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19 Acids, Bases, and Salts

Big idea REACTIONS

19.1 Acid-Base Theories

For students using the Foundation edition, assign problems 1–7, 9–11, 14, 16–18.

Essential Understanding Acids and bases can be classified in terms of hydrogen ions or hydroxide ions, or in terms of electron pairs.

Reading Strategy

Use Prior Knowledge When you use prior knowledge, you think about your own experience before you read. You will learn new material better if you can relate it to something you already know.

Before you read Lesson 19.1, write your definition for *acid* and *base* in the table below. After you read, write the scientific definition for each term, and compare it to your own definition.

Term	Your definition	Scientific definition
Acid	*Answers will vary.*	*An acid is a compound that produces hydronium ions (H_3O^+) when it is dissolved in water.*
Base	*Answers will vary.*	*A base is a compound that produces hydroxide ions (OH^-) when it is dissolved in water.*

EXTENSION **Name the theory that matches the scientific definition in the table. List three compounds that are acids and three that are bases according to that definition.**

Sample answer: Arrhenius; HCl, HNO_3, H_2SO_4; NaOH, KOH, $Ca(OH)_2$.

Lesson Summary

Arrhenius Acids and Bases Compounds are classified as Arrhenius acids or bases based on whether they ionize to yield hydrogen or hydroxide ions.

- Arrhenius acids contain a hydrogen atom that is released in water to form a hydronium ion (H_3O^+).
- Arrhenius bases contain a hydroxide group which is released in water to form a hydroxide ion (OH^-).

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Brønsted-Lowry Acids and Bases Brønsted-Lowry acids are hydrogen ion donors, while bases are hydrogen ion acceptors.

- Brønsted-Lowry acids and bases include all the Arrhenius acids and bases plus additional substances that accept or donate hydrogen ions.
- The transfer of a hydrogen ion from one compound to another creates two conjugate acid-base pairs.
- An amphoteric compound, such as water, can be either a Brønsted-Lowry acid or base.

Lewis Acids and Bases Lewis classified substances as acids or bases depending on whether they accepted or donated a pair of electrons.

- The Lewis definitions are the most general for acids and bases since they are not limited to hydrogen ions.
- It is often necessary to write the electron dot formula of a compound to determine whether it is a Lewis acid or base.

After reading Lesson 19.1, answer the following questions.

Arrhenius Acids and Bases

1. Circle the letters of all the terms that complete the sentence correctly. The properties of acids include _____.

a. reacting with metals to produce oxygen

(**b.**) giving foods a sour taste

(**c.**) forming solutions that conduct electricity

(**d.**) causing indicators to change color

2. Bases are compounds that react with acids to form ***water*** _____ and a(n) ***salt*** _____.

3. Circle the letters of all the terms that complete the sentence correctly. The properties of bases include _____.

(**a.**) tasting bitter

(**b.**) feeling slippery

(**c.**) changing the color of an indicator

d. always acting as a strong electrolyte

4. Match the number of ionizable hydrogens with the type of acid.

c	one	**a.**	diprotic
a	two	**b.**	triprotic
b	three	**c.**	monoprotic

5. Hydrogen is joined to a very ***electronegative*** element in a very polar bond.

6. Alkali metals react with water to produce ***basic*** solutions.

7. How do concentrated basic solutions differ from other basic solutions?

They are extremely caustic.

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Brønsted-Lowry Acids and Bases

8. How does the Brønsted-Lowry theory define acids and bases?

The Brønsted-Lowry theory defines an acid as a hydrogen-ion donor and a base as a hydrogen-ion acceptor.

9. Is the following sentence true or false? Some of the acids and bases included in the Arrhenius theory are not acids and bases according to the Brønsted-Lowry theory.
false

10. Is the following sentence true or false? A conjugate acid is the particle formed when a base gains a hydrogen ion. *true*

11. A conjugate *base* is the particle that remains when an acid has donated a hydrogen ion.

12. What is a conjugate acid–base pair?

two substances related by the loss or gain of a single hydrogen ion

13. A substance that can act as both an acid and a base is said to be *amphoteric*.

14. In a reaction with HCl, is water an acid or a base?

Water is a base because it accepts a proton.

Lewis Acids and Bases

15. What is a Lewis acid?

A Lewis acid is a substance that can accept a pair of electrons to form a covalent bond.

16. A Lewis base is a substance that can *donate* a pair of electrons to form a covalent bond.

17. Is the following sentence true or false? All the acids and bases included in the Brønsted-Lowry theory are also acids and bases according to the Lewis theory.
true

18. Complete this table of acid-base definitions.

Acid–Base Definitions		
Type	**Acid**	**Base**
Brønsted-Lowry	*H^+ donor*	H^+ acceptor
Lewis	electron-pair acceptor	*electron-pair donor*
Arrhenius	H^+ producer	*OH^- producer*

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19.2 Hydrogen Ions and Acidity

For students using the Foundation edition, assign problems 1–9, 11–14, 19, 20, 22, 26, 28, 29.

Essential Understanding Water-based solutions may be acidic, basic, or neutral depending on the concentration of hydrogen ions present.

Lesson Summary

Hydrogen Ions From Water Water self-ionizes into equal numbers of H^+ and OH^- ions.

- In aqueous solutions, $[H^+] \times [OH^-] = 1.0 \times 10^{-14} M = K_w$, the ion product constant for water.
- If the concentration of hydrogen ions is greater than the concentration of hydroxide ions, the solution is acidic.
- An alkaline solution is basic and has a higher concentration of hydroxide ions.

The pH Concept The concentration of hydrogen ions is commonly expressed on the pH scale, which runs from 0 to 14.

- The mathematical expression of pH is $pH = -\log[H^+]$.
- A pH of less than 7 is acidic, equal to 7 is neutral, and greater than 7 is basic.

Measuring pH The pH of a solution can be measured with either a chemical acid-base indicator or with an electronic pH meter.

- An acid-base indicator will change color over a small range of pH.
- There are different indicators that change color over various pH ranges.
- An electronic pH meter gives a more accurate measurement of pH.

BUILD Math Skills

Calculating Logarithms Multiplication is a shortcut for addition. Logarithms are a shortcut for exponents.

To calculate the pH of a solution, you must use a logarithm. The logarithm, or log, of a number is written with a *base* number that is placed as a subscript following *log*.

If you're given a logarithmic formula in the form $\log_b (x) = y$, remember that ***b*** is the **b**ase number, ***y*** is the number that the base will be raised to, and b^y will equal ***x***. In other words $b^y = x$.

A simple way to remember this is to think of a circle that begins at the base, flows to *y*, and ends at *x*.

$\log_b (x) = y$

For example: $\log_3 (x) = y$ has a base of 3 and would be read as "log, base 3 of *x* is equal to *y*."

Turn to the next page to learn more about calculating logarithms.

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When calculating logarithms, here are a few rules to remember:

- If you are given b and y to find x, just take b and raise it to y. That will equal x.
- If you are given b and x to determine y, think of how many times b must be multiplied by itself to get x.
- If no base is given, then the default base number is equal to 10.
- $\log(cd) = \log(c) + \log(d)$
- $\log(c/d) = \log(c) - \log(d)$
- If you are given $\log_b(x^c)$, the exponent applied to x is moved to be a coefficient. For example: $\log_{10}(2^3) = 3 \bullet \log_{10}(2)$
- The log of $10 = 1$; the log of $1 = 0$; you cannot take the log of a negative number.

Sample Problem Determine x given the following equation: $\log_5(x) = 3$.

First, determine what you are given.

$b = 5$ and $y = 3$

Next, take the base and raise it to the power of y to obtain x.

$5^3 = x = 125$

$x = 125$

Sample Problem Determine y for the following equation: $\log(10^2) = y$.

First, rewrite the equation in its simplest form using any rules that apply. Since the number designated as x has an exponent, it must be transferred to a coefficient.

$2 \bullet \log(10) = y$

Hint: Remember that since no base is specified, it is equal to 10.

Next, determine what the log of 10 is by using your calculator.

$\log(10) = 1$

Finally, multiply the log of 10 by the coefficient to find y.

$2 \bullet \log(10) = 2 \bullet 1 = 2$

$2 = y$

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Now it's your turn to practice calculating logarithms. Remember that it is not possible to take the log of a negative number.

1. Rewrite the following equation in log form: $2^2 = 4$.

   $\log_2 (4) = 2$

2. Determine x given $\log_3 (x) = 4$.

   $x = 81$

3. Determine y for the following equation: $\log (9/8) = y$.

   $y = 1.125$

4. Determine y for the following equation: $\log_4 (16^2) = y$.

   $y = 4$

After reading Lesson 19.2, answer the following questions.

Hydrogen Ions From Water

5. What does a water molecule that loses a hydrogen ion become?

   It becomes a negatively charged hydroxide ion (OH^-).

6. What does a water molecule that gains a hydrogen ion become?

   It becomes a positively charged hydronium ion (H_3O^+).

7. The reaction in which water molecules produce ions is called the *self-ionization* of water.

8. In water or aqueous solution, *hydrogen ions (H^+)* are always joined to *water molecules* as hydronium ions (H_3O^+).

9. Is the following sentence true or false? Any aqueous solution in which $[H^+]$ and $[OH^-]$ are equal is described as a neutral solution. *true*

10. What is the ion-product constant for water (K_w)? Give the definition, the expression, and the value.

    The ion-product constant for water is the product of the concentrations of the hydrogen ions and hydroxide ions in water.

    $K_w = [H^+] \times [OH^-] = 1.0 \times 10^{-14}$

11. A(n) *acidic* solution is one in which $[H^+]$ is greater than $[OH^-]$. A(n) *basic* solution is one in which $[H^+]$ is less than $[OH^-]$.

12. Match the type of solution with its hydrogen-ion concentration.

    b acidic
    c neutral
    a basic

    a. less than $1.0 \times 10^{-7} M$
    b. greater than $1.0 \times 10^{-7} M$
    c. $1.0 \times 10^{-7} M$

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The pH Concept

13. The *pH* of a solution is the negative logarithm of the hydrogen-ion concentration.

14. Match the type of solution with its pH.

c	acidic	**a.** pH > 7.0
b	neutral	**b.** pH = 7.0
a	basic	**c.** pH < 7.0

15. Look at Table 19.5. What is the approximate $[H^+]$, the $[OH^-]$, and the pH of household ammonia?

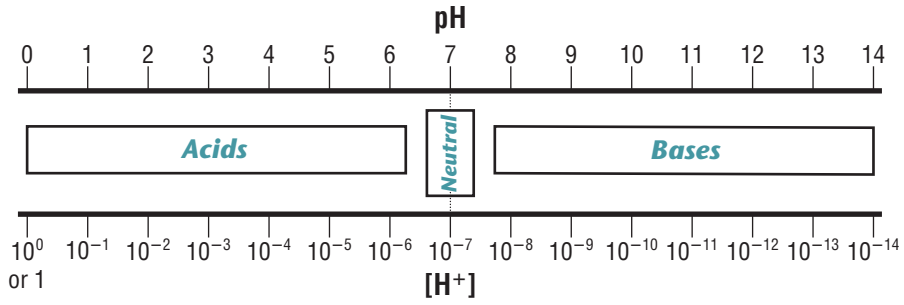
1×10^{-12} mol/L, 1×10^{-2} mol/L, and 11.5

16. The pOH of a solution is the negative logarithm of the *hydroxide ion* concentration.

17. What is the pOH of a neutral solution? *7*

18. For pH calculations, in what form should you express the hydrogen-ion concentration?
scientific notation

19. Look at the pH scale below. Label where you would find acids, bases, and neutral solutions.



20. Is the following sentence true or false? Most pH values are whole numbers.
false

21. If $[H^+]$ is written in scientific notation but its coefficient is not 1, what do you need to calculate pH?

You need either a table of common logarithms or a calculator with a log function key.

22. Is the following sentence true or false? You can calculate the hydrogen-ion concentration of a solution if you know the pH. *true*

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Measuring pH

23. When do you use indicators and when do you use a pH meter to measure pH?

You use indicators for preliminary measurements and for small-volume samples. You use a pH meter for precise and continuous measurements.

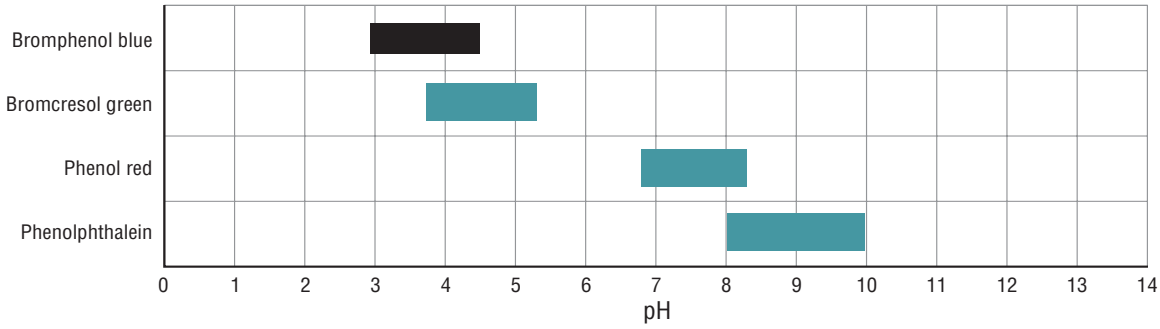
24. Why is an indicator a valuable tool for measuring pH?

It is a valuable tool for measuring pH because its acid form and base form have different colors in solution.

25. Why do you need many different indicators to span the entire pH spectrum?

For each indicator, the change from dominating acid form to dominating base form occurs in a narrow range of approximately two pH units.

26. Look at the figure below. Fill in the missing pH color change ranges for the indicators.



27. List three characteristics that limit the usefulness of indicators.

a. *At temperatures other than 25°C, an indicator may change color at a different pH.*

b. *Indicator color can be distorted if a solution is not colorless.*

c. *Dissolved salts in a solution can affect the dissociation of the indicator.*

28. What is the pH of each of the following liquids?

a. water *7*

b. lemon juice *2.5*

c. milk of magnesia *10.5*

29. Is the following sentence true or false? Measurements of pH obtained with a pH meter are typically accurate to within 0.001 pH unit of the true pH. *false*

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19.3 Strengths of Acids and Bases

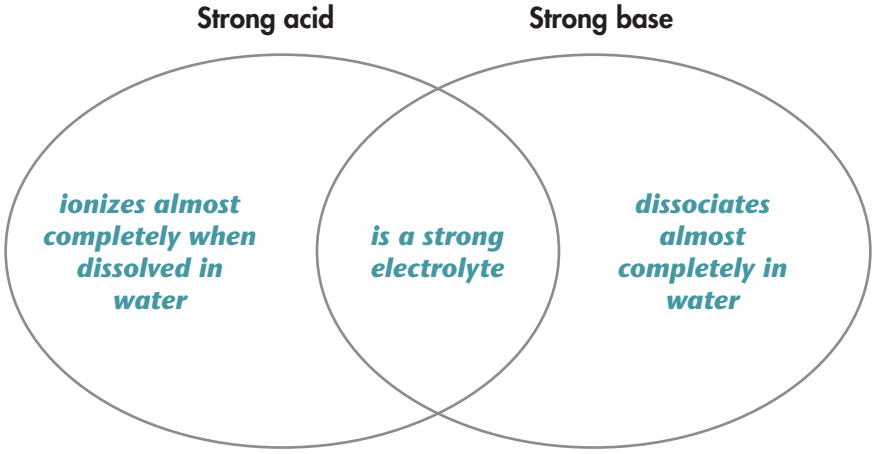
For students using the Foundation edition, assign problems 2, 3, 7–10, 12, 13, 16.

Essential Understanding The strength of acids and bases is determined by the degree to which they ionize in water solution.

Reading Strategy

Venn Diagram A Venn diagram is a useful tool in visually organizing related information. A Venn diagram shows which characteristics the concepts share and which characteristics are unique to each concept.

As you read Lesson 19.3, complete the Venn diagram by comparing and contrasting acids and bases.



Lesson Summary

Strong and Weak Acids and Bases The strength of acids and bases depends on the degree to which they ionize.

- Strong acids ionize completely; weak acids only ionize slightly.
- The acid and base dissociation constants K_a and K_b are measures of the strength of an acid or base.

After reading Lesson 19.3, answer the following questions.

Strong and Weak Acids and Bases

1. What factor is used to classify acids as strong or weak?

   Acids are classified by the degree to which they ionize in water.

2. Strong acids are *completely* ionized in aqueous solution; weak acids ionize *only slightly* in aqueous solution.

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3. Look at Table 19.6. Which acid is the weakest acid in the table? Which base is the weakest base?

Hypochlorous acid is the weakest acid. Ammonia is the weakest base.

4. What do you use to write the equilibrium-constant expression?

You use a balanced chemical equation.

5. An acid dissociation constant (K_a) is the ratio of the concentration of the ***dissociated*** form of an acid to the concentration of the ***undissociated*** form.

6. What is another name for dissociation constants?

Another name is ionization constants.

7. Is the following sentence true or false? The stronger an acid is, the smaller its K_a value. ***false***

8. A diprotic acid has ***two*** dissociation constants.

9. Look at Table 19.7. What is the second dissociation constant for the triprotic phosphoric acid? $K_a = 6.2 \times 10^{-8}$

10. Is the following sentence true or false? You can calculate the acid dissociation constant (K_a) of a weak acid from experimental data. ***true***

11. To measure the equilibrium concentrations of all substances present at equilibrium for a weak acid, what two conditions must you know?

You must know the initial molar concentration of the acid and the pH (or $[H_3O^+]$) of the solution at equilibrium.

12. Weak bases react with water to form the hydroxide ion and the ***conjugate acid*** of the base.

13. A base dissociation constant (K_b) is the ratio of the concentration of the ***conjugate acid*** times the concentration of the hydroxide ion to the concentration of the ***conjugate base***.

14. What does the magnitude of the base dissociation constant (K_b) indicate?

It indicates the ability of a weak base to compete with the very strong base OH^- for hydrogen ions.

15. The words *concentrated* and *dilute* indicate how much acid or base is ***dissolved*** in solution.

16. Is the following sentence true or false? The words *strong* and *weak* refer to the extent of ionization or dissociation of an acid or base. ***true***

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19.4 Neutralization Reactions

For students using the Foundation edition, assign problems 1–3, 5, 7–9.

Essential Understanding In a neutralization reaction, a strong acid and strong base produce a neutral solution.

Lesson Summary

Acid-Base Reactions Generally, an acid reacts with a base to form a salt and water.

- A salt is an ionic compound formed from the positive ion of the base and the negative ion of the acid.
- The salt formed from the neutralization of HCl and NaOH is NaCl, which is commonly called table salt.

Titration The pH of an acid or base can be determined by running a titration.

- An acid-base indicator is used to determine the equivalence point of the titration.
- By using careful measurements and calculations, the concentration of the unknown can be determined.

After reading Lesson 19.4, answer the following questions.

Acid–Base Reactions

1. Is the following sentence true or false? Acids react with compounds containing hydroxide ions to form water and a salt. ***true***
2. What does the reaction of an acid with a base produce?

   It produces water and a salt.
3. In general, reactions in which an acid and a base react in an aqueous solution to produce a salt and water are called ***neutralization*** reactions.
4. When is a neutralization reaction complete?

   when the solution contains equal numbers of hydrogen ions and hydroxide ions
5. Salts are compounds consisting of a(n) ***anion*** from an acid and a(n) ***cation*** from a base.

Titration

6. How can you determine the concentration of an acid or base in a solution?

   You can perform a neutralization reaction.

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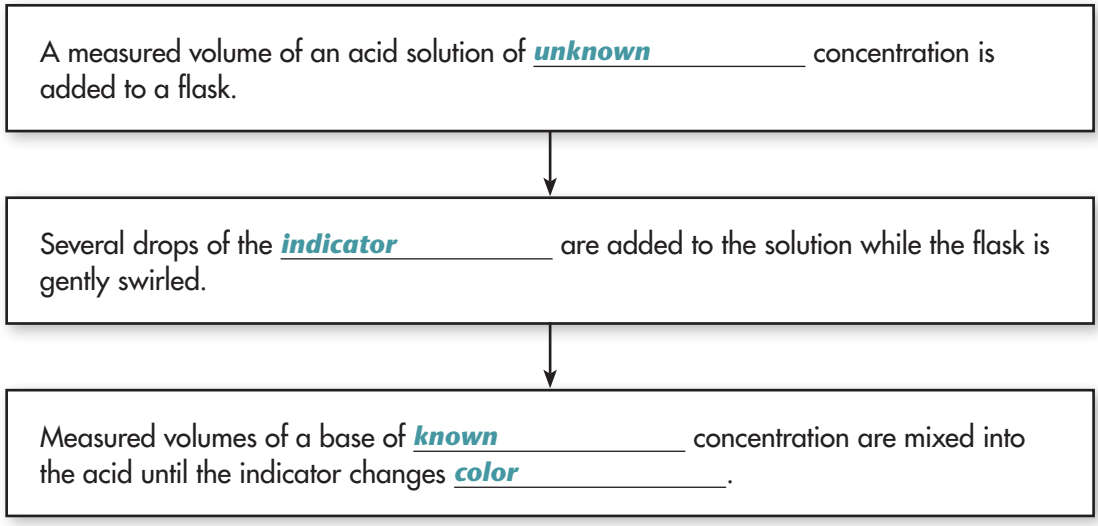
7. Complete the flow chart below showing the steps of a neutralization reaction.



8. The process of adding a known amount of solution of known concentration to determine the concentration of another solution is called ***titration***.

9. What is the solution of known concentration called?

It is called the standard solution.

19.5 Salts in Solution

For students using the Foundation edition, assign problems 2, 4, 5.

Essential Understanding Salts in solution may be neutral, acidic, or basic depending on the acid and base from which they formed.

Lesson Summary

Salt Hydrolysis When salts dissolve in water, the ions produced react with hydrogen ions from water.

- If a salt donates hydrogen ions to water, it will produce an acidic solution.
- If a salt removes hydrogen ions from water, it will produce a basic solution.

Acidic or Basic Salt Solution?	
Acid + Base →	**Salt solution**
Strong acid + Strong base →	Neutral solution – neither reactant is stronger
Strong acid + Weak base →	Acidic solution – will donate more hydrogen ions
Weak base + Strong acid →	Basic solution – will remove more hydrogen ions

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Buffers A buffer is a solution that can absorb small amounts of acids or bases without significant change in pH.

- A buffer contains a weak acid and one of its salts or a weak base and one of its salts.
- The weak acid can donate H^+ ions to neutralize the addition of a base, while the salt cation will neutralize an added acid by removing H^+ ions.

After reading Lesson 19.5, answer the following questions.

Salt Hydrolysis

1. What is salt hydrolysis?

Salt hydrolysis occurs when the cations or anions of a dissociated salt remove hydrogen ions from or donate hydrogen ions to water.

2. Complete this table of the rules for hydrolysis of a salt.

Reactants	Products
Strong acid + *Strong* base	Neutral solution
Strong acid + Weak base	*Acidic* solution
Weak acid + *Strong* base	Basic solution

Buffers

3. What are buffers?

Buffers are solutions in which the pH remains relatively constant when small amounts of acid or base are added.

4. A buffer is a solution of a *weak* acid and one of its salts, or a solution of a *weak* base and one of its salts.

5. Is the following sentence true or false? The buffer capacity is the amount of acid or base that can be added to a buffer solution before a significant change in pH occurs.
true

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Guided Practice Problems

Answer the following questions about Practice Problem 17b.

Calculate the pH of this solution: $[OH^-] = 8.3 \times 10^{-4} M$.

Step 1. Identify the known and unknown values.

Known

$[OH^-] =$ **8.3** $\times 10^{-4} M$

Unknown

pH = ?

Step 2. Calculate the $[OH^-]$ using the K_w equation.

$$K_w = [OH^-] \times [H^+]$$

$$[H^+] = \frac{K_w}{[OH^-]}$$

$$[H^+] = \frac{1 \times 10^{-14}}{8.3 \times 10^{-4}}$$

$$= 1.2 \times 10^{-11}$$

Step 3. Substitute values into the pH equation.

$$pH = -\log [H^+]$$

$$= -\log (1.2 \times \boxed{10^{-11}})$$

Step 4. The logarithm of a product equals the sum of the logs of its factors.

$$= -(\log \boxed{1.2} + \log \boxed{10^{-11}})$$

Step 5. Evaluate log 1.2 by using a calculator. Evaluate log 10^{-11} by using the definition of logarithm.

$$= -(0.079 + \boxed{-11})$$

Step 6. Add and simplify. Write your answer with two significant figures to the right of the decimal point.

$$= -(-10.921) = \boxed{10.92}$$

Answer the following questions about Practice Problem 26.

In a 0.1000*M* solution of methanoic acid, $[H^+] = 4.2 \times 10^{-3} M$. Calculate the K_a of methanoic acid.

Analyze

Step 1. What is known about the acid?

It is a 0.1M solution, $[H^+] = 4.2 \times 10^{-3}$M, and the equation for dissociation is $HCOOH \rightleftharpoons HCOO^- + H^+$.

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Step 2. What is the unknown? K_a

Step 3. What is the expression for the K_a of methanoic acid?

$$K_a = \frac{[HCOO^-] \times [H^+]}{[HCOOH]}$$

Calculate

Step 4. What expression can you write to find the equilibrium concentration of HCOOH?

$0.1000 - 4.2 \times 10^{-3} - 0.0958$

Step 5. Substitute values into the formula for K_a and solve.

$$K_a = \frac{(4.2 \times 10^{-3}) \times (4.2 \times 10^{-3})}{0.09508} = \frac{1.764 \times 10^{-5}}{0.0958}$$

$$= 184.1 \times 10^{-6} = 1.8 \times 10^{-4}$$

Evaluate

Step 6. Look at Table 19.7. Explain why your answer is reasonable.

The value for K_a is the same as the one given in the table.

Extra Practice

Find the value of $[OH^-]$ for a solution with a pH of 8.00.

If pH = 8.00, pOH = 6.00 because pH + pOH = 14.

$pOH = -\log [OH^-]$

$6.00 = -\log [OH^-]$

$-6.00 = \log [OH^-]$

$10^{-6.00} = 10^{\log [OH^-]}$

$[OH^-] = 10^{-6}$

Apply the Big idea

How many moles of H_2SO_4 are needed to neutralize 1.56 moles of KOH?

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

$$1.56 \text{ moles} \times \frac{2 \text{ moles KOH}}{1 \text{ mole } H_2SO_4} = 3.12 \text{ moles KOH}$$

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19 Self-Check Activity

For Questions 1–11, complete each statement by writing the correct word or words. If you need help, you can go online.

19.1 Acid–Base Theories

1. According to Arrhenius, acids ionize to yield ***hydrogen ions (H^+)*** and bases ionize to yield ***hydroxide ions (OH^-)*** in aqueous solution.
2. According to the Brønsted-Lowry theory, an acid is a hydrogen-ion ***donor***, and a base is a hydrogen-ion ***acceptor***.
3. According to Lewis, an acid is an electron-pair ***acceptor***, and a base is an electron-pair ***donor***.

19.2 Hydrogen Ions and Acidity

4. For an aqueous solution, the product of $[H^+]$ and $[OH^-]$ equals ***1×10^{-14}***.
5. A solution with a pH less than 7.0 is ***acidic***. A solution with a pH of 7 is ***neutral***. A solution with a pH greater than 7.0 is ***basic***.
6. Either acid-base ***indicators*** or pH meters can be used to measure pH.

19.3 Strengths of Acids and Bases

7. Acids and bases are classified as strong or weak based on the degree to which they ***ionize*** in water.

19.4 Neutralization Reactions

8. In general, acids and bases react to produce a ***salt*** and ***water***.
9. Neutralization will occur when the number of moles of ***hydrogen ions*** is equal to the number of moles of ***hydroxide ions***.

19.5 Salts in Solution

10. Salts that produce ***acidic*** solutions have positive ions that release hydrogen ions to water. Salts that produce ***basic*** solutions have negative ions that attract hydrogen ions from water.
11. A buffer is a solution of a ***weak acid*** and one of its salts or a ***weak base*** and one of its salts.

If You Have Trouble With…											
Question	1	2	3	4	5	6	7	8	9	10	11
See Page	646	649	651	654	656	660	664	672	674	677	678

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Review Key Equations

Read the answer and find the question that matches.

Answer	Question
E 1. 0.08 M H_2SO_4	A. Which represents the ion product constant for water?
A 2. $[H^+] \times [OH^-] = 1 \times 10^{-14}$	B. What is the definition of pH?
G 3. 0.1 M NH_4OH	C. How do you measure pH?
C 4. indicator or meter	D. Which represents the acid dissociation constant?
F 5. 10 M CH_3COOH	E. Which is an example of a strong acid?
B 6. $-\log[H^+]$	F. Which is an example of a concentrated acid?
D 7. $\frac{[H^+] \times [A^-]}{[HA]}$	G. Which is an example of a basic salt?

Review Vocabulary

Choose a synonym from the list below for each of the four vocabulary words. Then come up with a way that will help you remember the meaning of the words. One has been done for you.

linked | split water | cushion | disconnect

Vocabulary	Synonym	How I'm going to remember the meaning
dissociation	disconnect	Dissociated ions are disconnected.
conjugate	*linked*	*An acid and its conjugate are linked as a pair.*
hydrolysis	*split water*	*In hydrolysis, water molecules are split into H^+ and OH^-.*
buffer	*cushion*	*A buffer solution is a cushion against pH changes.*