
acid
base
reaction
pH
water
ions
solution
Lewis
bases
strong
acids
Arrhenius
weak
concentration
hydroxide
hydronium
Submicroscopic
submicroscopic
titration
Activity
following
molecules
theory
questions
observations
substances
evidence
Simulation
substance
simulation
equivalence
Observations
Sketch
scale
answer
point
Key
Support
explain
Base
Acid
solutions
Chemical
acidic
change
proton
Formula
reactant
graph
level
Use
sketch
conjugate
unknown
Weak
produced
pOH
theories
basic
time
answers
example
use
many
macroscopic
Strong
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reactions
electron
added
hydrogen
using
think
lab
curve
seconds
sketches
donated
create
accepted
Demonstration
Connecting
pair
different
changes
Based
claim
dissociate
foods
measure
called
formed
definition
Discussion
produce
Facilitated
Teacher
compounds
neutralization
sure
simulations
circle
body
amount
aqueous
chemists
buffers
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compound
color
number
Record
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ReactionAfter
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contain
just
Reaction
perspective
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include
classified
View
add
Calculate
ion
difference
adding
Key

The Connected Chemistry Curriculum

Acknowledgements

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The Connected Chemistry Curriculum

Technology

System Requirements

The Connected Chemistry Curriculum has a software component (a set of *Simulations*) which is available at The Connected Chemistry Curriculum website, connchem.org. This software is necessary to use the curriculum, and is open-source and free of charge.

Besides the CCC software, you will need:

- **A personal computer of recent vintage, with an OpenGL-enabled graphics card.**
- **A 13" screen (or larger), with at least 1280 × 800 (WXGA) pixel resolution**
  For most computer monitors this is not a problem. Projectors, on the other hand, sometimes only manage VGA resolution (640 x 480), which will not allow sufficient room for our Simulations.
- **The latest Java runtime environment (JRE)**
  As of this writing, the latest JRE is Java 6, version 29. Java is free of charge: http://www.java.com/en/download/
- **Macintosh OS X 10.6 (Snow Leopard) or later, or Windows 7 or later**
  Earlier versions of the Macintosh OS or Windows may run, but may suffer performance issues. The software should also run on Linux. None of these options have been tested, however, so make sure you run all simulations before using them live in the classroom.

Troubleshooting

Please consult The Connected Chemistry Curriculum website (connchem.org) for up-to-date troubleshooting information, and to download software

The Connected Chemistry Curriculum

Welcome

Welcome to *The Connected Chemistry Curriculum*! The Connected Chemistry Curriculum, or CCC, is designed to help students learn about chemistry by directly exploring the submicroscopic level of matter and phenomena that form the basis of study in chemistry. Educators designed CCC using direct feedback from teachers, students and researchers. CCC uses computer-based simulations to provide a unique submicroscopic perspective of the chemical world for students.

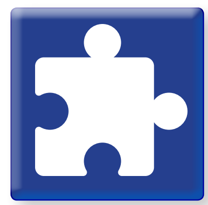
Activity Icons

These icons will be found throughout the teacher and student manuals.
The icons designate the purpose/theme of the activity or section.

Connecting

Hands-On Activity

Student Simulations

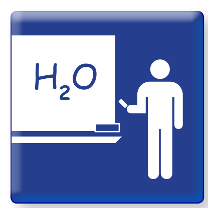


Putting It All Together

Questions

Lab Safety

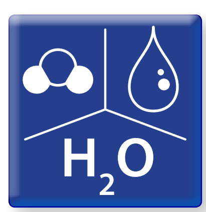
Sketching (without simulations)



Teacher Demonstration

Wet Lab

Teacher Facilitated Discussion



Chemistry Levels

Introductory Reading

Connected Chemistry
Acids & Bases Unit
Contents

Connected Chemistry
Acids & Bases Unit
Lesson 1: Arrhenius Theory

Student's Lesson at a Glance

Lesson Summary

This lesson contains four activities that overview the Arrhenius theory of acids and bases. Following a Connecting Activity, the teacher performs a demonstration on two unknown clear liquids to determine the pH before and after mixing. During this time, students make predictions about what they think is happening on a submicroscopic level. Students explore three sets of reactions via the computer simulations. Students are asked to create sketches and record observations. The lesson concludes with a teacher-facilitated discussion of the limitations of Arrhenius theory.

SWBAT (Students Will Be Able To)

- Know that the Arrhenius theory states that acids generate H^+ ions (H_3O^+) and bases generate OH^- ions in water
- Apply Arrhenius theory to simulated reactions and identify the theory's limitations

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Don't forget to follow the CCC sketching observation protocol. When appropriate in your written observations, include the location, motion, interaction, and appearance of molecules.
- Ions will have halos in the simulation. When drawing keys for sketches, make sure to include halos for ions only.
- Hydroxide and hydronium are easily confused when naming ions. Hydroxide ions are OH^- and hydronium ions are H_3O^+.
- You will need to know how to write ionic equations. Review your notes in Solutions and Reactions unit for help.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. What do you think is the difference between an acid and a base?

2. What characteristics do you think are common in foods that are acidic?

3. Why is it nearly impossible to measure the concentration of hydrogen ions (H^+) in a solution?

Acids and bases are everywhere in our daily lives. Oranges and lemons contain citric acid, while antacids contain magnesium hydroxide. Recall that the definition of acids and bases has a relationship with the concentration of hydronium ions (H_3O^+). In this lesson, we will explore the behavior and definition of acid and base molecules at the submicroscopic level.

Many years ago, chemists attempted to define acids and bases on the submicroscopic level by proposing three major theories that explained macroscopic observations in the laboratory. In the next two lessons, you will examine these theories – the Arrhenius, Brønsted-Lowry and Lewis theories – of acids and bases. Your observations of teacher demonstrations, formulas, and simulations will help you learn the differences and relationships among these three theories according to the submicroscopic behavior of acidic and basic substances.

In 1884, Svante Arrhenius proposed a theory that defined acids and bases from his study of ion formation in aqueous solutions. He studied the dissociation of ionic compounds in water. Recall that dissociation is the process by which ionic compounds separate into their component ions. Arrhenius constructed definitions for acids and bases from his data:

- An **acid** is a substance that dissociates in water to produce one or more hydrogen ions (H^+).
- A **base** is a substance that dissociates in water to produce

one or more hydroxide ions (OH^-).

Recall that today, chemists have discovered that H^+ ions only exist for very extremely short time periods before forming H_3O^+ ions in water in the following equilibrium reaction.

$$H^+ (aq) + H_2O (l) \rightleftharpoons H_3O^+ (aq)$$

Given this, modern version of the Arrhenius' definition is as follows:

- An **acid** is a substance that dissociates in water to produce one or more hydronium ions (H_3O^+).
- A **base** is a substance that dissociates in water to produce one or more hydroxide ions (OH^-).

4. Using the modern Arrhenius' definition of an acid, identify the acid in the following reaction:

$$HNO_3 (aq) + H_2O (l) \rightarrow H_3O^+ (aq) + NO_3^- (aq)$$

5. Arrhenius' definition of acid and bases was partially incorrect. In science, it is common for scientists to later revise their explanations or solutions to a problem. Why is the process of trial and error important in scientific research?

Activity 2: Demonstration

Demonstration: *Your teacher will run a series of demonstrations that involve acidic and basic solutions. Answer the following questions as your teacher conducts each demonstration.*

Clear liquid #1	Clear liquid #2
6. What is the pH of this solution? **acidic or basic** 7. What color is the litmus paper when it touches the liquid? ____________________ 8. What happens when the indicator is added to the solution? ____________________ ____________________ ____________________ ____________________	9. What is the pH of this solution? **acidic or basic** 10. What color is the litmus paper when it touches the liquid? ____________________ 11. What happens when the indicator is added to the solution? ____________________ ____________________ ____________________ ____________________

Mixture of liquid #1 and liquid #2

12. What is the pH of this solution? **acidic or basic**

13. What is the color of the litmus paper when it touches the liquid?

____

14. What happens when the indicator is added to the solution?

____

____

____

15. Sketch how you think each solution appears at the submicroscopic level before and after mixing. Be sure to include a key.

	Before Mixing	After Mixing
Submicroscopic Sketches	HCl (aq)	
	NaOH (aq)	
Key		

16. Why might it be difficult to classify different substances as acids or bases based only on how they appear on the macroscopic level?

Activity 3: Simulation of Arrhenius Theory

Set 1: *Use Simulation 1, **Set 1***

For each of the following sets:

- *Create a submicroscopic sketch before the reaction is started.*
- *Play the simulation for 10 seconds, pause the simulation, and create a submicroscopic sketch.*
- *Record your observations and create a key.*

	Before (at time 0 seconds)	**After** (at time 15 seconds)
Submicroscopic Sketch		
Complete Ionic Equation		
	Observations	
	Key	

Using your sketches and observations, answer the following questions.

17. Were hydronium ions (H_3O^+) produced when HCl dissociated in water? If so, which substance in water created the H_3O^+ ions?

18. Were hydroxide ions (OH-) produced when HCl dissociated in water? If so, which substance in water produced the OH- ions?

19. Why is water included in the chemical equation?

20. Is HCl an Arrhenius acid or an Arrhenius base? *Support your claim with evidence.*

Set 2: *Use Simulation 1, **Set 2***

	Before (at time 0 seconds)	After (at time 15 seconds)
Submicroscopic Sketch		
Complete Ionic Equation		
Observations		
Key		

Using your sketches and observations, answer the following questions.

21. Were hydronium ions (H_3O^+) produced when NaOH dissociated in water? If so, which substance in water created the H_3O^+ ions?

22. Were hydroxide ions (OH^-) produced when NaOH dissociated in water? If so, which substance in water produced the OH^- ions?

23. Why is water included in the chemical equation?

24. Is NaOH an Arrhenius acid or Arrhenius base? *Support your claim with evidence.*

Set 3: *Use Simulation 1, **Set 3***

	Before (at time 0 seconds)	**After** (at time 15 seconds)
Submicroscopic Sketch		
Complete Ionic Equation		

Observations

Key

Using your sketches and observations, answer the following questions.

25. Were hydronium ions (H_3O^+) produced in the reaction? If so, which substance in water created the H_3O^+ ions?

26. Were hydroxide ions (OH^-) produced in the reaction? If so, which substance in water produced the OH^- ions?

27. What would you expect the final pH of the solution to be after mixing? *Support your claim with evidence.*

Activity 4: Teacher Facilitated Discussion

28. How are the reactions in set 1 and 2 different from the reaction in set 3 above?

29. In the reaction in set 3 above, if you evaporate all of the water from the solution that forms "after mixing," what compound would be left behind as a solid?

30. Do you think that all acids and bases dissociate in the exact same way when they are dissolved in water? *Support your claim with evidence.*

Lesson Reflection Question

31. What are the limitations of the Arrhenius theory?

Student's Lesson at a Glance

Lesson Summary

This lesson contains six activities that offer an extensive overview of the Brønsted-Lowry and Lewis theories of acids and bases. Following a Connecting Activity, teachers can demonstrate how to use a submicroscopic simulation to differentiate the theories. In this simulation, the user can switch between the Brønsted-Lowry view of an acid-base reaction and the Lewis view of the same reaction. Students continue the lesson by creating working definitions of these two theories and further explore other reactions via computer simulations to better understand the different acid-base perspectives. Students create detailed sketches and record observations. Students apply the theories to identify different substances. In the final activity, students complete a Venn diagram of the theories as well as a final review of the limitations of each model.

SWBAT (Students Will Be Able To)

- Compare and contrast the Arrhenius, Brønsted-Lowry, and Lewis theories of acids
- Know that the Arrhenius theory states that acids generate H^+ (H_3O^+) ions and bases generate OH^- ions in water
- Know that according to the Brønsted-Lowry theory of acids, acids donate protons and bases accept protons
- Know that the Lewis acids are electron acceptors and bases are electron donors

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

Do not forget to follow the CCC sketching observation protocol. When appropriate, include the location, motion, interaction, and appearance of molecules in your written observations.

- Ions will have halos in the simulation. When drawing keys for sketches, make sure to include halos only for ions.
- Hydroxide and hydronium are easily confused when naming ions. Hydroxide ions are OH^- and hydronium ions are H_3O^+.
- This lesson includes activities that involve writing complete and net ionic equations. Review your notes from the Solutions and Reactions Units for help with writing equations.
- In Simulation 2, the Brønsted-Lowry view focuses on the submicroscopic level. For the Lewis view, you will focus on the subatomic level. You will be able to view the electrons on the subatomic level.
- A Venn diagram is a group of circles that overlap to compare and contrast ideas. Similarities are placed in the area where the circles overlap. Differences are placed on the areas where the circles do not overlap.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. In your own words, define an acid and a base.

Introduction to Brønsted-Lowry and Lewis Theories

The Arrhenius theory of acids and bases was a milestone in the history of chemistry. However, this theory is quite specific and does not account for all situations. There are three limitations with Arrhenius theory. First, Arrhenius defined an acid as a substance that produces free protons (H^+) in water. However, free protons do not exist for long in aqueous solutions since they form hydronium (H_3O^+) ions almost immediately with water.

Second, Arrhenius theory only explains the acidic or basic nature of substances that are soluble in water. The theory cannot explain whether substances that are insoluble in water or substances dissolved in solvents other than water are acidic or basic. For example, hydrochloric acid (HCl) is defined as an acid when it is dissolved in water according to Arrhenius theory. But when HCl is dissolved in a solvent other than water, it cannot produce hydronium ions because there are no water molecules present to react with H^+ ions. In this case, it becomes unclear how to define HCl as an acid.

Finally, Arrhenius theory indicates that acids and bases must produce hydronium (H_3O^+) ions or hydroxide (OH^-) ions, respectively. However, some substances, such as aluminum trichloride ($AlCl_3$), do not contain hydrogen atoms of their own, yet still have acidic properties! Similarly, ammonia (NH_3) and a few other substances behave as bases even though they contain no hydroxide ions. Since the Arrhenius definition of an acid and base limits how a chemist classifies acids and bases, a new theory for classification was needed. Two new theories of acids and bases were proposed that are more general than the Arrhenius theory. These theories can account for the acidic and basic properties of many more substances.

In 1923 on nearly the same date, two chemists, Johannes Nicolaus Brønsted, a scientist from Denmark, and Thomas Martin Lowry, a scientist from England, published nearly identical theories about acids and bases. Because of this, both of the scientists are recognized as the discoverers of the Brønsted-Lowry theory of acids and bases. In formulating the theory, Brønsted stated that ". . . acids and bases are substances that are capable of splitting off or taking up hydrogen ions, respectively." In other words, the Brønsted-Lowry theory defines acids as **proton**

donors and bases as **proton acceptors**.

Sometime later, Gilbert Lewis recognized that there were limitations to the Brønsted-Lowry theory similar to the limitations of Arrhenius theory. Specifically, Lewis argued that the Brønsted-Lowry theory could not account for acidic or basic substances that did not have protons in their molecular structure. In 1938, he presented a theory that included substances that contained no protons. The Lewis theory classified acids and bases on the movement of pairs of electrons rather than the movement of protons. Lewis' theory focuses on the *subatomic* level and defined acids as **electron pair acceptors** and bases as **electron pair donors**.

2. What is the difference between a Brønsted-Lowry acid and a Brønsted-Lowry base?

3. What is the difference between a Lewis acid and a Lewis base?

4. What do you think the relationship is between the Brønsted-Lowry and Lewis theories of acids and bases?

5. What are the limitations of the Brønsted-Lowry and Lewis theories?

Activity 2: Brønsted-Lowry and Lewis Theories

Demonstration: *Use Simulation 2,* ***Set 1***

This simulation highlights the differences between the Brønsted-Lowry and Lewis theories on the submicroscopic level.

- *Before your teacher plays the simulation, predict the products of the reaction in the chemical equation. Be sure to include phases.*
- *Your teacher will first select "Brønsted-Lowry" to demonstrate the theory.*
- *Before the reaction plays in the simulation, create a submicroscopic sketch of what you observe. Be sure to include a key.*
- *Your teacher will then play the reaction in the simulation.*
- *After the reaction stops, create a submicroscopic sketch of what you observed. Be sure to include a key.*
- *Your teacher will then change the view to "Lewis" to demonstrate acid and base behavior. You should repeat the procedure of sketching and recording your observations as you did with the Brønsted-Lowry view.*

View #1: Brønsted-Lowry theory

	Before	After
Submicroscopic Sketch		

Chemical Equation

$NaOH\ (s) + HCl\ (g) \rightarrow$ ____________________

Observations

Key

View # 2: Lewis theory

	Before	After
Submicroscopic Sketch		

Chemical Equation (same as previous page)

$NaOH\ (s) + HCl\ (g) \rightarrow$ ______________________

Observations

Key

6. Which reactant donated a proton? *Explain your answer.*

7. Which reactant accepted a proton? *Explain your answer.*

8. Which reactant donated an electron pair? *Explain your answer.*

9. Which reactant accepted an electron pair? *Explain your answer.*

In the following two questions, circle all answers that are applicable.

10. In the reaction, HCl is a:

    a. Brønsted-Lowry acid
    b. Brønsted-Lowry base
    c. Lewis Acid
    d. Lewis Base

    Support your answer with evidence.

11. In the reaction, NaOH is a:

    a. Brønsted-Lowry acid
    b. Brønsted-Lowry base
    c. Lewis Acid
    d. Lewis Base

    Support your answer with evidence

Activity 3: Simulating Brønsted-Lowry and Lewis Theories

Part 1: *Use Simulation 2,* ***Set 2***

For each of the following sets:

- *Predict the products of the reaction in the chemical equation space below the sketching area.*
- *For both Brønsted-Lowry and Lewis views, complete before and after sketches. Record your observations as you did during the demonstration in Activity 2. Make sure to include a key.*
- *Use your sketches and observations to answer the analysis questions.*

View #1: Brønsted-Lowry perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation

$HCl\ (g) + NH_3\ (g) \rightarrow$ ____________________

Observations

Key

View #2: Lewis perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation (same as previous page)

$HCl\,(g) + NH_3\,(g) \rightarrow$ ______________________

Observations

Key

12. Which reactant donated a proton? *Explain your answer.*

13. Which reactant accepted a proton? *Explain your answer.*

14. Which reactant donated an electron pair? *Explain your answer.*

15. Which reactant accepted an electron pair? *Explain your answer.*

For the following questions, circle all answers that are applicable.

16. In the reaction, HCl is a:

a. Brønsted-Lowry acid
b. Brønsted-Lowry base
c. Lewis Acid
d. Lewis Base

Support your answer with evidence.

17. In the reaction, NH_3 is a:

a. Brønsted-Lowry acid
b. Brønsted-Lowry base
c. Lewis Acid
d. Lewis Base

Support your answer with evidence

Part 2: *Use Simulation 2, **Set 3***

View #1: Brønsted-Lowry perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation

$CN^{-}(g) + HBr(g) \rightarrow$ ____________________

Observations

Key

View #2: Lewis perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation (same as previous page)

$CN^{-}\,(g) + HBr\,(g) \rightarrow$ ____________________

Observations

Key

18. Which reactant donated a proton? *Explain your answer.*

19. Which reactant accepted a proton? *Explain your answer.*

20. Which reactant donated an electron pair? *Explain your answer.*

21. Which reactant accepted an electron pair? *Explain your answer.*

For the following questions, circle all answers that are applicable.

22. In the reaction, HBr is a:

 a. Brønsted-Lowry acid
 b. Brønsted-Lowry base
 c. Lewis Acid
 d. Lewis Base

 Support your answer with evidence.

23. In the reaction, CN^- is a:

 a. Brønsted-Lowry acid
 b. Brønsted-Lowry base
 c. Lewis Acid
 d. Lewis Base

 Support your answer with evidence

Activity 4: Demonstration

Demonstration: *Use Simulation 2, **Set 4***

For the following sets:

- *Your teacher will demonstrate the simulation.*
- *Complete sketches, create a key, and record your observations as you did in the previous activity.*
- *Use your sketches and observations to answer the analysis questions.*

View #1: Brønsted-Lowry perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation

$BCl_3\,(g) + Cl^-\,(g) \rightarrow$ ____________________

Observations

Key

View #2: Lewis perspective

	Before	After
Submicroscopic Sketch		

Chemical Equation (same as previous page)

$BCl_3\,(g) + Cl^-\,(g) \rightarrow$ ______________________

Observations

Key

24. At a glance, what do you notice about the reaction above that is different from the previous three sets?

25. Which reactant donated a proton? *Explain your answer.*

26. Which reactant accepted a proton? *Explain your answer.*

27. Which reactant donated an electron pair? *Explain your answer.*

28. Which reactant accepted an electron pair? *Support your answer with evidence.*

29. In the reaction, BCl_3 is a:

   a. Brønsted-Lowry acid

   b. Brønsted-Lowry base

   c. Lewis Acid

   d. Lewis Base

   Support your answer with evidence.

30. In the reaction, Cl^- is a:

   a. Brønsted-Lowry acid

   b. Brønsted-Lowry base

   c. Lewis Acid

   d. Lewis Base

   Support your answer with evidence

Activity 5: Putting It All Together

Applying Different Acid and Base Theories

Look at the following reactions and determine which theory (Arrhenius, Brønsted-Lowry, or Lewis) can describe the reactants. More than one theory may apply!

Teacher Example

$$HNO_3\ (aq) + H_2O\ (l) \rightarrow H_3O^+\ (aq) + NO_3^-\ (aq)$$

For the following questions, circle all answers that are applicable.

31. In the reaction, HNO_3 is a:

 a. Arrhenius acid
 b. Arrhenius base
 c. Brønsted-Lowry acid
 d. Brønsted-Lowry base
 e. Lewis acid
 f. Lewis base

 Support your answer with evidence.

32. In the reaction, H_2O is a:

 a. Arrhenius acid
 b. Arrhenius base
 c. Brønsted-Lowry acid
 d. Brønsted-Lowry base
 e. Lewis acid
 f. Lewis base

 Support your answer with evidence.

$$HCl\ (aq) + NaSCN\ (s) \rightarrow HSCN\ (aq) + NaCl\ (g)$$

33. In the reaction, SCN^- is a:

 a. Arrhenius acid
 b. Arrhenius base
 c. Brønsted-Lowry acid
 d. Brønsted-Lowry base
 e. Lewis acid
 f. Lewis base

 Support your answer with evidence.

34. In the reaction, HCl^- is a:

 a. Arrhenius acid
 b. Arrhenius base
 c. Brønsted-Lowry acid
 d. Brønsted-Lowry base
 e. Lewis acid
 f. Lewis base

 Support your answer with evidence.

For the following questions, circle all answers that are applicable.

$$LiCN\ (aq) + H_2O\ (l) \rightarrow HCN\ (aq) + LiOH\ (aq)$$

35. In the reaction, H_2O is a:

    a. Arrhenius acid
    b. Arrhenius base
    c. Brønsted-Lowry acid
    d. Brønsted-Lowry base
    e. Lewis acid
    f. Lewis base

    Support your answer with evidence.

36. In the reaction, CN^- is a:

    a. Arrhenius acid
    b. Arrhenius base
    c. Brønsted-Lowry acid
    d. Brønsted-Lowry base
    e. Lewis acid
    f. Lewis base

    Support your answer with evidence.

With your knowledge of the different acid/base theories, try the following questions independently.

$$HBr\ (aq) + H_2O\ (l) \rightarrow H_3O^+\ (aq) + Br^-\ (aq)$$

37. In the reaction, is HBr an acid or base?

38. In the reaction, is H_2O an acid or base?

Consider the reverse of the reaction. $H_3O^+\ (aq) + Br^-\ (aq) \rightarrow HBr\ (aq) + H_2O\ (l)$

39. In the reaction, is H_3O^+ an acid or base?

40. In the reaction, is Br^- an acid or base?

$$H_2SO_4\ (aq) + NH_3\ (l) \rightarrow NH_4^+\ (aq) + HSO_4^-\ (aq)$$

41. In the reaction, is H_2SO_4 an acid or base?

42. In the reaction, is NH_3 an acid or base?

Consider the reverse of the reaction. $NH_4^+\ (aq) + HSO_4^-\ (aq) \rightarrow H_2SO_4\ (aq) + NH_3\ (l)$

43. In the reaction, is HSO_4^- an acid or base?

44. In the reaction, is NH_4^+ an acid or base?

Activity 6: Teacher Facilitated Discussion

As you have learned, there are three major theories that explain the behavior of acids and bases. These theories all focus on how acids and bases interact on the submicroscopic level. If we rely solely on the macroscopic level to explain acids and bases, we can determine the acidity or basicity of a compound either by measuring the pH, using litmus paper for a solution, or identifying specific reactions with known reactants. The macroscopic level only allows for observations and does not provide reasons why these observations occur.

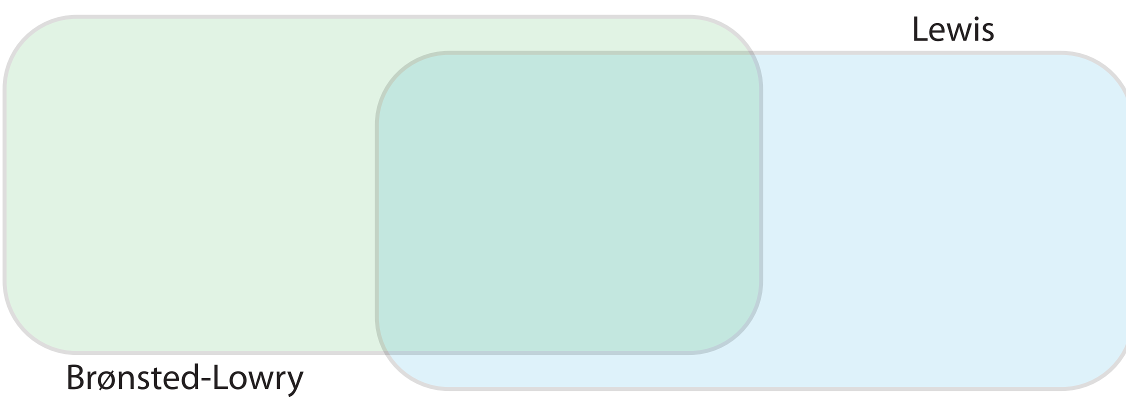
On the submicroscopic level, we can better understand why certain compounds act either as a base or acid. The determination of acidity and basicity is examined through many factors, such as how the compounds react when added to water, how the molecules donate or receive protons, and how the molecules accept or donate electron pairs.

45. In your own words describe the Arrhenius theory of acids and bases.

____

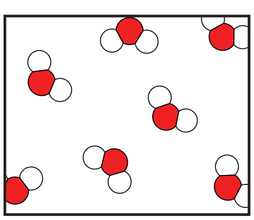
____

46. Compare and contrast the Brønsted-Lowry theory with the Lewis theory using the Venn Diagram below.

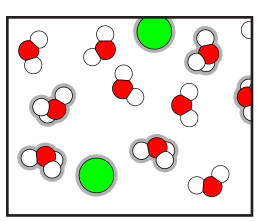


Determine whether the submicroscopic images are an example of an Arrhenius acidic solution, an Arrhenius basic solution, or a neutral solution.

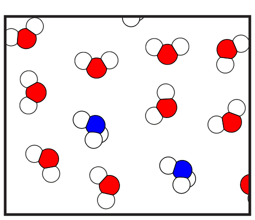
47. Label each diagram as acidic, basic, or neutral.



A________________



B________________



C________________

48. Provide two reactions that can be explained for each of the acid-base theories listed below.

Arrhenius

Brønsted-Lowry

Lewis

49. Select one of the reactions below. Identify whether it can be classified as a Arrhenius, Brønsted-Lowry , or Lewis reaction. *Provide evidence to support your claim.*

$$NaHCO_3\ (aq) + H_2O\ (l) \rightarrow H_2CO_3\ (aq) + NaOH\ (aq)$$

$$CH_3CO_2H\ (aq) + H_2O\ (l) \rightarrow CH_3CO_2^-\ (aq) + H_3O^+\ (aq)$$

$$I_2\ (g) + I^-\ (g) \rightarrow I_3^-\ (g)$$

Lesson Reflection Question

50. Compare and contrast each of the acid-base theories and their limitations in the table below.

Theory	Definition	Limitation
Arrhenius	Acid: Base:	
Lewis	Acid: Base:	
Brønsted-Lowry	Acid: Base:	

Student's Lesson at a Glance

Lesson Summary

This lesson contains four activities to help students understand how acids and bases are classified. Acids and bases are often classified as "weak" or "strong" based on how much the acid dissociates in water. After a brief Connecting Activity, students will look at computer simulations of different substances in water. Students will create sketches and record their observations. The lesson ties these activities together by asking the students to create definitions of weak acid, strong acid, weak base, and strong base based on their observations of the computer simulations.

SWBAT (Students Will Be Able To)

- Know that according to the Brønsted-Lowry theory of acids, strong acids dissociate completely in water into hydronium ions and conjugate bases
- Know that according to the Brønsted-Lowry theory of acids, strong bases dissociate completely in water into hydroxide ions and conjugate acids
- Know that according to the Brønsted-Lowry theory of acids, weak acids and weak bases do not dissociate completely in water

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- When acids dissociate, they produce ions, which are represented by halos in the simulation.
- Not all substances are dissociated completely in a solution. Acids and bases also vary in their levels of dissociation. The classification of strong or weak acids and bases is based on these levels of dissociation in water.
- When drawing keys for sketches, make sure to include ions and neutral atoms.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting

1. What ions do you think the following salts dissociate into when mixed with water?

$NaF\ (s) + H_2O\ (l) \rightarrow$ ______________________________

$MgCl_2\ (s) + H_2O\ (l) \rightarrow$ ______________________________

$Ba(NO_3)_2\ (s) + H_2O\ (l) \rightarrow$ ______________________________

Following the prompts in the headers of the table below, complete a sketch that illustrates how water promotes the dissociation of ionic compounds.

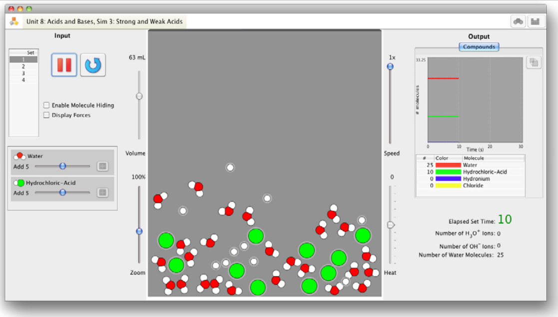
Draw a submicroscopic picture of an ionic compound dissociating in water.	Create a written explanation of your sketch.
Key	

You may have noticed that acidic foods tend to have a sour taste. For example, lemon juice, coffee, and cola all have a sour taste because each of these foods contain acids. Although there are many compounds in each of these solutions that give them their respective flavors, it is the acids that give them their sour taste. Because of this, many people add sweeteners to such foods to make them more ***palatable***. You may realize that lemon juice is much more sour than coffee. To understand why some foods taste more sour than others, we need to examine how different acids react when they are dissolved in water.

In prior chemistry lessons, you may have encountered the concept of dissociation. **Dissociation** is the process by which ionic compounds separate into their component ions. Recall that in CCC simulations, ions have grey halos. Most commonly, this occurs when an ionic compound is mixed with water as a solvent to form an aqueous solution. For example, when solid sodium chloride (NaCl) mixes with water, the compound dissociates into aqueous Na^+ and Cl^- ions. Similarly, acids and bases also dissociate when they are mixed with water. However, not all acids and bases dissociate in the same manner, as you will see in the next simulation activity.

Like water-soluble ionic compounds, strong acids and strong bases dissociate completely in water into their constituent ions. Weak acids and weak bases, however, do not dissociate completely; weak acids and bases only partially dissociate in water. Recall that pH is a measure of acidity or basicity of a solution. However, the pH of a solution does not inform us if the solution contains a **strong acid**, **weak acid**, **strong base,** or **weak base**. To classify an acid or base as strong or weak, knowledge of how the compound dissociates is necessary. You will use the next few simulations to discover how to distinguish between the strong and weak acids and bases.

Activity 2: Demonstration



Set 1: *Use Simulation 3,* ***Set 1***

- *Your teacher will display a simulation for you to view.*
- *Create a submicroscopic sketch before starting the reaction.*
- *Play the reaction for 10 seconds and then pause.*
- *Create a submicroscopic sketch after the reaction has been paused. Record your observations and the data from monitors.*

<table>
<tr><td></td><td colspan="4">Before Reaction</td><td colspan="4">After Reaction</td></tr>
<tr><td>Submicroscopic Sketch</td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td rowspan="3"># of Molecules</td><td>HCl</td><td></td><td>H_3O^+</td><td></td><td>HCl</td><td></td><td>H_3O^+</td><td></td></tr>
<tr><td>OH^-</td><td></td><td>H_2O</td><td></td><td>OH^-</td><td></td><td>H_2O</td><td></td></tr>
<tr><td>Cl^-</td><td></td><td colspan="2"></td><td>Cl^-</td><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Chemical Equation
$HCl\ (g) + H_2O\ (l) \rightarrow$ ____________________</td></tr>
<tr><td></td><td colspan="8">Observations</td></tr>
<tr><td></td><td colspan="8">Key</td></tr>
</table>

Using the simulations that you just viewed, answer the following questions.

2. Describe the interaction as the hydrochloric acid (HCl) molecules collide with the water molecules (H_2O).

____

____

3. Are the numbers of HCl molecules larger, smaller, or staying the same compared to the number of H_3O^+ molecules?

4. Do you observe any OH^- ions being formed in this reaction?

5. Would you describe HCl as an acid or base? *Support your claim with evidence.*

6. Based on your evidence, is HCl is a (*circle one, and support your claim with evidence*).

   - Strong Acid
   - Weak Acid
   - Strong Base
   - Weak Base

Activity 3: Simulations

Set 2: *Use Simulation 3, **Set 2***

- Create a submicroscopic sketch before starting the reaction.
- Play the reaction for 10 seconds and then pause.
- Create a submicroscopic sketch after the reaction has been paused.
- Record your observations and the data from monitors.

	Before Reaction				**After Reaction**			
Submicroscopic Sketch								
# of Molecules	HF		H_3O^+		HF		H_3O^+	
	OH^-		H_2O		OH^-		H_2O	
	F^-				F^-			

Chemical Equation
$HF\ (l) + H_3O\ (l) \rightarrow$ ______________________
Observations
Key

Using the simulations that you just viewed, answer the following questions.

7. Describe the interaction as the hydrofluoric acid (HF) molecules collide with the water molecules (H_2O).

8. How is the collision of HF with H_2O different than what you observed when hydrochloric acid (HCl) collides with H_2O?

9. Are the numbers of HF molecules larger, smaller, or staying the same compared to the number of H_3O^+ molecules?

10. Compared with the H_3O^+ molecules formed from HF, what do you observe about the number of H_3O^+ molecules formed from HCl?

11. Do you observe any OH^- molecules being formed in this reaction?

12. Would you describe HF as an acid or a base? *Be sure to include which theory you used to make this determination.*

13. Based on your evidence, HF is a *(circle one, and support your claim with evidence).*
    1. Strong Acid
    2. Weak Acid
    3. Strong Base
    4. Weak Base

Set 3: *Use Simulation 3, **Set 3***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
# of Molecules	NaOH		H_3O^+		NaOH		H_3O^+	
	OH^-		H_2O		OH^-		H_2O	
	Na^+				Na^+			

Chemical Equation
$NaOH\ (s) + H_2O\ (l) \rightarrow$ ________________________
Observations
Key

Using the simulations that you just viewed, answer the following questions.

14. Describe the interaction as the sodium hydroxide (NaOH) compound collides with the water molecules (H_2O).

15. Are the numbers of NaOH molecules larger, smaller, or staying the same compared to the OH^- ions?

16. Do you observe any H_3O^+ ions being formed in this reaction?

17. Would you describe NaOH as an acid or base? *Be sure to include which theory you used to make this determination.*

18. Based on your evidence, is NaOH a *(circle one, and support your claim with evidence)*.

    1. Strong Acid
    2. Weak Acid
    3. Strong Base
    4. Weak Base

Set 4

*Use Simulation 3, **Set 4***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
# of Molecules	NH_3		H_3O^+		NH_3		H_3O^+	
	OH^-		H_2O		OH^-		H_2O	
	NH_4^+				NH_4^+			

Chemical Equation

NH_3 (l) + H_2O (l) → ______________________

Observations

Key

Using the simulations that you just viewed, answer the following questions.

19. Describe the interaction as the ammonia (NH_3) molecules collide with the water molecules (H_2O).

20. How is the collision of NH_3 with H_2O different than what you observed when NaOH collided with H_2O?

21. Are the numbers of NH_3 molecules larger, smaller, or the same compared to the number of OH^- ions?

22. Compared with the OH^- molecules formed from NaOH, what do you observe about the number of OH^- molecules formed from NH_3?

23. Would you describe NH_3 as an acid or a base? *Be sure to include which theory you used to make this determination.*

24. Based on your evidence, is NH_3 a *(circle one, and support your claim with evidence).*

1. Strong Acid	3. Strong Base
2. Weak Acid	4. Weak Base

Activity 4: Teacher Facilitated Discussion

25. Based on the submicroscopic observations and the numbers you reported, how can we define the following terms?

Strong Acid

Weak Acid

Strong Base

Weak Base

26. What do strong acids and weak acids have in common?

27. What do strong bases and weak bases have in common?

Lesson Reflection Questions

28. Is there a relationship between pH and the strength of an acid? *Support your claim with evidence.*

29. Draw a submicroscopic picture of a weak acid and a strong acid at equal concentrations to show the difference between them. *Be sure to describe your pictures.*

Draw a submicroscopic picture of a weak acid.	Draw a submicroscopic picture of a strong acid.
Description of drawing:	**Description of drawing:**

Student's Lesson at a Glance

Lesson Summary

This lesson contains three activities that briefly introduce students to the pH scale. The purpose of this unit is to create real-world connections to pH and the study of acids and bases. This lesson contains the first wet lab in the unit.

SWBAT (Students Will Be Able To)

- Know pH is a scale to measure the acidity of a solution based on the relative concentration of OH^- ions and/or H_3O^+ ions

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- When drawing keys for sketches, make sure to include ions and neutral atoms.
- Hydroxide and hydronium are easily confused when naming ions. Hydroxide is OH^- and hydronium is H_3O^+.
- Depending on the textbooks being used in your class, the term "basic" may also be referred to as "alkaline."
- Remember that molar concentration is represented by enclosing the substance in square brackets. For example: $[OH^-]$ refers to the molar concentration of OH^- ions.

Notes

Homework

Upcoming Quizzes/Tests

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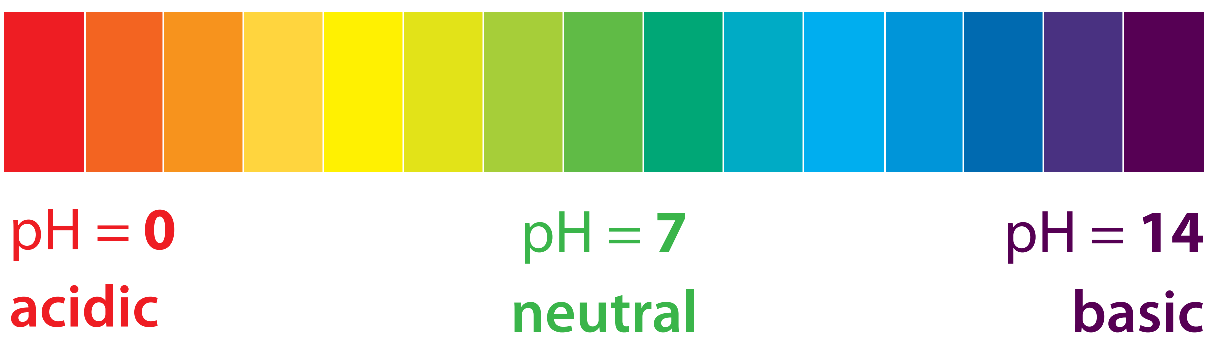
Activity 1: Connecting

1. Draw a submicroscopic picture of how you think acids and bases look. *Describe your answer.*

Draw a submicroscopic picture of an acid.	Draw a submicroscopic picture of a base
Description of your answer:	**Description of your answer:**

pH Scale



This lesson explores the pH scale and its relationship to acids and bases. You may have heard of the pH scale in other science classes. In 1909, a Danish scientist named S.P.L. Sørensen proposed the use of a logarithmic pH scale to express the concentration of **hydrogen ions** (H^+) and **hydroxide ions** (OH^-) in aqueous solutions. Scientists later discovered that hydrogen ions only exist for a brief time because they react almost instantly with water to form **hydronium ions** (H_3O^+).

$$H^+ (aq) + H_2O (l) \rightleftharpoons H_3O^+ (aq)$$

Thus, scientists today use the concentration of hydronium ions instead of the hydrogen ions originally proposed by Sørensen to determine pH. The pH scale was developed from the measurement of the concentration of hydroxide and hydronium ions. The figure above shows an example of a pH scale. **Acidic** substances have a pH value less than 7 on the scale. **Basic**

substances have a pH greater than 7 on the scale. Basic substances can also be called **alkaline substances**. **Neutral** substances have a pH of exactly 7, which is the midpoint of the pH scale.

Many of the substances that you come into contact with at home represent a wide range of pH values. Acids, such as hydrochloric acid, phosphoric acid, and citric acid are used in industry to make stain removers, toilet bowl cleaners, and rust removers. Bases, such as sodium hydroxide, potassium hydroxide, and ammonium hydroxide, are used to make soaps, oven cleaners, and drain openers. Even the foods you eat and drink, like fruits, may be acidic or basic!

2. What other food items do you think may be acidic?

3. Do you think bases have more hydroxide or hydronium ions? Why?

4. Do you think acids have more hydroxide or hydronium ions? Why?

Activity 2: pH Wet Lab

Students use an inquiry-based approach to design procedures, create hypotheses, and develop data collection methods for determining the pH of household items.

Activity 3: Teacher Facilitated Discussion

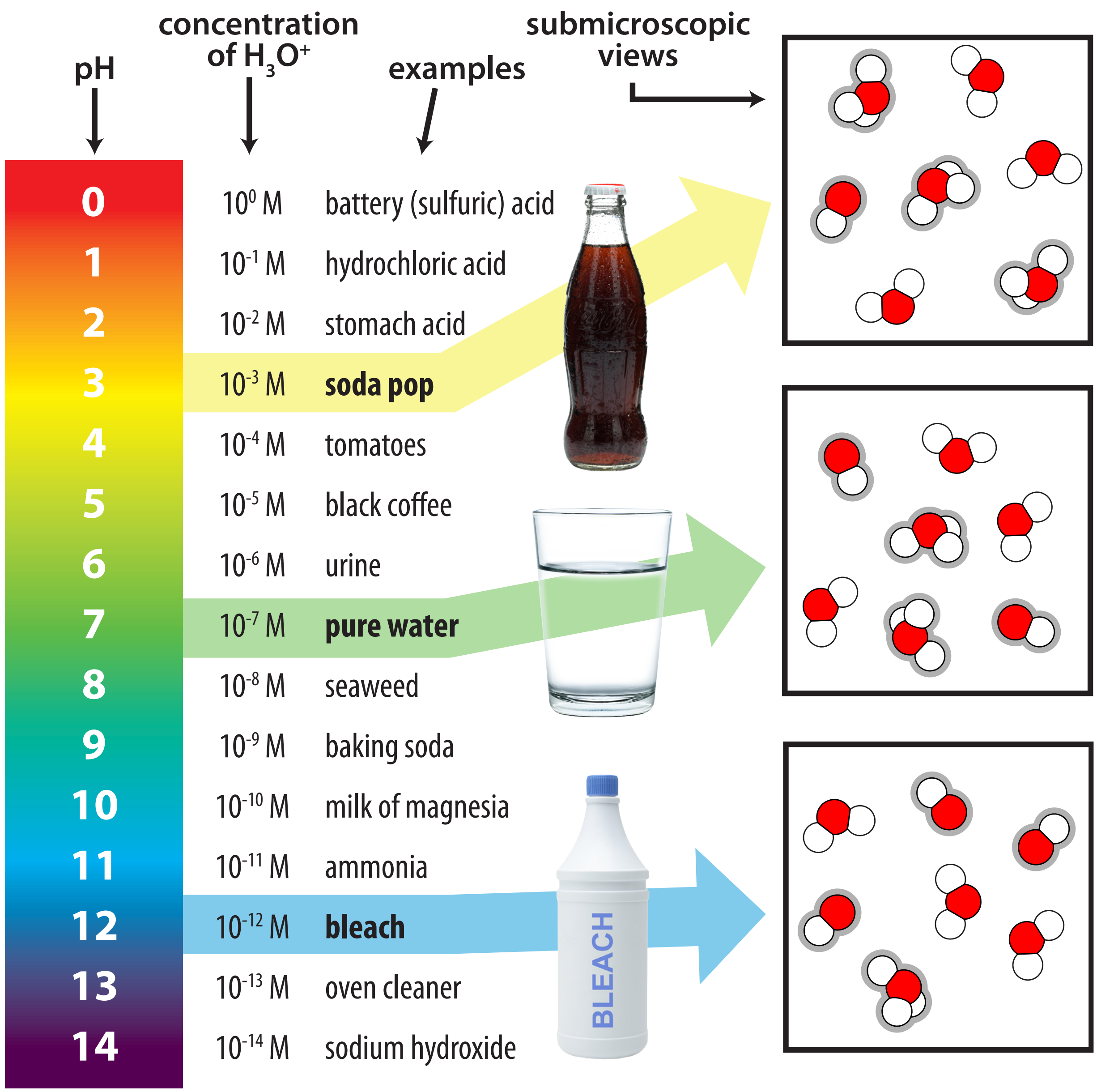
Read the following paragraph as a class.

pH	$[H_3O^+]$
0	$10^0 = 1\ M$
1	$10^{-1} = 0.1\ M$
2	$10^{-2} = 0.01\ M$
3	$10^{-3} = 0.001\ M$

The pH scale has many real-world applications. Understanding how pH is measured is important to the work of many professionals, such as doctors, hair dressers, and chefs. Eating foods with certain pH levels can have effects on the internal functions of your body. For example, eating foods that have high concentrations of acid (low pH) can cause damage over time to the enamel on your teeth and irritate ulcers in your digestive system.

The pH scale is based on a **logarithmic base-10 scale.** This means that a change of one pH unit indicates that the hydronium ion concentration changes by a factor of ten. For example, take a look at the table above for hydrochloric acid.

A pH of 0 has 10 times more hydrogen ion concentration than a solution with pH of 1. A pH of 0 also has 100 times more hydrogen ion concentration than a solution with pH of 2. As the pH increases by 1 unit, the change in concentration changes by a factor of 10. The hydronium concentration on the pH scale varies over fifteen **powers of 10** on a pH scale that ranges from 0-14.



The picture above gives you a look at pH from the macroscopic view all the way down to the submicroscopic view of a few of the substances listed on the pH scale. It also tells you the concentration of H_3O^+ for each pH. *As a small group, answer the following questions and be ready to discuss your ideas with the whole class. Make sure you take notes so you can discuss the ideas generated by your group.*

5. What is the relationship between the concentration of H_3O^+ ions and how it is classified on the pH scale? Be as specific as possible.

6. Using the picture above, what is the difference between the soda, water, and bleach from the submicroscopic view? Be as specific as possible.

7. Based on your answers for questions 5 and 6, define an acid in your own words.

8. Based on your answers for number 5 and 6, define a base in your own words.

9. How much greater is the concentration of hydronium ions in soda than in water?

The role of acids and bases can also be observed in the natural world. Some plants and flowers change color based on the pH of the soil in which they grow. Hydrangea flowers planted in acidic soils produce blue flowers. In comparison, hydrangea flowers planted in neutral soils produce very pale, cream-colored petals and basic soils produce pink or purple flowers.

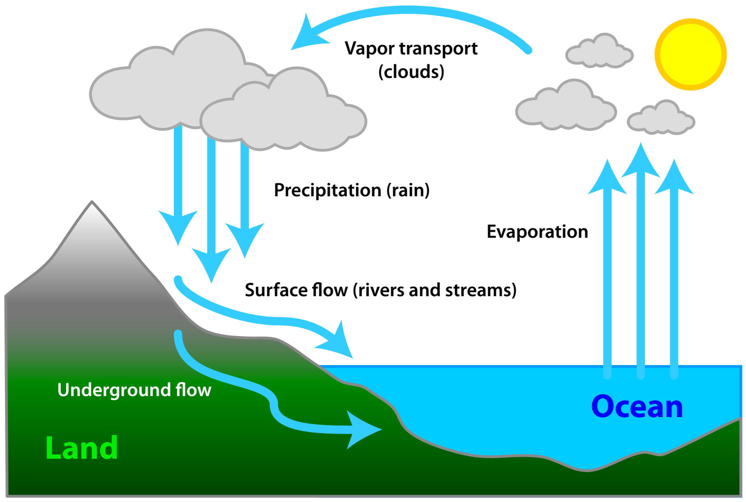
The pH level of the human body is also very important because the speed of the body's biochemical reactions, including those utilizing enzymes, are dependent on pH. Enzymes will only properly function within a specific pH range. If the environment changes out of that range, the enzymes will no longer help to speed up biochemical reactions, which can lead to poor health.

10. Blood has a pH of 7.4. Why do you think that blood has an almost neutral pH?

11. What do you think happens if your blood becomes too acidic or basic?

12. What could be the result of eating foods with a high concentration of H_3O^+?

Acid rain is an environmental threat caused by the combination of industrial air pollution and the water cycle. Your teacher may have discussed with you some safety concerns while working with acids and bases.



Lesson Reflection Question

13. Using the water cycle diagram above, what can you infer about the effects of acid rain on the environment? *Be specific when discussing what living and nonliving things could be impacted.*

Connected Chemistry

Acids & Bases Unit

Lesson 5: Calculating pH

Student's Lesson at a Glance

Lesson Summary

This lesson contains three activities which help students further examine acids and bases on the submicroscopic level. Students will also get a chance to practice calculating pH values. Students are introduced to calculating pH and pOH. Students explore how pH and pOH are related to concentration in the Connecting Activity. Using simulations, students will complete sketches before and after and record their observation of several compounds dissolved in water. In the provided data table, students should record the concentration of H_3O^+ and OH^- before and after the reaction and record the number of H_3O^+ and OH^- ions. Students use the value for H_3O^+ to calculate pH and the value for OH^- to calculate the pOH. Finally, students answer questions about the simulations. Students determine if each compound can be classified as either as a weak or strong acid or base based on submicroscopic observations.

SWBAT (Students Will Be Able To)

- Know that pH (power of H^+) is mathematically defined as the –log $[H_3O^+]$
- Know that pOH (power of OH^-) is mathematically defined as the –log $[OH^-]$
- Know pH is a scale to measure the acidity of a solution based on the relative concentration of OH^- and/or H_3O^+
- Identify a solution as acidic, neutral, or basic given $[H_3O^+]$, $[OH^-]$, pOH, or pH
- Calculate the pOH and pH of an acidic, basic or neutral solution given the $[H_3O^+]$, $[OH^-]$
- Know that pH is determined by the concentration of an acid and not a function of whether an acid is strong or weak

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Ions will have halos in the simulation. When drawing keys for sketches, make sure to include ions and neutral atoms.
- Hydroxide and hydronium are easily confused when naming ions. Hydroxide is OH^- and hydronium is H_3O^+.
- Square brackets around a substance represent concentration. For example: $[OH^-]$. This represents the concentration as Molarity (M) with units of mol/L.

Notes

Homework

Upcoming Quizzes/Tests

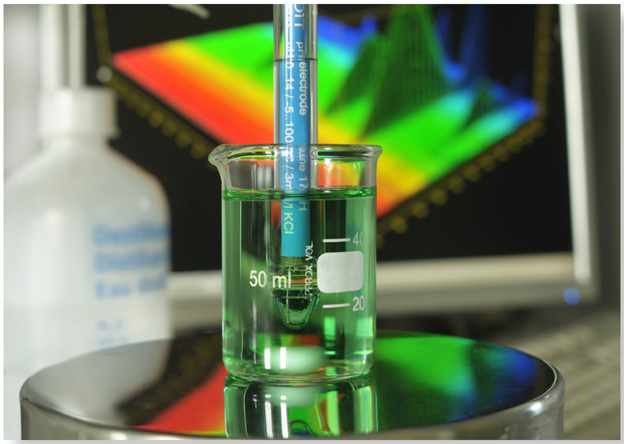
Activity 1: Connecting

1. If there is a higher concentration of hydronium (H_3O^+) ions than hydroxide (OH^-) ions in a solution, would the solution be classified as above or below 7 on the pH scale? *Support your claim with evidence.*

2. If there is a higher concentration of hydroxide ions than hydronium ions in a solution, would the solution be classified as above or below 7 on the pH scale? *Support your claim with evidence.*

3. For a solution to be classified as neutral, what relationship must exist between the pH and pOH?

Carbon dioxide from vehicle exhausts, decaying plants and animals, and chemicals released into the environment from factories can all affect the pH of the water in our environment. Extreme pH levels are harmful to both humans and animals who must consume water to survive. Because of this, the Environmental Protection Agency (EPA) has set standards for pH levels in drinking water to prevent illness. According to the EPA, a pH lower than 6.5 or higher than 8.5 is considered unhealthy to drink (EPA, 2012). Chemists and environmental scientists determine the pH of water samples with a special device called a *pH meter*. The pH meter is able to directly measure the relative amount of hydronium and hydroxide ions in a water sample to give a precise pH value.



Why is the value labeled pH? pH is the abbreviation for the phrase "**p**ower of the concentration of **H**ydrogen ion." Since hydrogen ions do not exist alone in solutions for very long, pH is calculated with the following equation that uses the concentration of hydronium ions instead of hydrogen ions:

$$pH = -\log [H_3O^+]$$

Because some basic solutions contain many more hydroxide ions than hydronium ions, chemists sometimes use a **pOH scale** to complement the pH scale. pOH is a measure of the concentration of hydroxide ions in a solution.

pOH is calculated with the following equation:

pOH = -log [OH⁻]

Note that the measures of pH and pOH are only useful for aqueous solutions which contain hydronium or hydroxide ions. If there are no hydronium ions or hydroxide ions in a solution, a pH meter has nothing to measure! Also, the formulas to calculate pH and pOH only work for strong acids and bases.

Activity 2: Simulating pH and pOH

- *In this simulation there are four sets, each containing a compound you will add to water.*
- *For each substance, complete a before and after sketch, and record your observations.*
- *Record the concentration of the substance before and after the reaction, and record the number of H_3O^+ and OH^- ions.*
- *Use the concentration for H_3O^+ to calculate pH, and the value for OH^- to calculate the pOH.*
- *Use your sketches and data to answer the questions that follow each set.*

Set 1: *Use Simulation 4, **Set 1***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
Data	**[HNO_3]**		[H_3O^+]		**[HNO_3]**		[H_3O^+]	
	[OH^-]		[NO_3^-]		[OH^-]		[NO_3^-]	
	K_{eq}				K_{eq}			

Chemical Formula

HNO_3 (l) + H_2O (l) → ____________________

Observations

Key

4. Calculate the pH of the solution after the reaction.

5. Calculate the pOH of the solution after the reaction.

6. Is HNO_3 a strong acid, weak acid, strong base, or weak base? *Support your claim with two pieces of evidence.*

Set 2: *Use Simulation 4, **Set 2***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
Data	[LiOH]		$[H_3O^+]$		[LiOH]		$[H_3O^+]$	
	$[OH^-]$		$[Li^-]$		$[OH^-]$		$[Li^-]$	
	K_{eq}				K_{eq}			

Chemical Formula

LiOH (s) + H_2O (l) → ______________________

Observations

Key

7. Calculate the pOH of the solution after the reaction.

8. Calculate the pH of the solution after the reaction.

9. Is LiOH a strong acid, weak acid, strong base, or weak base? *Support your claim with two pieces of evidence.*

Set 3: *Use Simulation 4, **Set 3***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
Data	$[CH_3NH_2]$		$[H_3O^+]$		$[CH_3NH_2]$		$[H_3O^+]$	
	$[OH^-]$		$[CH_3NH_3^+]$		$[OH^-]$		$[CH_3NH_3^+]$	
	K_{eq}				K_{eq}			

Chemical Formula

CH_3NH_2 (l) + H_2O (l) → ____________________

Observations

Key

10. Is CH_3NH_2 a strong acid, weak acid, strong base, or weak base? *Support your claim with two pieces of evidence.*

11. Calculate the pOH given that the pKb of CH_3NH_2 is 3.19:

12. Calculate the pH of CH_3NH_2.

Set 4: *Use Simulation 4,* ***Set 4***

	Before Reaction				After Reaction			
Submicroscopic Sketch								
Data	$[HC_2H_3O_2]$		$[H_3O^+]$		$[HC_2H_3O_2]$		$[H_3O^+]$	
	$[OH^-]$		$[C_2H_3O_2^-]$		$[OH^-]$		$[C_2H_3O_2^-]$	
	K_{eq}				K_{eq}			

Chemical Formula

$HC_2H_3O_2$ (aq) + H_2O (l) $\rightarrow$ ______________________________

Observations

Key

13. Is $HC_2H_3O_2$ a strong acid, weak acid, strong base, or weak base? *Support your claim with two pieces of evidence.*

14. Calculate the pH for CH_3COOH given that the pKa is 4.75.

15. Calculate the pOH for CH_3COOH.

Activity 3: Teacher Facilitated Discussion

Substance	Classification	Concentration	pH
HCl	Strong Acid	0.10 M	1.00
$HC_2H_3O_2$	Weak Acid	0.10 M	2.90
HF	Strong Acid	0.008 M	3.10

16. Based on the data above, what is relationship between pH and whether a substance is classified as strong or weak? *Support your claim with evidence.*

Lesson Reflection Questions

You are provided with two solutions. One is a weak acid and one is a strong acid. When a pH probe is put into both solutions, the meter indicates that both of them have a pH of 2.0. The pH probe is not malfunctioning .

17. What does the scenario above imply about pH?

18. How is it possible that the weak acid solution and the strong acid solution have the same pH?

19. Consider the three acid-base theories from previous lessons. Would you be able to calculate the pH of a solution using all of them? *Describe your answer.*

Connected Chemistry

Acids & Bases Unit

Lesson 6: Titration

Student's Lesson at a Glance

Lesson Summary

This lesson contains two activities that are designed to follow up the titration lab. These activities help students interpret titration curves and explore known and unknown concentrations of acid and base solutions.

SWBAT (Students Will Be Able To)

- Identify the components of a titration curve
- Use a titration curve to determine the acidity or basicity of the titrand and titrants used in a titration experiment

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Make sure to read the titration lab the night before you complete the lab. Make notes in the margin if you have questions. By preparing ahead of time for the lab, this will make completing the lab easier.
- Handle all acids and bases in lab with care. Make sure to follow your teacher's instructions so that the lab is conducted safely.
- Titrations can be challenging to do because it requires a steady hand and patience to get the desired results. Do not rush through the procedure. Go slowly so that you can accurately see the pH indicator gradually change color as you add the base to the acid.
- You will be constructing a titration curve graph. Make sure you accurately record the data collected in lab so that you can easily construct your graph.
- Make sure that you accurately label graphs and do not confuse what belongs on the x- and y-axis for the titration graphs. The volume of the titrant is placed on the x-axis while the pH is on the y-axis.
- Ions will have halos in the simulation. When drawing keys for sketches, make sure to include ions and neutral atoms.
- Hydroxide and hydronium are easily confused when naming ions. Hydroxide ion's formula is written as OH^- and hydronium's is H_3O^+.
- Volume and concentration are not the same thing. Concentration can be measured as the amount of moles of acid or base that has dissociated into the solution per volume (moles solute per liters of solution). Volume is a measure of the three-dimensional space a solution occupies.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting

Many people suffer from heartburn (or acid reflux disease). Heartburn occurs when stomach acid moves towards the esophagus. The stomach acid causes irritation to this sensitive area. To combat the stomach acid, people suffering from heartburn often take antacids, like Tums™, Rolaids™, and Pepto-Bismol™. All of these antacids have ingredients to neutralize the stomach acid so that the acid is less irritating. Recall that neutralization reactions are reactions between acids and bases that completely consume both the acid and base and form a salt. The reaction below is a **neutralization reaction**:

HCl (aq)	+	NaOH (aq)	→	NaCl (aq)	+	H_2O (l)
(acid)		(base)		(sodium chloride)		(water)

In the laboratory, chemists use neutralization reactions to determine the concentration of unknown solutions with an aqueous solution called a **pH indicator**. The pH indicator solution is sensitive to pH changes. The pH indicator solution undergoes a color change when added to solutions that are basic or acidic. In this activity, you will use a pH indicator to help you perform a technique called **titration**. Titration is the gradual addition of a standard solution (either an acid or a base) of known concentration called the **titrant** to a different solution of unknown concentration (either a base or an acid) called the **titrand** until the acid and bases are neutralized.

1. Based on what you already know, predict what will happen to the pH of an unknown acid if you add a very small amount of an acid to a base.

2. What would happen if you add a large amount of acid to a base?

3. Why do you think the word "neutralization" is used to describe a neutralization reaction?

4. A person taking antacid creates a neutralization reaction between the antacid and stomach acid. What does this imply about what type of ingredients are used to make the antacid?

5. If a titration results in the complete neutralization of both the acid and the base in a solution, what would you expect the resultant pH of the products to be?

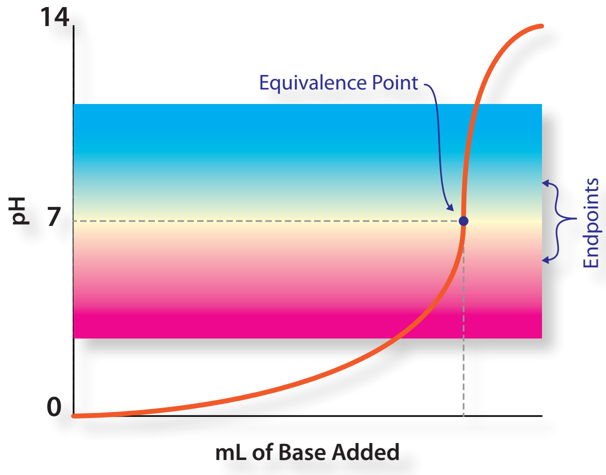
Activity 2: Titration Wet Lab

For this experiment, the concentration of the aqueous HCl solution is unknown. A pH indicator will be added to the HCl to indicate when the neutralization reaction is complete. The resulting products will be H_2O and NaCl. During this lab, you will create a titration curve from the data generated in the experiment, determine the amount of titrant needed to reach equivalence point, and determine the value of the pH at equivalence point.

Activity 3: Creating and Interpreting Titration Curves

Teacher Facilitated Discussion

Use the graph you created from the data you gathered in the titration lab or the graph provided to you by your teacher. This graph is called a **titration curve**. A titration curve is drawn by plotting data obtained during a titration experiment. When constructing the titration curve, the titrant volume is placed on the x-axis and pH on the y-axis. The titration curve serves to characterize the unknown solution.



1. Based on the passage above, what is the titrant in the experiment you performed?

When the solution of known concentration and the solution of unknown concentration are reacted to the point where the number of moles of acid and the number of moles of base are equal, the **equivalence point** is reached. The equivalence point of a strong acid or a strong base will occur at a pH of 7 when the base and acid are fully neutralized. For combinations of weak acids and strong bases, weak bases and strong acids, and weak bases and weak acids, the equivalence point does not occur at a pH of 7.

On the titration curve, the equivalence point is the point on a titration graph when the moles of base is equal to the starting amount of acid. This is seen in the graph where the slope of the line is undefined.

The **endpoint** of the reaction is when the pH indicator changes color. The colors produced in the solution are specific to what indicator is being used. To help visualize where this occurs, the color for thymol blue indicator has been overlaid on the titration graph above. Acids are indicated by a pink colored solution, while bases are blue. Color is a macroscopic observation. Most titration experiments require the use of a pH probe to measure the pH before, during, and when the endpoint of the reaction is reached to help validate the results.

2. What does the term "equivalent" mean?

3. On your graph, what are the coordinates of your equivalence point? What is its pH?

Activity 4: Simulating Titration

Demonstration: *Use Simulation 6,* ***Set 1***

This is a simulation of what occurred in the titration lab. Follow along as your teacher demonstrates it.

1. How does the addition of the base (titrant) by your teacher affect the unknown acid solution?

____

____

2. When you performed the titration lab, what color represented each level of the pH scale?

____

____

____

3. On the macroscopic level, why does the color change not occur immediately after you add the base to the acid?

____

You have seen the equivalence point represented on a graph. How would you represent the equivalence point on a submicroscopic scale?

4. Sketch what you think the equivalence point looks like on the submicroscopic level. Include a description of your sketch and a key.

Sketch the Equivalence Point	Describe your sketch
Key	

- *Your teacher will now add enough base to take the unknown solution to the equivalence point.*
- *You can change which graph is displayed by clicking the button on the top right corner of the graph display.*

5. Was your prediction correct? If not, how would you change your sketch to accurately represent the equivalence point?

6. After the equivalence point is reached, what do you observe happening on a submicroscopic level to the unknown acid solution?

7. On the macroscopic level, what physical observations can be made before reaching the equivalence point, at the equivalence point, and after reaching the equivalence point in the unknown solution?

Lesson Reflection Question

8. Why do you think chemists conduct titration experiments? Give one example of a real-life scenario in which a scientist might use a titration. *Be sure to explain your answer with evidence.*

Connected Chemistry

Acids & Bases Unit

Lesson 7: Titration for Acid-Base Combinations

Student's Lesson at a Glance

Lesson Summary

This lesson contains three activities. Following a brief Connecting Activity, students engage in lessons that use computer simulations to show what happens to different combinations of weak and strong acid and bases on the submicroscopic level. The goal of this lesson is to examine how different combinations of titrants and titrands affect the equivalence point. From their observations, students sketch graphs from the simulations.

SWBAT (Students Will Be Able To)

- Identify the components of a titration curve
- Use a titration curve to determine the acidity or basicity of the titrand and titrants used in a titration experiment

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Make sure that you clearly understand the difference between the classifications of strong and weak acids and bases. It may be helpful to review what these substances look like from the submicroscopic level in Lesson 4 and 5 of the unit.
- The equivalence point of a strong acid or a strong base will occur at a pH of 7. For combinations of weak acids and strong bases, weak bases and strong acids, and weak acids and weak bases, the equivalence point does not have to occur at a pH of 7.
- This simulation will require you to switch between views of different graphs. One graph will be a molecular count over time. The other graph will be pH vs the volume of the titrant. In these simulations you will need to add base (titrant) to acid (titrand).

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting

Prior to this activity, you have either generated your own titration curve or have been given an example of a titration curve by your teacher for a strong base of known concentration into a strong acid of unknown concentration. When doing titration labs, chemists may select to use different known and unknown acid and bases.

1. The reaction in the titration lab showed a strong acid and strong base reacting together. What other combinations of acids and bases can be used? Fill in the first column in table below with other possible combinations.

2. If the equivalence point for a strong acid and base is pH of 7, do you think the other combinations you came up with above will have the same equivalence point? Fill in your predictions for the other combinations that you wrote down in the second column below.

Combination:	pH Equivalance Point Prediction:
Strong Acid + Strong Base	7

3. Explain how you made your predictions for pH.

Activity 2: Titration Simulation

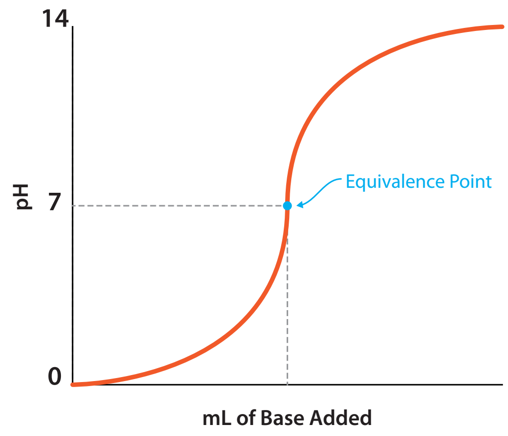
Weak Base into Strong Acid: *Use Simulation 6, **Set 2***

4. What is the difference at the submicroscopic level between a weak base and a strong base?

____

____

- *Add the weak base to the strong acid. Keep adding until you have just passed the equivalence point of the reaction.*
- *Once you are finished, sketch the titration graph you have generated.*

Sketch titration graph	Titration graph of strong acid and strong base from titration lab
	

5. Compare this titration curve to the curve from the strong acid and base. What is different?

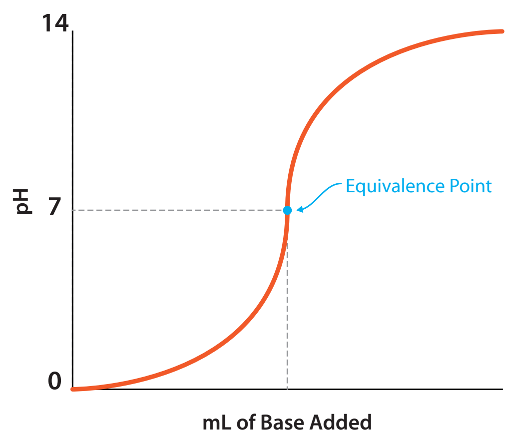
____

____

Strong Base into Weak Acid: *Use Simulation 6, **Set 3***

6. What is the difference at the submicroscopic level between a weak acid and a strong acid?

- *Add the strong base to the weak acid. Keep adding until you have just passed the equivalence point of the reaction.*
- *Once you are finished, sketch the titration graph you have generated.*

Sketch titration graph	Titration graph of strong acid and strong base from titration lab
	

7. Compare this titration curve to the curve from the strong acid and base. What is different?

Activity 3: Capstone Activity

You and your group will be given time to answer the question below and provide evidence to support your claim. You will then discuss your group's answer with the class. You may also use drawings to support your claim. Be prepared to defend your answers with evidence you have gained from past activities. You may also use drawings from your past activities to support your claim.

8. What is the relationship between concentration and pH?

9. Does a weak acid always have a higher pH than a strong acid? *Support your claim with evidence.*

10. What is the final pH in a neutralization reaction of a strong acid and strong base? What does that mean about the number of H_3O^+ and OH^- ions in the solution after neutralization?

Sketch your prediction of what neutralization looks like on a submicroscopic level.

Sketch a submicroscopic picture of a neutralized HCl and NaOH solution	Describe sketch
Key	

11. Assume you start off with 10 mL of a 1.0 M hydrochloric acid solution. If the concentration of the acid solution is greater than that of the base solution, will you add more or less than 10 mL of the sodium hydroxide base solution in neutralization reaction?

Connected Chemistry

Acids & Bases Unit

Lesson 8: Buffers and Conjugate Acid-Base Pairs

Student's Lesson at a Glance

Lesson Summary

This lesson contains four activities that introduce students to the concept of conjugate acid base pairs and buffers. The Connecting Activity generates real-world connections to the concepts of buffers and conjugate acids and bases. In the Teacher Facilitated Discussion, students practice identifying conjugate acids and bases in various chemical equations. Following a teacher demonstration on using the buffer simulation, students generate self-selected trials in which they record data and describe changes from a submicroscopic perspective.

SWBAT (Students Will Be Able To)

- Know that buffers are solutions that contain conjugate pairs of a weak acid or base and resist changes in pH
- Buffers have a buffering capacity, which is defined as the amount of acid or base that can be added to the buffer without changing the pH
- Know that deprotonated acids are conjugate bases
- Know that protonated bases are conjugate acids

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Make sure to always include phases when writing out chemical reactions.
- Remember that the arrows in a reaction indicate if a reaction is reversible or irreversible.
- Familiarize yourself with common acids and bases and whether they can be classified as strong or weak. This will help you interpret what is happening in the CCC simulations.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. In your own words, what does the word buffer mean?

If an acid or base is added to water, the pH of the resultant solution will drastically change. Pure water has no ability to resist the change in pH. However, there are some real-life scenarios in which systems need to resist changes in pH if an acid or base is added. To prevent changes in pH in solution from the addition of acid or base, chemists add a buffer to the solution in the lab. **Buffers** are solutions that resist changes in pH. Buffers are regularly added to substances in the lab that need to be placed into acidic or basic conditions to regulate pH.

Buffers are composed of a combination of a weak acid and the salt of its conjugate base or a combination of a weak base and the salt of its conjugate acid. For example, a mixture of the weak acid HF and its conjugate base (F^-) is a buffer. Similarly, a mixture of the weak base NH_3 and its conjugate acid (NH_4^+) is also a buffer. The buffer is made of two components because one part **neutralizes** any acid added to the solution, while the other part neutralizes any base added to the solution.

Your body has natural buffers to maintain a condition called *homeostasis*. Homeostasis plays an important role in the body. For example, muscle cramps can occur after long periods of exercise. When a person exercises, the body produces waste products that must be removed. One of these waste products is lactic acid, which builds up in muscles and reduces the body's pH. The result is that a person feels sore after long periods of exercise. It takes a while to feel sore, however, because muscles contain several natural buffers that can resist the change in pH. The body's pH remains relatively stable until the lactic acid completely neutralizes the buffer. At this point, the **buffering capacity** of the muscles is exceeded, and the local pH begins to decrease. Once this happens, muscle cramps and soreness are felt.

Recall that the Brønsted-Lowry theory states that an acid is a proton (H^+) donor and the base is a proton (H^+) acceptor. We can also consider Brønsted-Lowry theory using a general equation for the reaction between an acid and a base. The equation looks like this:

Acid + Base ⇄ Conjugate Acid + Conjugate Base

accepts H^+ to form

donates H^+ to form

- The products of the acid and base reaction are a **conjugate acid** and a **conjugate base**.
- The conjugate acid is the ion that forms after a base has accepted a H^+.
- The conjugate base is the ion that forms after an acid has donated a H^+.

2. What do the arrows in the middle suggest about the reaction?

3. What does the word neutralize mean?

4. What would the pH of a neutralized acid and base solution be? *Support your claim with evidence.*

5. Write an equation to show how an acid added to a base becomes a neutral solution. Be *sure to describe your answer in words.*

Activity 2: Teacher Facilitated Discussion

Consider the following reaction:

$$H_2O\ (l) + NH_3\ (l) \leftrightarrows OH^-\ (aq) + NH_4^+\ (aq)$$

6. Which reactant is the acid? *Please explain.*

7. Which product is the conjugate base? *Please explain.*

8. Which reactant is the base?

9. Which product is the conjugate acid?

Note that in the reaction, the reactants are water and ammonia. Even though we consider water a neutral substance, it can act as either an acid or a base in any given reaction. Water's ability to be both an acid or a base makes it **amphoteric**. If water donates H^+, it is an acid. If water accepts H^+, it is a base.

Consider the reaction between the following:

$$CH_3CO_2H\ (aq) + H_2O\ (l) \leftrightarrows CH_3CO_2^-\ (aq) + H_3O^+\ (aq)$$

10. Is water behaving as an acid or a base in the reaction? Please explain.

11. What is the conjugate base in the reaction? Please explain.

12. Is CH_3CO_2H behaving as an acid or a base in the reaction? Please explain.

13. What is the conjugate acid in the reaction? Please explain.

Activity 3: Buffer Demonstration

Demonstration: *Use Simulation 5, **Set 1***

- *Your teacher will demonstrate how to use Simulation 5.*
- *In the simulation, there are two sliders to set up the buffer solution.*
- *Based on the simulation that your teacher demonstrates, record answers to the following questions.*
- *You can change which graph is displayed by clicking the button on the top right corner of the graph display.*

14. What is the pH of the solution in the simulation?

15. How many hydronium ions and hydroxide ions are present in the solution?

16. How are these numbers related to pH?

- *Your teacher will start the simulation.*
- *Observe that the molecules are moving randomly around and colliding with each other.*
- *Adding one drop of acid represents adding 5 molecules of acid to the system.*
- *Use the simulation to answer the following questions:*

17. Is the addition of 5 molecules of acid in the simulation the same thing as adding 5 mL of acid in the lab?

18. What happened to the pH when the 5 mL of acid was added? *Explain why you think this happened.*

19. How many hydroxide and hydronium ions are present after the addition?

20. Are the hydroxide and hydronium ions destroyed in the reaction?

- *Your teacher will add 1 drop of base, this represents adding 5 molecules of base to the system.*
- *Observe and answer questions below:*

21. What changes do you see happening at the submicroscopic level?

22. Why do these changes occur?

23. Did the buffer prevent a pH change in the solution? *Support your claim with evidence.*

Activity 4: Buffer Simulations

Simulation

Continue to use Simulation 5, ***Set 1***

- *Explore the simulation using settings you select in your small groups.*
- *Complete two simulations in the time allowed.*
- *For each simulation, record what you start with and what you add (how many molecules of acid or base). Once you start the simulations, record what happens to the system. This includes pH changes, concentration of hydroxide and hydronium ions, and the amount of water.*

	$[NH_4Cl]$	$[NH_3]$	$[OH^-]$	$[H_3O]$	Final pH
Initial State of Equilibrium					
Add 5 HCl at Equilibrium					
Add 10 HCl at Equilibrium					

24. When you ran the simulation, what changes did you see over time?

Trial 1

Trial 2

25. In the simulation, there is the possibility of adding a large amount of acid or base into the buffer. How does the addition of large amounts of acid or base affect the buffer?

Activity 5: Teacher Facilitated Discussion

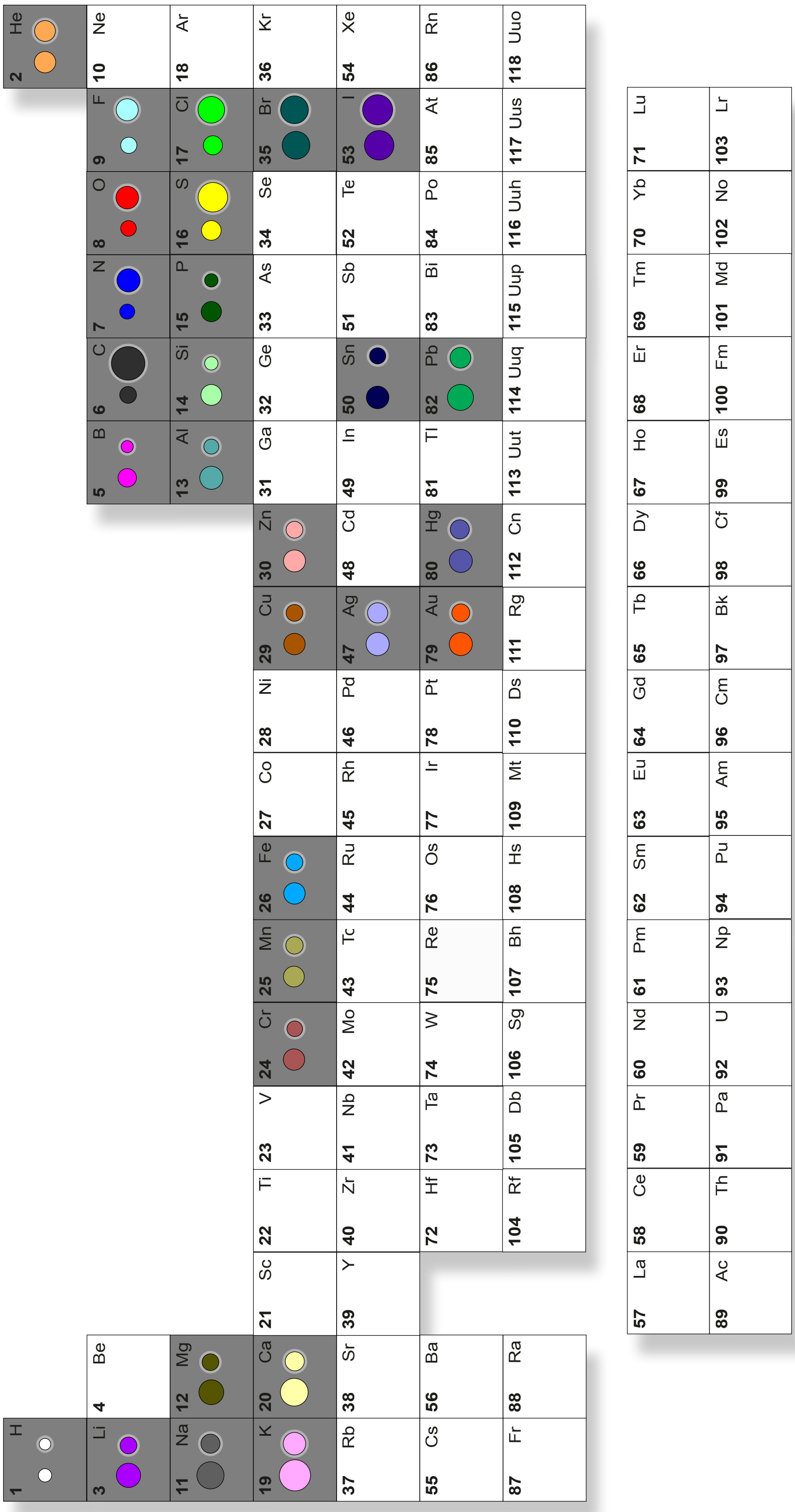
Working in your small groups, you will:

Pretend that you are in a company that sells buffers. In the time given by the teacher, your group needs to create a short ad that highlights the benefits of using buffers, how buffers work, and state a disclaimer about the limitations the capability of buffers. Once your ad is ready, have your salesperson present the advertisement to the class. During this time, evaluate each group's presentations for accuracy, how easy it was to understand, and how convincing they are. Your teacher may also ask clarifying questions if something is hard to understand.

Lesson Reflection Question

26. In your own words, define a buffer and describe how your definition has changed from the beginning of this lesson.

Elements Used in the Connected Chemistry Curriculum



Name	Symbol	Atomic Number	Atomic Weight
Hydrogen	H	1	1.00794
Helium	He	2	4.00260
Lithium	Li	3	6.941
Boron	B	5	10.811
Carbon	C	6	12.0107
Nitrogen	N	7	14.0067
Oxygen	O	8	15.9994
Fluorine	F	9	18.9984
Sodium	Na	11	22.9898
Magnesium	Mg	12	24.3050
Aluminum	Al	13	26.9815
Silicon	Si	14	28.0855
Phosphorus	P	15	30.9738
Sulfur	S	16	32.065
Chlorine	Cl	17	35.453
Potassium	K	19	39.0983
Calcium	Ca	20	40.078
Chromium	Cr	24	51.9961
Manganese	Mn	25	54.9380
Iron	Fe	26	55.845
Copper	Cu	29	63.54
Zinc	Zn	30	65.38
Bromine	Br	35	79.904
Silver	Ag	47	107.8682
Tin	Sn	50	118.710
Iodine	I	53	126.904
Gold	Au	79	196.967
Mercury	Hg	80	200.59
Lead	Pb	82	207.2