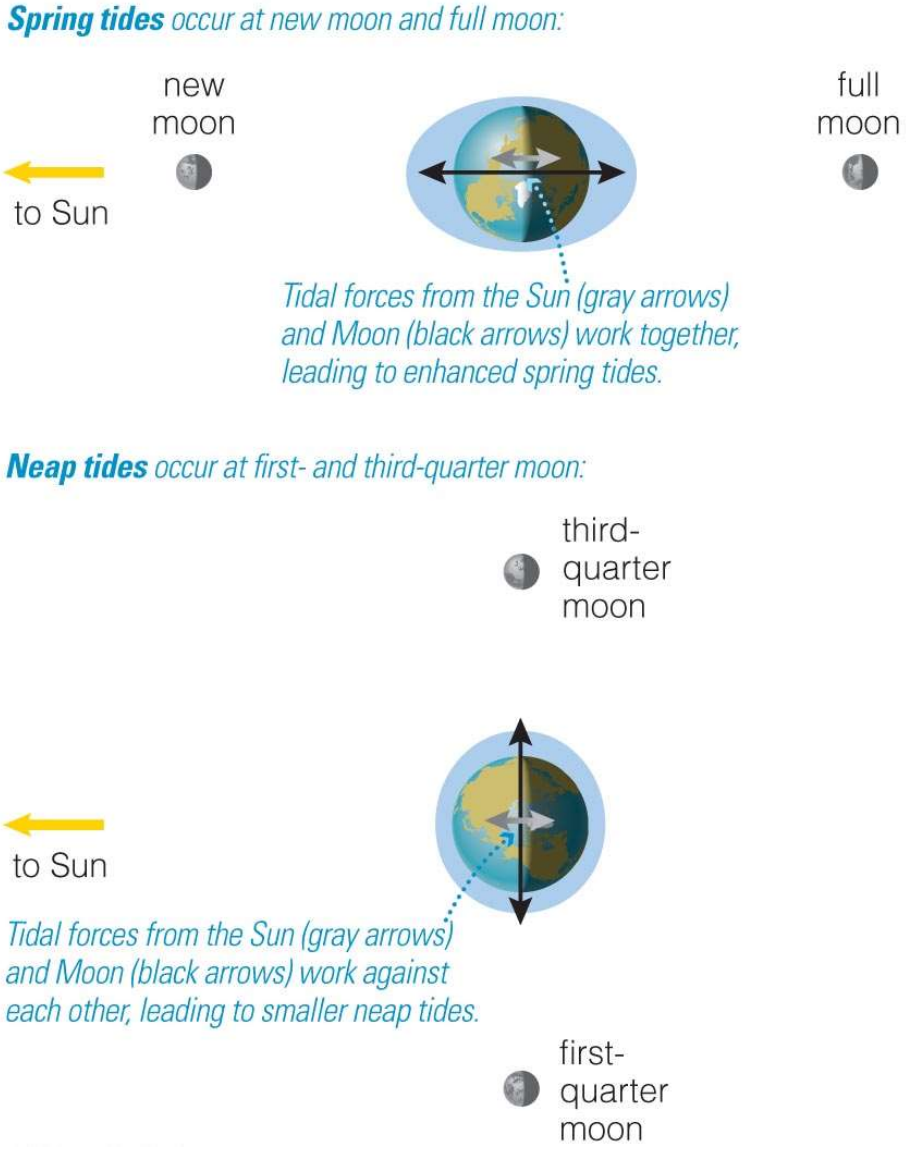


- **Gravitational force decreases with (distance)^2**
  - **The Moon's pull on Earth is strongest on the side facing the Moon, and weakest on the opposite side.**
- **The Earth gets stretched along the Earth-Moon line.**
- **The oceans rise relative to land at these points.**

Tides and Phases

Size of tides depends on the phase (relative position) of the Moon.

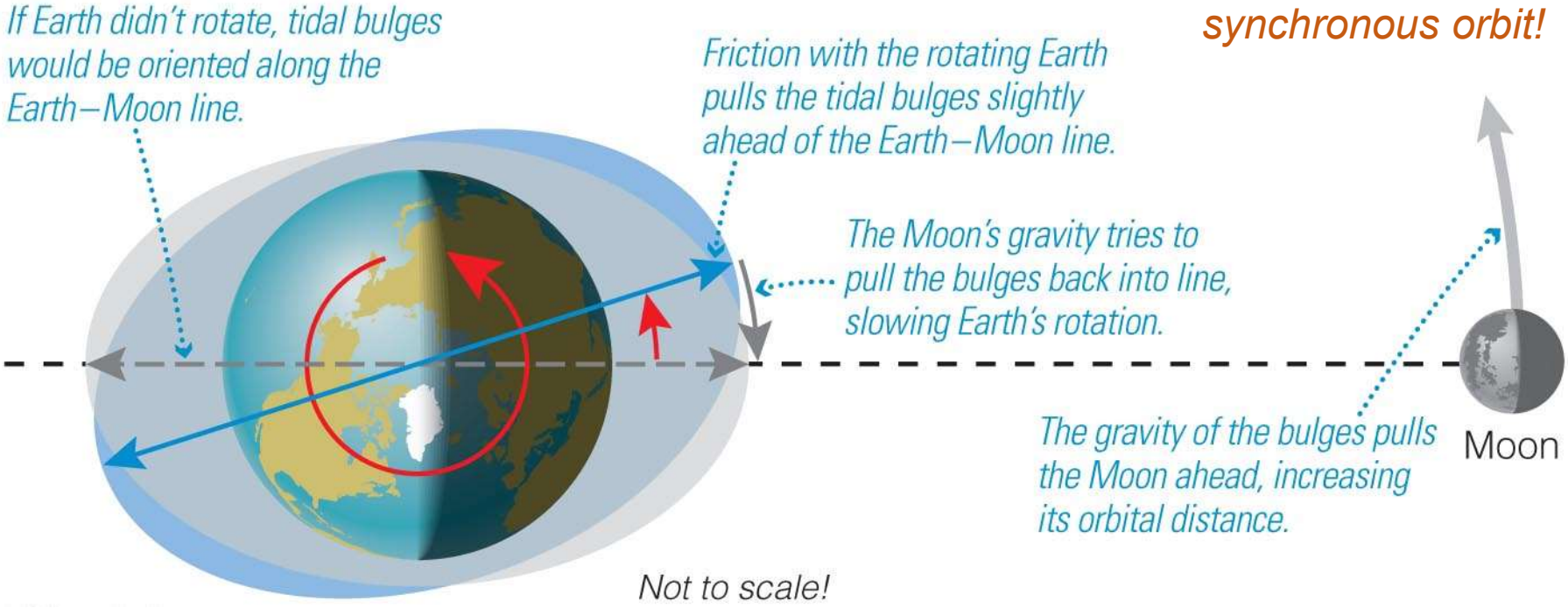




https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html

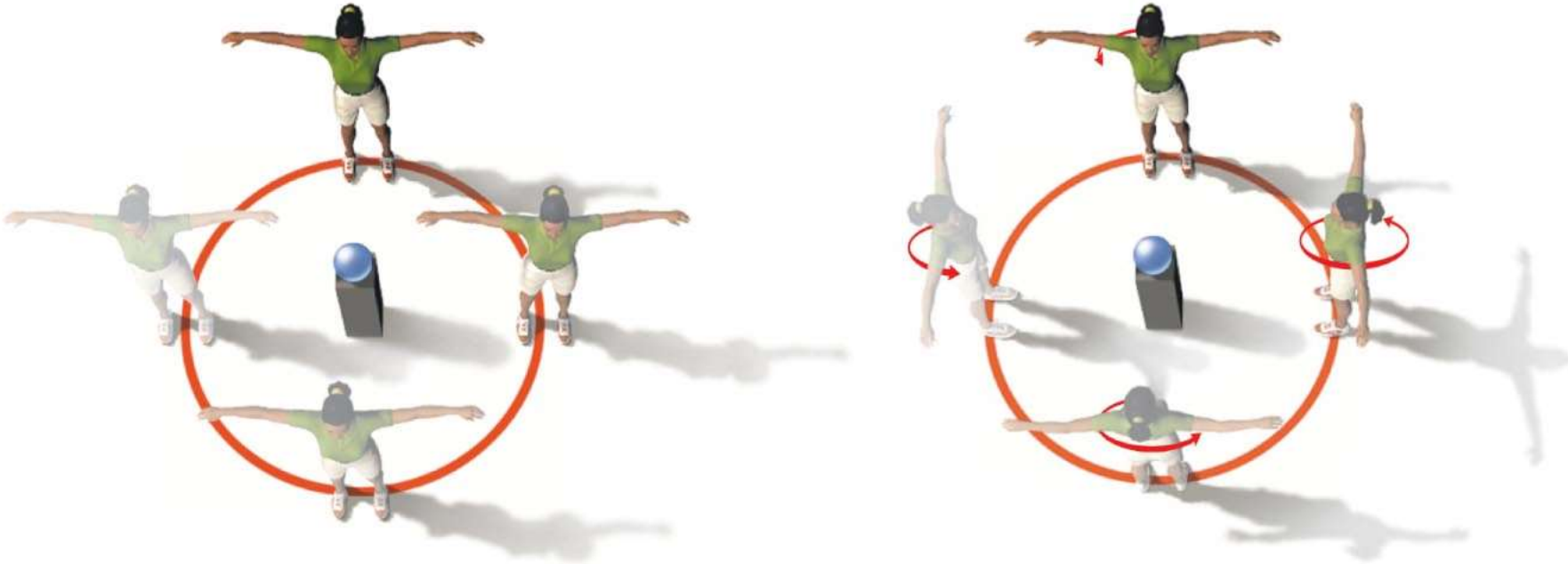
Why does the moon always show us the same face?

There is no tidal friction on the moon anymore as it has a synchronous orbit!



Energy is being transferred from the Earths rotation to the Moon's orbit

Tidal Friction



- Tidal friction gradually slows Earth's rotation (and makes the Moon get farther from Earth).
- Moon once orbited faster (or slower); tidal friction caused it to "lock" in synchronous rotation.
- There is no Dark Side of the Moon, only a face which we cannot see from Earth

iClicker Question

(Code = BC)

Question: How does the gravitational force between two objects change if the distance between them is tripled?

A. The force increases by a factor of three

B. The force increases by a factor of nine

C. The force remains the same

D. The force decreases by a factor of three

E. The force decreases by a factor of nine

iClicker Question

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iClicker Question #2

(Code = BC)

Question: Which of the following is an example of changing gravitational potential energy into kinetic (motion) energy?

A. Eating food and releasing the energy

B. Riding a bicycle

C. Falling off a ladder

D. A gas cloud in space contracting due to gravity and heating up

E. c and d

iClicker Question #2

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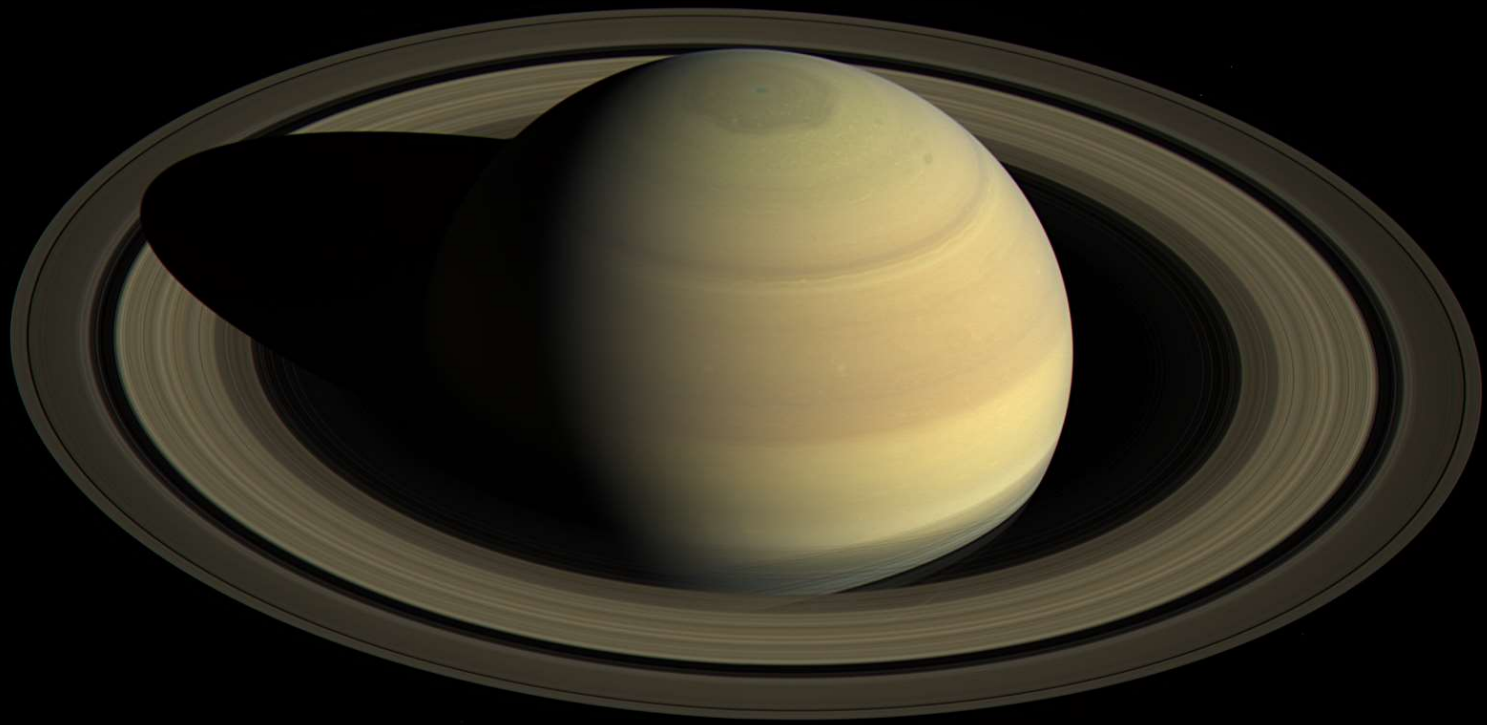
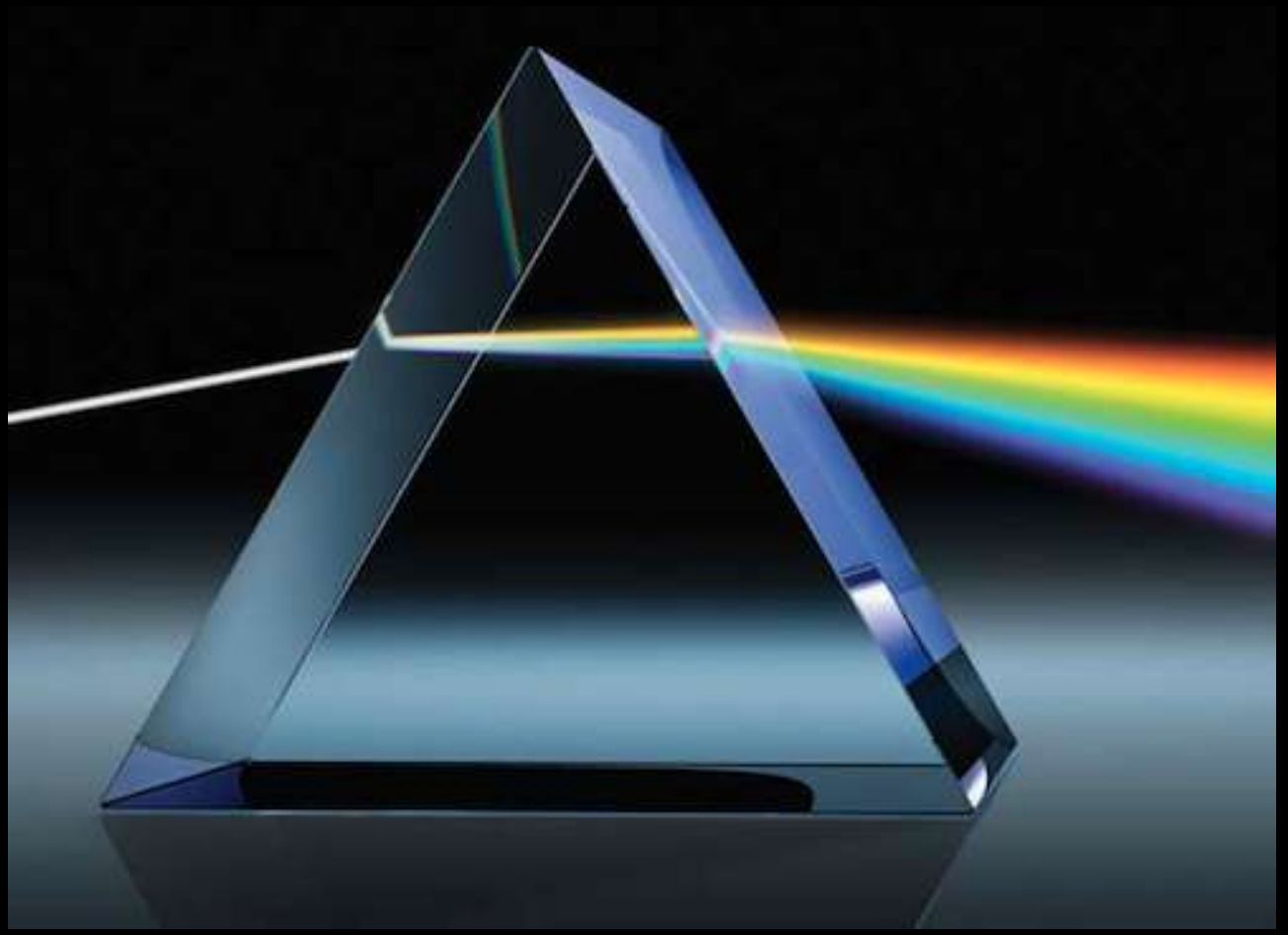
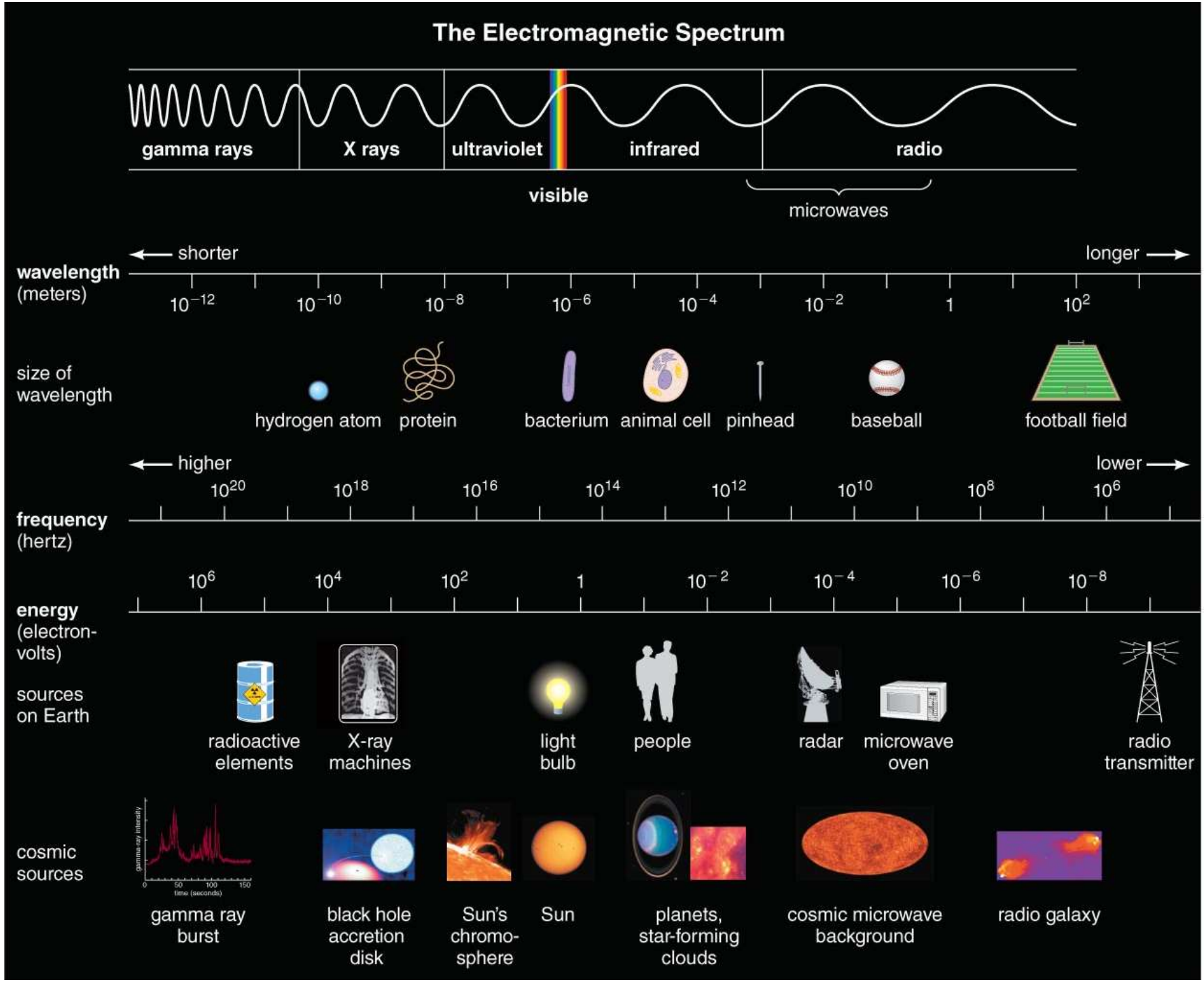


Chapter 5

What is Light?

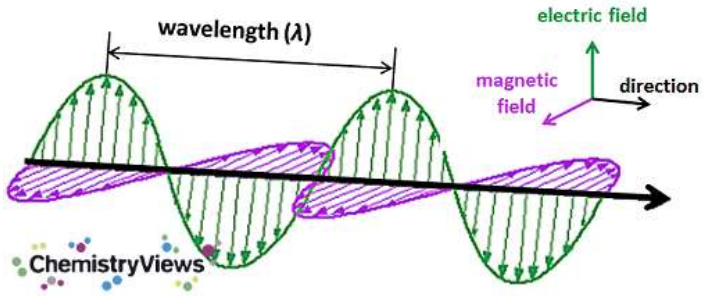



The Electromagnetic Spectrum
gamma rays
X rays
ultraviolet
infrared
radio
visible
microwaves
wavelength (meters)
shorter
longer
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
size of wavelength
hydrogen atom
protein
bacterium
animal cell
pinhead
baseball
football field
higher
lower
frequency (hertz)
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
energy (electron-volts)
10^{6}
10^{4}
10^{2}
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
sources on Earth
radioactive elements
X-ray machines
light bulb
people
radar
microwave oven
radio transmitter
cosmic sources
gamma-ray intensity
time (seconds)
gamma ray burst
black hole accretion disk
Sun's chromo-sphere
Sun
planets, star-forming clouds
cosmic microwave background
radio galaxy

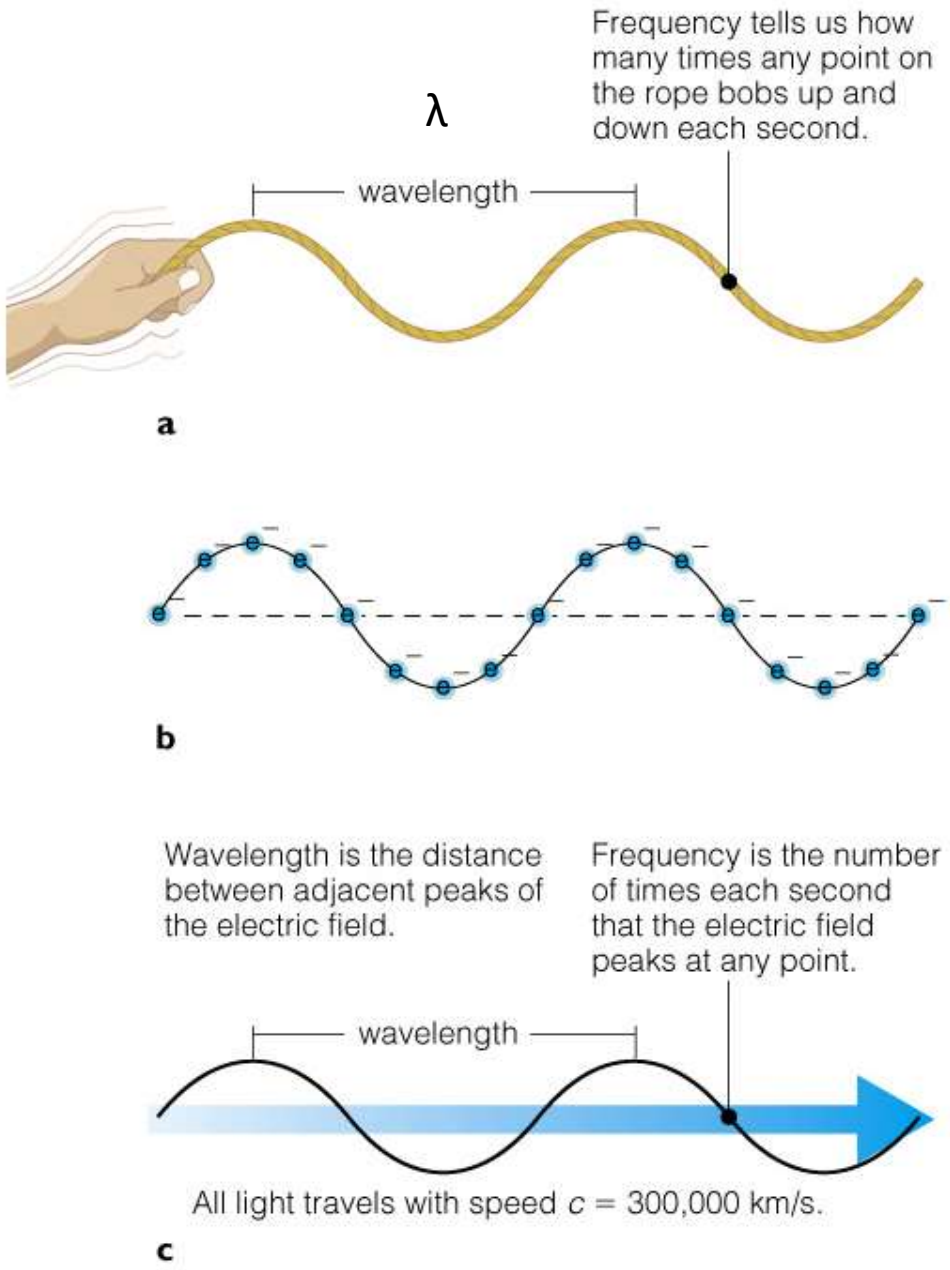
What is Light?

Light can act as both an electromagnetic wave and a particle, in different circumstances

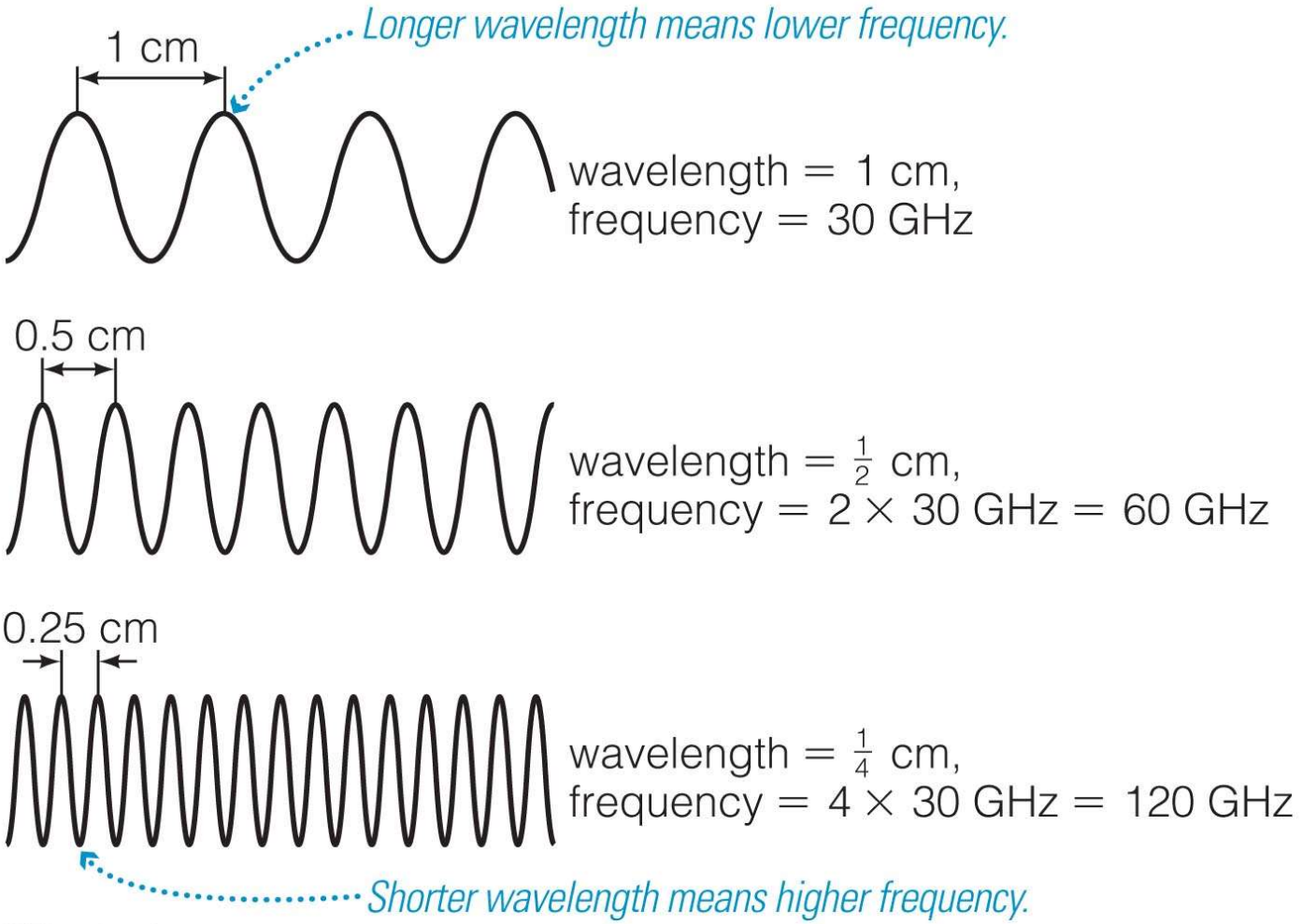
Wave-particle duality



Photons: "pieces" of light, each with precise wavelength, frequency, and energy. This leads to the idea that energy is *quantized* and can inform us how light and matter interact.



Wavelength and Frequency



wavelength x frequency = speed of light $\lambda f = c$

Wavelength, Frequency, and Energy

Relationship between frequency and wavelength:

$$\lambda \times f = c$$

λ = wavelength, f = frequency

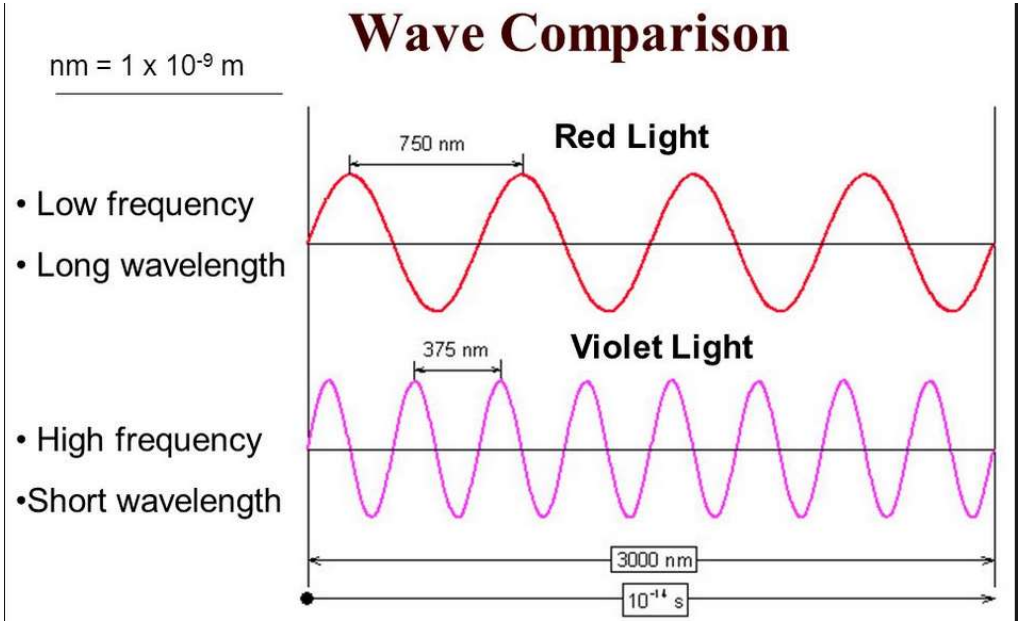
c = 3.00 × 10^8 m/s (speed of light)

Relationship between frequency and energy:

$$E = h \times f = \text{photon energy}$$

h = 6.626 × 10^{-34} joule × s

(h = Planck's constant)



- Our eyes are sensitive to changes in wavelength (or frequency).
- We can see from ~400 nm (violet) to ~700 nm (red)
- Our eyes are most sensitive to green light (~ 530 nm)

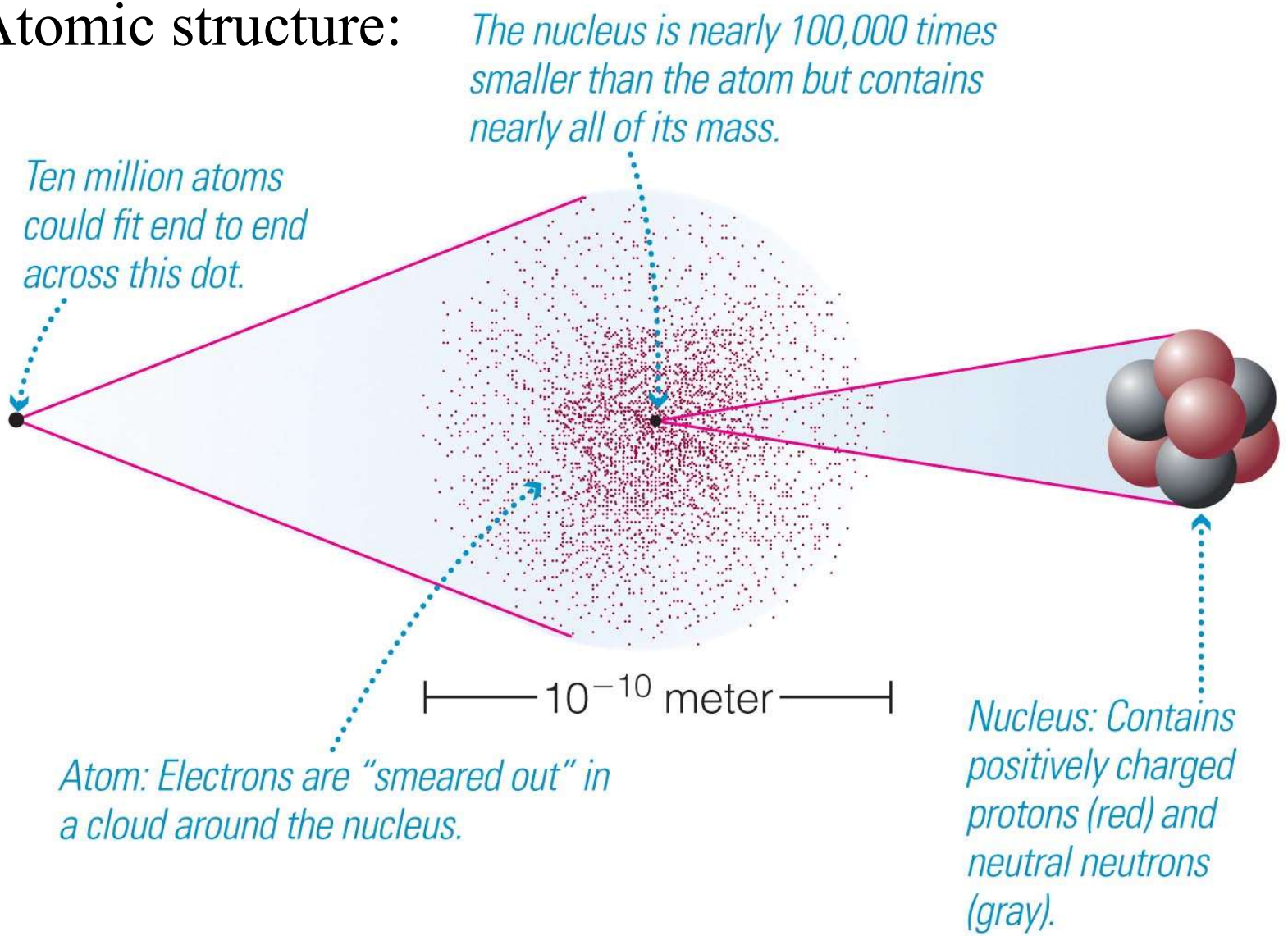
Red-shifted: Longer wavelength, lower frequency, lower energy

Blue-shifted: Shorter wavelength, higher frequency, higher energy

What is matter?

"Matter" is mostly empty space

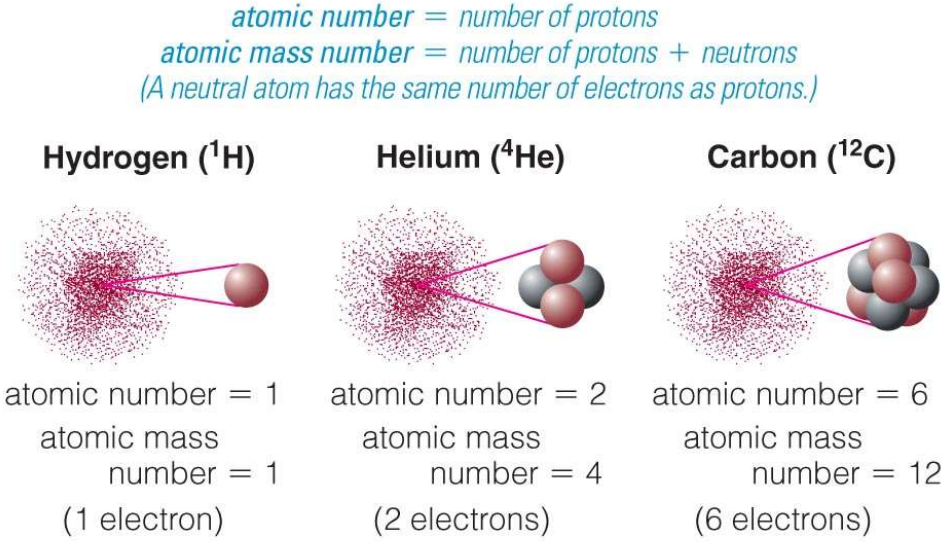
Atomic structure:

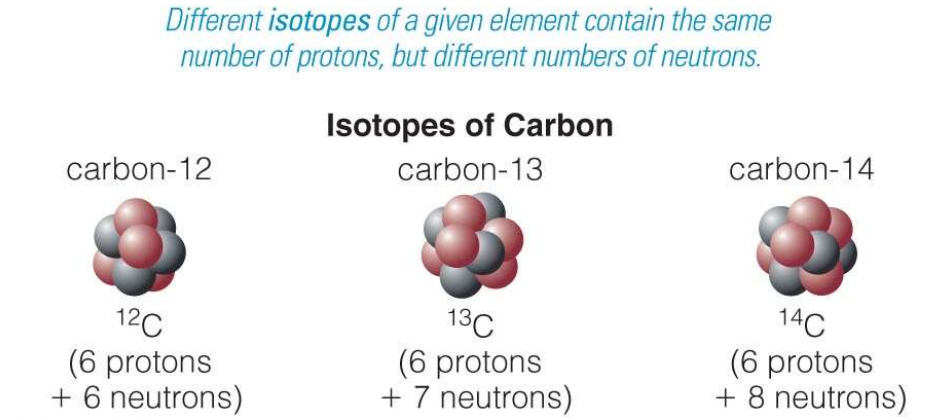


Atomic Terminology

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

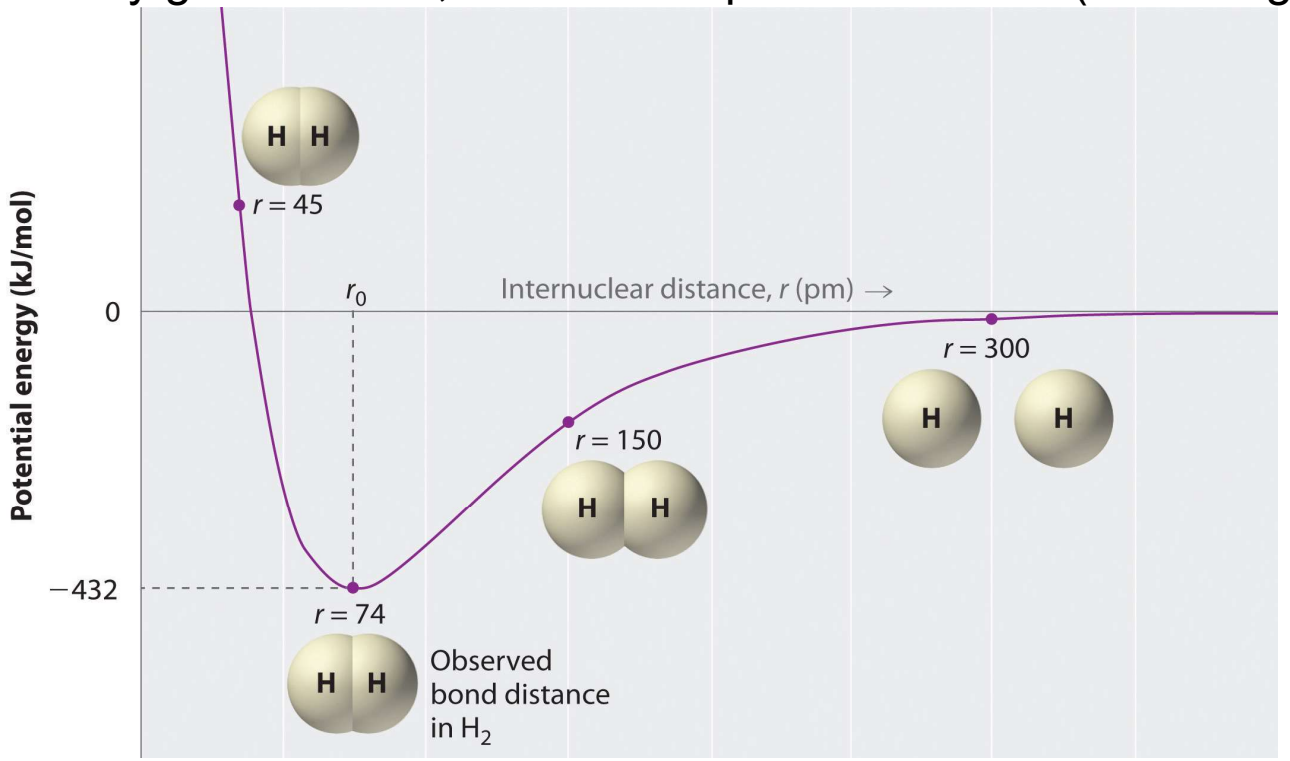
- Isotope: same # of protons but different # of neutrons (^{4}He, ^{3}He)
- Molecules: consist of two or more atoms (H_2O, CO_2)

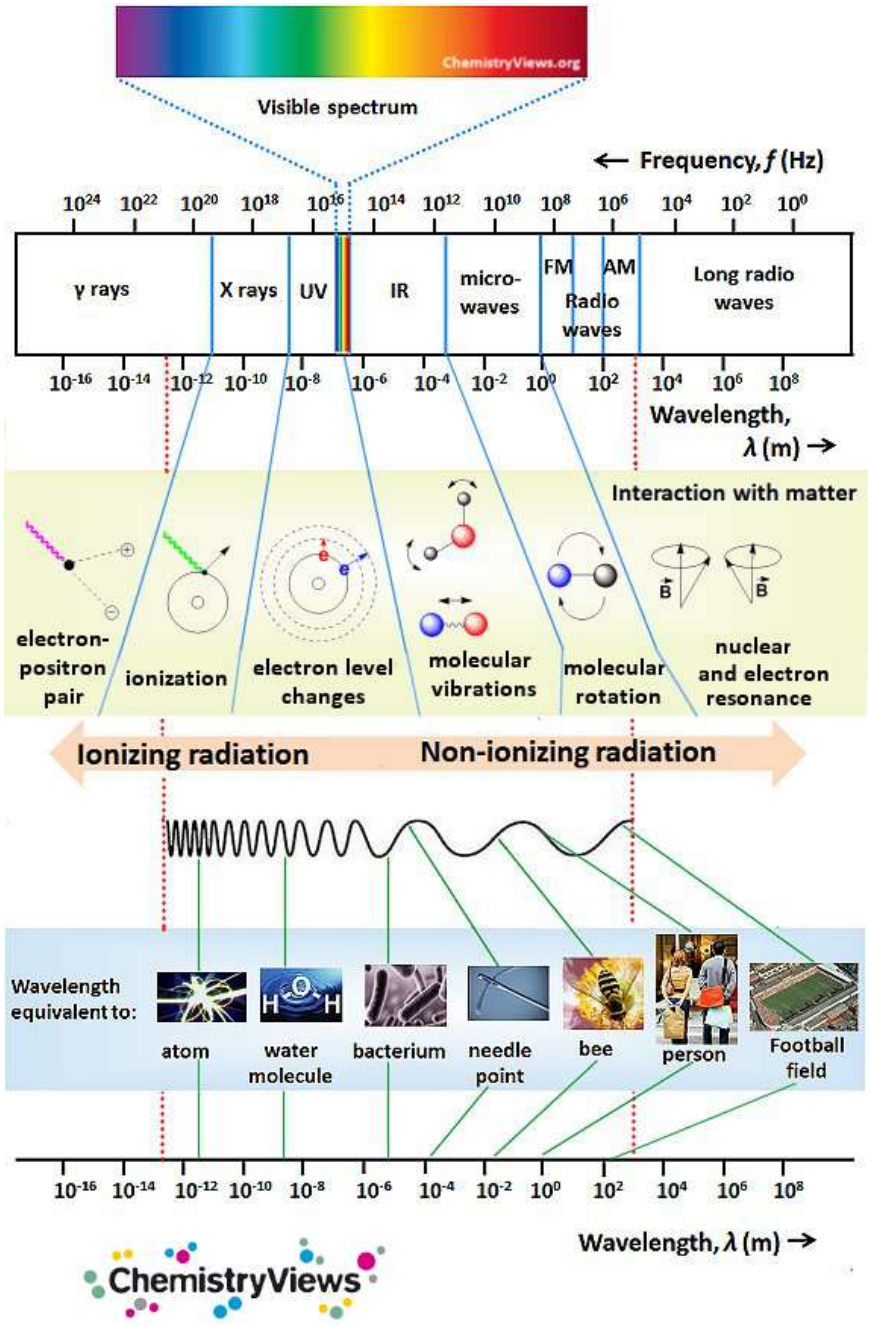


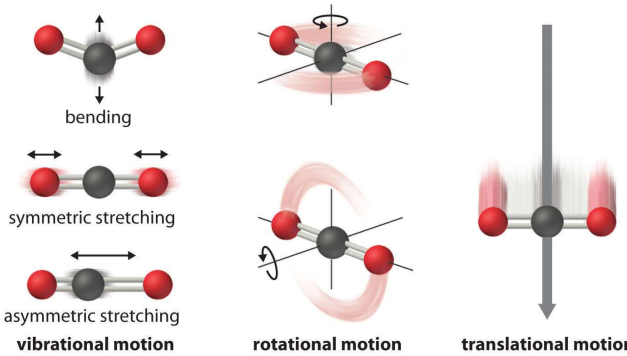


What is a Chemical Bond?

- Most elements have ‘open-shell’ electron configurations (except Noble Gases)
- As a consequence, they ‘get together’ to share electrons, which in general is more stable (lower energy), usually trying to get a ‘closed-shell’ (Noble) configuration.
- When they get too close, the nuclei repel one another (like charges repel)





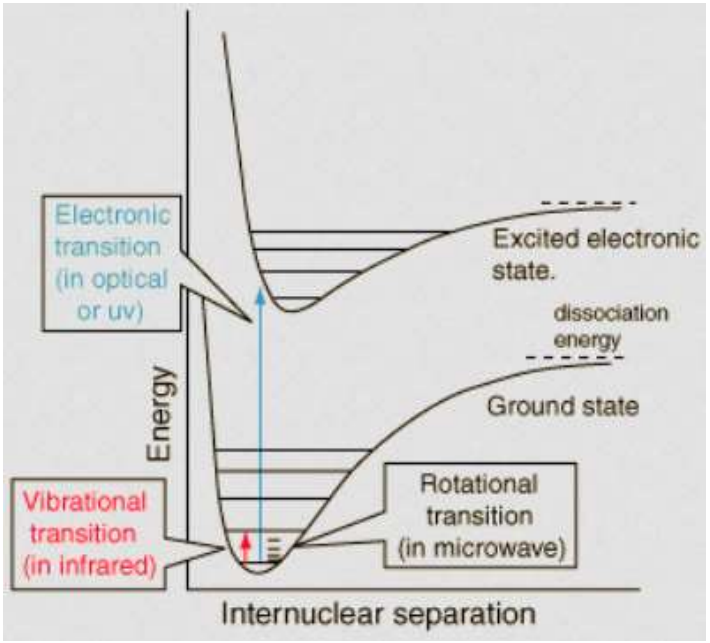


Molecular rotations don't require much energy (microwave region)

Molecular vibrations require a bit more energy (infrared region)

Electronic transitions require more energy still (visible light and UV light)

Higher energy levels causes bonds to start breaking and ionization to occur (X-rays and UV)



iClicker Question #3

(Code = BC)

Question: The higher the photon energy…

A. the longer its wavelength, and the higher its frequency
B. the shorter its wavelength, and the higher its frequency
C. energy and frequency are independent of wavelength
D. the longer its wavelength, and the lower its frequency
E. the shorter its wavelength, and the lower its frequency

iClicker Question #3

(Code = BC)

Question: The higher the photon energy…

A. the longer its wavelength, and the higher its frequency

B. the shorter its wavelength, and the higher its frequency

C. energy and frequency are independent of wavelength

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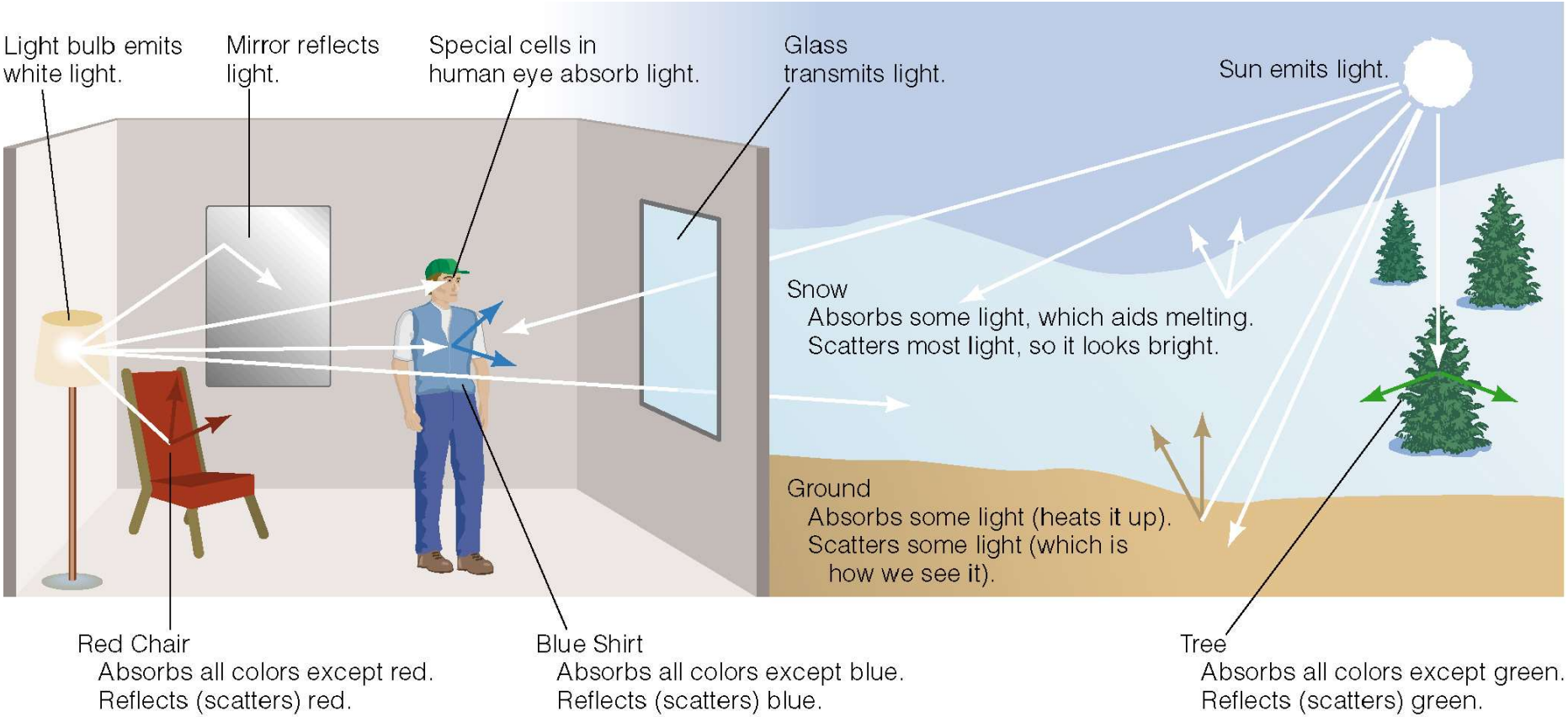
Interactions of light and matter



- **Absorbed:** matter takes energy from light
- **Transmitted:** matter allows light to pass through it
- **Reflected:** matter repels light in another direction
- **Emitted:** matter releases energy as light

iClicker Question #4

(Code = BC)

Question: Why is a rose red?

A. The rose absorbs red light.

B. The rose transmits red light.

C. The rose emits red light.

D. The rose reflects red light.

iClicker Question #4

(Code = BC)

Question: Why is a rose red?

A. The rose absorbs red light.

B. The rose transmits red light.

C. The rose emits red light.

D. The rose reflects red light.

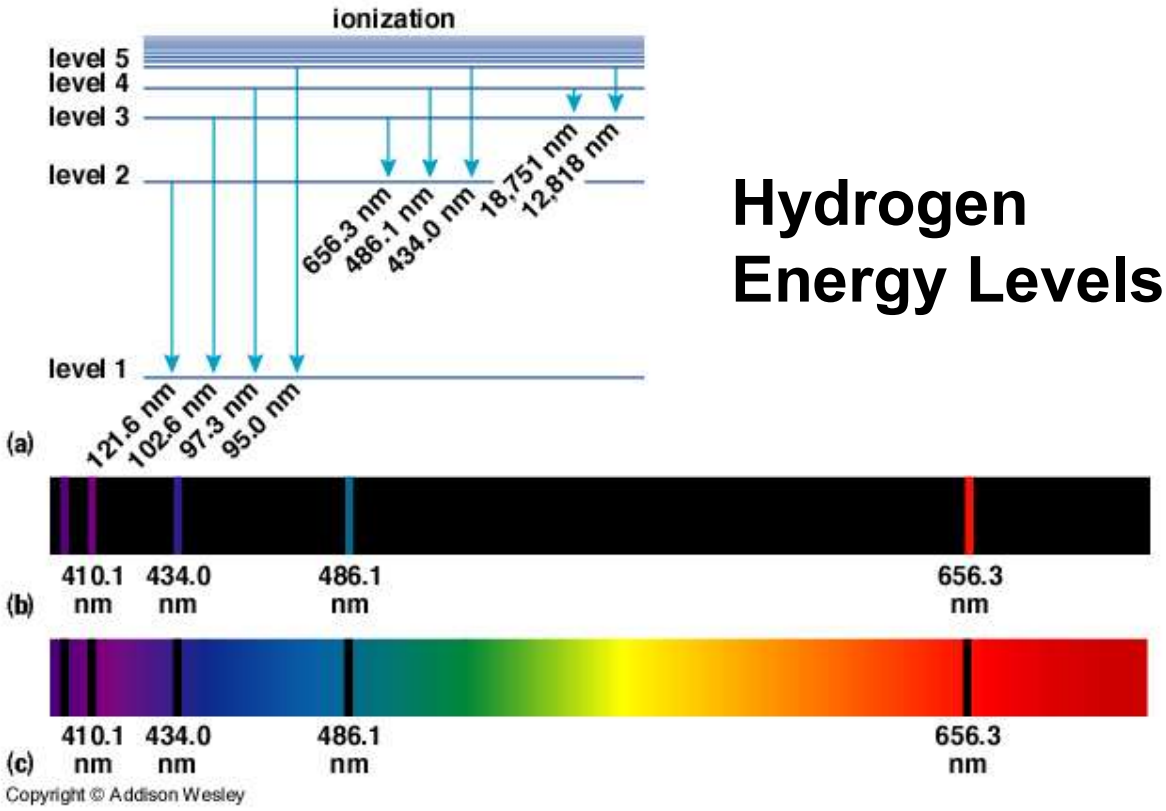
Energy Levels in Matter Are Quantized *(specific energy levels!)*

A fundamental part of the rules that govern the universe

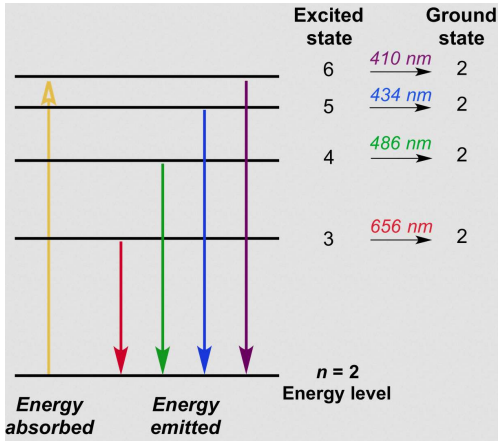
Electrons in atoms have distinct energy levels.

Each chemical element, ion, molecule, has a unique set of energy levels.

- **Distinct energy levels lead to distinct emission or absorption lines.**



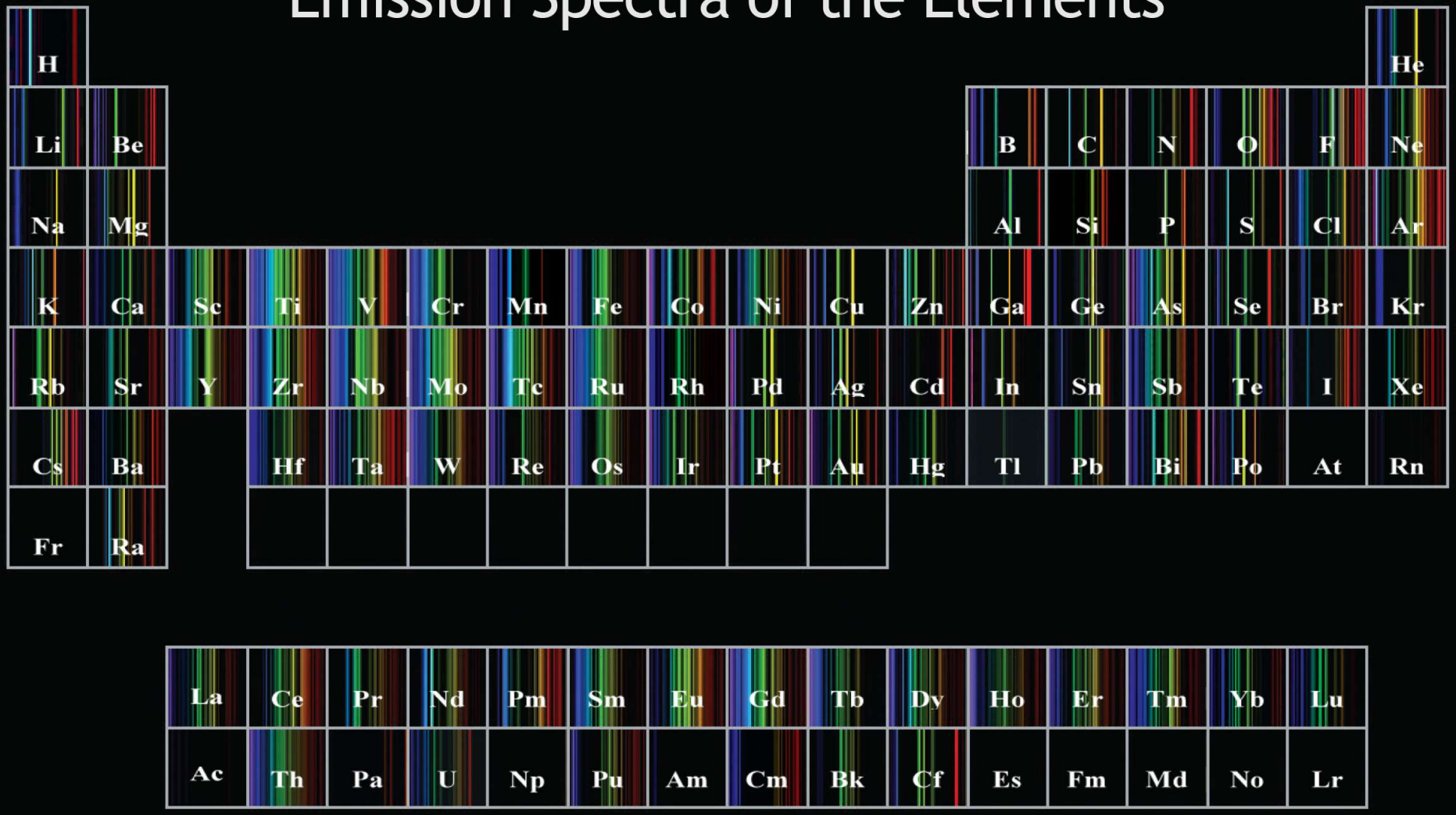
Hydrogen Energy Levels



Emission Lines
(depopulating energy levels)

Absorption Lines
(populating energy levels)

Emission Spectra of the Elements



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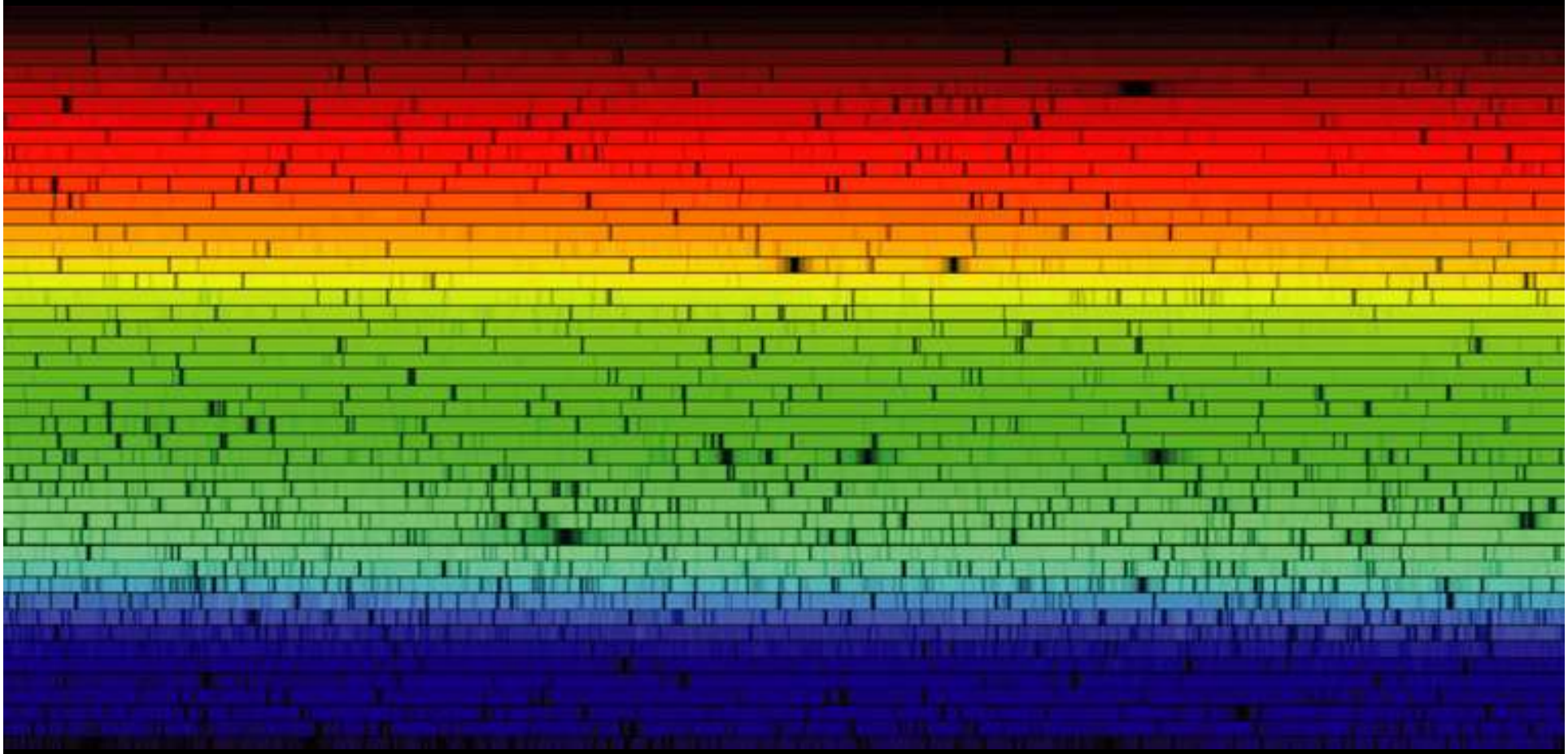
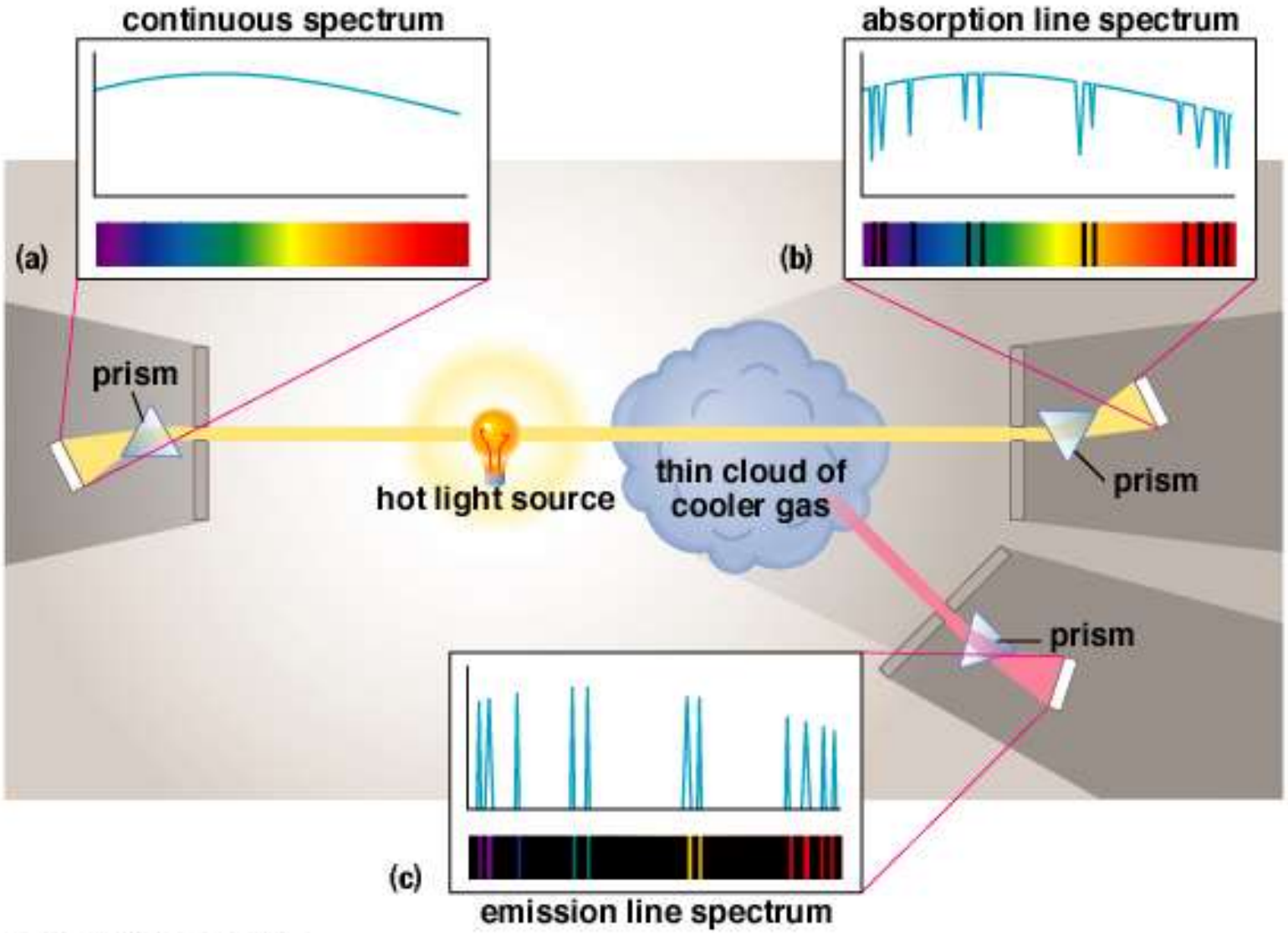
REAL-TIME CLASSROOM SPECTROSCOPY

Example: Solar Spectrum

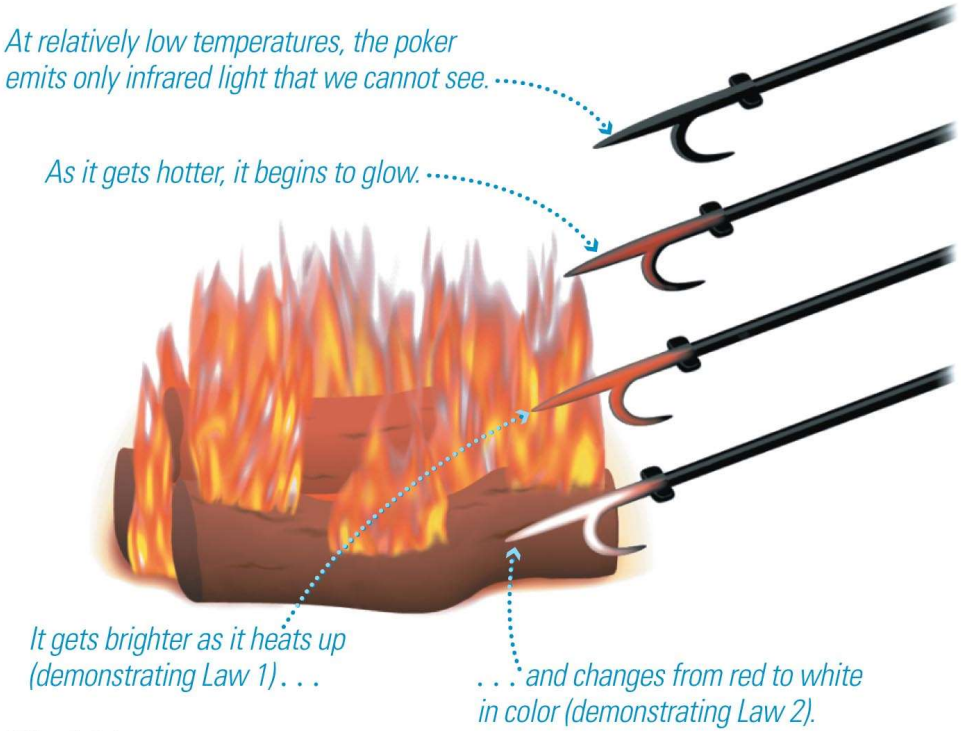


These actually indicate a combination of emission and absorption processes

What types of light spectra can we observe?



Warm Objects Emit Thermal Radiation

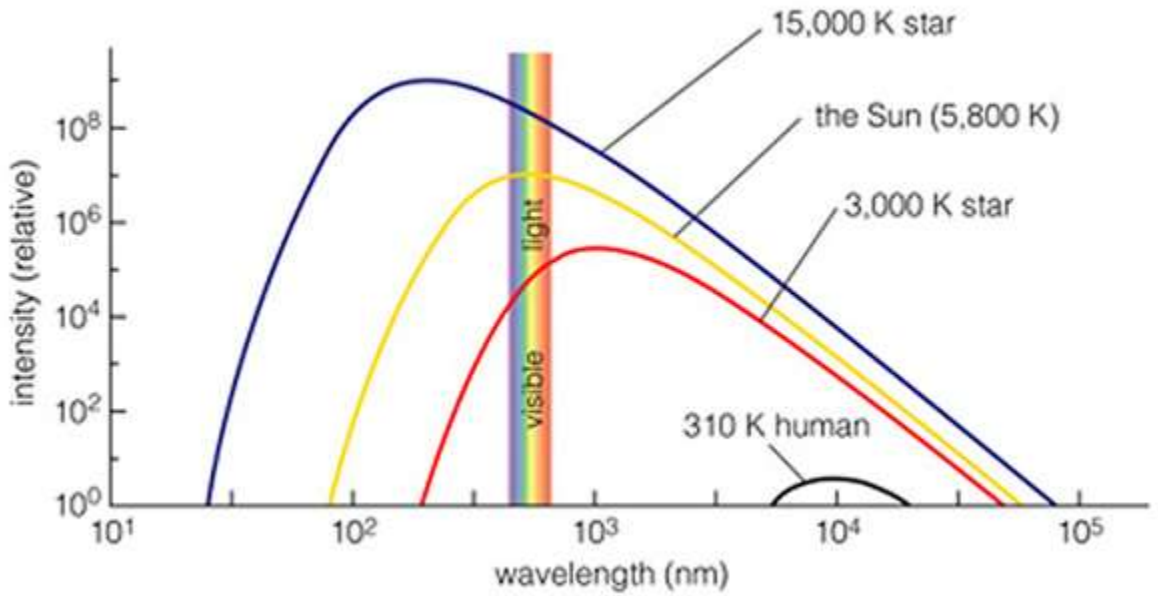


As you give energy to an atom or molecule, you start to populate the rotational energy levels (very low temperatures, microwave region)

… then start populating the vibrational energy levels (room temperature, IR region),

…as you continue heating the electronic energy levels start getting populated and you start being able to see visible light, like when a poker is heated.

Black-Body Radiation



- **The origin of the 'continuous spectrum'**
- **Hotter objects emit more light at all frequencies per unit area.**
- **Hotter objects emit photons with a higher average energy.**
- **We can determine from the λ_{max} the temperature of an object**

End of Todays Lecture