Why particles spread out (disperse)

- Structure of liquid water (Section 7.2)
- Solute, solvent, and solution (Section 7.2)
- Why ethanol and water mix

Hydrophobic and hydrophilic substances and groups

- Structure of triglycerides
- Making soap from triglycerides

- Why soaps and detergents work

Types of compounds, types of attractions and particles (Section 12.2)

Describe hydrogen bonds (Section 12.3)
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.

<table>
<thead>
<tr>
<th>State A</th>
<th>State B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less probable</td>
<td>More probable</td>
</tr>
<tr>
<td>Fewer ways to arrange particles and energy</td>
<td>More ways to arrange particles and energy</td>
</tr>
<tr>
<td>Less dispersed (spread out)</td>
<td>More dispersed (spread out)</td>
</tr>
</tbody>
</table>
9-Point Universe

<table>
<thead>
<tr>
<th>Solid-like states</th>
<th>4 possible arrangements of the red particles produce a less dispersed, solid-like state.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas-like states</td>
<td>122 possible arrangements produce a more dispersed, gas-like state.</td>
</tr>
</tbody>
</table>
• 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.
• 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.
Solids shift spontaneously to gases.

- Why does dry ice, CO$_2$(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 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

$\text{CO}_2(s) \rightarrow \text{CO}_2(g)$

Less dispersed $\rightarrow$ More dispersed
Fewer ways to arrange particles $\rightarrow$ More ways to arrange particles
Less probable $\rightarrow$ More probable
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 $\rightarrow$ Gas in both chambers

Fewer ways to arrange particles $\rightarrow$ More ways to arrange particles

Less probable $\rightarrow$ More probable

Less dispersed $\rightarrow$ 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

Diagram showing the breaking and formation of hydrogen bonds.
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**.
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.
“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 nonpolar solvents.
  - For example, ionic compounds are insoluble in hexane.
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
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

Nonpolar

CH$_3$NH

Slightly polar

methamphetamine

Nonpolar

CH$_2$NH$_2$$^+$ Cl$^-$

Very polar

methamphetamine hydrochloride
Triglycerides
(Fats and Oils)

\[
\begin{align*}
\text{H} & \quad \text{O} \\
\text{H-C-O-C-R}_1 & \\
\text{H-C-O-C-R}_2 & \quad \text{Hydrocarbon groups} \\
\text{H-C-O-C-R}_3 & \\
\text{H} & \quad \text{triglyceride}
\end{align*}
\]
Tristearin – Line Drawing
Typical Liquid Triglyceride
Making Soap

Triglyceride in fat or oil

\[ \text{3NaOH} \]

\[ \text{glycerol} \]

\[ \text{soap} \]
Cleaning Greasy Dishes

Oil

Agitation

Oil breaks into droplets.

Without soap or detergent, droplets recombine.

Soap or detergent anions keep droplets suspended.
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.

Coated with negative charges, droplets repel each other.
Chapter 13 – part 2

Ionic compound dissolving in water (Section 7.2)

- Effect of surface area
- Effect of agitation
- Effect of changing temperature

Rate of solution of a solid in a liquid

Dynamic equilibrium in a saturated solution

Rate of return from solution to solid

Dynamic equilibrium (Section 12.1)

- Rate of solution of a gas in a liquid
- Rate of escape from solution to gas

Effect of gas pressure on solubility

- Gas pressure and breathing
- Gas solubility and scuba diving
- Gas solubility and soft drinks

Effect of changing concentration
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.
Rate of Solution
Dependent on:

• Surface area of the solute
• Degree of agitation or stirring
• Temperature
Surface Area and Rate of Solution

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

\[ \downarrow \]

Decreased concentration of dissolved solute particles near the solid

\[ \downarrow \]

Decreased rate of return to the solid

\[ \downarrow \]

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

\[ \downarrow \]

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

- Increased temperature
  - Increased velocity of particles
    - Easier for particles to escape attractions and move into solution
    - Increased rate of solution
      - Increased net rate of solution
    - Particles in solution move away from the solid more rapidly
      - Decreased rate of return
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

Rate of return equals rate of solution

No net change in the amount of solid or of dissolved solute
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 $\rightarrow$ Net shift of particles into solution

$\downarrow$

Increased rate of escape...

$\downarrow$

Increased concentration of dissolved gas

$\downarrow$

...Until the rate of escape equals rate of solution $\rightarrow$ 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)

Increased rate of collision between gas particles and liquid $\rightarrow$ Increased rate of solution

Net movement of gas particles into solution $\leftarrow$ Rate of solution greater than rate of escape

Increased concentration of solute in solution $\rightarrow$ Increased rate of escape until it equals the higher rate of solution

Greater solubility