

Many chemical reactions that occur in water solutions are reactions involving ions. Soluble ionic compounds dissociate into ions when they dissolve, and some molecular compounds,

including acids, ionize when they dissolve. An ionic equation represents the species actually present more accurately than an equation that uses full formulas.

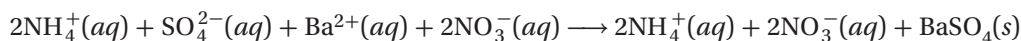
Problem-Solving TIPS

- All soluble ionic compounds are dissociated into ions. Therefore, soluble ionic compounds are shown as the separated ions in the full ionic equation. Strong acids and bases are also shown as the separated ions in the full ionic equation because they are 100% ionized.
- Ions that do not take part in the reaction are called *spectator ions*. In other words, spectator ions stay in solution and will be labeled “(aq)” on both sides of the equation. Eliminating spectator ions reduces the “clutter” of the full ionic equation and produces a net ionic equation that shows only the species that actually react.

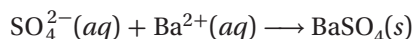
Sample Problem

Write the net ionic equation for the reaction of aqueous ammonium sulfate and aqueous barium nitrate to produce a precipitate of barium sulfate. The balanced formula equation is $(\text{NH}_4)_2\text{SO}_4(\text{aq}) + \text{Ba}(\text{NO}_3)_2(\text{aq}) \longrightarrow 2\text{NH}_4\text{NO}_3(\text{aq}) + \text{BaSO}_4(\text{s})$

Rewrite the equation in full ionic form; because ammonium sulfate and barium nitrate are soluble, they are written as separated ions:

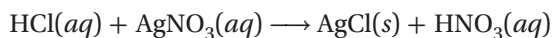


Eliminating spectator ions, NH_4^+ and NO_3^- , yields the net ionic equation:

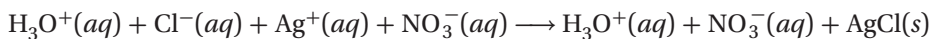


Write full and net ionic equations for the reaction that occurs when hydrochloric acid solution is combined with silver nitrate solution.

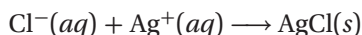
Hydrochloric acid is a strong acid, so it is completely ionized in solution. Silver nitrate is a soluble ionic compound, so its ions are separated in solution. Although most chlorides are soluble, silver chloride is not, so silver chloride will precipitate. The balanced formula equation is



The full ionic equation is



Eliminate spectator ions to obtain the net ionic equation:



Practice

Answers in Appendix E

1. Aqueous copper(II) sulfate reacts with aqueous sodium sulfide to produce a black precipitate of copper(II) sulfide. Write the formula equation, the full ionic equation, and the net ionic equation for this reaction.
2. Write full and net ionic equations for the reaction that occurs when a solution of cadmium chloride, CdCl_2 , is mixed with a solution of sodium carbonate, Na_2CO_3 . Cadmium carbonate is insoluble.

CHAPTER 14 Summary

BIG IDEA Acids are substances that donate hydrogen ions in aqueous solutions. Bases are substances that accept hydrogen ions in aqueous solutions.

SECTION 1 Properties of Acids and Bases

KEY TERMS

- Acids have a sour taste and react with active metals. Acids change the colors of acid-base indicators, react with bases to produce salts and water, and conduct electricity in aqueous solutions.
- Bases have a bitter taste, feel slippery to the skin in dilute aqueous solutions, change the colors of acid-base indicators, react with acids to produce salts and water, and conduct electricity in aqueous solution.
- An Arrhenius acid contains hydrogen and ionizes in aqueous solution to form hydrogen ions. An Arrhenius base produces hydroxide ions in aqueous solution.
- The strength of an Arrhenius acid or base is determined by the extent to which the acid or base ionizes or dissociates in aqueous solutions.

binary acid
oxyacid
Arrhenius acid
Arrhenius base
strong acid
weak acid

SECTION 2 Acid-Base Theories

KEY TERMS

- A Brønsted-Lowry acid is a proton donor. A Brønsted-Lowry base is a proton acceptor.
- A Lewis acid is an electron-pair acceptor. A Lewis base is an electron-pair donor.
- Acids are described as monoprotic, diprotic, or triprotic depending on whether they can donate one, two, or three protons per molecule, respectively, in aqueous solutions. Polyprotic acids include both diprotic and triprotic acids.

Brønsted-Lowry acid
Brønsted-Lowry base
Brønsted-Lowry acid-base reaction
monoprotic acid
polyprotic acid
diprotic acid
triprotic acid
Lewis acid
Lewis base
Lewis acid-base reaction

SECTION 3 Acid-Base Reactions

KEY TERMS

- In every Brønsted-Lowry acid-base reaction, there are two conjugate acid-base pairs.
- A strong acid has a weak conjugate base; a strong base has a weak conjugate acid.
- Proton-transfer reactions favor the production of the weaker acid and weaker base.
- The acidic or basic behavior of a molecule containing $-OH$ groups depends on the electronegativity of other atoms in the molecule and on the number of oxygen atoms bonded to the atom that is connected to the $-OH$ group.
- A neutralization reaction produces water and an ionic compound called a salt.
- Acid rain can create severe ecological problems.

conjugate base
conjugate acid
amphoteric
neutralization
salt



SECTION 1

Properties of Acids and Bases **REVIEWING MAIN IDEAS**

- Compare the general properties of acids with the general properties of bases.
- Distinguish between binary acids and oxyacids in terms of their component elements and the systems used in naming them.
 - Give three examples of each type of acid.
- Identify and describe the characteristic properties of five common acids used in industry. Give some examples of the typical uses of each.
- Although $\text{HCl}(aq)$ exhibits properties of an Arrhenius acid, pure HCl gas and HCl dissolved in a nonpolar solvent exhibit none of the properties of an Arrhenius acid. Explain why.
- What distinguishes strong acids from weak acids?
 - Give two examples each of strong acids and weak acids.
- H_3PO_4 , which contains three hydrogen atoms per molecule, is a weak acid, whereas HCl , which contains only one hydrogen atom per molecule, is a strong acid. Explain why.
- What compounds are strong Arrhenius bases?
 - Give an example of an aqueous solution of a strong base and one of a weak base.

PRACTICE PROBLEMS

- Name each of the following binary acids:
 - HCl
 - H_2S
- Name each of the following oxyacids:
 - HNO_3
 - H_2SO_3
 - HClO_3
 - HNO_2
- Write formulas for the following binary acids and common bases:
 - hydrofluoric acid
 - hydriodic acid
 - sodium bicarbonate
 - aluminum hydroxide

- Write formulas for the following oxyacids:
 - perbromic acid
 - chlorous acid
 - phosphoric acid
 - hypochlorous acid

SECTION 2

Acid-Base Theories **REVIEWING MAIN IDEAS**

- Distinguish between a monoprotic, a diprotic, and a triprotic acid. Give an example of each.
- Which of the three acid definitions is the broadest? Explain.

PRACTICE PROBLEMS

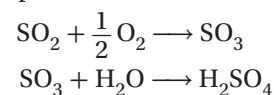
- Write the balanced equations that describe the two-step ionization of sulfuric acid in a dilute aqueous solution.
 - How do the degrees of ionization in the two steps compare?
- Dilute $\text{HCl}(aq)$ and $\text{KOH}(aq)$ are mixed in chemically equivalent quantities. Write the following:
 - formula equation for the reaction
 - full ionic equation
 - net ionic equation
- Repeat item 15, but mix $\text{H}_3\text{PO}_4(aq)$ and $\text{NaOH}(aq)$.
- Write the formula equation and net ionic equation for each of the following reactions:
 - $\text{Zn}(s) + \text{HCl}(aq) \longrightarrow$
 - $\text{Al}(s) + \text{H}_2\text{SO}_4(aq) \longrightarrow$
- Write the formula equation and net ionic equation for the reaction between $\text{Ca}(s)$ and $\text{HCl}(aq)$.

SECTION 3

Acid-Base Reactions **REVIEWING MAIN IDEAS**

- Define and give an equation to illustrate each of the following substances:
 - a conjugate base
 - a conjugate acid

20. a. What is the relationship between the strength of an acid and the strength of its conjugate base?
b. What is the relationship between the strength of a base and the strength of its conjugate acid?
21. a. What trend is there in the favored direction of proton-transfer reactions?
b. What determines the extent to which a proton-transfer reaction occurs?
22. a. What is meant by the term *amphoteric*?
b. Give an example of a substance or ion that has amphoteric characteristics.
23. For each reaction listed, identify the proton donor or acid and the proton acceptor or base. Label each conjugate acid-base pair.
- a. $\text{CH}_3\text{COOH}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{CH}_3\text{COO}^-(aq)$
- b. $\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq) + \text{OH}^-(aq)$
- c. $\text{HNO}_3 + \text{SO}_4^{2-} \longrightarrow \text{HSO}_4^- + \text{NO}_3^-$
24. Using the information given in **Figure 3.1**, determine the following relative to HF, H₂S, HNO₃, and CH₃COOH:
- a. strongest acid
b. weakest acid
c. strongest conjugate base among the four conjugate bases produced by the acids listed
d. weakest conjugate base among the four conjugate bases produced by the acids listed
25. Explain why the conjugate base of a strong acid is a weak base and the conjugate acid of a strong base is a weak acid.
28. Write the balanced chemical equation for each of the following reactions between water and the non-metallic oxide to form an acid.
- a. $\text{CO}_2(g) + \text{H}_2\text{O}(l) \longrightarrow$
b. $\text{SO}_3(g) + \text{H}_2\text{O}(l) \longrightarrow$
c. $\text{N}_2\text{O}_5(g) + \text{H}_2\text{O}(l) \longrightarrow$
29. Write the formula equation, the overall ionic equation, and the net ionic equation for a neutralization reaction that would form each of the following salts.
- a. RbClO₄ c. CaCl₂
b. BaSO₄ d. K₂SO₄
30. Zinc reacts with 100.0 mL of 6.00 M cold, aqueous sulfuric acid through single replacement.
- a. How many grams of zinc sulfate can be produced?
b. How many liters of hydrogen gas could be released at STP?
31. A 211 g sample of barium carbonate, BaCO₃, reacts with a solution of nitric acid to give barium nitrate, carbon dioxide, and water. If the acid is present in excess, what mass and volume of dry carbon dioxide gas at STP will be produced?
32. A seashell that is composed largely of calcium carbonate reacts with a solution of HCl. As a result, 1500 mL of dry CO₂ gas at STP is produced. The other products are CaCl₂ and H₂O.
- a. How many grams of CaCO₃ are consumed in the reaction?
b. What volume of 2.00 M HCl solution is used in this reaction?
33. *Acid precipitation* is the term generally used to describe rain or snow that is more acidic than it normally is. One cause of acid precipitation is the formation of sulfuric and nitric acids from various sulfur and nitrogen oxides produced in volcanic eruptions, forest fires, and thunderstorms. In a typical volcanic eruption, for example, 3.50×10^8 kg SO₂ may be produced. If this amount of SO₂ were converted to H₂SO₄ according to the two-step process given below, how many kilograms of H₂SO₄ would be produced from such an eruption?



PRACTICE PROBLEMS

26. Complete the following neutralization reactions. Balance each reaction, and then write the overall ionic and net ionic equation for each.
- a. $\text{HCl}(aq) + \text{NaOH}(aq) \longrightarrow$
b. $\text{HNO}_3(aq) + \text{KOH}(aq) \longrightarrow$
c. $\text{Ca}(\text{OH})_2(aq) + \text{HNO}_3(aq) \longrightarrow$
d. $\text{Mg}(\text{OH})_2(aq) + \text{HCl}(aq) \longrightarrow$
27. Write the formula equation, the overall ionic equation, and the net ionic equation for the neutralization reaction involving aqueous solutions of H₃PO₄ and Mg(OH)₂. Assume that the solutions are sufficiently dilute so that no precipitates form.

Mixed Review

REVIEWING MAIN IDEAS

34. Suppose that dilute $\text{HNO}_3(aq)$ and $\text{LiOH}(aq)$ are mixed in chemically equivalent quantities. Write the following for the resulting reaction:
- formula equation
 - overall ionic equation
 - net ionic equation
35. Write the balanced chemical equation for the reaction between hydrochloric acid and magnesium metal.
36. Write equations for the three-step ionization of phosphoric acid, H_3PO_4 . Compare the degree of ionization for the three steps.
37. Name or give the molecular formula for each of the following acids:
- | | |
|----------------------------|----------------------------|
| a. HF | f. hydrobromic acid |
| b. acetic acid | g. HClO |
| c. phosphorous acid | h. H_2CO_3 |
| d. HClO_4 | i. sulfuric acid |
| e. H_3PO_4 | |

CRITICAL THINKING

38. **Analyzing Conclusions** In the 18th century, Antoine Lavoisier experimented with oxides, such as CO_2 and SO_2 . He observed that they formed acidic solutions. His observations led him to infer that to exhibit acidic behavior, a substance must contain oxygen. However, today that inference is known to be incorrect. Provide evidence to refute Lavoisier's conclusion.

USING THE HANDBOOK

39. Group 16 of the *Elements Handbook* (Appendix A) contains a section covering the acid-base chemistry of oxides. Review this material, and answer the following questions:
- What types of compounds form acidic oxides?
 - What is an acid anhydride?
 - What are three examples of compounds that are classified as acid anhydrides?
 - What types of compounds form basic oxides? Why are they basic oxides?

- Look at Table 7A in the *Elements Handbook* (Appendix A). What periodic trends regarding the acid-base character of oxides do you notice?
- How is the nature of the product affected by the concentrations of the reactants?

RESEARCH AND WRITING

41. Explain how sulfuric acid production serves as a measure of a country's economy. Write a report on your findings.
42. **Performance** Conduct library research to find out about the buffering of solutions. Include information on why solutions are buffered and what kinds of materials are used as buffers. Write a brief report on your findings.
43. Research how to determine whether the soil around your house is acidic or basic using pH paper obtained from your teacher. Write a brief description of what you should do. Then follow the directions, and test the soil. Find one type of plant that would grow well in the type of soil around your home and one that would not grow well.

ALTERNATIVE ASSESSMENT

44. Antacids are designed to neutralize excess hydrochloric acid secreted by the stomach during digestion. Carbonates, bicarbonates, and hydroxides are the active ingredients in the most widely used antacids. These ingredients act to drive the neutralization reactions. Examine the labels of several common antacids, and identify the active ingredients.
45. Design an experiment that compares three brands of antacids in terms of the speed of symptom relief and amount of acid neutralized.