Section 4.1 and 7.1

Energy

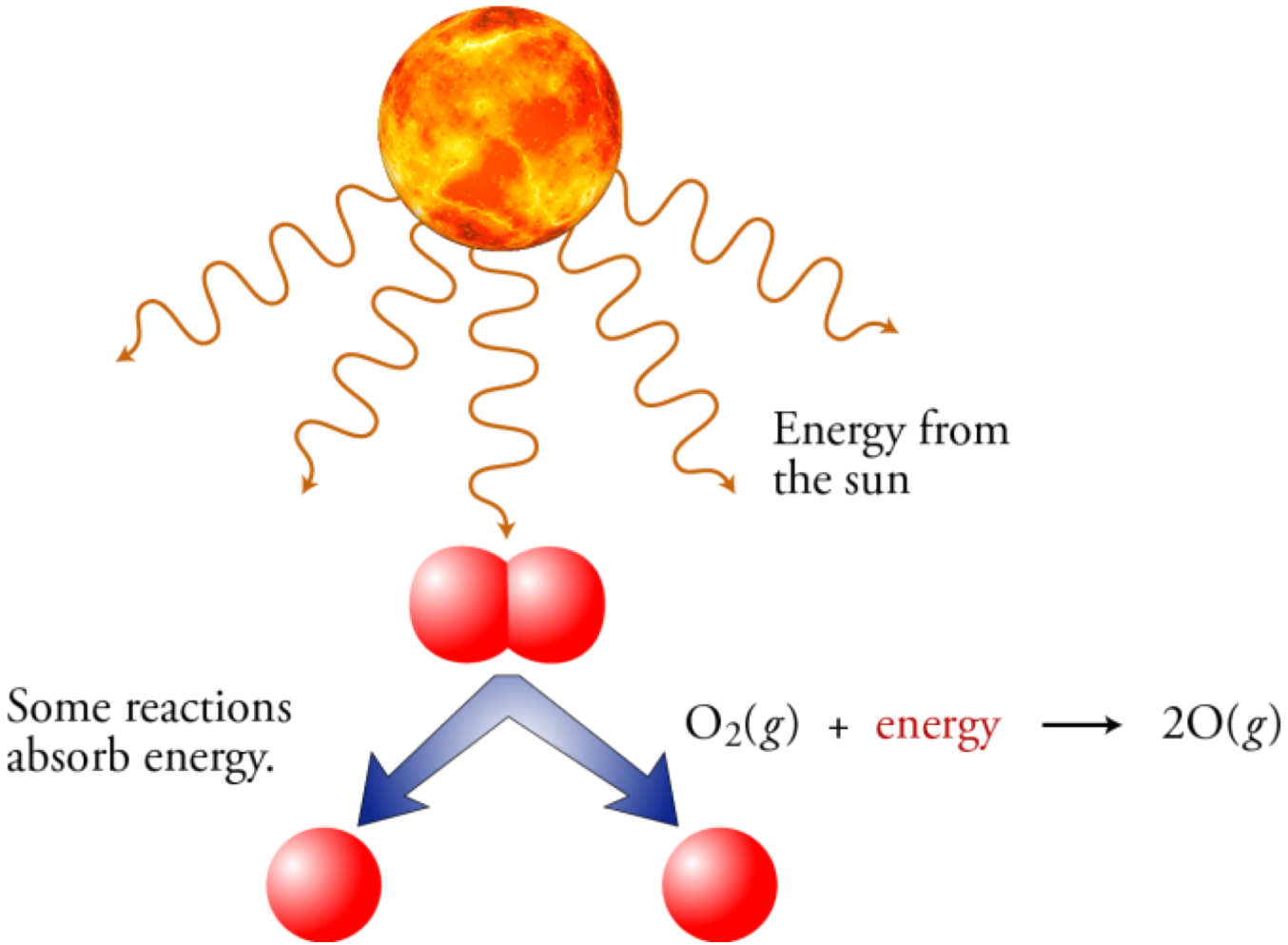
An Introduction to Chemistry

by Mark Bishop

Some Chemical Changes Release Energy

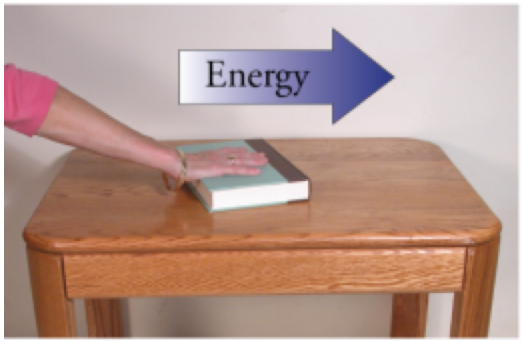
- For example, the methane in natural gas reacts with oxygen gas to form carbon dioxide, water, and energy.

Some Chemical Changes Absorb Energy



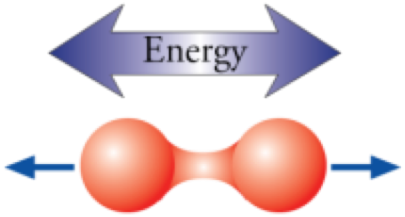
Energy Terms

- **Energy** = the capacity to do work
- **Work**, in this context, may be defined as what is done to move an object against some sort of resistance.



Energy is required to push a book across a table and overcome the resistance to movement due to friction.

Energy is required to lift a book and overcome the resistance to movement due to gravity.



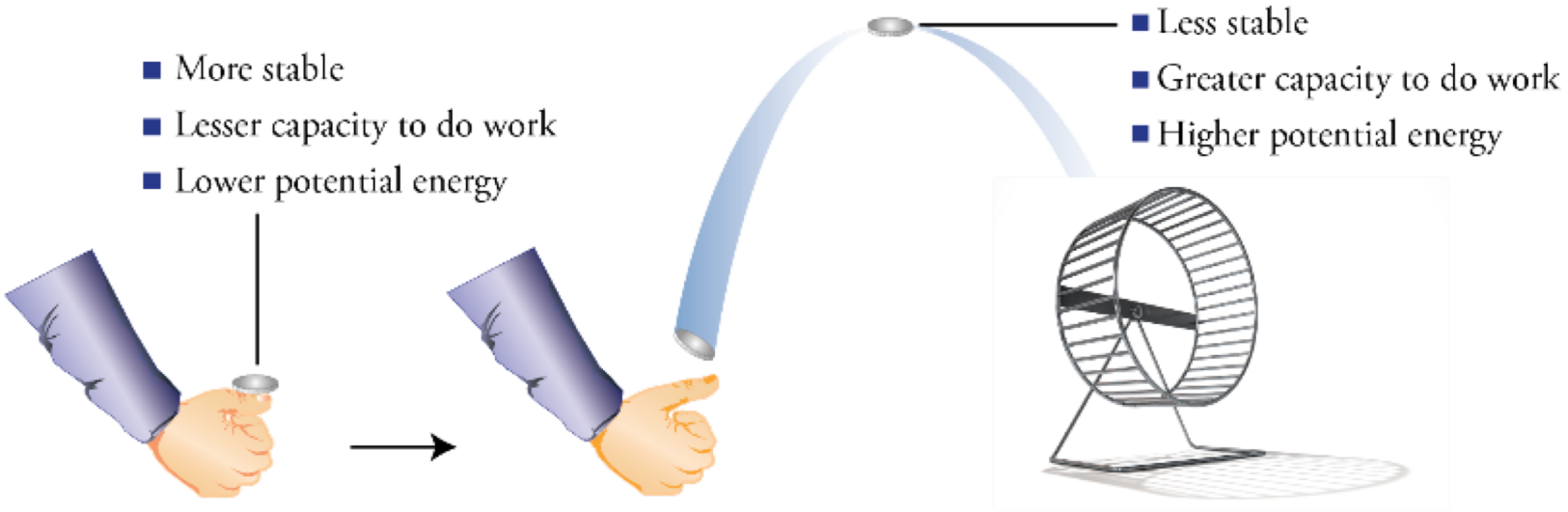
Energy is required to separate two atoms in a molecule and overcome the resistance to movement due to the chemical bond between them.

Kinetic energy, momentum, force of collisions, and work

- **Kinetic Energy** = the energy of motion = $\frac{1}{2}m\mu^2$. (m = mass, μ = velocity)
- The force of collisions is proportional to the momentum (mass × velocity, $m\mu$) of the objects colliding.
- Therefore, if two objects are moving at the same velocity, the more massive object will have greater momentum, so it will collide with more force, giving it a greater capacity to do work, and a greater kinetic energy.
- If two objects have the same mass but are moving at different velocities, the faster moving object will have greater momentum, so it will collide with more force, giving it a greater capacity to do work, and a greater kinetic energy.

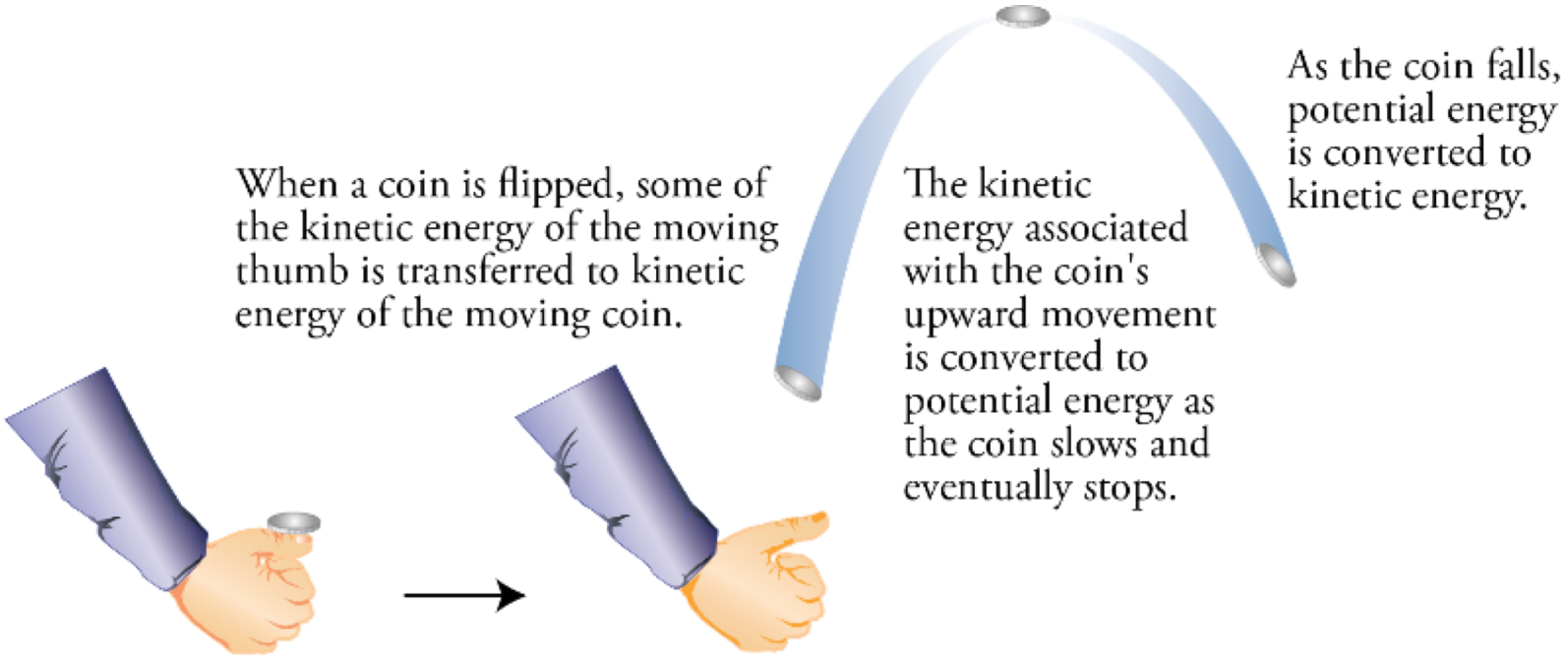
Coin and Potential Energy

- **Potential Energy** = energy by virtue of position or state



Law of Conservation of Energy

- Energy can be neither created nor destroyed, but it can be transferred from one system to another and changed from one form to another.



Endergonic Change

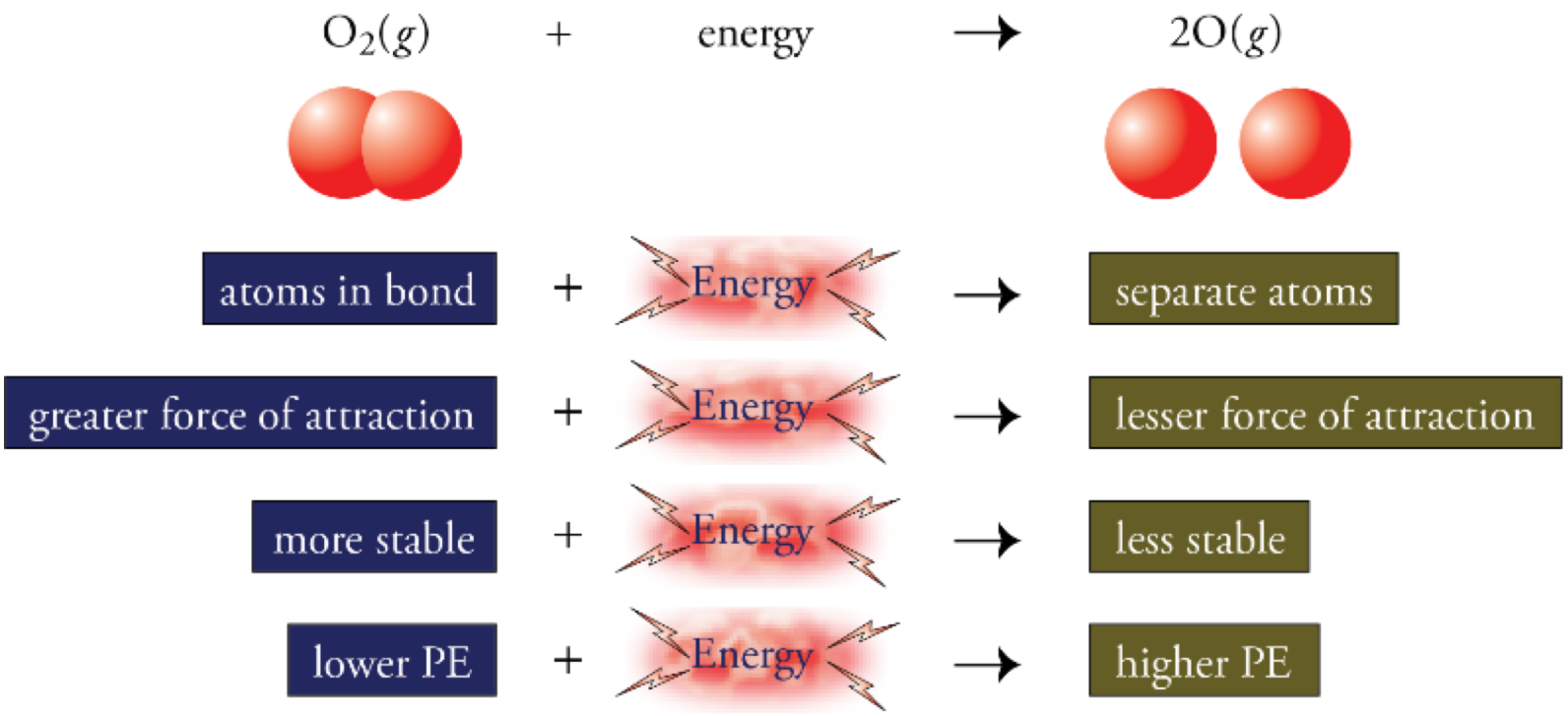
coin in hand $\rightarrow$ coin in air above hand

more stable $\rightarrow$ less stable system

lesser capacity to do work $\rightarrow$ greater capacity to do work

lower PE + energy $\rightarrow$ higher PE

Bond Breaking and Potential Energy



Exergonic Change

coin in air above hand → coin on ground

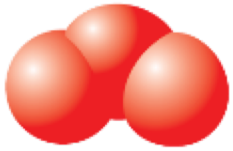
less stable system → more stable

greater capacity to do work → lesser capacity to do work

higher PE → lower PE + energy

Bond Making and Potential Energy

$O(g) + O_2(g) \rightarrow O_3(g) + \text{energy}$



separate atoms → atoms in bond + Energy

lesser force of attraction → greater force of attraction + Energy

less stable → more stable + Energy

higher PE → lower PE + Energy

Which higher energy? Is it kinetic or potential?

- Incandescent light bulbs burn out because their tungsten filament gradually evaporates, weakening until it breaks. Argon gas is added to these bulbs to reduce the rate of evaporation. Collisions between the argon atoms and the higher-temperature wire leads to KE being transferred to the argon atoms, cooling the wire. Which has greater energy, (1) an argon atom, Ar, with a velocity of 428 m/s or (2) the same atom moving with a velocity of 456 m/s? (These are the average velocities of argon atoms at 20 ºC and 60 ºC.)

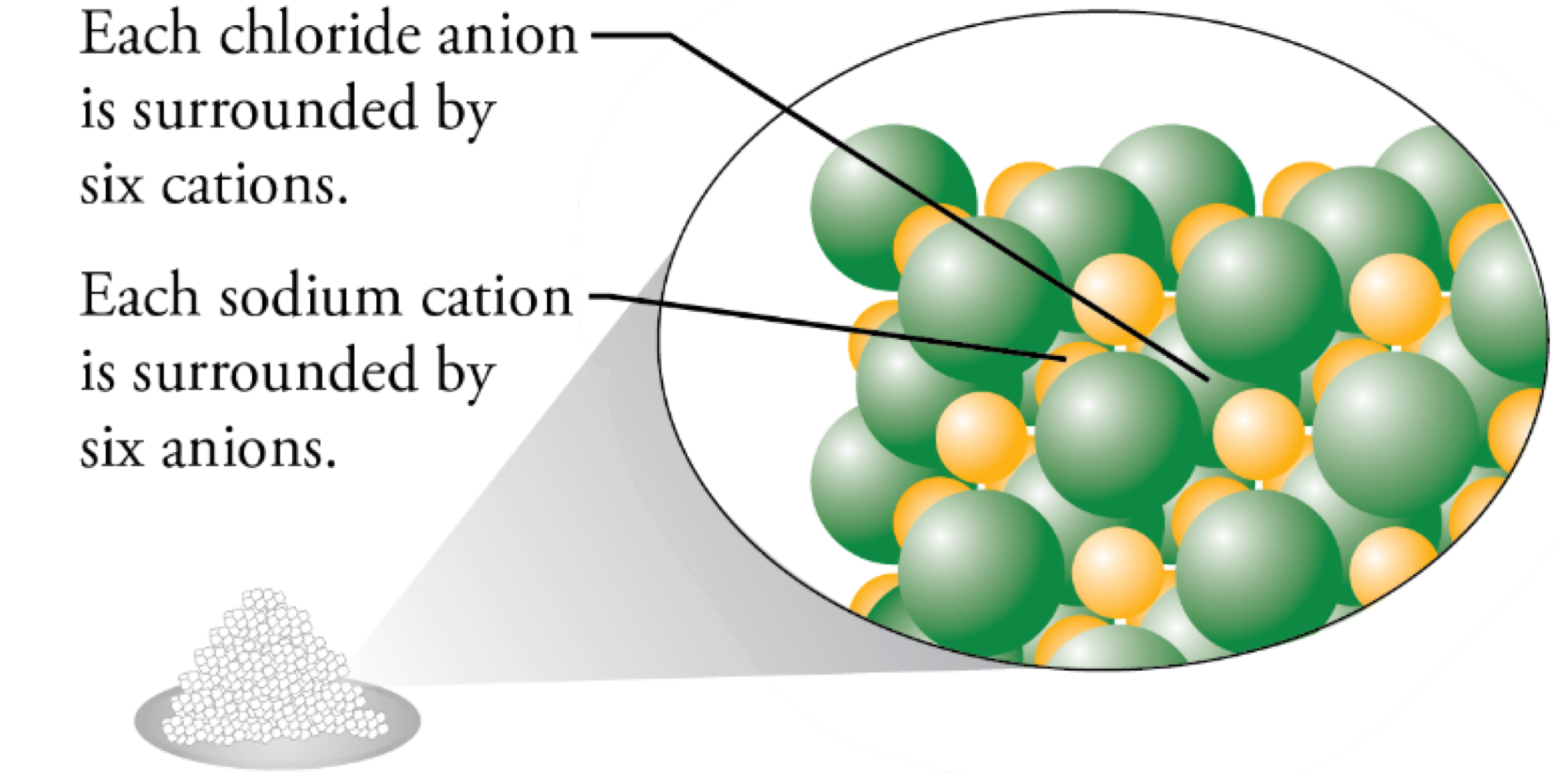
Which higher energy? Is it kinetic or potential?

- Because krypton, Kr, atoms have a greater mass than argon atoms, krypton gas does a better job than argon of reducing the rate of evaporation of the tungsten filament in an incandescent light bulb. Because of krypton's higher cost, however, krypton is only used when longer life is worth the extra cost. Which has higher energy, (1) an argon atom with a velocity of 428 m/s or (2) a krypton atom moving at the same velocity?

Which higher energy? Is it kinetic or potential?

- According to our model for ionic solids, the ions at the surface of an ionic crystal are constantly moving out and away from the other ions and then being attracted back to the surface. Which has more energy, (1) a stationary sodium ion well separated from the chloride ions at the surface of a sodium chloride crystal or (2) a stationary sodium ion located quite close to the chloride ions on the surface of the crystal?

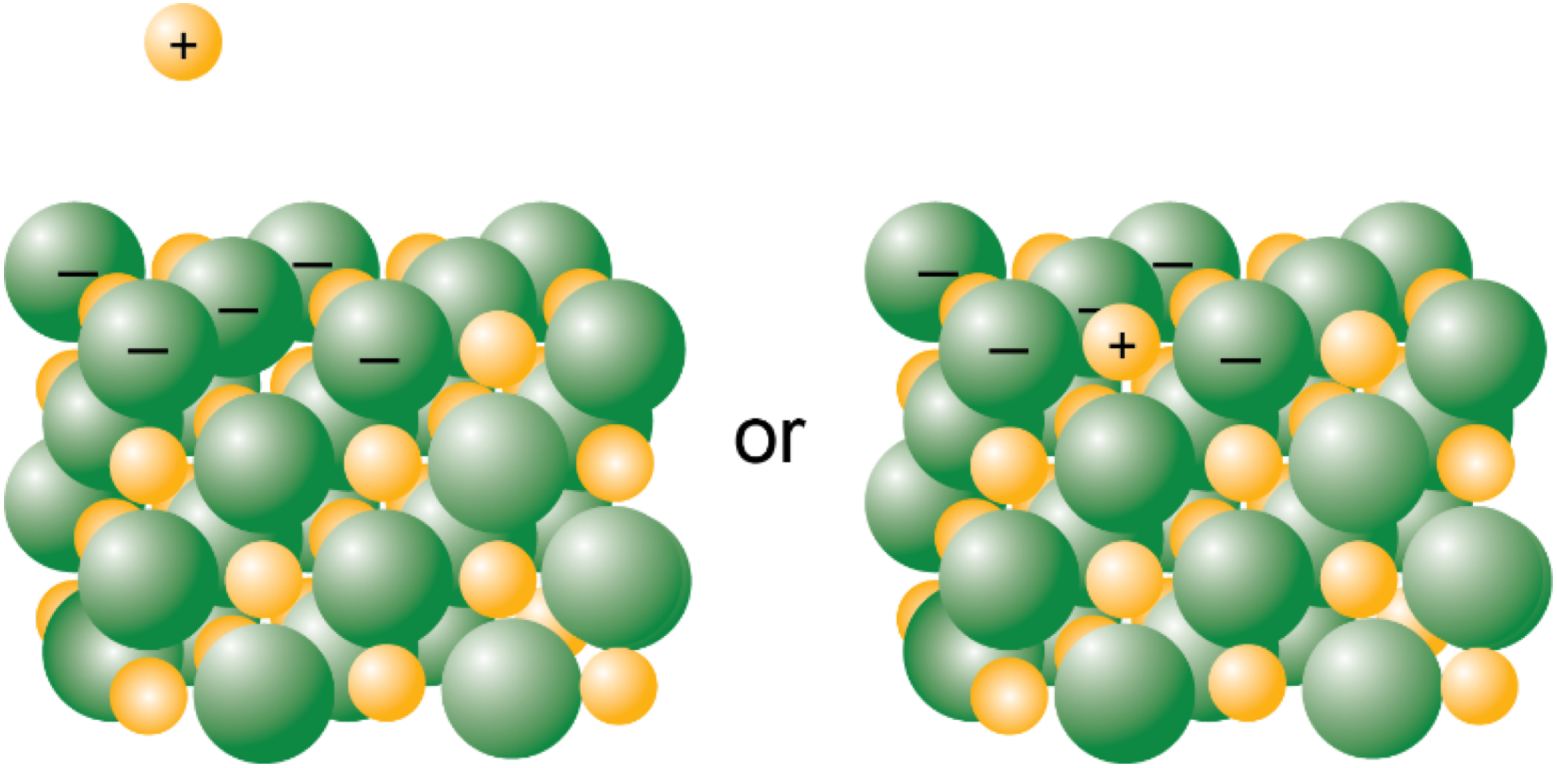
Sodium Chloride, NaCl



What we know about charge.

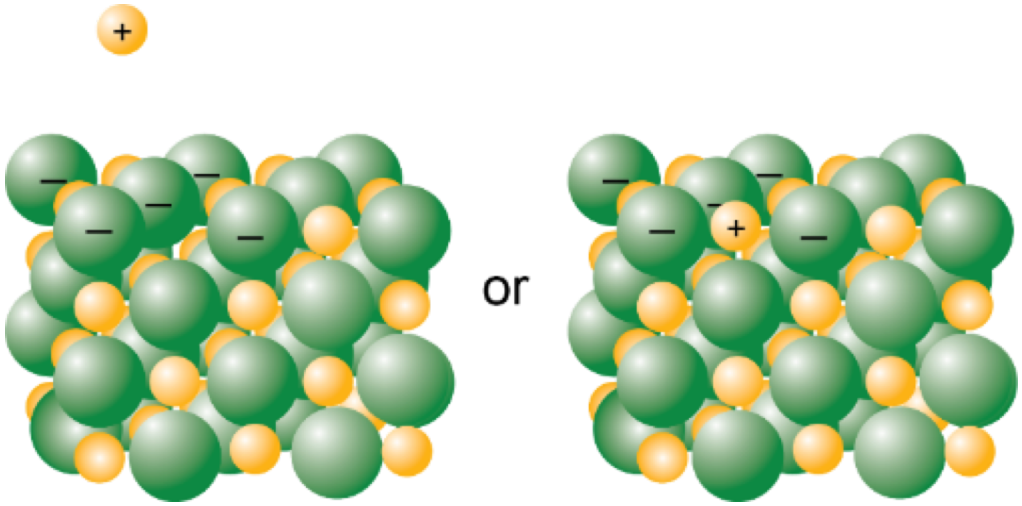
- It's the characteristic of matter that gives rise to electromagnetic forces.
- Some particles have charge and some do not.
- There are two types of charge, plus and minus.
- Like charges repel each other.
- Opposite charges attract each other.
- The closer the charged particles are, the stronger the repulsion or attraction.

Sodium Chloride, NaCl



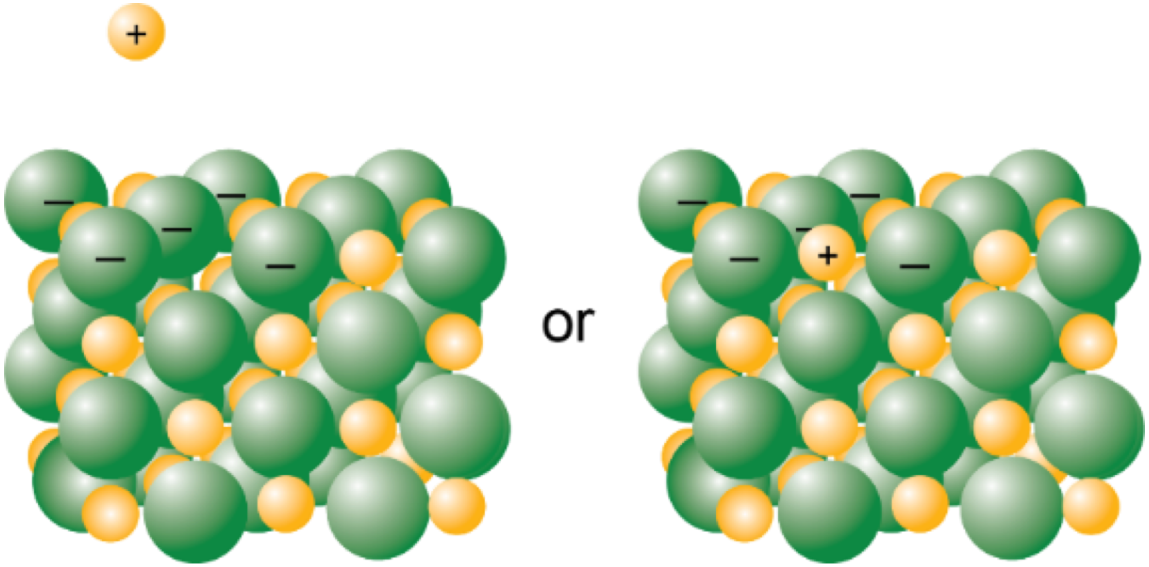
Potential energy for the Na^+ and Cl^- attraction

- Na^+ cations and Cl^- anions attract each other.
- The closer the Na^+ and Cl^- ions are, the stronger the attraction is between them. This makes the Na^+ cation that is closer to the Cl^- ions in the system on the right less likely to change, more stable, and lower PE.



Potential energy for the Na^+ and Cl^- attraction

- Energy is required to pull the Na^+ cation and Cl^- anions apart in the system on the right, and this energy goes to increased PE of the less stable, higher PE ions that are less attracted to each other in the system on the left.



Which higher energy? Is it kinetic or potential?

- The chemical reactions that lead to the formation of polyvinyl chloride (PVC), which is used to make rigid plastic pipes, are initiated by the decomposition of peroxides. The simplest peroxide is hydrogen peroxide, H_2O_2 or HOOH. Which has more energy, (1) a hydrogen peroxide molecule or (2) two separate HO molecules that form when the relatively weak O–O bond in an HOOH molecule is broken?

$$HOOH \rightarrow 2HO$$

Which higher energy? Is it kinetic or potential?

- Hydrogen atoms react with oxygen molecules in the earth's upper atmosphere to form HO_2 molecules. Which has higher energy, (1) a separate H atom and O_2 molecule or (2) an HO_2 molecule?

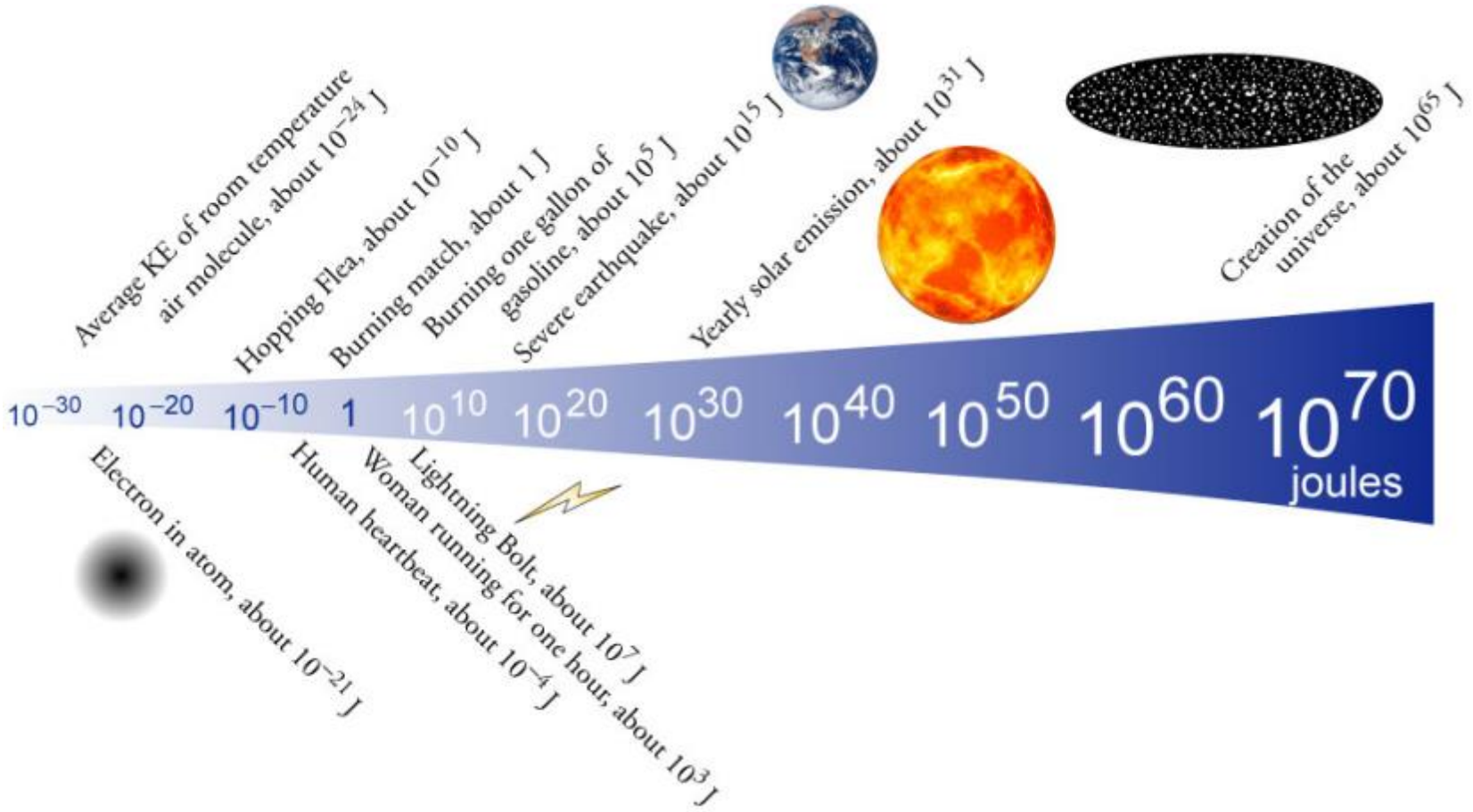
$$H(g) + O_2(g) \rightarrow HO_2(g)$$

Units of Energy

- Joule (J) = $\frac{\text{kg m}^2}{\text{s}^2}$

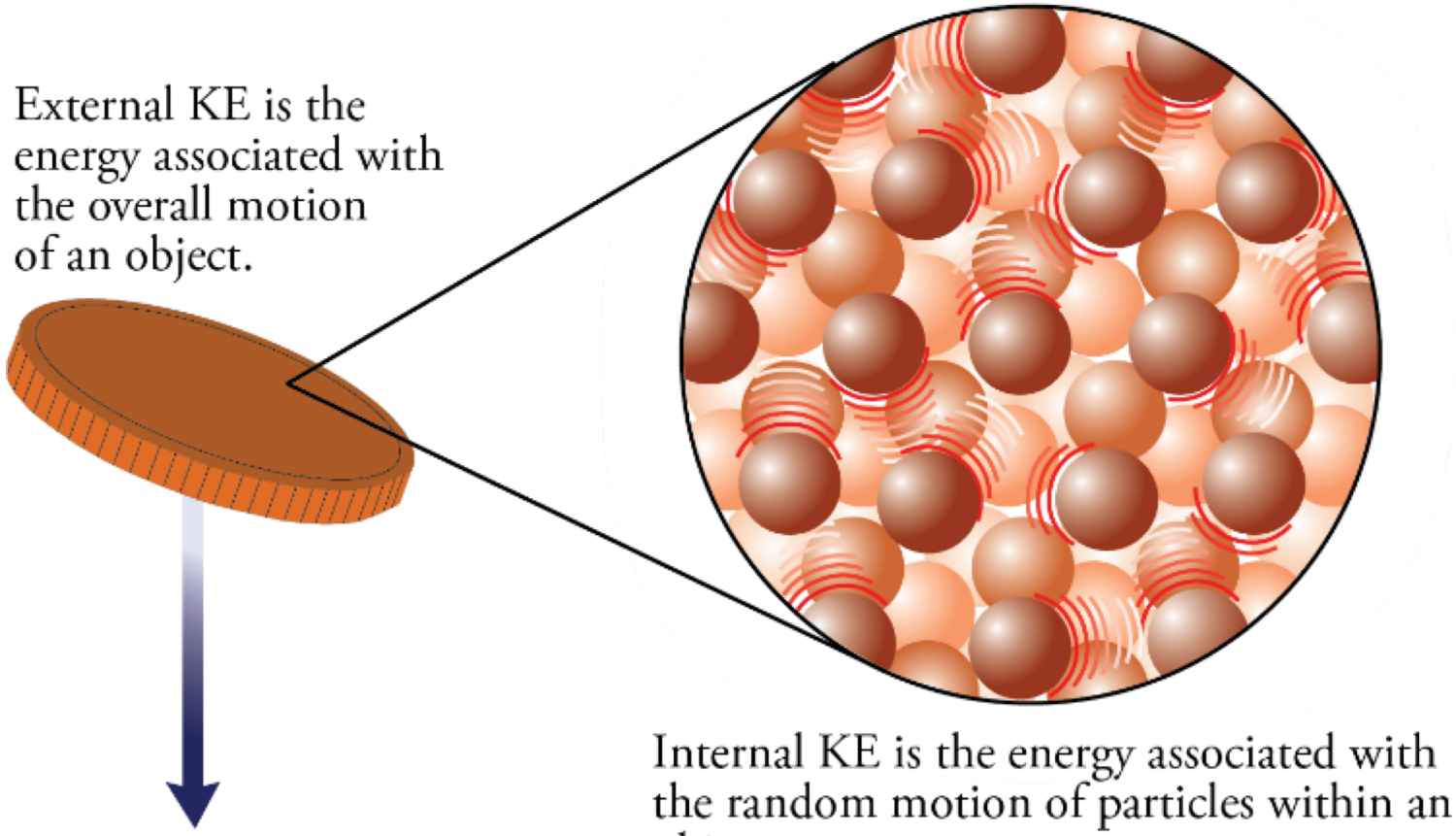
- 4.184 J = 1 cal
- 4.184 kJ = 1 kcal
- 4184 J = 1 Cal (dietary calorie)
- 4.184 kJ = 1 Cal

Approximate Energy of Various Events



External and Internal Kinetic Energy

External KE is the energy associated with the overall motion of an object.



Internal KE is the energy associated with the random motion of particles within an object.

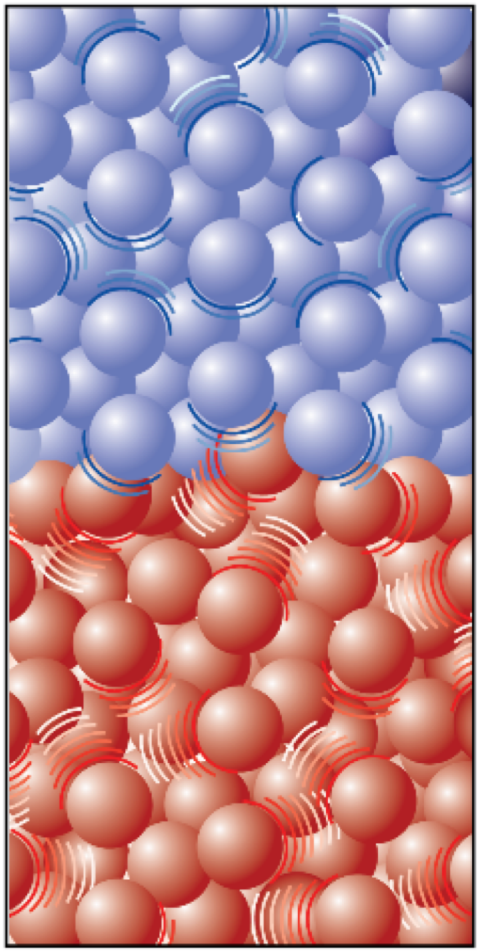
External and Internal Kinetic Energy

- **External Kinetic Energy** = Kinetic energy associated with the overall movement of a body
- **Internal Kinetic Energy** = Kinetic energy associated with the random motion of the particles within a body

Temperature and heat transfer

- Temperature reflects the average internal KE ($\frac{1}{2}m\mu^2$) of the particles.
- Higher temperature means greater average internal KE for the particles.
- The force of collisions is proportional to the momentum (mass × velocity, $m\mu$) of the objects colliding.
- Therefore, the higher the temperature, the greater the average internal KE of the particles, the greater their average momentum, and the greater the average force of collisions.

Heat Transfer



heat

Lower-temperature object
↓
Lower average force of collisions
↓
Particles speed up when they collide with particles of the higher-temperature object.
↓
Increased energy

Higher-temperature object
↓
Higher average force of collisions
↓
Particles slow down when they collide with particles of the lower-temperature object.
↓
Decreased energy

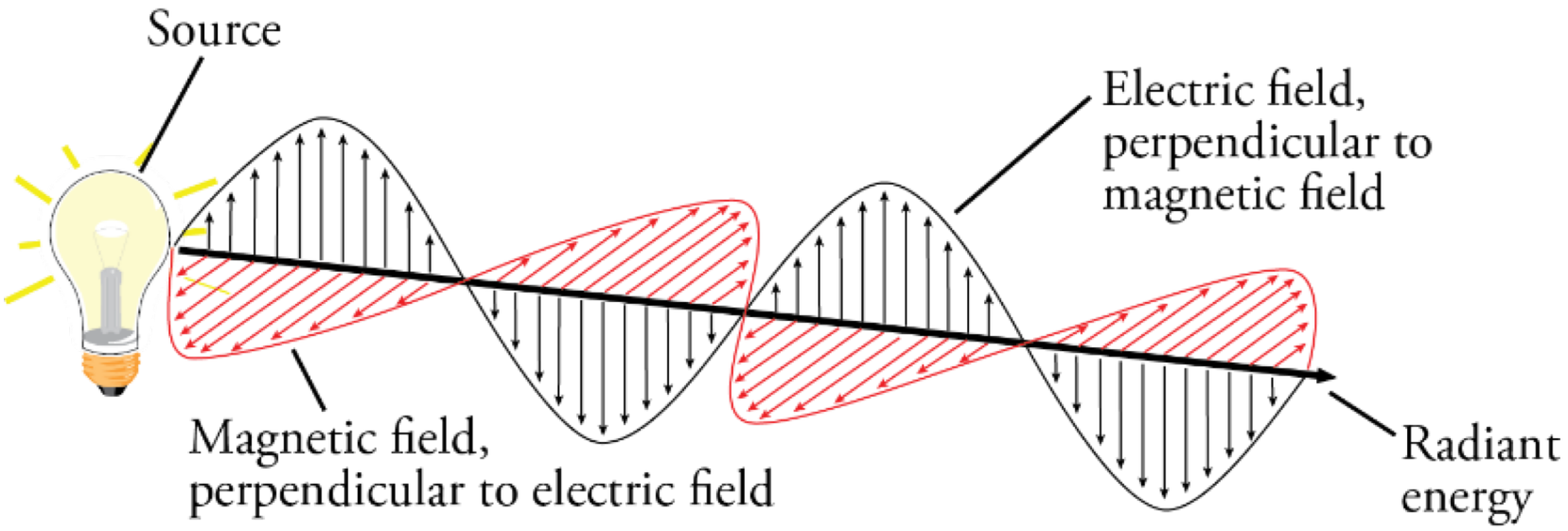
Heat

- **Heat** = the process by which internal kinetic energy is transferred from a region of higher temperature to a region of lower temperature due to collisions of particles.

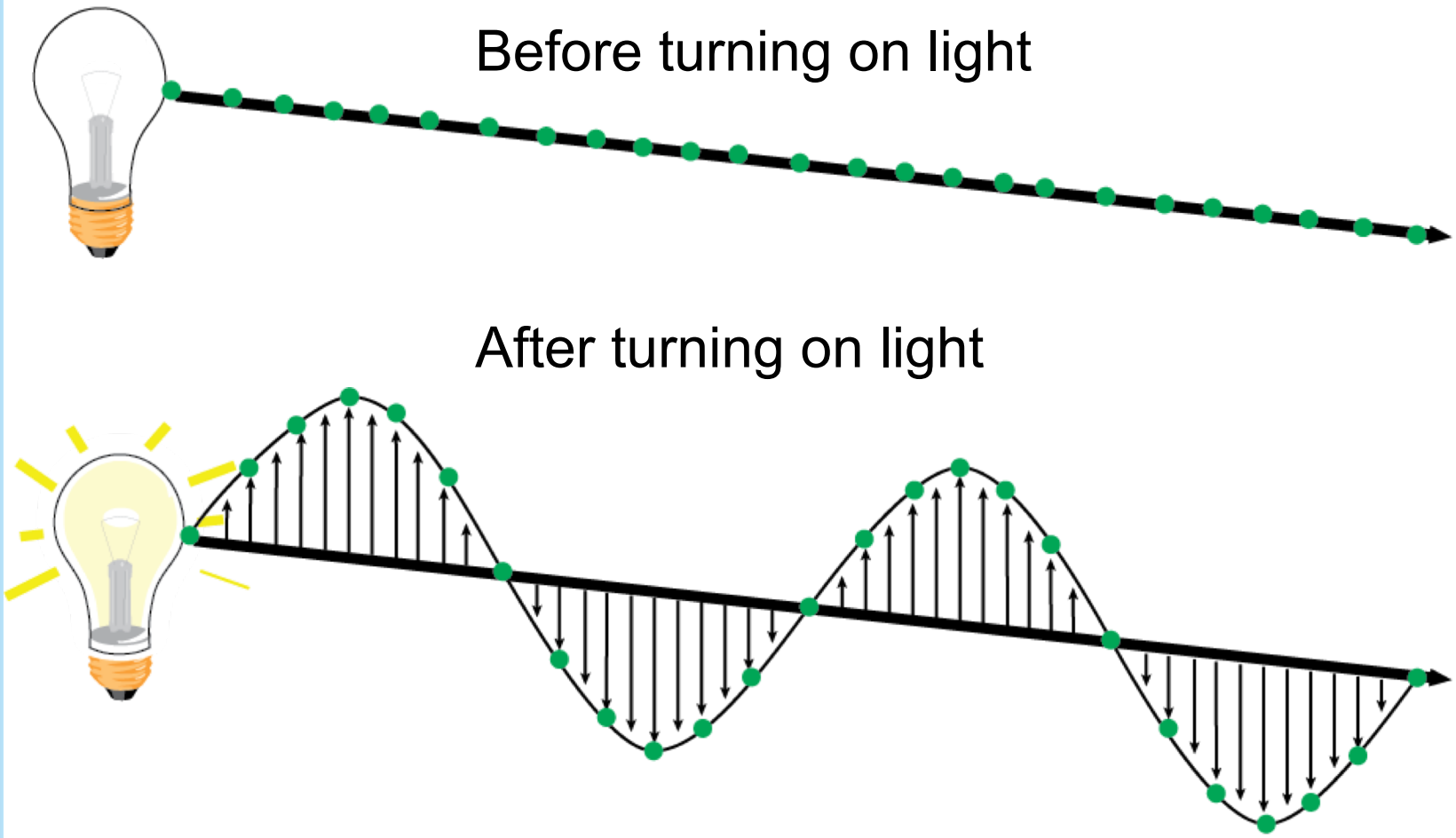
Radiant Energy

- **Radiant Energy** is electromagnetic energy that behaves like a stream of particles.
- It has both particle and wave character.
  - Particle
    - photons = tiny packets of radiant energy
    - 10^{17} photons/second from a flashlight bulb
  - Wave
    - oscillating electric and magnetic fields
    - describes effect on space, not true nature of radiant energy

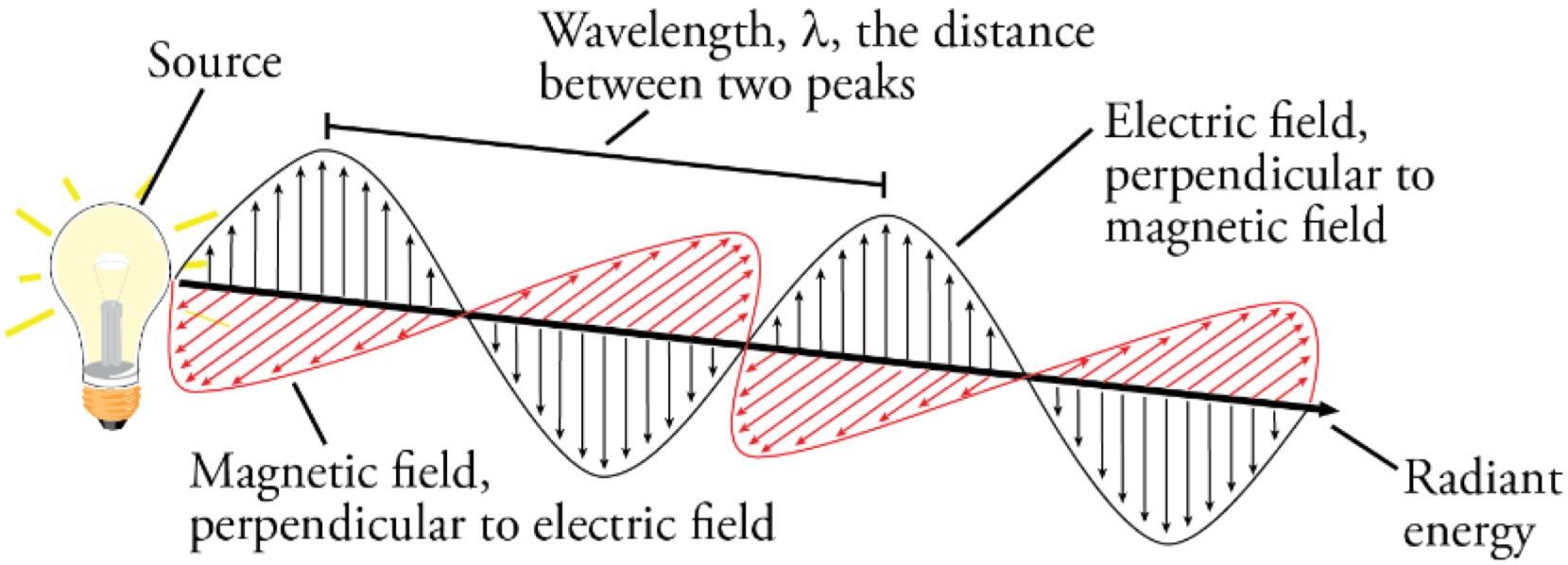
A Light Wave's Electric and Magnetic Fields



A Light Wave's Electric Field



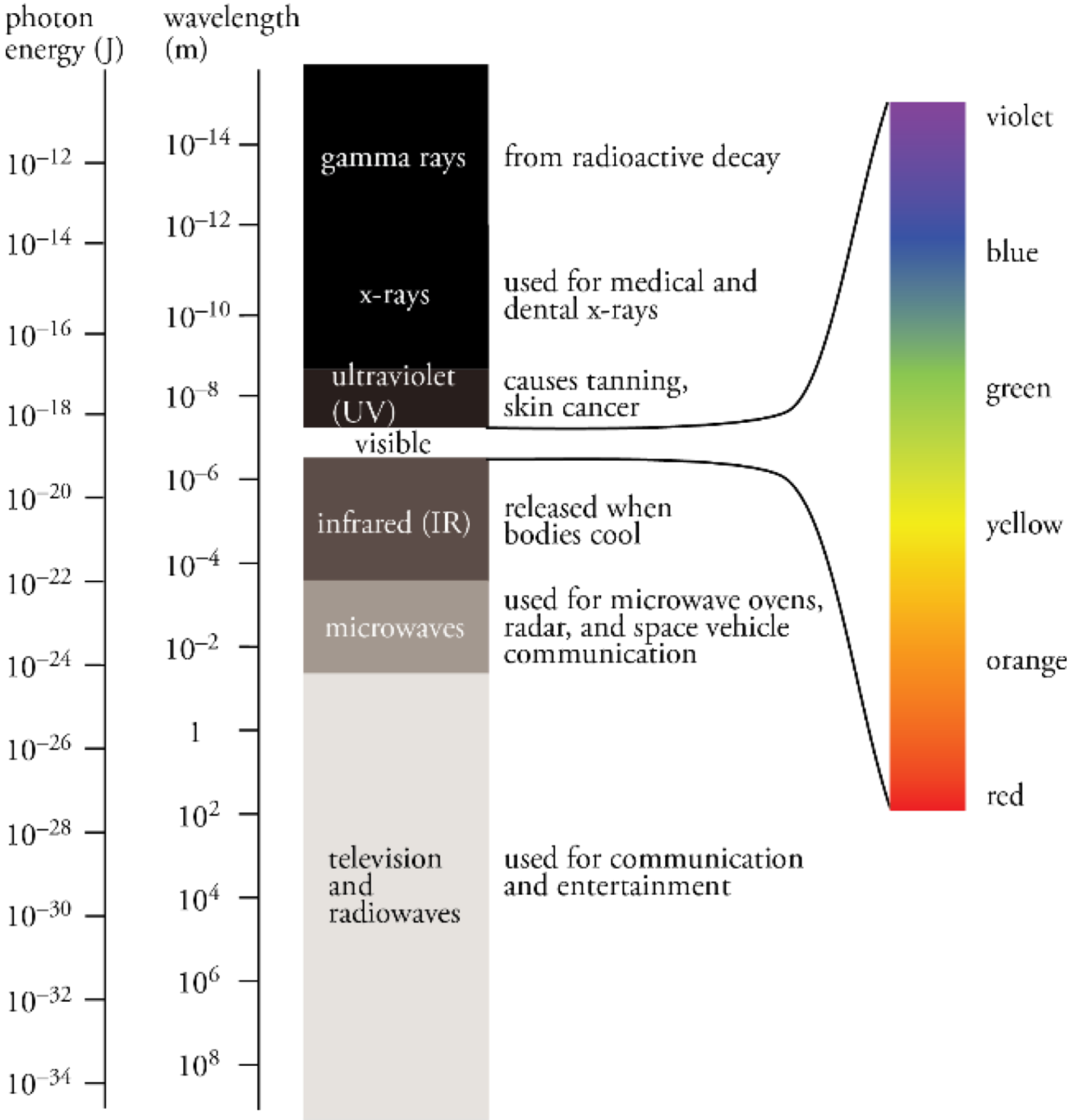
A Light Wave's Electric and Magnetic Fields



Wavelength and Photon Energy

- The shorter the wavelength is, the higher the energy of the photon.
- The longer the wavelength is, the lower the energy of the photon.
- There is a huge range of wavelengths and energies for radiant energy.
- We divide the complete radiant energy spectrum into categories based on how they are formed and how they effect us.

Radiant Energy Spectrum



Practice

- Now it's time for you to get some practice to develop the skills related to this section.
  - Exercise 4.1 (atoms-first) or 7.1 (chemistry-first)
  - Problems 62-78 (atoms-first) or 43-59 (chemistry first)