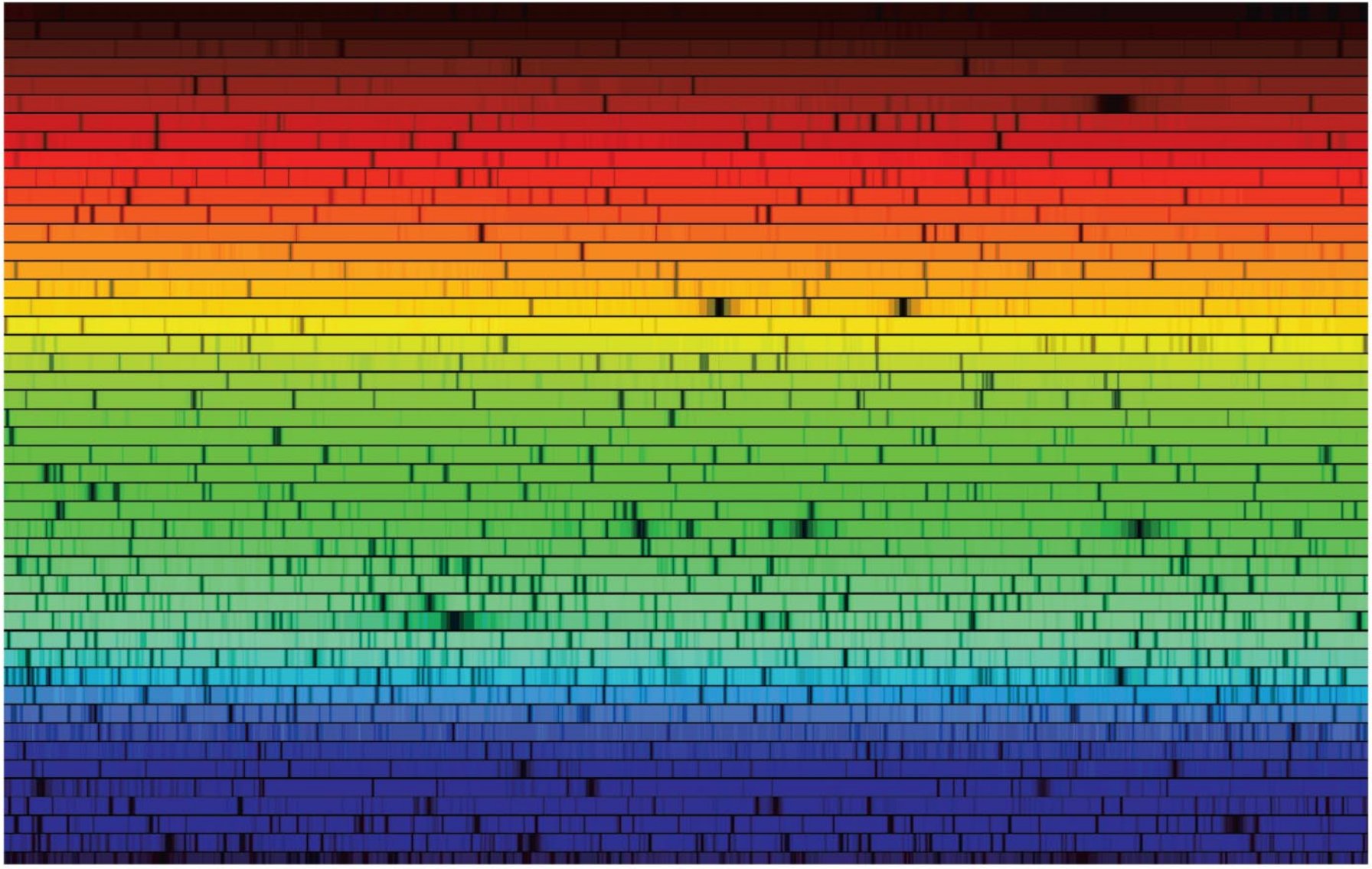
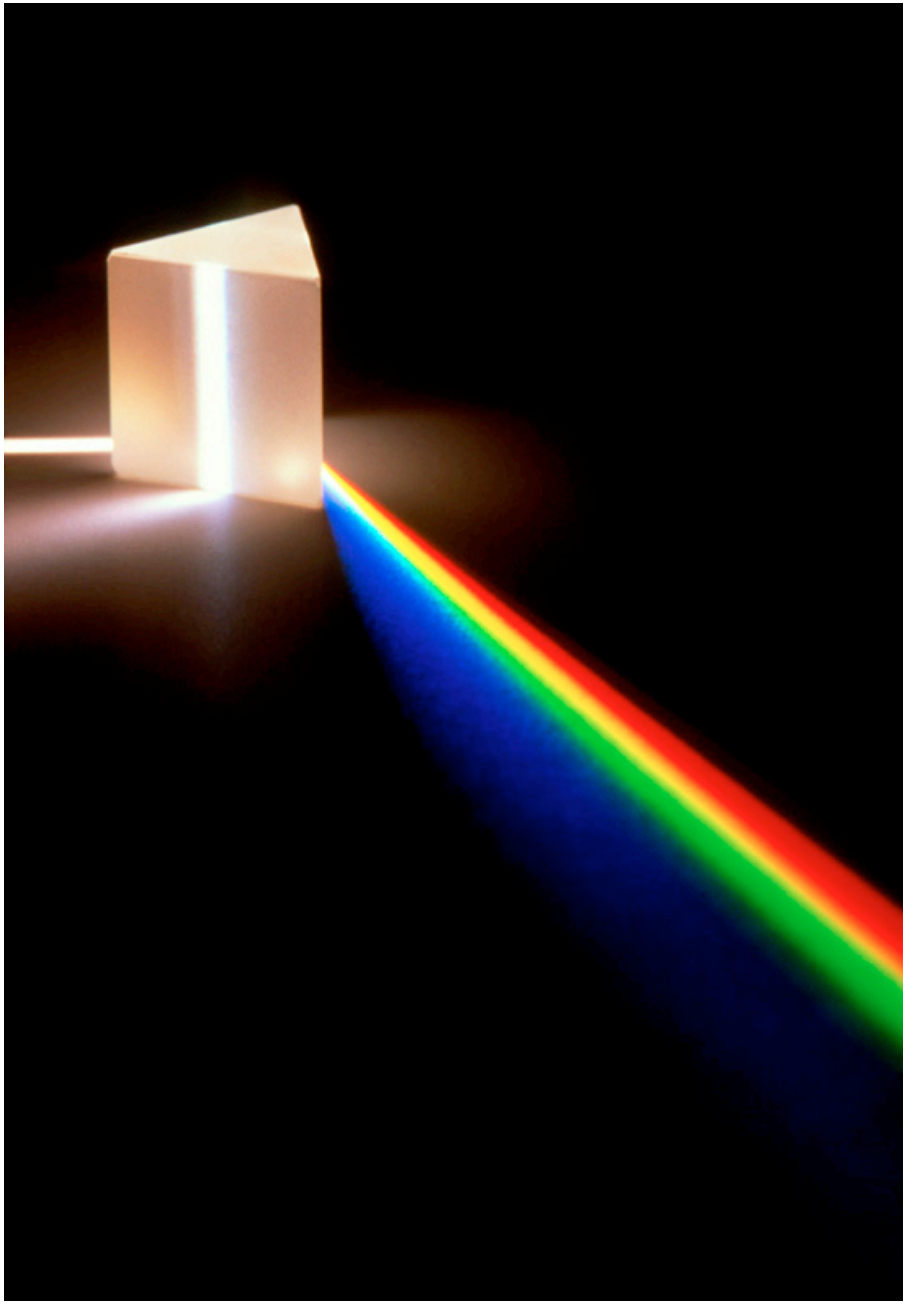
Light and Matter: Reading Messages from the Cosmos



Light and Color

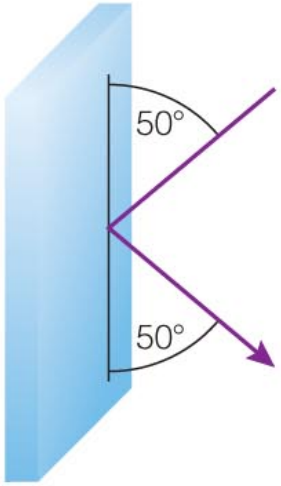
- Light is a form of energy (think of the warmth of sunlight or a lightbulb)
- “White light” is actually made up of many different colors.

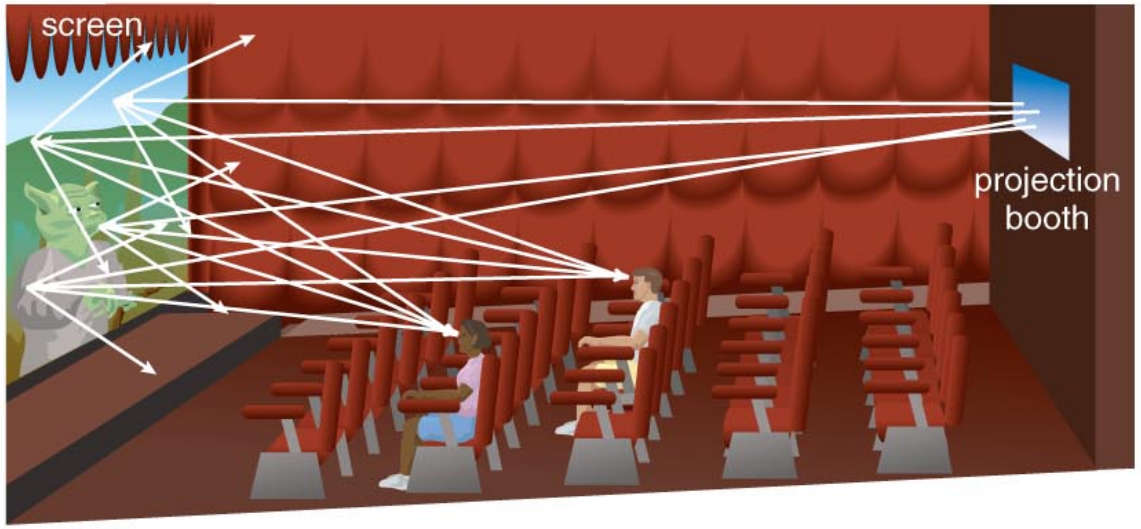


How do light and matter interact?

- Emission: matter can emit light
- Absorption: matter can absorb light
- Transmission
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection/scattering: light can ”bounce” off matter

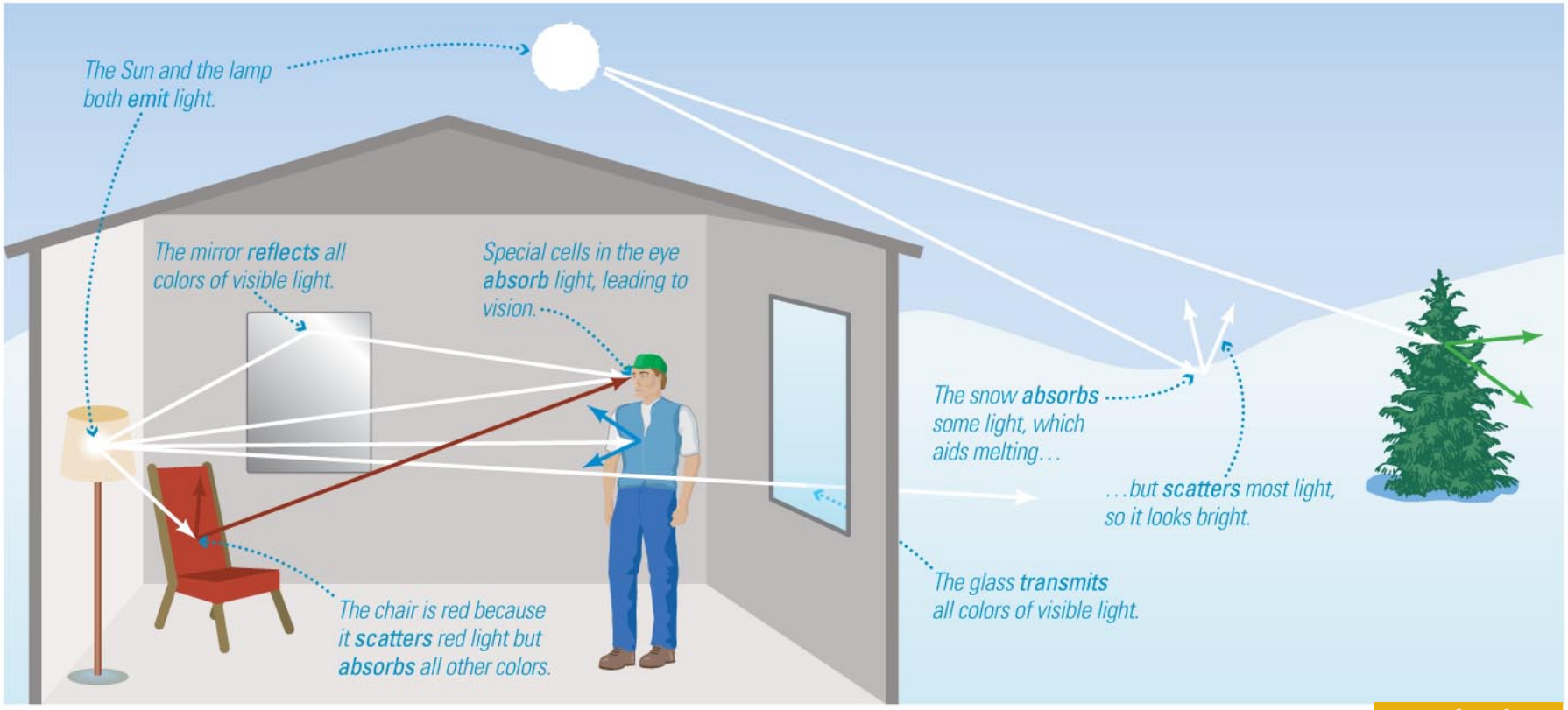
Reflection and Scattering





- 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.

Thought 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.

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A. The rose absorbs red light.
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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

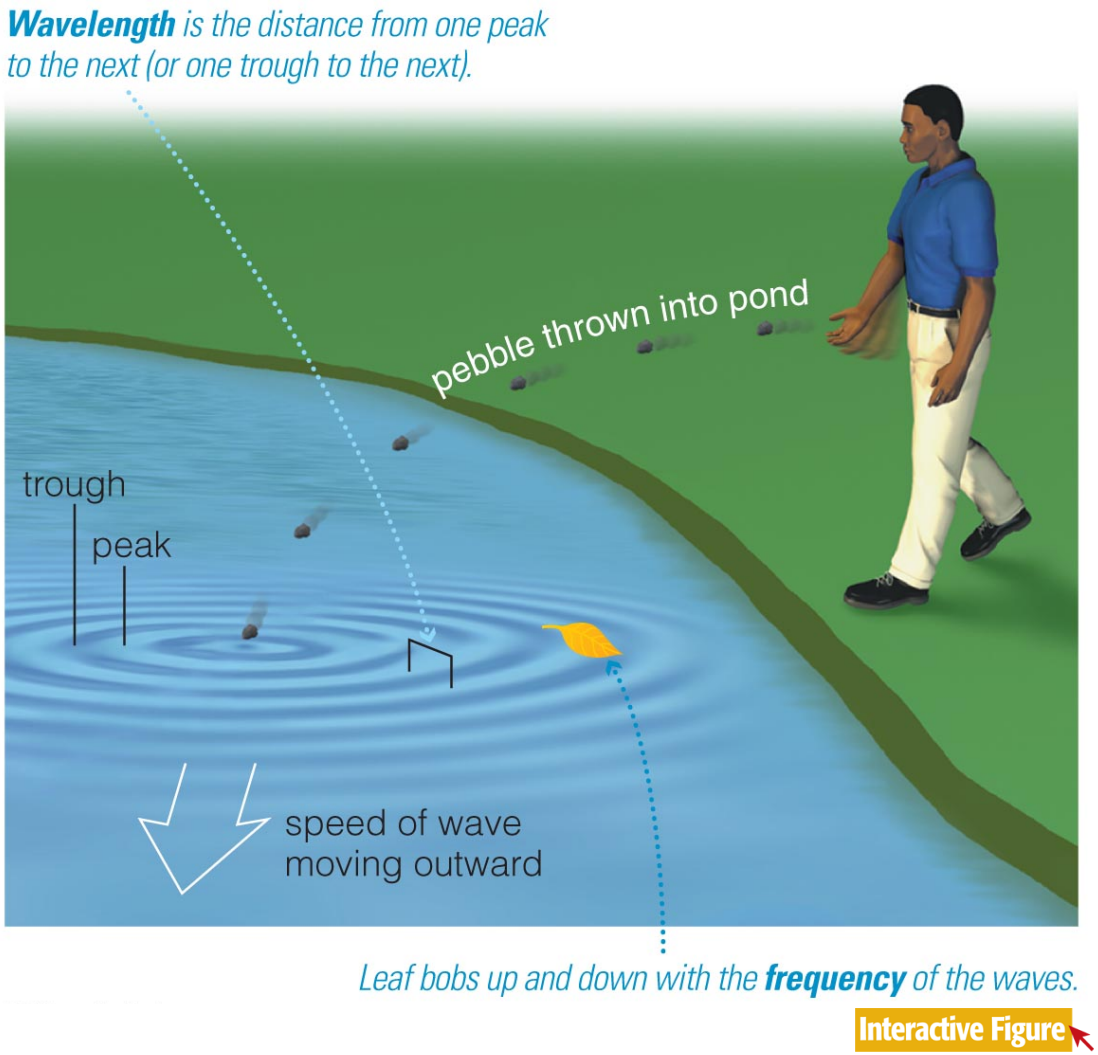
- Our goals for learning:
  - **What is light?**
  - **What is the electromagnetic spectrum?**

What is light?

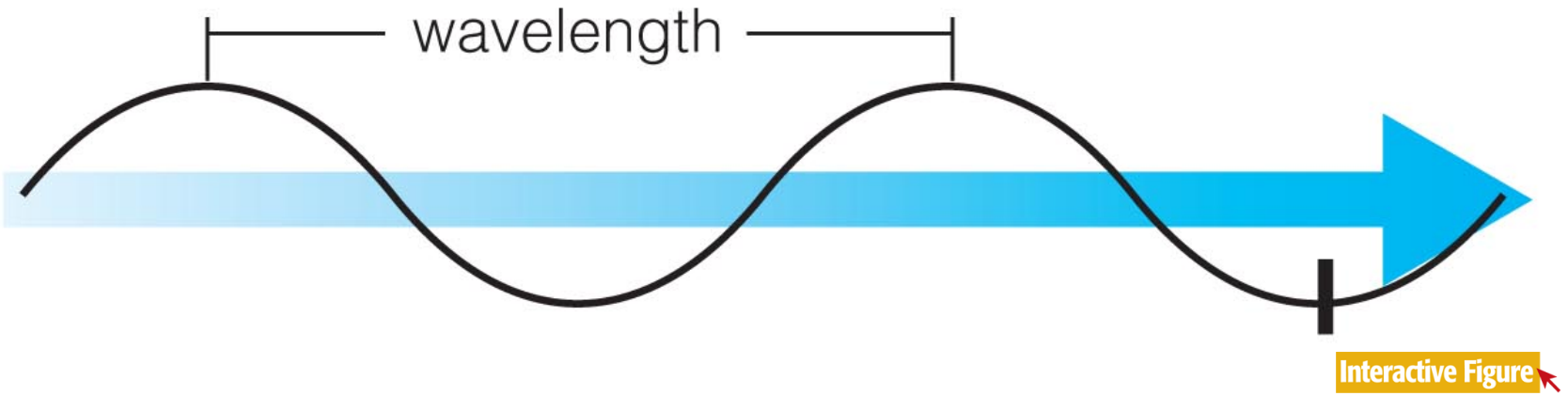
- Light can act either like a wave or like a particle.
- Particles of light are called **photons.**

Waves

- A **wave** is a pattern of motion that can carry energy without carrying matter along with it.



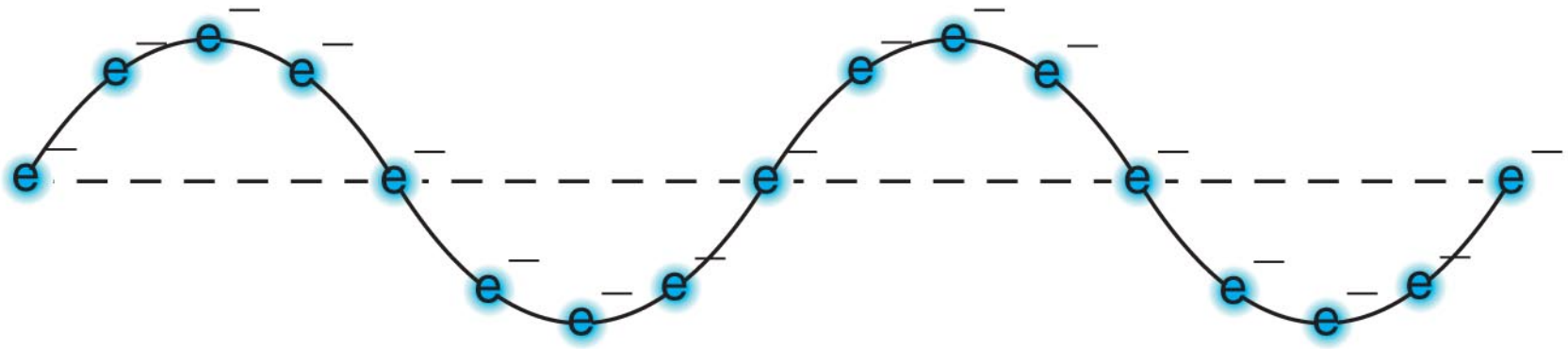
Properties of Waves



- **Wavelength** is the distance between two wave peaks.
- **Frequency** is the number of times per second that a wave vibrates up and down.

Wave speed = wavelength x frequency

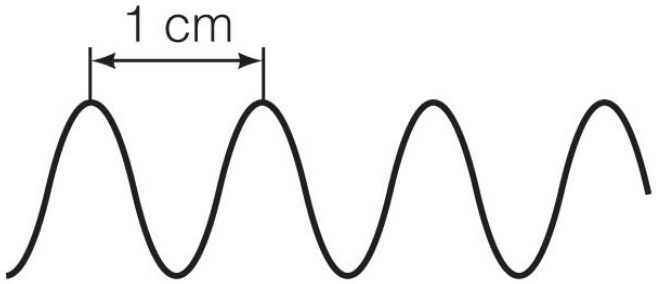
Light: Electromagnetic Waves



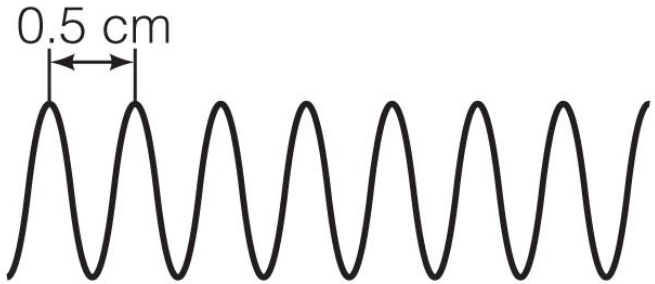
a Electrons move when light passes by, showing that light carries a vibrating electric field.

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

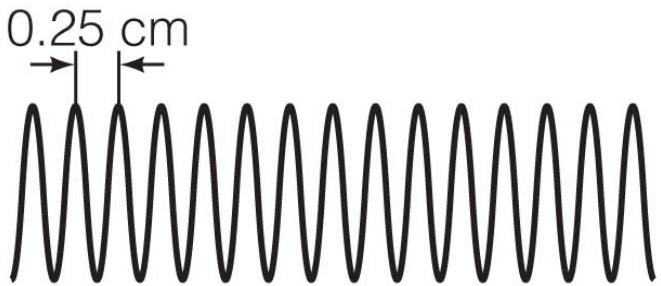
Wavelength and Frequency



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

$$\lambda \times f = c$$

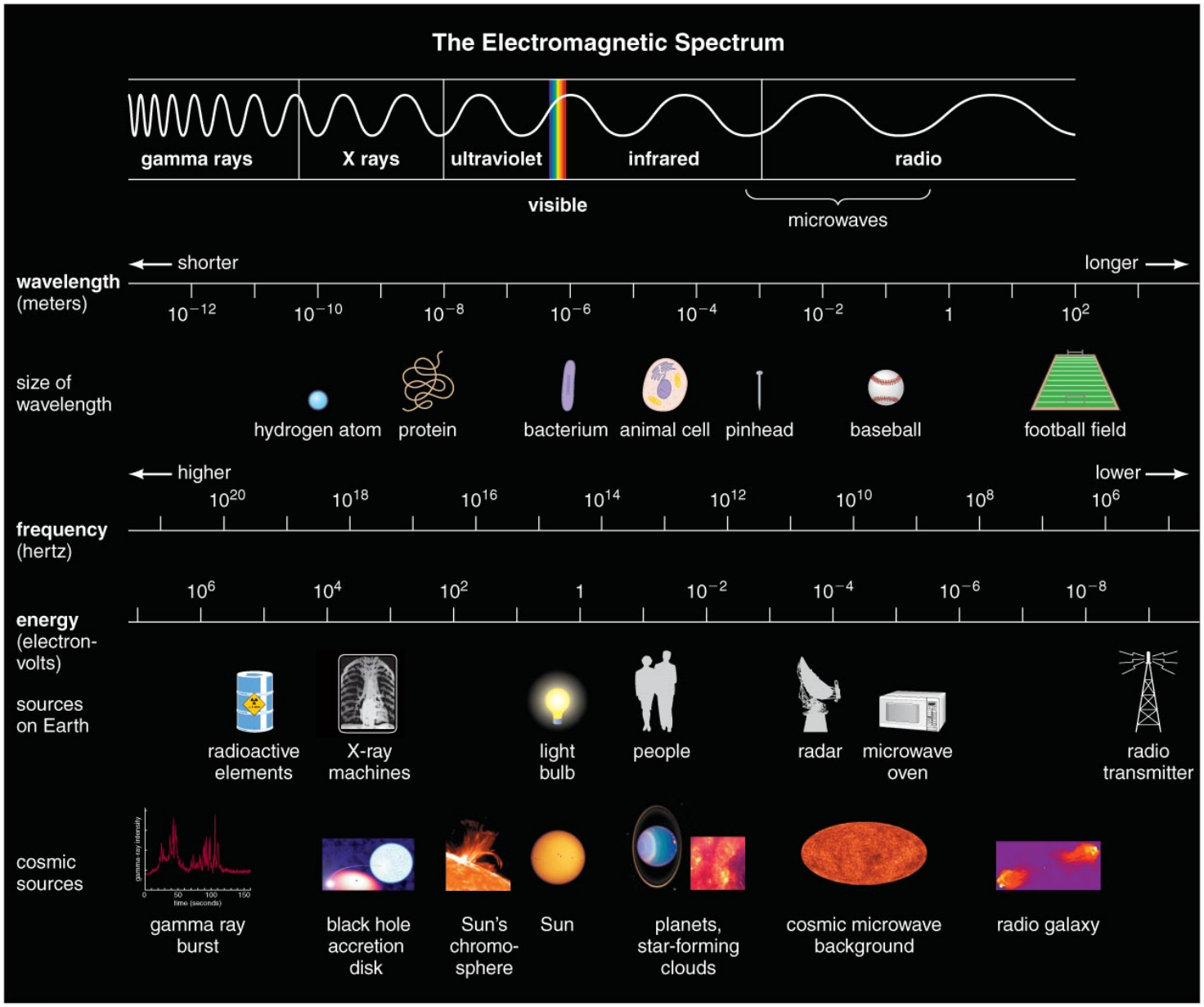
λ = wavelength, f = frequency

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

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

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

What is the electromagnetic spectrum?



Thought Question

The higher the photon energy,

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

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B. the shorter its wavelength.
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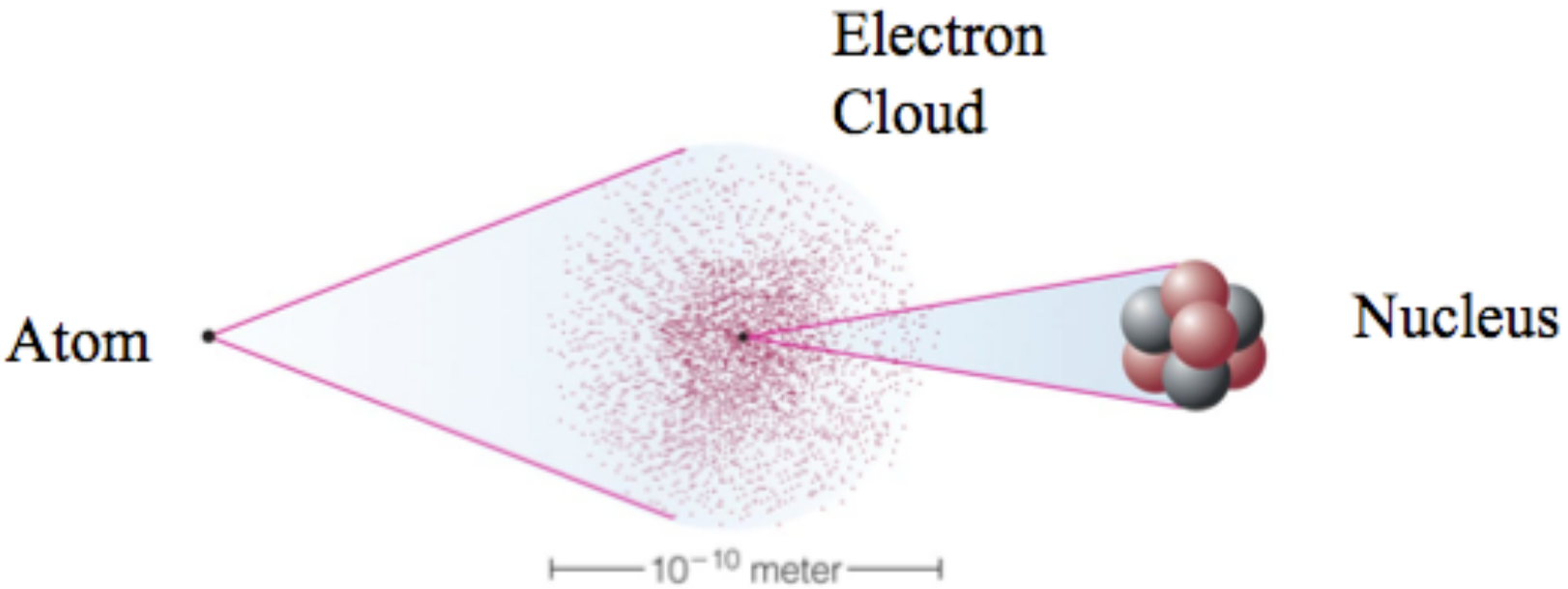
What have we learned?

- **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?



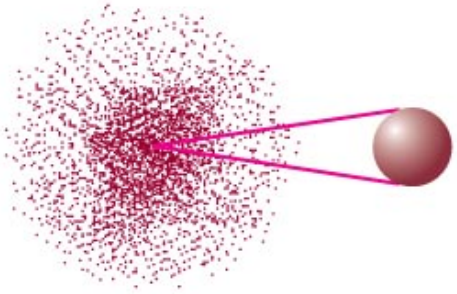
Proton: particle in nucleus, positive charge
Neutron: particle in nucleus, no charge
Electron: particle in a "cloud" around the nucleus, negative charge

In a normal (un-ionized) atom, # of protons = # of electrons.

Atomic Terminology

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

Hydrogen (^{1}H)

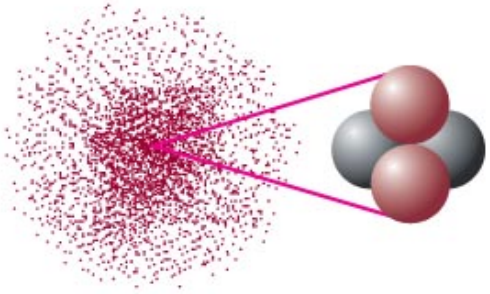


atomic number = 1

atomic mass number = 1

(1 electron)

Helium (^{4}He)

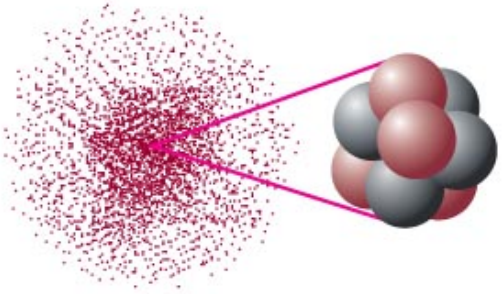


atomic number = 2

atomic mass number = 4

(2 electrons)

Carbon (^{12}C)



atomic number = 6

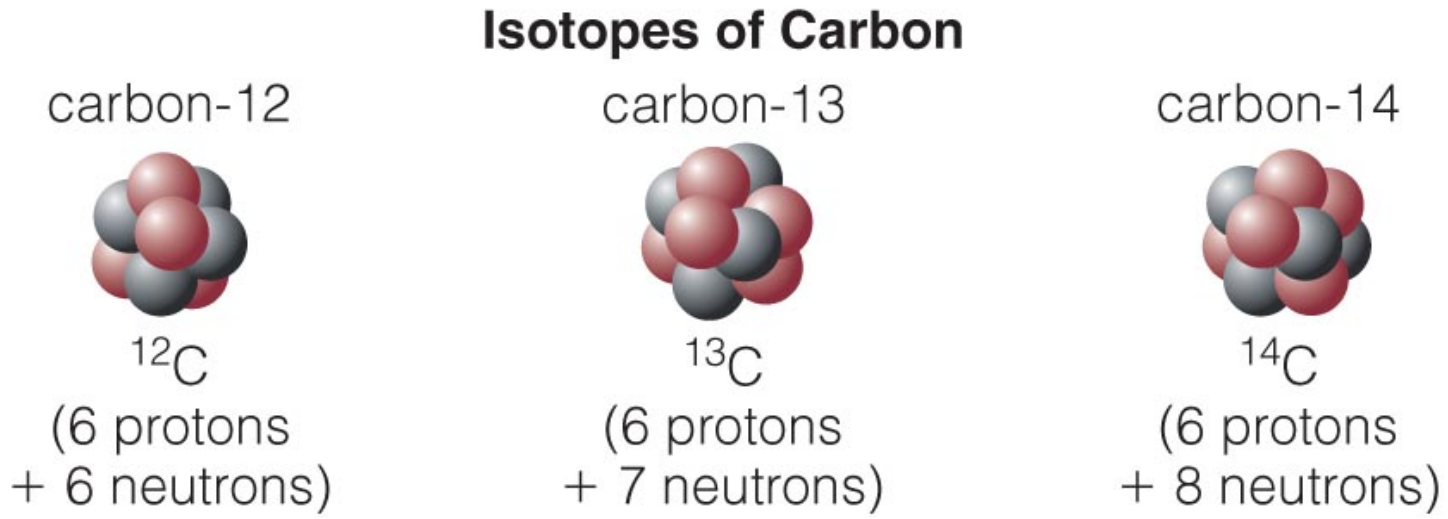
atomic mass number = 12

(6 electrons)

- *Number of protons defines the element!*

Atomic Terminology

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



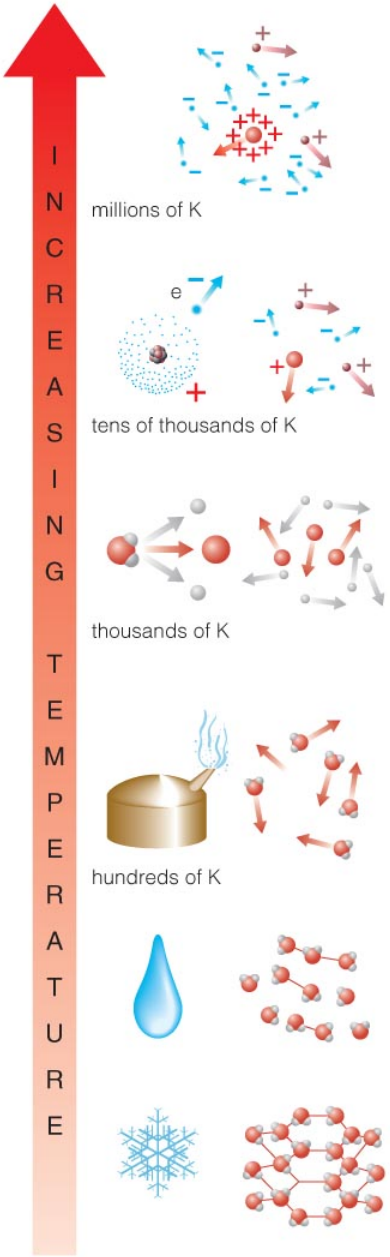
- **Molecule**: consists of two or more atoms bound together (water: H_2O, carbon dioxide: CO_2)

What are the phases of matter?

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

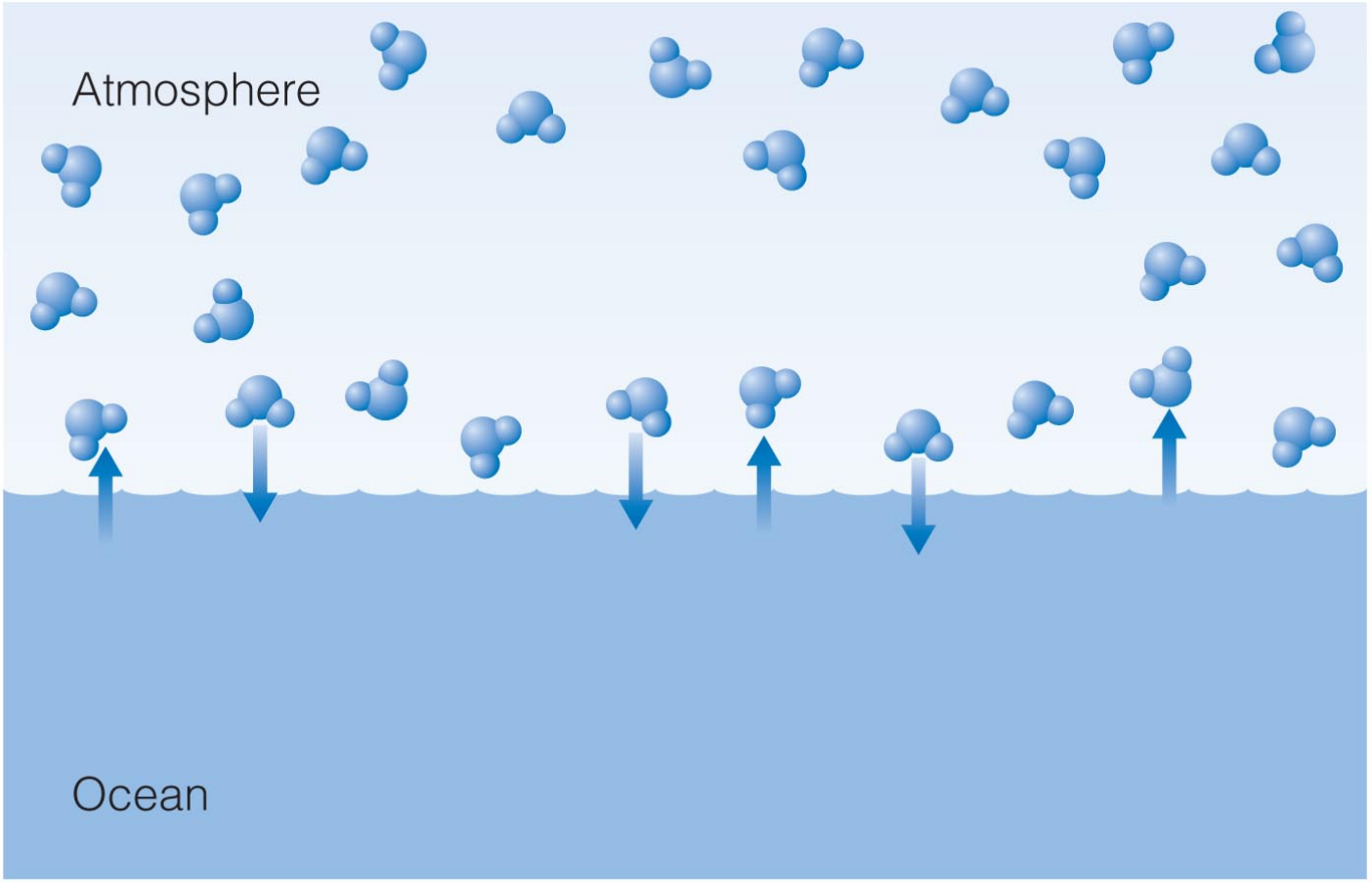
- Phases of same material behave differently because of differences in chemical bonds.

Phase Changes



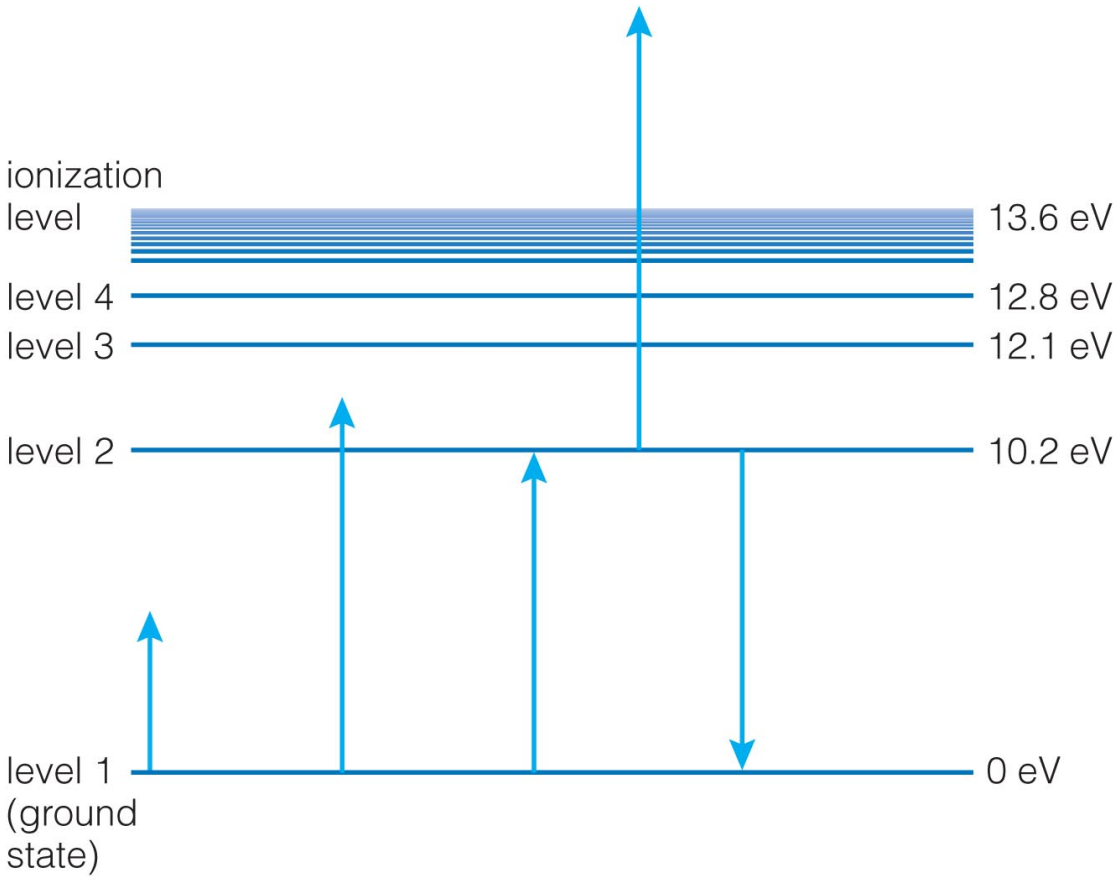
- **Ionization:** stripping of electrons, changing atoms into **plasma**
- **Dissociation:** breaking of molecules into atoms
- **Evaporation:** breaking of flexible chemical bonds, changing liquid into gas
- **Melting:** breaking of rigid chemical bonds, changing solid into liquid

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?

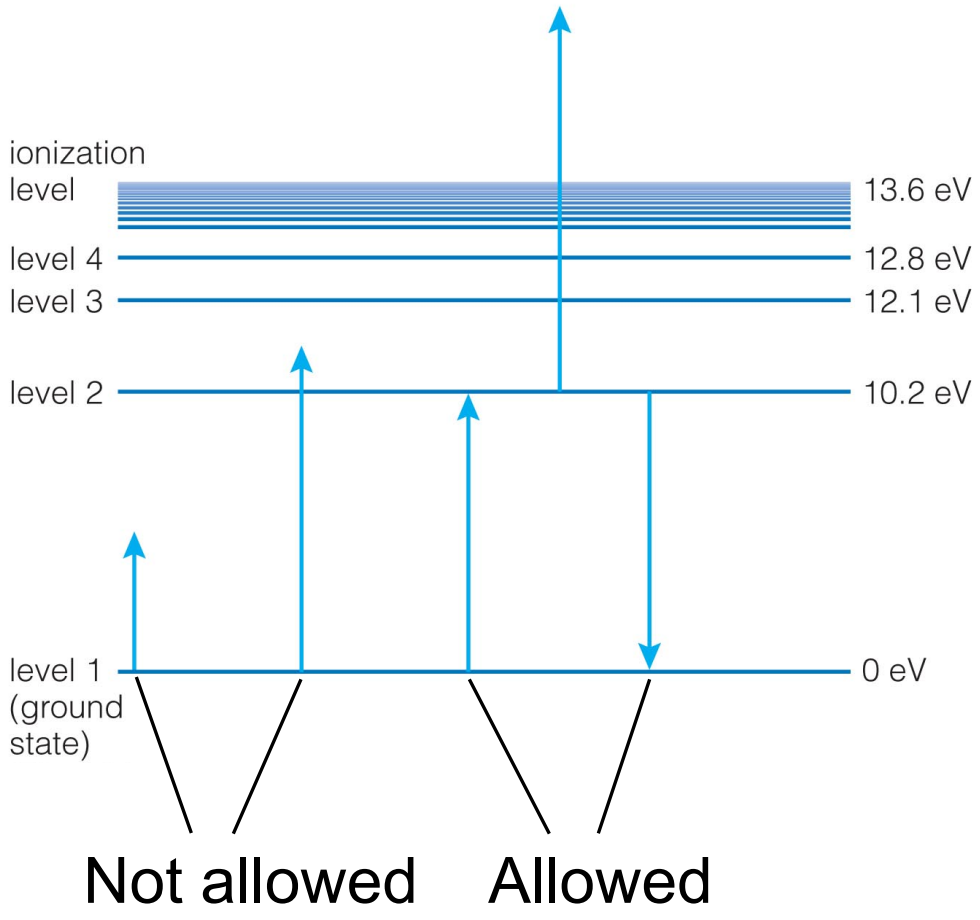


Excited states

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.