What is pH? Can pH be balanced?

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Teacher material

California Science Standards:
Chemistry Standards, Acid & Bases.
5. a. Students know the observable properties of acids, bases, and salt solutions.
5. b. Students know acids are hydrogen-ion-donating and bases are hydrogen-ion-accepting substances.
5. c. Students know strong acids and bases fully dissociate and weak acids and bases partially dissociate.
5. d. Students know how to use the pH scale to characterize acid and base solutions.
Investigation and Experimentation Standards.
1.c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
1.d. Formulate explanations by using logic and evidence.

Synopsis: Students learn about acids, bases and the pH scale by using indicators to test different beauty products that are sometimes advertised as "pH-balanced" (e.g. shampoos, deodorants, etc.). They first watch a demonstration where purple cabbage water indicator is added to a weak acid, water, and a weak base. Then they use the cabbage water to determine whether household substances are acidic or basic. They follow this up by using pH paper/Universal Indicator to determine the pH of those substances, hopefully correlating acidity with lower pH's and alkalinity with higher pH's. Finally, they test the pH of beauty products that they have brought from home to discover that the phrase "pH-balanced" has no meaning.
This activity reinforces California State High School Chemistry Standards #5a, 5b, 5c, 5d, as well as Investigation and Experimentation Standards #1c, d.

***Important Note*:** Some of these activities (especially the cabbage water demonstration and the investigation of common substances using cabbage water indicator) were influenced and/or duplicated from two sources (1) ICS textbook – *Integrated Coordinated Science for the 21st Century*; It's About Time, Herff Jones Education Division, 2004: New York; pp. 480-489; and (2) Miami Museum of Science pH Factor WebSite http://www.miamisci.org/ph/

Suggested Class Time: 2 class periods

Background Information:
This lesson is designed to be the introduction to the subject – no prior knowledge about acids and bases is assumed. Although this activity is designed for students to make discoveries about acids and bases, there are some aspects of the lesson that will probably need to be taught by the instructor, especially if the students have low reading comprehension. But this instruction should come after the **Engagement Demonstration** and the **Exploration Activity**; following the model of Inquiry-based

Instruction, students should be allowed to make some general discoveries on their own before the instruction of the specific details (**Term Introduction**) are explained. The specific details that may need to be reinforced are reproduced from the Student Handout (in the **Term Introduction** section below). The instructor should be aware of common misperceptions that students may have (e.g. acids are strong and bases are weak; low pH means weak acid, high pH means strong acid; only acids can burn skin; pH must be balanced in health and beauty products).

Advance Preparation/Materials:

- See also "List of Substances for Acid/Base Lab" (page 5)
- Red Cabbage
- 100ml Beakers – 3 for demo + 1 per group (1 for cabbage water, 1 for universal indicator) + 1 per substance
- Well plate – 1 per group
- Droppers – 1 for each substance + 2 per group
- Waste Jar/Large Beaker – 1 per group
- Universal indicator
- pH paper – 2 strips per group
- Q-tips - ~5 per group
- Spray bottle
- Health/beauty products (e.g. shampoo, deodorant, lotion, etc.) – Students should be encouraged to bring their own; however, teacher should have some on hand.

1. Prepare Cabbage water indicator – (1) CHOP one large red cabbage into small pieces (blackberries, red onions, or hibiscus flowers can be used as a substitute). (2) SIMMER the cabbage pieces until the water turns a deep shade of purple. (3) SEPARATE cabbage pieces from the purple cabbage water. (4) DISCARD cabbage pieces, allow cabbage water to cool. (5) REFRIGERATE when not in use.

2. Mix chemicals to proper concentration – see also "List of Substances for Acid/Base Lab." Before the lab begins, a small labeled quantity of each substance should be placed around the room. Each substance should have its own dropper.

3. Make copies of Student Handout

Engagement:- (Section I of Student Handout - **The Purple Cabbage Indicator – *a demonstration***). Prepare three beakers, one with water, one with water + clear vinegar, one with water + clear ammonia. Without explaining too much about acid/base indicators, tell the students to write down their observations as you add a small amount of cabbage water is added to each of the beakers. (The water + indicator will turn a light shade of purple; the water + vinegar will turn bright pink; the water + ammonia will turn green).

Exploration/Activities: (Section II – **Testing Other Solutions with Purple Cabbage** Indicator and Section III – **Confirm with Universal Indicator**) - Students can work in

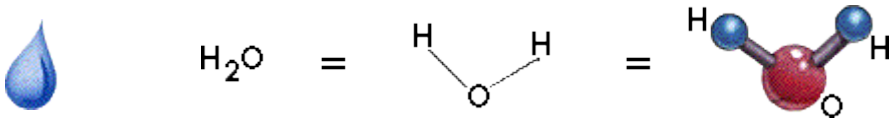
small groups for these activities, ideally between 3-5 students in a group. Most of the instructions for this activity are clearly written in the student handout. However, it is important to have a safety discussion with the students before they start the activity.

As the students are working on Step 3 of Section II, the instructor can project the "List of Substances for Acid/Base Lab" which is a table that contains some common and scientific names, and the chemical formula for some of the substances. Alternatively, a copy of this list can be provided to each group (our teachers put them in sheet protectors and used the same set for all their classes).

At the end of Day 1 of the lab (or even before), ask the students to bring in health/beauty products from home that they would like to test for "pH balance"

Term Introduction: Most of this information should be presented after the students have finished Section II and before they start Section III.

The Water Molecule. All substances are made up of millions of tiny atoms. These atoms form small groups called molecules. In water, for example, each molecule is made up of two hydrogen atoms and one oxygen atom. The formula for a molecule of water is H2O. "H" means hydrogen, "2" means 2 hydrogen atoms, and the "O" means oxygen.



Acids in water: When an acid is poured into water, it "**dissociates**" or breaks into two pieces. One of those pieces is H+ (hydrogen ion), which it gives up to the water. Thus, acids are known as **hydrogen-donating** substances.

Bases in water: When a base is poured into water, it also **dissociates**, but with bases, one of the pieces is OH- (hydroxide ion), which it gives up to the water. This OH- ion is very reactive – if it comes into contact with an H+ ion, it will bond to form a water molecule. Thus, bases are known as **hydrogen-accepting** substances.

The pH scale - Chemists use the pH scale to describe the strength of an acid or a base. The pH scale goes from 0 to 14 and is based on the amount of dissolved

H+ ions. But it is the opposite of what you might expect. When there are more H+ ions in the water, the pH is ***lower***. When there are fewer H+ ions in the water the pH is ***higher***. Substances with a pH of 7 are "neutral"; substances with pH less than 7 are acidic; and substances with pH greater than 7 are basic.

The following information should be presented as the students are finishing Section III:

Strong Acids: When they are placed in water, ***all*** the molecules of a strong acid dissociate, putting lots of H+ ions in the water. These substances have very low pH.

Weak Acids: When they are placed in water, only some of the molecules of a weak acid dissociate, putting some H+ ions in the water, but not as many as the strong acids. These substances have pH of less than 7 (but usually greater than 3 or 4)

Strong Bases: When they are placed in water, ***all*** the molecules of a strong base dissociate, putting lots of OH- ions in the water. The OH- ions lower the number of free H+ ions. These substances have very high pH.

Weak Acids: When they are placed in water, only some of the molecules of a weak base dissociate, putting some OH- ions in the water, but not as many as the strong bases. These substances have pH of greater than 7 (but usually less than 10 or 11)

Concept Application/Assessment: (Section IV – **Write a Secret Message** and Section V – **Testing the pH of your Health/Beauty Products**)

Section IV – Secret Message. For acidic "ink" prepare some beakers of vinegar and water. For basic "ink" prepare some beakers of ammonia and water. We had mixed success using the cabbage water indicator from the spray bottle. It worked for a few of the groups, but not for others… Be sure to test this procedure before having the students do it. An alternative (which gave us much better success) is to have the students write their secret messages with phenolphtalein indicator, and spray the messages with a weak solution of clear ammonia (the words show up bright pink, then disappear when the ammonia dries).

Section V – Testing pH of Health/Beauty Products. After the students test the pH of their products, they should report out their findings. The instructor may want to create a large data table on the classroom board for the students to record their results. Taken collectively, the students should see that some beauty products are weakly acidic, some are weakly basic, and some are neutral. After the data table is completed, ask the students if they can draw any other conclusions from the table. Or if the information on the table raises any other questions – if so, how could these questions be tested and/or answered?

The questions at the end of each section are also designed to assess the student's

comprehension of the activity. Instructors can grade the completed student handout as part or all of the assessment of this activity.

List of Substances for Acid/Base Lab

Common name	*"Scientific" name*	*Chemical Formula*
	hydrochloric acid	**HCl**
lemon juice	**citric acid**	
vinegar	**acetic acid**	**CH_3COOH**
	sulfuric acid	**H_2SO_4**
oven cleaner		
water		**H_2O**
Coca-cola		*contains* **H_2CO_3**
Sprite		
milk		
dishwashing soap		
	sodium hydroxide	**NaOH**
Milk of Magnesia		**$Mg(OH)_2$**
apple juice	*contains* **malic acid**	*contains* **C_4H_6O**
	potassium hydroxide	**KOH**
	barium hydroxide	**$Ba(OH)_2$**
window cleaner	**ammonia**	**NH_4OH**

Acid/Base Lab Equipment List

From Grocery Store

- red cabbage
- lemon juice
- orange juice
- vinegar
- mineral water
- Sprite
- milk
- dishwashing solution
- Milk of Magnesia
- apple juice
- household ammonia
- oven cleaner?

Part of Acid/Base kits?

- hydrochloric acid
- sulfuric acid
- sodium hydroxide
- potassium hydroxide
- calcium hydroxide
- beakers?
- sample trays
- zinc
- universal indicator

Other Stuff

- spray bottles
- pH paper
- q-tips – to write secret msgs

Student Handout

Acids and Bases… Can pH be "Balanced"?

Health and beauty products like shampoo and deodorant are often advertised as "pH-balanced." What does this mean? Does it make them work better? Does it make them safer? Does it mean anything?

To find out, we first need to understand more about pH. And to understand pH, we need to learn more about acids and bases…

I. The Purple Cabbage Indicator – *a demonstration*

When we boil red cabbage, we get a purple liquid that is an acid/base indicator. Watch what happens when your teacher adds the cabbage water to three different liquids and record your observations in the table below:

Cabbage water added to…	Observations
Water	
Vinegar	
Ammonia	

Question:
How can you explain what has happened here?

II. Testing Other Solutions with Purple Cabbage Indicator

Let's see how the cabbage indicator reacts with some other substances. But before we start, a word about safety:

BE CAREFUL WHEN WORKING WITH ACIDS AND BASES!
If you spill them on your clothes, they may burn holes in them. If you get them on your skin, be sure to rinse them off with plenty of water. You must wear your safety goggles for this entire lab activity!

STEP 1. Assign jobs

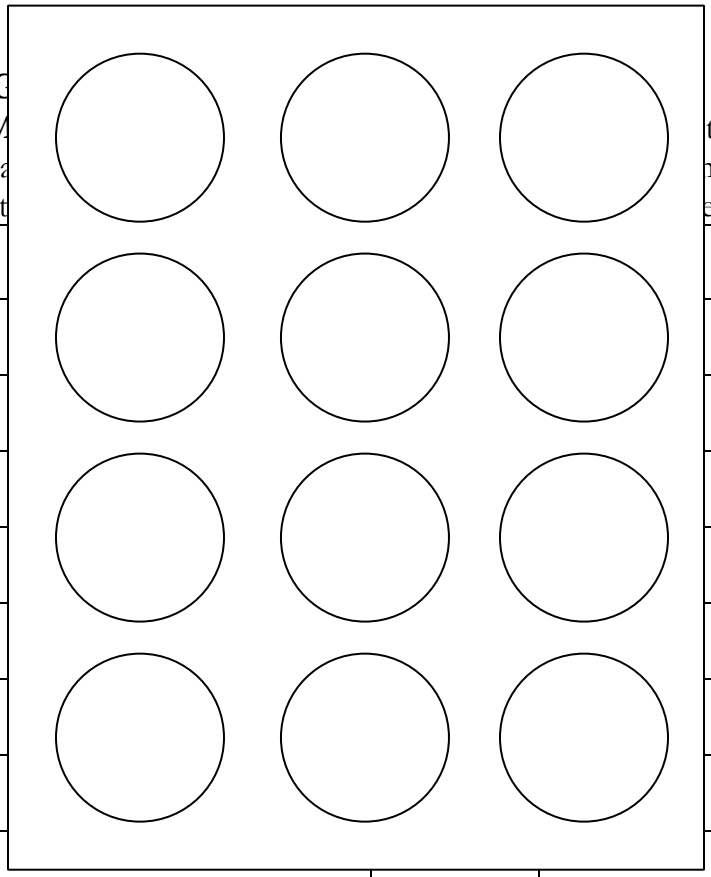
Assign the following jobs to a member of your group:

1. **Leader/Safety Advisor** – ensures the group stays on task and that all safety rules are followed.
2. **Materials Expert** – gets the materials from the front of the classroom.
3. **Chemical Mixer** – adds the indicator to the substances.
4. **Recorder** – records observations when mixing, writes secret messages.

STEP 2. Decide what to test

Your instructor will provide a list of substances that you can test. Some of them will be lab chemicals, some will be household products, some will be food items.

BEFORE you send your **Materials Expert** to get some of these substances, decide which 12 you would like to test. Write the names of the substances you will be testing on the diagram of the well plate below. Your **Materials Expert** will use this diagram to know which substance to put in each well.



STEP 3. C

Send your **M** the rest of the group should prepa nces in the first column. If t e second column.

			Acid or Base?	Universal indicator	pH

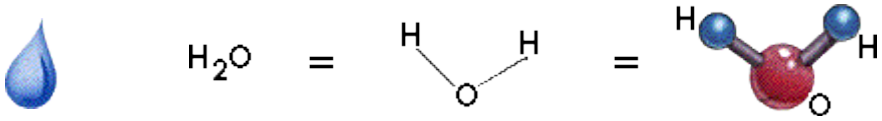
STEP 4. Add cabbage water indicator

Using a dropper, the **Chemical Mixer** adds 5 drops of the cabbage water to one of the wells. What color did the substance turn? Record your observation in the "Cabbage Water" column of the data table. Continue to add 5 drops of cabbage water to each of the other wells, recording your observations each time.

STEP 5. Decide which are acids, which are bases

Look at the results of your cabbage water test and try to decide which of your substances are acids and which are bases. The information on the next page will help you. Also, take a good look at the chemical formulas that you have written in your table. Do some of the formulas have things in common with some of the others? When you have decided which are acids and which are bases, write down your answers in the "Acid or Base" column of the data table.

The Water Molecule. All substances are made up of millions of tiny atoms. These atoms form small groups called molecules. In water, for example, each molecule is made up of two hydrogen atoms and one oxygen atom. The formula for a molecule of water is H2O. "H" means hydrogen, "2" means 2 hydrogen atoms, and the "O" means oxygen.



Acids in water: When an acid is poured into water, it "**dissociates**" or breaks up into two pieces. One of those pieces is H+ (hydrogen ion), which it gives up to the water. Thus, acids are known as **hydrogen-donating** substances.

Bases in water: When a base is poured into water, it also **dissociates**, but with bases, one of the pieces is OH- (hydroxide ion), which it gives up to the water. This OH- ion is very reactive – if it comes into contact with an H+ ion, it will bond to form a water molecule. Thus, bases are known as **hydrogen-accepting** substances.

STEP 6. Discard waste, wash well plate

When you have finished deciding which of your substances are acids and which are bases, discard the liquids in your well plate in the sink. Rinse your well plate off with water, and carefully dry it.

Questions

1. Why are acids called "hydrogen-donating" substances?

2. Why are bases called "hydrogen-accepting substances?

3. Which substances (acids or bases) tend to have the following properties:

(a) taste sour _____

(b) taste bitter _____

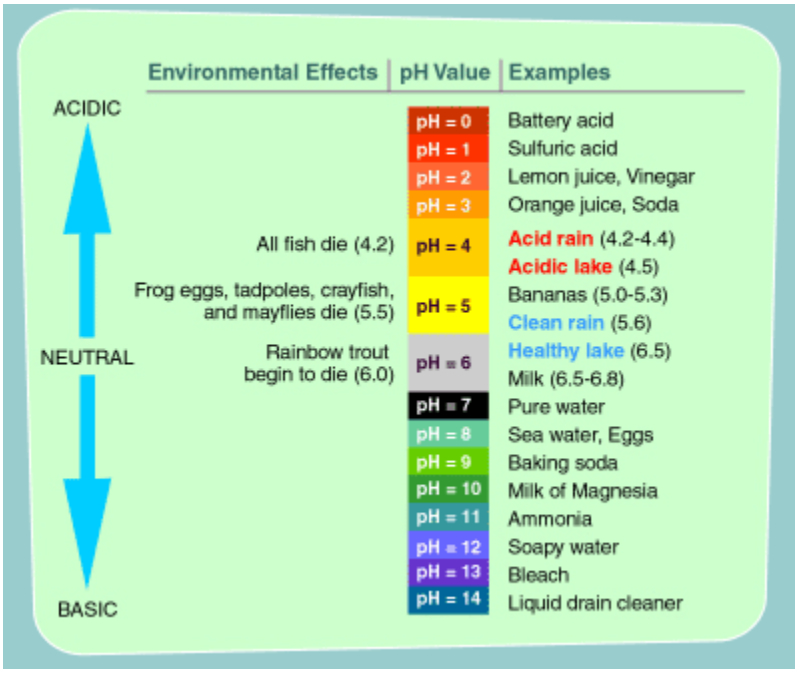
(c) feel slippery _____

(d) highly reactive _____

III. Confirm with Universal Indicator

Some of the substances that you tested are strong acids or bases, that will react with your skin or clothing. But some of them are liquids that you can drink or that you can use for washing your body or your dishes. How can you tell if an acid or base is strong or weak?

Chemists use the pH scale to describe the strength of an acid or a base. The pH scale goes from 0 to 14 and is based on the amount of dissolved H+ ions. But it is the opposite of what you might expect. When there are more H+ ions in the water, the pH is ***lower***. When there are fewer H+ ions in the water the pH is ***higher***. Substances with a pH of 7 are "neutral"; substances with pH less than 7 are acidic; and substances with pH greater than 7 are basic.



You can use liquid Universal indicator to measure the pH of certain substances.

STEP 1. Safety check

Leader/Safety Advisor should first run a safety check. Everyone still have their goggles on? Is your work area clean? Are there any spills that need to be wiped up?

STEP 2. Get substances

Send **Materials Expert** to the front of the room ***with*** the well plate chart that you made on page 2. He/she should get the same substances as before to measure pH.

STEP 3. Add Universal Indicator

Chemical Mixer adds 4 drops of Universal indicator to the first well. Write your observations in the fifth column of your data table (labeled "Universal Indicator).

STEP 4. Match color with Universal Indicator Color Guide

Use the Universal Indicator Color guide to match the color of the liquid in the well with the color on the chart. Write the pH in the sixth column, labeled "pH". Add 4 drops of Universal indicator to each well, writing observations and the pH in the data table each time.

STEP 5. Decide if it is strong or weak

Decide which of your substances are strong acids and bases, and which ones are weak acids and bases. Your biggest clue will be the pH that you just measured. (Remember: strong acids have very low pH. Strong bases have very high pH's…). The information below will also help. When you have decided, add the word "strong" or "weak" to your "acid" or "base" label in column three.

Strong Acids: When they are placed in water, ***all*** the molecules of a strong acid dissociate, putting lots of H+ ions in the water. These substances have very low pH.

Weak Acids: When they are placed in water, only some of the molecules of a weak acid dissociate, putting some H+ ions in the water, but not as many as the strong acids. These substances have pH of less than 7 (but usually greater than 3 or 4)

Strong Bases: When they are placed in water, ***all*** the molecules of a strong base dissociate, putting lots of OH- ions in the water. The OH- ions lower the number of free H+ ions. These substances have very high pH.

Weak Acids: When they are placed in water, only some of the molecules of a weak base dissociate, putting some OH- ions in the water, but not as many as the strong bases. These substances have pH of greater than 7 (but usually less than 10 or 11)

STEP 6. Discard waste, wash well plate

Questions

1. Were there any substances that were classified as acid with cabbage water and base with Universal indicator? Were there any that were classified as base with cabbage water and acid with Universal indicator? Were they strong or weak?

2. What is the difference between a strong acid and a weak acid?

3. If a substance has a pH of 13, is it acidic or basic? strongly or weakly?

IV. Write a Secret Message

If you write a message using a clear acid or base as "ink," it will dry and nothing will be visible on the paper. But when it is sprayed with cabbage water indicator: **PRESTO**!! Your message will be revealed.

STEP 1. Decide on message, decide on "ink"

Choose one of the statements below and decide whether it describes an acid or a base. You could also make your own statement that describes an acid or a base – if you do, write it below. If your statement describes an acid, send your **Materials Expert** to the front of the room to get acidic "ink". If your statement describes a base, send your **Materials Expert** to the front of the room to get basic "ink".

It tastes sour.
It is slippery.
It tastes bitter.
Burns clothing.
Accepts H+ ions.
Donates OH- ions.
Donates H+ ions.
Has pH of 2.
Has pH of 9.

STEP 2. Write your secret message.

Have the **Recorder** use a Q-tip to write the statement (your secret message) on a clean piece of paper. Be sure the Q-tip is always wet with your "ink." Put your initials in the bottom corner of the paper. Set it out to dry. We will be doing the next step as a class. If you finish this part early, go on the Part V.

STEP 3. Spray with cabbage water.

We will be doing this as a class, when the class sees the secret message, they will have to determine if they think this describes an acid or a base (your "ink" will help them!).

V. Testing the pH of your Health/Beauty Products

You have been asked to bring in some health or beauty products that you use (such as shampoo, deodorant, hair gel, lotion, etc). Now is your chance to find out the pH of what you are putting on your body!

STEP 1. Create solution

First, record the brand and the type of health/beauty product being tested in the data table below (for example: Old Spice deodorant). Put a bit of the product in one of the wells and add water. Mix it with Q-tip until it is dissolved.

STEP 2. Apply to pH paper

Touch the Q-tip to one end of a piece pH paper. Match the wet end of the pH paper to the color scale provided. Record the color and the pH in the appropriate columns of the data table. Discard the Q-tip.

STEP 3. Measure pH with Universal Indicator

Add 3 or 4 drops of Universal Indicator to the product in the well. Record the color and the pH in the appropriate columns of the data table.

Repeat STEP 1-3 for at least three other health/beauty products from people in your group.

Product type and brand	*using pH paper*		*Universal indicator*	
	Color	pH	Color	pH

Questions

1. Did your results from the Universal indicator match those from the pH paper?

2. What do you think it means for pH to be "balanced"? Is there a perfect pH for health products?