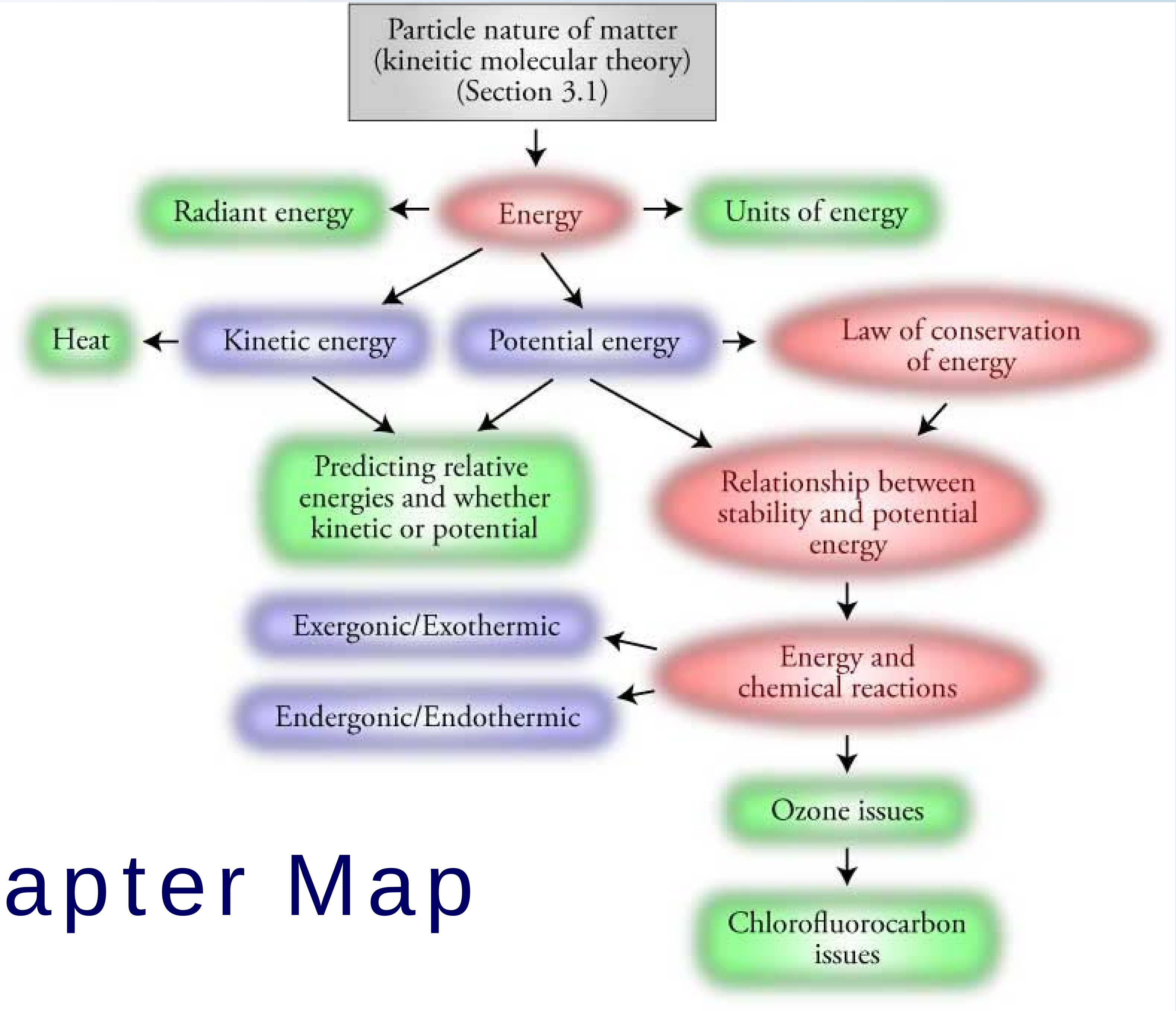
Chapter 8

Energy and Chemical Reactions

Chapter Map

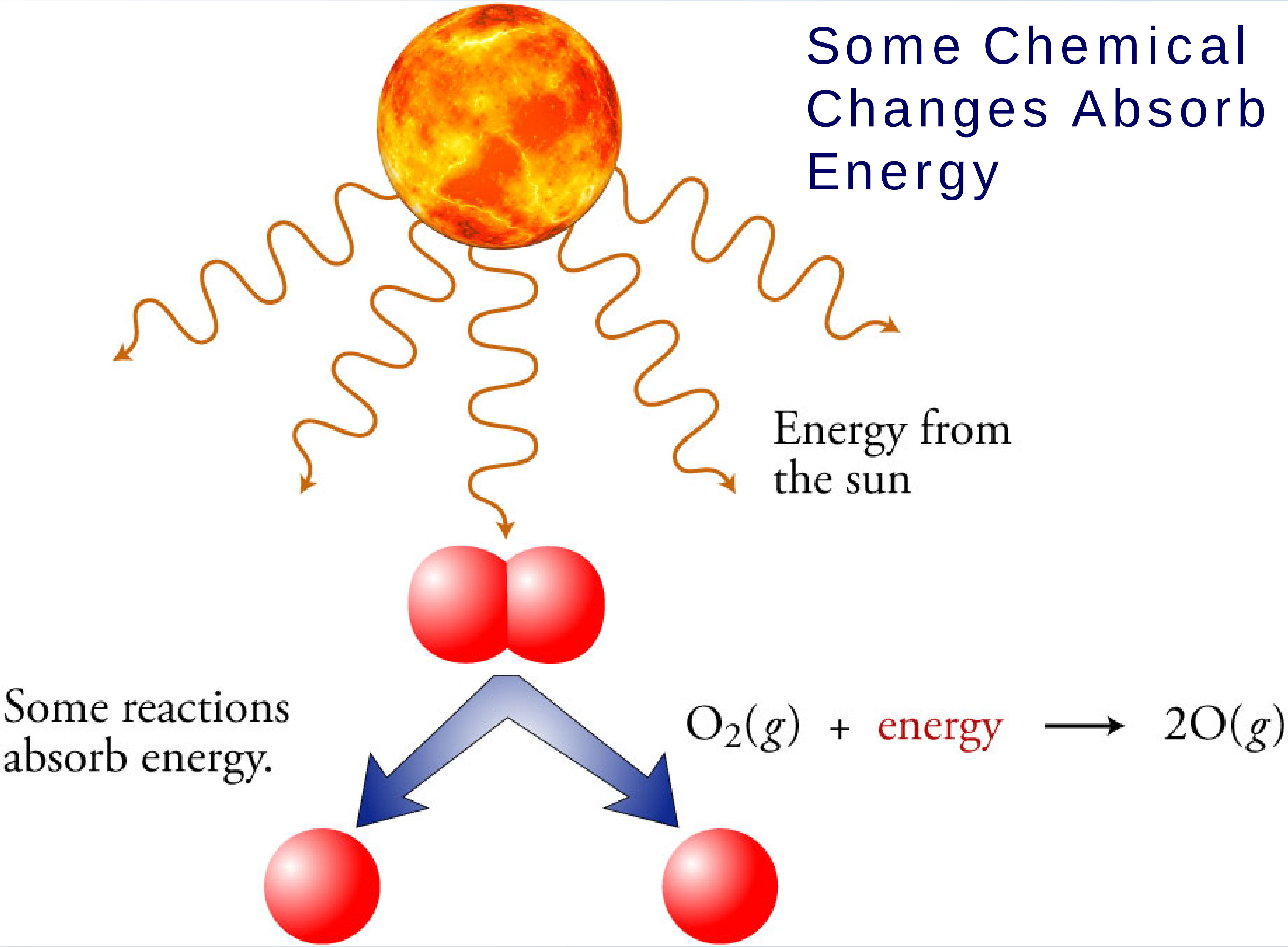

Particle nature of matter
(kineitic molecular theory)
(Section 3.1)
Radiant energy
Energy
Units of energy
Heat
Kinetic energy
Potential energy
Law of conservation of energy
Predicting relative energies and whether kinetic or potential
Relationship between stability and potential energy
Exergonic/Exothermic
Endergonic/Endothermic
Energy and chemical reactions
Ozone issues
Chlorofluorocarbon issues

Some Chemical Changes Release Energy

Combustion of Methane

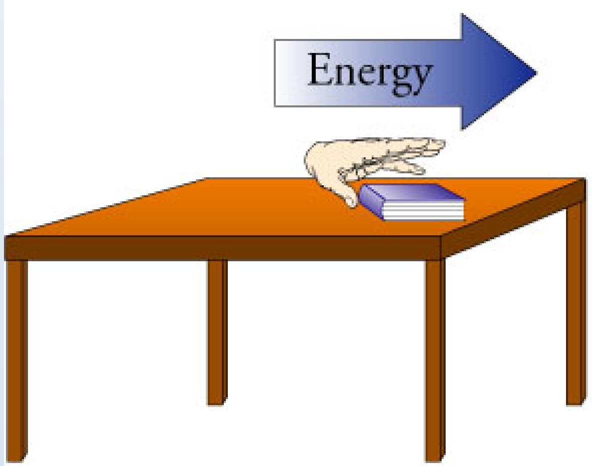
$CH_4(g) + 2O_2(g)$
$\rightarrow CO_2(g) + 2H_2O(l)$ +

Some Chemical Changes Absorb Energy

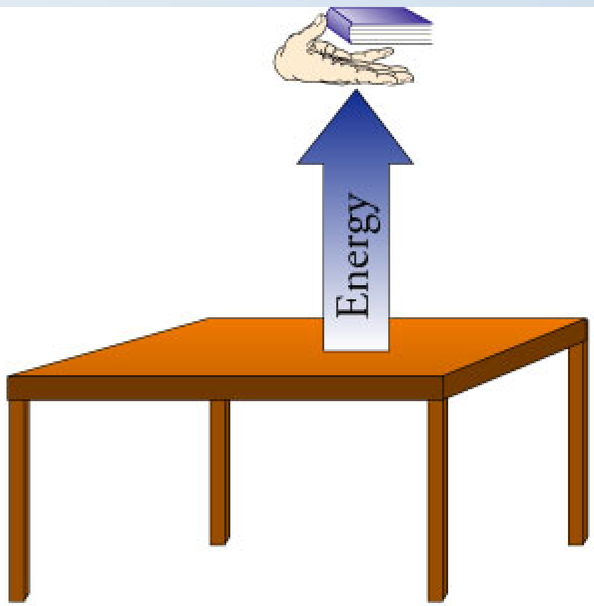


Energy Terms

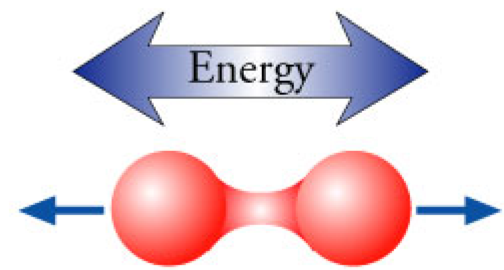
- **Energy** = the capacity to do work
- **Work**, in this context, may be defined as what is done to move an object against some sort of resistance.



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



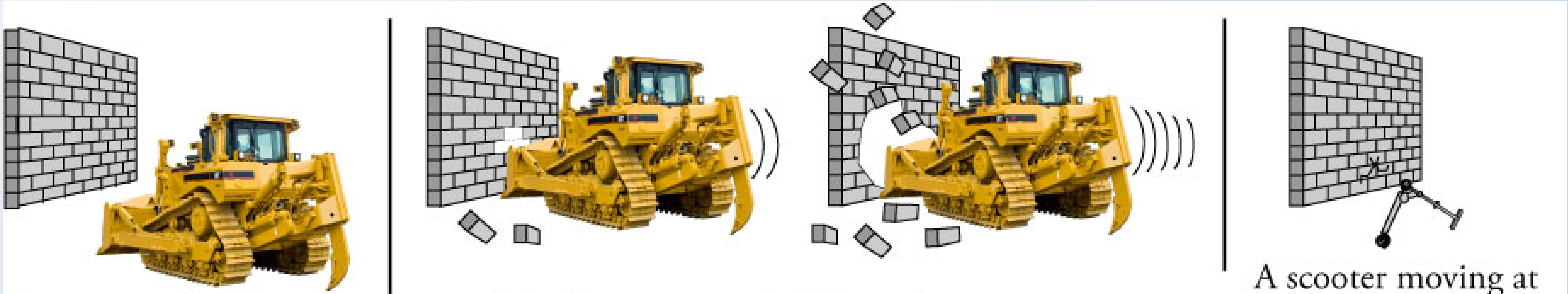
Energy is required to lift a book and overcome the resistance to movement due to gravity.



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

Two Types of Energy

- **Kinetic Energy** = the energy of motion
  = $1/2\ m\mu^2$



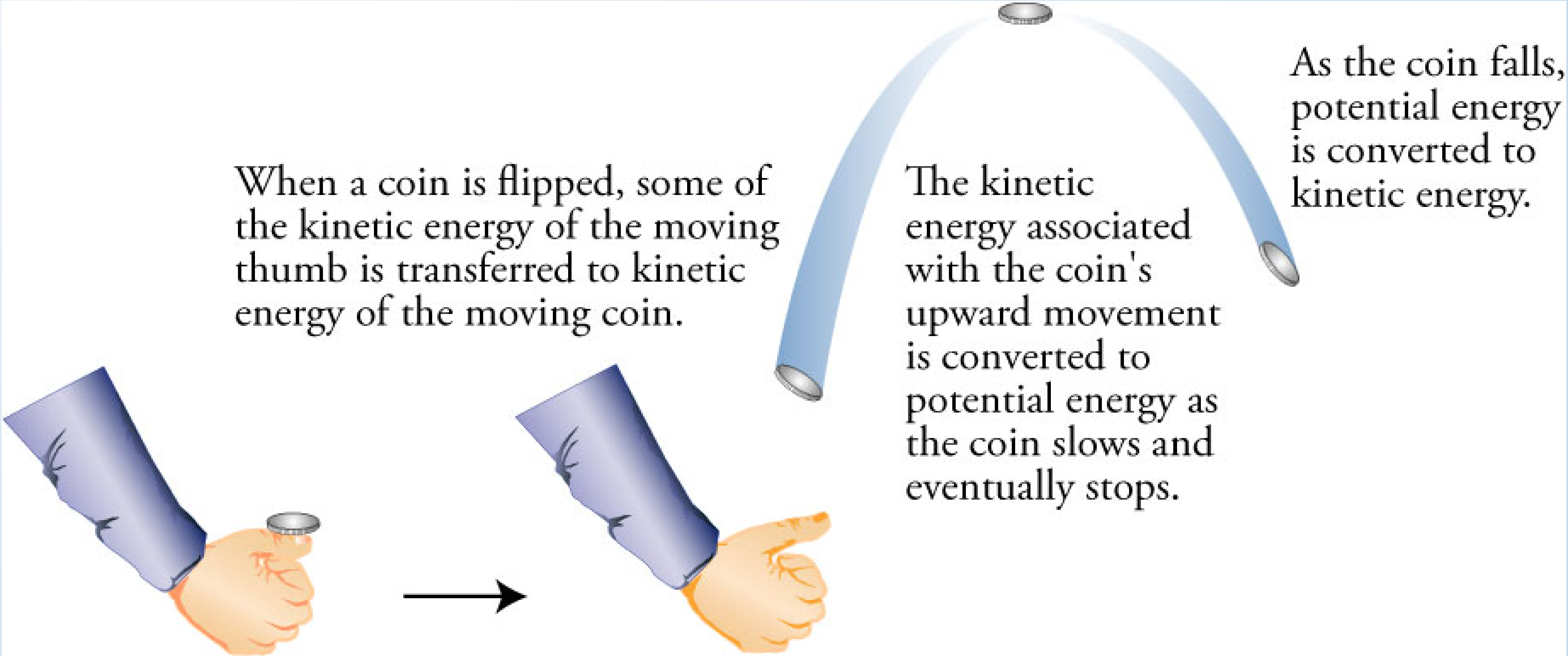
A stationary buldozer does not have the capacity to do the work of moving a wall.

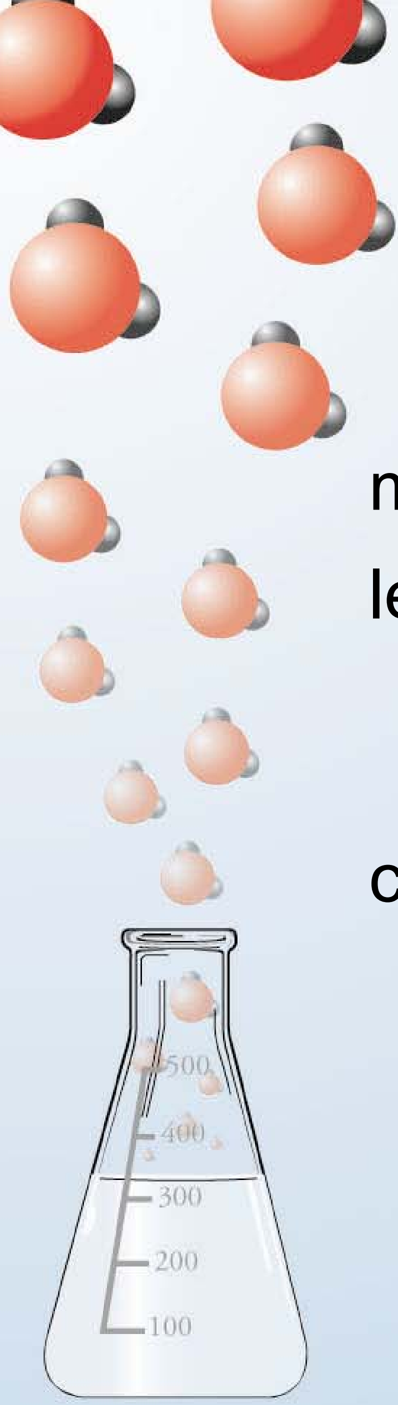
The faster moving bulldozer does more of the work of moving the wall. The faster an object moves, the more work it can do, and the more kinetic energy it has.

A scooter moving at the same velocity as a bulldozer will do less work and therefore has less energy.

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

Law of Conservation of Energy





Endergonic Change

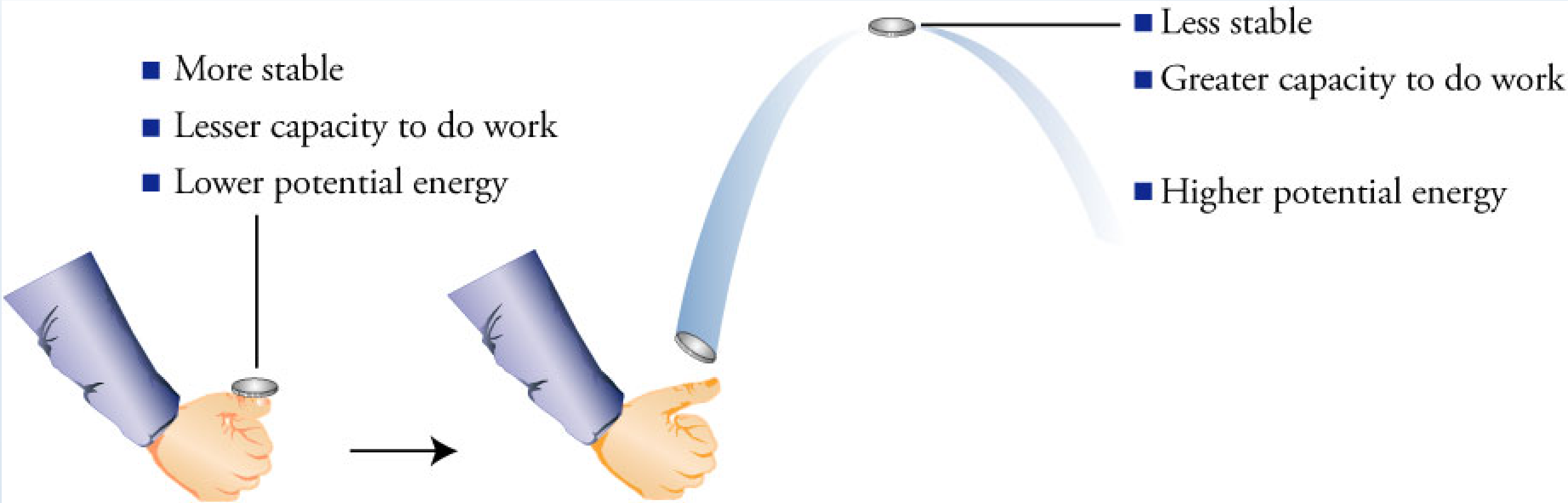
more stable + energy → less stable system

lesser capacity to do work + energy → greater capacity to do work

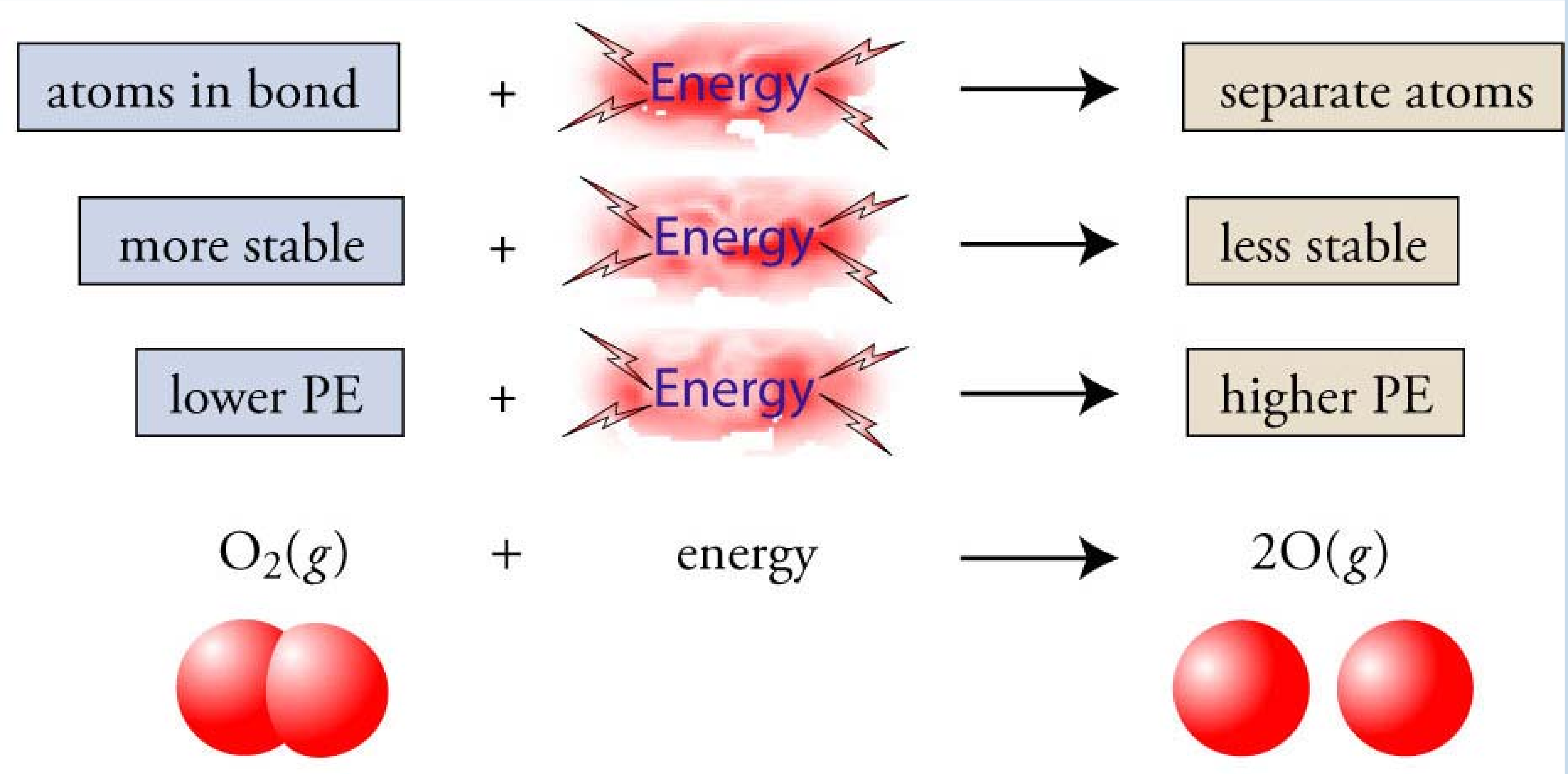
lower PE + energy → higher PE

coin in hand + energy → coin in air above hand

Coin and Potential Energy



Bond Breaking and Potential Energy



Exergonic Change

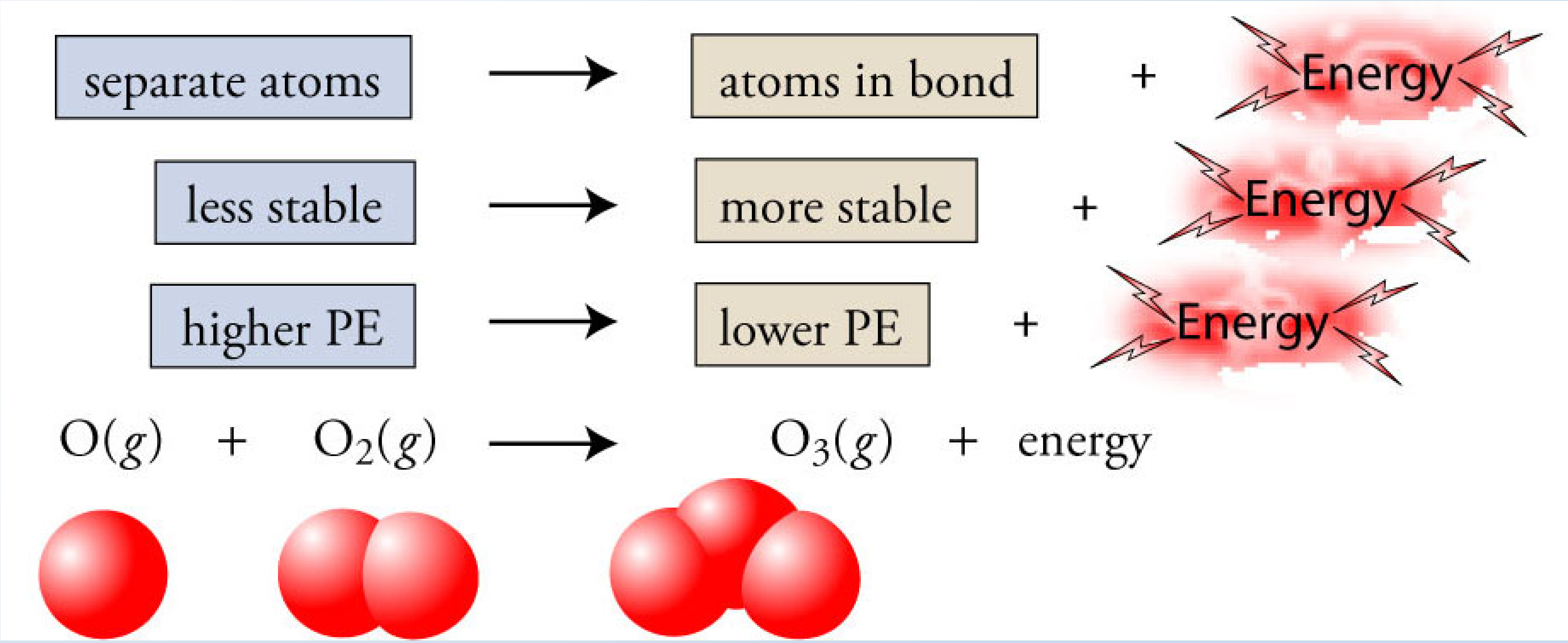
less stable system $\rightarrow$ more stable + energy

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

higher PE $\rightarrow$ lower PE + energy

coin in air above hand $\rightarrow$ coin on ground + energy

Bond Making and Potential Energy



Which higher energy? Is it kinetic or potential?

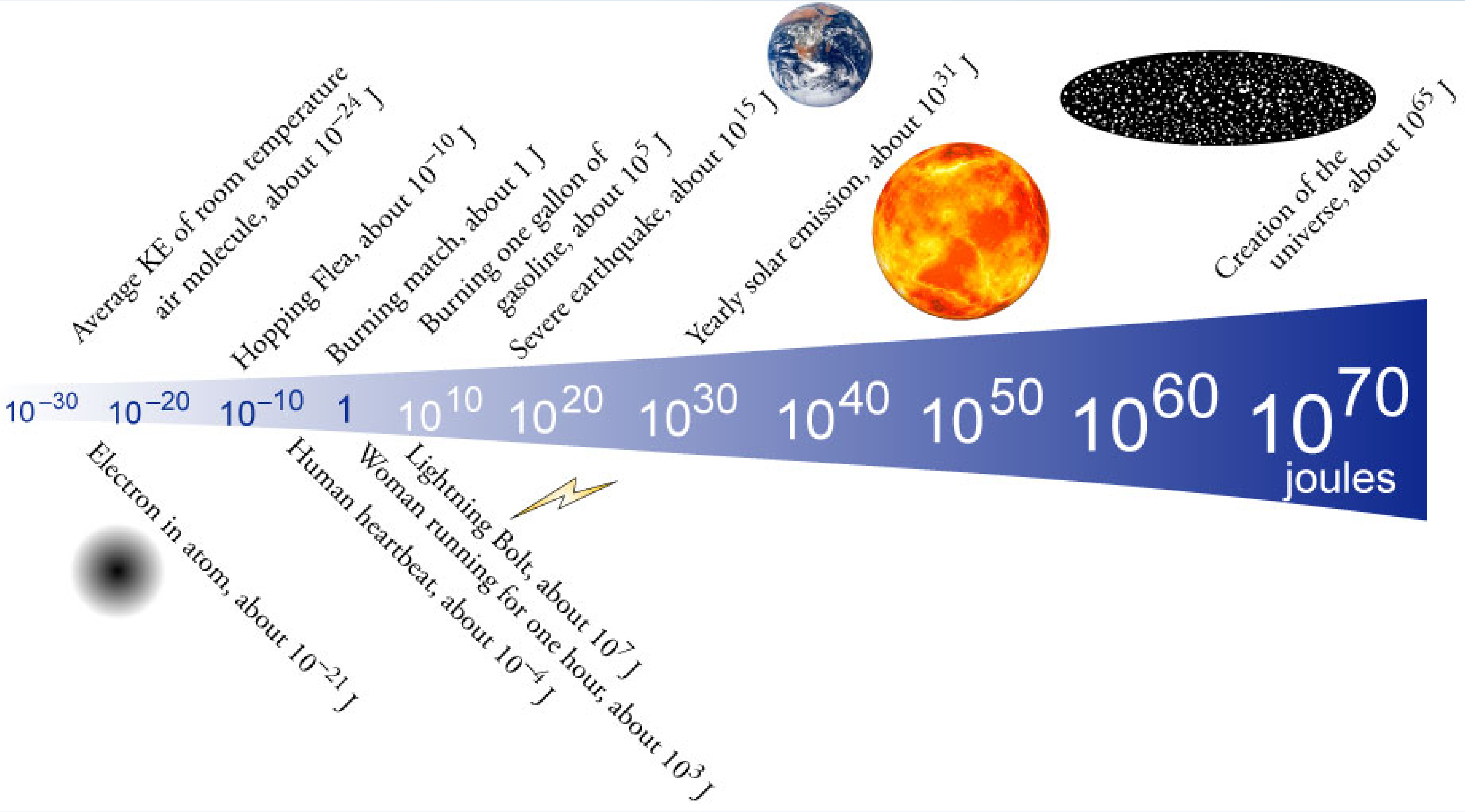
- 428 m/s Ar atoms or 456 m/s Ar atoms?
- 428 m/s Ar atoms or 428 m/s Kr atoms?
- Na^+ close to Cl^- or Na^+ and Cl^- far apart?
- ROOR or 2 RO
- H*(g)* and O_2*(g)* or HO_2*(g)*
- Solid CO_2 or gaseous CO_2

Units of Energy

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

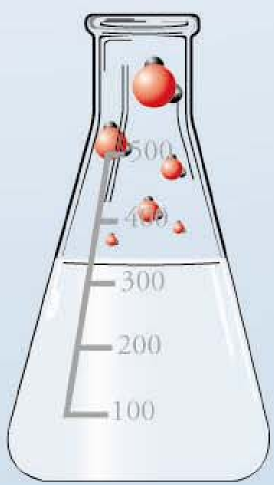
- 4.184 J = 1 cal
- 4.184 kJ = 1 kcal
- 4184 J = 1 Cal (dietary calorie)
- 4.184 kJ = 1 Cal

Approximate Energy of Various Events



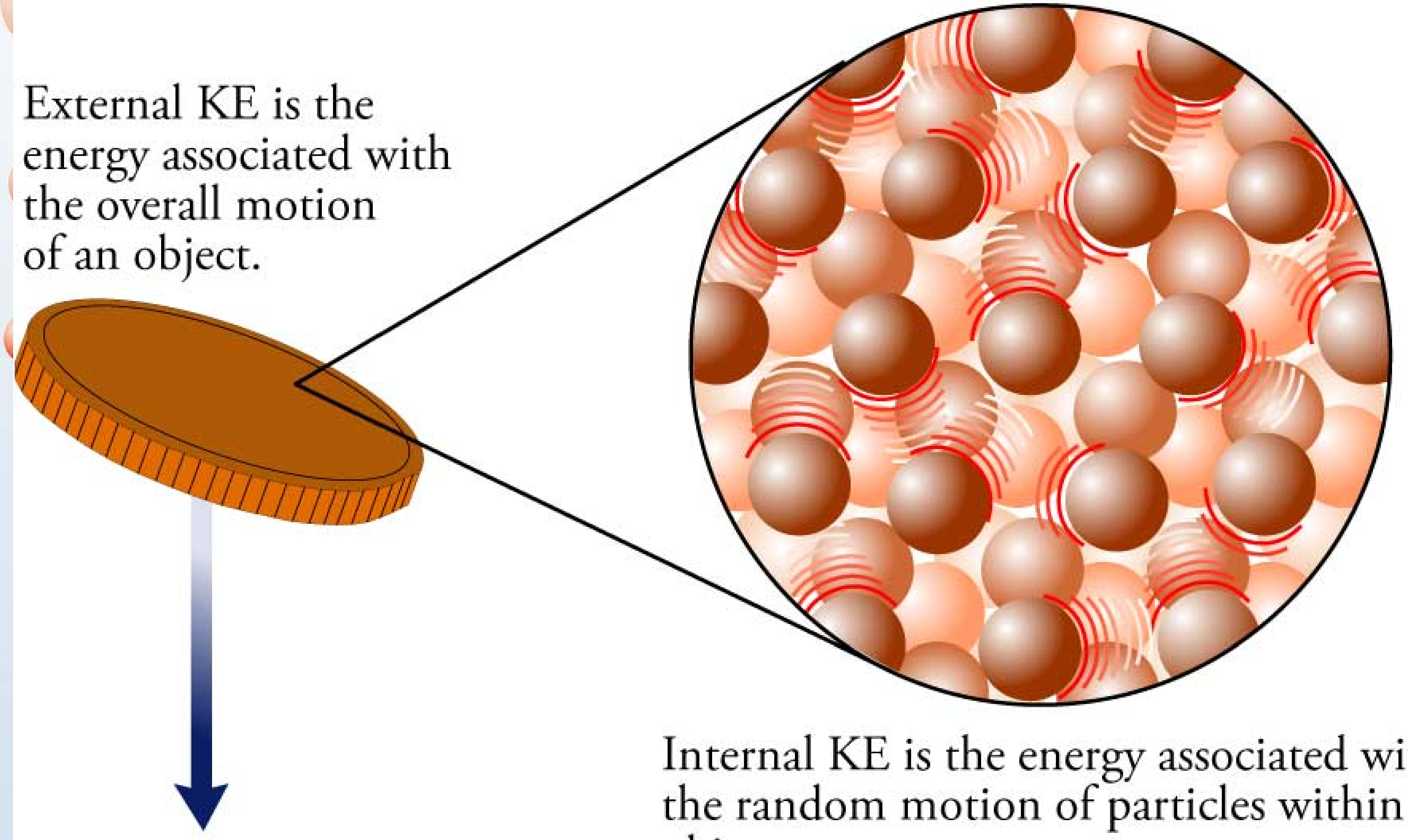
More Terms

- **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



External and Internal Kinetic Energy

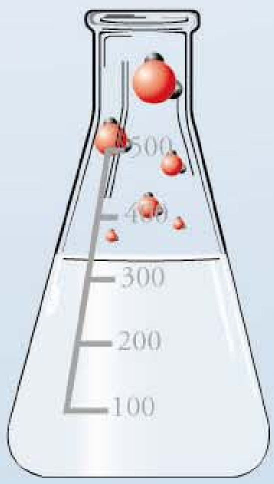
External KE is the energy associated with the overall motion of an object.



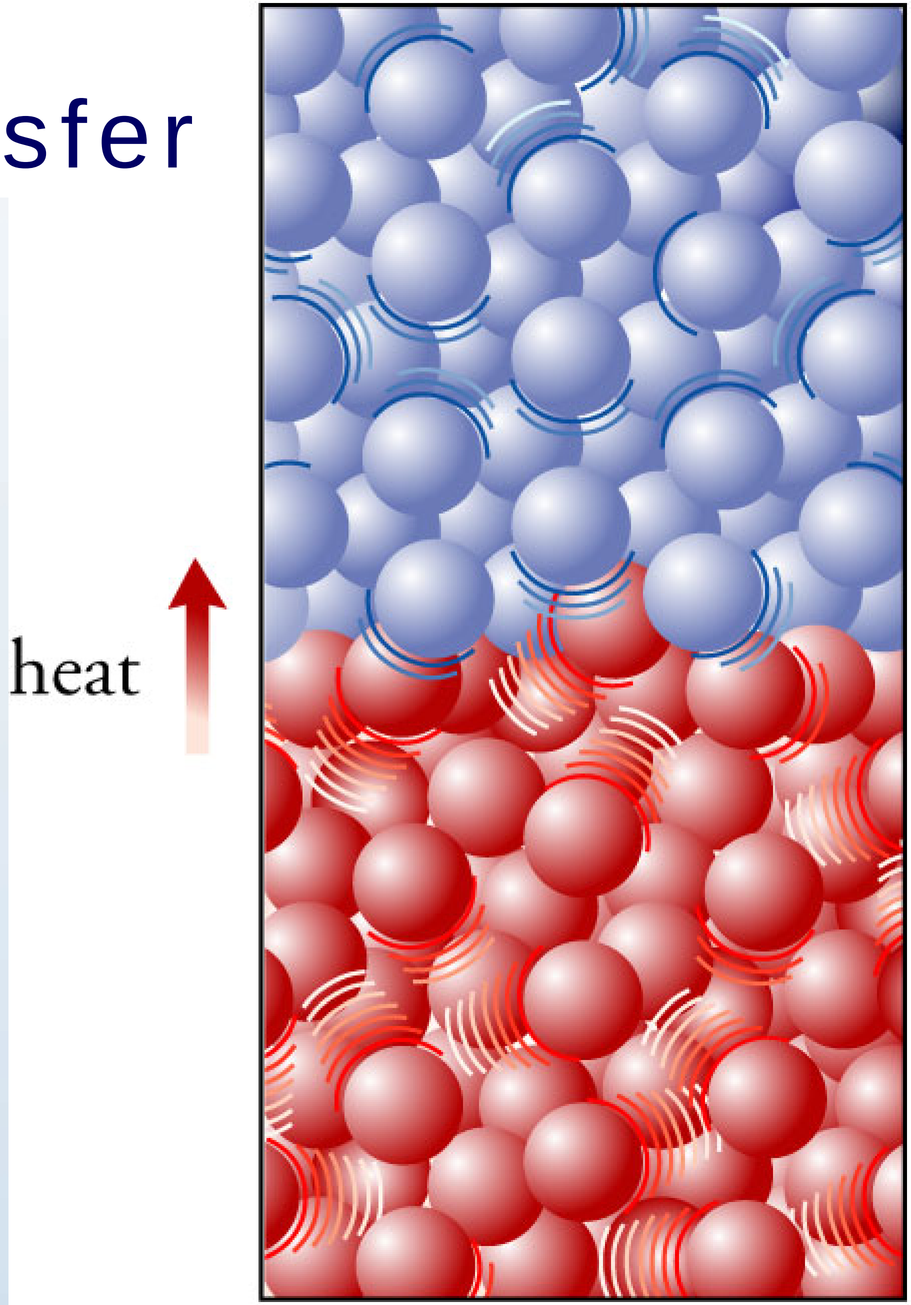
Internal KE is the energy associated with the random motion of particles within an object.

Heat

- **Heat** = Energy transfer from a region of higher temperature to a region of lower temperature due to collisions of particles.



Heat Transfer



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.

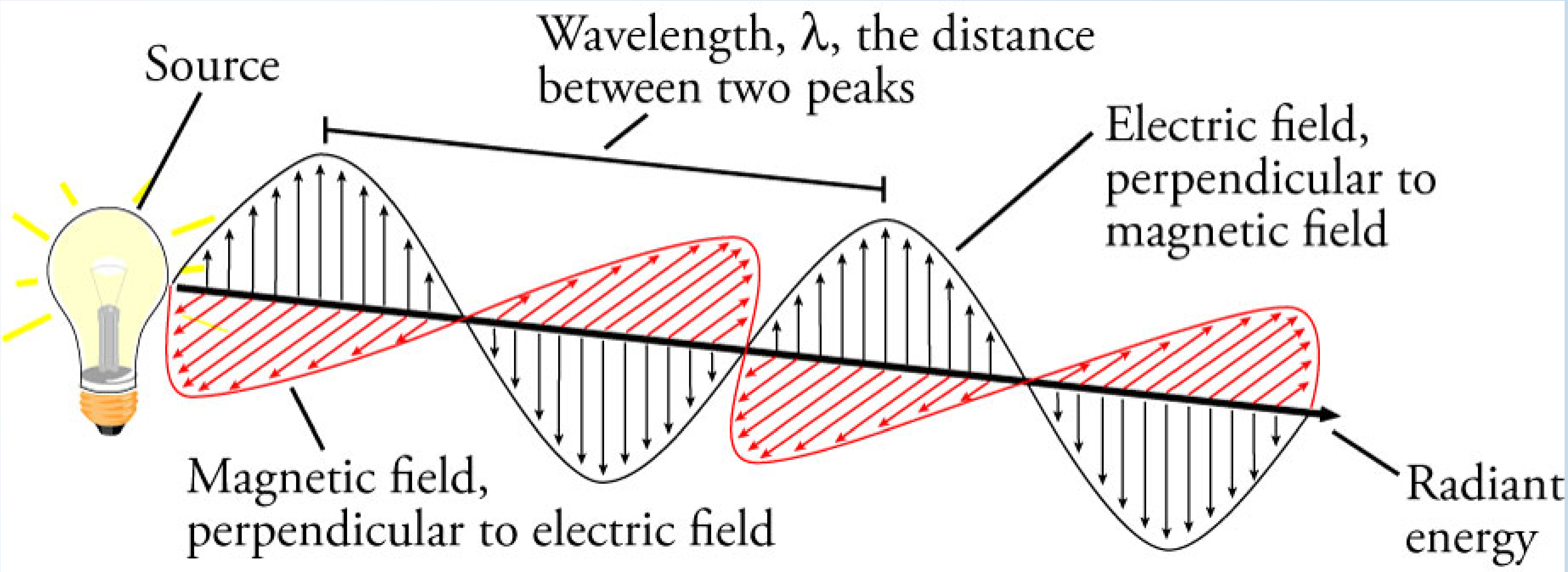
↓

Decreased energy

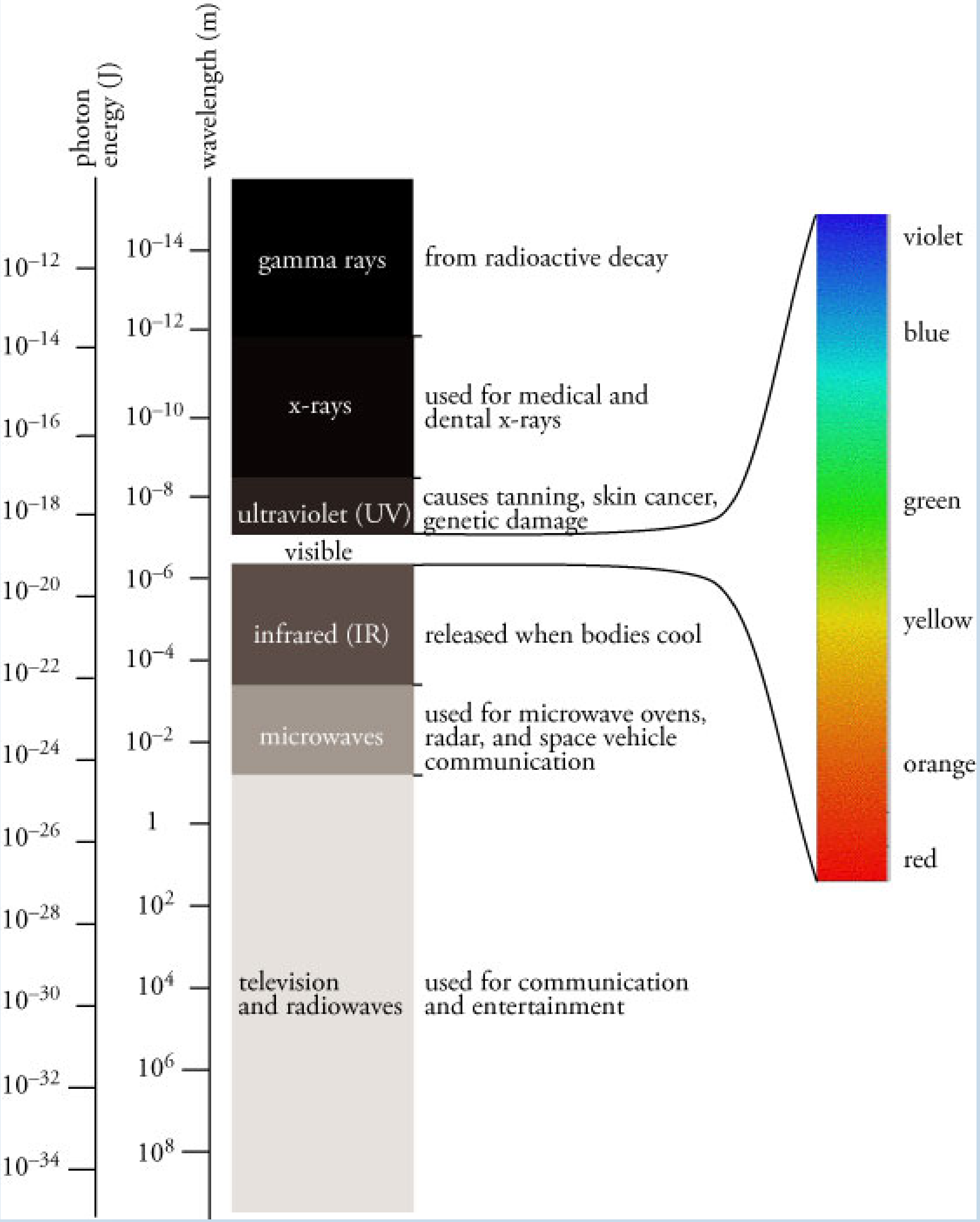
Radiant Energy

- **Radiant Energy** is electromagnetic energy that behaves like a stream of particles.
- It has a dual Nature
  - 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



Radiant Energy Spectrum



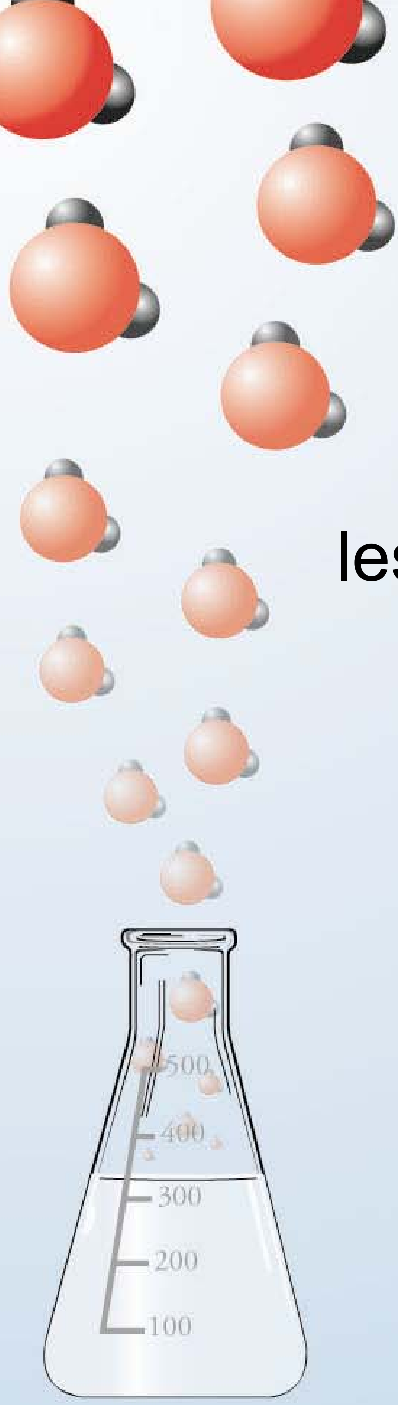
Endergonic Change

more stable + energy → less stable system

lesser capacity to do work + energy → greater capacity to do work

lower PE + energy → higher PE

Exergonic Change

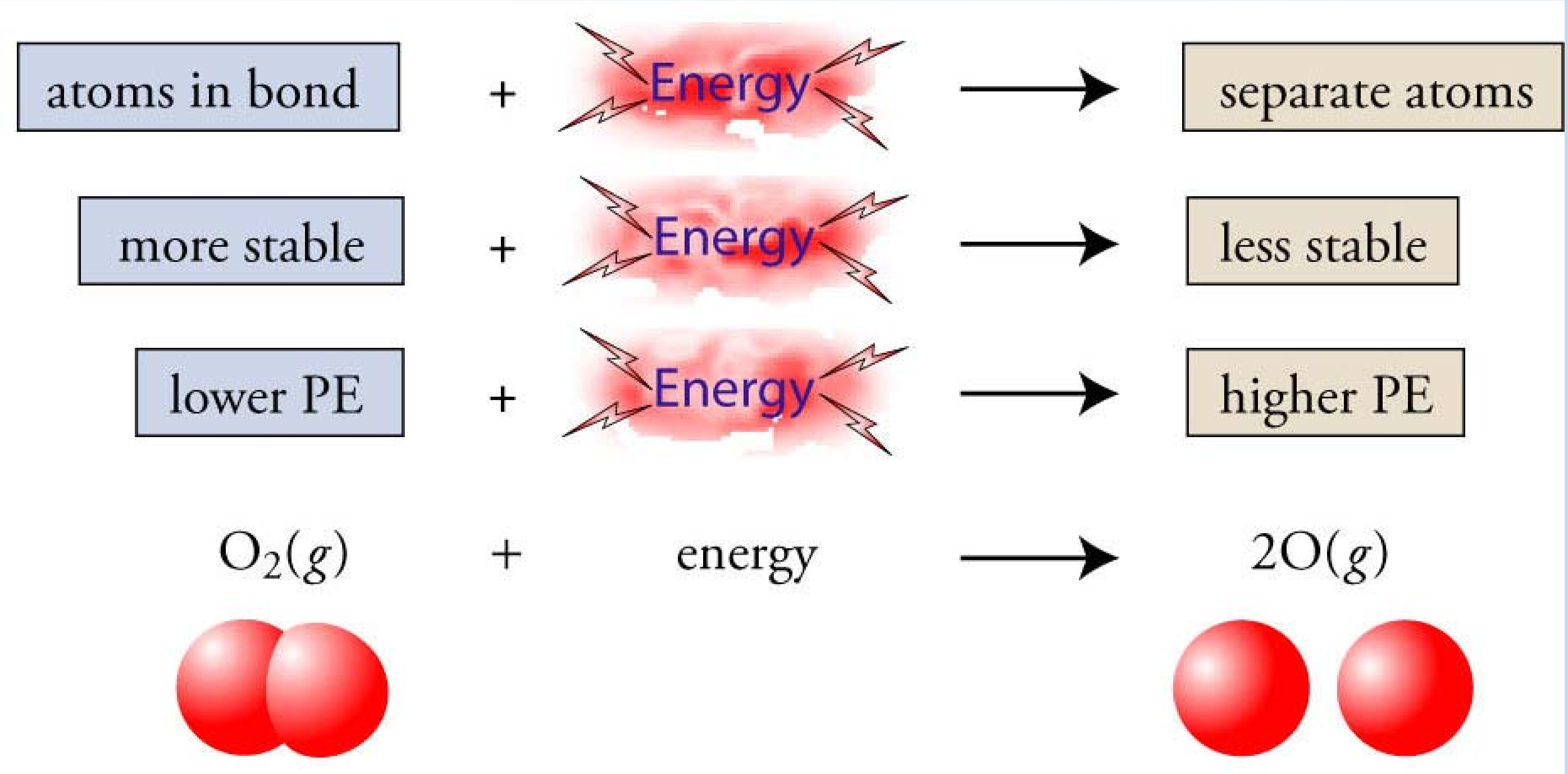


less stable system → more stable + energy

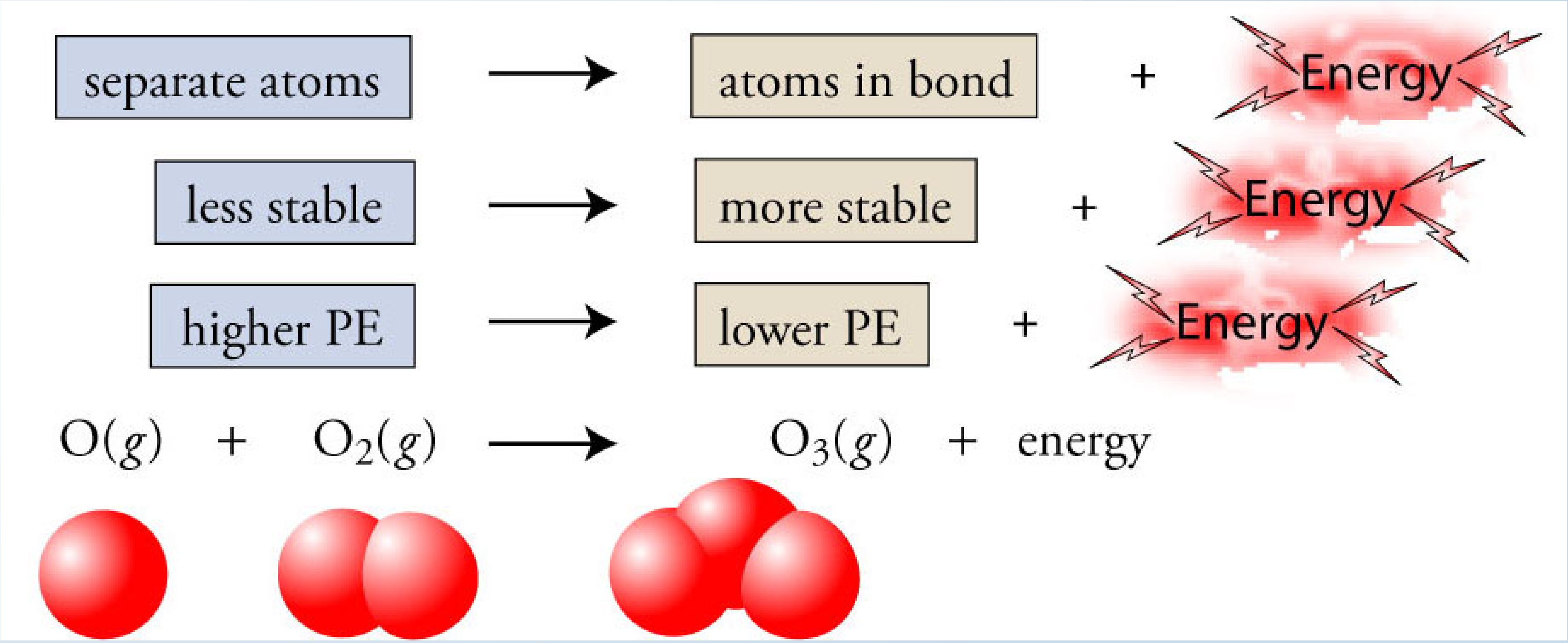
greater capacity to do work → lesser capacity to do work + energy

higher PE → lower PE + energy

Bond Breaking and Potential Energy



Bond Making and Potential Energy

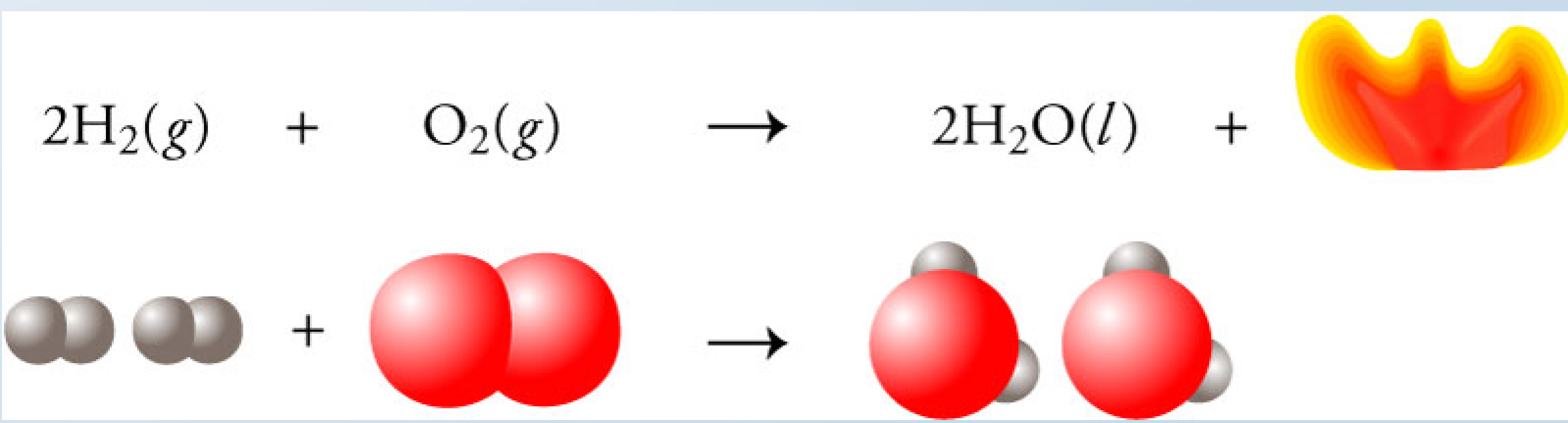


Exergonic (Exothermic) Reaction

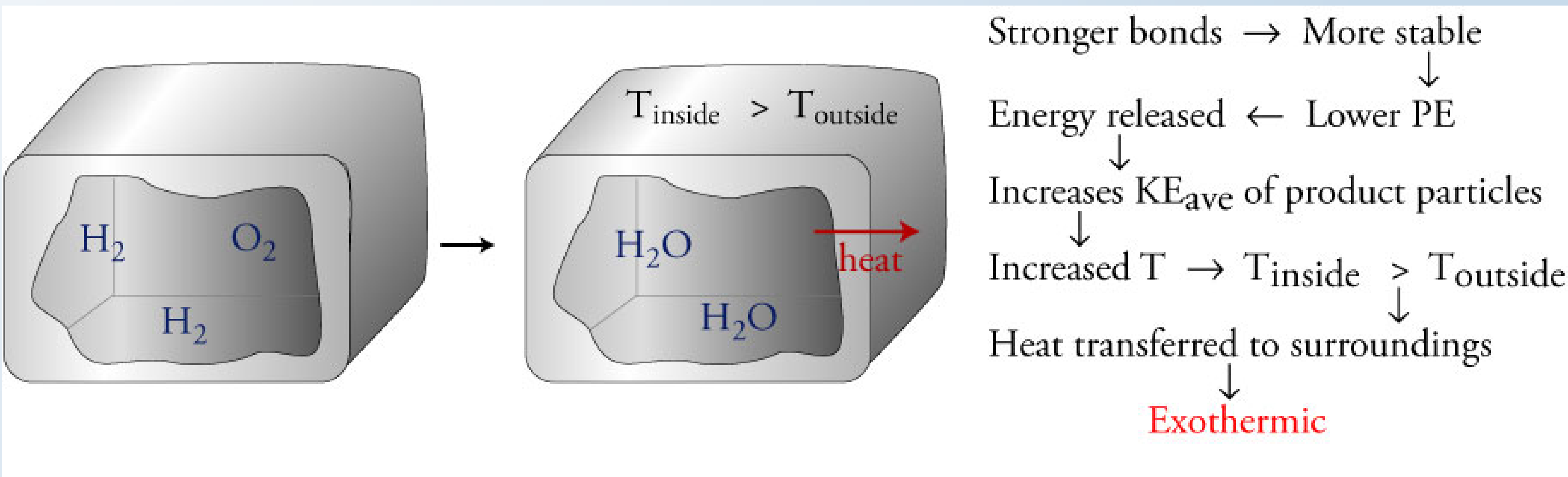
weaker bonds → stronger bonds + energy

less stable → more stable + energy

higher PE → lower PE + energy



Exothermic Reaction



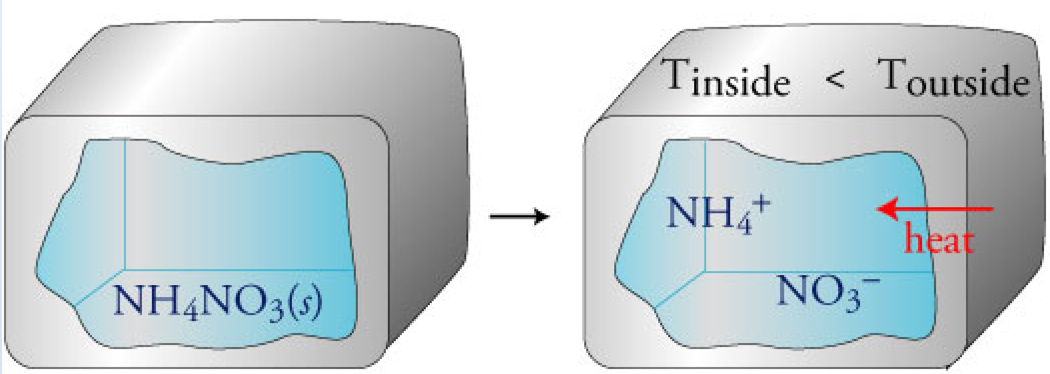
Endothermic Reaction

stronger bonds + energy → weaker bonds

more stable + energy → less stable

lower PE + energy → higher PE

$$\mathbf{NH_4NO_3}(\boldsymbol{s}) + \textbf{energy} \rightarrow \mathbf{NH_4^+}(\boldsymbol{aq}) + \mathbf{NO_3^-}(\boldsymbol{aq})$$



Weaker bonds → Less stable

↓

Energy absorbed ← Higher PE

↓

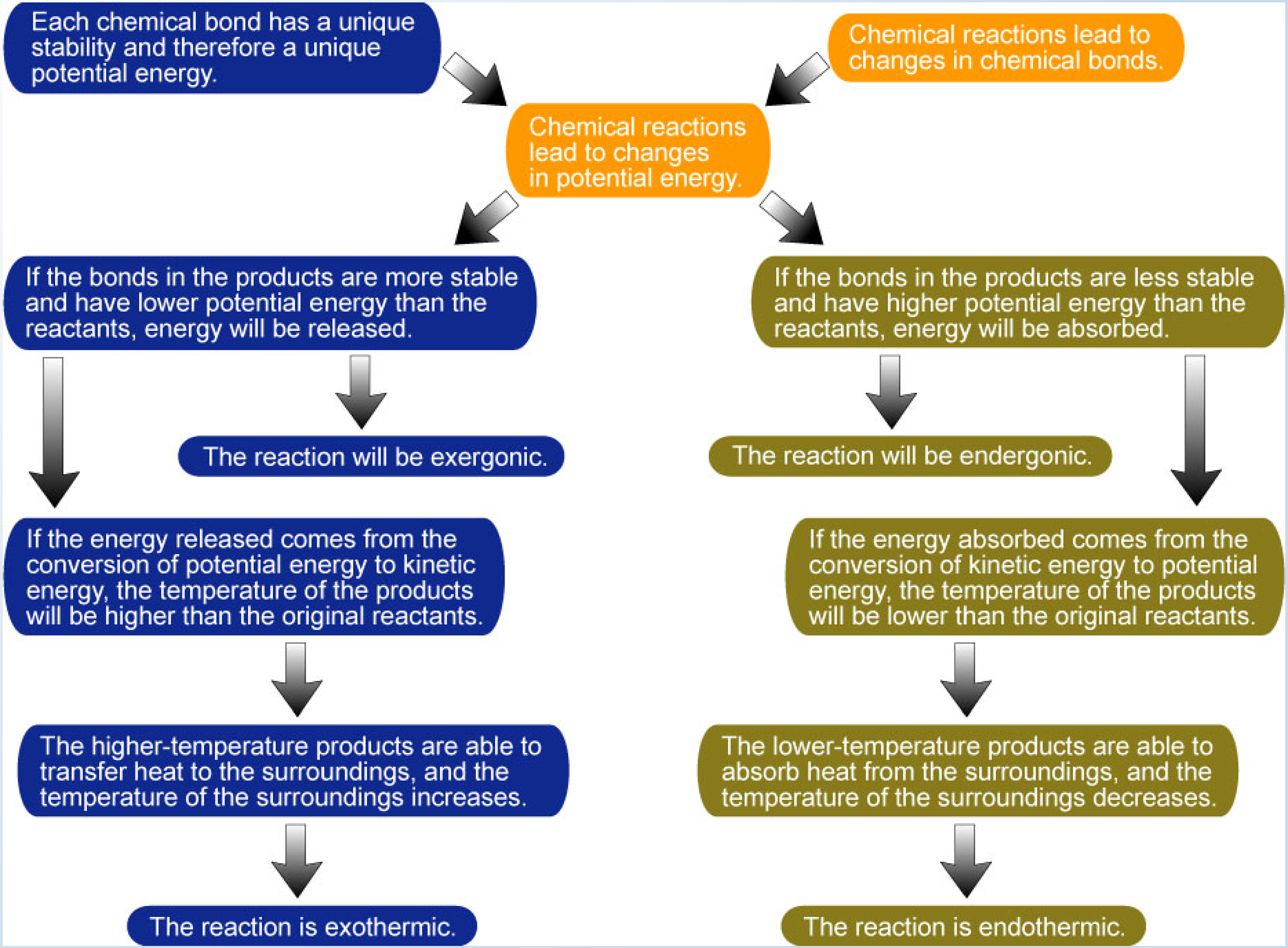
Decreases KE_{ave} of product particles

↓

Decreased T → T_{inside} < $T_{outside}$

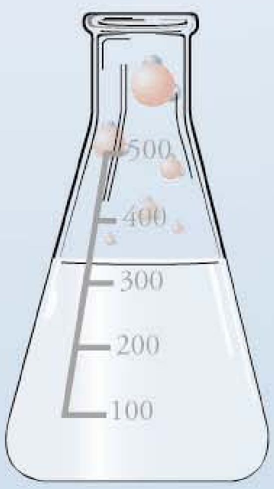
↓

Heat transferred to system → Endothermic



Each chemical bond has a unique stability and therefore a unique potential energy.
Chemical reactions lead to changes in chemical bonds.
Chemical reactions lead to changes in potential energy.
If the bonds in the products are more stable and have lower potential energy than the reactants, energy will be released.
If the bonds in the products are less stable and have higher potential energy than the reactants, energy will be absorbed.
The reaction will be exergonic.
The reaction will be endergonic.
If the energy released comes from the conversion of potential energy to kinetic energy, the temperature of the products will be higher than the original reactants.
If the energy absorbed comes from the conversion of kinetic energy to potential energy, the temperature of the products will be lower than the original reactants.
The higher-temperature products are able to transfer heat to the surroundings, and the temperature of the surroundings increases.
The lower-temperature products are able to absorb heat from the surroundings, and the temperature of the surroundings decreases.
The reaction is exothermic.
The reaction is endothermic.

Ozone, O_3, as Oxidizing Agent



- Used to sanitize hot tubs
- Used in industry to bleach waxes, oils, and textiles.
- Strong respiratory irritant that can lead to shortness of breath, chest pain when inhaling, wheezing, and coughing
- Damages rubber and plastics, leading to premature deterioration of products made with these materials.
- Ozone damages plants.

Ozone as Pollutant

- Highest concentrations found in large industrial cities with lots of cars and lots of sun.

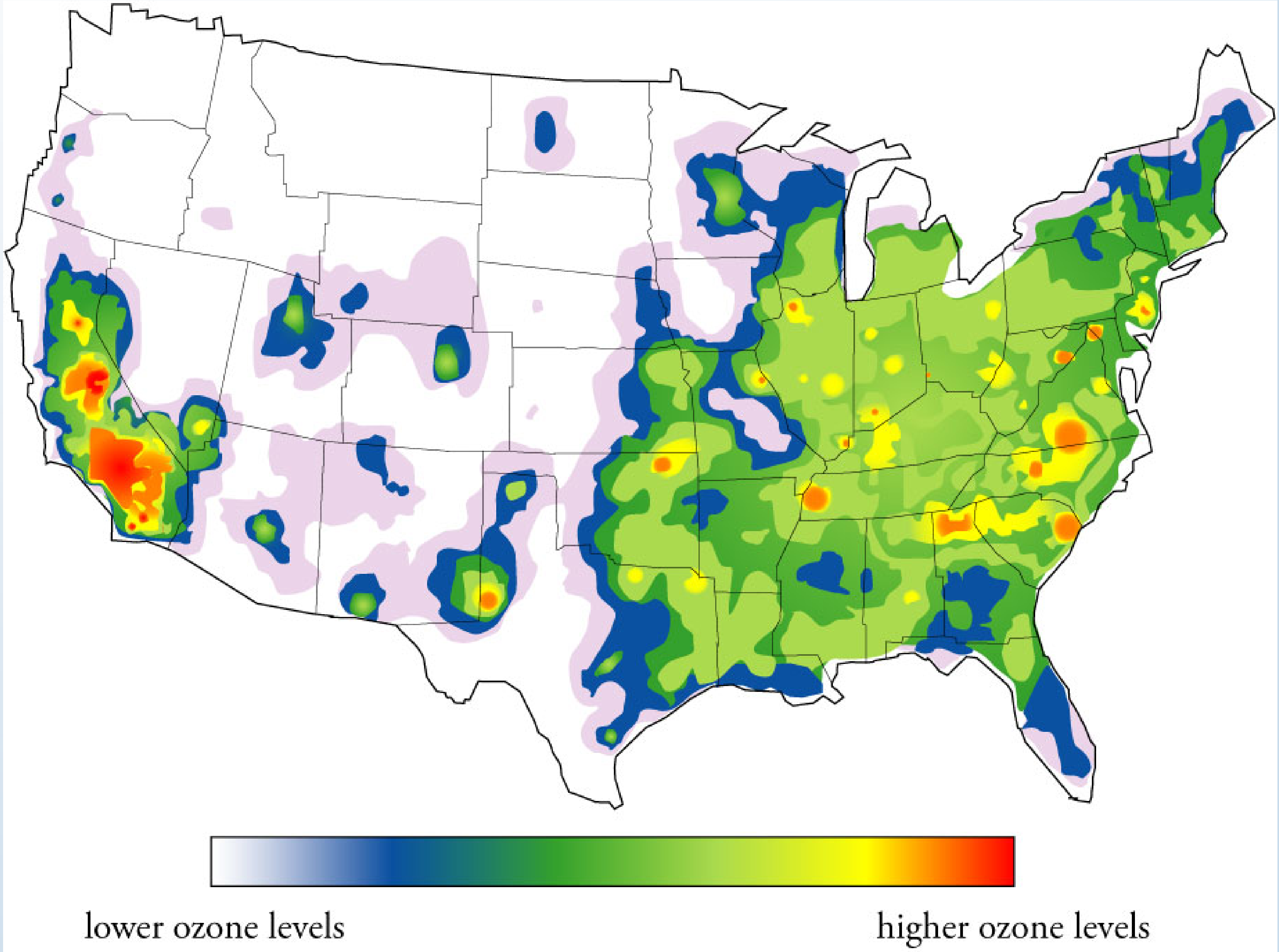
$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

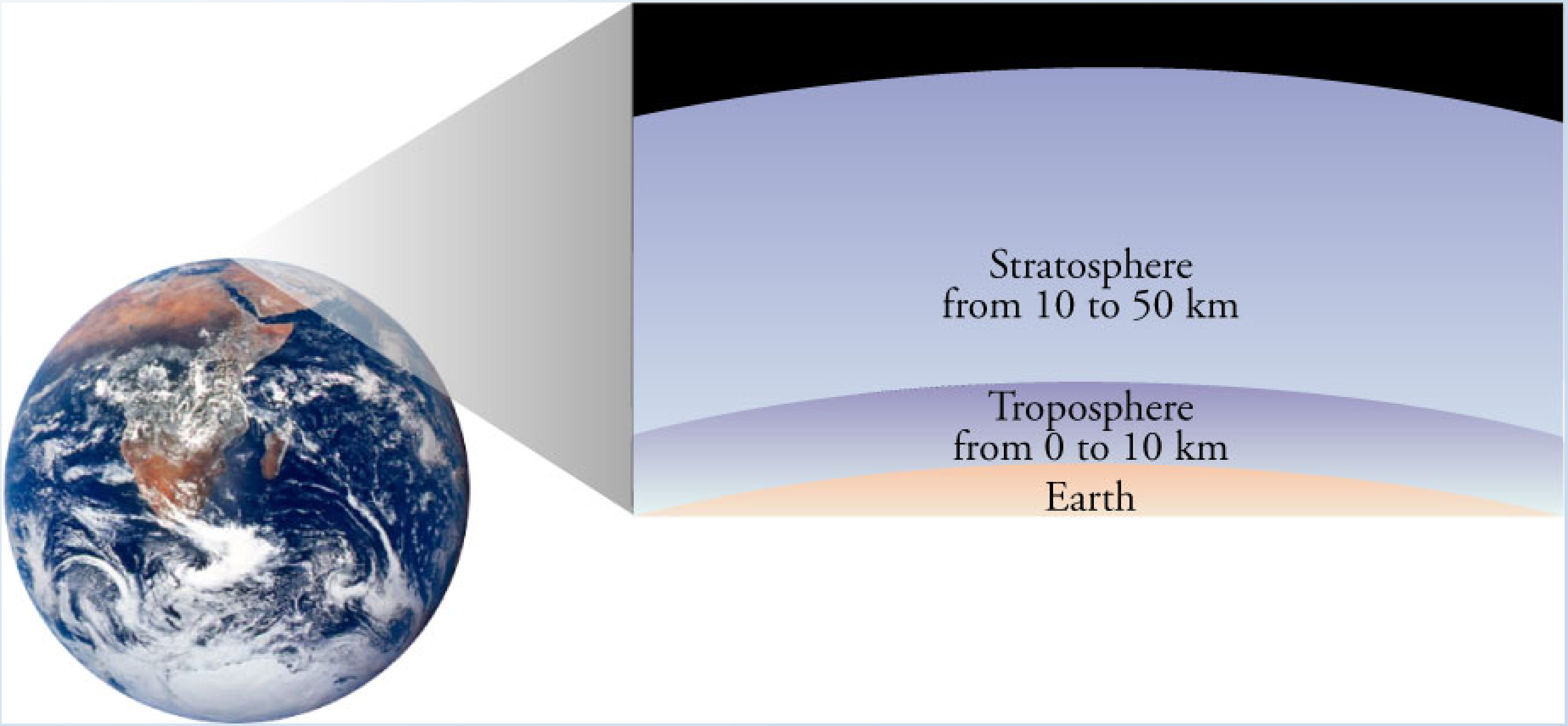
$$NO_2(g) \xrightarrow{\lambda < 400\ \text{nm}} NO(g) + O(g)$$

$$O(g) + O_2(g) \rightarrow O_3(g)$$

National Ozone Concentrations



The Earth's Atmosphere



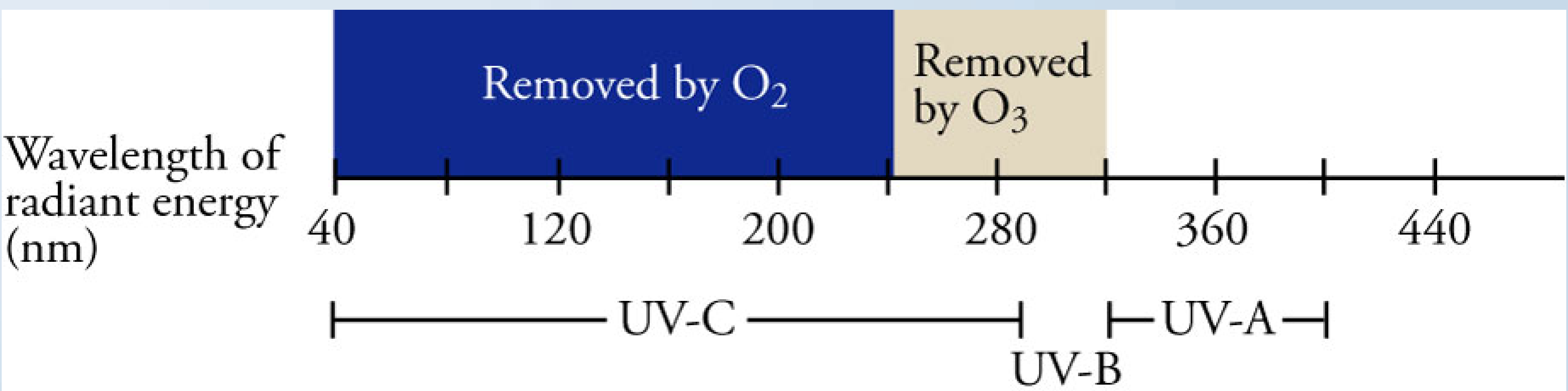
Ultraviolet Radiation

- **UV-A** 320-400 nm
  - reaches the surface of the Earth
  - helps create Vitamin D
- **UV-B** 290-320 nm
  - some reaches the surface of the Earth
  - leads to sunburn, skin aging, and skin cancer
- **UV-C** 40-290 nm
  - mostly removed in upper atmosphere
  - alters DNA (≈260 nm) and protein (≈280 nm)

Removal of UV in Stratosphere

$$O_2(g) \xrightarrow{\text{UV with } \lambda < 242 \text{ nm}} 2O(g)$$

$$O_3(g) \xrightarrow{\text{UV with } \lambda \text{ from 240 to 320 nm}} O(g) + O_2(g)$$



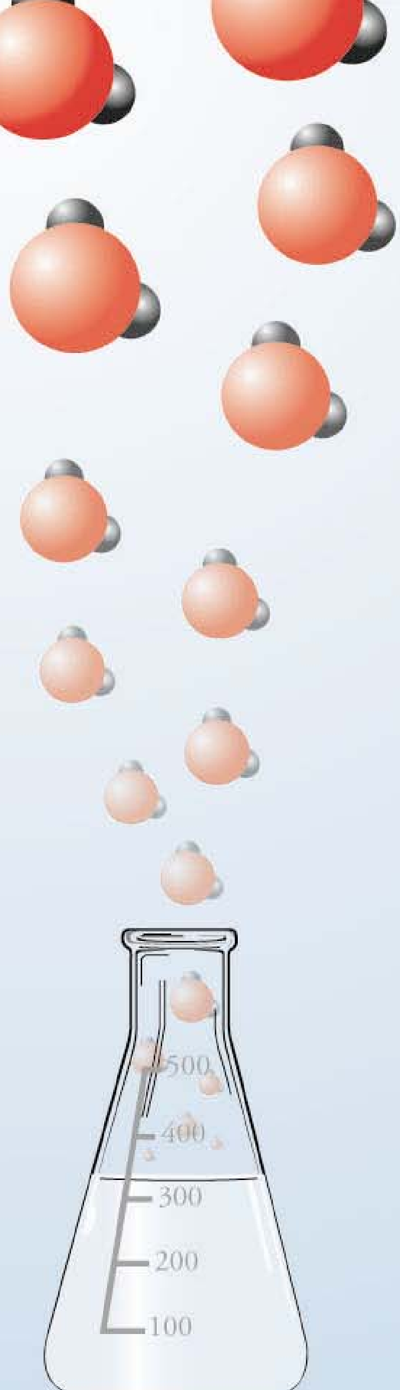
Ozone Destruction

$$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$$

$$NO_2(g) + O(g) \rightarrow NO(g) + O_2(g)$$

net reaction

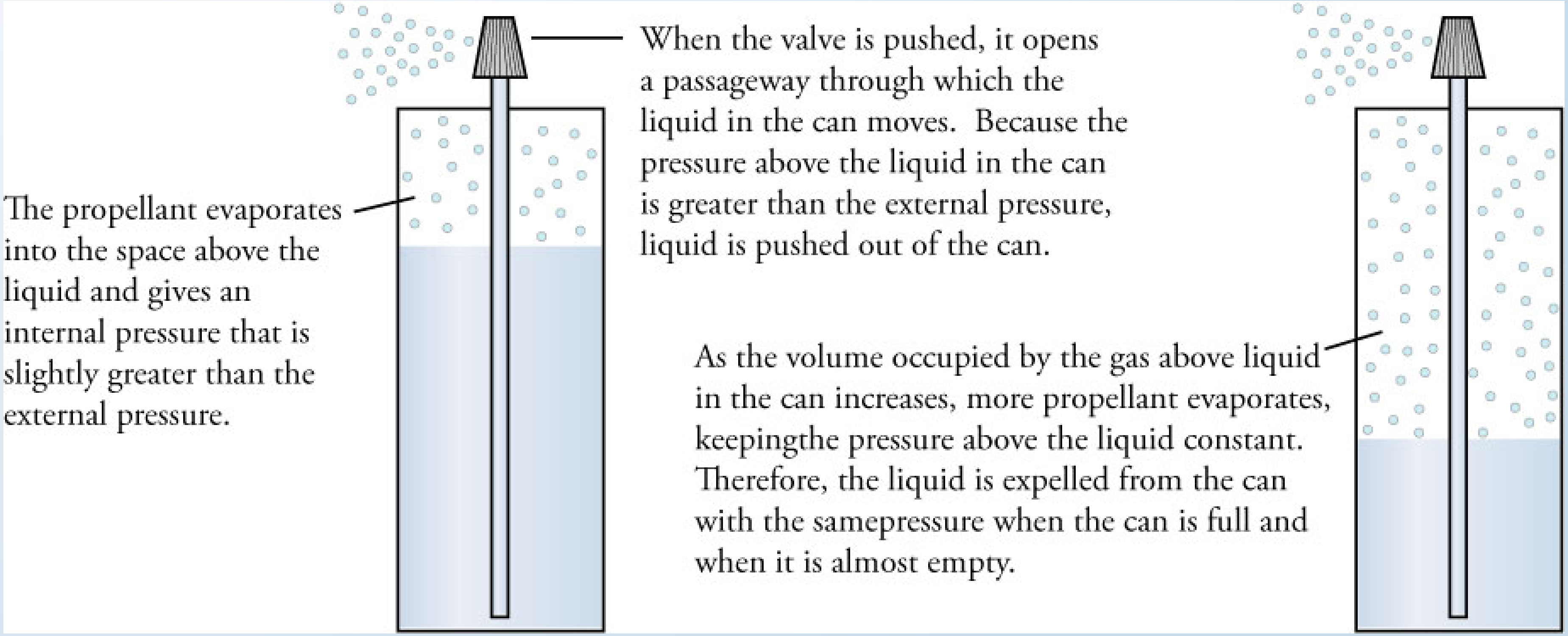
$$O_3(g) + O(g) \xrightarrow{\text{NO catalyst}} 2O_2(g)$$



Chlorofluorocarbons (CFCs)

- CFC-11 $CFCl_3$
  - average lifetime in atmosphere is ≈ 50 years
- CFC-12 CF_2Cl_2
  - average lifetime in atmosphere is ≈ 102 years
- used as propellants in aerosol cans, solvents, blowing agents for foams, coolant in refrigerators, and other uses
- very stable, nontoxic, and can be liquefied with minimal pressure

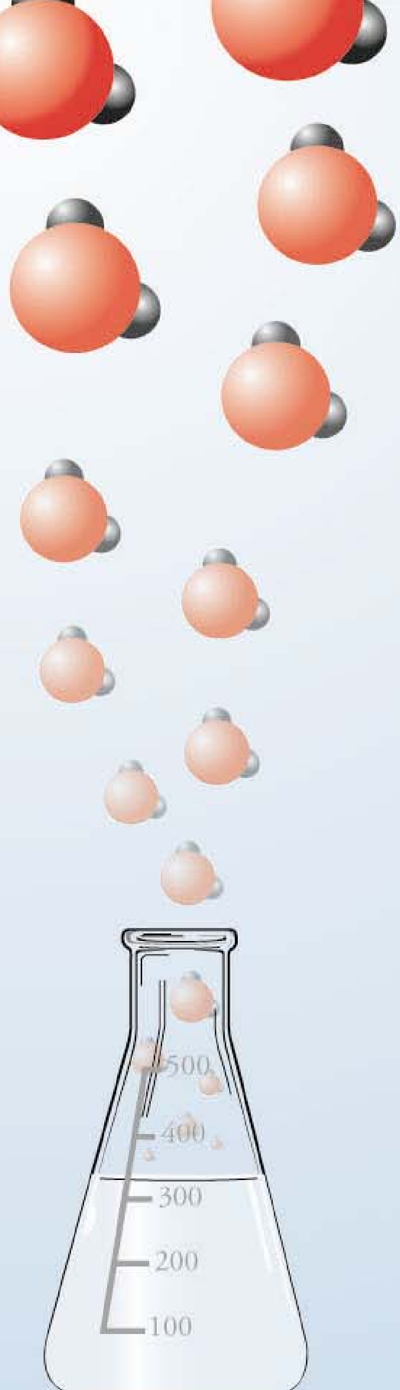
Aerosol Can Propellants



Refrigeration

- The refrigerant is a substance that is a gas at normal pressures but one that can be converted into a liquid at slightly greater than normal pressures.
- Outside the refrigerator, gas is compressed to liquid. Increased attractions leads to increased stability, lower PE, and the release of energy into the room.
- Inside the refrigerator, the liquid is allowed to form a gas. Decreased attractions leads to decreased stability, higher PE, and energy is absorbed. This decreases the temperature inside the refrigerator.

CFC Threat to Ozone (1974) Mario Molina and F. Sherwood Rowland



$$CF_2Cl_2(g) \xrightarrow{\lambda < 215\text{ nm}} CF_2Cl(g) + Cl(g)$$

$$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$$

$$ClO(g) + O(g) \rightarrow Cl(g) + O_2(g)$$

net reaction

$$O_3(g) + O(g) \xrightarrow{\text{Cl catalyst}} 2O_2(g)$$

Another Possible Mechanism for the CFC Threat to Ozone

$$CF_2Cl_2(g) \xrightarrow{\lambda < 215\text{ nm}} CF_2Cl(g) + Cl(g)$$

$$2Cl(g) + 2O_3(g) \rightarrow 2ClO(g) + 2O_2(g)$$

$$2ClO(g) \rightarrow ClOOCl(g)$$

$$ClOOCl(g) \rightarrow ClOO(g) + Cl(g)$$

$$ClOO(g) \rightarrow Cl(g) + O_2(g)$$

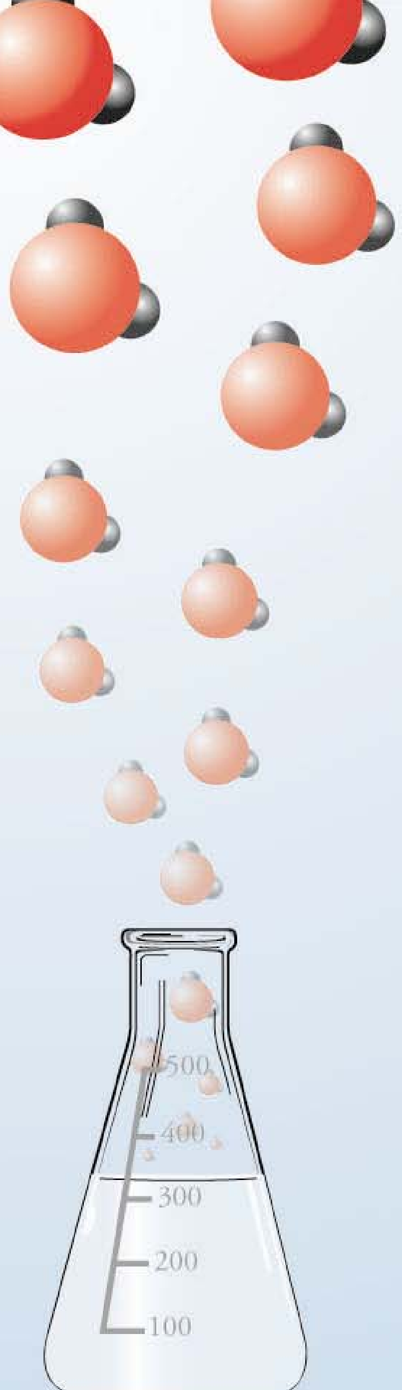
net reaction

$$2O_3(g) \xrightarrow{\text{Cl catalyst}} 3O_2(g)$$

Inactive Chlorine

$$CH_4(g) + Cl(g) \rightarrow CH_3(g) + HCl(g)$$

$$ClO(g) + NO_2(g) \rightarrow ClONO_2(g)$$



1985 - Ozone Hole - Reactions on the surface of ice crystals

$$ClONO_2(g) + HCl(s) \rightarrow Cl_2(g) + HNO_3(s)$$

$$ClONO_2(g) + H_2O(s) \rightarrow HOCl(g) + HNO_3(s)$$

$$HOCl(g) + HCl(s) \rightarrow Cl_2(g) + H_2O(s)$$

$$HOCl(g) \xrightarrow{\text{radiant energy}} Cl(g) + OH(g)$$

$$Cl_2(g) \xrightarrow{\text{radiant energy}} 2Cl(g)$$