**4.1 Introduction for Reactions**
**4.4 Physical and Chemical Changes**

Essential knowledge statements from the AP Chemistry CED:

- A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.
- A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.
- Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.
- Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

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| Examples of Physical Changes | Examples of Chemical Changes |
|---|---|
| • a change of phase occurs when a pure substance is heated or cooled<br>• a change in particle size, texture, or shape occurs when the form of a substance changes, without changing its chemical composition<br>• a mixture is formed by combining two or more substances; no new substances are formed<br>• a mixture is separated into simpler substances based on a technique such as distillation, chromatography, or filtration; no new substances are formed | • a change in energy occurs, especially involving heat or light<br>• a new substance is formed with a different chemical composition than any of the original substances<br>• a solid precipitate is formed when aqueous solutions are combined<br>• a gas is formed that is not the result of a simple phase change for a pure substance<br>• an odor is produced, associated with the formation of a new gaseous substance<br>• a change in color occurs that is not the result of a physical change* |

*Note that a change in color is not necessarily an indicator of a chemical change. Mixing a sample of blue dye and yellow dye can produce a new green color. However, this is still classified as a physical change because it is simply the formation of a mixture. There is no change in the chemical composition of either dye. On the other hand, if an acid-base indicator changes color from yellow to blue, this event is likely the result of a change in the chemical structure of the indicator.

| What Happens at the Particle Level During a Physical Change? | What Happens at the Particle Level During a Chemical Change? |
|---|---|
| • attractive forces between molecules of a pure substance are broken or formed during a phase change<br>• attractive forces between particles of solute and solvent are broken or formed during the separation or the formation of a mixture | • chemical bonds are broken or formed during a process in which a new chemical substances with different chemical compositions are produced |

1. A pure sample of liquid water is added to a previously evacuated, rigid flask. The pressure inside the flask increases, eventually reaching a constant value of 20 torr after 30 seconds. The temperature inside the flask is kept at 300 K, and liquid water is observed to remain present at the bottom of the container. Which of the following best describes the change that occurs immediately after the sample of liquid water is added to the flask and gives a correct justification?

| | Type of Change | Justification |
|---|---|---|
| (A) | Physical | Covalent bonds are broken. |
| (B) | Physical | Intermolecular attractions are overcome. |
| (C) | Chemical | Covalent bonds are broken. |
| (D) | Chemical | Intermolecular attractions are overcome. |

$$2\ HI(g) \rightarrow H_2(g) + I_2(g)$$

2. Which of the following describes the change represented by the equation above and gives a correct justification?

| | Type of Change | Justification |
|---|---|---|
| (A) | Physical | A mixture of hydrogen and iodine is separated into simpler substances. |
| (B) | Physical | Covalent bonds are broken and new covalent bonds are formed |
| (C) | Chemical | A mixture of hydrogen and iodine is separated into simpler substances. |
| (D) | Chemical | Covalent bonds are broken and new covalent bonds are formed |

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

3. A student had two dilute, colorless solutions, HCl(*aq*) and NaOH(*aq*), which were at the same temperature. The student combined the solutions, and the process represented by the equation above occurred. Which of the following results would be evidence that a chemical reaction took place?

(A) The resulting solution is colorless.

(B) The temperature of the reaction mixture increases.

(C) The total volume of the mixture is approximately equal to the sum of the initial volumes.

(D) The resulting solution conducts electricity.

4. A student places a 5.00-gram sample of a dark grey solid into a crucible. The crucible and solid are heated strongly in air for several minutes. The student makes the claim that a chemical reaction has taken place between the dark grey solid and a substance present in the air. Which of the following observations is most likely to support the claim that a chemical reaction has occurred?

   (A) The final mass of the solid in the crucible is equal to 5.00 grams after heating.

   (B) The final mass of the solid in the crucible is equal to 8.00 grams after heating.

   (C) The solid present in the crucible after heating is dark grey in appearance.

   (D) The solid present in the crucible after heating is not soluble in water.

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**4.2 Net Ionic Equations**

Essential knowledge statements from the AP Chemistry CED:

- All physical and chemical processes can be represented symbolically by balanced equations.
- Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass is conserved in chemical reactions.
- Balanced molecular, complete ionic, and net ionic equations are differing symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.

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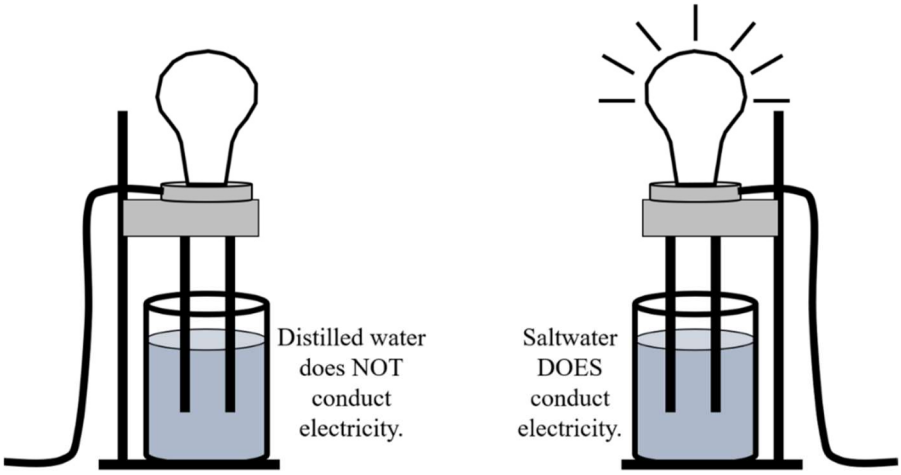
In order to master the skill of writing a net ionic equation, it is important to understand why substances behave as electrolytes or nonelectrolytes.




Distilled water, $H_2O$, is an example of a **nonelectrolyte**. It is a covalent molecular substance that consists of neutral molecules. The absence of charged particles explains why a sample of pure $H_2O$ does not conduct electricity.

Saltwater, NaCl(*aq*), is an example of an **electrolyte**. NaCl is an ionic substance. When NaCl dissolves in water, the $Na^+$ and $Cl^-$ ions break away from the solid crystal lattice. A solution of NaCl(*aq*) contains positive and negative ions that can move freely throughout the solution. The movement of ions allows electricity to flow through the solution.

5. A substance can conduct electricity when there are mobile charged particles. Explain each of the following observations related to conductivity. Each of your explanations should refer to the presence or absence of charged particles in the sample and whether or not the charged particles can move or flow freely.

   (a) A piece of solid silver metal, Ag(*s*), does conduct electricity.

   (b) A sample of solid crystals of sodium chloride, NaCl(*s*), does not conduct electricity.

   (c) A sample of molten (i.e., melted) sodium chloride, NaCl(*l*), does conduct electricity.

   (d) A sample of aqueous sucrose, $C_{12}H_{22}O_{11}(aq)$, does not conduct electricity.

   (e) A sample of aqueous methanol, $CH_3OH(aq)$, does not conduct electricity.

   (f) A sample of aqueous potassium hydroxide, KOH(*aq*), does conduct electricity.

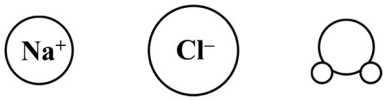
6. Each of the following solutes can be dissolved in water to form an aqueous solution. Write a balanced chemical equation that represents what happens to the solute particles when the solute is dissolved in water.

| Solute | Equation for the Dissolution of the Solute in Water |
|---|---|
| copper(II) chloride, $CuCl_2$ | |
| glucose, $C_6H_{12}O_6$ | |
| sodium sulfate, $Na_2SO_4$ | |
| ammonium nitrate, $NH_4NO_3$ | |
| ethanol, $CH_3CH_2OH$ | |
| barium hydroxide, $Ba(OH)_2$ | |

7. Students were asked to write an equation that represents what happens to the solute particles when solid calcium nitrate, $Ca(NO_3)_2$, is dissolved in water. Give a reason to explain why each of the following responses is incorrect.

| Student Response | Why is This Response Incorrect? |
|---|---|
| $Ca(NO_3)_2(s) \rightarrow Ca(NO_3)_2(aq)$ | |
| $Ca(NO_3)_2(s) \rightarrow Ca(aq) + N_2(aq) + 3\ O_2(aq)$ | |
| $Ca(NO_3)_2(s) \rightarrow Ca(aq) + 2\ NO_3(aq)$ | |
| $Ca(NO_3)_2(s) \rightarrow Ca^{+}(aq) + 2\ NO_3^{-}(aq)$ | |
| $Ca(NO_3)_2(s) \rightarrow Ca^{2+}(aq) + 2\ N^{3-}(aq) + 6\ O^{2-}(aq)$ | |
| $Ca(NO_3)_2(s) \rightarrow Ca^{2+}(aq) + NO_3^{-}(aq)$ | |
| $Ca(NO_3)_2(s) + H_2O(l) \rightarrow Ca^{2+}(aq) + 2\ NO_3^{-}(aq) + H_2O(l)$ | |

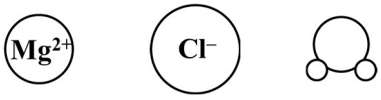
8. Draw two different particle diagrams below. On the left, represent solid sodium chloride, NaCl(*s*). On the right, represent aqueous sodium chloride, NaCl(*aq*). Use the following symbols to create your particle diagrams.




NaCl(*s*)

NaCl(*aq*)

9. Draw a particle diagram to represent aqueous magnesium chloride. Use the following symbols to create your particle diagram.



10. A student combines a clear, colorless solution of potassium iodide, KI(*aq*), with a clear, colorless solution of lead(II) nitrate, $Pb(NO_3)_2(aq)$.

    You can watch a video of this experiment by scanning the QR code shown at right. Describe what you observe in the video when solutions of KI(*aq*) and $Pb(NO_3)_2(aq)$ are combined.

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- A **precipitation reaction** occurs when two different aqueous solutions containing ions are combined, resulting in the formation of an insoluble (or slightly soluble) solid ionic compound. The solid product is called the **precipitate**.
- There are three different ways to write a balanced equation for a precipitation reaction: a molecular equation, a complete ionic equation, and a net ionic equation
  - **molecular equation** – each reactant and product is written as a neutral compound
  - **complete ionic equation** – any substance that ionizes completely is broken up into separate ions; any substance that does not ionize (or is only partially ionized) is written as a neutral compound
  - **spectator ions** – ions that appear in identical forms on both sides of a complete ionic equation
  - **net ionic equation** – the balanced equation that describes the actual reaction that occurs in aqueous solution; it is obtained after the spectator ions are eliminated from the complete ionic equation

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11. The experiment described in Question #10 involves the chemical reaction between aqueous solutions of potassium iodide and lead(II) nitrate. The yellow solid precipitate formed in this experiment is lead(II) iodide.

    (a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

Here is a list of ions that are commonly encountered in chemistry.

| Monoatomic Ions | | | | | |
|---|---|---|---|---|---|
| 1+ | 2+ | 3+ | 3– | 2– | 1– |
| lithium, $Li^+$<br>sodium, $Na^+$<br>potassium, $K^+$<br>rubidium, $Rb^+$<br>cesium, $Cs^+$<br>copper(I), $Cu^+$<br>silver, $Ag^+$ | magnesium, $Mg^{2+}$<br>calcium, $Ca^{2+}$<br>strontium, $Sr^{2+}$<br>barium, $Ba^{2+}$<br>manganese(II), $Mn^{2+}$<br>iron(II), $Fe^{2+}$<br>cobalt(II), $Co^{2+}$<br>nickel(II), $Ni^{2+}$<br>copper(II), $Cu^{2+}$<br>zinc, $Zn^{2+}$<br>lead(II), $Pb^{2+}$<br>tin(II), $Sn^{2+}$ | aluminum, $Al^{3+}$<br>chromium(III), $Cr^{3+}$<br>iron(III), $Fe^{3+}$ | nitride, $N^{3-}$<br>phosphide, $P^{3-}$ | oxide, $O^{2-}$<br>sulfide, $S^{2-}$ | fluoride, $F^-$<br>chloride, $Cl^-$<br>bromide, $Br^-$<br>iodide, $I^-$ |

| Polyatomic Ions | | | |
|---|---|---|---|
| 1+ | 1– | 2– | 3– |
| ammonium, $NH_4^+$ | hydroxide, $OH^-$<br>nitrate, $NO_3^-$<br>hydrogen carbonate, $HCO_3^-$<br>cyanide, $CN^-$<br>acetate, $C_2H_3O_2^-$<br>permanganate, $MnO_4^-$<br>hypochlorite, $ClO^-$<br>chlorite, $ClO_2^-$<br>chlorate, $ClO_3^-$<br>perchlorate, $ClO_4^-$ | carbonate, $CO_3^{2-}$<br>sulfate, $SO_4^{2-}$<br>chromate, $CrO_4^{2-}$ | phosphate, $PO_4^{3-}$ |

Writing a net ionic equation is a very important skill that requires practice. When you study Topic 4.7 (Types of Chemical Reactions), you will learn the following information from the AP Chemistry Course and Exam Description (CED).

- Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound.

- All sodium ($Na^+$), potassium ($K^+$), ammonium ($NH_4^+$), and nitrate ($NO_3^-$) salts are soluble in water.

One way to remember these four soluble ions is to think of them as the "SNAP" ions.

(S = sodium, N = nitrate, A = ammonium, and P = potassium)

12. A student combines solutions of ammonium nitrate, $NH_4NO_3(aq)$, and sodium sulfate, $Na_2SO_4(aq)$.

    (a) Write the chemical formulas for the two compounds that are formed as a result of the chemical reaction between $NH_4NO_3(aq)$ and $Na_2SO_4(aq)$.

    (b) Do you predict that a precipitate will be formed when solutions of $NH_4NO_3(aq)$ and $Na_2SO_4(aq)$ are combined? Justify your answer based on the solubility rules for the "SNAP" ions.

13. A student combines solutions of silver nitrate, $AgNO_3(aq)$, and ammonium chloride, $NH_4Cl(aq)$, and a precipitate is formed.

    (a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

14. A student combines solutions of barium chloride, $BaCl_2(aq)$, and potassium sulfate, $K_2SO_4(aq)$, and a precipitate is formed.

    (a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

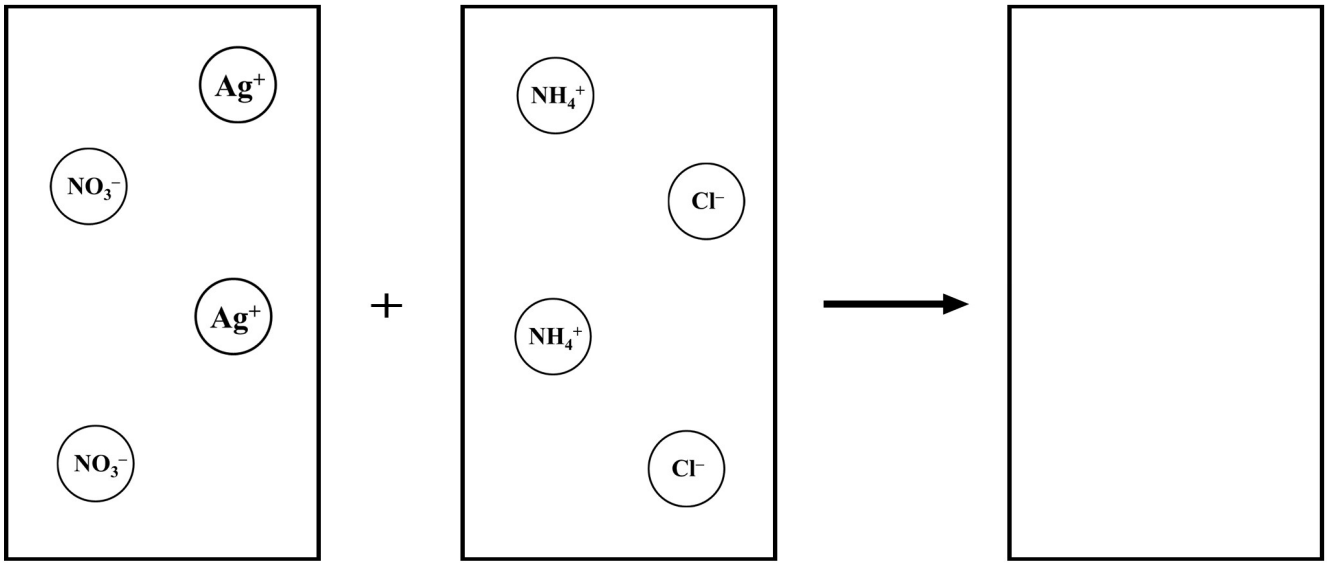
15. A student combines solutions of copper(II) chloride, $CuCl_2(aq)$, and sodium hydroxide, $NaOH(aq)$, and a precipitate is formed.

    (a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

    (b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

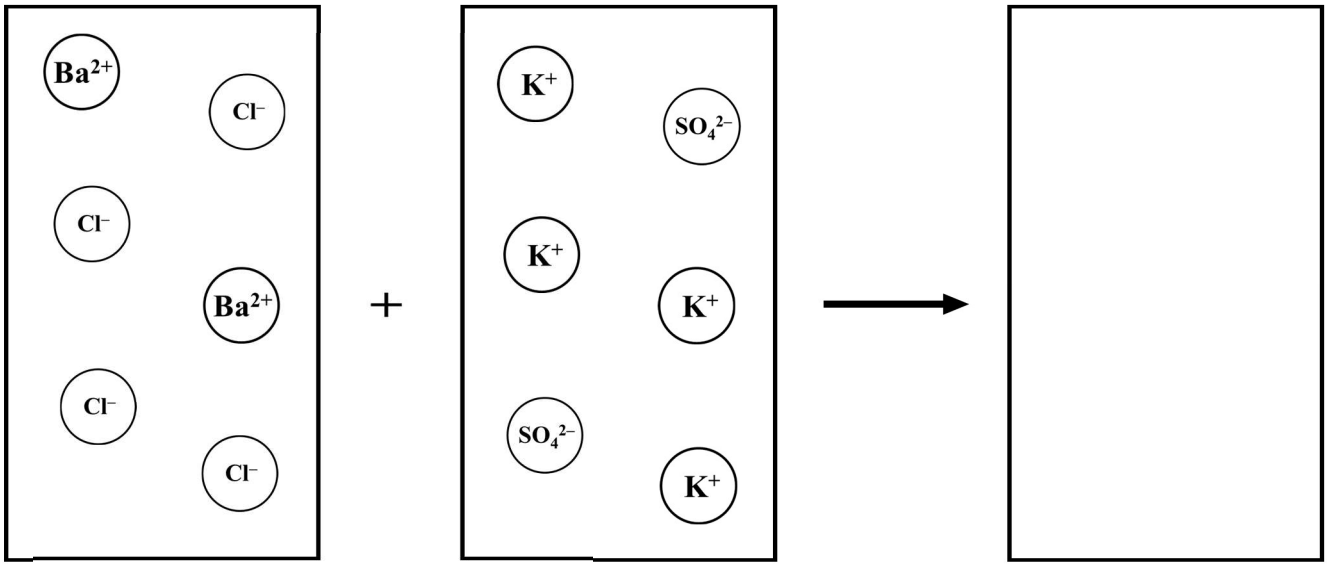
    (c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

16. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.



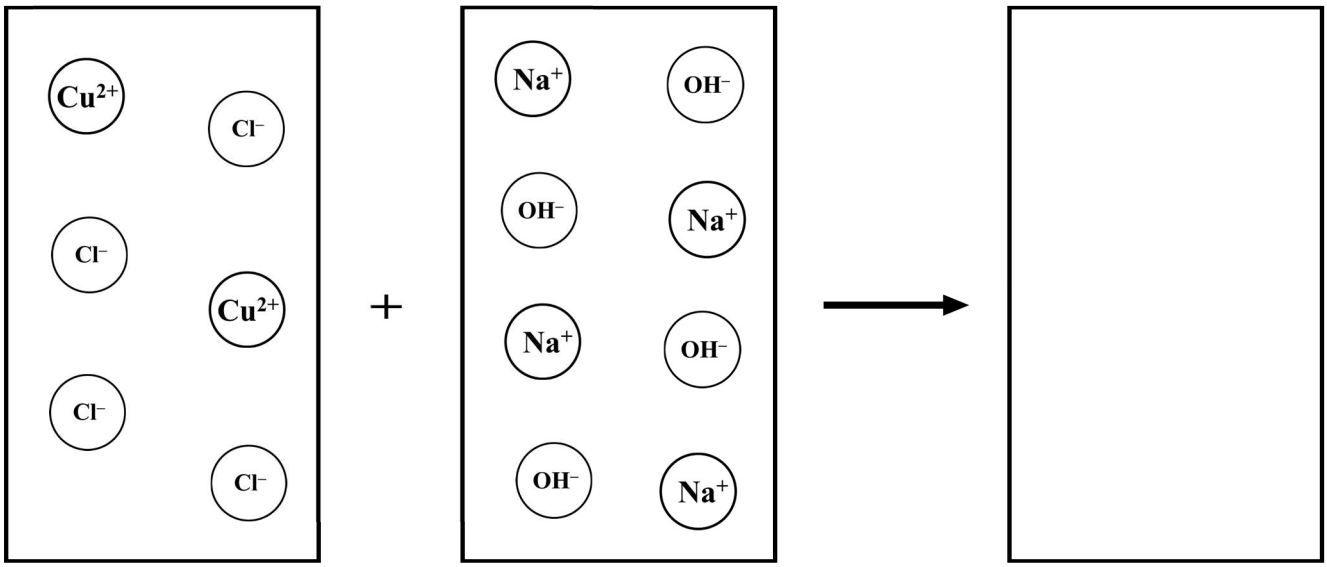

$AgNO_3(aq)$ $NH_4Cl(aq)$

17. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.




$BaCl_2(aq)$ $K_2SO_4(aq)$

18. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.




$CuCl_2(aq)$ $NaOH(aq)$

## 4.3 Representations of Reactions

Essential knowledge statements from the AP Chemistry CED:

- Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

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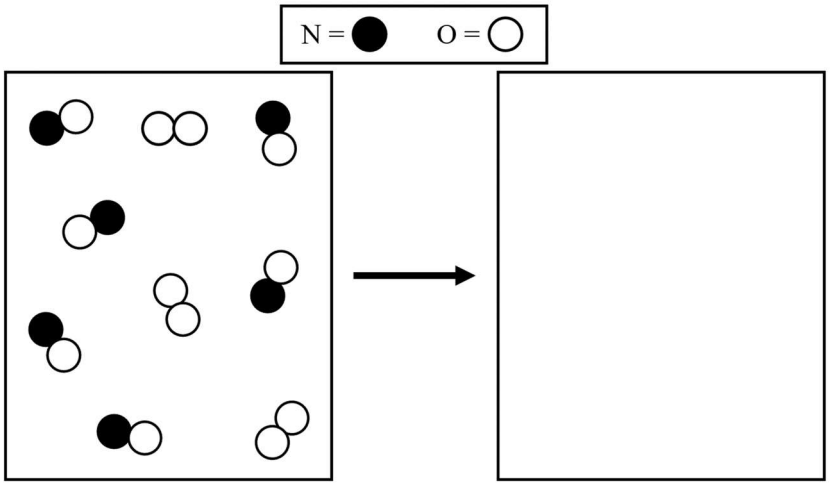
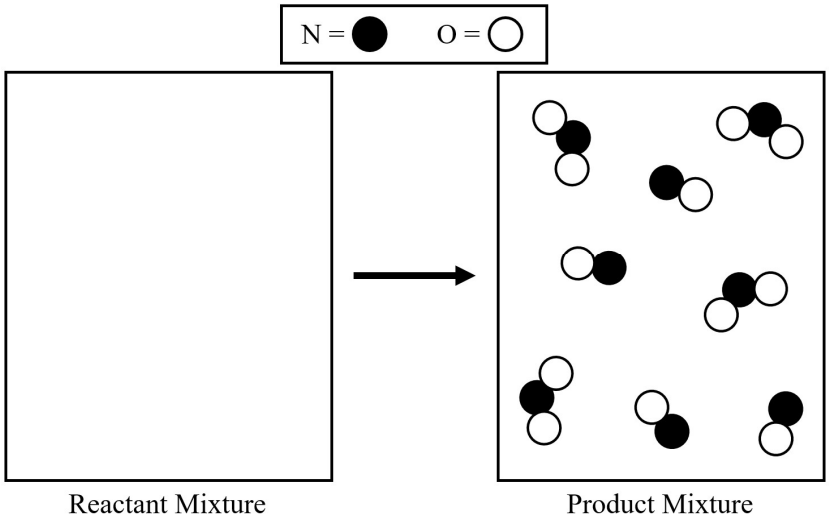
$$2\ NO(g)\ +\ O_2(g)\ \rightarrow\ 2\ NO_2(g)$$

19. A particle diagram representing a mixture of $NO(g)$ and $O_2(g)$ in a reaction vessel is shown below in the box on the left. A chemical reaction takes place according to the equation above until one of the reactants is completely consumed. In the box below on the right, draw a particle diagram representing the contents of the reaction vessel at the completion of the reaction. Represent nitrogen atoms and oxygen atoms as indicated below.

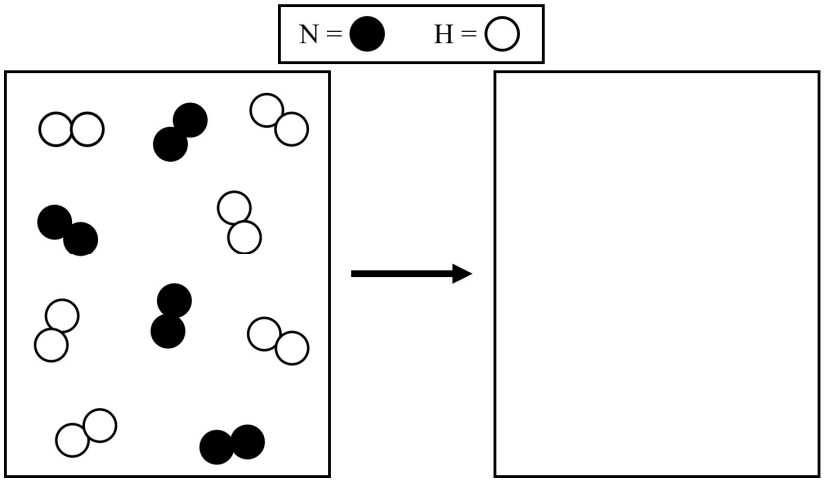



20. A particle diagram representing a mixture of $NO(g)$ and $NO_2(g)$ in a reaction vessel is shown below in the box on the right. A chemical reaction has already taken place according to the equation shown in Question #19 until one of the reactants was completely consumed. In the box below on the left, draw a particle diagram representing the reaction mixture of $NO(g)$ and $O_2(g)$ in the reaction vessel at the beginning of the reaction. Represent nitrogen atoms and oxygen atoms as indicated below.

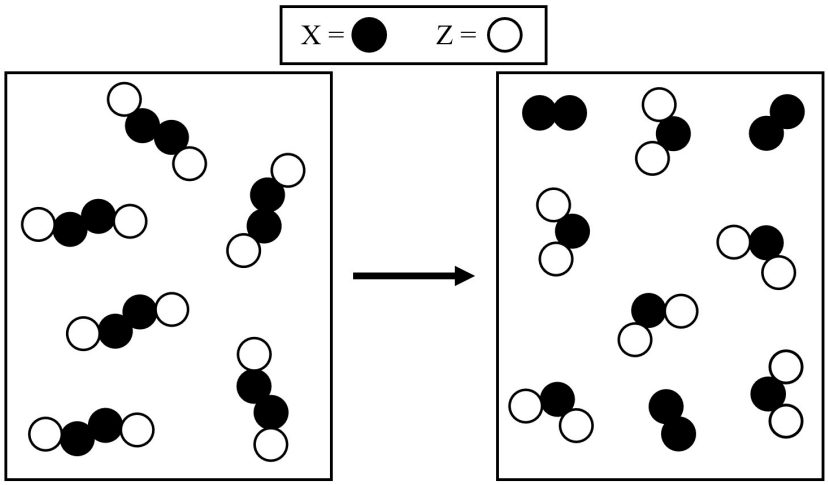


$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

21. A particle diagram representing a mixture of $N_2(g)$ and $H_2(g)$ in a reaction vessel is shown below in the box on the left. A chemical reaction takes place according to the equation above until one of the reactants is completely consumed. In the box below on the right, draw a particle diagram representing the contents of the reaction vessel at the completion of the reaction. Represent nitrogen atoms and hydrogen atoms as indicated below.




Reactant Mixture Product Mixture




Reactant Mixture Product Mixture

22. Based on the information in the particle diagrams shown above, write a balanced chemical equation for the decomposition of $X_2Z_2$.