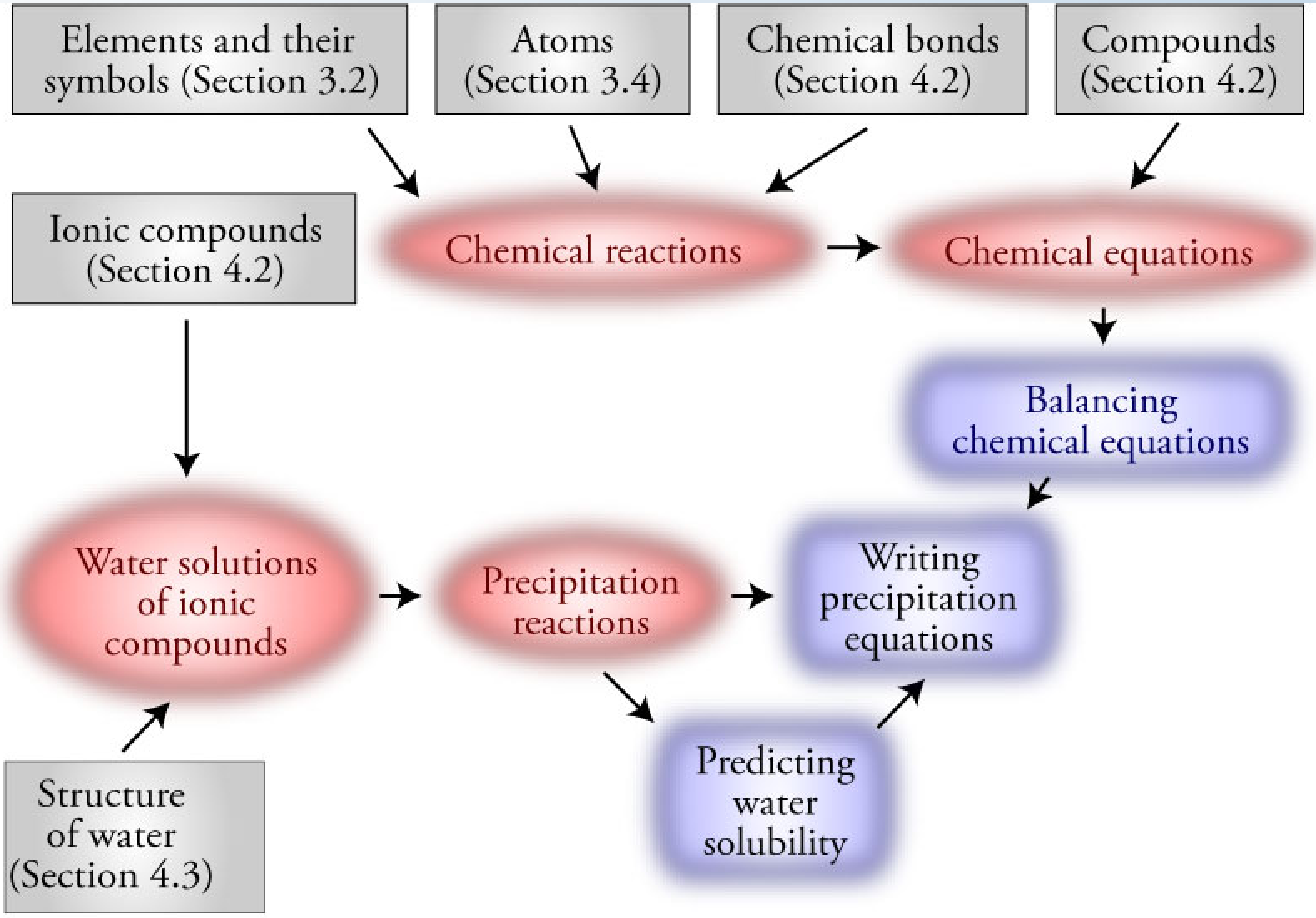
Chapter 5

An Introduction to Chemical Reactions

Chapter Map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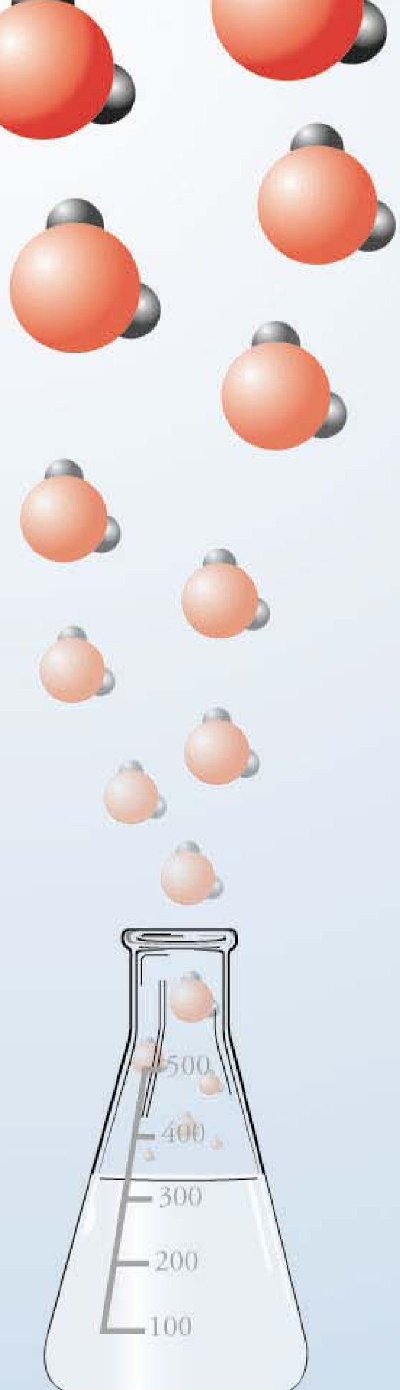
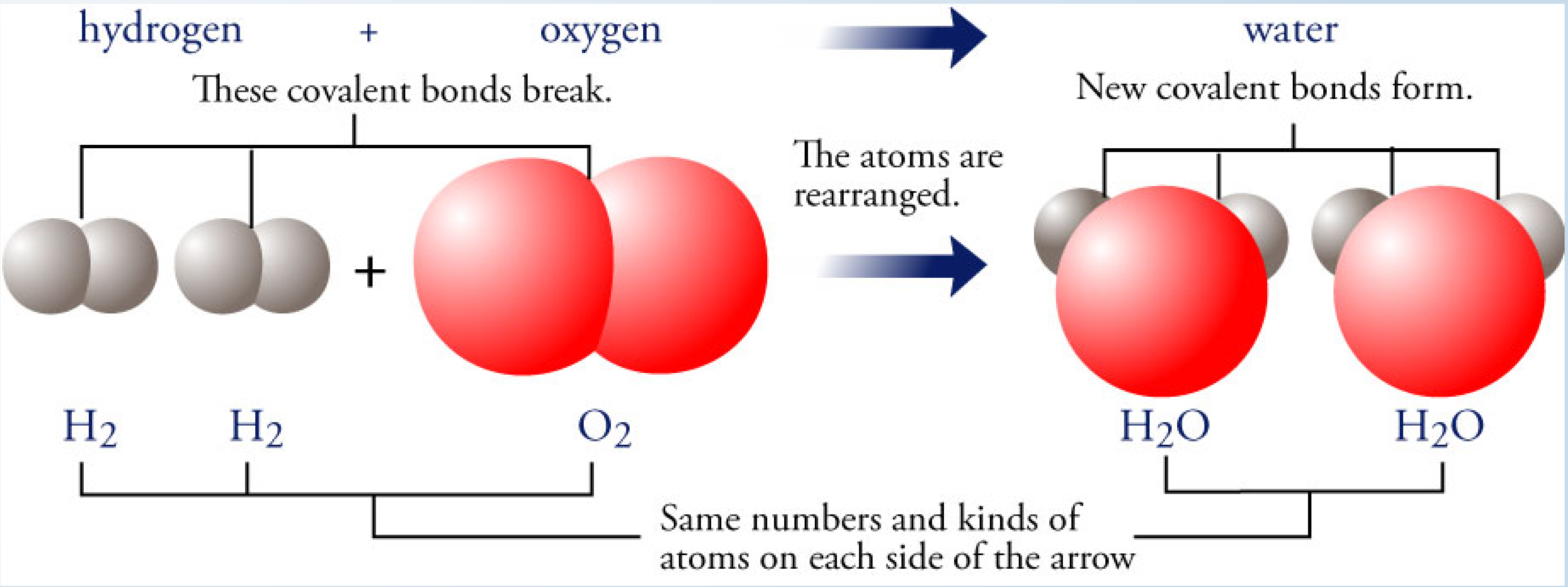
Chemical Reaction



- A ***chemical change*** or ***chemical reaction*** is a process in which one or more pure substances are converted into one or more different pure substances.

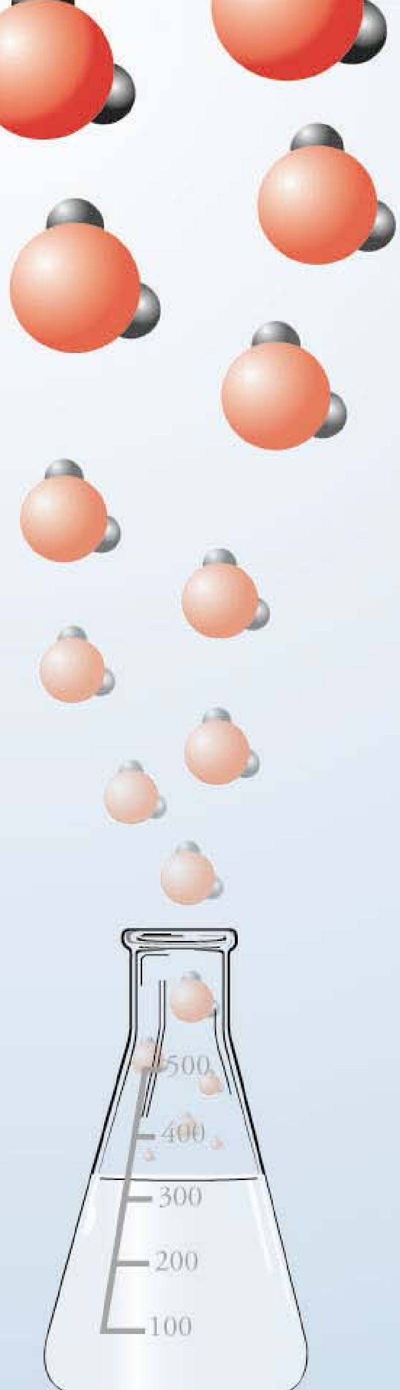
Chemical Reactions - Example



Chemical Equations (1)

- Chemical equations show the formulas for the substances that take part in the reaction.
  - The formulas on the left side of the arrow represent the ***reactants***, the substances that change in the reaction. The formulas on the right side of the arrow represent the ***products***, the substances that are formed in the reaction. If there are more than one reactant or more than one product, they are separated by plus signs. The arrow separating the reactants from the products can be read as *“goes to”* or *“yields” or “produces.”*

Chemical Equations (2)



- The physical states of the reactants and products are provided in the equation.
  - A *(g)* following a formula tells us the substance is a gas. Solids are described with *(s)*. Liquids are described with *(l)*. When a substance is dissolved in water, it is described with *(aq)* for “aqueous,” which means “mixed with water.”

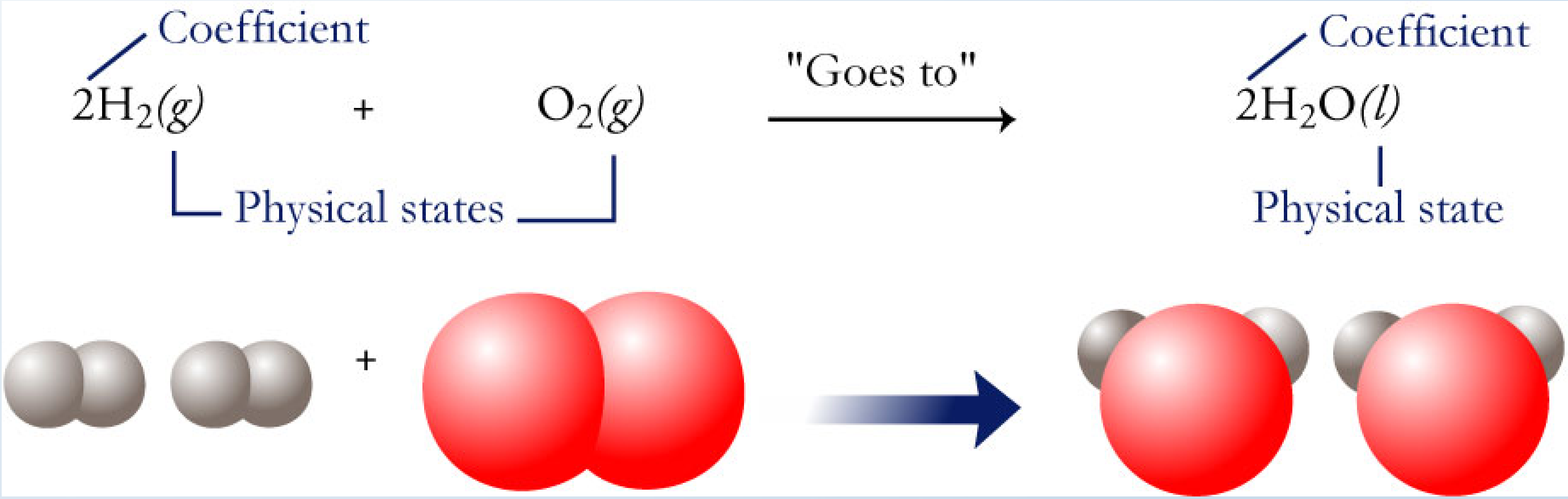
Chemical Equations (3)

- The relative numbers of particles of each reactant and product are indicated by numbers placed in front of the formulas.
  - These numbers are called ***coefficients***. An equation containing correct coefficients is called a balanced equation.
  - If a formula in a balanced equation has no stated coefficient, its coefficient is understood to be 1.

Chemical Equations (4)

- If special conditions are necessary for a reaction to take place, they are often specified above the arrow.
  - Some examples of special conditions are electric current, high temperature, high pressure, or light.

Chemical Equation Example



Special Conditions

A special condition

$$2H_2O(l) \xrightarrow{\text{Electric current}} 2H_2(g) + O_2(g)$$

This indicates the continuous addition of heat.

$$2KClO_3(s) \xrightarrow{\Delta} 2KCl(s) + 3O_2(g)$$

Balancing Chemical Equations

- Consider the first element listed in the first formula in the equation.
  - If this element is mentioned in two or more formulas on the same side of the arrow, skip it until after the other elements are balanced.
  - If this element is mentioned in one formula on each side of the arrow, balance it by placing coefficients in front of one or both of these formulas.
- Moving from left to right, repeat the process for each element.
- When you place a number in front of a formula that contains an element you tried to balance previously, recheck that element and put its atoms back in balance.

Balancing Equations – Strategies (1)

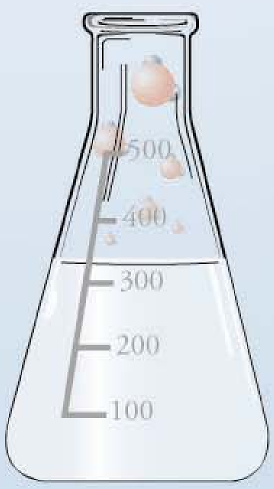
- **Strategy 1:** Often, an element can be balanced by using the subscript for this element on the left side of the arrow as the coefficient in front of the formula containing this element on the right side of the arrow and vice versa (using the subscript of this element on the right side of the arrow as the coefficient in front of the formula containing this element on the left side).

Balancing Equations – Strategies (2)

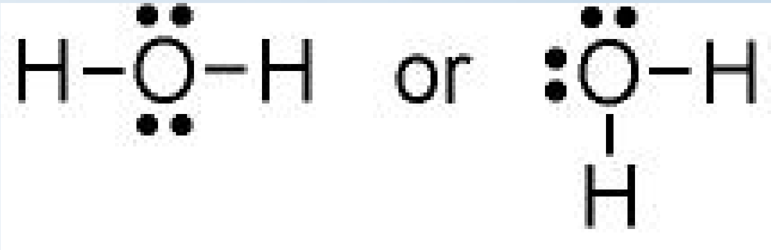
- **Strategy 2:** The pure nonmetallic elements (H_2, O_2, N_2, F_2, Cl_2, Br_2, I_2, S_8, Se_8, and P_4) can be temporarily balanced with a fractional coefficient (1/2, 3/2, 5/2, etc.). If you do use a fraction during the balancing process, you can eliminate it later by multiplying each coefficient in the equation by the fraction’s denominator.

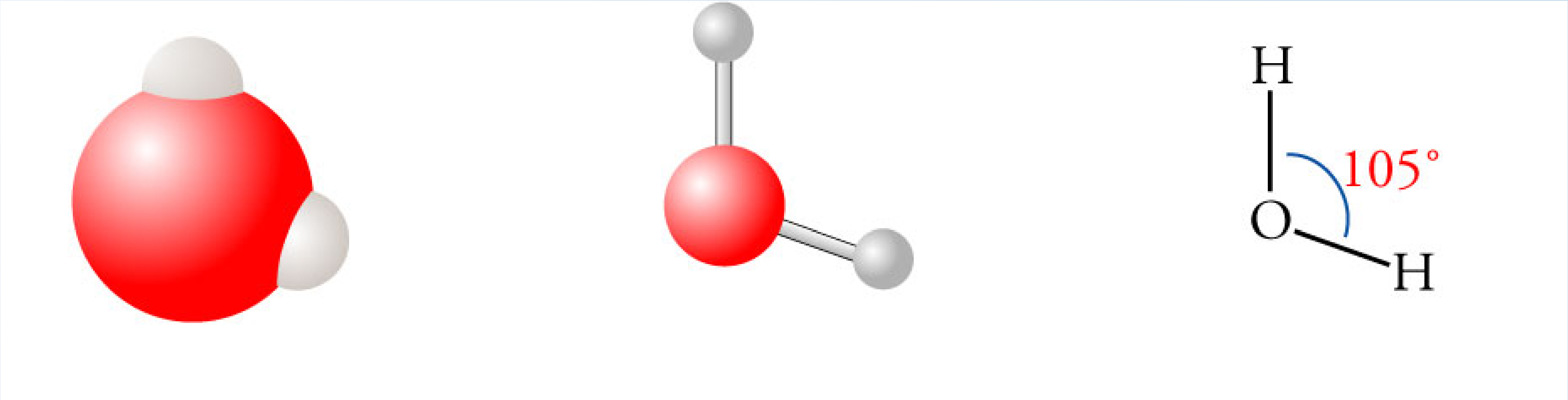
Balancing Equations – Strategies (3)

- **Strategy 3:** If polyatomic ions do not change in the reaction, and therefore appear in the same form on both sides of the chemical equation, they can be balanced as if they were single atoms.
- **Strategy 4:** If you find an element difficult to balance, leave it for later.



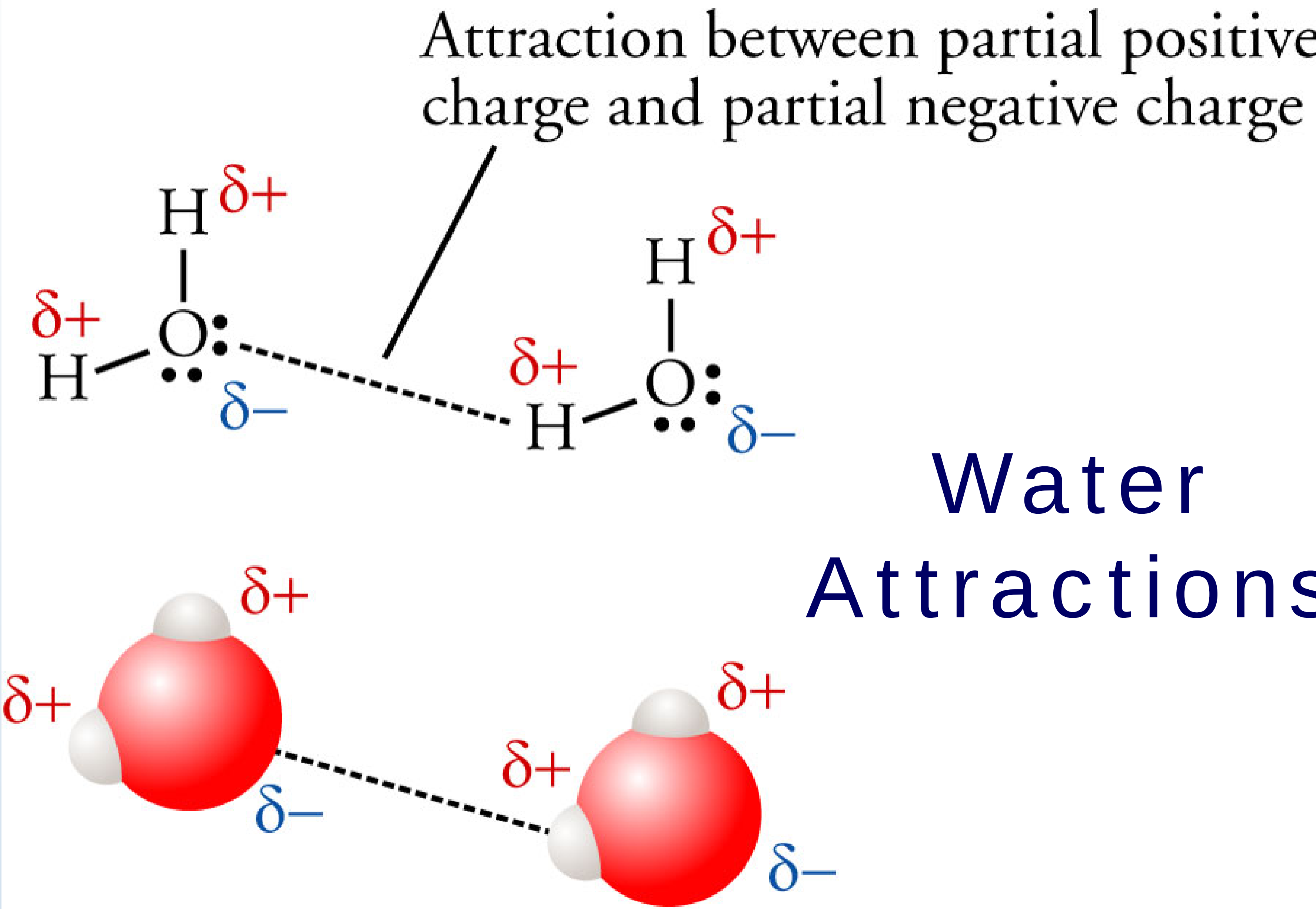
Water, H_2O



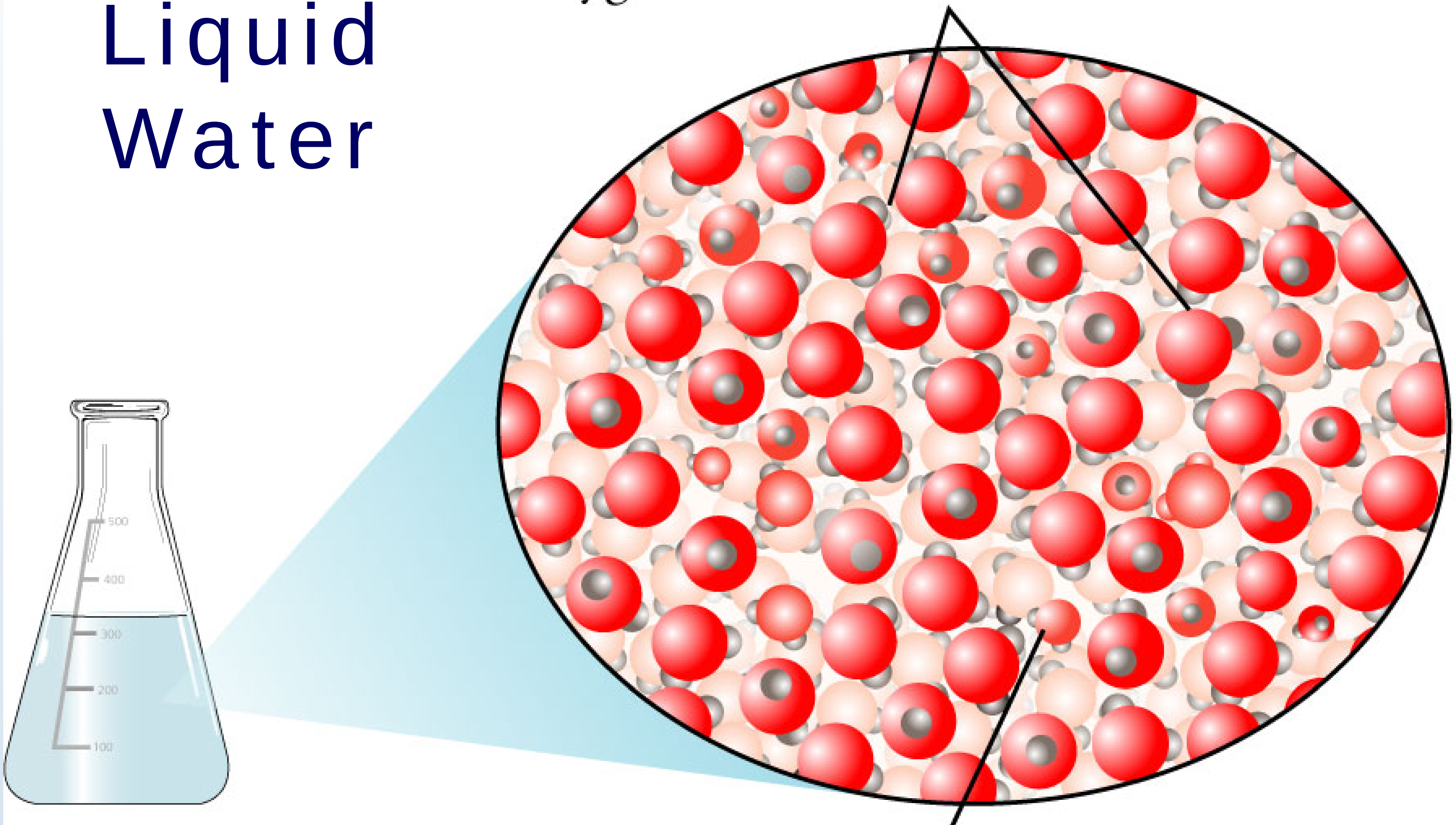


Space-filling model Ball-and-stick model Geometric Sketch

Water Attractions

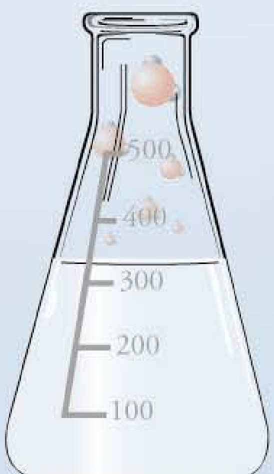


Liquid Water

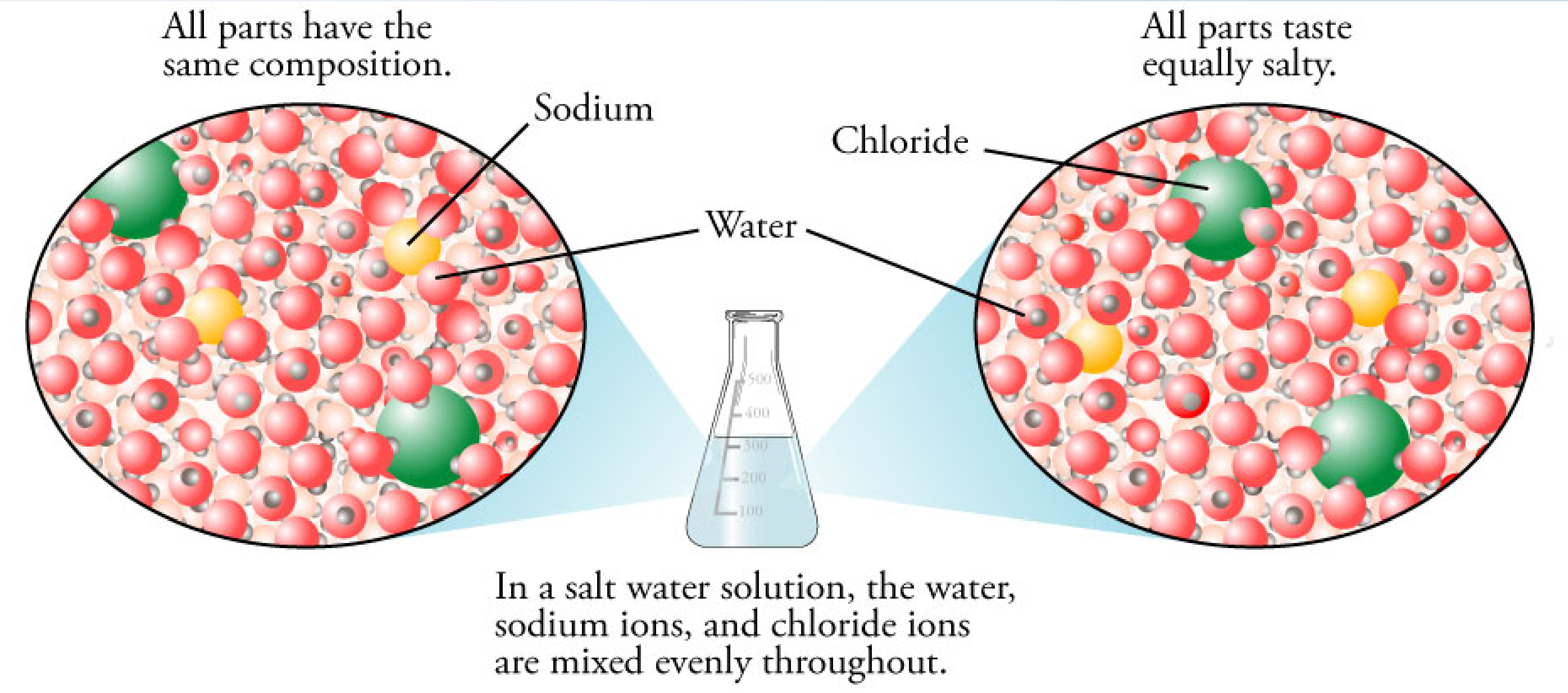


Solutions

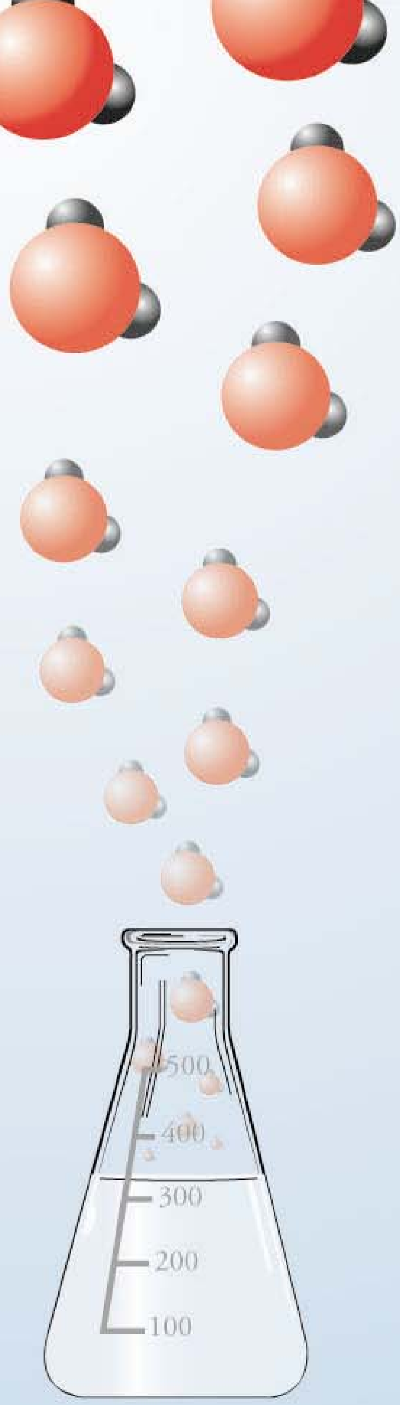
- A ***solution***, also called a homogeneous mixture, is a mixture whose particles are so evenly distributed that the relative concentrations of the components are the same throughout.
- Water solutions are called ***aqueous solutions***.



Solution (Homogeneous Mixture)

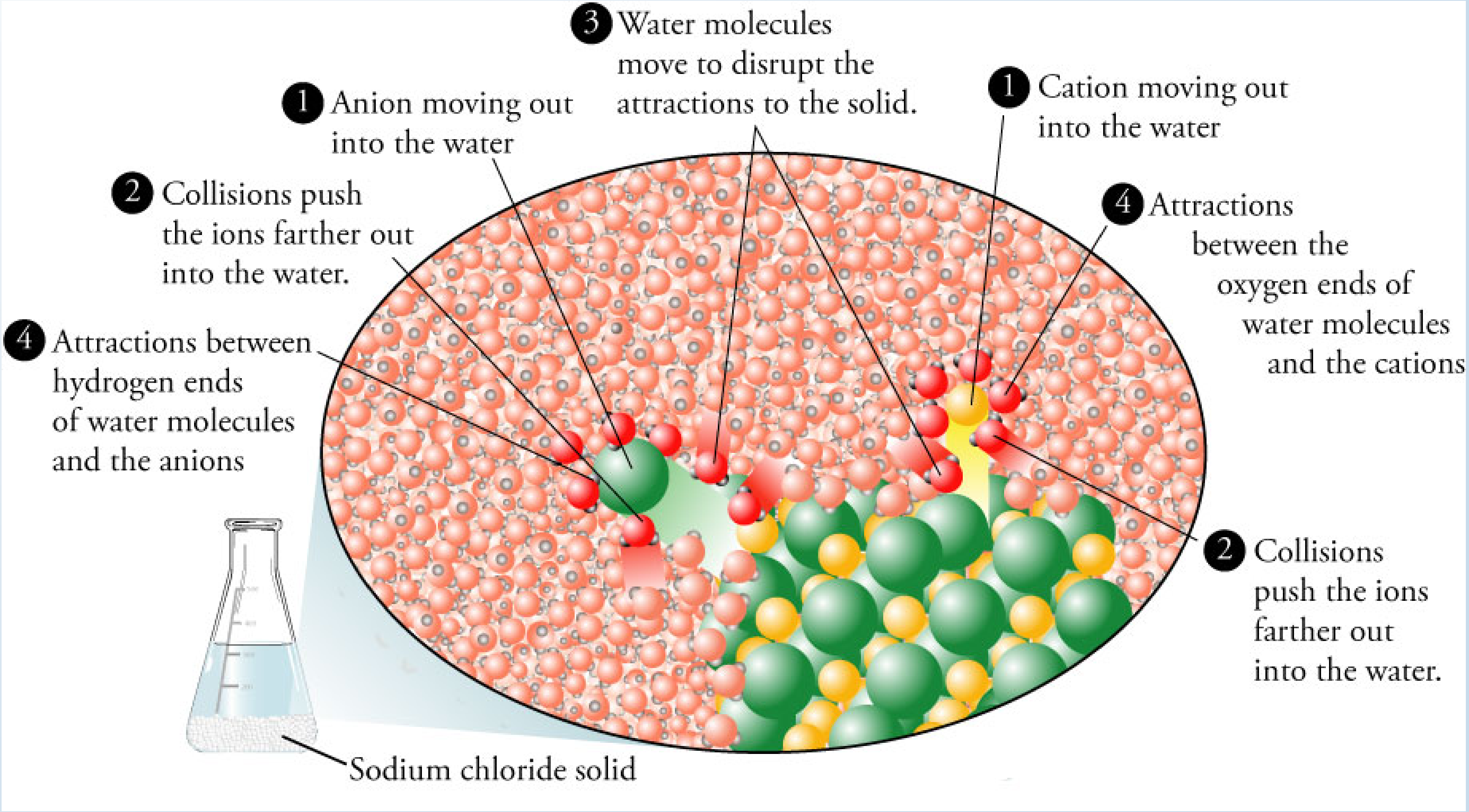


Solute and Solvent

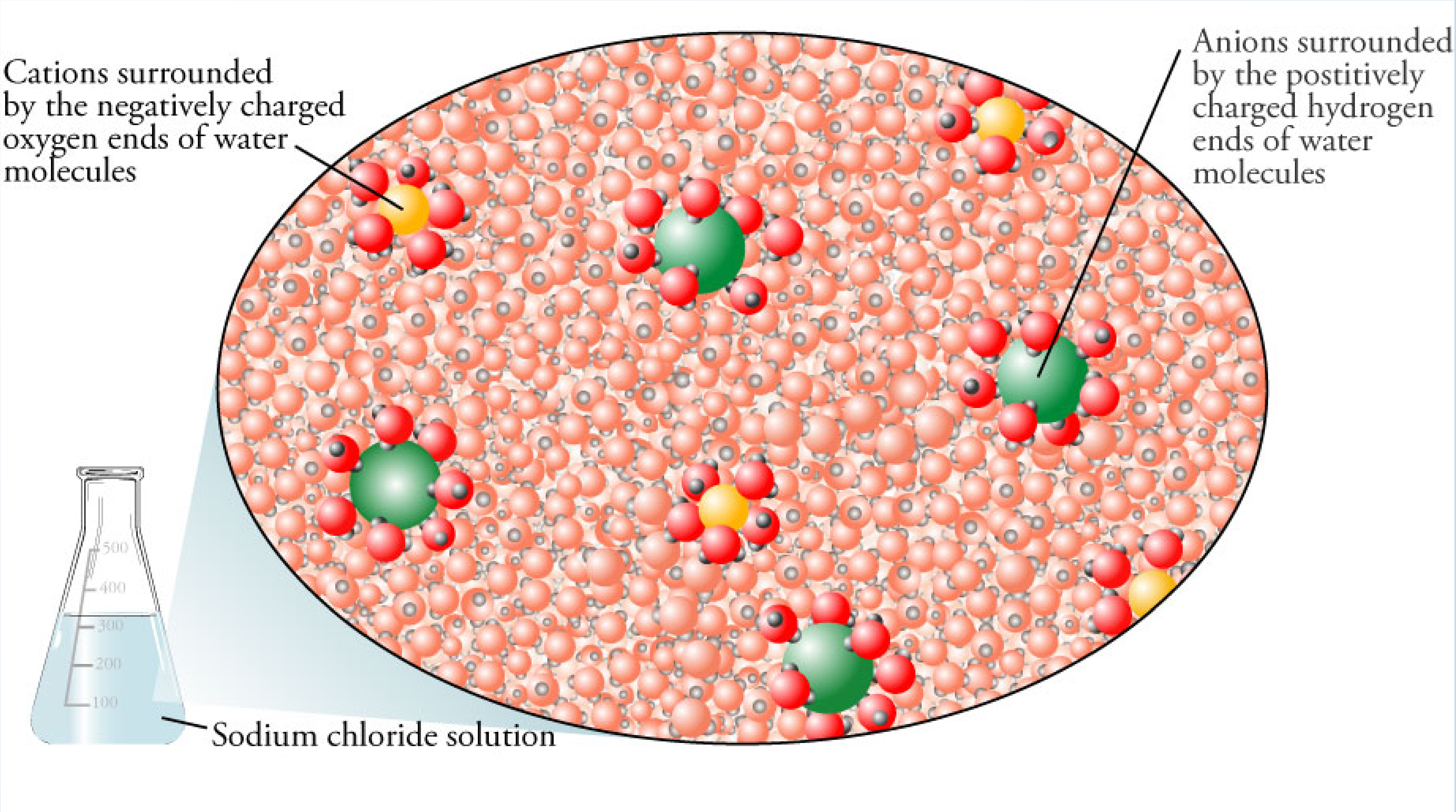


- In solutions of solids dissolved in liquids, we call the solid the ***solute*** and the liquid the ***solvent***.
- In solutions of gases in liquids, we call the gas the ***solute*** and the liquid the ***solvent***.
- In other solutions, we call the minor component the ***solute*** and the major component the ***solvent***.

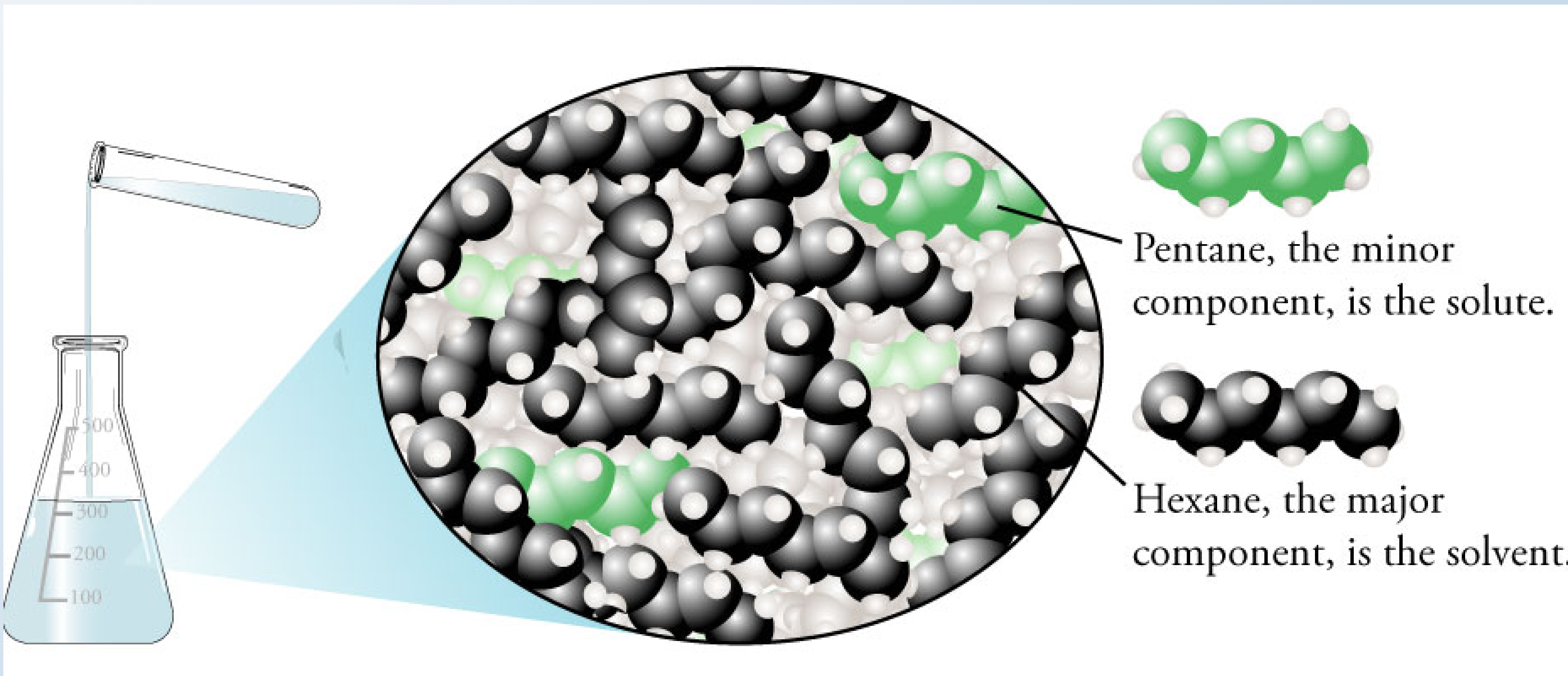
Solution of an Ionic Compound

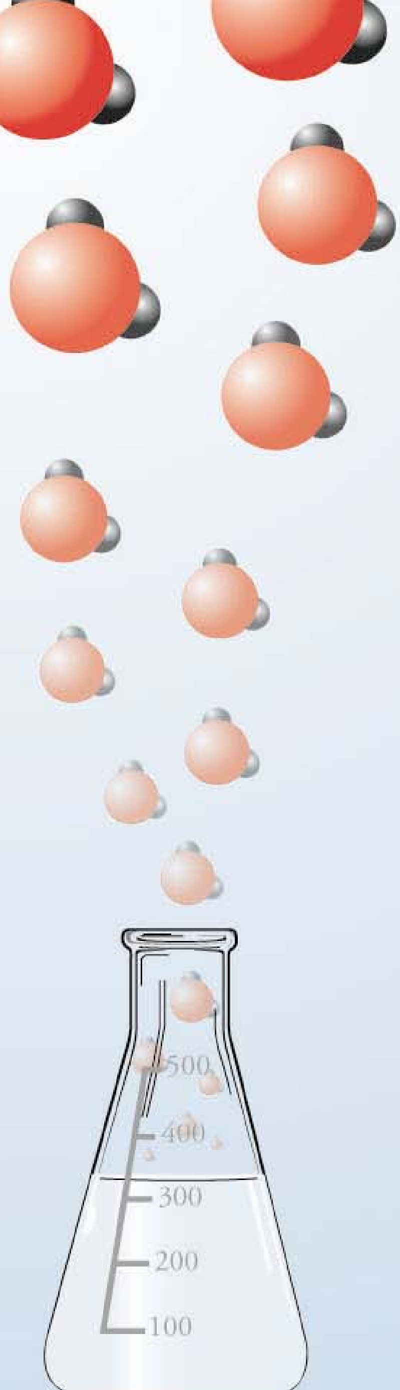


Solution of an Ionic Compound (cont.)



Liquid-Liquid Solution

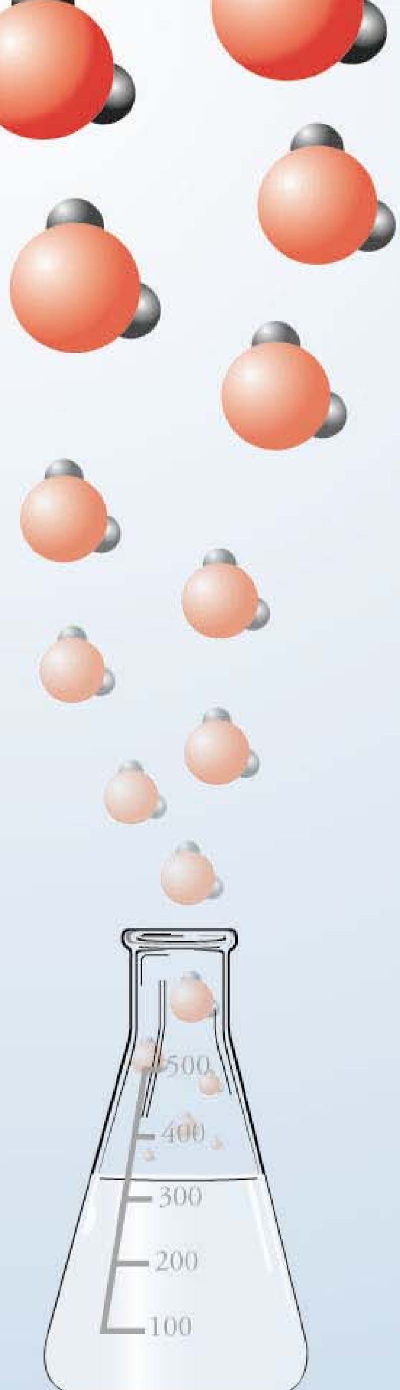




Precipitation Reactions

- In a ***precipitation reaction***, one product is insoluble in water.
- As that product forms, it emerges, or ***precipitates***, from the solution as a solid.
- The solid is called a ***precipitate***.
- For example,

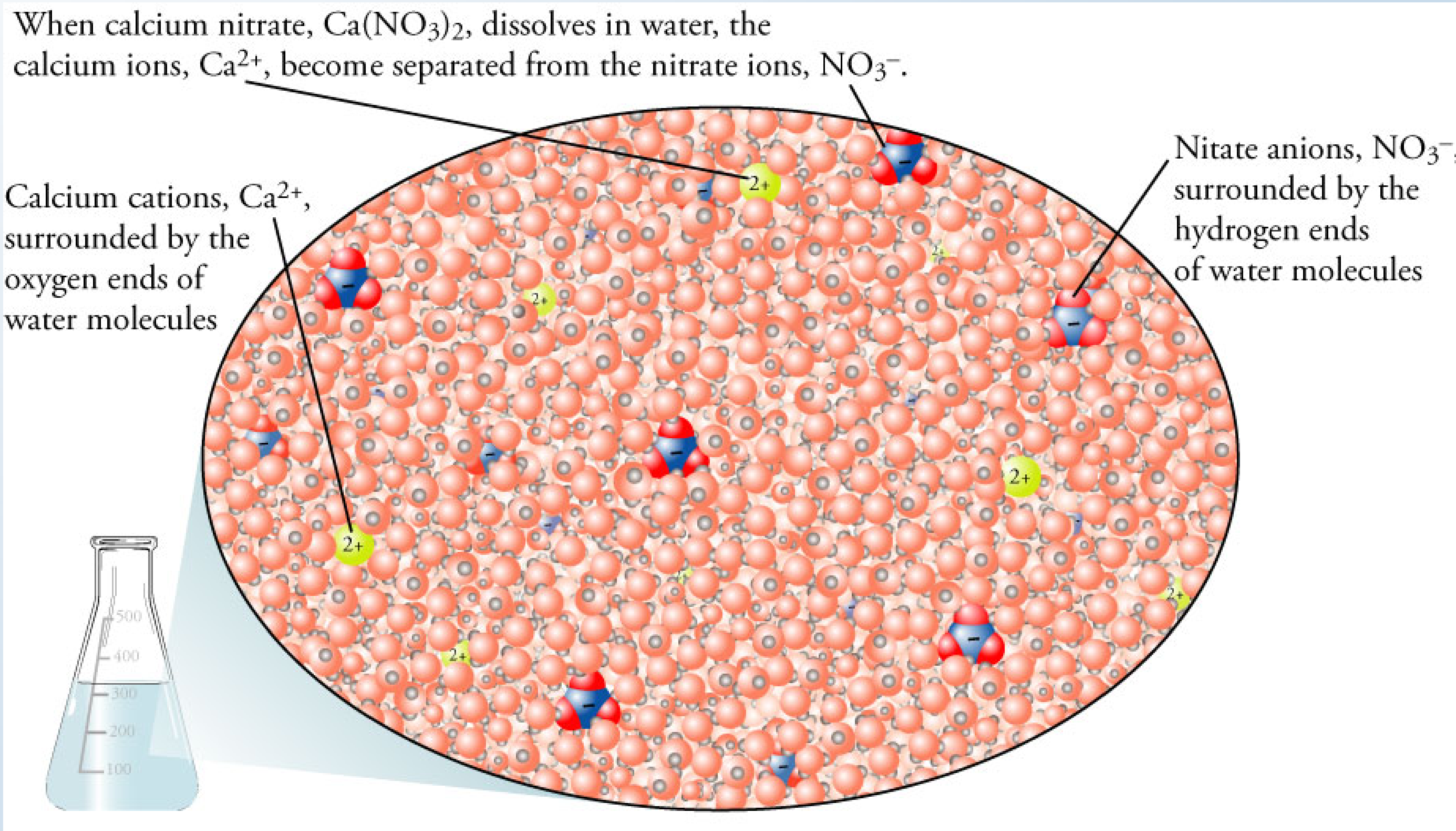
$$Ca(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaNO_3(aq)$$



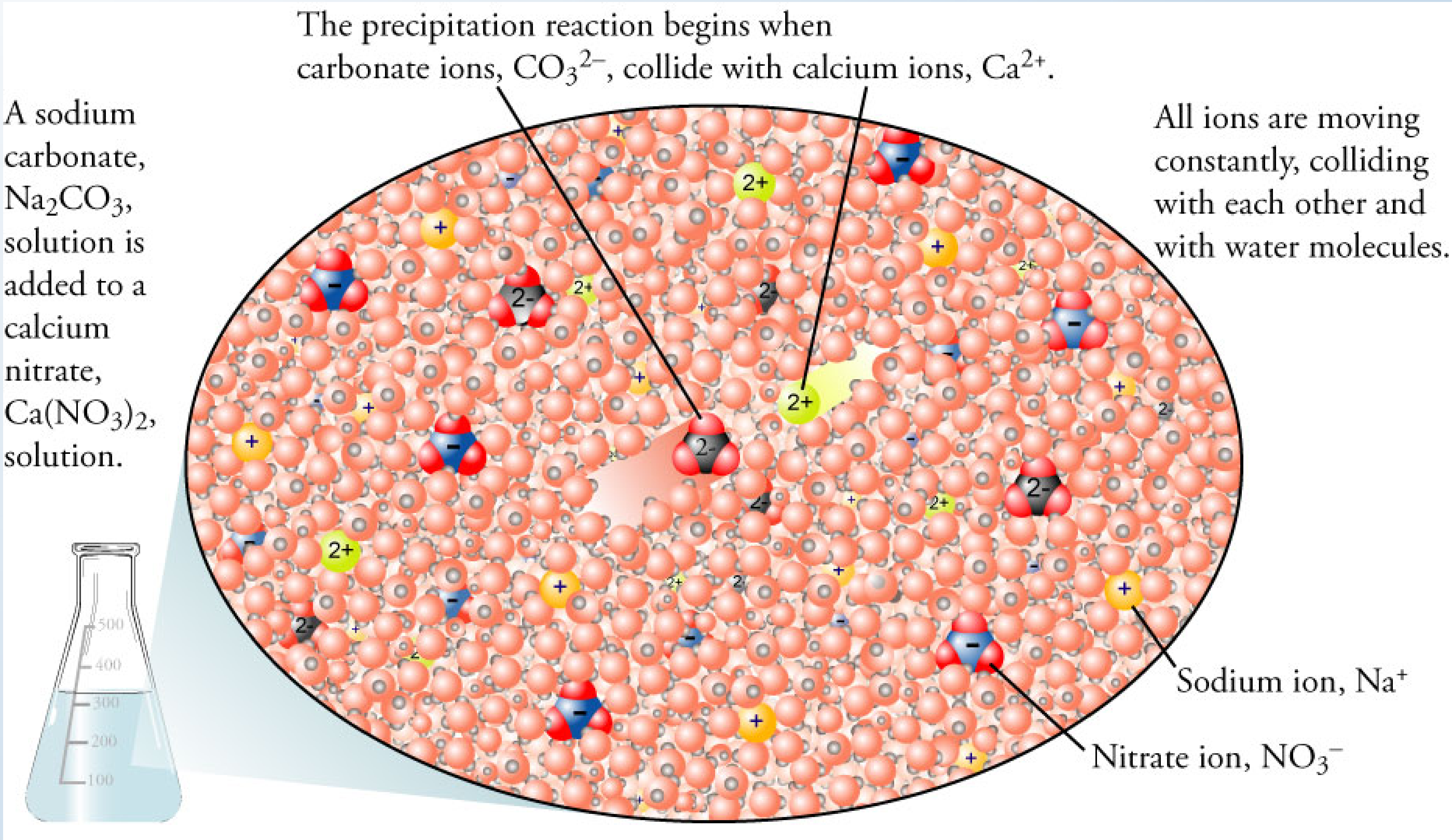
Precipitation Questions

- Describe the solution formed at the instant water solutions of two ionic compounds are mixed (before the reaction takes place).
- Describe the reaction that takes place in this mixture.
- Describe the final mixture.
- Write the complete equation for the reaction.

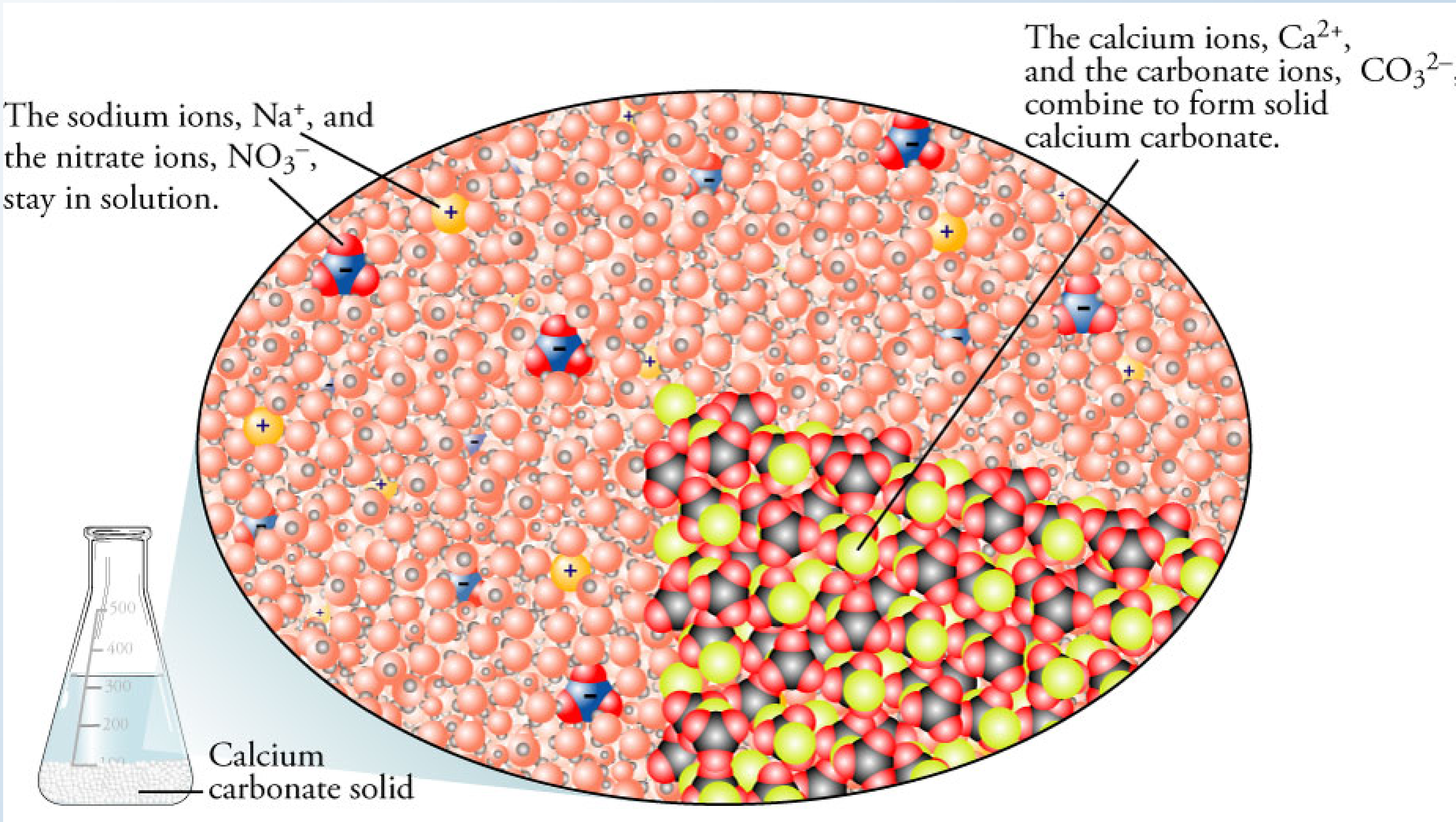
Solution of $Ca(NO_3)_2$



Solution of $Ca(NO_3)_2$ and Na_2CO_3 at the time of mixing, before the reaction



Product Mixture for the reaction of $Ca(NO_3)_2$ and Na_2CO_3



Complete Ionic Equation

This solid precipitates from the solution. It is a precipitate.

$$Ca(NO_3)_2\,(aq) + Na_2CO_3\,(aq) \longrightarrow CaCO_3(s) + 2NaNO_3\,(aq)$$

Described as separate ions.

$$Ca^{2+}(aq) + 2NO_3^-(aq) + 2Na^+(aq) + CO_3^{2-}(aq)$$

$$\longrightarrow CaCO_3(s) + 2Na^+(aq) + 2NO_3^-(aq)$$

Solid precipitate

Described as separate ions.

Spectator Ions

- Ions that are important for delivering other ions into solution but that are not actively involved in the reaction are called ***spectator ions***.
- Spectator ions can be recognized because they are separate and surrounded by water molecules both before and after the reaction.

Net Ionic Equations

- An equation written without spectator ions is called a *net ionic equation*.

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$$

Writing Precipitation Equations

- Step 1: Determine the formulas for the possible products using the general double-displacement equation.

$$AB + CD \rightarrow AD + CB$$

- Step 2: Predict whether either of the possible products is water insoluble. If either possible product is insoluble, a precipitation reaction takes place, and you may continue with step 3. If neither is insoluble, write “No reaction”.

Water Solubility

- Ionic compounds with the following ions are soluble.
  - NH_4^+, group 1 metal ions, NO_3^-, and $C_2H_3O_2^-$
- Ionic compounds with the following ions are usually soluble.
  - Cl^-, Br^-, I^- except with Ag^+ and Pb^{2+}
  - SO_4^{2-} except with Ba^{2+} and Pb^{2+}
- Ionic compounds with the following ions are insoluble.
  - CO_3^{2-}, PO_4^{3-}, and OH^- except with NH_4^+ and group 1 metal cations
  - S^{2-} except with NH_4^+ and group 1 and 2 metal cations

Writing Precipitation Equations (cont)

- Step 3: Follow these steps to write the complete equation.
  - Write the formulas for the reactants separated by a "+".
  - Separate the formulas for the reactants and products with a single arrow.
  - Write the formulas for the products separated by a "+".
  - Write the physical state for each formula.
    - The insoluble product will be followed by *(s)*.
    - Water-soluble ionic compounds will be followed by *(aq)*.
  - Balance the equation.

Skills to Master (1)

- Convert between names and symbols for the common elements.
- Identify whether an element is a metal or a nonmetal.
- Determine the charges on many of the monatomic ions.
- Convert between the name and formula for polyatomic ions.

Skills to Master (2)

- Convert between the name and formula for ionic compounds.
- Balance chemical equations.
- Predict the products of double displacement reactions.
- Predict ionic solubility.