Pearson

8.5: Precipitation Reactions

Key Concept Video **Reactions in Solution**

We discussed an example of a **precipitation reaction**—a reaction in which a solid forms upon the mixing of two solutions—in Section 8.1. You have probably seen another precipitation reaction if you have taken a bath in hard water. Hard water contains dissolved ions such as Ca^{2+} and Mg^{2+} that form a **precipitate** when they react with ions in soap. This precipitate is a gray curd that may appear as "bathtub ring" after you drain the tub.

Hard water is particularly troublesome when washing clothes. Consider how your white shirt would look covered with the gray curd from the bathtub. Most laundry detergents include substances designed to remove Ca^{2+} and Mg^{2+} from the laundry mixture. The most common substance used for this purpose is sodium carbonate, which dissolves in water to form sodium cations (Na^+) and carbonate (CO_3^{2-}) anions:

$$Na_2CO_3\,(aq) \rightarrow 2\,Na^+\,(aq) + CO_3^{2-}\,(aq)$$

Sodium carbonate is soluble, but calcium carbonate and magnesium carbonate are not (see the solubility rules in Table 8.1). Consequently, the carbonate anions react with dissolved Mg^{2+} and Ca^{2+} ions in hard water to form solids *that precipitate* from (or come out of) solution:

$$Mg^{2+}\,(aq) + CO_3^{2-}\,(aq) \rightarrow MgCO_3\,(s)$$
$$Ca^{2+}\,(aq) + CO_3^{2-}\,(aq) \rightarrow CaCO_3\,(s)$$

The precipitation of these ions prevents their reaction with the soap, eliminating curd and preventing white shirts from turning gray.

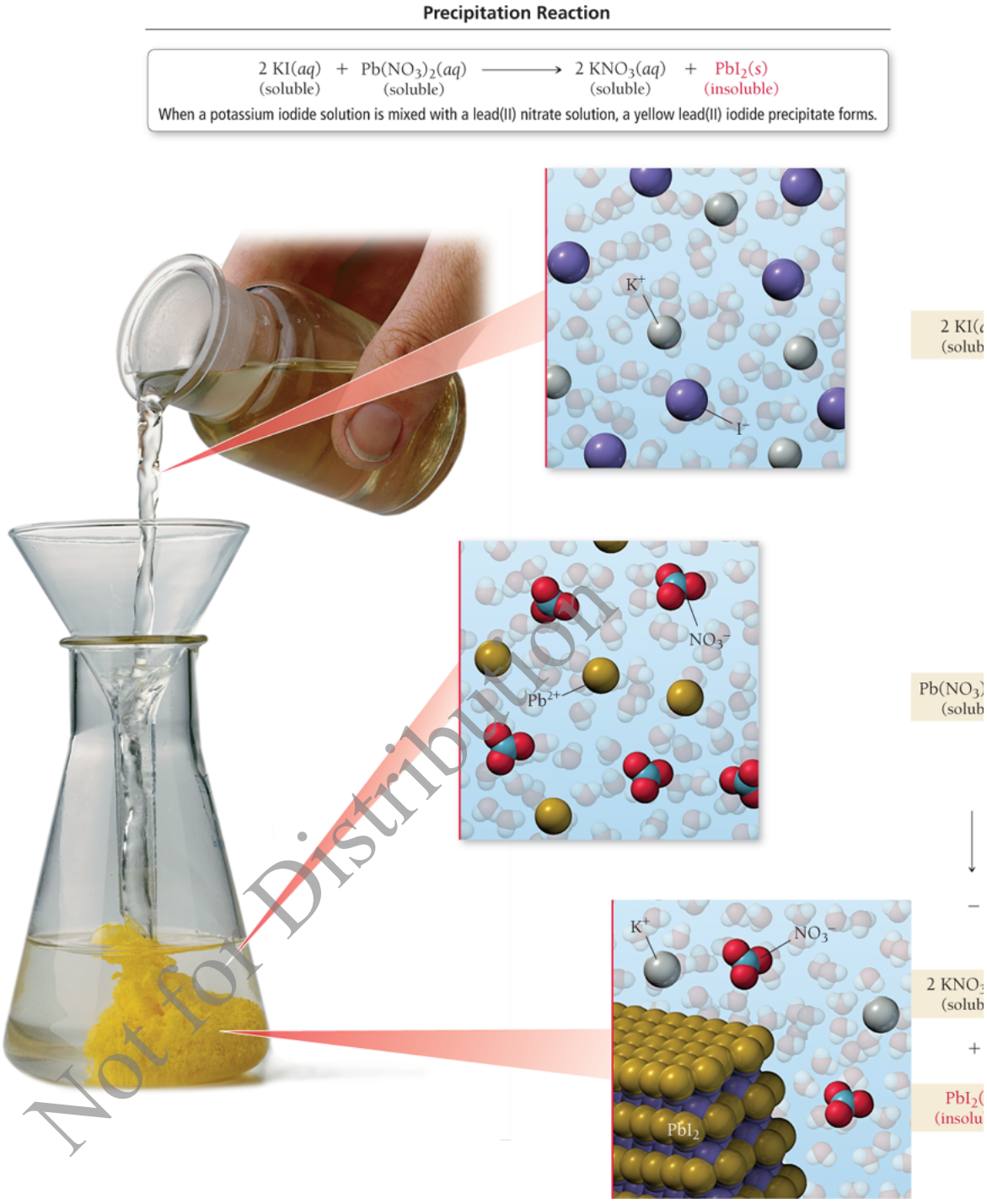
The reaction of ions in hard water with soap produces a gray curd you can see after you drain the bathwater.

The reactions between CO_3^{2-} and Mg^{2+} and Ca^{2+} are also examples of precipitation reactions. Precipitation reactions are common in chemistry. Potassium iodide and lead(II) nitrate, which each form colorless, strong electrolyte solutions when dissolved in water, form a brilliant yellow precipitate when combined (Figure 8.13). We describe this precipitation reaction with the following chemical equation:

$$2\,KI\,(aq) + Pb(NO_3)_2\,(aq) \rightarrow PbI_2\,(s) + 2\,KNO_3\,(aq)$$

Figure 8.13 **Precipitation of Lead(II) Iodide**

When we mix a potassium iodide solution with a lead(II) nitrate solution, a yellow lead(II) iodide precipitate forms.

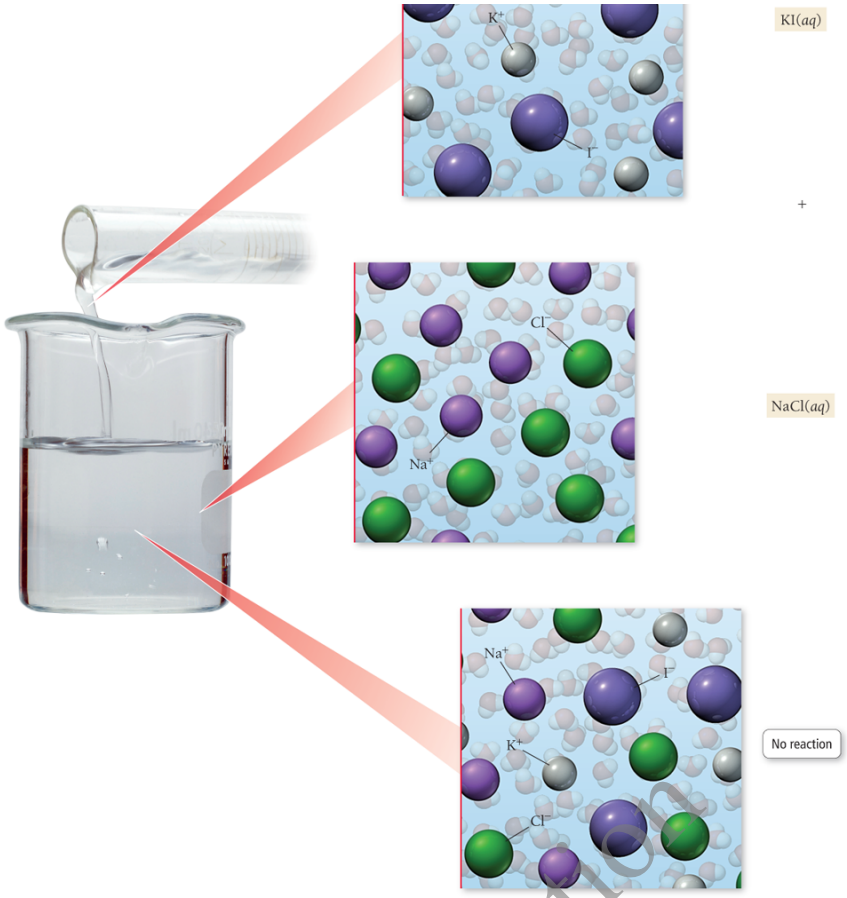


Precipitation reactions do not always occur when two aqueous solutions are mixed. For example, if we combine solutions of KI(aq) and NaCl(aq), nothing happens (Figure 8.14):

$$\mathrm{KI}\,(aq) + \mathrm{NaCl}\,(aq) \rightarrow \text{NO REACTION}$$

Figure 8.14 No Precipitation

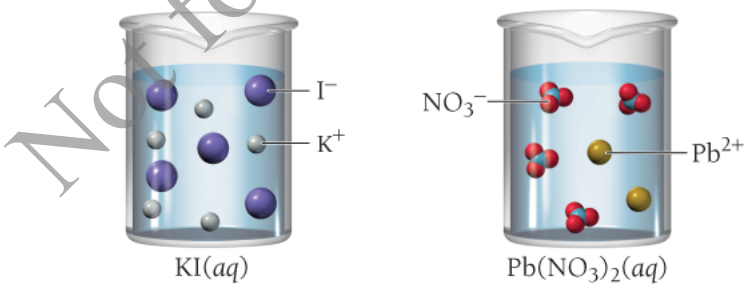
When we mix a potassium iodide solution with a sodium chloride solution, no reaction occurs.



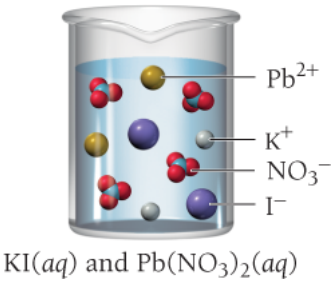
The key to predicting precipitation reactions is understanding that *only insoluble compounds form precipitates*. In a precipitation reaction, two solutions containing soluble compounds combine and an insoluble compound precipitates. Consider the precipitation reaction described previously:

$$\underset{\text{soluble}}{2\,KI\,(aq)} + \underset{\text{soluble}}{Pb(NO_3)_2\,(aq)} \rightarrow \underset{\text{insoluble}}{PbI_2\,(s)} + \underset{\text{soluble}}{2\,KNO_3\,(aq)}$$

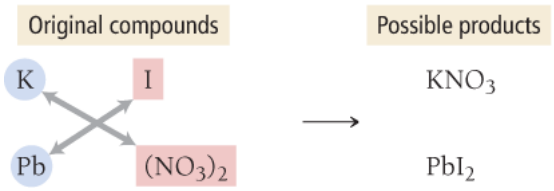
KI and $Pb(NO_3)_2$ are both soluble, but the precipitate, PbI_2, is insoluble. Before mixing, $KI(aq)$ and $Pb(NO_3)_2\,(aq)$ are both dissociated in their respective solutions:



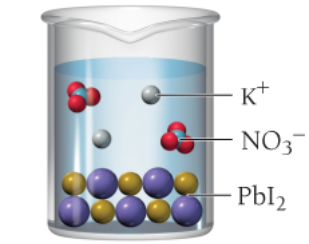
The instant that the solutions come into contact, all four ions are present:



Now, new compounds—one or both of which might be insoluble—are possible. Specifically, the cation from either compound can pair with the anion from the other to form possibly insoluble products:



If the possible products are both soluble, no reaction occurs and no precipitate forms. If one or both of the possible products are insoluble, a precipitation reaction occurs. In this case, KNO_3 is soluble, but PbI_2 is insoluble. Consequently, PbI_2 precipitates:



$PbI_2(s)$ and $KNO_3(aq)$

To predict whether a precipitation reaction will occur when two solutions are mixed and to write an equation for the reaction, we use the procedure that follows. The steps are outlined in the left column, and two examples illustrating how to apply the procedure are shown in the center and right columns.

Example 8.6 Writing Equations for Precipitation Reactions

PROCEDURE FOR

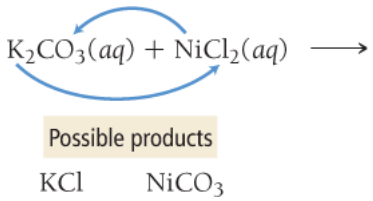
Writing Equations for Precipitation Reactions

Write an equation for the precipitation reaction that occurs (if any) when you mix solutions of potassium carbonate and nickel(II) chloride.

1. Write the formulas of the two compounds being mixed as reactants in a chemical equation.

$$K_2CO_3\,(aq) + NiCl_2\,(aq) \rightarrow$$

2. Below the equation, write the formulas of the products that could form from the reactants by combining the cation from each reactant with the anion from the other. Make sure to write correct formulas for these ionic compounds, as described in Section 4.6.



3. Refer to the solubility rules in Table 8.1 to determine whether any of the possible products are

insoluble.

KCl is soluble. (Compounds containing Cl^- are usually soluble and K^+ is not an exception.)

$NiCO_3$ is insoluble. (Compounds containing CO_3^{2-} are usually insoluble and Ni^{2+} is not an exception.)

4. If all of the possible products are soluble, there will be no precipitate. Write NO REACTION after the arrow.

Since this example has an insoluble product, we proceed to the next step.

5. If any of the possible products are insoluble, write their formulas as the products of the reaction using (s) to indicate solid. Write any soluble products with (aq) to indicate aqueous.

$$K_2CO_3\,(aq) + NiCl_2\,(aq) \rightarrow NiCO_3\,(s) + KCl\,(aq)$$

6. Balance the equation. Remember to adjust only coefficients, not subscripts.

$$K_2CO_3\,(aq) + NiCl_2\,(aq) \rightarrow NiCO_3\,(s) + 2\,KCl\,(aq)$$

FOR PRACTICE 8.6

Write an equation for the precipitation reaction that occurs (if any) when you mix solutions of ammonium chloride and iron(III) nitrate.

Example 8.7 Writing Equations for Precipitation Reactions

PROCEDURE FOR

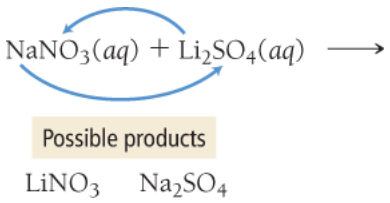
Writing Equations for Precipitation Reactions

Write an equation for the precipitation reaction that occurs (if any) when you mix solutions of sodium nitrate and lithium sulfate.

1. Write the formulas of the two compounds being mixed as reactants in a chemical equation.

$$NaNO_3\,(aq) + Li_2SO_4\,(aq) \rightarrow$$

2. Below the equation, write the formulas of the products that could form from the reactants by combining the cation from each reactant with the anion from the other. Make sure to write correct formulas for these ionic compounds, as described in Section 4.6.



3. Refer to the solubility rules in Table 8.1 to determine whether any of the possible products are insoluble.

$LiNO_3$ is soluble. (Compounds containing NO_3^- are soluble and Li^+ is not an exception.)

Na_2SO_4 is soluble. (Compounds containing SO_4^{2-} are generally soluble and Na^+ is not an exception.)

4. If all of the possible products are soluble, there will be no precipitate. Write NO REACTION after the arrow.

Since this example has no insoluble product, there is no reaction.

$$NaNO_3\,(aq) + Li_2SO_4\,(aq) \rightarrow \text{NO REACTION}$$

FOR PRACTICE 8.7

Write an equation for the precipitation reaction that occurs (if any) when you mix solutions of sodium hydroxide and copper(II) bromide.

Interactive Worked Example 8.6 **Writing Equations for Precipitation Reactions**

Conceptual Connection 8.4 **Precipitation Reactions**

Interactive