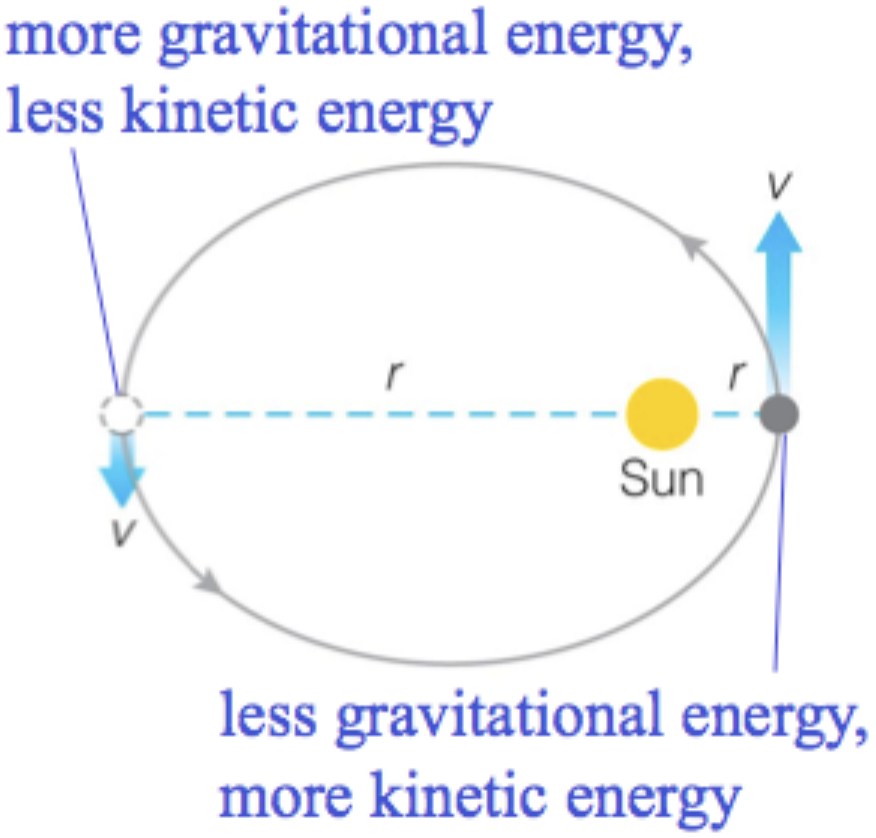
4.5 Orbits, Tides, and the Acceleration of Gravity

- Our goals for learning:
  - **How do gravity and energy together allow us to understand orbits?**
  - **How does gravity cause tides?**
  - **Why do all objects fall at the same rate?**

How do gravity and energy together allow us to understand orbits?

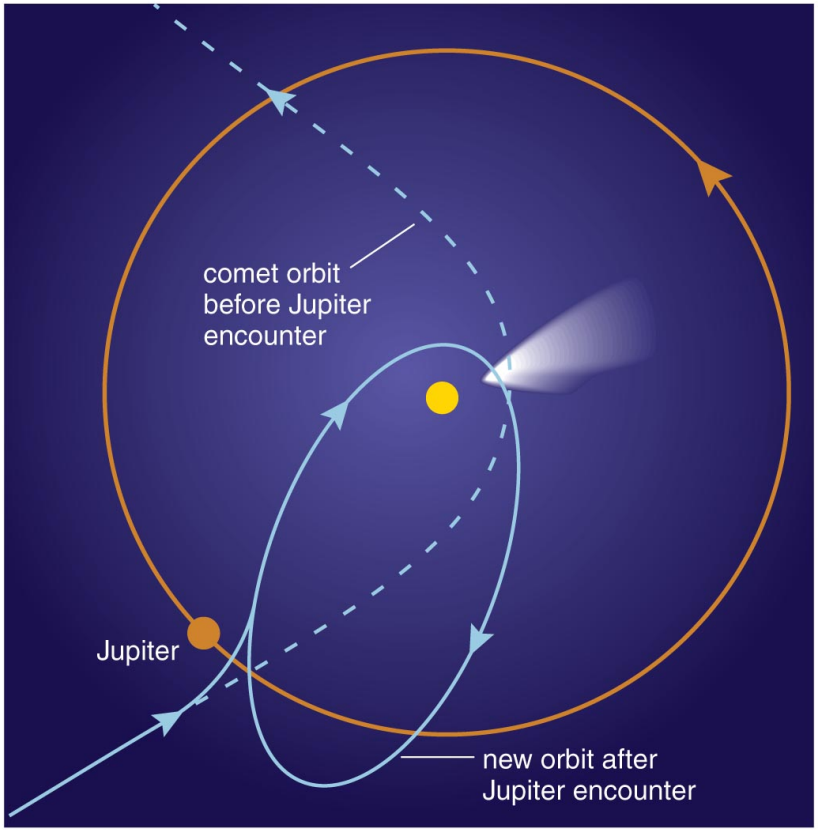


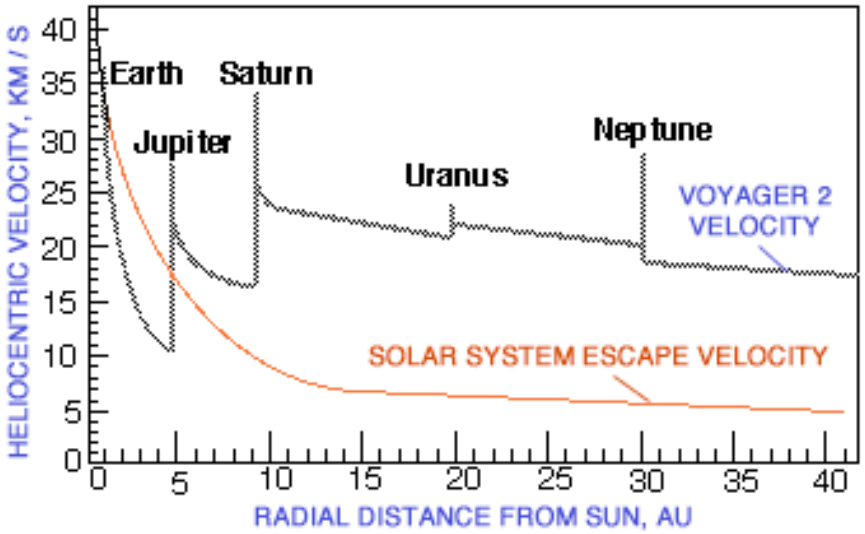
- Total orbital energy (gravitational + kinetic) stays constant if there is no external force.
- Orbits cannot change spontaneously.

Total orbital energy stays constant.

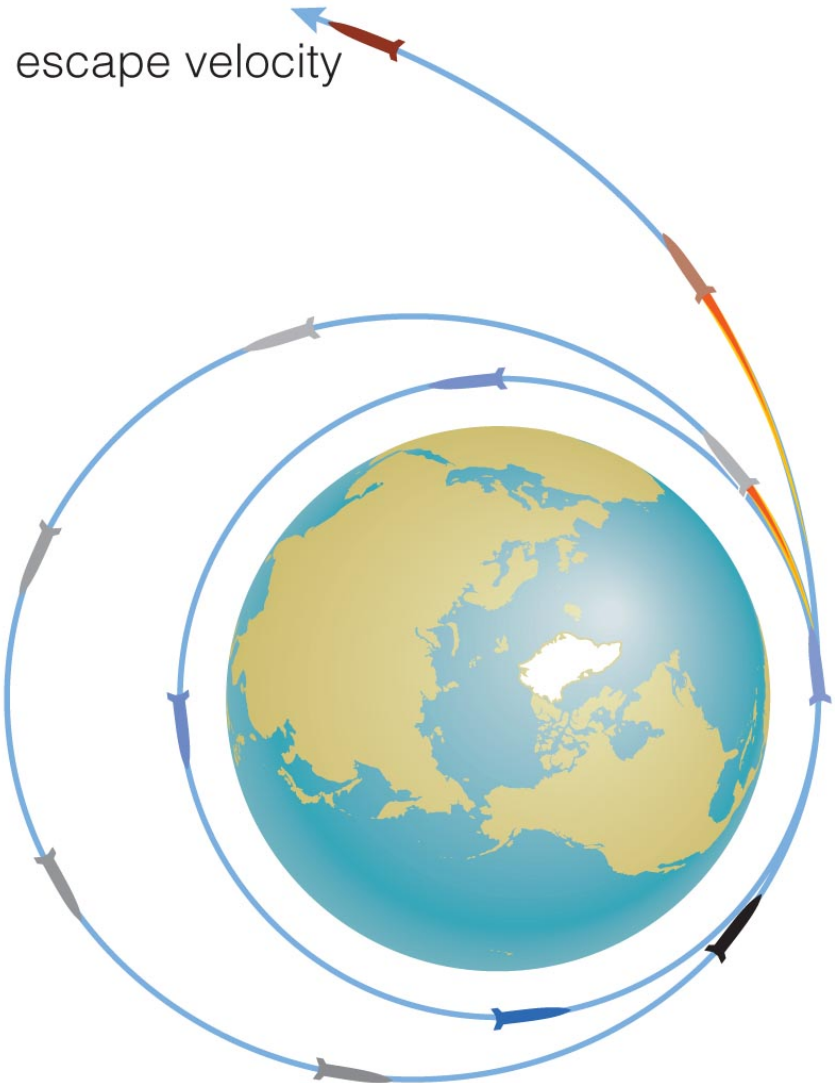
Changing an Orbit

- So what can make an object gain or lose orbital energy?
- Friction or atmospheric drag
  - This is how we slow down spacecraft going to Mars
- A gravitational encounter
  - "Gravity assist" can speed up orbits of solar system spacecraft



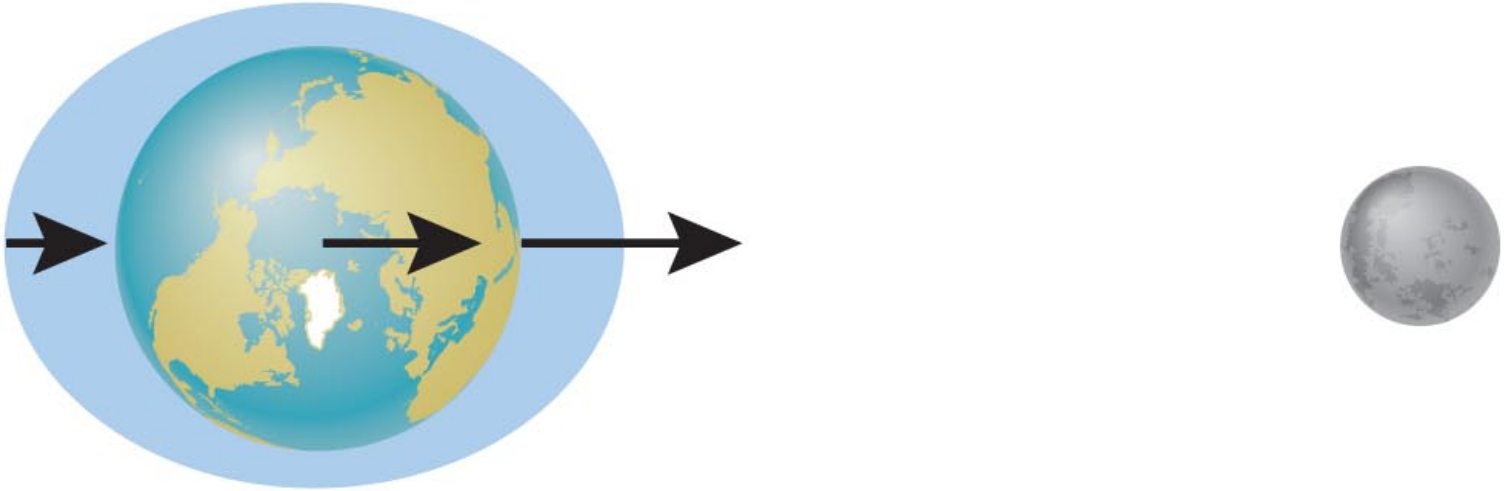


Escape Velocity



- If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit).
- **Escape velocity** from Earth ≈ 11 km/s from sea level (about 40,000 km/hr)
- Escape and orbital velocities don't depend on the mass of the cannonball.

How does gravity cause tides?

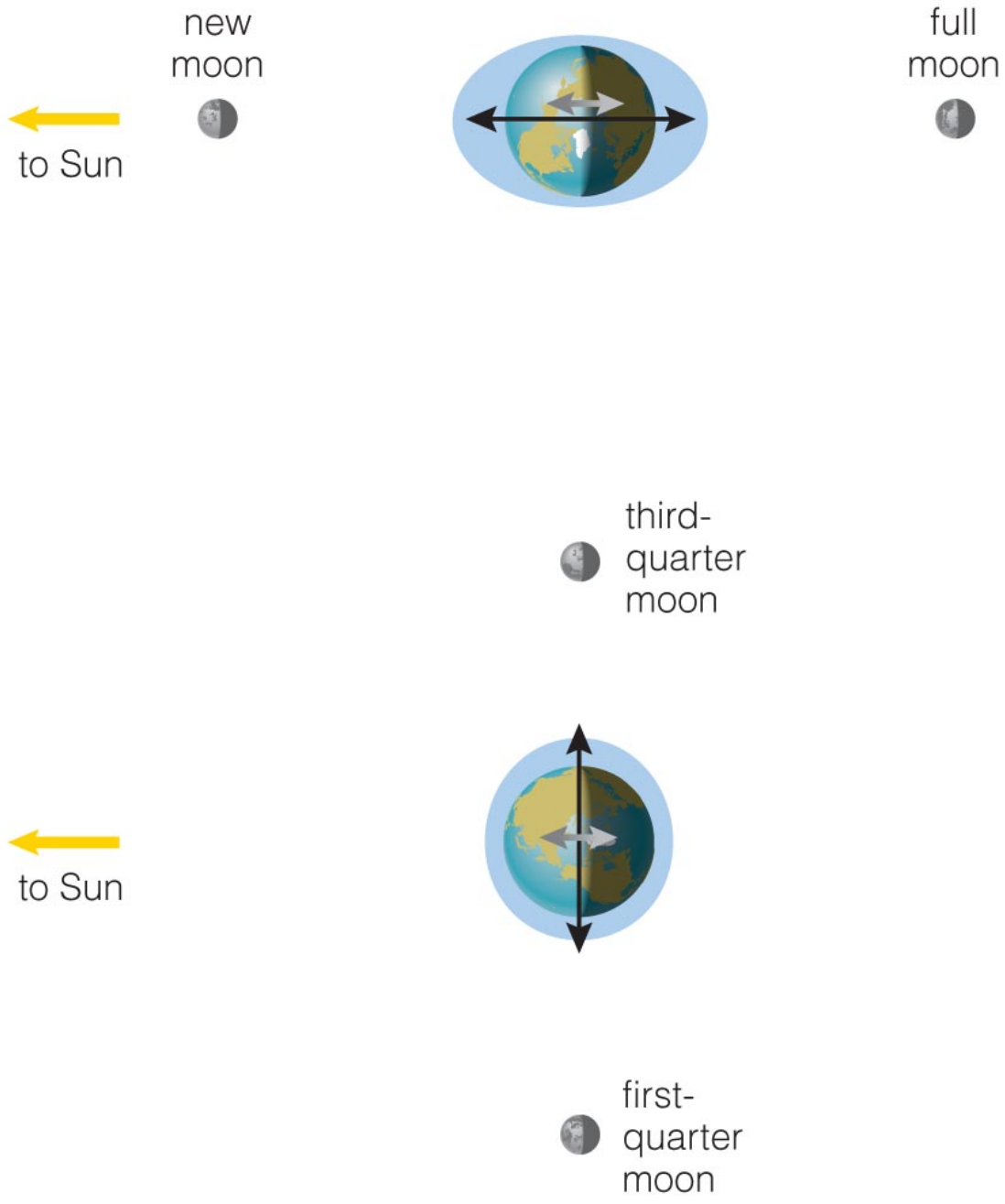


- Moon's gravity pulls harder on near side of Earth than on far side.
- Difference in Moon's gravitational pull stretches Earth.

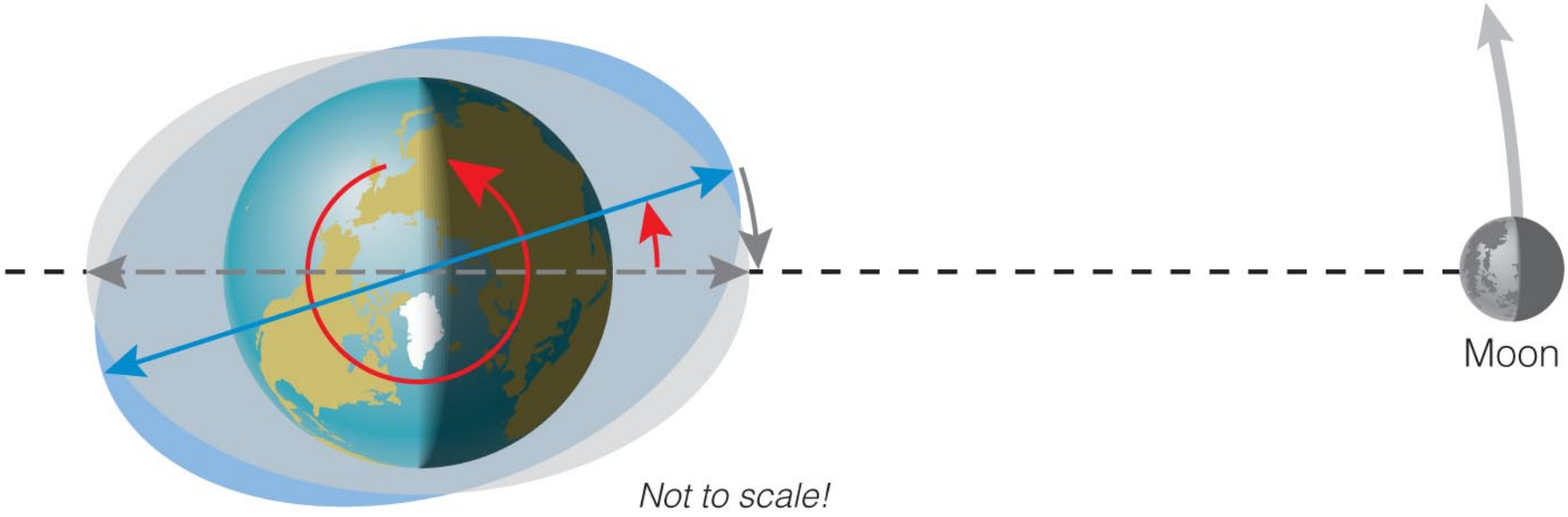
Not to scale!

Tides and Phases

- For Earth, tides are largest due to Moon, then 2nd largest due to Sun
- Size of tides depends on phase of Moon
- Maximum tides are at full and new moon

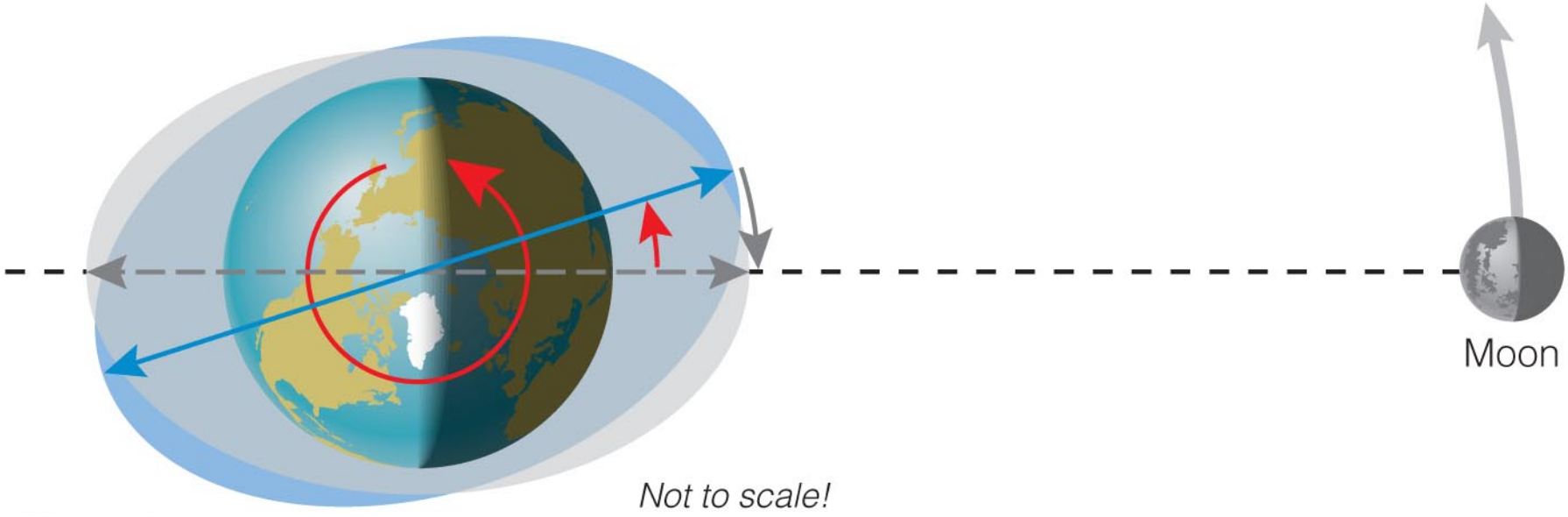


Tidal Friction



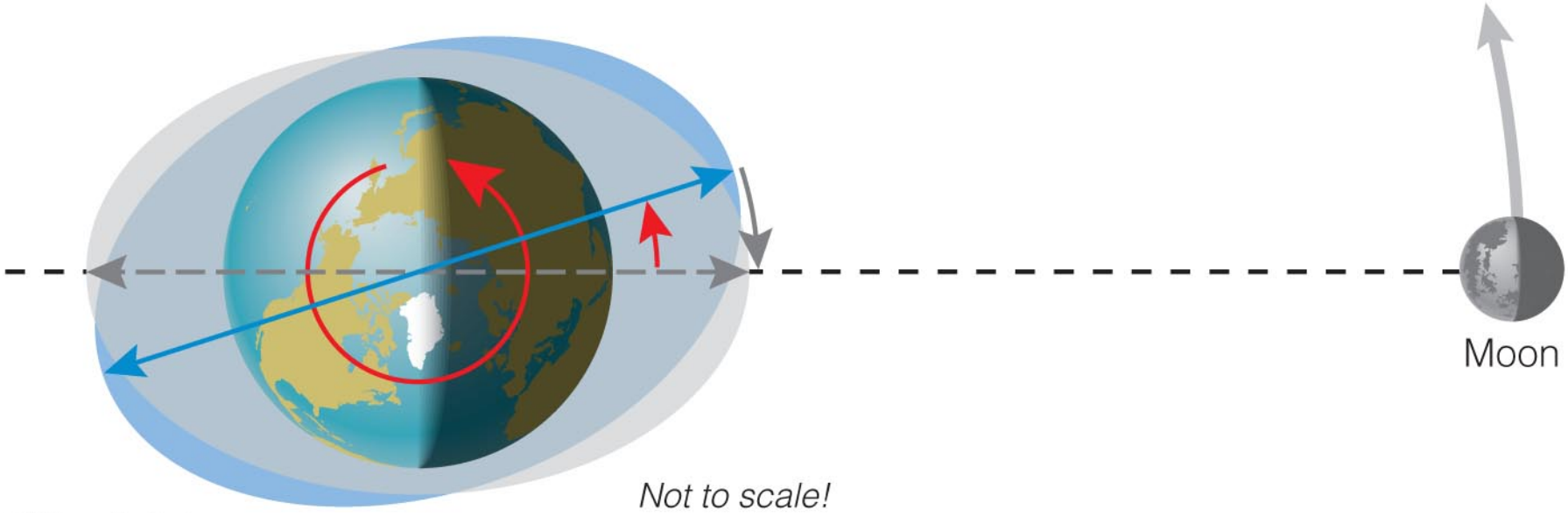
- The Earth is also rotating much faster (1 day) than the moon's orbit (~28 days)
- This fast rotation pushes the Earth's tidal bulge slightly "ahead" of the dashed line
- But bulge feels a force from the Moon trying to pull it back "in line"

Tidal Friction



- Tidal friction gradually slows Earth's rotation
  - Energy lost must be conserved and goes into the Moon’s orbit
  - The Moon gets farther from Earth

Tidal Friction



- Tides are also raised on the Moon by the Earth
  - The Moon once orbited faster (or slower); tidal friction caused it to "lock" in synchronous rotation.
  - The Moon's tidal bulge now points nearly precisely at the Earth

Clicker Question

- You're at the beach at midnight doing totally wholesome activities that your parents would obviously approve of and the full moon is overhead. Is the tide:

- A) high, but a bit higher than usual
- B) high, but a bit lower than usual
- C) low, but a bit higher than usual
- D) low, but a bit lower than usual

Last question: why do all objects fall at the same rate?

$$a_{\text{rock}} = \frac{F_g}{M_{\text{rock}}} \qquad F_g = G\frac{M_{\text{Earth}} M_{\text{rock}}}{R_{\text{Earth}}^2}$$

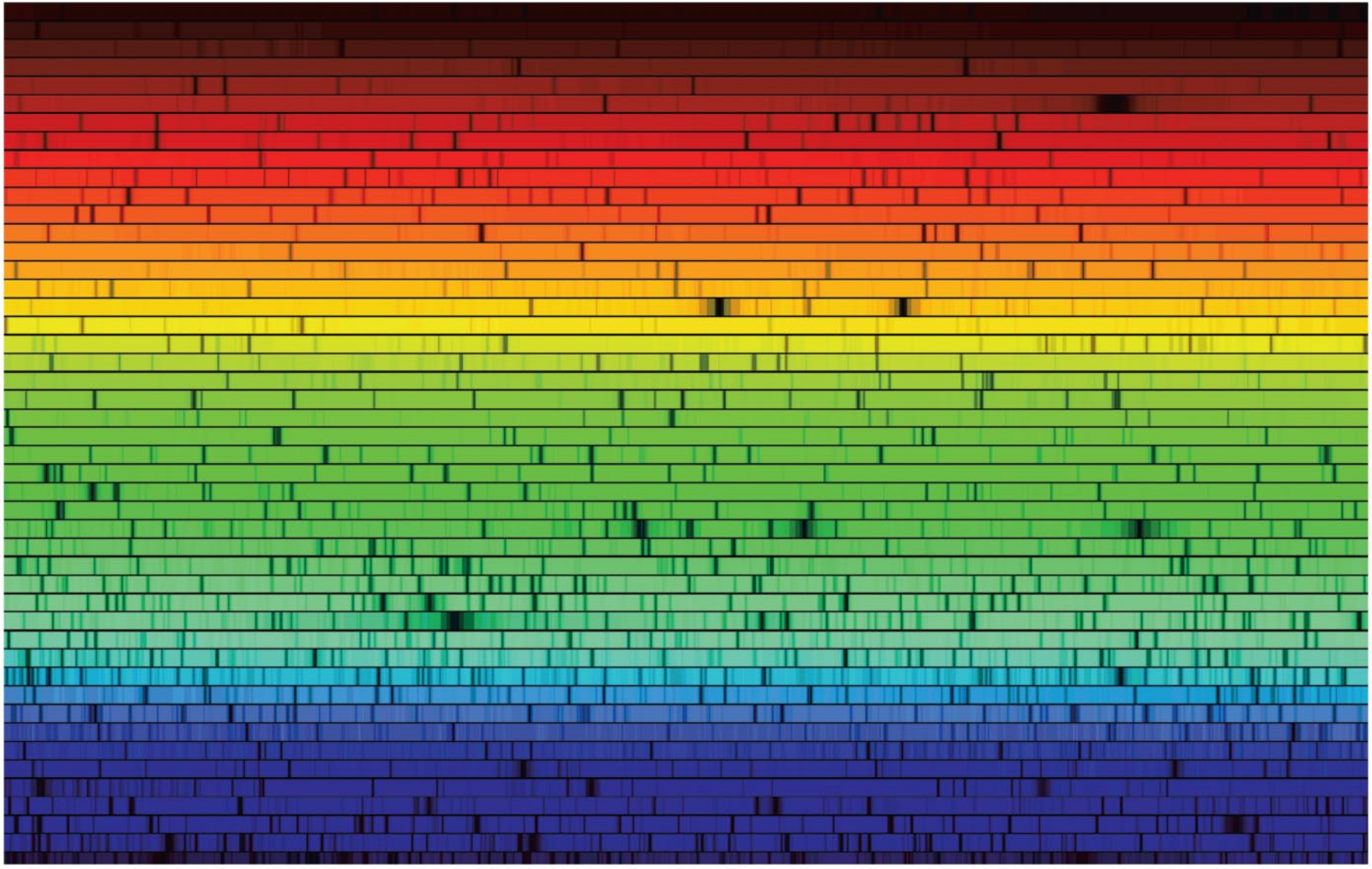
$$a_{\text{rock}} = G\frac{M_{\text{Earth}} M_{\text{rock}}}{R_{\text{Earth}}^2 M_{\text{rock}}} = G\frac{M_{\text{Earth}}}{R_{\text{Earth}}^2}$$

- The gravitational acceleration of an object like a rock does not depend on its mass because M_{rock} in the equation for acceleration cancels M_{rock} in the equation for gravitational force.
- This "coincidence" was not understood until Einstein's general theory of relativity.

What have we learned?

- **How do gravity and energy together allow us to understand orbits?**
  - Change in total energy is needed to change orbit
  - Add enough energy (escape velocity) and object leaves.
- **How does gravity cause tides?**
  - The Moon's gravity stretches Earth and its oceans.
- **Why do all objects fall at the same rate?**
  - Mass of object in Newton's second law exactly cancels mass in law of gravitation.

Chapter 5: Light and Matter: Reading Messages from the Cosmos



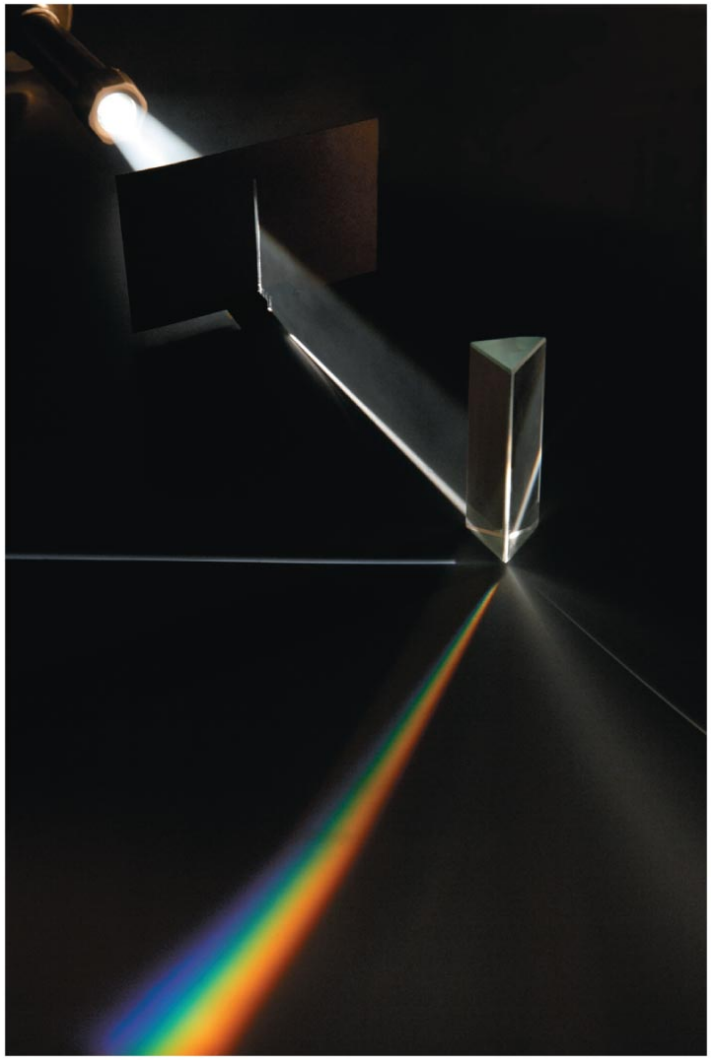
5.1 Light in Everyday Life

- Our goals for learning:
  - **How do we experience light?**
  - **How do light and matter interact?**

How do we experience light?

- The warmth of sunlight tells us that light is a form of energy.
- We can measure the flow of energy in light in units of **watts:** 1 watt = 1 joule/s.
- More energy per second is more watts

Colors of Light

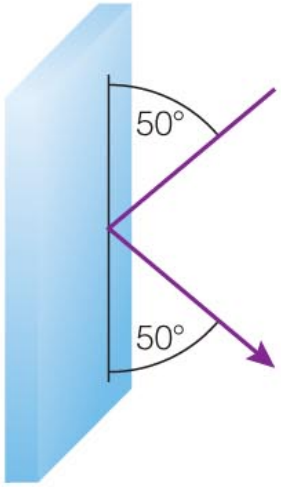


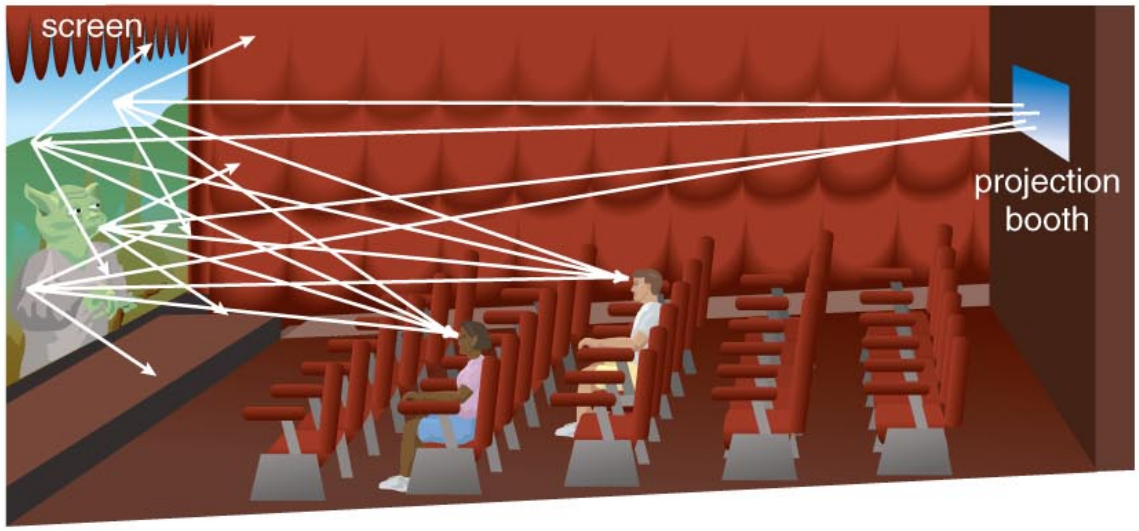
- White light is made up of many different colors.

How do light and matter interact?

- Emission
- Absorption
- Transmission
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection/scattering

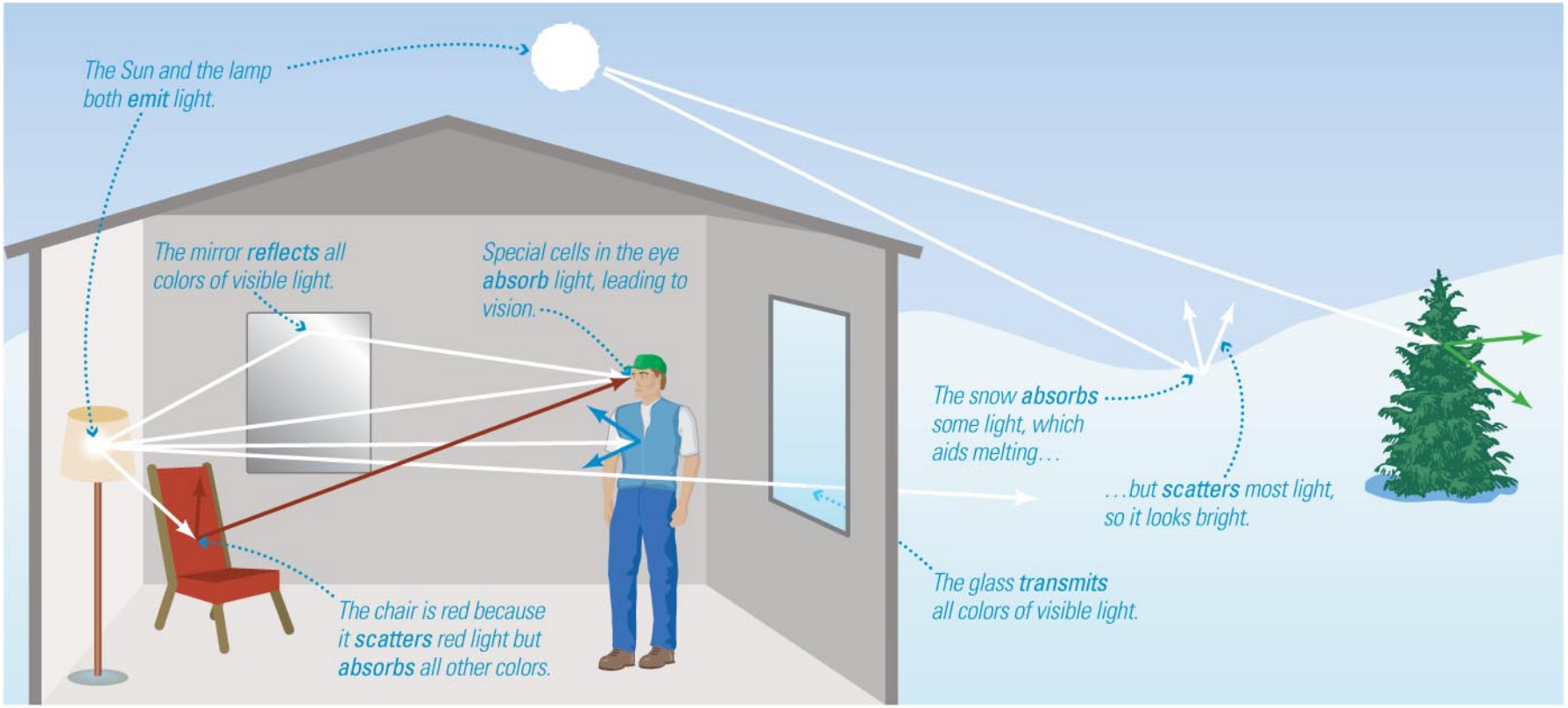
Reflection and Scattering





- Mirror reflects light in a particular direction.
- Movie screen scatters light in all directions.

Interactions of Light with Matter



- Interactions between light and matter determine the appearance of everything around us.

What have we learned?

- **How do we experience light?**
  - Light is a form of energy.
  - Light comes in many colors that combine to form white light.
- **How do light and matter interact?**
  - Matter can emit light, absorb light, transmit light, and reflect (or scatter) light.
  - Interactions between light and matter determine the appearance of everything we see.

5.2 Properties of Light

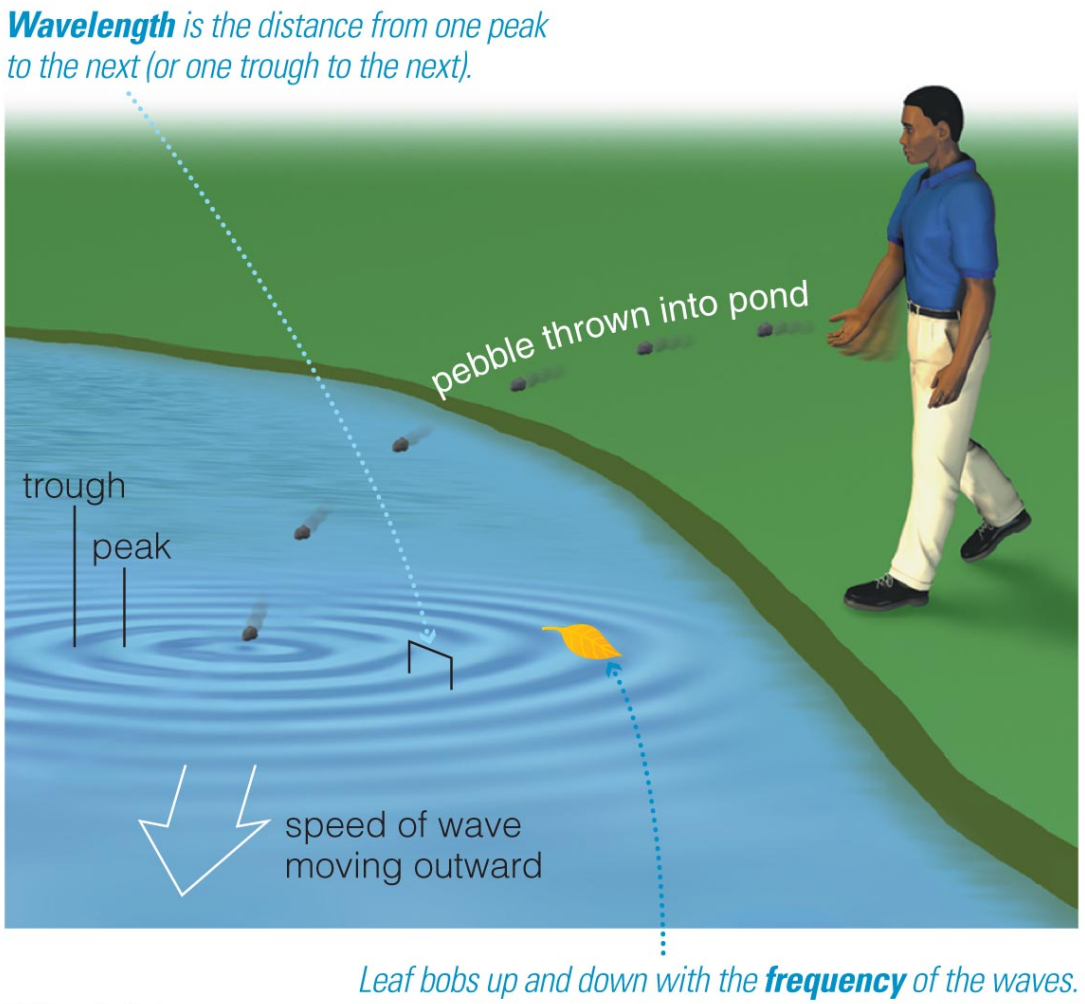
- Our goals for learning:
  - **What is light?**
  - **What is the electromagnetic spectrum?**

What is light?

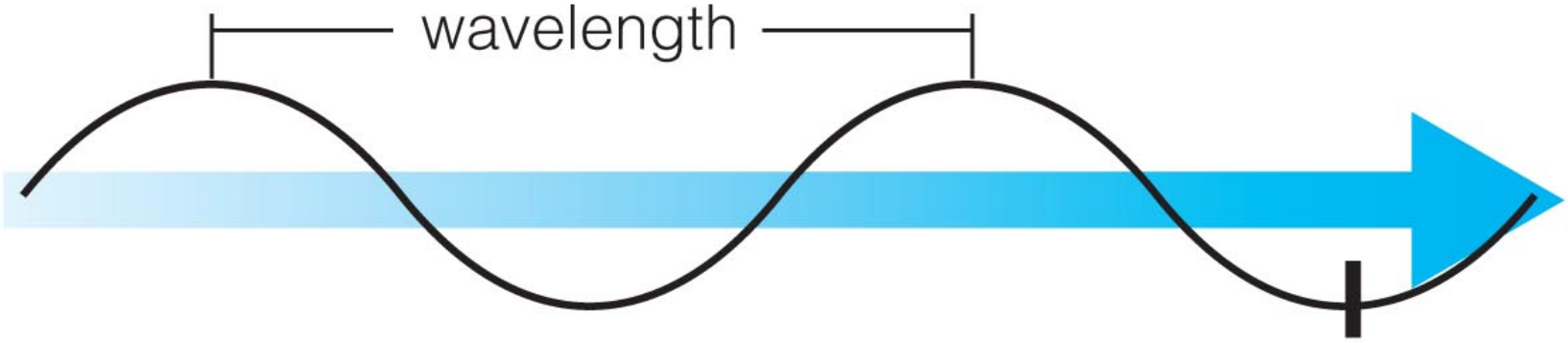
- Light can act either like a wave or like a particle.
- Particles of light are called **photons.**

Waves

- A **wave** is a pattern of motion that can carry energy without carrying matter along with it.
- The water molecules bob *up and down* while the energy moves out



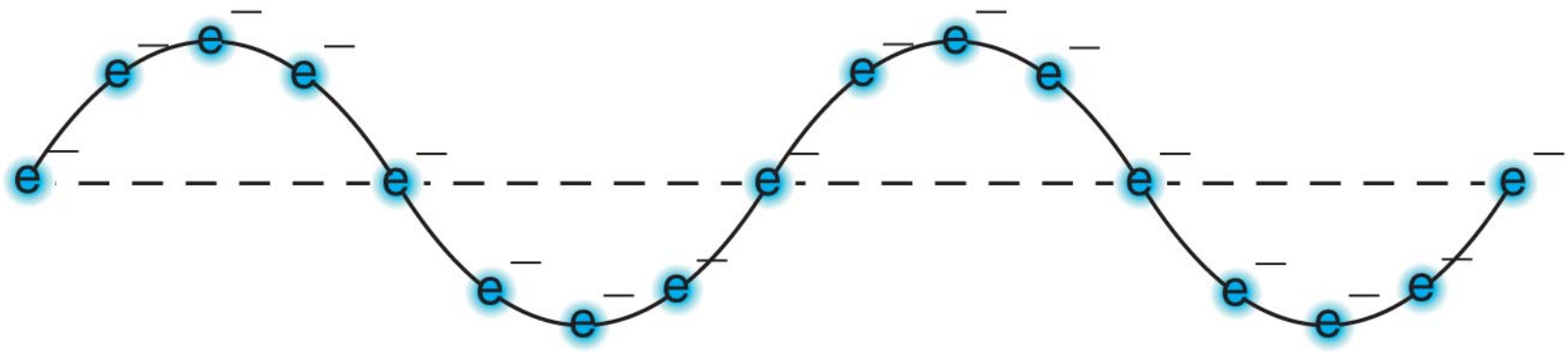
Properties of Waves



- **Wavelength** is the distance between two wave peaks
  - A distance, often in meters (m)
- **Frequency** is the number of times per second that a wave vibrates up and down.
  - Often in number of times per second
  - The unit of “per second” is Hertz (Hz)
- Wave speed = wavelength x frequency

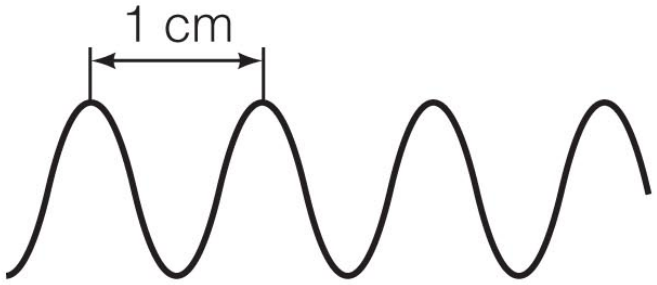
Light: Electromagnetic Waves

- A light wave is a vibration of electric and magnetic fields.
- Light interacts with charged particles through these electric and magnetic fields.

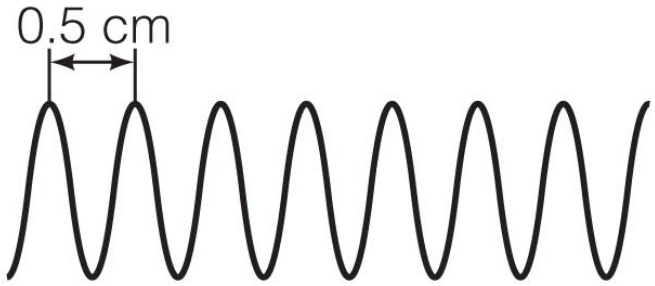


a Electrons move when light passes by, showing that light carries a vibrating electric field.

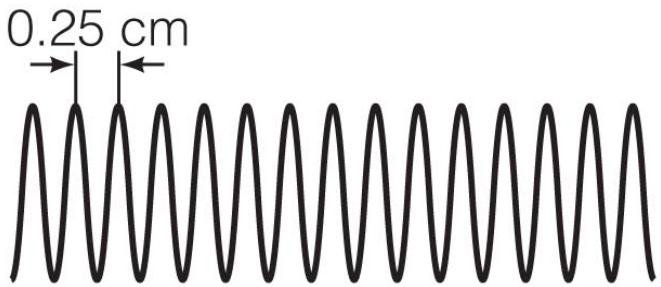
Wavelength and Frequency



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

wavelength x frequency = speed of light = constant

Particles of Light

- Particles of light are called **photons.**
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.

Wavelength, Frequency, and Energy

$$\lambda \times f = c$$

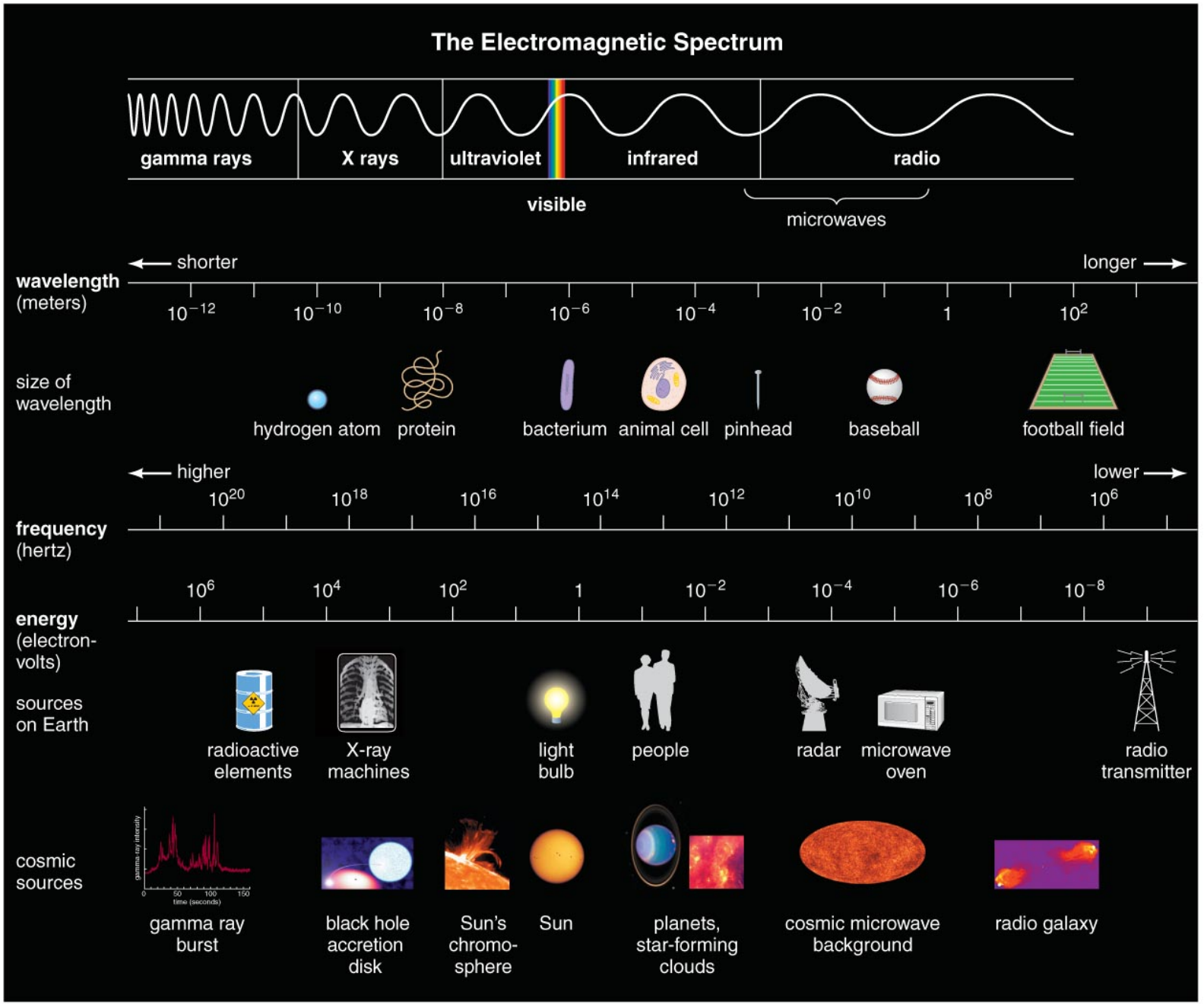
λ = wavelength, f = frequency

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

$E = h \times f$ = photon energy

$h = 6.626 \times 10^{-34}$ joule x s = Planck's constant

What is the electromagnetic spectrum?



Clicker Question

The higher the photon energy,

A. the longer its wavelength.
B. the shorter its wavelength.
C. energy is independent of wavelength.

Clicker Question

The higher the photon energy,

A. the longer its wavelength.

B. ***the shorter its wavelength.***

C. energy is independent of wavelength.

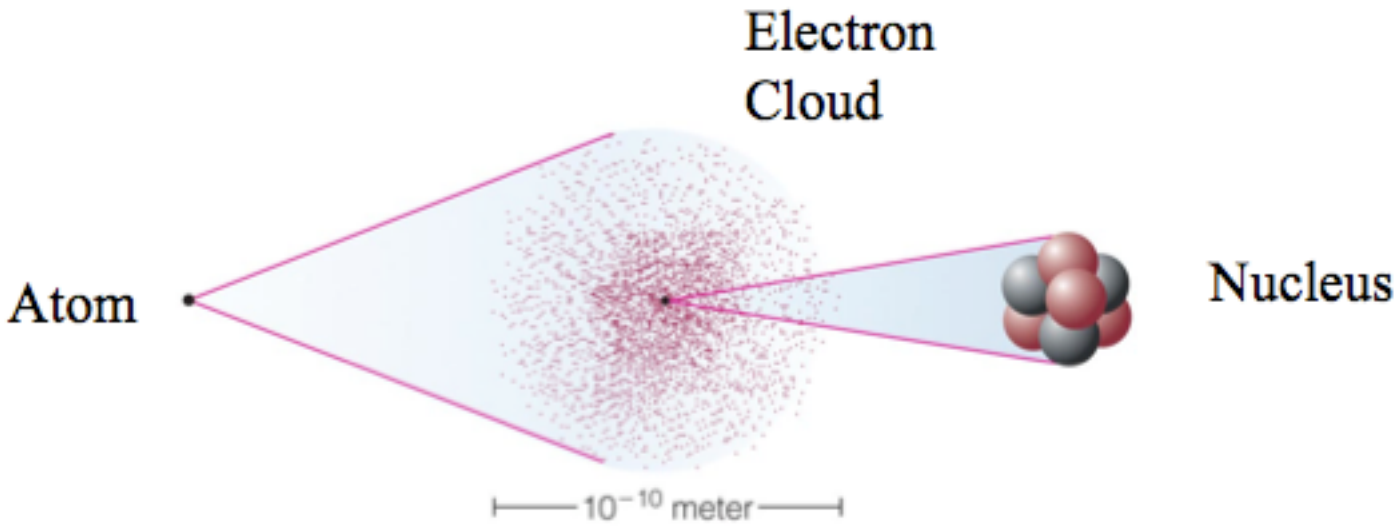
What have we learned?

- **What is light?**
  - Light can behave like either a wave or a particle.
  - A light wave is a vibration of electric and magnetic fields.
  - Light waves have a wavelength and a frequency.
  - Photons are particles of light.
- **What is the electromagnetic spectrum?**
  - Human eyes cannot see most forms of light.
  - The entire range of wavelengths of light is known as the electromagnetic spectrum.

5.3 Properties of Matter

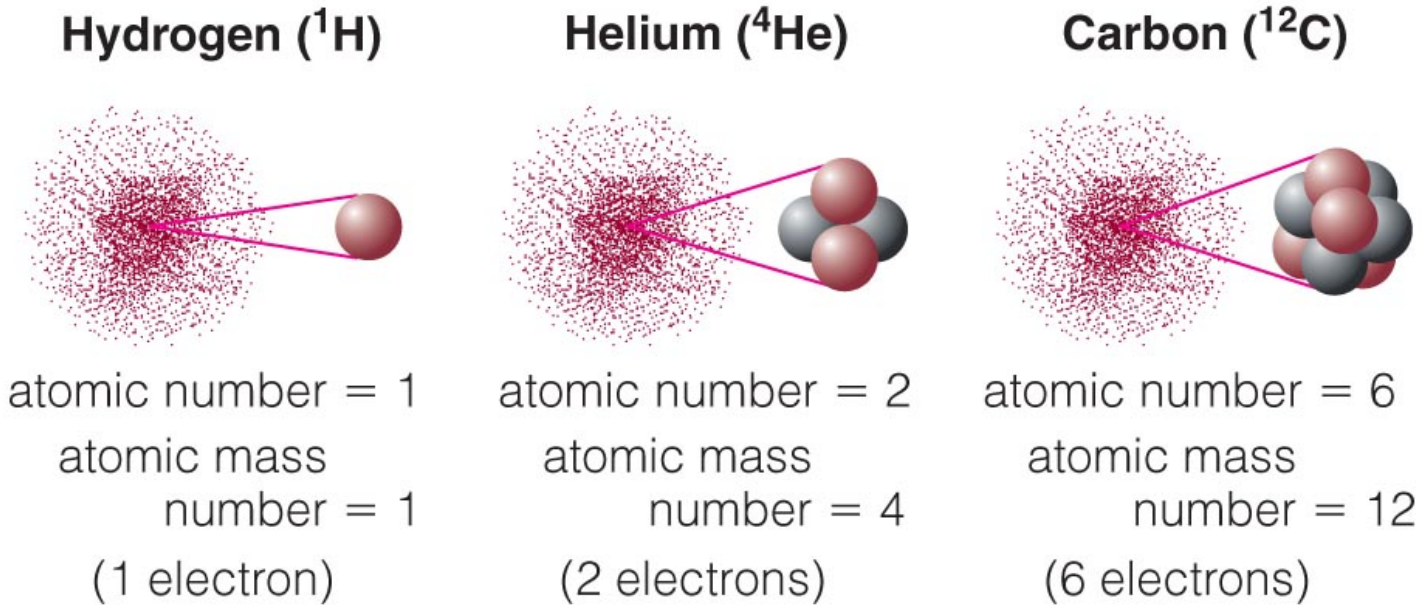
- Our goals for learning:
  - **What is the structure of matter?**
  - **What are the phases of matter**
  - **How is energy stored in atoms?**

What is the structure of matter?



Atomic Terminology

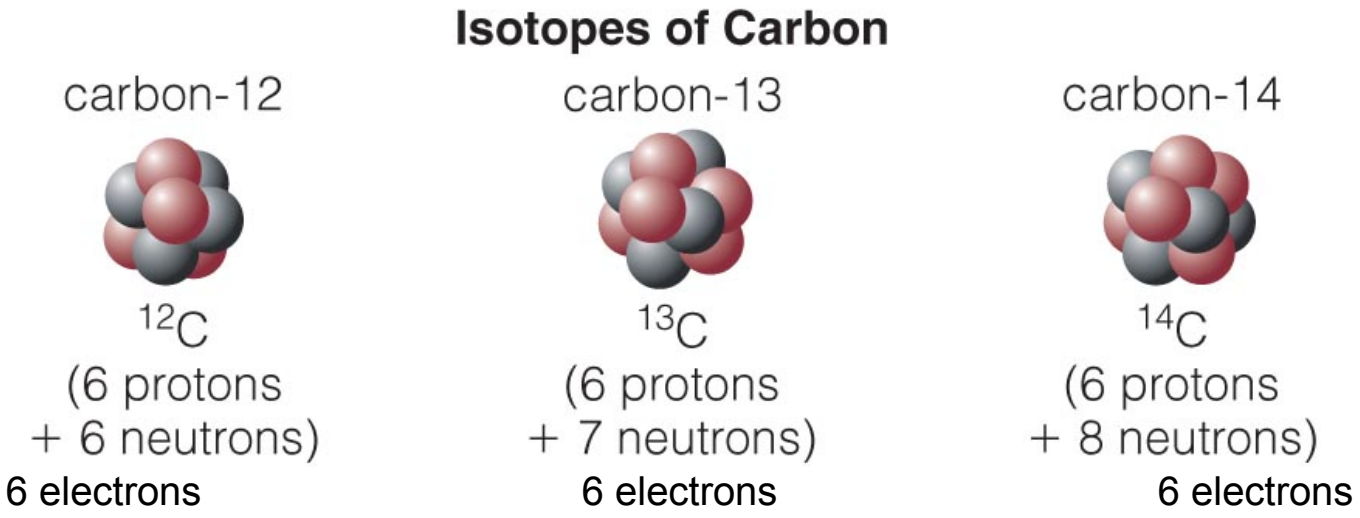
- Atomic number = # of protons in nucleus
- Atomic mass number = # of protons + neutrons



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

Atomic Terminology

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

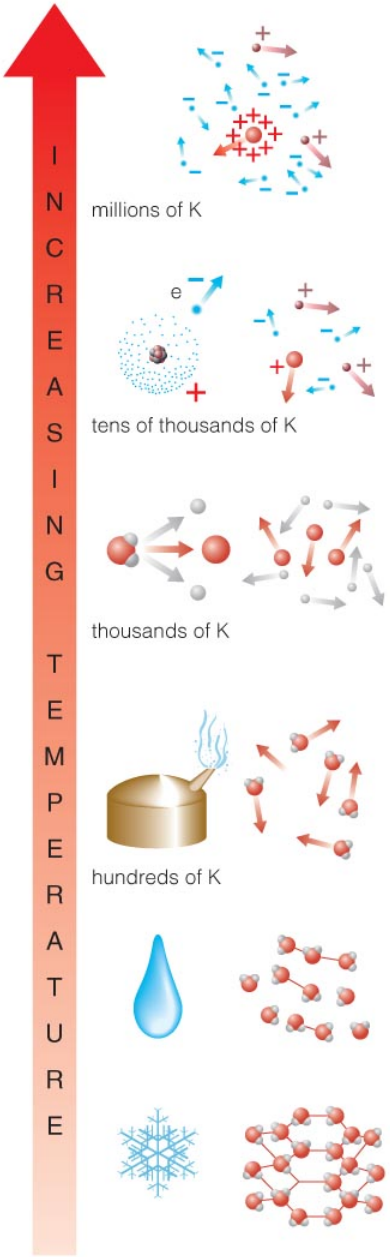


What are the phases of matter?

- Familiar phases:
  - Solid (ice)
  - Liquid (water)
  - Gas (water vapor)

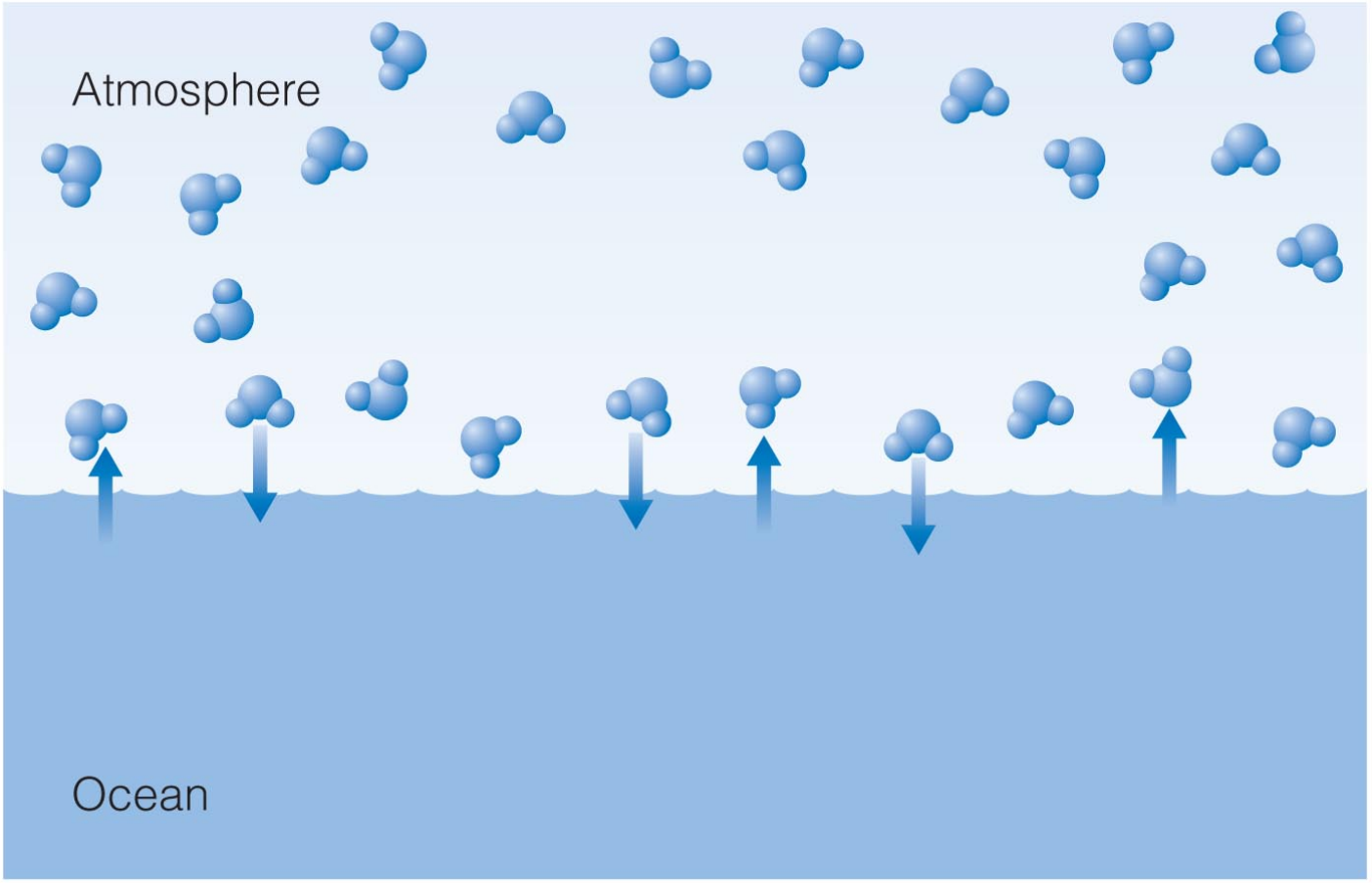
- Phases of same material behave differently because of differences in chemical bonds.

Phase Changes



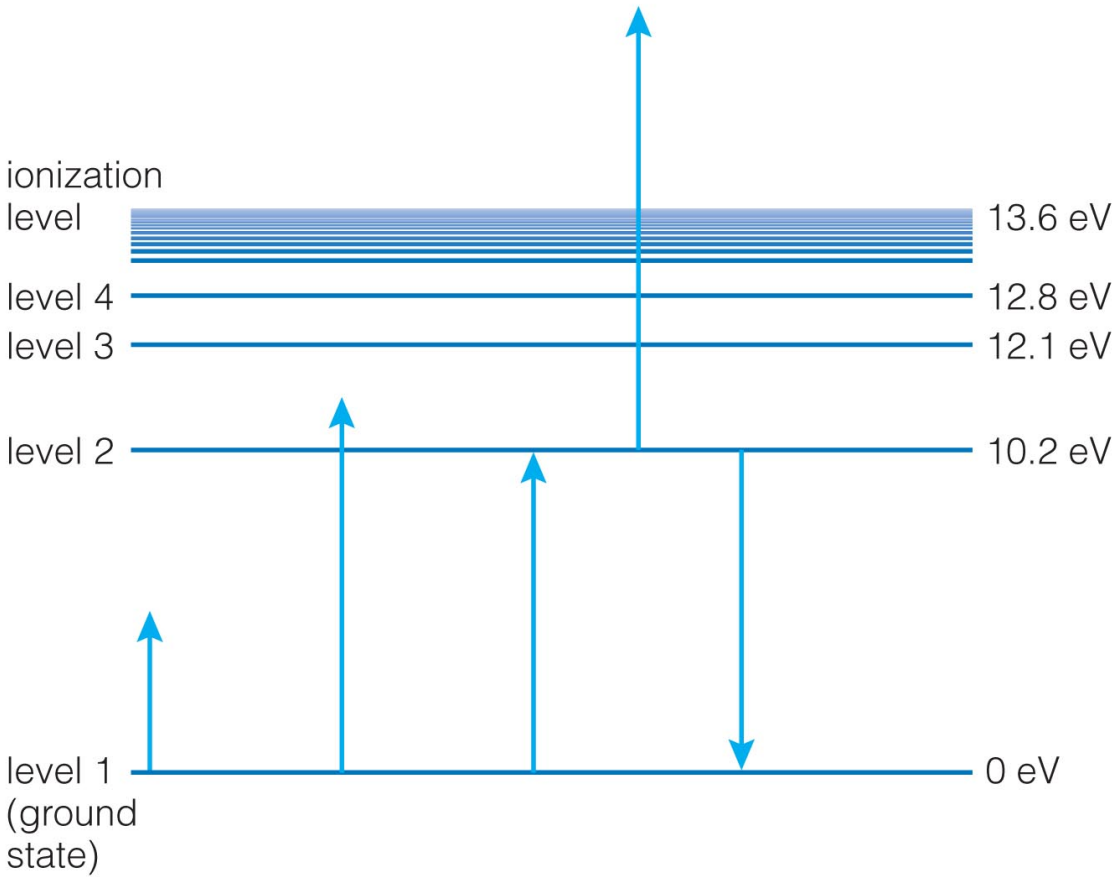
- **Ionization:** stripping of electrons, changing atoms into **plasma**
- **Dissociation:** breaking of molecules into atoms
- Evaporation: breaking of flexible chemical bonds, changing liquid into solid
- **Melting:** breaking of rigid chemical bonds, changing solid into liquid

Phases and Pressure



- Phase of a substance depends on both temperature and pressure.
- Often more than one phase is present.

How is energy stored in atoms?

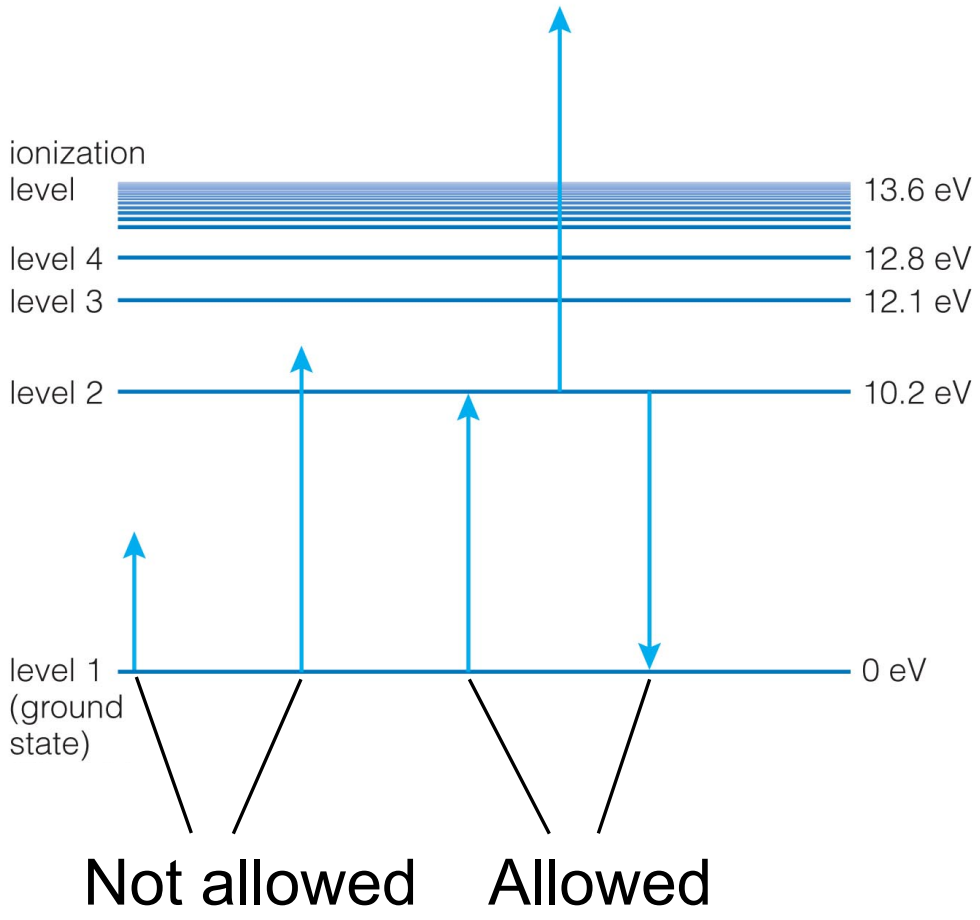


Excited states

Ground state

- Electrons in atoms are restricted to particular energy levels.

Energy Level Transitions



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

What have we learned?

- **What is the structure of matter?**
  - Matter is made of atoms, which consist of a nucleus of protons and neutrons surrounded by a cloud of electrons.
- **What are the phases of matter?**
  - Adding heat to a substance changes its phase by breaking chemical bonds.
  - As temperature rises, a substance transforms from a solid to a liquid to a gas, then the molecules can dissociate into atoms.
  - Stripping of electrons from atoms (ionization) turns the substance into a plasma.

What have we learned?

- **How is energy stored in atoms?**
  - The energies of electrons in atoms correspond to particular energy levels.
  - Atoms gain and lose energy only in amounts corresponding to particular changes in energy levels.