

# 17A Chemical Equations

## How are atoms conserved in a chemical reaction?

A chemical reaction involves changes in substances that react to form new products. This process involves the breaking of chemical bonds and the formation of new ones. A chemical equation shows the chemical formulas of the substances that react, called reactants, and the chemical formulas of the substances that are produced, called products. The number and type of atoms in the reactants must be exactly equal to the number and type of atoms in the products. How do you write a chemical equation so that the number and type of atoms on the reactants and products sides are balanced?

### Materials

- Periodic table tiles

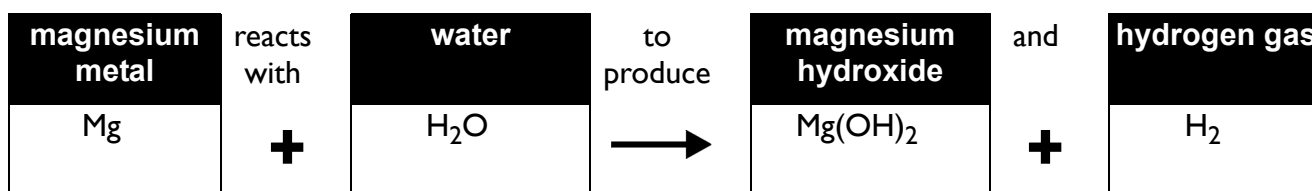
## 1 Writing chemical equations

**Magnesium metal reacts with water to produce magnesium hydroxide and hydrogen gas.**

The statement above is the word form of a chemical reaction. It tells you the names of the reactants and the products. To write it as a chemical equation, you need to determine the chemical formulas of each of the substances in the reaction:

1. Magnesium metal is an element and exists as an atom. Its chemical formula is Mg.
2. The chemical formula for water is H<sub>2</sub>O.
3. Magnesium hydroxide is an ionic compound. To write its chemical formula, you need to find out the charges of each ion it is made out of. The magnesium ion is Mg<sup>2+</sup>. The hydroxide ion is OH<sup>-</sup>. You need 1 Mg<sup>2+</sup> and 2 OH<sup>-</sup> to make a neutral compound so the formula is Mg(OH)<sub>2</sub>.
4. Pure hydrogen gas always exists as a diatomic molecule so its chemical formula is H<sub>2</sub>.

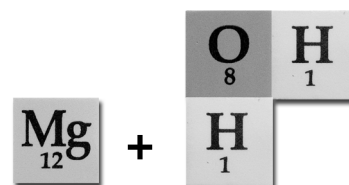
The chemical equation is written as:



## 2 Trying out the reaction with periodic table tiles

Use periodic table tiles to make the reactants above.

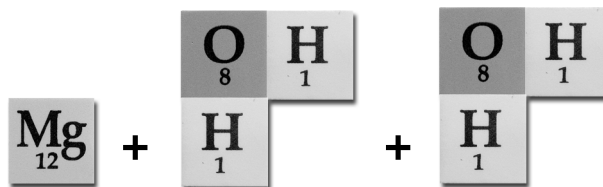
Rearrange the reactants to make the products. Is there any problem? What are you missing?



### 3 Balancing the reaction

Chemical equations must always balance. This means that you must use all of the atoms you start with and you cannot have any leftover atoms when you are finished. If you need more atoms to make the products, you can only add them in the form of a chemical formula.

You cannot simply add the extra atoms that you need, unless the chemical formula is a single atom - like Mg. Which atoms did you need more of for the reaction you tried? Since you needed more oxygen and hydrogen atoms, you can only add them in the form of another water molecule. Try adding another water molecule to the reactants and rearrange them to form the products again. Did the reaction work this time?



### 4 Writing balanced chemical equations

To balance the equation for this reaction, you needed to add another water molecule to the reactants side. You ended up with the correct amount of products. Since one magnesium atom reacted with two water molecules to form one magnesium hydroxide molecule and one hydrogen gas, the proper way to write the balanced chemical equation is:

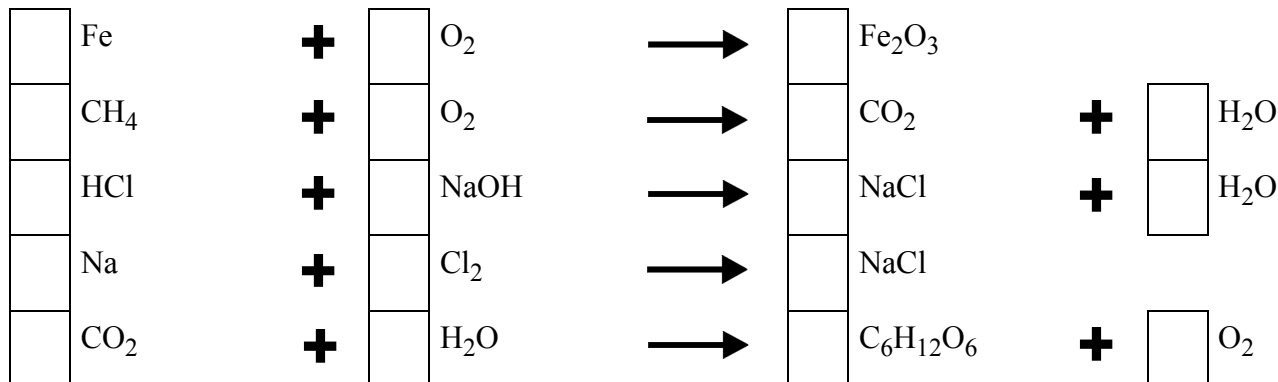


The 2 in front of water is called a coefficient. This number tells you how many water molecules are needed in the reaction. The rest of the reactants and products in the reactants show no coefficients. This is because when the coefficient is 1, there is no need to write it.

### 5 Try balancing these chemical equations

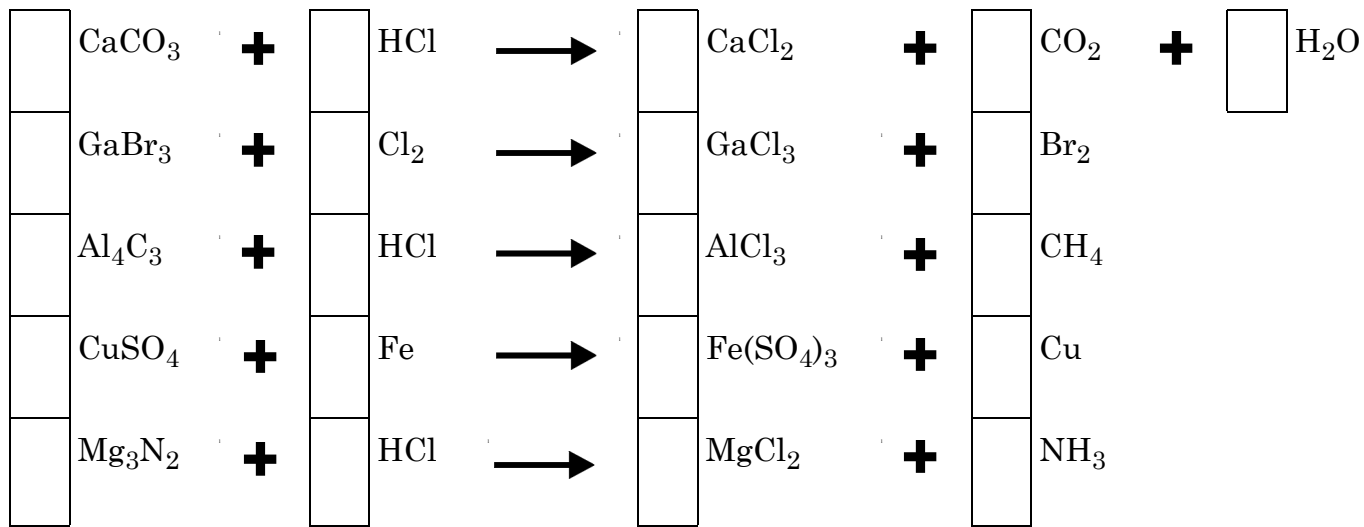
The following chemical equations have the proper reactants and products. Try to balance each using the following steps:

1. Assemble the reactants out of the appropriate tiles.
2. Rearrange the reactants to form the products.
3. Figure out the number of each reactant and product required to make the equation balance and write the numbers (the coefficients) in the boxes.

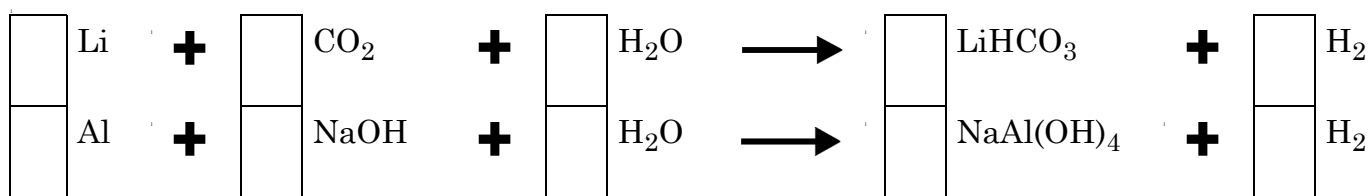


## 6 Challenge! Balancing difficult equations

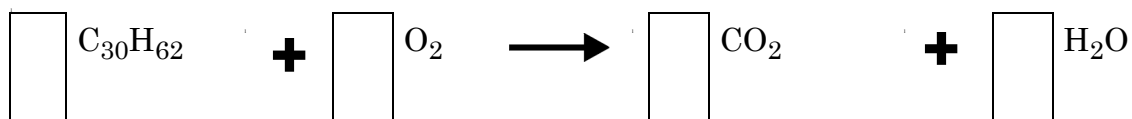
Use the Periodic Table Tiles to help you balance these harder equations.



Each of these equations has three reactants:



Can you balance this equation without using the tiles?



# 17B Conservation of Mass

*How do scientists describe what happens in a chemical reaction?*

A French chemist named Antoine Lavoisier was the first to prove the law of conservation of mass. This law says that the total mass of the reactants in a chemical reaction is always equal to the total mass of the products. This is not as easy to see as you might think! As you do this investigation, you will discover how tricky it is to show the law of conservation of mass.

## Materials

- Periodic Table Tiles
- Effervescent tablet
- Digital scale
- water
- small paper cup



**WARNING** — This lab contains chemicals that may be harmful if misused. Read cautions on individual containers carefully. Not to be used by children except under adult supervision.

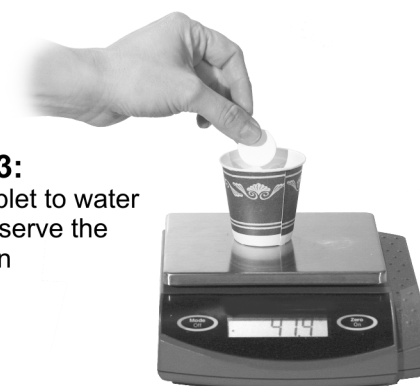
## 1 Testing the reaction



**Step 1:**  
Tare the balance to zero with the empty cup



**Step 2:**  
Measure the mass of water and tablet



**Step 3:**  
Add tablet to water and observe the reaction

**Table 1: Conservation of mass data**

Step	Data and observations
1. Find the mass of the effervescent tablet.	
2. Put the paper cup on the balance and tare it to zero. Fill the cup about halfway with water. Record the mass.	
3. Put the tablet on the balance beside the cup, but don't put it in the water yet. Record the total starting mass.	
4. Drop the tablet into the cup of water. You can do this while the cup is still on the balance. Record your observations.	

Step	Data and observations
5. Wait for the reaction to stop. Then, tap the cup gently to release as many bubbles as you can. Measure the mass.	
6. Subtract the final mass (5) from the starting mass (3). This is the mass difference between the products and reactants.	

## 2 Stop and think

- a. Does this experiment agree with the law of conservation of mass? Look at the data that you just recorded. Use it to help you to explain why or why not.

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- b. Explain why you observed a difference in mass. Where did the missing mass go? Did it really disappear?

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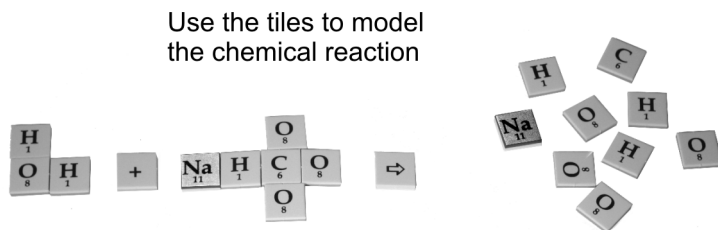


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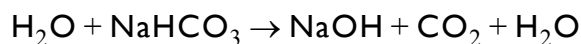
## 3 Modeling the reaction

Scientists write chemical reactions like mathematical formulas. The reactants are to the left of the arrow and the products are to the right of the arrow.

Reactants → Products



The effervescent tablet contains a chemical called sodium bicarbonate. This chemical reacts with water according to the following reaction.



1. Build the reactants side ( $\text{H}_2\text{O} + \text{NaHCO}_3$ ) of the chemical reaction above using the periodic table tiles.

2. Build the products side ( $\text{NaOH} + \text{CO}_2 + \text{H}_2\text{O}$ ) of the chemical reaction using more periodic table tiles.

#### 4 Stop and think

Table 2: Counting atoms of each element

Element	Reactants	Products
Hydrogen		
Carbon		
Oxygen		
Sodium		

- a. Fill in Table 2 with the numbers of each type of atom on the reactant side of the equation and on the product side of the equation.

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- b. How do the numbers of atoms of each element compare on the reactant and product side of the equation? What does this imply for the law of conservation of mass?

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- c. In what phase are each of the reactants (solid, liquid, or gas)? In what phase are each of the three products (solid, liquid, or gas)?

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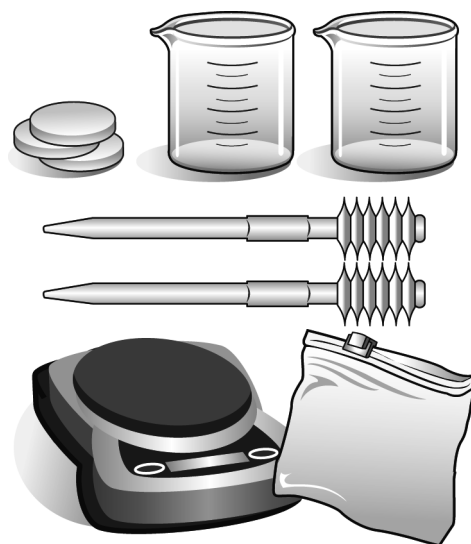
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## 5 Proving that mass is conserved in a reaction

According to the law of conservation of mass, the mass of the products of the reaction should be exactly equal to the mass of the reactants. Can you design an experiment to prove this is true for the reaction you just observed?

Examine the materials your teacher has given you. These include:

- effervescent tablet
- 2 beakers
- beaker of water
- 2 plastic pipettes
- 2 baggies with zippers
- electronic balance or mass scale



1. Working with your lab partner, devise an experiment that will prove that mass is conserved in the reaction of the tablet and water. You may request additional materials if your teacher has them available.
2. List the materials you will need and their use in the experiment.
3. List the steps you will follow in the experiment.
4. Before you try out your experiment, request approval from your teacher.
5. If your experiment does not work, adjust your procedures and/or materials and try it again.
6. Record your procedures, data, and results.

## 6 Presenting your results to the class

Prepare a brief presentation for the class about your experiment. Use the following format for your presentation:

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|-----------------------|--|
| <b>a. Purpose</b>     | What questions were you trying to answer?  |
| <b>b. Materials</b>   | What materials and equipment did you choose and why?   |
| <b>c. Procedures</b>  | What were the steps you followed? You may demonstrate your procedures if time and materials allow.   |
| <b>d. Data</b>        | What was the data you collected?   |
| <b>e. Conclusions</b> | What does your data prove? If your experiment did not yield satisfactory results, what would you change in your procedures or materials and why? |

# 18A Energy and Chemical Changes

## How do chemical changes involve energy?

Atoms come together in compounds by making chemical bonds with other atoms. Chemical bonds are a form of energy. When atoms change their bonds in a chemical reaction, energy can either be used or given off. In this investigation, you will make chemical reactions and deduce whether they use energy or give off energy.

**WARNING** — This lab contains chemicals that may be harmful if misused. Read cautions on individual containers carefully. Not to be used by children except under adult supervision.

### Materials

- Temperature probe
- Data collector
- 5 grams of sodium hydrogen carbonate (baking soda)
- Safety goggles
- Safety apron
- Electronic balance
- 100 mL graduated cylinder
- 100 mL vinegar
- 2 foam cups
- 4 cm piece of Magnesium ribbon
- 50 mL hydrochloric acid solution
- Paper towels



**Special Safety Note:** Use extreme caution when handling hydrochloric acid and other chemicals. Wear safety goggles and an apron during the entire investigation.

### 1 Stop and think

What evidence should you look for that indicates a chemical change (a chemical reaction) is taking place?

### 2 Reaction #1: Magnesium and hydrochloric acid

In this reaction, you will observe the temperature while adding a 4 cm piece of magnesium ribbon to 50 mL of hydrochloric acid solution.

1. Measure 50 mL of hydrochloric acid solution and place it in a pair of nested Styrofoam cups.
2. Place temperature probe in the solution. Set the Data Collector to record 1 sample per second (default setting).
3. Measure a 4 cm piece of magnesium ribbon with a ruler.
4. When the temperature of the solution has stabilized, press start and drop the magnesium ribbon in the hydrochloric acid solution.
5. Stir the reaction continuously with the temperature probe.
6. Collect data until all the magnesium ribbon has disappeared and the temperature has stabilized.
7. Save the experiment and note the file name.

**3 Thinking about what you observed**

- a. Study the temperature vs. time graph on the Data Collector. Did the temperature go up, down, or stay the same when you did the experiment?

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- b. Why does a change in temperature indicate a change in energy?

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**4 Reaction #2: Vinegar and baking soda**

In this reaction, you will add 5 grams of baking soda (sodium hydrogen carbonate) to 50 mL of vinegar (acetic acid solution).

1. Rinse the Styrofoam cup with water and dry it with a paper towel.
2. Put 50mL of vinegar in the pair of nested Styrofoam cups.
3. Place the temperature probe in the vinegar. Select a new experiment on the Data Collector and make sure it is set up to record 1 sample per second.
4. Measure 5 grams of baking soda with an electronic balance.
5. When the temperature of the vinegar has stabilized, press start and drop the baking soda in the vinegar.
6. Stir the reaction continuously with the temperature probe.
7. Collect data until the temperature stabilizes.
8. Save the experiment and note the file name.

**5 Thinking what you observed**

- a. Study the temperature vs. time graph for the second experiment. Did the temperature go up, down, or stay the same?

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- b. Look at the graph of each reaction. What is the maximum temperature change in each reaction? What does each graph show about energy changes in each reaction?

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- c. A reaction that gives off energy is called exothermic. Which reaction(s) are exothermic? Support your answer with your data.

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- d. A reaction that uses energy is called endothermic. Which reaction(s) are endothermic? Support your answer with your data.

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# 18B Thermodynamics of Hot Packs/Cold Packs

*Can we measure the heat released/energy absorbed by instant hot and cold packs?*

All chemical reactions are either exothermic (release energy) or endothermic (absorb energy). However, some physical processes such as dissolution (dissolving) can also release/absorb energy. This is the basis for commercially available instant hot packs and cold packs. Most hot and cold packs work by breaking a membrane that separates a solid and water. Once the membrane is broken, the solid dissolves in the water. Depending on the nature of the compound, heat is either released (hot pack) or absorbed (cold pack) during the process. In this investigation, you will examine the temperature changes of hot and cold packs and determine the energy absorbed or released during the chemical reactions that take place.

## Materials

- 2 foam cups
- Temperature probe
- Datacollector
- Safety goggles
- Lab Apron
- Water
- Calcium chloride (from an instant hot pack or ice melt)
- Ammonium nitrate (from an instant cold pack)
- Balance



**WARNING** — This lab contains chemicals that may be harmful if misused. Read cautions on individual containers carefully. Not to be used by children except under adult supervision.

## 1 Stop and think

Calcium chloride is used to melt ice on winter roads. Would that process be exothermic or endothermic? Why?

## 2 Doing the experiment

### Part A: Hot Pack - Record all measurements in Table 1.

1. Use a graduated cylinder to measure 50 mL of water. Record the mass of the water in Table 1 (HINT: 1 mL of water = 1g).
2. Pour the water into 2 nested foam cups and place the temperature probe into the water.
3. Use a balance to measure out about 10 g of calcium chloride ( $\text{CaCl}_2$ ). Record the mass of the  $\text{CaCl}_2$  in Table 1.
4. Select new experiment on the Data Collector and press Go. Wait for the temperature of the water to stabilize and record that temperature in Table 1 (initial temperature).
5. Pour the  $\text{CaCl}_2$  into the water and stir with the temperature probe.
6. Watch the graph and the temperature reading as the reaction proceeds.
7. Watch for the highest temperature reading before the temperature starts to go down again. Record that temperature in Table 1 (final temperature).

- Pour the solution down the drain and then rinse and dry your foam cups.

Table 1: Hot pack mass and temperature data

Mass of water (g)	Mass of $\text{CaCl}_2$ (g)	Initial temp. (°C)	Final temp. (°C)

**Part B: Cold Pack**

- Use a graduated cylinder to measure 50 mL of water. Record the mass of the water in Table 2 (HINT: 1 mL of water = 1g).
- Pour the water into 2 nested foam cups and place the temperature probe into the water.
- Use a balance to measure out about 10 g of ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ). Record the mass of the  $\text{NH}_4\text{NO}_3$  in Table 2.
- Select new experiment on the Data Collector and press Go. Wait for the temperature of the water to stabilize and record that temperature in Table 2 (initial temperature).
- Pour the  $\text{NH}_4\text{NO}_3$  into the water and stir with the temperature probe.
- Watch the graph and the temperature reading as the reaction proceeds.
- Watch for the lowest temperature reading. Record that temperature in Table 2 (final temperature).
- Pour the solution down the drain and then rinse and dry your foam cups.

Table 2: Cold pack mass and temperature data

Mass of water (g)	Mass of $\text{NH}_4\text{NO}_3$ (g)	Initial temp. (°C)	Final temp. (°C)

**3 Analyzing the Data**

- Calculate the temperature change of the  $\text{CaCl}_2$  and water reaction.

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- b. Calculate the heat gained by the solution using the equation below: Assume the specific heat of the solution is equal to the specific heat of water. (specific heat of water is  $4.184 \text{ J/g } ^\circ\text{C}$ )

**HEAT EQUATION**

$$E = mC_p (T_2 - T_1)$$

Where:  $E$  = heat lost or gained

$m$  = mass of solution in the calorimeter

$C_p$  = specific heat of substance

$T_2 - T_1$  = change in temperature (also referred to as  $\Delta T$ )

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- c. Calculate the amount of energy (in Joules) released per gram of  $\text{CaCl}_2$ . Remember:  $Q$  is the opposite sign of the value you calculate.

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- d. Calculate the temperature change of the  $\text{NH}_4\text{NO}_3$  reaction.

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- e. Calculate the heat lost by the solution using the heat equation: Assume the specific heat of the solution is equal to the specific heat of water. (specific heat of water is  $4.184 \text{ J/g } ^\circ\text{C}$ )

Where:  $E$  = heat lost or gained

$m$  = mass of solution in the calorimeter

$C_p$  = specific heat of substance

$T_2 - T_1$  = change in temperature (also referred to as  $\Delta T$ )

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- f. Calculate the amount of energy (in Joules) absorbed per gram of  $\text{NH}_4\text{NO}_3$ . Remember:  $Q$  is the opposite sign of the value you calculate.

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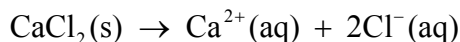
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#### 4 Thinking about what you observed

- a. Look at the reactions below. Place the energy value on the appropriate side of the two equations.



- b. When  $\text{CaCl}_2$  dissolves in water the true value for  $E = -747 \text{ J/g}$ . When  $\text{NH}_4\text{NO}_3$  dissolves in water the true value for  $E = 326 \text{ J/g}$ . Compare your experimental values by calculating the percent error for each reaction.

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- c. Describe why your skin feels cool when a cold pack is applied and warm when a hot pack is applied.

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# 19A Solubility Curve of $\text{KNO}_3$

## What is a solubility curve?

Solubility refers to the amount of solute that can be dissolved in a certain volume of solvent under certain conditions. In this experiment, you will be examining the relationship between temperature and the solubility of potassium nitrate ( $\text{KNO}_3$ ). The solvent will be water. Using class data, you will construct a solubility curve for  $\text{KNO}_3$ .

**WARNING** — This lab contains chemicals that may be harmful if misused. Read cautions on individual containers carefully. Not to be used by children except under adult supervision.

### Materials

- 5 test tubes
- 400 mL beaker
- Hot plate
- Thermometer
- Test tube holder (a spare 250 mL beaker works well)
- Potassium nitrate ( $\text{KNO}_3$ )
- 10 mL graduated cylinder
- Water
- Digital balance
- 400 or 600 mL beaker
- Ice



## 1 Stop and think

Based on what you know about dissolving substances in water, do you think the solubility of  $\text{KNO}_3$  will increase or decrease with temperature?

## 2 Doing the experiment

1. Fill a 400 mL beaker  $\frac{3}{4}$  full with water. Place it on a hot plate. Allow it to heat and go on to the next step.
2. Your teacher will assign you a specific amount of  $\text{KNO}_3$ . Use a balance to obtain the exact mass of potassium nitrate you will be using and put it in a test tube. Record the mass in Table 1.
3. Add 5 mL of water to your test tube containing your  $\text{KNO}_3$ . Record this volume in Table 1.
4. Place the test tube with the  $\text{KNO}_3$  and water into your hot water bath. Allow it to heat until all the  $\text{KNO}_3$  dissolves, while stirring. The temperature of the water may need to reach approximately  $85^\circ\text{C}$ .
5. Once all solid has dissolved, remove the test tube from the hot water bath and allow it to cool.
6. Place a thermometer in the test tube and watch for the first signs of crystallization. (Hint: Stirring occasionally may help you see the small crystals that form). When you start to see your first crystal gather at the bottom of the test tube, record your temperature in Table 1.
7. If crystals still do not form when the temperature cools down to 30 degrees, place the test tube in a beaker of room temperature water.

8. If the crystals still do not form when the temperature cools down to 25 degrees, take the test tube out of the room temperature water and place it in a beaker of ice water (provided by your teacher).
9. Show your teacher your results. If your teacher gives you permission, place your test tube back in the hot water bath and re-dissolve the solid. Flush the solution down the drain with plenty of hot water.
10. Rinse and clean all remaining apparatus and put it away.

Table 1:  $KNO_3$  crystal formation data

Mass of $KNO_3$ (g)	Volume of water (mL)	Mass of water (g)	Temp. when crystals first appeared (°C)

### 3 Calculations

- a. In the lab you measured out 5.0 mL of water. What is the mass of 5.0 mL of water? Explain.

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- b. Knowing how many grams of your solid can dissolve in 5.0 g of water, how many grams could dissolve in 100.0 g of water? Report this value to the class (Hint: Set up a ratio). Record your results and those of the other groups in Table 2.

Table 2:

	Group #1 1 g	Group #2 2 g	Group #3 4 g	Group #4 6 g	Group #5 8 g
Temperature (°C)					
Solubility (g/100g $H_2O$ )					

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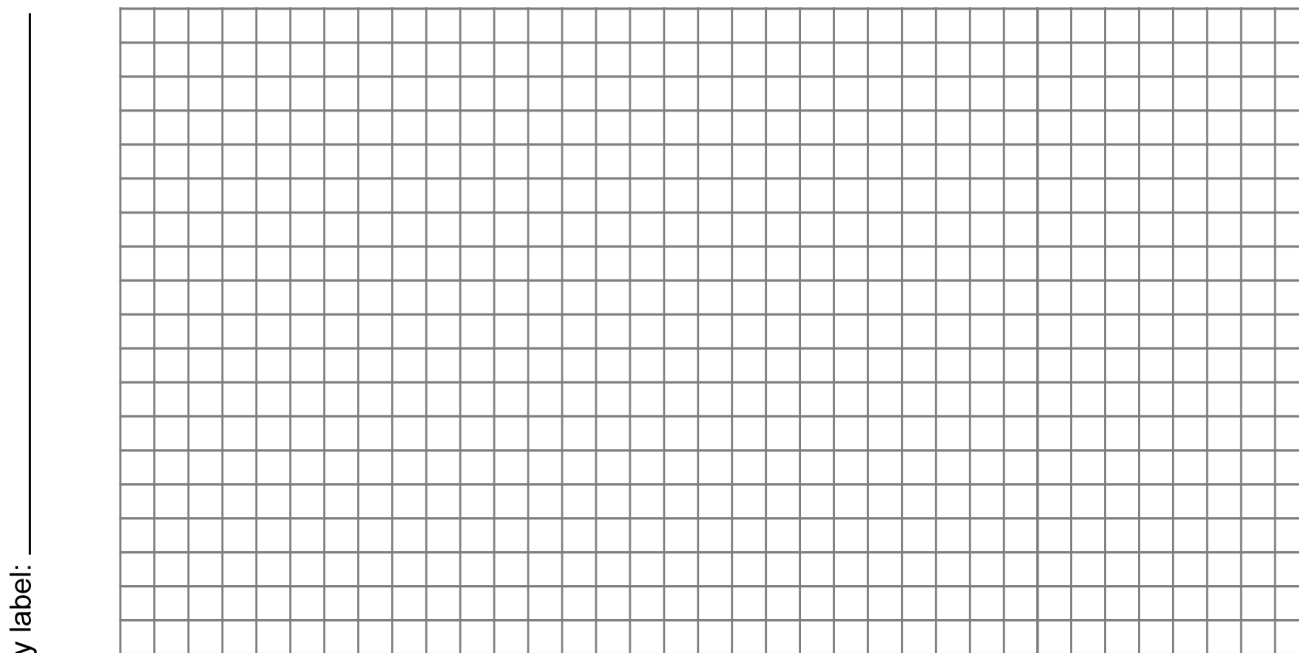


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**4** Thinking about what you observed

- a. Using the class data, construct a solubility curve. Plot the temperature ( $0\text{ }^{\circ}\text{C} - 100\text{ }^{\circ}\text{C}$ ) on the  $x$ -axis and the solubility of potassium nitrate ( $\text{g KNO}_3/100\text{g H}_2\text{O}$ ) on the  $y$ -axis. Make sure your graph has a title and the axes are labeled including units. Connect all points with a smooth curve when complete.

Title: \_\_\_\_\_



- b. In your own words, explain how solubility of  $KNO_3$  varies with temperature.

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- c. From your solubility curve, predict the solubility of  $KNO_3$  at

1.  $65\text{ }^{\circ}\text{C}$
2.  $50\text{ }^{\circ}\text{C}$
3.  $25\text{ }^{\circ}\text{C}$

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d. Is this solubility curve useful for temperature values above 100 °C?

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e. How many grams of KNO<sub>3</sub> can be dissolved in 200.0 mL of water at 35 °C?

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# 19B Acids, Bases, and pH

## What is pH?

Life exists inside a certain range of pH values. A pH value describes whether a solution is acidic, basic (alkaline), or neutral by describing the concentration of hydronium ions in a solution. An acid is a substance that produces hydronium ( $\text{H}_3\text{O}^+$ ) ions when dissolved in water, and a base (or alkali) is a substance that produces hydroxide ( $\text{OH}^-$ ) ions when dissolved in water. Neutral solutions have equal numbers of  $\text{H}_3\text{O}^+$  and  $\text{OH}^-$  ions.

In this investigation, you will learn the pH of several common solutions by making a pH scale using a pH indicator and chemicals of known pH. You will also identify two 'mystery' chemicals with your pH scale.

### Materials (per group)

- 2 or 3 well plates depending on the size (need 12 wells)
- permanent marker
- eyedroppers or pipettes
- 5 milliliters of red cabbage juice (a pH indicator)
- 12 each red and blue litmus papers (pH indicators)
- 2 milliliters each of the 12 solutions listed in the data table
- two 250 mL beakers – one contains warm water for rinsing pipettes, one empty beaker for discarded rinse water



## 1 Stop and think

Look at the table in the investigation. Using the pH values listed, predict whether the antibacterial soap will be acidic or basic and whether the apple juice will be acidic or basic. Of the solutions in the list, to which are they most closely related?

## 2 Doing the experiment

### A. Make a pH scale using indicators

1. To create your pH scale, you will be using solutions 1 to 7 in the table below. Place the following labels for these solutions in order on a well plate. If you don't have seven wells in a row on one well plate, place two plates side by side. The labels should describe the solution and its pH: Lemon – pH 2, Vinegar – pH 3, Seltzer water – pH 4, Red cabbage juice (the control) – pH 6.5, Baking soda – pH 8.5, Bar soap – pH 10, and Ammonia – pH 11.
2. Using a pipette, place three drops of red cabbage juice in each of the seven labeled wells.

**WARNING** — This lab contains chemicals that may be harmful if misused. Read cautions on individual containers carefully. Not to be used by children except under adult supervision.

- Using a pipette, add two drops of each of the solutions to the appropriately labeled well. Use a different eyedropper or pipette for each solution. However, if you must use the same dropper or pipette, thoroughly rinse it in fresh water after each solution before using it for a new solution. Record the color changes in your data table. The color series you see on the plate(s) represents a pH scale. We will refer to it as the pH test plate. You will use it to identify the pH of other solutions.
- Dip the red litmus paper and the blue litmus paper into each well of the pH test plate. Record the results according to the directions in the data table.

Name of solution	Color when mixed with red cabbage juice	Red litmus paper: if paper turns blue, write "base" or make an "x"	Blue litmus paper: if paper turns red, write "acid" or make an "x"	pH
1. Lemon				2
2. Vinegar				3
3. Seltzer				4
4. Red cabbage juice				6.5
5. Baking soda solution				8.5
6. Bar soap solution				10
7. Ammonia				11
8. Green tea				
9. Antibacterial cleaner				
10. Apple juice				
11. Mystery solution A				
12. Mystery solution B				

**B: Using pH indicators to measure unknown pH**

1. Repeat steps A2 through A4 for solutions 8 to 12. Use another well plate for these five solutions. The labels should describe the solution. At this point, you do not know the pH of these solutions.
2. Identify the pH of solutions 8 to 12. Compare the color reactions and the litmus paper results for solutions 8 to 12 with the pH test plate.

**3 Thinking about what you observed**

- a. What is the role of a pH indicator? What is the range of pH measured by each of the indicators you used (red cabbage juice, red litmus paper, blue litmus paper)?

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- b. Which of your solutions has the highest concentration of  $\text{H}_3\text{O}^+$  ions? Which has the highest concentration of  $\text{OH}^-$  ions? Explain your reasoning.

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- c. The red cabbage juice used in the investigation has two roles. It is the pH indicator and, in the series on the pH test plate, it is a control. Why is a control needed on the pH test plate?

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- d. Mystery solutions A and B are identical to two other solutions you used in this lab. Use your results to identify these solutions. What is the identity of mystery solution A? What is the identity of mystery B? List evidence to support your claims.

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- e. List the pros and cons of using red cabbage juice and litmus paper as pH indicators.

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- f. Various professions use pH indicators. For example, photographers traditionally used and still sometimes use stop bath in developing, and swimming pools are maintained using information from pH indicators. Find out how these pH indicators work in these (or other) situations, and what the color changes mean.

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