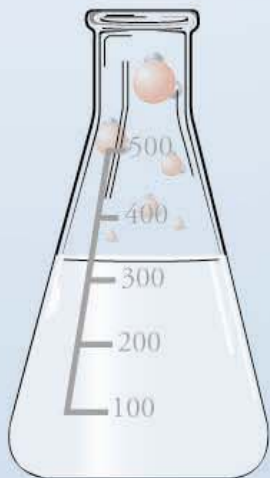


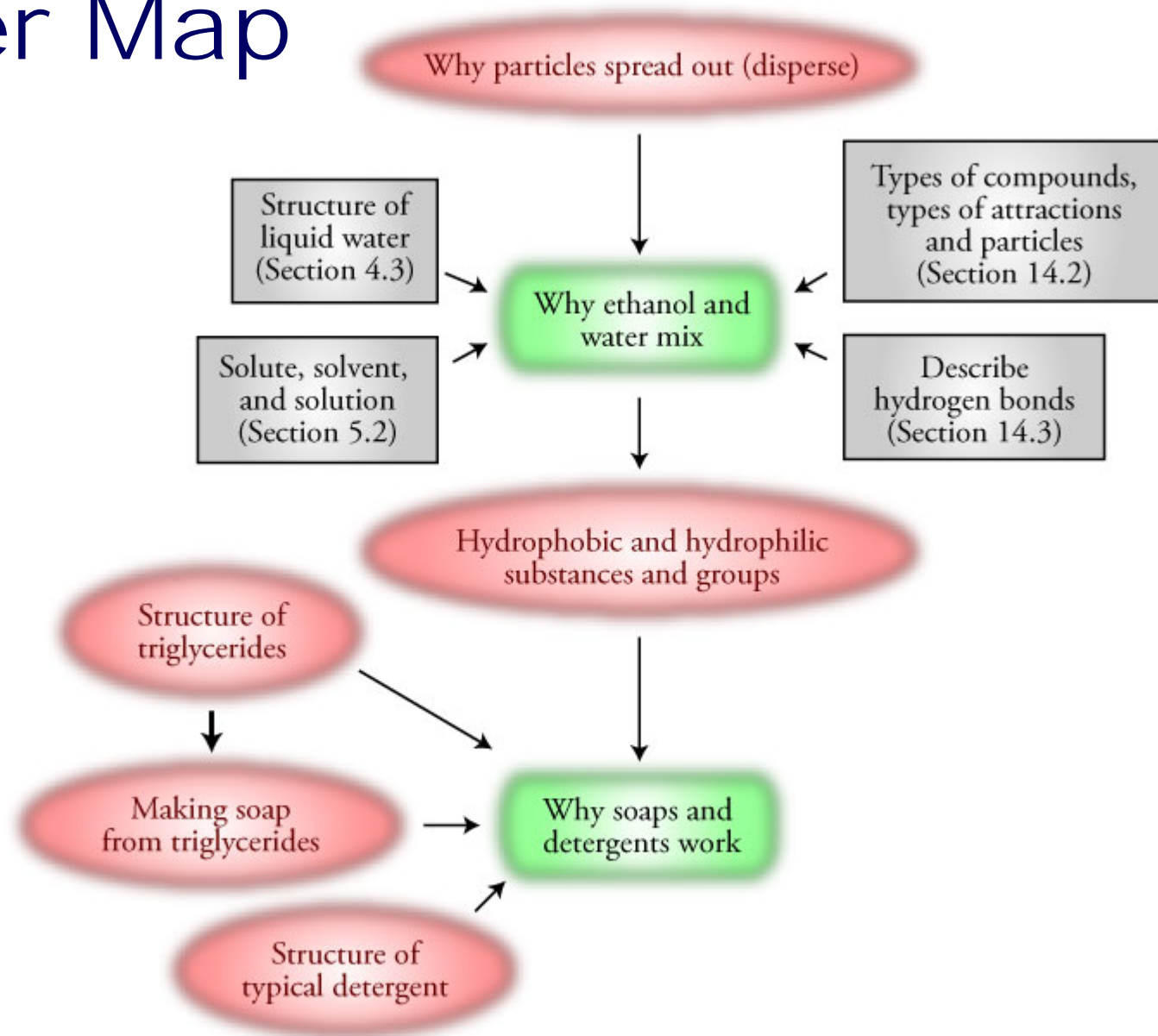


# Chapter 15

## Solution Dynamics

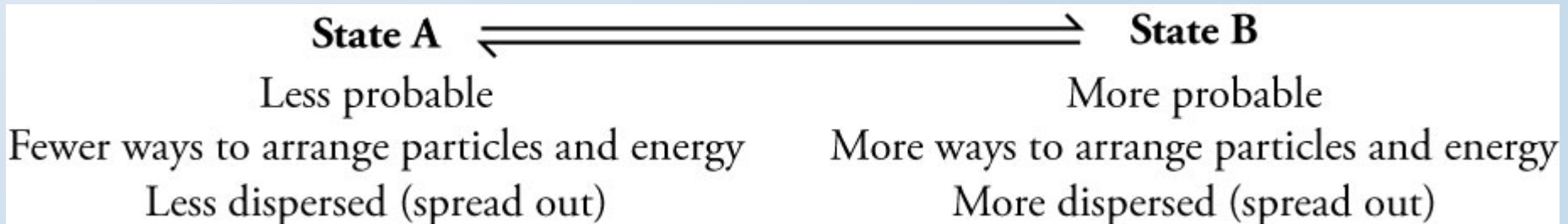


# Chapter Map



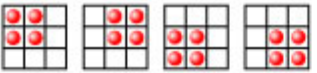
# Why Changes Happen

- Consider a system that can switch freely between two states, A and B.
- Probability helps us to predict that the system will shift to state B if state B has its particles and energy more dispersed, leading to more ways to arrange the particles and energy in the system.



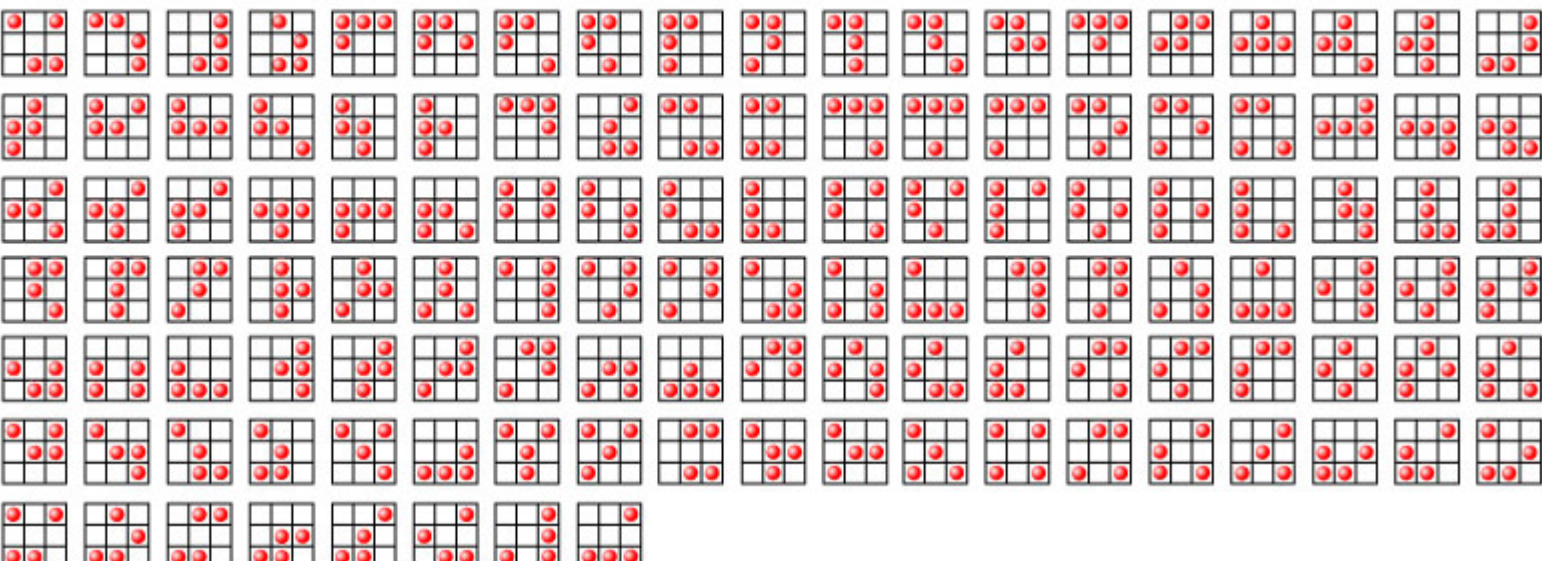
# 9-Point Universe

Solid-like states



4 possible arrangements of the red particles produce an organized, solid-like state.

Gas-like states

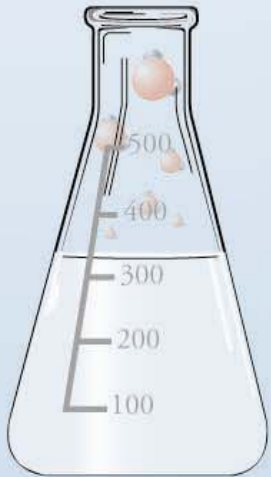


122 possible arrangements produce a less-organized, gas-like state.

A vertical column of water molecules (one red oxygen atom and two black hydrogen atoms) is positioned on the left side of the slide, extending from the top to the flask. The molecules are arranged in a way that suggests they are rising from the flask.

# Probability of Gas

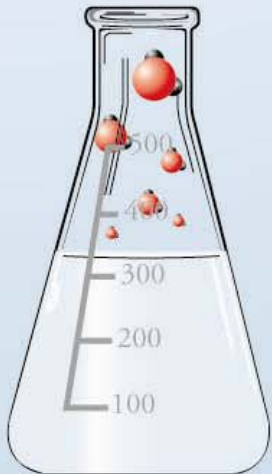
- In 9-point universe, 96% of the arrangements of 4 particles are gas-like.
- In 16-point universe, 99.5% of the arrangements of 4 particles are gas-like.
- Therefore, an increase in the number of possible positions leads to an increase in the probability that the system will be in the more dispersed, gas-like state.
- In real systems, there are huge numbers of particles in huge numbers of positions, so there is an extremely high probability that the systems will be in the more dispersed, gas-like state.





# General Statement

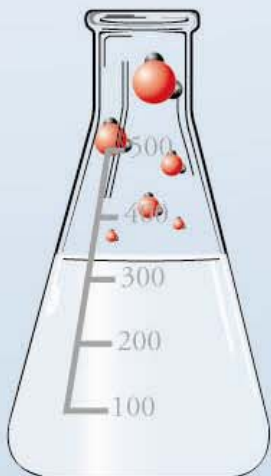
- Changes tend to take place to shift from less probable, less dispersed arrangements that have fewer ways to arrange the particles to more probable, more dispersed states that have more ways to arrange the particles.



A series of ball-and-stick models of carbon dioxide (CO2) molecules, arranged in a descending staircase pattern from the top left towards the center. Each molecule consists of one large orange sphere (carbon) and two smaller grey spheres (oxygen) bonded to it.

# Solids shift spontaneously to gases.

- Why does dry ice,  $\text{CO}_2(\text{s})$ , sublime? Why does the change favor the gas?
  - Internal kinetic energy is associated with the random movement of particles in a system.
  - Internal kinetic energy makes it possible for  $\text{CO}_2$  molecules to move back and forth between solid and gas.
  - If the particles can move freely back and forth between solid and gas, they are more likely to be found in the more dispersed gas state, which has more equivalent ways to arrange the particles.



# Solid to Gases



Fewer ways to  
arrange particles

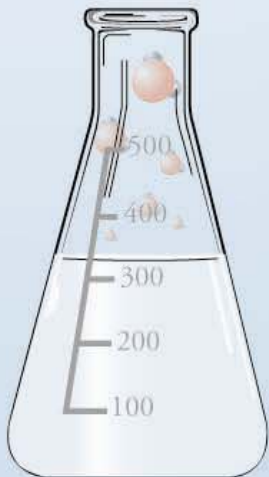
Less probable

Less dispersed

More ways to  
arrange particles

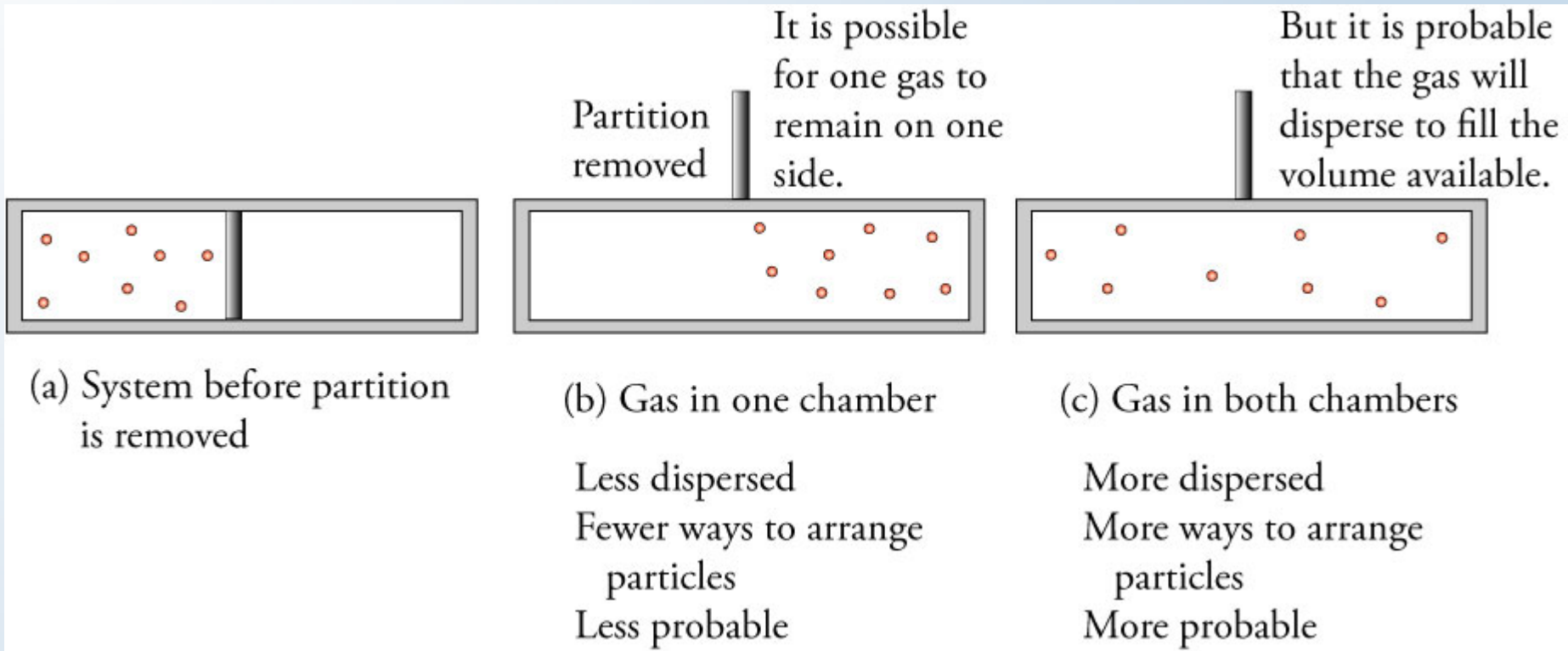
More probable

More dispersed

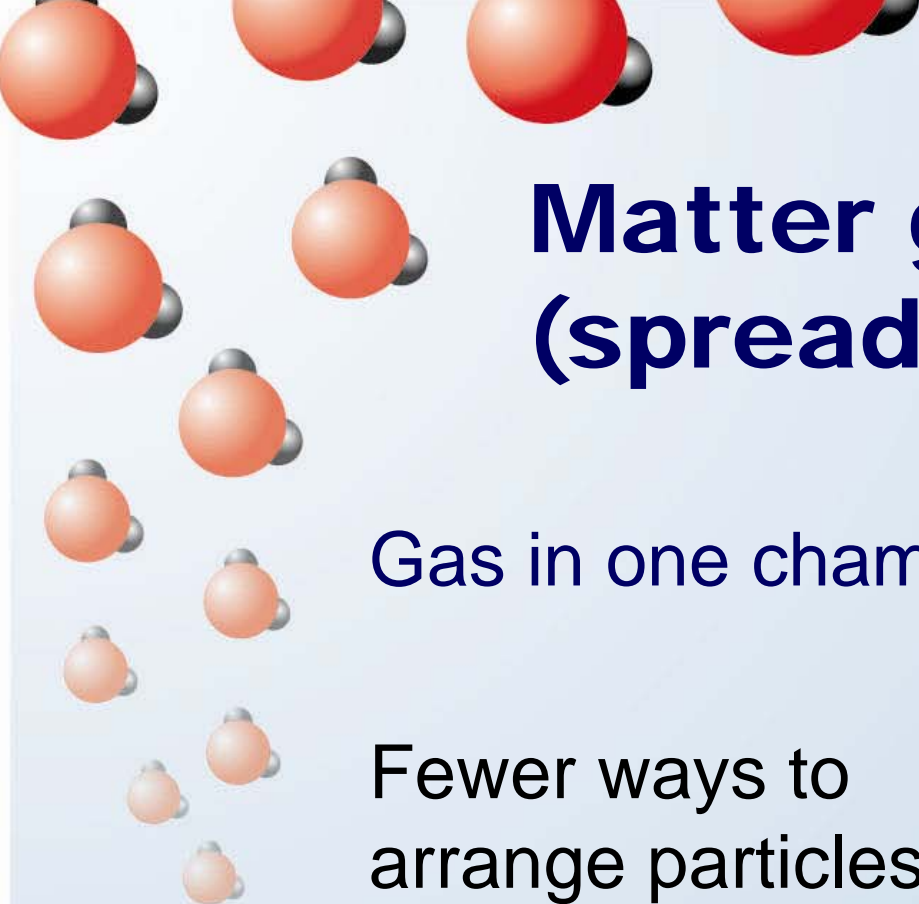




# Gases Expand



When the barrier between the two chambers in the container shown in (a) is raised, it is possible that the gas will end up in one chamber, like in (b), but it is much more likely that it will expand to fill the total volume available to it, like in (c).



Matter gets dispersed  
(spread out).

Gas in one chamber → Gas in both chambers

Fewer ways to  
arrange particles

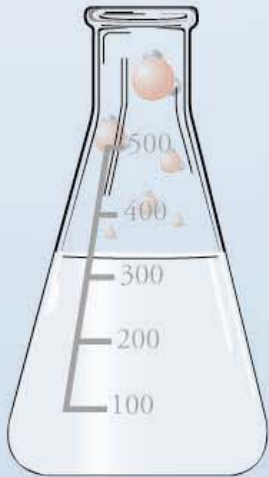
More ways to  
arrange particles

Less probable

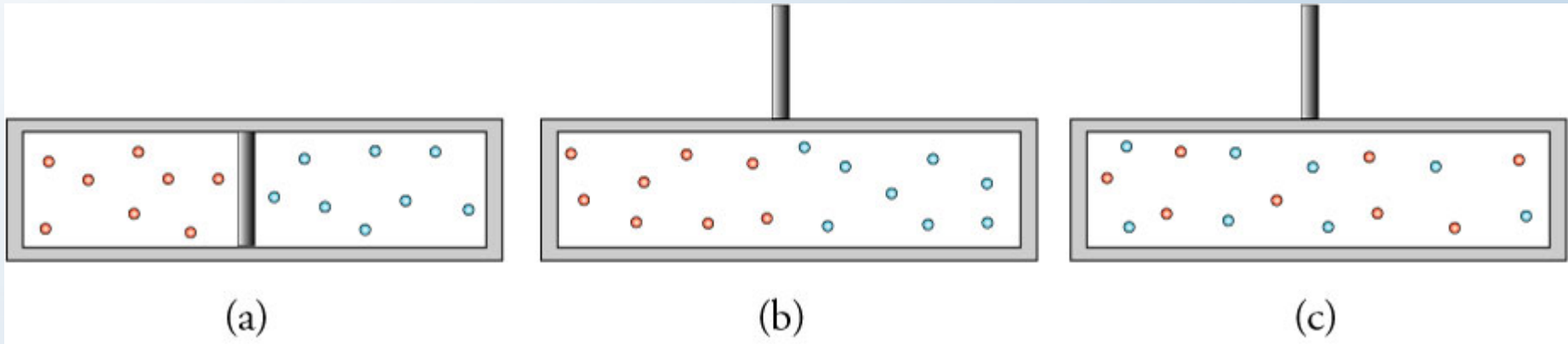
More probable

Less dispersed

More dispersed



# Substances tend to mix.

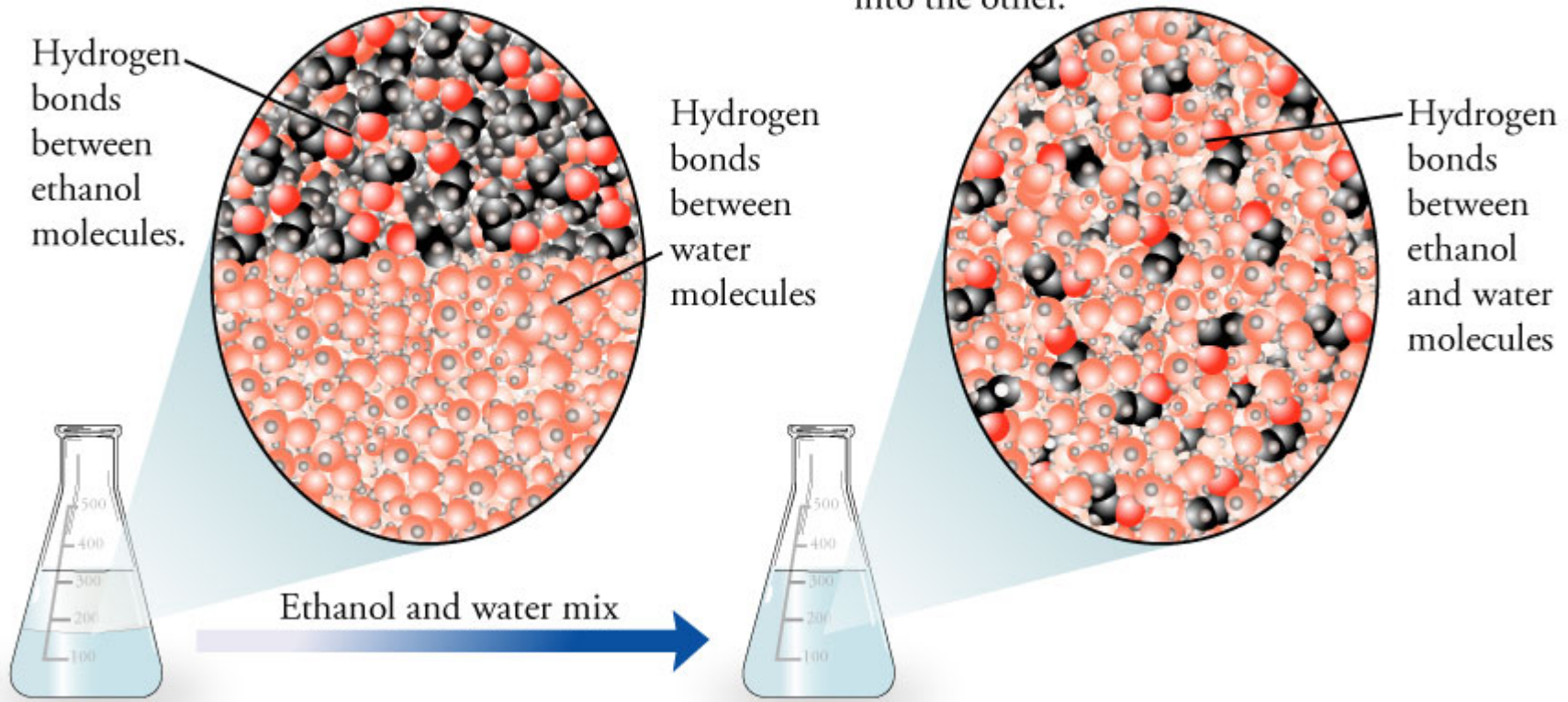


When the barrier between the two gases in the container shown in (a) is raised, it is possible that the gases will stay separated, like in (b), but it is much more likely that they will mix, like in (c).

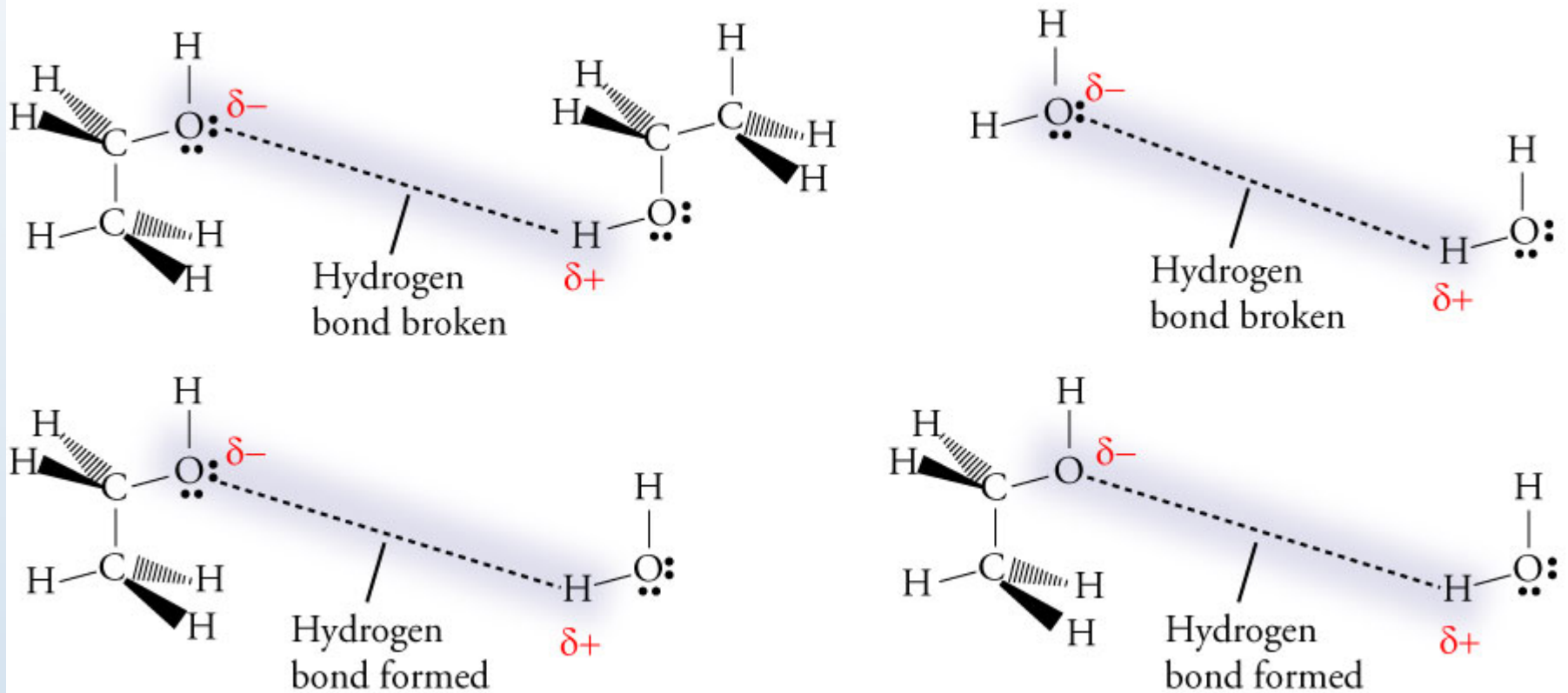
# Ethanol and Water Mixing

At the instant ethanol and water are mixed, the ethanol floats on top of the water.

Because the attractions between their molecules are similar, the molecules mix freely, allowing each substance to disperse into the other.



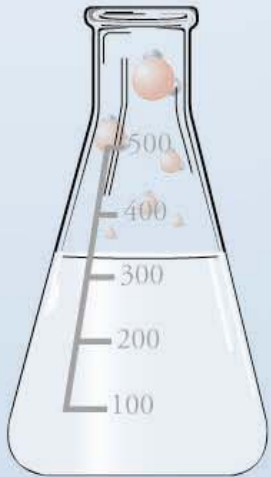
# Attractions Broken and Made





# Solubility

- If less than one gram of the substance will dissolve in 100 grams (or 100 mL) of solvent, the substance is considered ***insoluble***.
- If more than ten grams of substance will dissolve in 100 grams (or 100 mL) of solvent, the substance is considered ***soluble***.
- If between one and ten grams of a substance will dissolve in 100 grams (or 100 mL) of solvent, the substance is considered ***moderately soluble***.





A vertical column of water molecules (H<sub>2</sub>O) is shown on the left side of the slide. Each molecule consists of one red oxygen atom and two white hydrogen atoms. The molecules are arranged in a way that suggests they are being added to or are present in a liquid. At the bottom of this column is a 500 mL Erlenmeyer flask containing a clear liquid, with the liquid level marked at approximately 350 mL. The flask has volume markings at 100, 200, 300, 400, and 500 mL.

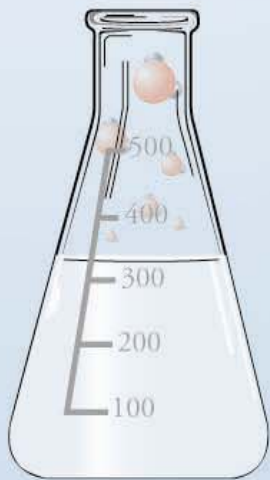
## “Like Dissolves Like”

- Polar substances are expected to dissolve in polar solvents.
  - For example, ionic compounds, which are very polar, are often soluble in the polar solvent water.
- Nonpolar substances are expected to dissolve in nonpolar solvents.
  - For example, nonpolar molecular substances are expected to dissolve in hexane, a common nonpolar solvent.

A vertical column of water molecules (H<sub>2</sub>O) is shown on the left side of the slide. Each molecule consists of one red oxygen atom and two white hydrogen atoms. The molecules are arranged in a way that suggests they are falling into a flask below.

## “Like Does Not Dissolve Unlike”

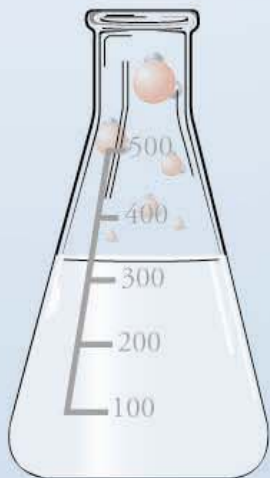
- Nonpolar substances are not expected to dissolve to a significant degree in polar solvents.
  - For example, nonpolar molecular substances are expected to be insoluble in water.
- Polar substances are not expected to dissolve to a significant degree in polar solvents.
  - For example, ionic compounds are insoluble in hexane.



A vertical column of water molecules (red and black spheres) is positioned on the left side of the slide, extending from the top to the neck of the flask below. The molecules are arranged in a way that suggests they are being added to or are present in the liquid.

# Summary of Solubility Guidelines

- Ionic Compounds
  - Often soluble in water
  - Insoluble in hexane
- Molecular compounds with nonpolar molecules
  - Insoluble in water
  - Soluble in hexane
- Molecular Compounds with small polar molecules
  - Usually soluble in water
  - Often soluble in hexane

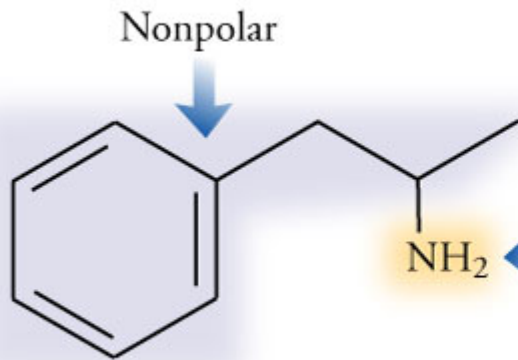


A series of water molecules, each consisting of a large red sphere (oxygen) and two smaller black spheres (hydrogen), are shown falling from the top left towards a flask at the bottom left. The flask is a standard Erlenmeyer flask with a scale on its side, ranging from 100 to 500. The water level is indicated at approximately 300. The molecules are shown in various stages of falling, with some already inside the flask.

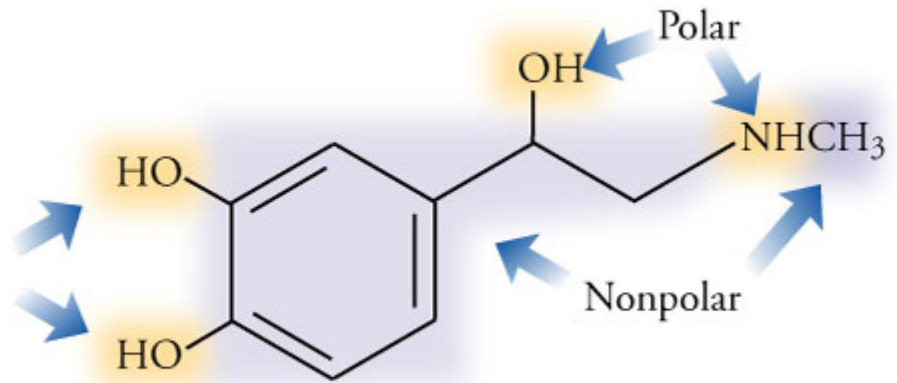
# Water Solubility

- If we are comparing the water solubility of two similar molecules, the one with the higher percentage of the molecule that is polar (***hydrophilic***) is expected to have higher water solubility.
- We predict that the molecule with the higher percentage of its structure that is nonpolar (***hydrophobic***) to be less soluble in water.

# Hydrophobic and Hydrophilic

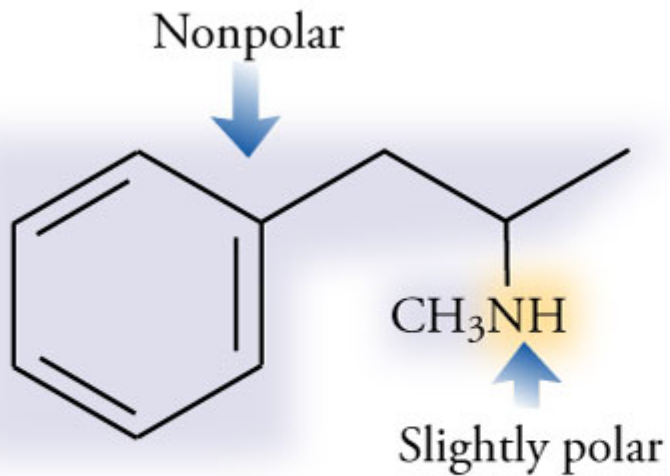


amphetamine

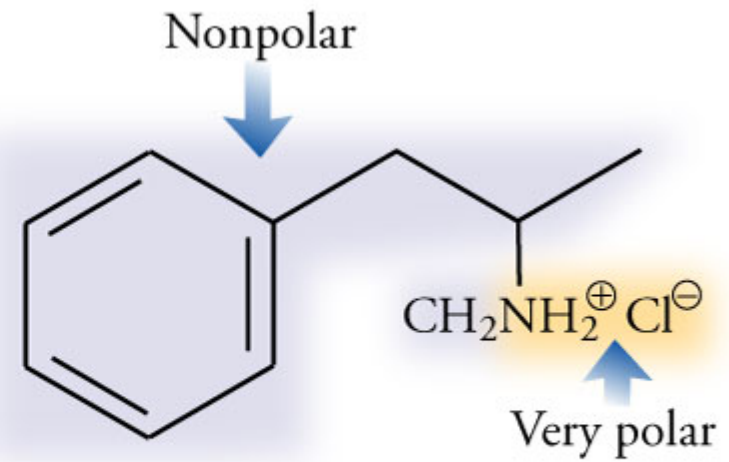


epinephrine

# Methamphetamine



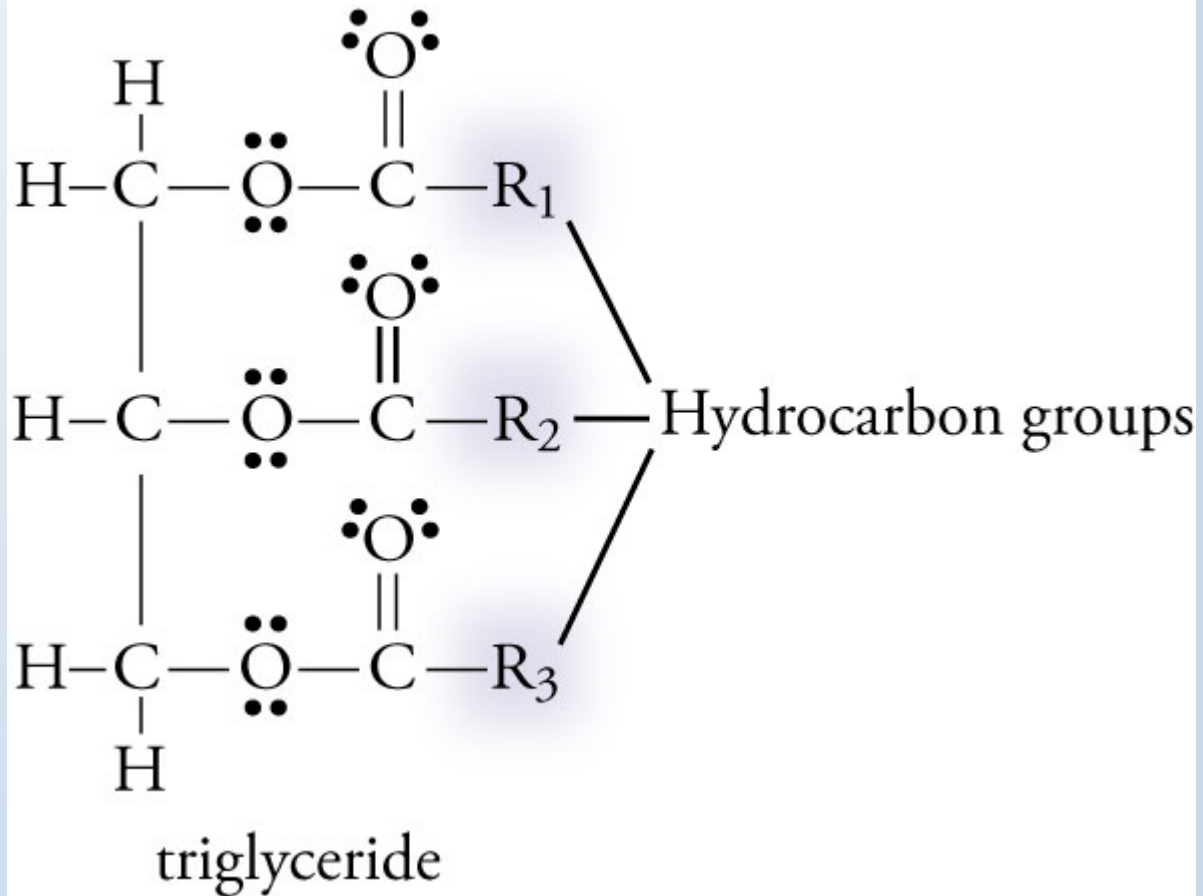
methamphetamine



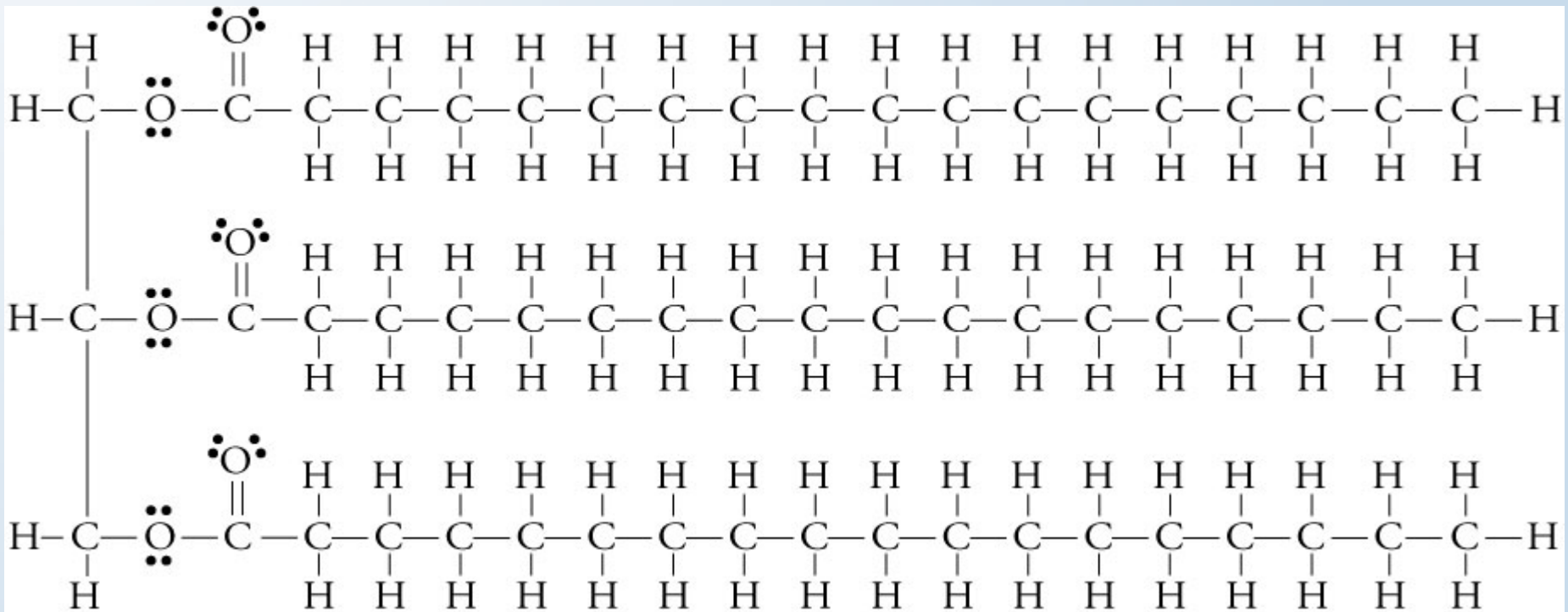
methamphetamine hydrochloride



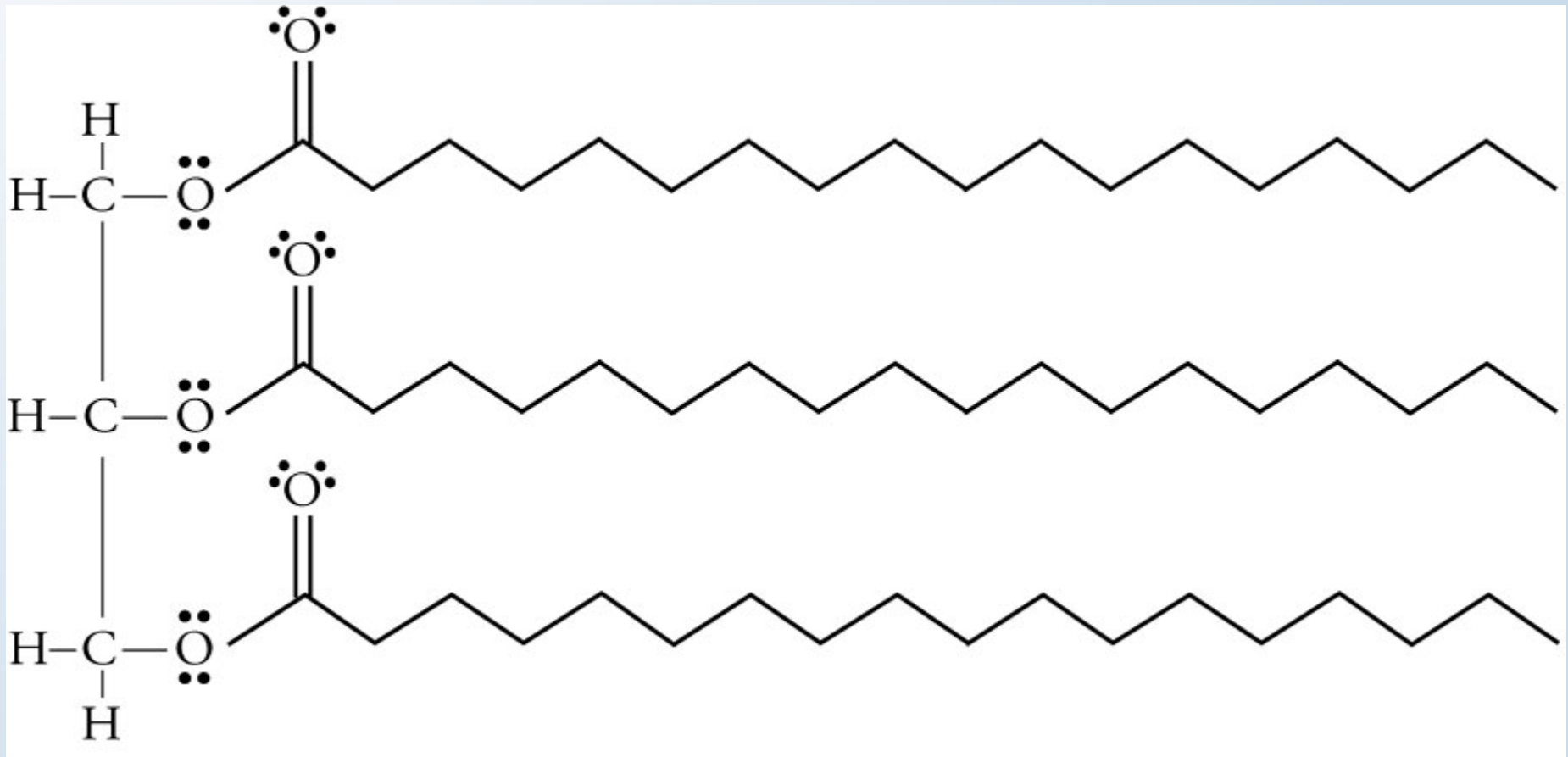
# Triglycerides (Fats and Oils)



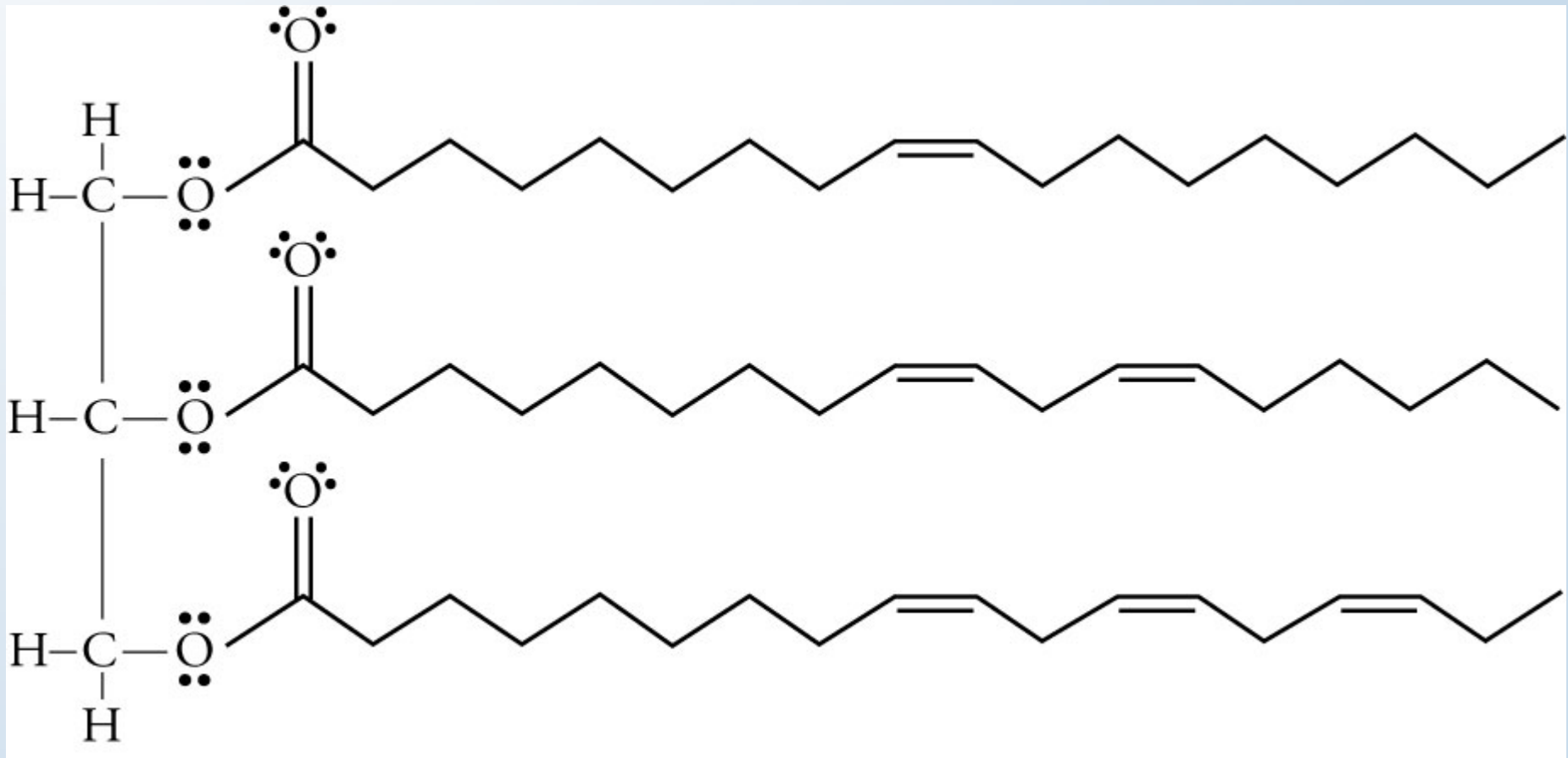
# Tristearin

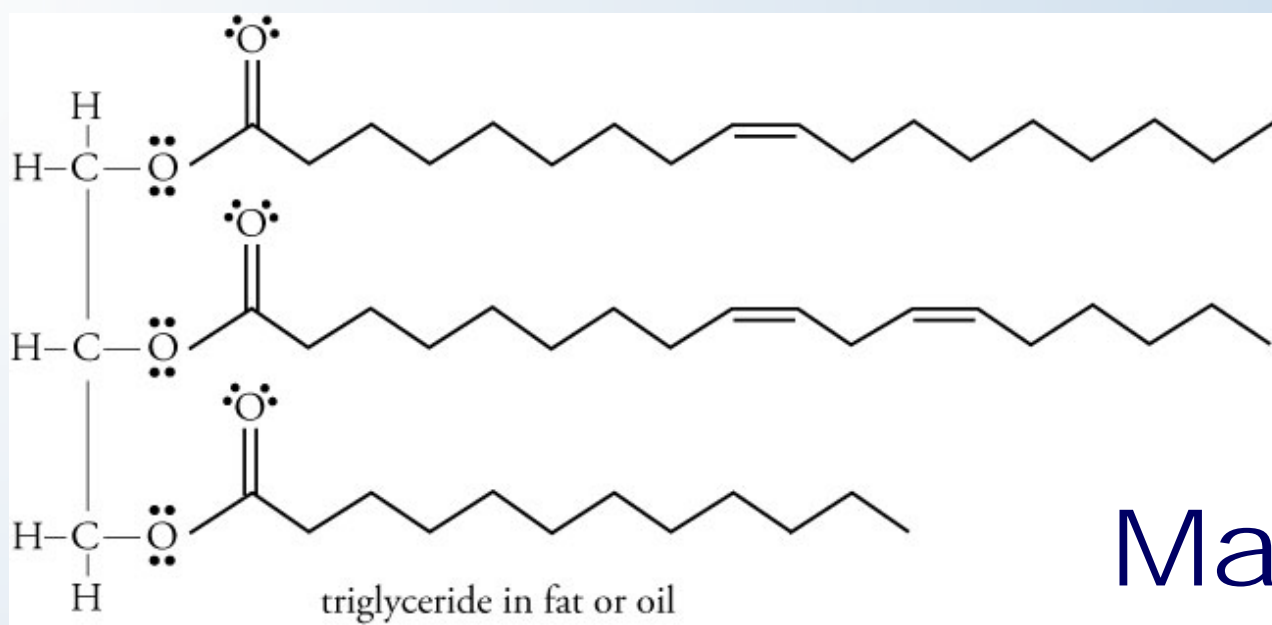


# Tristearin - Line Drawing

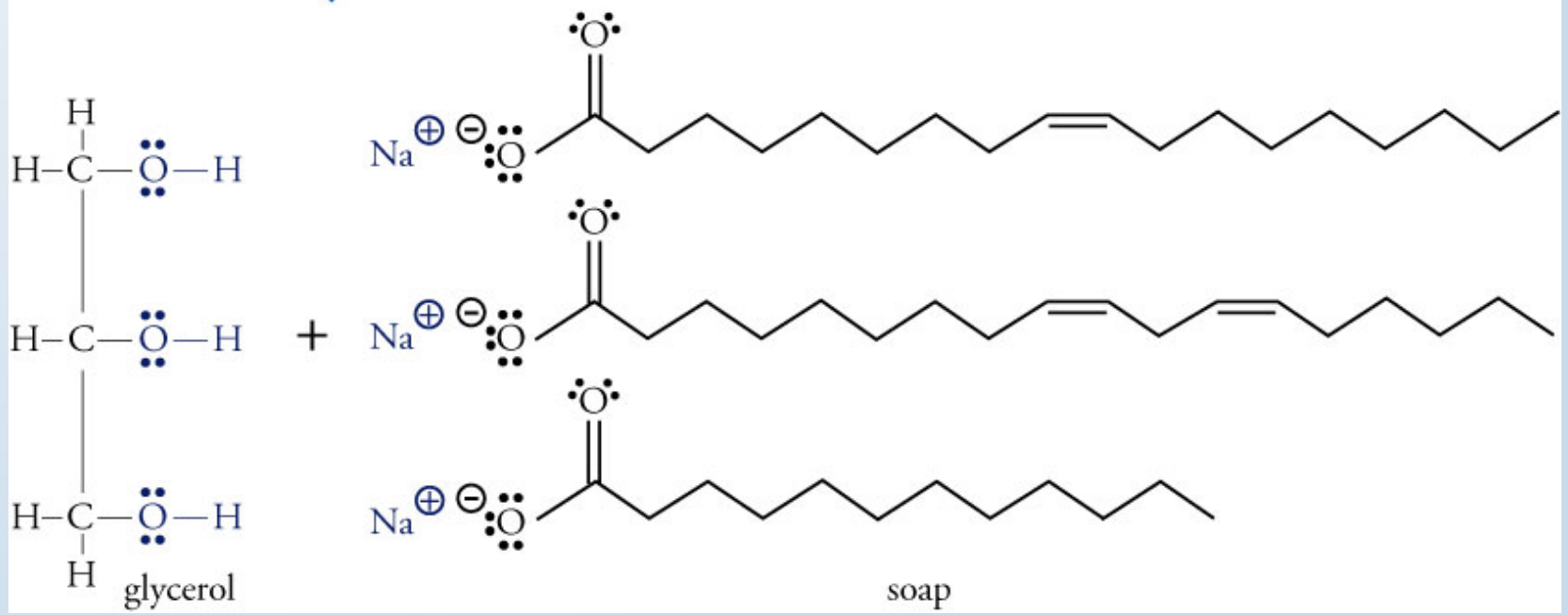


# Typical Liquid Triglyceride



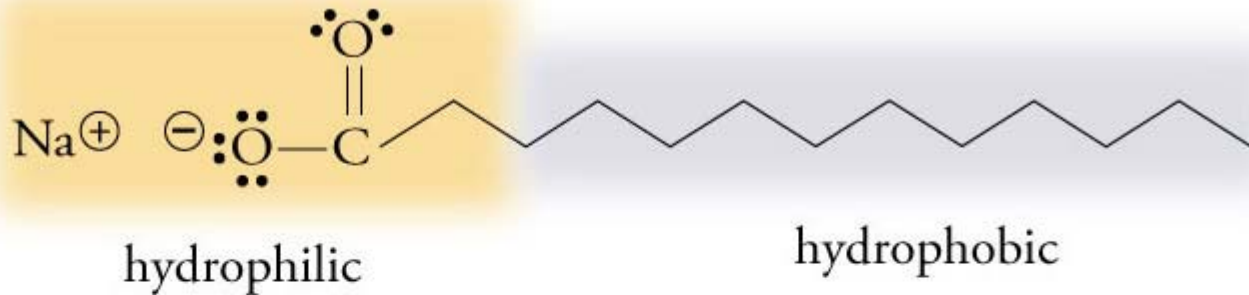


# Making Soap

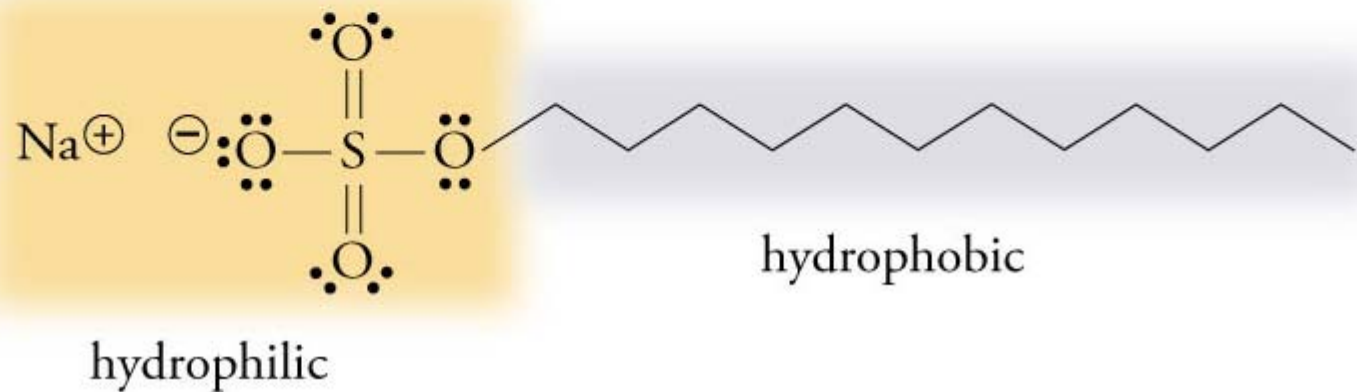


# Soap and Detergent

Typical soap

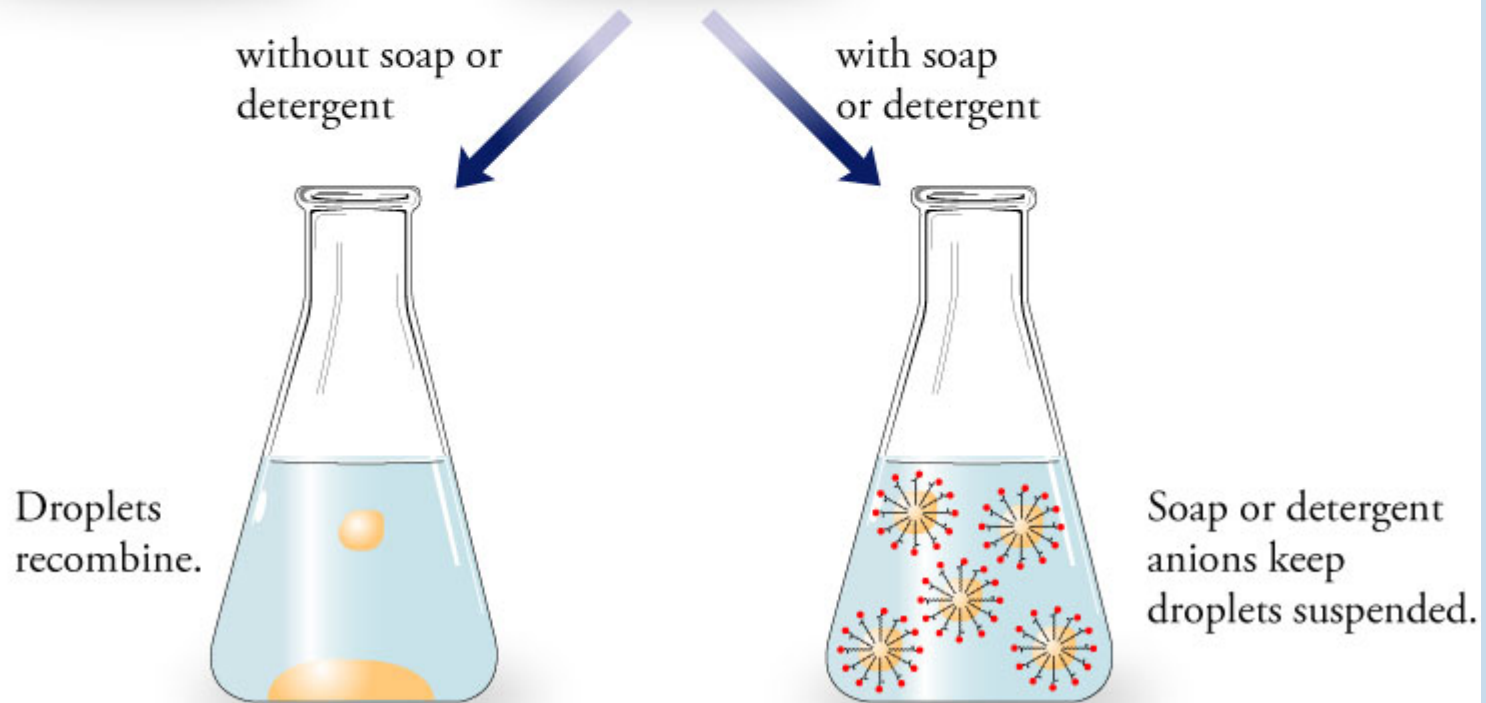
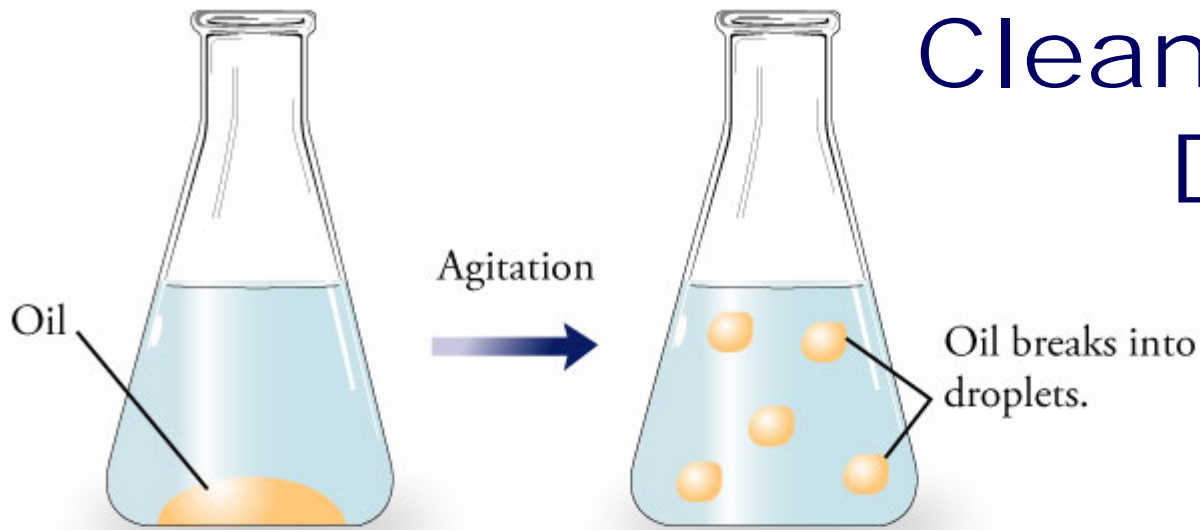


SDS, a typical ionic detergent





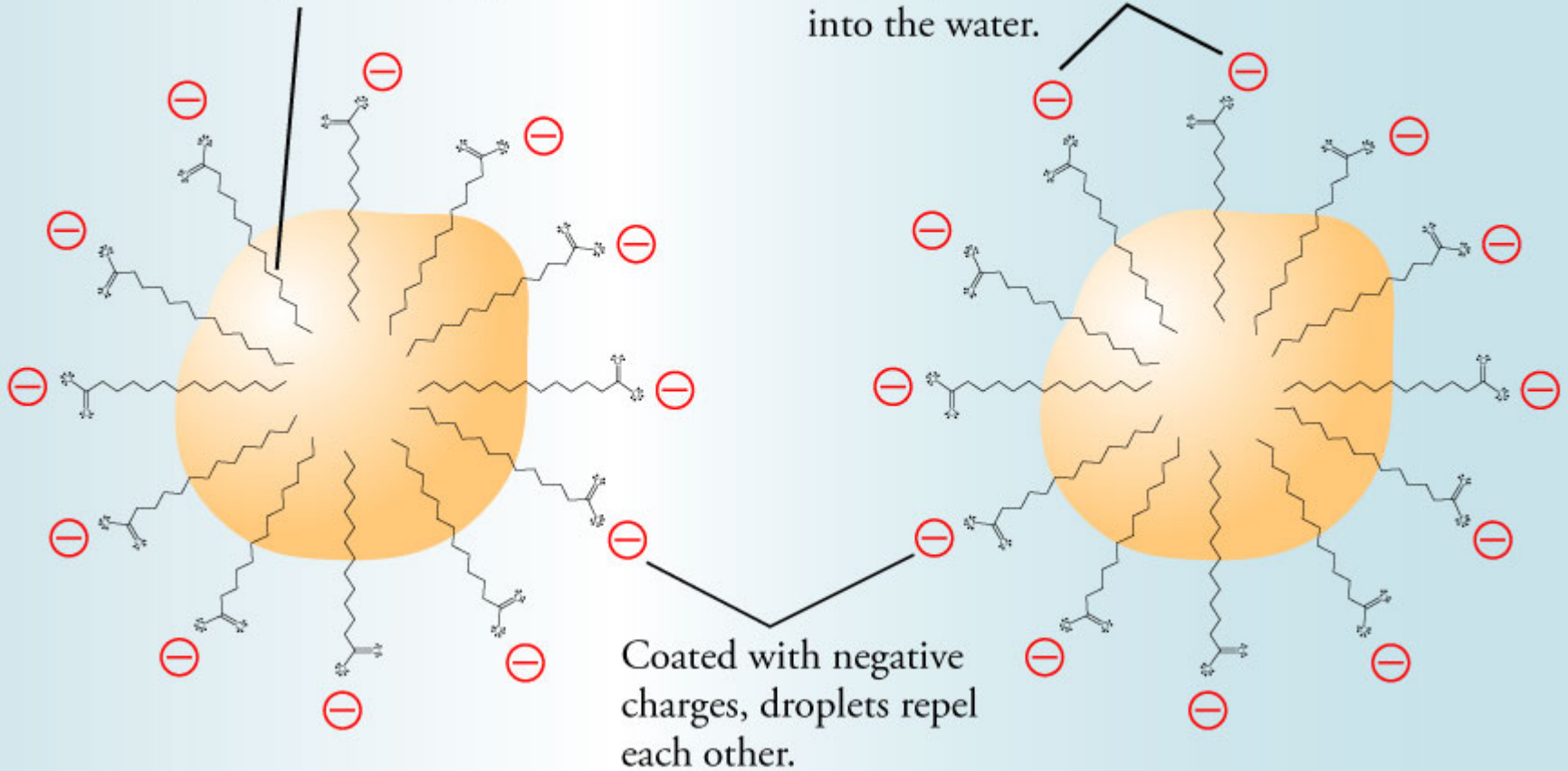
# Cleaning Greasy Dishes

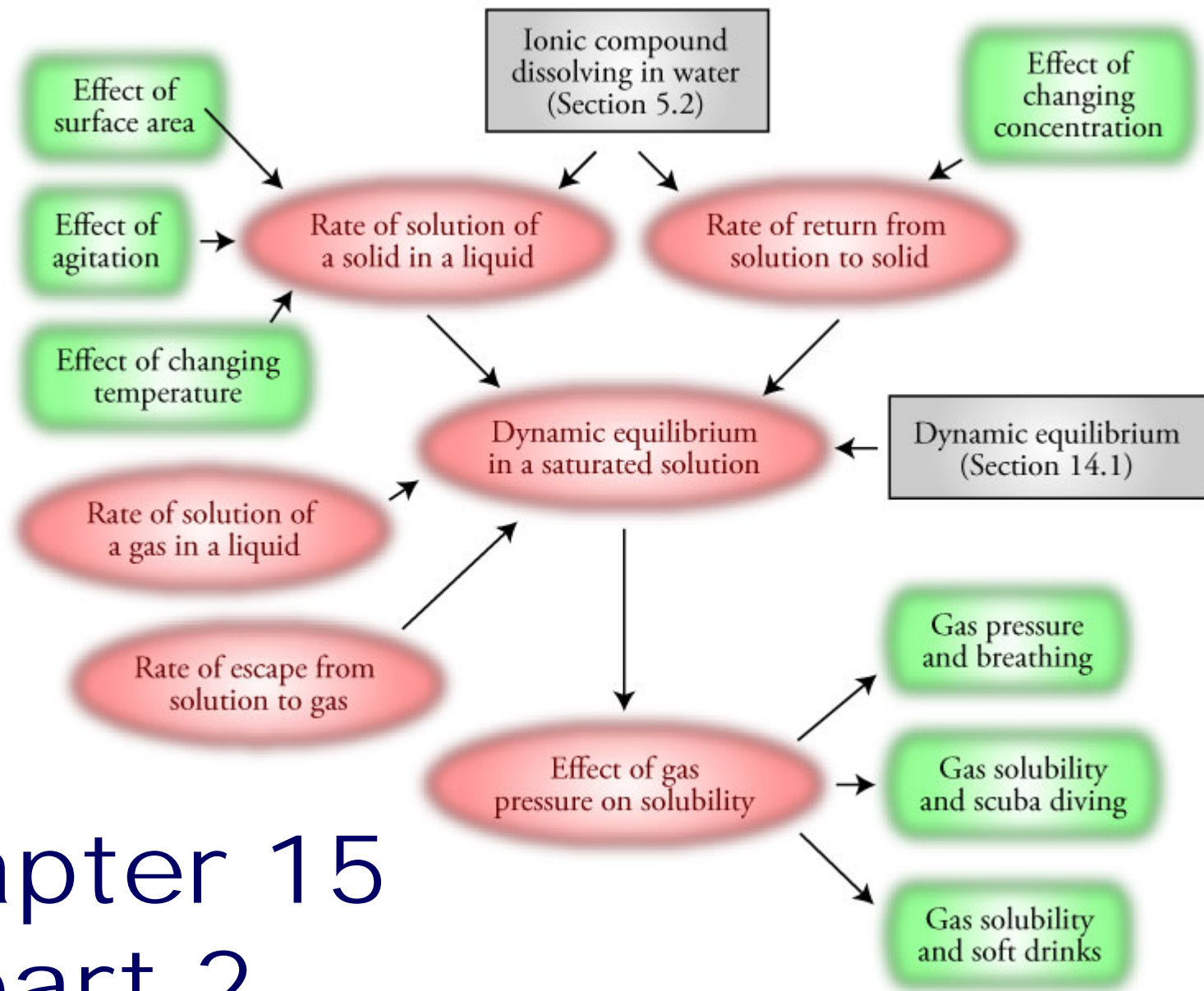


# Oil Droplets and Soap or Detergent

Hydrophobic ends of soap or detergent enter droplet.

Hydrophilic ends of soap or detergent stick out into the water.





# Chapter 15 part 2

# Solute Concentration and Rate of Return to Solid Form

**Higher concentration of solute particles in solution**



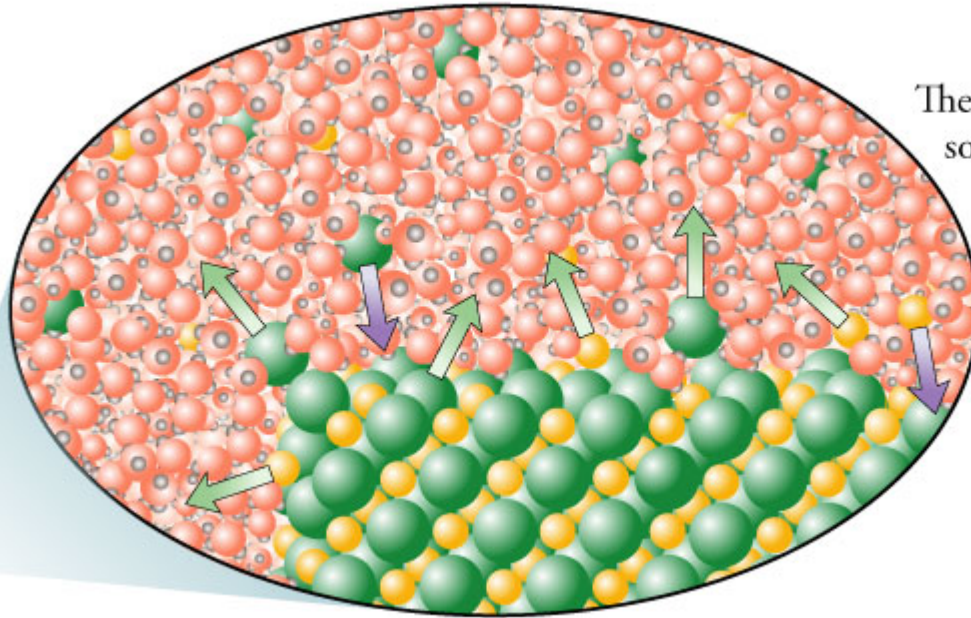
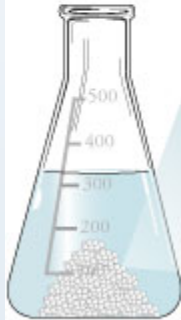
More collisions per second between solute and solid



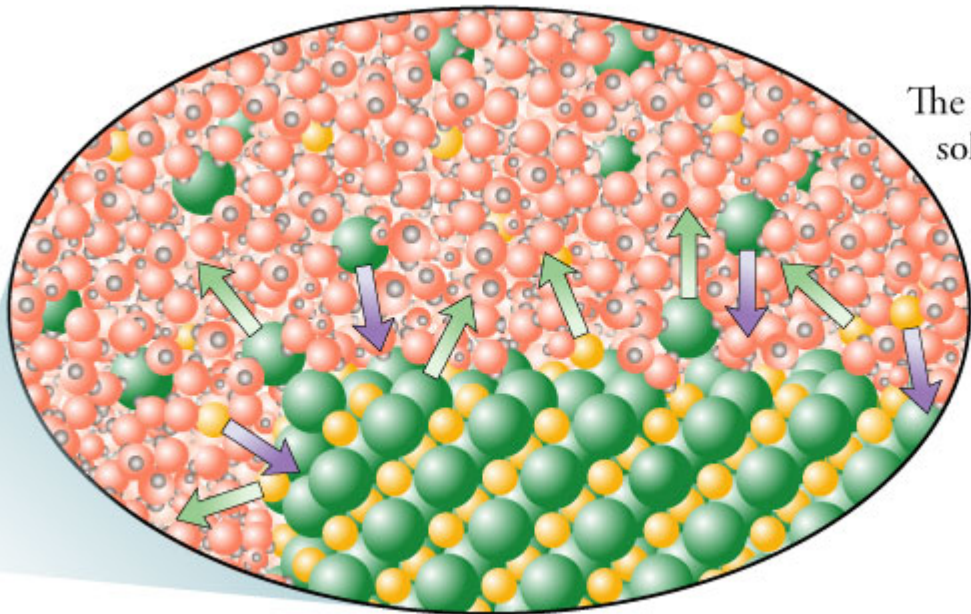
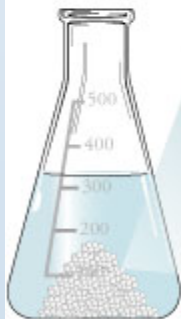
**Increased rate of return to the solid**



# Concentration and Rate of Return



The concentration of solute in the solution is low, so the rate of return is low.

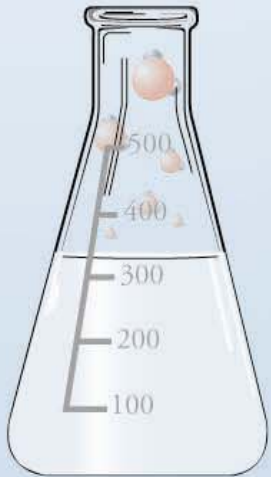


The concentration of solute in the solution is higher, so the rate of return is higher.

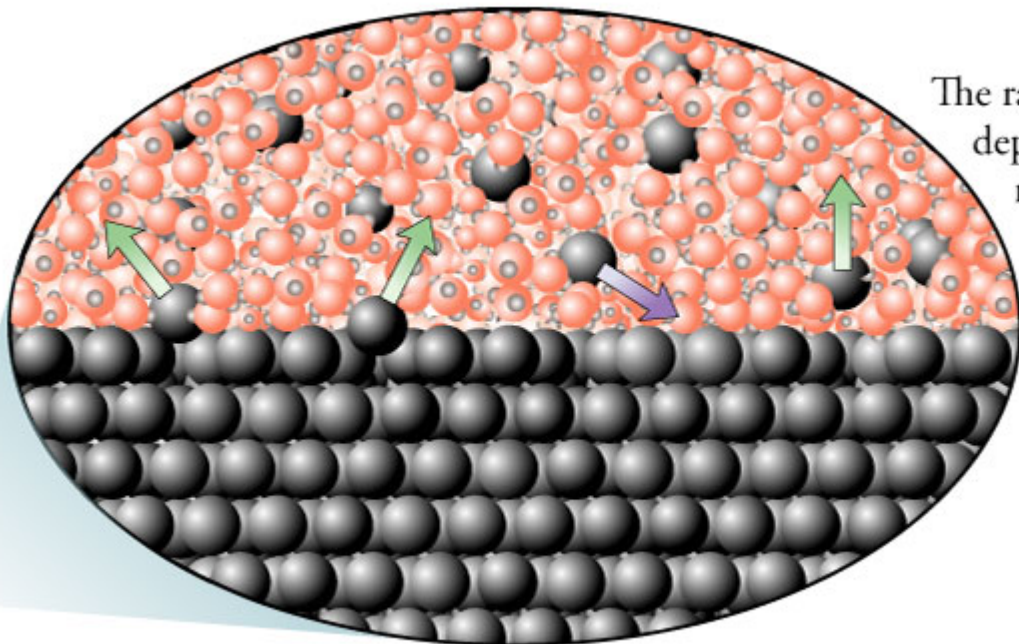
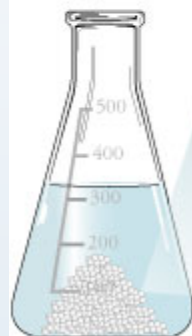
A vertical column of water molecules (red and black spheres) is positioned on the left side of the slide, extending from the top to the neck of the flask below. The molecules are arranged in a way that suggests they are being drawn into the flask.

# Rate of Solution Dependent on:

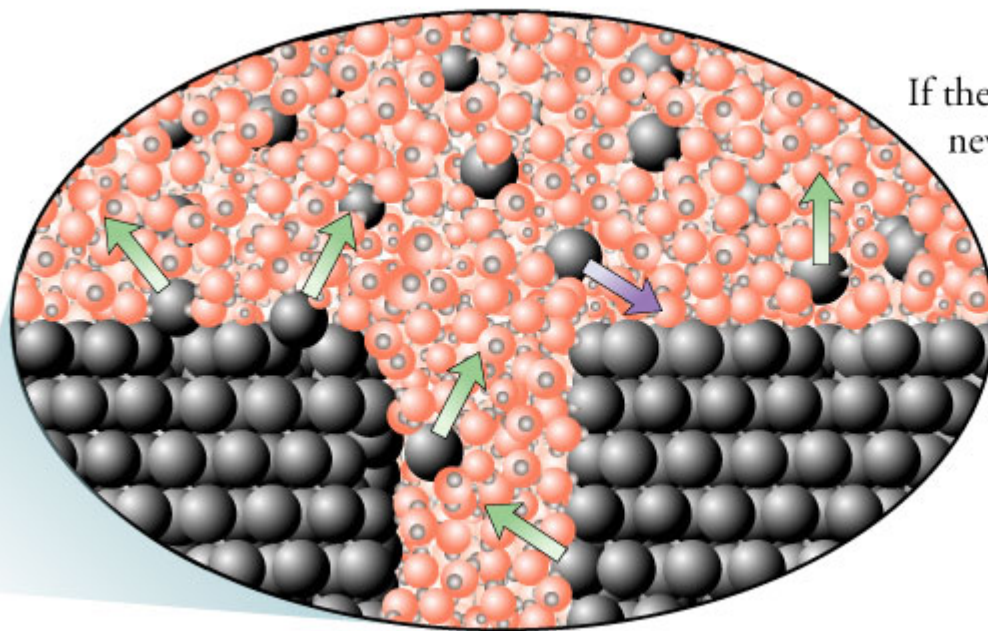
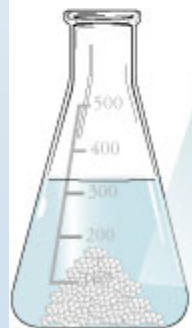
- Surface area of the solute
- Degree of agitation or stirring
- Temperature







The rate of solution depends on the number of particles at the solid's surface.



If the solid is fragmented, new surfaces are exposed, allowing more particles to escape into solution.

# Agitation and Rate of Solution

Increased agitation



Decreased concentration of dissolved solute particles near the solid



Decreased rate of return to the solid



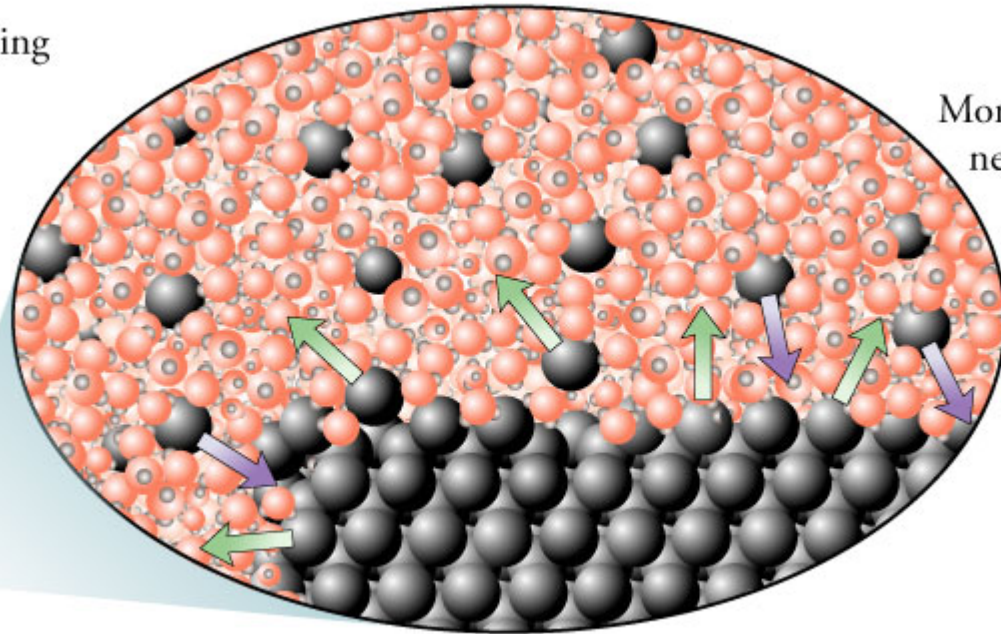
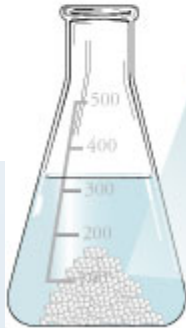
Increased difference between the rate of solution and the rate of return



Increased net rate of solution

# Agitation and Rate of Solution

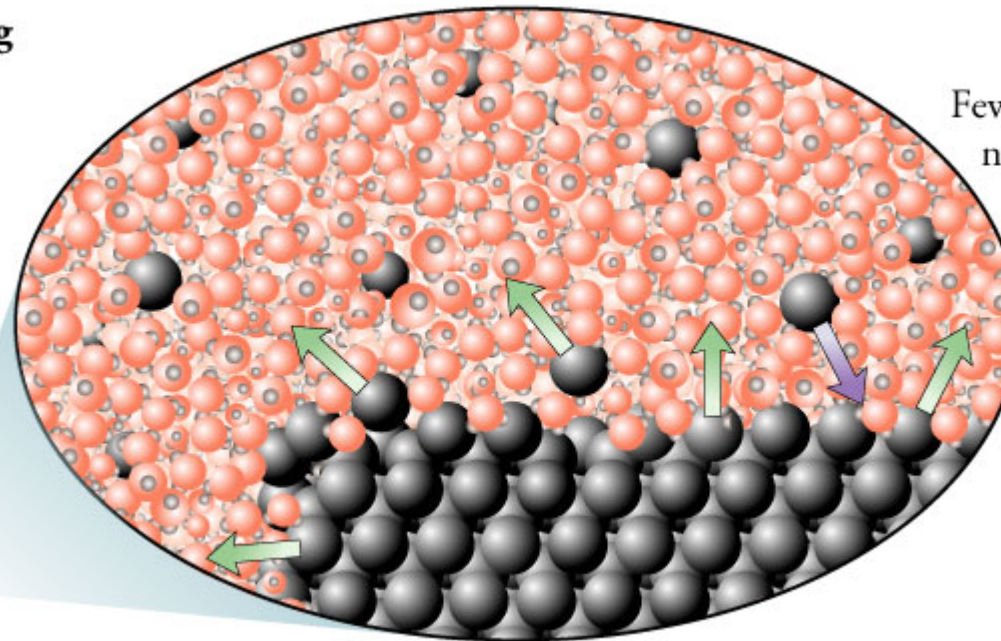
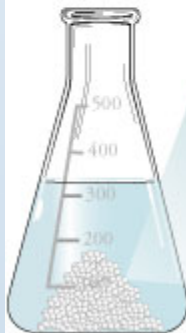
Without stirring



More particles near the solid leads to a higher rate of return.

**Lower net rate of solution**

With stirring

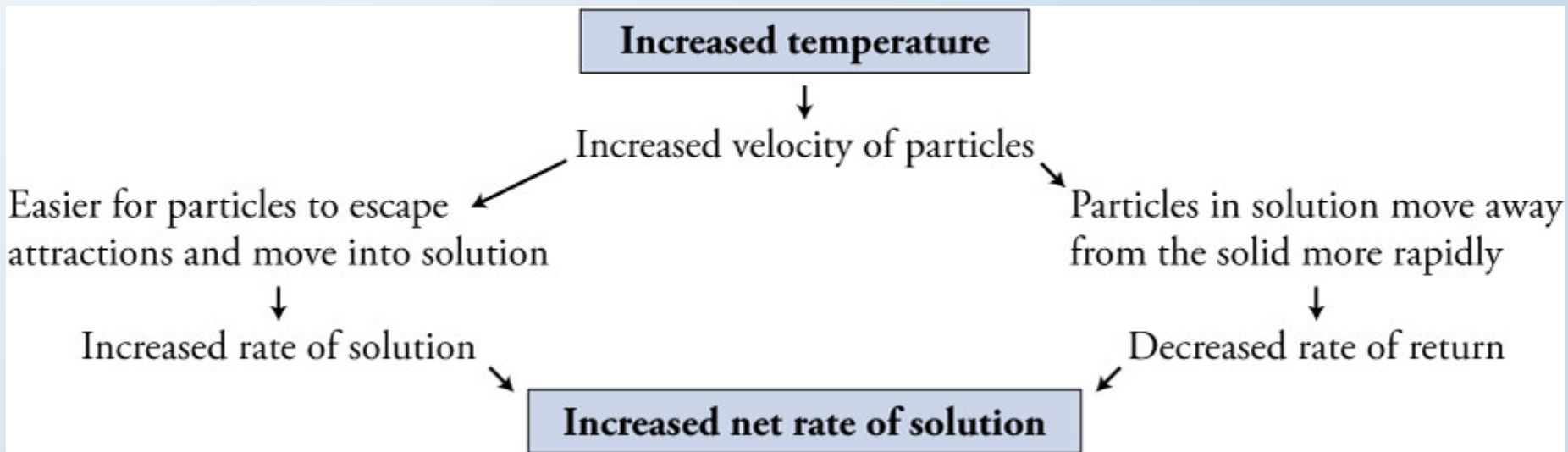


Fewer particles near the solid leads to a lower rate of return.

**Higher net rate of solution**



# Temperature and Rate of Solution



# Dynamic Equilibrium and Saturated Solutions

**Addition of a large amount of solid to a liquid**

Initially, rate of solution is greater than the rate of return

Net increase in number and concentration of particles in solution

Increased rate of collision between dissolved particles and solid

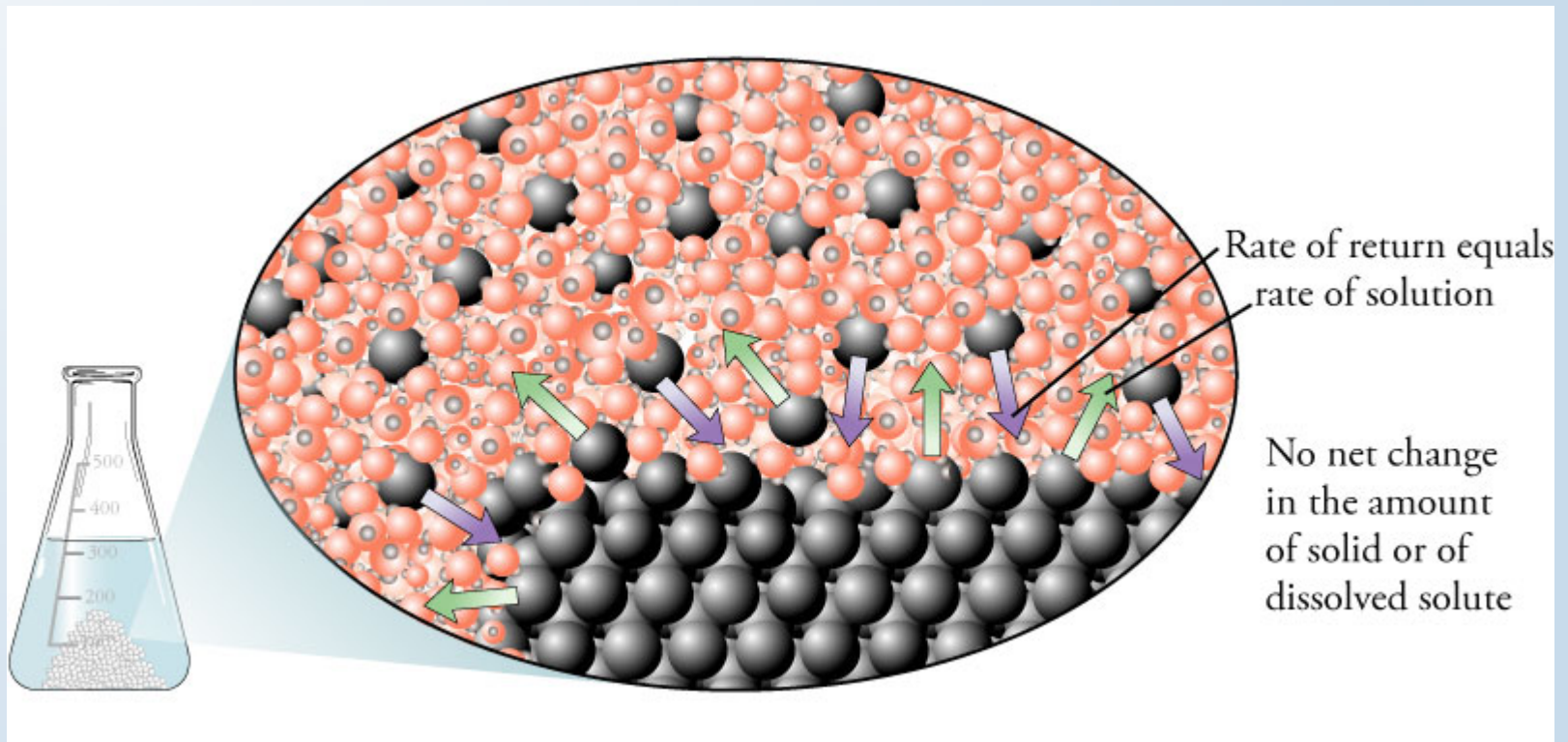
Increased rate of return...

...Until rate of return equals rate of solution

Constant changes from solid to dissolved solute and back,  
but no net change in amounts of solid and dissolved solute

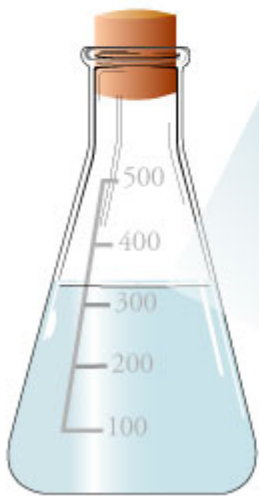
**Saturated solution due to dynamic equilibrium**

# Dynamic Equilibrium in a Saturated Solution



# Dynamic Equilibrium for Gas Dissolved in Liquid

The solubility limit is reached when the rate of solution equals the rate of escape.



For every gas particle that escapes from the liquid, another gas particle collides with the surface and goes into solution.



# Gas Solubility

**Add a gas above a liquid in a closed container**

Initially, the rate of solution is greater than the rate of escape → Net shift of particles into solution  
↓  
Increased rate of escape... ← Increased concentration of dissolved gas  
↓  
...Until the rate of escape equals rate of solution → Constant changes between dissolved and undissolved gas, but no net change in amount of either  
↙  
**Dynamic equilibrium (solubility limit)**

# Partial Pressure and Gas Solubility

**Increased partial pressure of a gas over a liquid in a system initially at dynamic equilibrium (Rate of solution = Rate of escape)**

