“Matter”
Content Background for Teachers

Introduction

As we start our content exploration, take a moment to think about what you already know about matter.

Most likely, you know the classic definition that *matter* is anything that takes up space and has mass. You might also know that there are three states of matter—solid, liquid, and gas. You may be familiar with using properties to identify substances. You may even know that matter is conserved. But what does that mean? You have some background knowledge about matter. But what do you feel comfortable explaining? What is happening when it looks like matter isn’t conserved? Can you explain how substances dissolve and what’s happening at the molecular level when they do? Why is it important for students to learn about these processes, and how much are they expected to understand and explain? Why is it important for *you* to learn about them?

In this content document, you will be challenged to broaden and deepen your understanding about matter based on what you already know. This document is written to support and further your own content learning about this topic with the goal of you developing a more conceptual understanding about ideas related to matter. The content is written with you, the teacher, in mind. It presents subject-matter content that is tied to teaching examples. It is at a level higher than what you will be teaching to elementary students. The purpose is to give you a content foundation around matter that will help you make instructional decisions that will best guide your students on their learning of matter and to give your students a solid content foundation that they will build on in later grades. Understanding matter at a deeper level will help you do this.

Properties of Matter

While observing matter of different types, you notice the properties of the matter. A *property* is a characteristic of a substance (or material) that can be measured or observed.

STOP AND THINK

Describe the properties of this spoon. If there are properties you could measure, list those too. List the properties in your notebook.

Did you describe the color, length, weight, density, shininess, hardness, or shape of the spoon? These are all physical properties. Physical properties can be observed or measured without changing the matter into something new. Now, what if the spoon were broken in half. What properties would change if you had only half of the spoon? Put a check mark next to the properties that would change if you only had half of the spoon.

Did you check length, weight, and shape? Those properties will all change if the size of the object changes. Those properties have a special name--they are called *extensive properties*. Extensive properties change when the amount of the matter you are describing changes.

Some properties can be used to identify matter. The properties that do not change with the amount of matter are useful for this purpose. Imagine that you find this rock on a trail while hiking in Colorado. You notice that it looks like gold, but you are skeptical. You measure and write down some properties of your find. You decide that properties that change with the amount might not be helpful in figuring out the identity of your rock. So instead of measuring the volume and the mass and recording those properties, you use those properties to calculate the density. You record properties that will not change with the amount. These properties are called *intensive properties*. These are the intensive properties you record:

- It has a metallic luster.
- Its color is brassy yellow.
- It has a hardness of 6–6.5 (Mohs hardness scale).
- It has a density of approximately 5 g/cm^3.

Rob Lavinsky, iRocks.com – CC-BY-SA-3.0

You look up the properties of gold to see if you have found a gold mine! Here is what you find:

Gold has a

- metallic luster,
- brassy yellow or golden color,
- hardness of 2.5–3 (Mohs hardness scale), and
- density of approximately 19.3 g/cm^3.

Did you find gold? No, the properties of the rock you found do not match the properties of gold. Upon further research, you figure out that your discovery matches the properties of a mineral called pyrite. Intensive properties are very helpful in identifying minerals and other forms of matter.

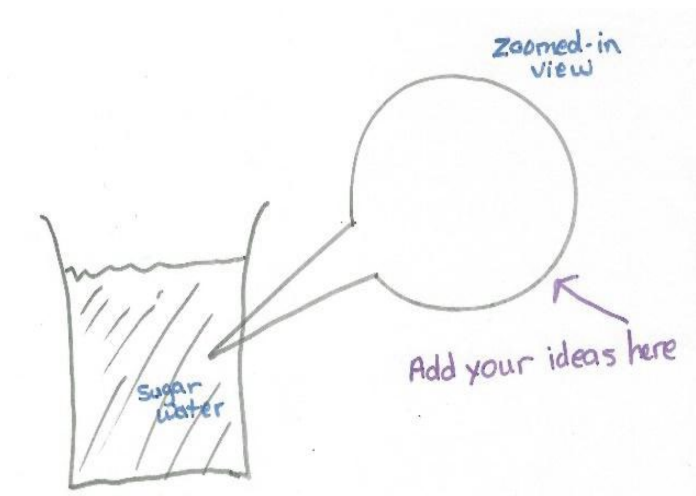
Your students will work with some intensive and some extensive properties, but they will not be required to know the difference. They will work through lessons to identify some matter that is dissolved in water.

The Particulate Nature of Matter

To understand matter—the different states, how it interacts with other matter or energy, the properties it has—it is helpful to think on a particulate scale. This scale would be zoomed in even closer than a microscope could go. Use this scale to think of matter as made of tiny particles. Your students will begin to develop this model of matter—a particulate model—in this unit. Thinking of matter as tiny particles will help you explain how matter exists in different states, how it behaves when energy is added to make it warmer, and how it interacts with matter made of different kinds of particles. Developing this model now will help prepare students for later grades when they will begin to explain how matter behaves at the atomic and molecular levels.

STOP AND THINK

Sketch a view of the liquid in a glass of sugar water as zoomed in as you can get. Start with a diagram like that pictured below. Add your ideas to the zoomed-in circle.



There are several common ways we see this mixture represented. Sometimes, even when we zoom way in, people picture liquid as one continuous substance, not a collection of tiny particles. It's also common to represent this mixture when zoomed way in as a combination of liquid and particles. You may have drawn the substances as made entirely of particles too small to be seen. You may have represented particles made of smaller particles like molecules are made from atoms bonded together.

Even if we know conceptually that matter is made of particles too small to be seen, that idea runs counter to what we can observe. Sometimes it takes a mental switch to go from knowing that matter is made of particles to creating models representing matter as entirely made up of particles (instead of a liquid-particle combination). In thinking about the fact that matter is made entirely of particles too small to be seen, is there anything you would add to or change in your diagram?

While you may have pictured the sugar water down to the atomic level—how atoms bond together to form molecules both of water and sugar—your students should only be expected to draw simple particles and not be expected to differentiate between particles that represent atoms and particles that represent molecules. Think now how your students might represent the particles in sugar water. Would the representation look similar to yours? Or would it be less complex?

Did you draw particles of water differently from the way you drew particles of sugar in your zoomed-in view of sugar water? You may have used different colors to represent different substances or different shapes of particles. This is important for you and your students to recognize—different substances have different particles. Revise your model now if you did not include a way to distinguish between the particles of water and the particles of sugar in your drawing.

Let’s think more about the particles that make up matter. These are some of the details that are beyond grade level for your students but will help you as you teach the unit.

Particles of Matter

All matter is made of particles. Those particles are either atoms or molecules that are made of two or more atoms. All matter—think about it! Everything that has mass—even a little—and takes up space is made of atoms. And there are only a few different types of atoms that exist! It is the combination of atoms with other atoms that makes all the zillions and zillions of different types of matter that exist. These different types of atoms are all arranged in the periodic table.

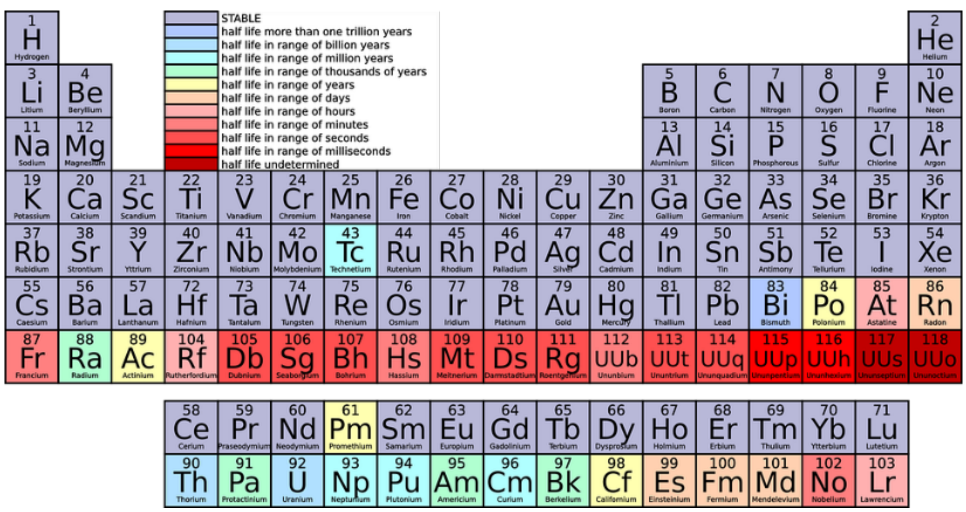


Figure 1: The periodic table. This table organizes all the elements we know to exist. Fewer than 100 of them occur naturally on Earth.

An element is made of all the same type of *atom*. Atoms are made of subatomic particles, and the most common of those are *protons* and *neutrons* in the *nucleus* or center of the atom and *electrons* that are around the outside of the nucleus. A proton of hydrogen is the same as a proton of copper. It is the number of protons in the atom that determines the type of element. An atom of hydrogen has one proton, and an atom of copper has 29 protons. The atomic number of an element on the periodic table shows the number of protons in an atom of that element.

Electrons and protons have a charge. Here is a table of these subatomic particles and some descriptions of each particle.

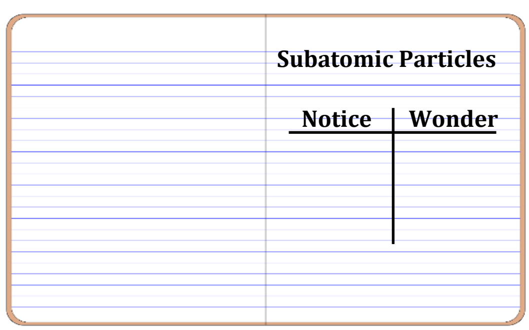
Subatomic particle	Location in the atom	Charge	Additional information
proton	nucleus	+ (positive)	• All atoms of an element have the same number of protons. • similar in mass to the neutron • along with the neutrons, make up most of the mass of the atom
neutron	nucleus	neutral	• Atoms of an element may have different numbers of neutrons. • similar in mass to the proton • along with the protons, make up most of the mass of the atom
electron	outside of the nucleus and far from its center	- (negative)	• determines which other elements it interacts with • has very little mass

Figure 2: Table of subatomic particles. Use the information in this table as you respond to the questions below.

In an atom, the number of electrons equals the number of protons. This is important to balance the charge of an atom. Atoms are neutral because all the negative charges of the electrons equal the positive charges of the protons--the net charge is zero.

STOP AND THINK

Examine the table in figure 2 describing subatomic particles. Make a Notice and Wonder chart and list the things you notice about these particles. What are their similarities? What are the differences? Also list any wonderings you might have about these particles and the atoms they make up.



To make all the different types of matter you observe around you, atoms bond with other atoms to form molecules. A *molecule* is made of two or more atoms bonded together. Bonding involves the electrons that surround the outside of atoms. You may be familiar with the chemical formula for water, H_2O. This is a type of model we use to represent water as having two hydrogen atoms bonded to one oxygen atom. This can also be represented by a different type of model—a structural model. It looks like this:

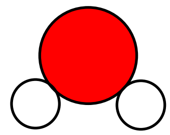


Figure 3: Structural model of a water molecule. A water molecule is made from two atoms of hydrogen and one atom of oxygen.

You can also represent atoms and molecules as simple particles, like a single shape to represent the whole particle. For example, this could be triangles or a particular color of circle. It is not important for students to know whether those particles are atoms or molecules, but you understand the difference. Try to only use the term *particles* with your students as you describe the particulate scale of matter. Doing so will keep students from worrying about the "right" way to represent matter at this scale. They will be expected to only use particles and to come to understand that if the matter is different, the particle is different. The science ideas about atoms, molecules, and subatomic particles will not be included in the lessons you teach to elementary students. However, for you to understand how the content from the lessons helps to prepare elementary students to learn about these science ideas, it is important for you to see where they will be going in later grades. Understanding this level of science content yourself will help you make pedagogical decisions in the moment that will set students up for success in later grades. It will also lay the foundation of solid science conceptual understanding of the particulate nature of matter.

Interactions of Matter

STOP AND THINK

1. Draw the structural model of water as shown in figure 3. Use these labels to annotate your sketch: "hydrogen", "oxygen", "molecule", "atom", and "water".
2. Now draw a structural model of carbon dioxide (CO_2) with labels similar to the ones you made for water.
3. Now think of how your students would draw a particle of water and a particle of carbon dioxide. Remember, they don't need to represent atoms. Draw what you would want your students to be able to represent in their model. Label each with only labels of "water" and "carbon dioxide".

What happens when you put two different types of matter together and mix them up? The different types can be different types of atoms, different types of molecules, or different types of both atoms and molecules. Take a moment to list different ways you think matter may behave when you mix it together. If it helps to think about tiny particles, do so.

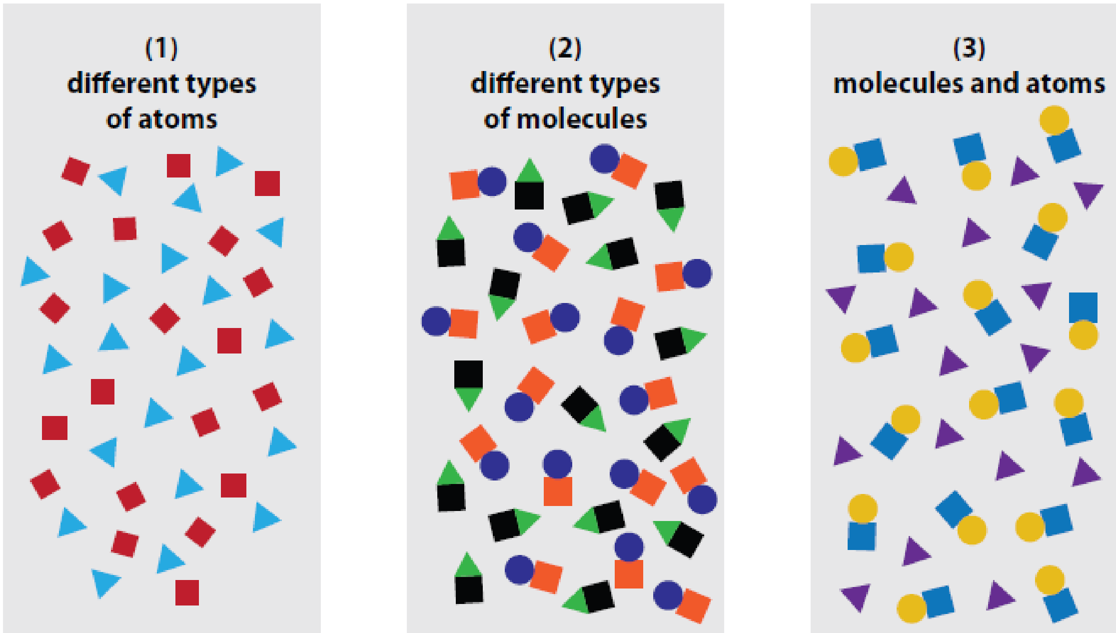


Figure 4: Different types of mixtures. Mixtures are made when you combine two or more substances. Those substances can be (1) different types of atoms, (2) different types of molecules, or (3) both atoms and molecules. What happens when they interact?

The answer to the question is, *it depends*. It depends on the properties of the different types of matter. When you stir sugar in water you know that it dissolves. But if you stirred sand in water, it doesn't dissolve. The properties of sugar are different from the properties of sand.

In the lessons you teach, students will consider what happens to the matter when it seems to disappear. Think about dissolving sugar in water. The white granular sugar seems to disappear in the water. What happens to the sugar? Is it still there? Can you get the sugar out? Did the water change in any way? Pause and answer these questions in your mind. Your students will likely have similar questions—how would you answer?

Dissolving

Look back to your initial model of sugar water from the second Stop and Think task. You may have represented the sugar water with two different colors. Did you use particles in your model? Sugar water is a special type of mixture called a solution. A *solution* forms when one substance completely dissolves in another. It seems to disappear, but we know if we were to take a sip of sugar water, we have evidence that the sugar is still there! The parts of a solution have names too. The sugar is called the solute, and the water is called the solvent. The *solute* is the matter that is dissolved, and the *solvent* is the matter that is doing the dissolving. Your students will not learn all these terms, but they will learn about solubility and dissolving.

Solutes do not always completely dissolve in water like sugar does. Sometimes they dissolve only partially and make the resulting liquid mixture cloudy. Or there may be some substances that do not dissolve at all in water. Your students will test the pond water's clarity by looking through the water at a Secchi disk. This is measuring the *turbidity* of the water. How well they can see the disk will tell them how cloudy or turbid the water is. The cloudiness of the water represents the particles that did not dissolve and are just floating undissolved in the water.

Remember thinking about mixing sand in water? Sand does not dissolve in water. Once you stir it up the liquid may look brown or dirty, but after a while the sand settles to the bottom of the container. This is another type of mixture called a *suspension*. The particles of sand do not dissolve but are suspended in the water. Eventually they settle to the bottom. If you must shake up or stir a liquid mixture to get it to get it to blend, at least part of it is a suspension. What everyday mixtures do you have to shake or stir before you use them? These are suspensions, and the suspended particles will ultimately settle to the bottom or you could trap them in a filter.

Mixtures that contain one or more substances that do not dissolve but remain dispersed evenly throughout another substance are called *colloids*. The dispersed particles in colloids are so small that the surrounding matter holds them suspended. A colloid will not separate and you cannot filter the particles out of the colloid easily. Consider adding a small amount of milk to water. Does it dissolve and make a solution? It looks like it does when you stir it. However, if you shine a light through the milk and water mixture, you can see the beam of light. Milk and jelly are two examples of colloidal mixtures. They often look the same as a solution, but sometimes the colloid will look cloudy. You can test the colloid using a light. The particles dispersed in a colloid are big enough to scatter light, and in a solution the particles are too small to scatter light. You can see the beam of light in a colloid (the Tyndall effect), but you cannot see the beam in a solution. The milk does not dissolve in the water, but the particles remain evenly dispersed throughout the water. You can see a beam of light in both a suspension and a colloid, but only a suspension will separate given enough time.

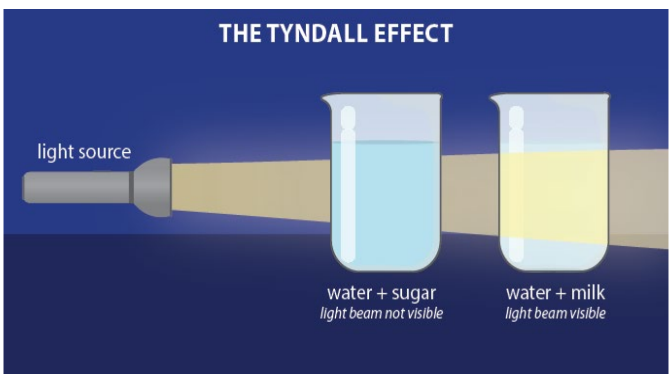


Figure 5: The Tyndall effect. The solution on the left is sugar water. On the right is a few drops of milk in water. The sugar dissolves completely in the water, and the particles in the solution are too small to scatter light. The milk particles do not dissolve in the water and are big enough to reflect light. The milk will not sink to the bottom.

Solutions That Conduct Electricity

What if you dissolved salt in water rather than sugar? Would the same thing happen? Visibly it appears that salt behaves exactly like sugar when dissolved in water--both form a clear solution. If you use salt from your saltshaker, it will dissolve faster than rock salt. If you stir the salt water or add salt to hot water, the salt dissolves faster. Everything is the same, right? Now check both the saltwater solution and the sugar water solution to see if either of them will conduct electricity. What is your prediction?

The two solutions behave differently. The sugar water solution (if you use distilled water) will not conduct an electric current, but a saltwater solution will. So, something must be different about the solutions. For something to conduct electricity, charged particles must be free to move. Since saltwater conducts electricity, a saltwater solution must have charged particles that can move. So, what is going on?

You learned earlier that atoms are neutral, and when atoms combine, the compounds are neutral too. This is because there are the same number of electrons with a negative charge as there are protons with a positive charge. Some compounds are ionic--like salt. The sodium atoms (Na) in salt (NaCl) actually lose an electron and give it to chlorine. This means that sodium now has a positive charge (more protons than electrons). We no longer call the sodium an atom but an ion. An *ion* is a charged atom. Since the chlorine atom (Cl) gained an electron, it is now a negatively charged ion (more electrons than protons). When an ionic compound like NaCl is dissolved in water, the NaCl dissociates. That means the sodium ions (charged sodium atoms) come apart from the chlorine ions (charged chlorine atoms). Because water is polar (further discussion below), it is able to pull apart the charged ions from the salt crystal much like a magnet is attracted to another magnet.

Recall that for something to conduct electricity, there must be charged particles that are free to move. Can you see how these sodium and chlorine ions in water are able to conduct electricity? Your students will test solutions for electrical conductivity as they are testing their pond water and pollutants.

STOP AND THINK

Compare the two illustrations of sugar dissolved in water and salt dissolved in water.

- Make a T-chart in your notebook and describe similarities and differences between the two types of solutions.
- Write a caption as it would appear under the two illustrations that would explain the similarities and differences in the two solutions.

The Universal Solvent

Water is a very good solvent—it will dissolve many things. Have you ever wondered why this is true? The reason can be best understood by knowing a bit about the water molecule's structure and microscopic properties. Because the water molecule resembles a "Mickey Mouse" shape and is not in a straight line, parts of the molecule have a slightly positive charge and other parts have a slightly negative charge. This makes water *polar*. The polar water molecule is similar to a magnet. However, a water molecule is neutral overall--it is not charged like ions are. It is polar because the charges that are in the molecule are not distributed evenly around the molecule.

Look at another way to represent molecular models in the model of water shown in figure 6. This representation shows electrons in orbits around the nuclei. Hydrogen has one proton, shown as the "+" in the nucleus. Hydrogen also has one electron that it shares with oxygen. Oxygen has 8 protons and 8 neutrons in its nucleus. It also has 8 electrons, and it shares one of these electrons with each hydrogen atom. This sharing of electrons forms the bonds that hold the water molecule together.

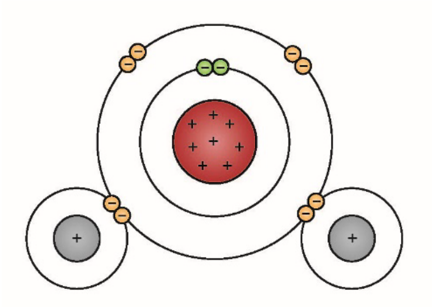


Figure 6: Water (H_2O) molecular model. The two hydrogen atoms have one electron each to share with the oxygen atom. The oxygen atom shares one electron with each hydrogen atom. This gives oxygen 8 electrons on the outside and each hydrogen two electrons on the outside.

STOP AND THINK

Look carefully at the figure 6 diagram. Which side of the water molecule do you expect to have a slightly negative charge and which side do you expect has a slightly positive charge? Draw this model in your notebook and explain your reasoning.

What does being polar have to do with dissolving? Being polar is the property of the water molecule that explains why water is such a good solvent. Many other substances are polar too—not just water. If the solute is polar and you stir it into water, water can interact with the solute and break it apart easily so that it dissolves. Water acts like a tiny magnet and pulls the polar particles of the solute away from each other to dissolve.

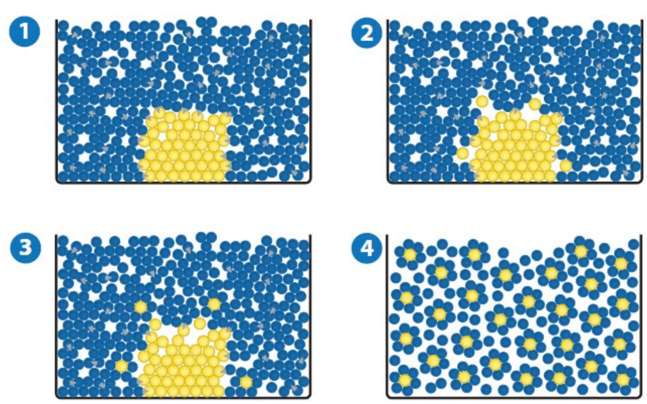


Figure 7: Dissolving sugar in water. Because water is polar it is attracted to itself like two magnets would be attracted to each other. Sugar is also polar. Water particles (shown in blue) attract the sugar particles (shown in yellow) and pull them away from the other sugar particles. The attraction between a water particle and a sugar particle is stronger than between two sugar particles.

Substances that do not dissolve in water are not polar, or nonpolar. These substances have evenly distributed charges all around the molecule. Because of this, water cannot pull the particles apart from each other. It would be like trying to pick up toothpicks with a magnet—it doesn't work!

STOP AND THINK

Look back to your picture of sugar water you drew in the second Stop and Think task or the images in figure 7. Now think of what it would look like after the cup of sugar water sat out long enough for all the water to evaporate. Draw a picture of what it would look like when all the water is evaporated. In your picture use labels to describe what happened to the sugar and the water.

Speeding Up Dissolving

STOP AND THINK

1. Before you begin this section, think of adding a sugar cube (remember those?) to water like is shown in figure 7. In that image, the cube is dropped into the water and allowed to dissolve on its own. Think of all the ways you could speed up the dissolving process.
2. List all the ways you can think of and explain why what you listed would speed up the process. These are just your initial ideas, don't worry if you don't know the "right" answer. Using the particulate nature of matter and thinking of the sugar and water as tiny particles may help you with your explanations.

There are many ways to speed up the process of dissolving sugar in water. Let's see how many you came up with. Did you say stirring? Stirring the sugar water will allow the sugar to dissolve faster. The stirring process moves the dissolved sugar out of the way for water particles to come into contact with more undissolved sugar particles.

Another thing you can do is to crush the sugar cube. The more the sugar particles are exposed to the water, the faster water can break apart the clumps of sugar particles. A single grain of sugar still has zillions of sugar molecules, so even if the sugar cube is crushed into grains of sugar, the water molecules have to separate the sugar molecules from each other in the grain to dissolve the sugar. So, a teaspoon of granulated sugar will dissolve faster than a cube of sugar--even if you don't stir it!

Did you say that heating the sugar water would cause the sugar to dissolve faster? Yes! But the explanation for why this is true and what it has to do with the particulate nature of matter is not as obvious. When water (and other matter) is warmed to a higher temperature, the molecules of water move faster. If the water molecules are moving faster, as the sugar is dissolved, the moving water can move it away from the undissolved sugar faster. This is similar to stirring. Particles of water are moving faster because the temperature is higher--bumping into the sugar more often and causing the sugar to dissolve faster.

You have learned a lot about the dissolving process and how matter behaves when mixed with water. You can also explain some of those interactions. Have you thought about what happens when the reverse happens--evaporation? Think about your sugar water or saltwater solution. What would happen if you left it out for a long time--until the cup was dry? What happens to the water? What happens to the sugar or salt? When left out to dry, the water will all evaporate. This means that the H_2O molecules that made up the liquid go into the air as a gas. Does the salt or sugar do that also? No, the salt or sugar would remain in the cup. You can speed up the evaporation process by heating the solution, making the water molecules go into the air faster.

Can you see how useful the particulate nature of matter is for explaining how matter behaves? Using this model to explain dissolving and the factors that speed up dissolving is something that your students will do in this unit.

Chemical Interactions

What if you stirred up baking soda and vinegar? You probably have done this in your kitchen. Is there an interaction? Yes—there is a *chemical reaction*! When something new is produced that has different properties, you know a chemical reaction has taken place. The molecules before the reaction are different from the molecules after the reaction. What is new that is produced when you mix baking soda and vinegar? The bubbles of gas! The fact that baking soda reacts with vinegar is a chemical property of baking soda. The same can be said about vinegar. *Chemical properties* describe how the substance reacts with other substances. Iron will rust when exposed to air and moisture. When you mix baking soda with vinegar you get a reaction, but when you mix baking soda with water, no reaction occurs. The fact that baking soda does not react with water is also a chemical property of baking soda. Rusting and burning are both chemical reactions, and some types of matter have these chemical properties. Can you name matter that will rust or burn?

Your students will not study chemical reactions or chemical properties. However, understanding physical properties will set them up well for learning in later grades how to determine if a chemical reaction has occurred or not.

Reflections on Models

What are models, and how can they be used?

A model is a representation of a phenomenon that is used as a tool to explain how or why something in the world works the way it does (NGSS Lead States, 2013; McNeill, Katsh-Singer, & Pelletier, 2015). In general, a model is defined by how it is used. For example, scientific models are sensemaking tools that help us predict and explain the world, while engineering models are used for analyzing, testing, and designing solutions (Passmore, Schwarz, & Mankowski, 2017). In general, models can be represented as diagrams, three-dimensional objects, mathematical representations, analogies, or computer simulations (NGSS Lead States, 2013). In lessons that are part of this program, students build conceptual understanding of science by creating and revising models to explain phenomena. The course of a storyline can be described as a sequential process of developing and revising models to describe and explain different aspects of a phenomenon.

Purpose

The purposes of engaging students in the development and use of models follow:

- **For students' own sensemaking:** Making visible students' ideas can help students consider the interrelationships between their ideas and consider nonvisible components and processes that might be relevant for explaining the phenomenon.
- **To support students' work with others:** Representations can be useful for sharing their ideas with others to reach consensus.

- **To track progress in student learning over time:** Tracking the gradual development of ideas can help students individually and collectively make explicit what they've figured out, consider how their ideas are interrelated, and identify what is still needed.

PROPERTIES OF MATTER PRE OR POST TEST

Name ______________________________________ **Date** ________________________

1. Mrs. Johnson, a 5th-grade teacher, was cleaning up her classroom after school when she discovered a solution bottle with no label. She did not know what was in the solution.

   a. Write one testable and one untestable question Mrs. Johnson might ask about the solution.

   Testable question: ____

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   Untestable question: ____

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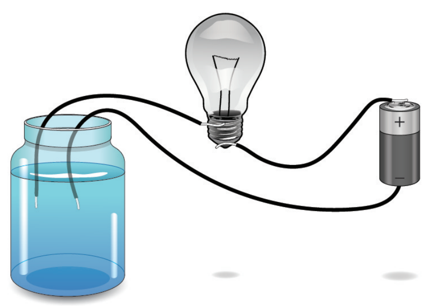
   b. Mrs. Johnson checked to see if a light bulb would light up when she put wires connected to the bulb and a battery in the solution. How could this test help her figure out what is in the solution?



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2. Saltwater

30 g water

Image by Wilson Blanco from Pixabay

2 g salt

Image by Bruno from Pixabay

a. Two grams of salt are dissolved in 30 grams of water. How much does the resulting salt solution weigh? Explain your answer.

b. Suppose you want to dissolve 10 more grams of salt in the water. What could you do to make it dissolve faster? Explain why this helps.

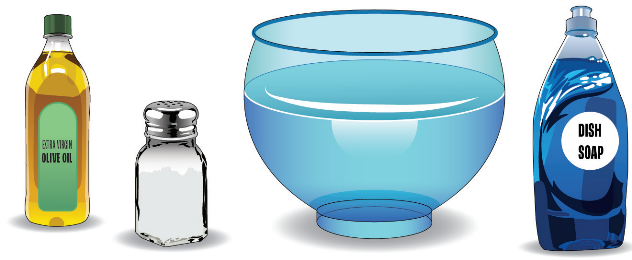
3. Use words and pictures to zoom in and show what happens when a saltwater solution is left out and the water is allowed to evaporate.

Zoom-in picture of saltwater solution	Zoom-in picture after water has evaporated

Explanation of pictures:

4. Sofia set up a fishbowl. She checked the water to make sure it was at the right temperature.

   When she came home from the pet store with her new fish, her 5-year-old cousin Mateo was waiting for her. He proudly told her he had made a "potion" in her fishbowl!



   Mateo did not remember exactly what he mixed into the water. But on the table beside the fishbowl Sofia found cooking oil, dishwashing soap, and salt. She needed to find out what was in the water before adding any fish.

   a. What should Sofia do to figure out what Mateo added to the water?

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Sofia wrote down the evidence she collected in her experiment:

- The water is clear.
- There is a layer of something on top of the water.
- No salt crystals can be seen in the water.
- A light bulb lights up when it is connected to a battery and wires from the bulb and battery are placed in the water.

b. Complete the table below based on the evidence above.

Substance	**Evidence about the substance**	**What this evidence means**
Cooking oil		
Dishwashing soap		
Salt		

c. What did Mateo add to the aquarium water? Circle the evidence in the table that supports your conclusion.