Physical Sciences
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Mixtures and Solutions

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

PS1g. Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_{12}O_6$), water (H_2O), helium (He), oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2).

Mixtures

The next time you are at the beach, pick up a handful of sand. Look at it closely. You will see that each grain of sand is really a tiny rock. Not only that, the grains are different colors. And some of the grains are not rocks at all, they are little pieces of seashells. Sand is a **mixture.** A mixture is two or more materials together. This sand is a mixture of black, white, tan, and gray rocks, and bits of shell. A handful of sand is a mixture of several different things.

Sand

Mixtures are everywhere. But if you are not looking for them, you could miss them. The sidewalk is a mixture you can walk on. It is several sizes of rock mixed with cement. A bag of mixed nuts is a mixture you can eat. So are vegetable soup and carrot-and-raisin salad. And if you ate some mixed nuts, vegetable soup, and salad, just think about the mixture in your stomach!

Mixed nuts

Carrot raisin salad

Making Mixtures

Mixtures like sand or mixed nuts are made with two or more **solid** materials put together. Solid is one of the three common states of **matter.** Solid objects have **mass,** take up space, and have a definite shape and **volume.** A peanut, for instance, stays the same size and shape in your hand, on a tabletop, or in a glass.

A peanut stays the same size and shape in any container.

Chocolate syrup and milk is a mixture. Lemon juice and water is a mixture. So is oil and vinegar. These are examples of mixtures made of two **liquid** materials. Liquid is the second common state of matter. Liquids have mass, take up space, and have a definite volume. But liquids do not have a definite shape. A volume of water can have a different shape depending on whether it is in your hand, on a tabletop, or in a glass. Liquids are the shape of the container they are in.

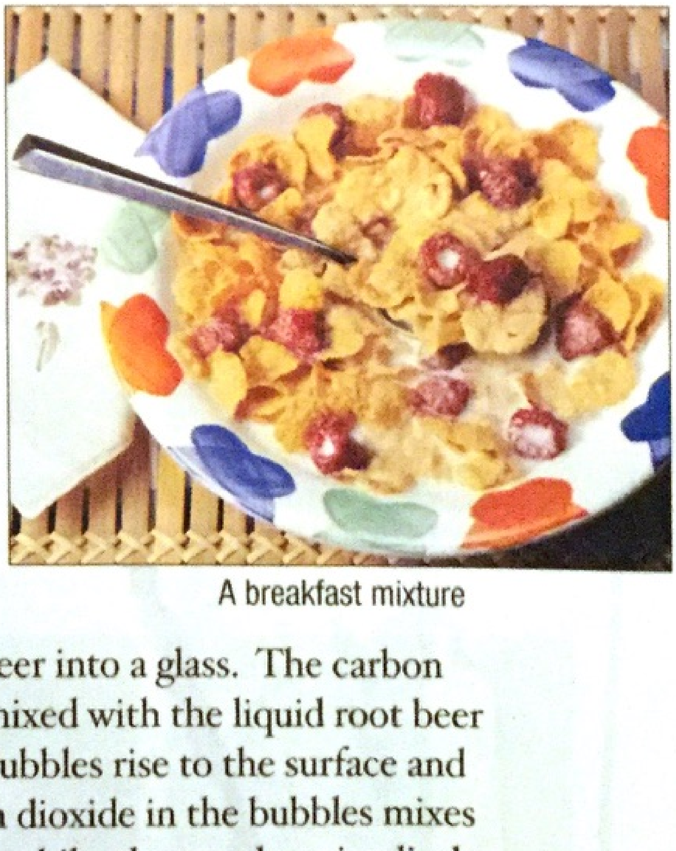
Water changes shape depending on what you put it in.

Your breath is a mixture. The exhaust coming out of a car is a mixture. The air that surrounds Earth is a mixture. These are examples of mixtures made of **gaseous** materials. **Gas** is the third common state of matter, but we don't see gases very often. Most gases are colorless and **transparent.** Some gases, however, have color, like those that make smog. We can see air on a smoggy day.

A smoggy day in Los Angeles

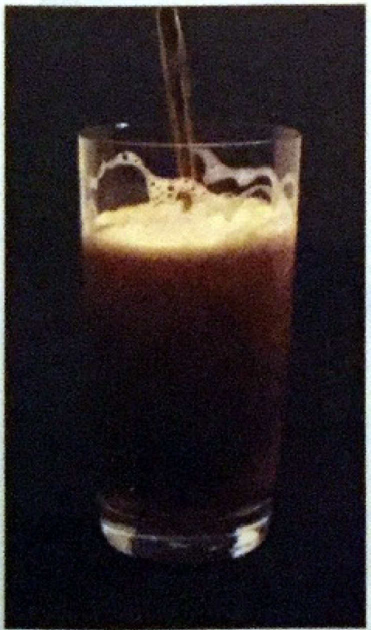
Gases have mass and take up space, but they do not have definite volume or shape. A mass of air will not stay in your hand, on a tabletop, or in a glass. Gases are shapeless and expand to fill any closed container they are placed in.

Solids and liquids are often mixed. Salt and pepper are mixed with oil and vinegar to add taste to salad dressing. Flour and water are mixed to make bread. Cereal and milk are mixed for breakfast. Rice is mixed with water to cook it.



A breakfast mixture

Gases and liquids are mixed sometimes, but often the gas separates from the liquid as bubbles. That's what happens when you pour root beer into a glass. The carbon dioxide gas that was mixed with the liquid root beer forms bubbles. The bubbles rise to the surface and pop. Then the carbon dioxide in the bubbles mixes with the air. But for a while, the root beer is a lively mixture of liquid and gas.



A mixture of liquid and gas

Mixtures of solid and gas aren't often made on purpose. But they happen all the time by accident. If you fill a glass with marbles, you have a mixture of marbles and air. The spaces between the marbles are filled with air. The same is true of any solid objects in a container. And when it snows, the air is mixed with frozen (solid) water. Dust floating around in the air is also a mixture of a solid and a gas.

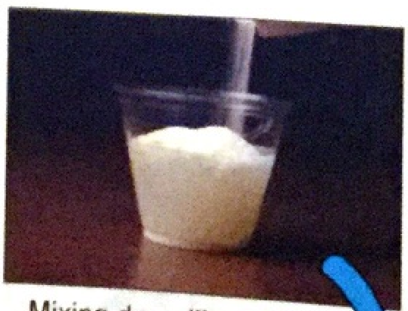
Can you have a mixture of solid, liquid, and gas? Yes. Remember that glass of root beer? Just add a few ice cubes. The glass of ice-cold root beer is a mixture of solid, liquid, and gas.

A mixture of solid, liquid, and gas

Mixing Solids and Liquids

Mixtures of solids and liquids are interesting. Several things can happen. When gravel and water are mixed, the gravel sinks to the bottom of the container. If you stir the mixture, things move around, but that's about it.

Mixing gravel and water



Mixing dry milk and water

Mixing salt and water

Gravel mixture after 5 minutes

Milk mixture after 5 minutes

Salt mixture after 5 minutes

When you mix **diatomaceous earth** and water, the powder makes the mixture cloudy white. After a while, the powder settles to the bottom of the container. When you mix powdered milk and water, the mixture stays cloudy white. When you mix salt and water, the salt disappears, and the mixture is transparent and colorless.

Gravel, powdered milk, and salt all make mixtures with water. After stirring, you can still see the gravel and milk, but the salt is gone. Salt is different in some way.

A mixture of salt and water forms a **solution.** When a solid and a liquid are mixed, the solid disappears into the liquid, and the mixture is transparent. This mixture is a solution. A solution is a special kind of mixture.

When the solid material disappears, it is *not* gone. It has **dissolved.** When a solid material dissolves, it breaks into pieces so tiny that they are invisible. When salt dissolves in water, it makes a saltwater solution.

Some solid materials dissolve in water and some don't. If a material dissolves, it is **soluble.** Salt is soluble in water. If a material doesn't dissolve, it is **insoluble.** Sand is insoluble in water.

The **solubility** of a material can help you identify it. For instance, if you have a white material and you are not sure if it is white sand or salt, you can put it in water. If it is soluble, the material is salt. If it is insoluble, it is sand.

Review Questions

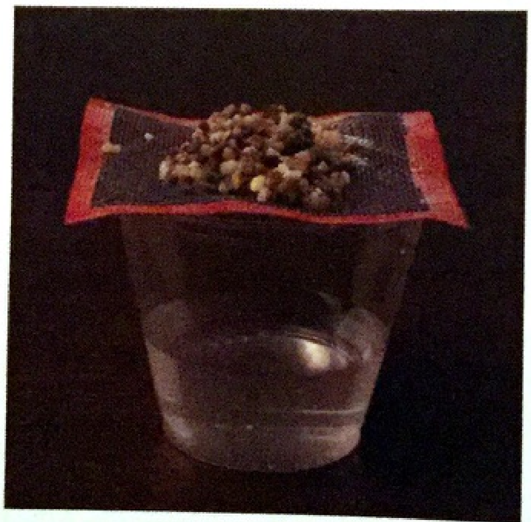
1. **The three common states of matter are solid, liquid, and gas. How are they the same? How are they different?**
2. **What is a mixture?**
3. **Is milk a mixture, a solution, or both? Explain why you think so.**

INVESTIGATION 1

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

Taking Mixtures Apart

You made a mixture of gravel and water. It was easy. You just put 50 milliliters (ml) of water and a spoon of gravel in a cup, and the job was done. And you separated the mixture of gravel and water. That was easy, too. You poured the mixture through a screen. The gravel stayed on the screen, and the water passed through.


A screen can separate gravel and water.

All mixtures can be separated. But not all mixtures can be separated in the same way. The **physical properties** of the materials in the mixture can be used to separate the mixture. Particle size is a physical property of gravel. Particle size is a physical property of water. The particles of gravel are larger than the holes in the screen. The particles of water are smaller than the holes in the screen. The screen can be used to separate the mixture.

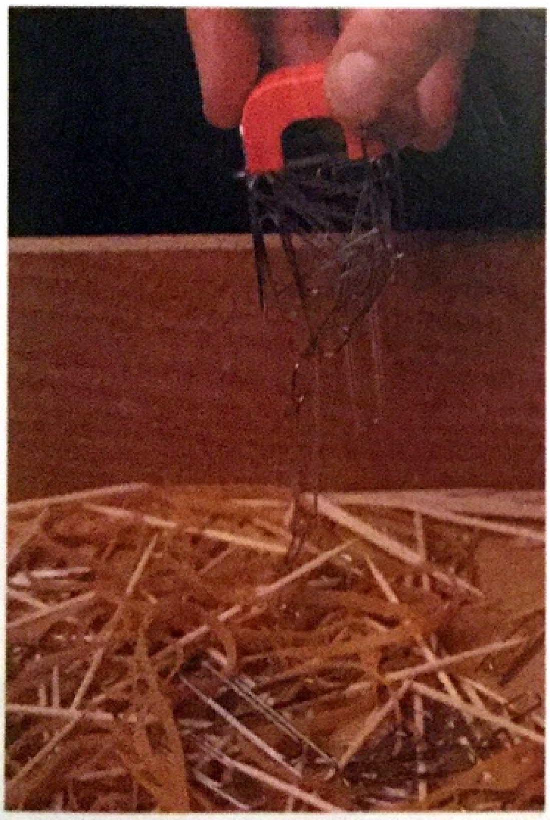
The mixture of diatomaceous-earth powder and water passed through the screen. The particles of powder and water are both smaller than the holes in the screen. What property will separate powder from water? Size again. Powder particles are larger than the holes in filter paper. Water particles are smaller. A filter paper will separate a mixture of powder and water.

Other Ways to Separate Mixtures

Imagine opening a kitchen drawer to get a rubber band. Oops, the rubber bands spilled. So did a box of toothpicks and a box of paper clips. The drawer contains an accidental mixture of rubber bands, toothpicks, and paper clips. How can you separate the mixture?

A mixture of paper clips, rubber bands, and toothpicks

You could use the property of shape. You could pick out each piece one at a time. It might take 10 minutes to separate the mixture.



Separating steel paper clips with a magnet

Paper clips are made of steel. Steel has a useful property. Steel sticks to magnets. If you have a magnet, you can separate the steel paper clips from the mixture in a few seconds. Magnetism is a property that can help separate mixtures.

What about the toothpicks and rubber bands? Wood floats in water. Rubber sinks in water. The properties of floating and sinking can be used to separate the wood toothpicks and rubber bands in seconds. Drop the mixture into a cup of water. Then scoop up the toothpicks from the surface of the water. Pour the water and rubber bands through a screen. The water will pass through the screen, but the rubber bands won't. Job done.

Separating toothpicks and rubber bands in water

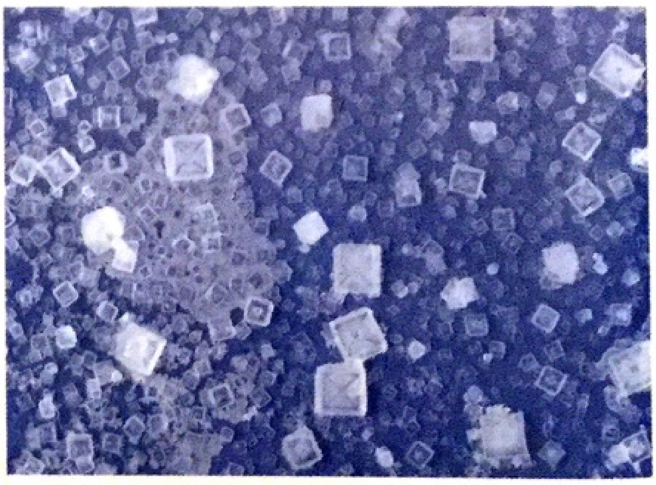
Separating Solutions

A mixture of salt and water is a solution. The dissolved salt particles and the water particles are both smaller than the holes in filter paper. The property of size is not useful for separating a solution of salt and water. What will work? **Evaporation.**

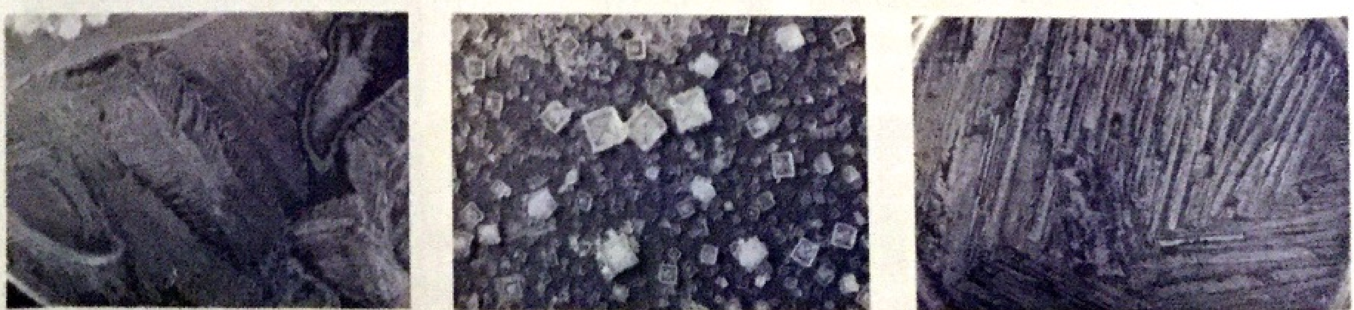
Evaporation is the change of state from liquid to gas. Water evaporates, but salt does not. When a salt solution is left open to air, the water slowly turns to gas and goes into the air. The salt is left behind. Solutions can be separated by evaporating the liquid.

The salt left behind after evaporation doesn't look like the salt that dissolved in the water. Yes, it is salt. When the water evaporates, the salt reappears as salt **crystals.** Salt crystals always look square. Salt crystals often have lines going from corner to corner, forming an X.

Many solid materials dissolve in water to make solutions. When the water evaporates, the materials reappear as crystals. Each different material has its own crystal shape. Some crystals are needle-shaped. Other crystals are six-sided. And others are like tiny fans.


Sodium chloride crystals

Crystal shape is a physical property. Crystal shape can be used to identify materials. Whenever you observe square-shaped crystals in an evaporation dish, you will know that salt might be one of the ingredients in the solution.


Three different crystal forms

Review Questions

1. How would you separate a mixture of marbles, corks, and nails?
2. Would a screen be useful for separating a mixture of gravel and diatomaceous-earth powder? Explain.
3. Would filter paper be useful for separating a sugar and water solution? Explain.
4. Why does salt separated from a saltwater solution look different than the salt that dissolved in the water?

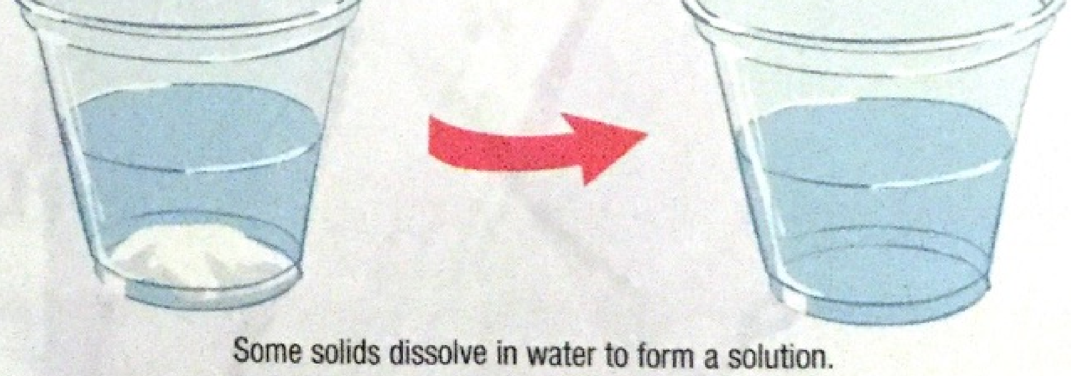
Summary: Separating Mixtures

What do fruit salad and hair gel have in common? They are both **mixtures.** A mixture is two or more materials together. Fruit salad is several kinds of fruit chopped up and put together. Hair gel is some sticky stuff and perfume put together.

Making Mixtures

On Earth, matter is found in three common forms, called states. These states are **solid, liquid,** and **gas.** Matter in any of its three states can be combined to make mixtures. A mixture can have solids, liquids, and gases all mixed together.

Some of the most interesting mixtures result from putting solids and liquids together. Sometimes solids seem to disappear when they are mixed with a liquid. This is what happens when salt is mixed with water. The salt **dissolves** in the water. This special kind of mixture is called a **solution.** Solutions made with water are **transparent,** that is, you can see through them clearly. If a solid is mixed with water and the liquid is not clear, like milk, the liquid is not a solution.



Some solids dissolve in water to form a solution.

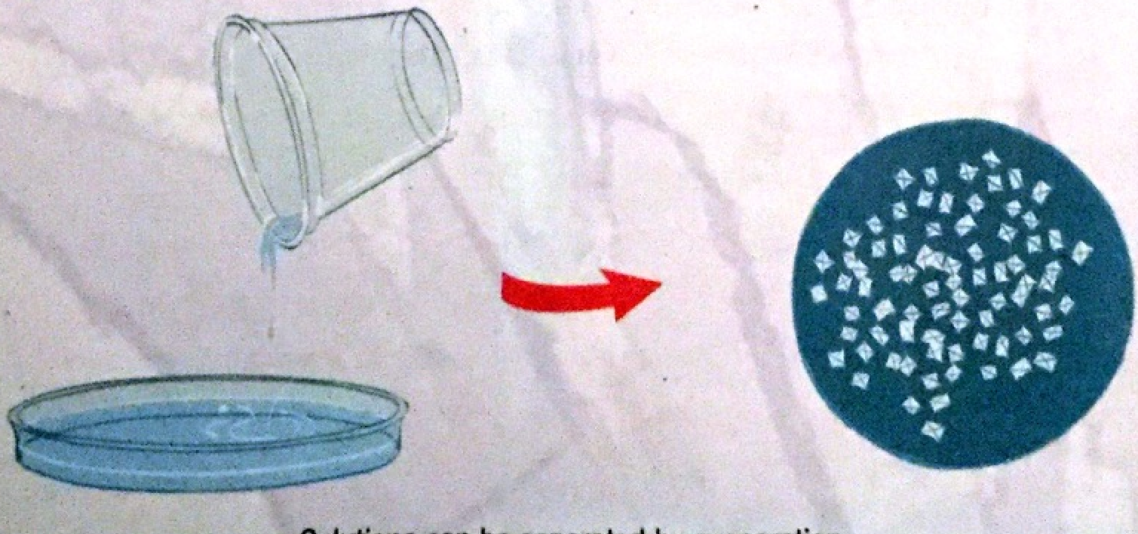
Separating Mixtures

Mixtures can be taken apart. You can take fruit salad apart with a spoon. You can pick out the strawberries first, then the grapes, and finally the oranges. You can identify the strawberries, grapes, and oranges by their **physical properties** of color and texture.

Other materials have different properties you can use to separate them. Screens and filters can separate materials with different particle sizes, such as gravel and water. Iron materials can be separated with a magnet. Floating materials can be separated with water, and so on.

Solutions, such as salt water, cannot be separated with filters. The particles of dissolved salt are smaller than the holes in the filter. Solutions can be separated by **evaporation.** During evaporation, the water changes to gas and moves into the air. Salt does not evaporate, so it is left behind in the evaporation dish. The salt reappears as square-shaped **crystals.**

A salt crystal looks square and usually has an X from corner to corner. Other materials make crystals that are different shapes, like needles, fans, or triangles. The shape of the crystal can help identify the solid material in a solution.



Solutions can be separated by evaporation.

Summary Questions

Now is a good time to review what you have recorded in your science notebook. Think about the investigations you have conducted with separating mixtures.

1. What is the difference between a liquid, a solution, and water?
2. What is a mixture?
3. What is a solution?
4. Is salt water a mixture or a solution? Explain.
5. Describe three ways to separate a mixture.

California Science Standards

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

PS1g. Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_{12}O_6$), water (H_2O), helium (He), oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2).

Vocabulary

mixture
solid
liquid
gas
dissolve
solution
transparent
physical property
evaporation
crystal

Extensions

Math Problem of the Week

Andy had a box of animal crackers. He counted them out and found 20 cookies: 7 elephants, 6 tigers, 5 monkeys, 2 zebras. Suppose Andy put all the animal crackers back into the box and took one out without looking. What is the probability of his choosing a. an elephant? b. a tiger? c. a monkey? d. a zebra?

Does the sum of the probabilities *a, b, c,* and *d* equal 1?

Home/School Connection

Make a mixture known as oobleck.

Materials

1 Mixing bowl and spoon
1 Measuring cup
- Cornstarch
- Water

Directions

1. Put about 1 cup of cornstarch in the mixing bowl.
2. Slowly add water to make a mixture, stirring as you go.
3. When the starch is all wet, it will turn into oobleck.
4. Explore the properties of oobleck.
   - Is it a solid or a liquid?
   - What happens when you place solids, like coins or spoons, on the surface?
   - Pick up a handful of oobleck. Can you hold it?
   - Can you cut a ribbon of oobleck with scissors?
   - What happens to the properties of oobleck when you change the amounts of the two ingredients in the mixture? More water? More cornstarch?

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

PS1i. Students know the common properties of salts, such as sodium chloride (NaCl).

Solutions Up Close

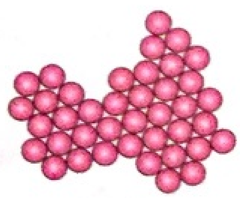
Salt solutions are transparent. You can't see anything in them. When you look at a salt solution with a hand lens, what do you see? Still nothing. In fact, you can't see anything in a salt solution even with the most powerful light microscope. Does that mean the salt is gone when it dissolves?

No, the salt is still there. To understand what happens to the salt, you have to think very small. You have to think about pieces of salt so small that it takes billions and billions of them to make a tiny salt crystal. We can call the tiniest piece of salt a salt **particle.**

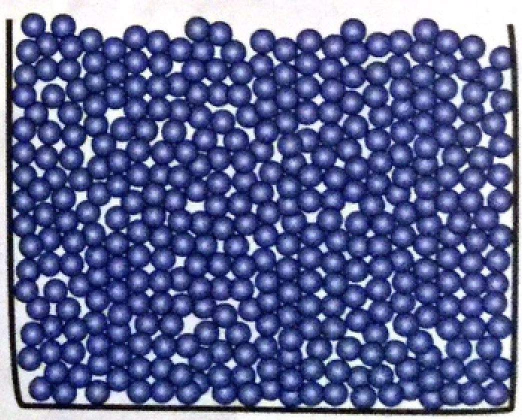
Water is also made of particles. Water particles are different than salt particles, but they are about the same size. In liquid water, the particles are always moving around and over one another.

Let's imagine that we can see the salt particles. We'll represent one sodium chloride particle with this pink circle.

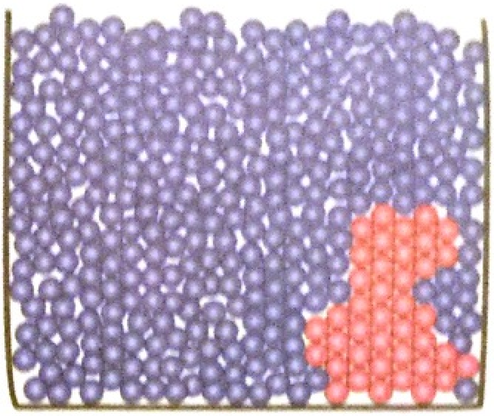
One tiny crystal of sodium chloride might look like this. The salt crystal is a solid. It has shape and occupies a definite volume.



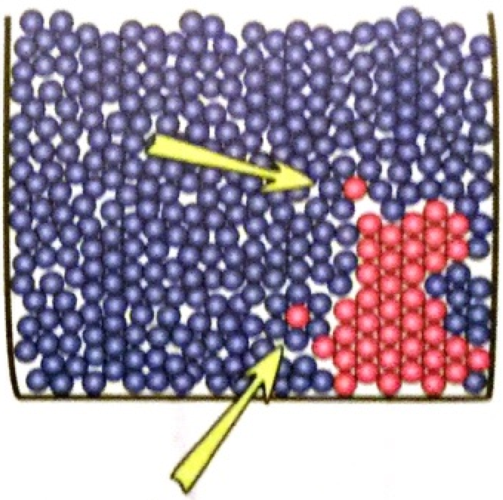
If we could see water particles, they might look like this. The water is liquid. The particles are moving over and around one another all the time. That's how water flows. The mass of water has a definite volume, but water changes shape to fit its container.



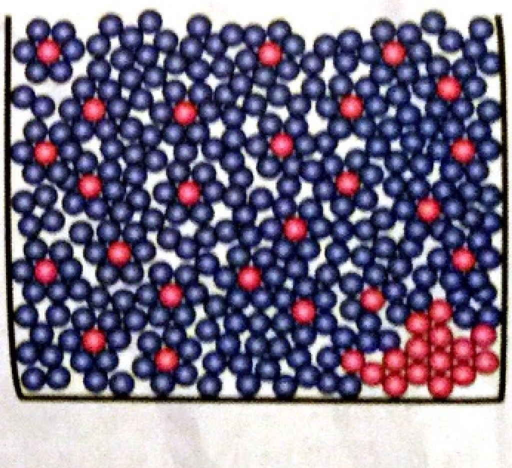
When you put a crystal of salt in a container of water, the salt sinks to the bottom.



The particles of water bump into the salt crystal. This action knocks salt particles off the crystal. The loose salt particles become surrounded by water particles.



The salt particles are carried into the water. They end up spread evenly among the water particles. The particles of salt among the water particles are the dissolved salt. The particles of salt still on the bottom of the container are undissolved salt crystals.



A solution forms when a **solute** dissolves in a **solvent.** The salt dissolves in the water. In this solution, the salt is the solute, and the water is the solvent.

Saturated Solutions

If you put one tiny crystal of salt in a bottle with 50 milliliters (ml) of water, the crystal will dissolve. You can imagine what the solution would look like at the particle level. There would be only a few salt particles among a lot of water particles.

If you add a spoon of salt crystals to the bottle, the salt will dissolve. Now there are a lot of salt particles throughout the volume of water. If you add ten more spoons of salt to the bottle, it will not all dissolve. No matter how much you shake the bottle or how long you wait, the salt won't dissolve. Why is that?

The solution is **saturated.** A solution is saturated when the solvent cannot dissolve any more solute. It's like there is no room for any more solute particles to fit in among the solvent particles.

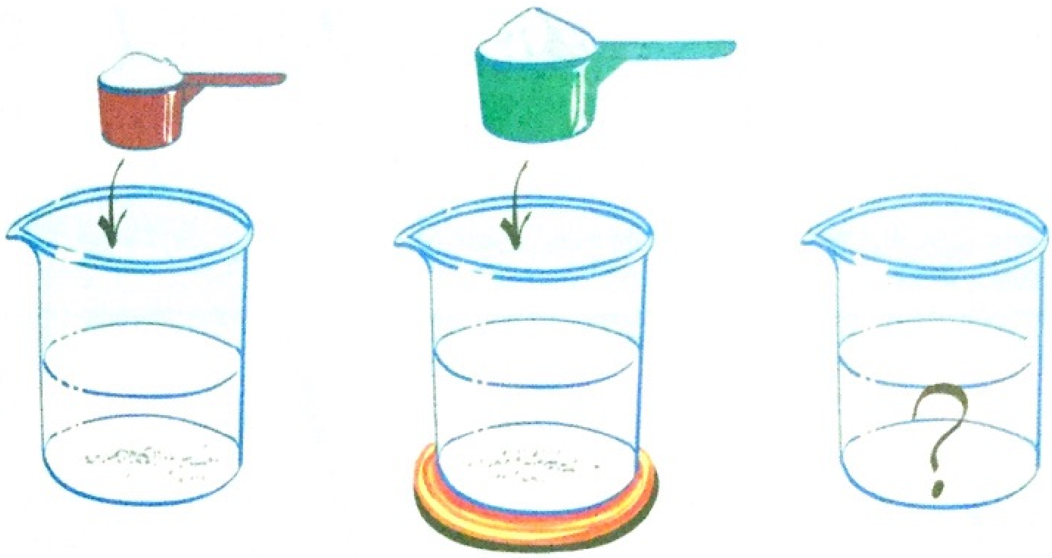
If you start with 50 ml of water in a bottle, it will be saturated when about 14 grams (g) of salt are dissolved. If you put more salt in the solution, it will stay on the bottom of the container. The salt just will not dissolve. If you add another 50 ml of water to the bottle, it will take 28 g of salt to saturate the 100 ml of water. If you increase the volume of water to 1,000 ml (1 liter), you will find that it takes 280 g of salt to saturate the liter of water.

Supersaturated Solutions

Have you ever heard of rock candy? It is crystals of sugar. To make rock candy, you need to know some things about the science of solutions.

Sugar dissolves in water. It takes about 100 g of sugar to saturate 50 ml of water at **room temperature.** But if you heat the solution, more sugar will dissolve. The hotter you get the solution, the more sugar dissolves.

When the solution reaches its boiling point, it won't get any hotter. When you see undissolved sugar in the pan of boiling sugar solution, you know the solution is saturated. But there is about twice as much sugar dissolved in the boiling-hot saturated solution as there is in a room-temperature saturated solution.



A saturated solution at room temperature

A saturated solution at boiling temperature

A supersaturated solution at room temperature

What will happen to all that extra sugar when the boiling-hot saturated solution cools down? Will it stay in solution? Or will it come out of solution and pile up on the bottom of the container?

The sugar will stay in solution. A solution that contains more solute than it should is a **supersaturated solution.** When the boiling-hot saturated sugar solution cools down, it is supersaturated.

Now the solution is ready to make rock candy. When you roll a wet string in sugar, the sugar sticks to the string. After the sugary string dries, it is covered with tiny sugar crystals. Then put the string in the supersaturated solution. The extra sugar in the solution comes out of solution in the form of sugar crystals. The crystals grow on tiny sugar crystals stuck to the string.

The crystals will grow for a couple of days and then stop. Why do they stop growing? Sugar comes out of solution until the solution is no longer supersaturated. Then no more sugar comes out of solution.

Review Questions

1. **Explain what happens at the particle level when a solid dissolves in a liquid.**
2. **How do you know when a solution is saturated?**
3. **Sugar crystals aren't very big when they stop growing. How could you make bigger sugar crystals?**

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

PS1g. Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_{12}O_6$), water (H_2O), helium (He), oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2).

The Bends

Hard-hat diving was invented in 1861. The diver climbed into a watertight suit with a brass helmet. An air hose was attached to the helmet. Air was pumped to the diver walking around on the bottom of the sea 20 meters (66 feet) below the surface.

The **bends** is a condition that used to happen to deep-sea divers after returning to the surface. Divers felt dizzy, confused, and uncoordinated. They felt pain in their knees, hips, shoulders, and elbows. It became impossible for them to straighten their arms and legs. The pain caused divers to bend their arms and legs for pain relief. That's where the name *bends* came from.

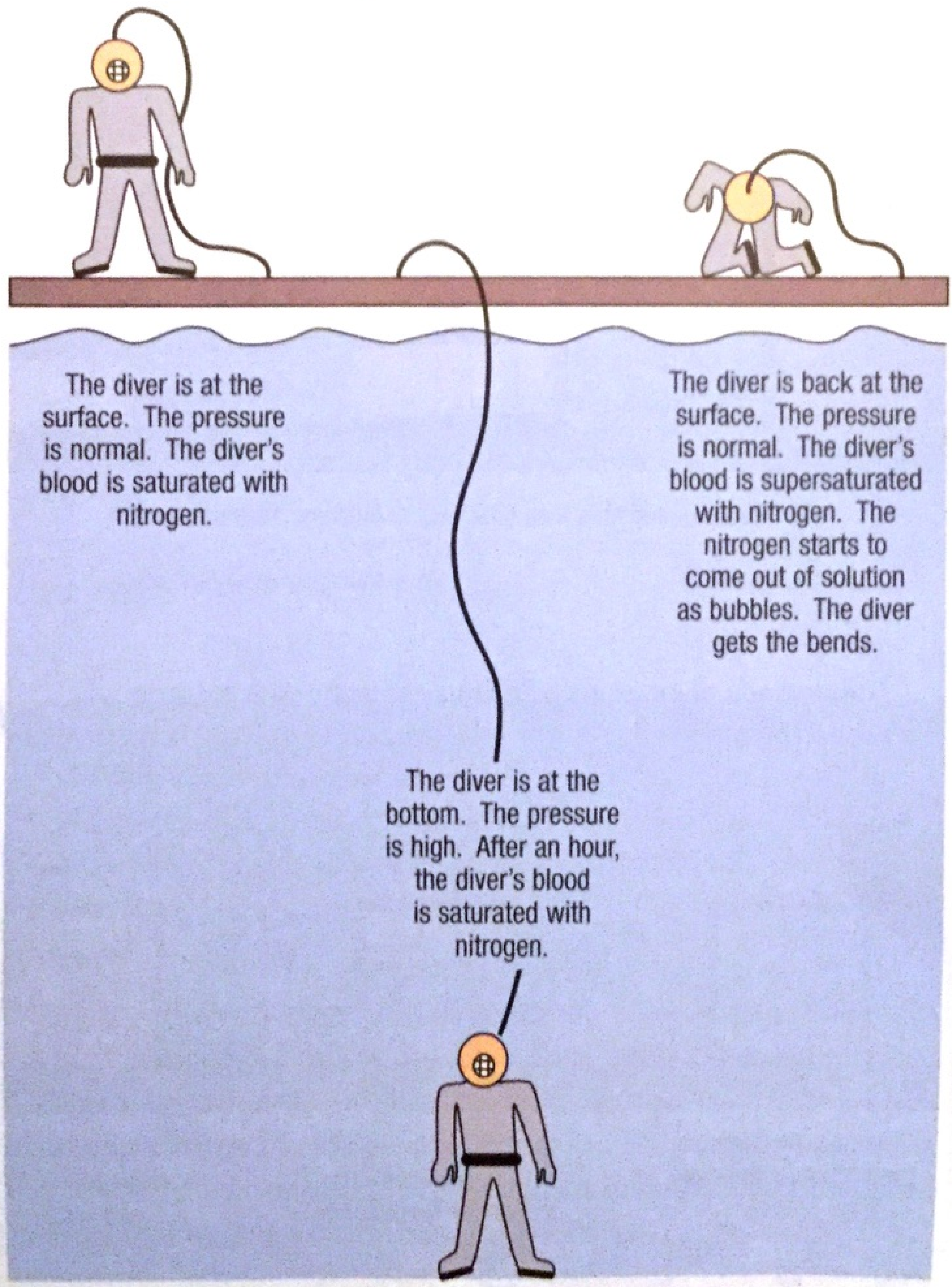
The cause of the bends wasn't known until 1878. French scientist Paul Bert figured it out. **Nitrogen** bubbles in the diver's blood and joints caused the bends. But where did the nitrogen bubbles come from? To answer that question you need to know more about supersaturated solutions.

A solution is a solute dissolved in a solvent. We know about solids (salt) dissolved in liquids (water). Solutions can also be made when gases dissolve in liquids. That's what happens in the human body. Gases in the air that divers take into their lungs dissolve in the blood. Under normal conditions, the blood is saturated with dissolved nitrogen. No more nitrogen can dissolve.

When a diver goes under water, the pressure increases. Pressure compresses the air in the diving suit. The air particles are pushed closer together. As a result, more air dissolves in the blood. Air is 78% nitrogen, so most of the additional gas that dissolves in the diver's blood is nitrogen. After the diver has been under water for an hour, his blood is again saturated with nitrogen. But now it is saturated at high pressure, so there is more nitrogen in his blood than there was when he was at the surface.

Trouble starts when the diver rises to the surface. The pressure drops to normal. The blood is holding much more nitrogen than it normally holds at surface pressure. The blood is supersaturated with nitrogen. The extra nitrogen comes out of solution (the diver's blood) as nitrogen bubbles. The bubbles get stuck in blood vessels and stop the flow of blood. Bubbles form in the fluids in joints, causing a lot of pain.

The bends is **decompression** sickness. *Decompression* means changing from higher pressure to lower pressure. That's when the effects of too much nitrogen in the blood are felt.

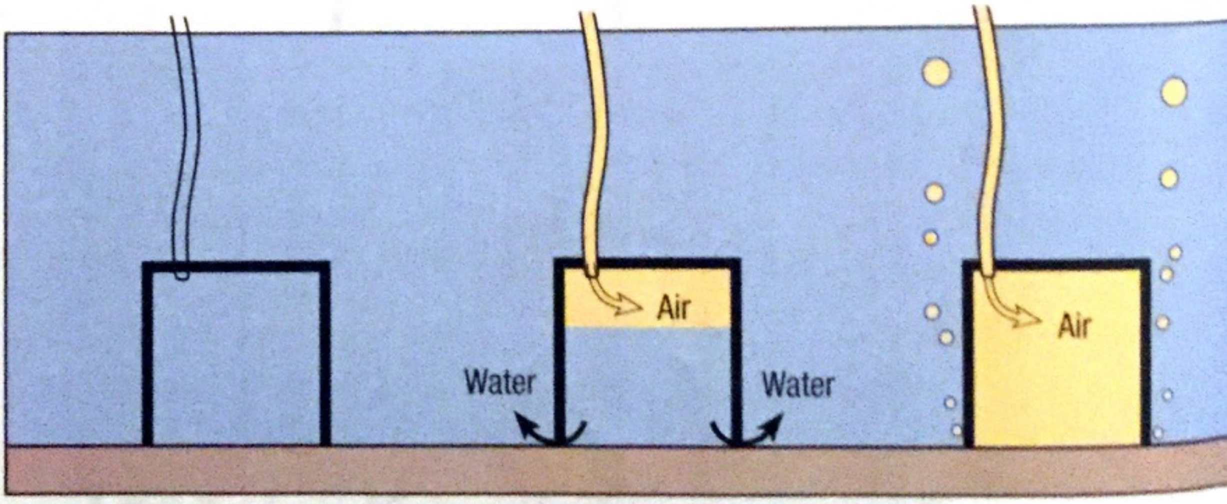


Caisson Disease

Decompression sickness also showed up in a different situation. In 1869 James Buchanan Eads began building a railroad bridge across the Mississippi River. The bridge needed support in the middle of the river. This required a lot of digging underwater. How could that be done?

Eads used **caissons.** A caisson is a huge box with no bottom. It is placed on the bottom of a river with the open side down. Air is then pumped into the box. The air pushes the water out under the bottom of the box. Now workers can dig and build foundations inside the caisson because it is filled with air.

The Eads Bridge

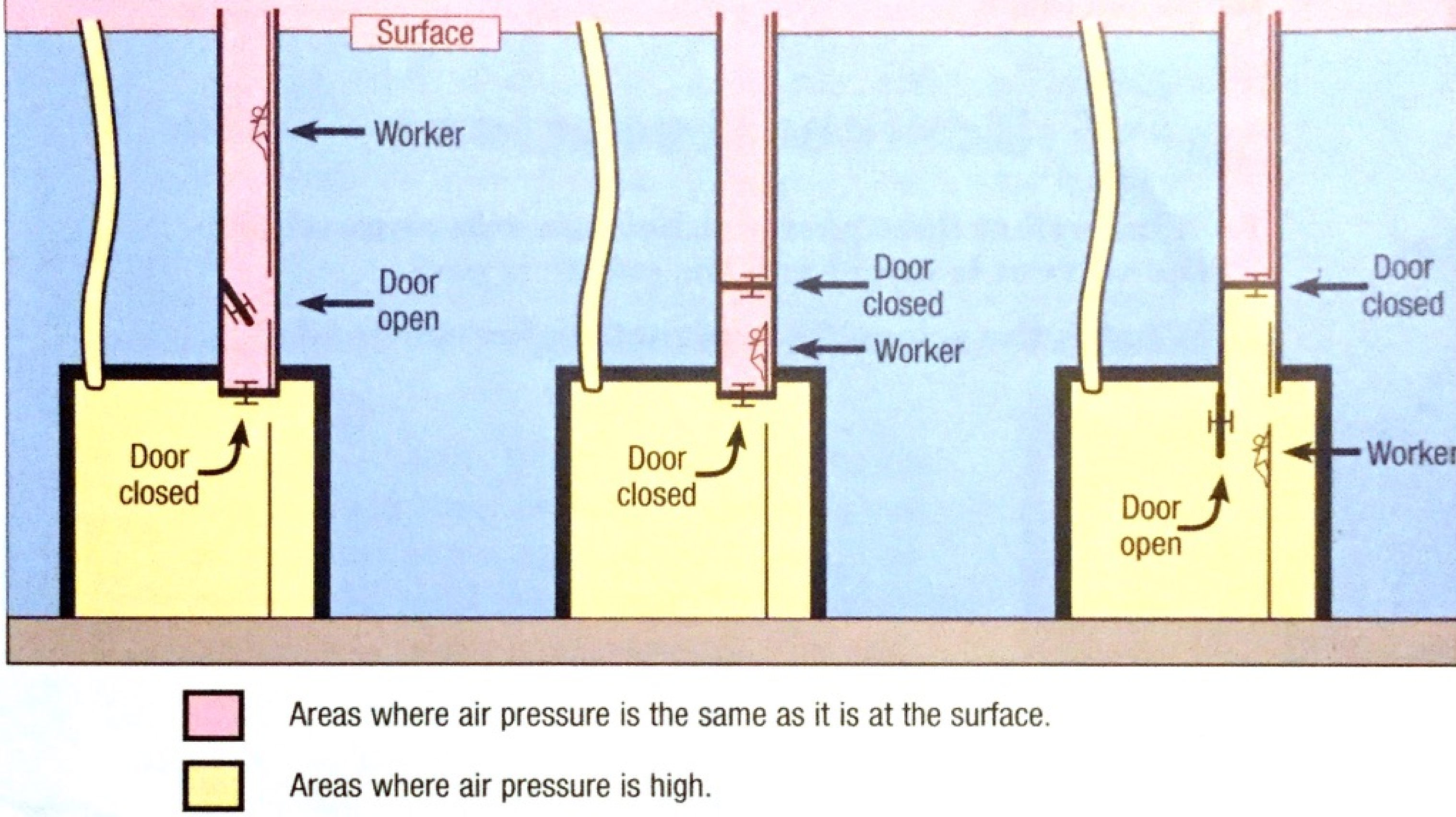


The caisson rests on the bottom of the river.

Pressurized air pushes water out under the bottom of the caisson.

Pressurized air keeps water out of the caisson.

The caisson was fitted with a tube that had tight-fitting doors. Workers climbed down the tube to the closed door at the top of the box. They closed a door behind them. Then they opened the door into the box. By using two doors, the pressure was maintained. This kept the water from flowing back under the bottom of the box.



The problem was the pressure. The pressure in the box had to be kept high enough to keep the water out. The workers were breathing concentrated nitrogen, so more nitrogen dissolved in their blood. At the end of a workday, their blood was saturated with nitrogen in the pressurized environment. When they returned to standard atmospheric pressure at the water's surface, they had the same symptoms as deep-sea divers.

At a depth of 10 m (33 ft.) underwater, the pressure is twice as high as standard atmospheric pressure. The workers were in no danger working in the higher pressure in the caisson. The extra nitrogen in their blood did no harm. It was the change of pressure between the caisson and the surface that caused the extra dissolved nitrogen to rush out of the blood as bubbles.

Solving the Bends

Once the cause of the bends was understood, the condition was easily cured. Divers had to take more time to change the pressure back to normal. That meant coming halfway back to the surface and waiting there for 15 minutes. The nitrogen came out of solution slowly, so it didn't form bubbles. The extra nitrogen left the blood in the lungs and was exhaled. Then divers could come to the surface safely.

Review Questions

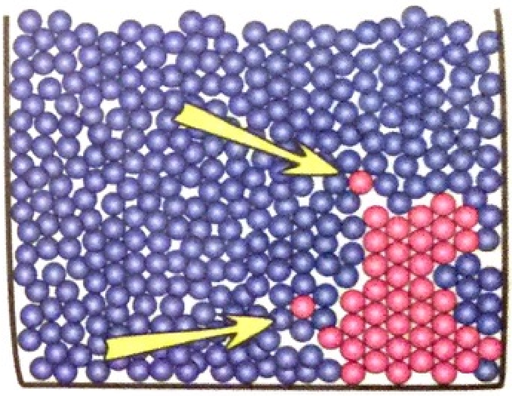
1. **What effect does pressure have on solutions where the solvent is liquid and the solute is gas?**
2. **What is the scientific explanation for the bends?**

Summary: Reaching Saturation

Substances are made of tiny **particles.** Every different substance has its own unique kind of particle. The water particle is different from the salt particle. The salt particle is different from the Epsom salts particle, and so on.

One particle of water, salt, or any other substance is too small to see. But you have to think about substances as particles to understand how things dissolve to make solutions. Here's what happens when you make a mixture of salt (sodium chloride) and water.

The salt particles are all stuck together. They form a solid crystal of salt. When a salt crystal is dropped into water, it sinks to the bottom.



Water is liquid. Water particles are moving around all the time. Water particles bang into salt particles on the edges of the crystal. The salt particles break free from the crystal and are carried away by the water particles. The salt particles get spread through the water particles.

When particles of one substance (a **solute**) spread evenly throughout the particles of a second substance (a **solvent**), the result is a solution.

If you keep adding solute to a solution, the solute will dissolve until the solution is **saturated.** A saturated solution is holding as much solute as it can. If more solute is added, it will pile up on the bottom of the container.

But if you heat a saturated solution, more solute will dissolve. In general, the hotter the solution, the more solute it takes to saturate it. A hot saturated solution has more solute dissolved in it than a cold saturated solution.

What happens to the hot saturated solution when it cools down? It becomes a **supersaturated solution.** A supersaturated solution has more solute dissolved in it than it should at that temperature. The extra solute will come out of solution as crystals until the solution is no longer supersaturated.

Gases dissolve in liquids to make solutions. Pressure affects how much gas will dissolve in a liquid. The greater the pressure, the more gas will dissolve. Carbonated drinks are saturated with carbon dioxide gas under pressure. When you open the bottle, the pressure is reduced. The solution becomes supersaturated. The extra gas comes out of solution as bubbles.

The same thing can happen to people, such as divers, who work in pressurized environments. Gases dissolve in blood. More gas dissolves when the diver is under water where the pressure is greater. When the diver returns to the surface, his blood is supersaturated with nitrogen. The nitrogen can come out of solution as bubbles, causing a serious condition called the bends.

Summary Questions

Now is a good time to review what you have recorded in your science notebook. Think about the investigations you have conducted with solutions.

1. **Describe what happens to a salt and water mixture.**
2. **How can you make a supersaturated Epsom salts solution?**
3. **How can you tell salt and Epsom salts apart?**

California Science Standards

PS1f. Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.

PS1g. Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_{12}O_6$), water (H_2O), helium (He), oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2).

PS1i. Students know the common properties of salts, such as sodium chloride (NaCl).

Vocabulary

particle

solute

solvent

saturated

supersaturated solution