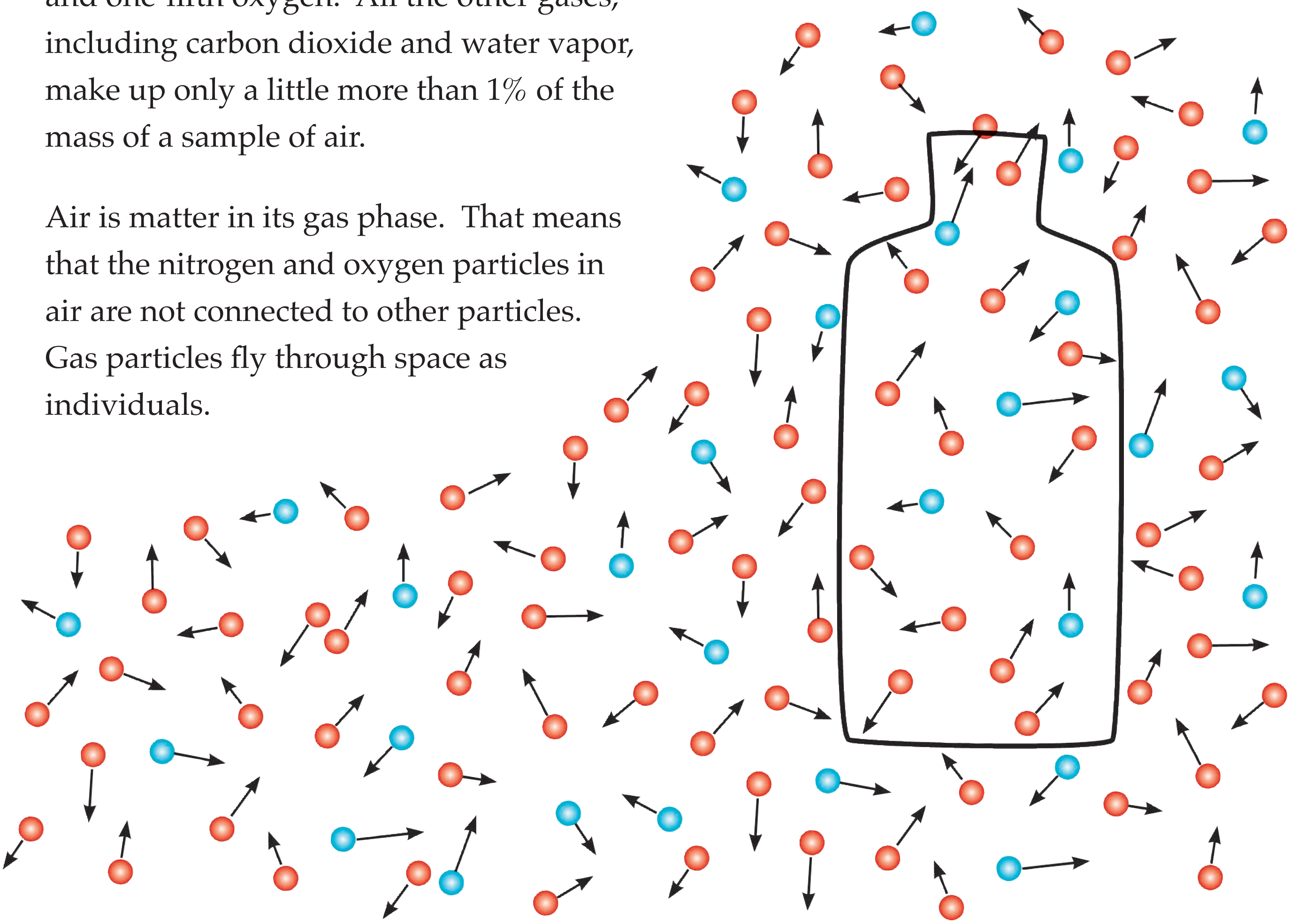
Particles in Motion

Air is matter. It has mass and occupies space. Air is a **mixture** of many gases. Air is approximately four-fifths nitrogen and one-fifth oxygen. All the other gases, including carbon dioxide and water vapor, make up only a little more than 1% of the mass of a sample of air.

Air is matter in its gas phase. That means that the nitrogen and oxygen particles in air are not connected to other particles. Gas particles fly through space as individuals.

After you drink a bottle of spring water, you have an excellent container for an air investigation. The empty bottle, of course, isn't empty. It is full of air. Because air particles are flying all around, they are going into and out of the open bottle all the time. The **density** of air in the bottle is exactly the same as the density of the air outside the bottle. That means that every cubic centimeter of air in the bottle has the same number of particles as every cubic centimeter of air outside the bottle.



Air particles fly through space as individual particles. Air particles fill an open bottle.

It is important to remember that air particles are really millions of times smaller than the representations in the illustrations. A cubic centimeter of air actually has about one quintillion air particles! A quintillion is a one followed by 18 zeroes (1,000,000,000,000,000,000). The illustrations are therefore not accurate, but they are good for thinking about what is going on at the particle level.

Particles Have Kinetic Energy

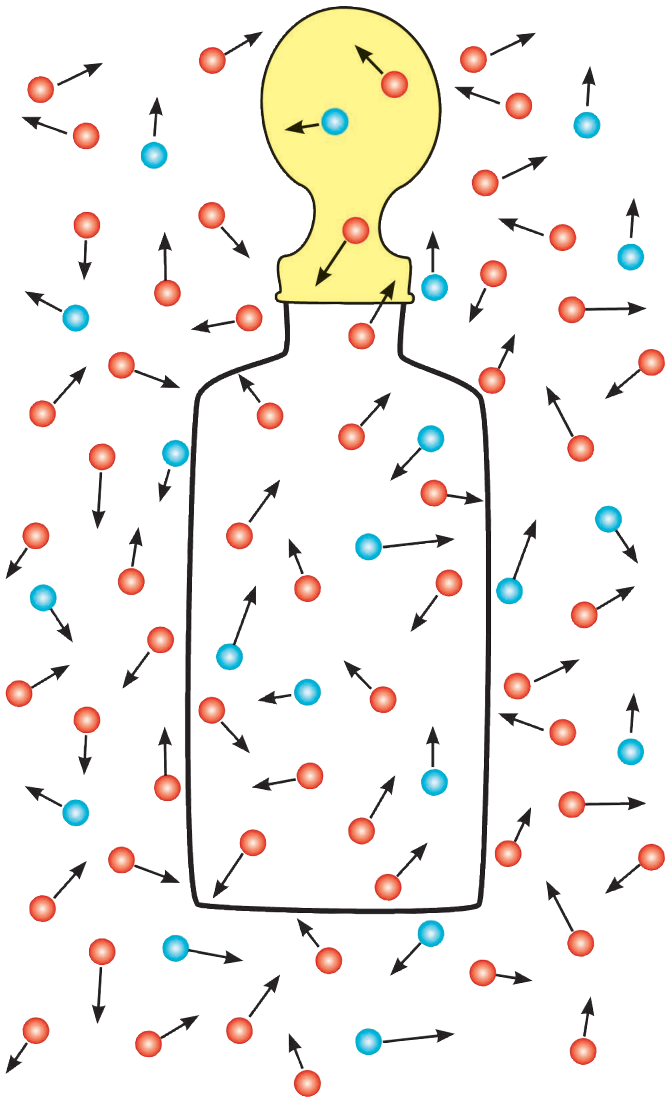
Not only are air particles incredibly small, they are always moving. And they move fast. At **room temperature**, they are going about 300 meters per second. That's equal to about 670 miles per hour.

Moving objects have energy. It's called **kinetic energy**. Anything that is in motion has kinetic energy, whether it is an ocean liner, a bicycle, a fly, a snail, you walking to class, water falling down a waterfall, or an oxygen particle in the air. They all have kinetic energy.

Kinetic energy, like all forms of energy, can do work. Air particles do work when they crash into things. Air particles push on each other, on you, on the walls of containers, and on everything else around them. Every air particle crashes into another particle about 10 billion times every second!

The amount of kinetic energy an object has depends on two things: the mass of the object and the speed at which it is moving. You can't change the mass of an air particle, but you can change its speed. By making a particle go faster, you increase its kinetic energy. Air particles can be made to move faster by heating a sample of air. Heat increases the kinetic energy of particles.

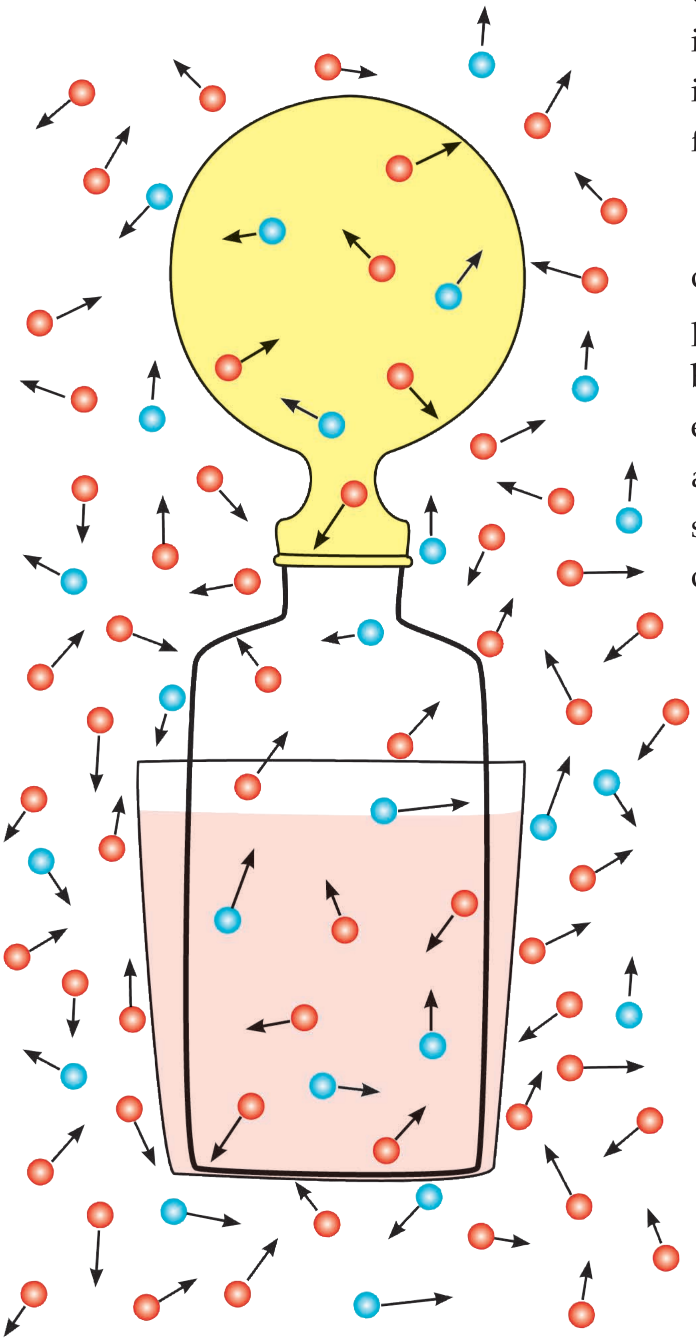
Back to the air investigation. Stretch a balloon over the top of the bottle full of air. Now the air is trapped inside the bottle-and-balloon system. No particles can get in or out.



A balloon can trap the air inside a bottle.

The density of air particles is the same in the bottle, in the balloon, and in the air surrounding the bottle-and-balloon system.

Now place the bottle-and-balloon system in a cup of hot water. The hot water warms the air inside the bottle. Particles in the warm air start to move faster. After a few minutes, the bottle-and-balloon system looks like this.



Hot water increases the kinetic energy of the air particles inside the bottle-and-balloon system. The particles fly faster and hit each other harder. The particles push farther apart, causing the gas to expand.

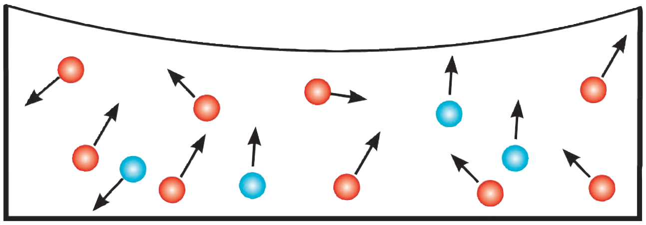
Why did the balloon inflate? The hot water heated the air in the bottle. As a result, the air particles began moving faster. Faster-moving particles have more kinetic energy. Faster-moving particles hit each other harder, which pushes them farther apart. You can see in the illustration that the particles of warm air inside the bottle-and-balloon system are farther apart.

The faster-moving particles also push on the balloon membrane harder. The particles push hard enough to stretch the balloon membrane. The increased kinetic energy of the particles pushes them farther apart (air **expansion**), and the membrane stretches to hold the increased volume of air.

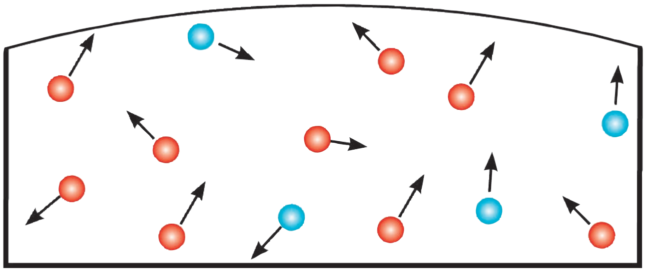
So what happens to the particles when the balloon gets smaller? Look back in your notes from the experiment and write your answer here.

What Happens When Gases, Liquids, and Solids Heat Up?

Gas. If a sample of matter is gas, its particles are not bonded (attached) to other particles. Each particle moves freely through space. When a sample of air



The particles in gases fly through space in all directions as individuals.

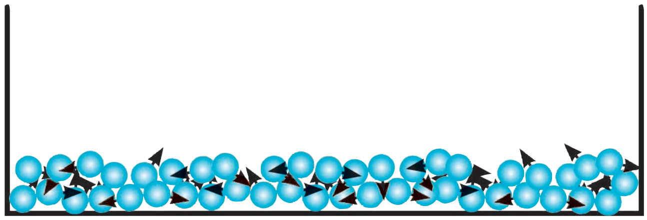


When gases get hot, the particles fly faster. Faster particles hit other particles harder, pushing the particles farther apart. This causes the gas to expand.

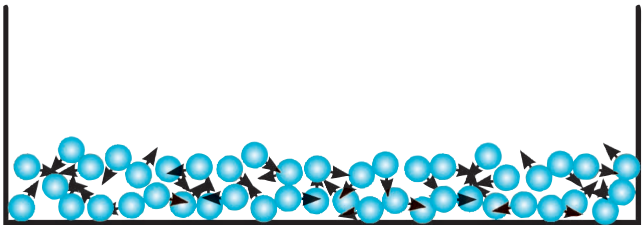
heats up, the particles move faster and hit each other harder. The result is that the particles push each other farther apart.

In the illustrations above, a container of gas has a flexible membrane across the top. When the gas gets warm, the kinetic energy of the particles increases, particles hit each other harder, and the gas expands. As the gas expands, it pushes the membrane upward.

Liquid. Particles in liquids are in close contact with one another. Attractions between the particles keep them from flying freely through space. The particles in liquids can, however, move over, around, and past one another. Individual particles in liquids are able to move all through the mass of liquid.



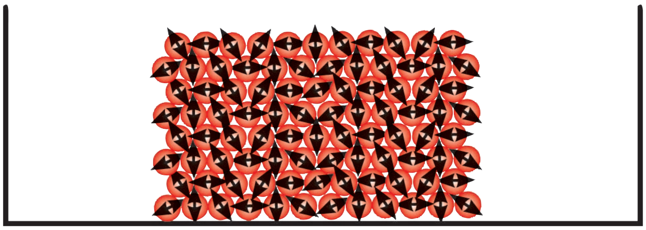
The particles in liquids are held close to each other. Particles bump and slide around and past each other.



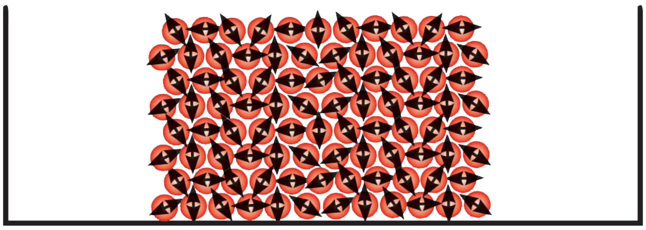
When liquids get hot, the particles bump and push each other more. Increased bumping pushes the particles farther apart. This causes the liquid to expand.

The motion of particles in a liquid is kinetic energy. When a liquid gets warm, the particles move faster. The particles have more kinetic energy. As a result, they hit other particles more often and hit harder. This pushes the particles farther apart. When particles are pushed farther apart, the liquid expands.

Solid. Particles in solids have bonds holding them tightly together. The particles cannot move around at all. The particles are, however, still in motion. Particles in solids are always **vibrating** (moving back and forth) in place.



The particles in solids are bonded. Particles move by vibrating, but do not change positions.



When solids get hot, the particles vibrate more. Increased vibration pushes the particles farther apart, causing the solid to expand.

The vibrational motion of particles in solids is kinetic energy. Heat makes the particles in a solid vibrate faster, giving them more kinetic energy. Faster-vibrating particles bump into one another more often and hit each other harder. This pushes the particles farther apart. When particles are pushed farther apart, the solid expands.

Summary

General Rule 1. When a sample of solid, liquid, or gas matter heats up, it expands. When matter gets hot, its particles gain kinetic energy. The increased kinetic energy pushes the particles farther apart. This causes the matter to expand.

General Rule 2. When a sample of solid, liquid, or gas matter cools down, it contracts. When matter cools down, its particles lose kinetic energy. The decreased kinetic energy lets the particles come closer together. This causes the matter to contract.

Review Questions

1. What is kinetic energy?
2. What are two ways to increase an object's kinetic energy?
3. Explain why a balloon inflates when a bottle-and-balloon system is placed in hot water.
4. What happens to a sample of matter when its particles lose kinetic energy?
5. How are particles in solids, liquids, and gases the same? How are they different?

Expansion and Contraction

We are surrounded by solids, liquids, and gases. And they all warm up and cool down from time to time. When they warm up, they expand. When they cool down, they contract. Sometimes expansion and **contraction** are useful. Other times they are a nuisance.

This bridge is made of solid steel with a solid surface of concrete. During the summer, the surface of the bridge heats up. The surface expands. When the surface gets bigger, what will happen to the bridge? If measures are not taken to allow the bridge to expand, it can buckle and break. Or the force of expansion may damage the steel structure.

Bridge engineers design the bridge's surface in sections. They place expansion joints where the sections meet. The bridge shown here has expansion joints with steel fingers that can move between each other. When the surface gets hot, the sections get longer and the fingers push between each other. When it gets cold, the sections get shorter, and the fingers pull apart. The finger design allows cars to cross the junctions between the surface sections smoothly.

This bridge has finger-type expansion joints between sections of its surface.

On a cold day, the bridge surface contracts. The fingers of the expansion joint don't overlap very much when the sections are short.

How are these thermometers like the ones you made in class? How are they different? Write about it in your notebook.

Thermometers are filled with liquid. The most commonly used liquid is alcohol. When the alcohol gets hot, it expands. When the alcohol gets cold, it contracts. Expansion and contraction of alcohol are useful properties for making a thermometer. Here's how it works.

If you want to know the temperature of the water in a vial, you place the bulb of a thermometer in the water. If the water is cold, heat moves from the warm thermometer bulb to the cold water. As the alcohol cools down, the kinetic energy of the alcohol particles declines. When the alcohol particles move less, they move closer together, and the alcohol contracts. When the alcohol contracts, it take up less space inside the thermometer. The level in the stem goes down.

When the thermometer is moved to a vial of warm water, the alcohol in the bulb heats up. The kinetic energy of the alcohol particles increases, and the volume of alcohol expands. The larger volume pushes farther up the thermometer stem.

By using the numbers on the thermometer stem, you can compare temperatures. These thermometers are **calibrated** in degrees Celsius (°C). The cool water in the picture is about 16°C. The warm water is about 51°C.

A thermometer contains alcohol, which expands when it gets warm and contracts when it gets cool. The height of the alcohol column indicates the temperature of the water around the thermometer bulb.

Did you ever see a container of fruit salad open itself? Here's the chain of events that can make that happen.

You mix up some grapes, strawberries, and melon. You eat some of the salad, but there is some left for a snack later. Snap a tight-fitting plastic lid on the container of fruit salad and pop it in the refrigerator to keep it fresh.


A container of fruit just out of the refrigerator

Later you take the salad out of the refrigerator and set it on the counter. If you don't open the container right away, in 10 or 15 minutes the lid pops off the container, reminding you to enjoy your snack. Why?


The container lid bulges upward after 10 minutes.

The air inside the container is gas. As the container of fruit salad warms up, so does the air in the container with the fruit. The kinetic energy of the air particles increases, and they push harder on each other and on the lid of the container. If you look closely, you can see the lid bulging as the air warms. Eventually the pressure created by the increased kinetic energy of the air particles will pop the lid right off the container.


When the catch is released, the lid pops off.

Expansion and contraction occur around us all the time. Air expands and contracts as it warms and cools. We don't see it happening, but we see the results. Weather, particularly wind, happens as a result of expanding and contracting air.

Review Questions

1. What are expansion joints, and why are they used?
2. What causes the cap to pop off a bottle of orange juice?
3. How does a thermometer work?

Have you ever been in an old, quiet building when there was a sudden creaking or cracking sound? Is it a haunted house? Probably not. Buildings expand and contract as they heat and cool. When they do, beams, walls, and roofs move a little bit. When parts of a building move, they can make sounds. Listen closely next time you are in a quiet building just after sunrise or just after sunset. Those are the times when you are most likely to hear unexpected sounds. Do you know why?

Train tracks are steel. Tracks expand when they get hot in the sunshine. What keeps them from buckling and bending? Expansion joints. Next time you are close to some train tracks, look for the expansion joints. What keeps sidewalks and roads from breaking and buckling? Expansion joints. These joints are spaces between the concrete sections. The spaces are filled with material that can compress when the concrete expands.

Keep your eyes open when you are looking at very large structures and huge expanses of solid surface. If you look closely, you will probably see how the engineers solved the problems presented by expansion and contraction caused by heating and cooling.

Train track expansion joint

Compressible concrete joint

What expansion joints can you find in your environment? Make a list in your notebook.

Energy on the Move

Everybody knows that a cup of too-hot cocoa can be cooled to sipping temperature by adding a splash of cold milk.

When you mix cold milk and hot cocoa, what happens to the cold milk? And what happens to the hot cocoa?

Kinetic Energy = Heat

Objects in motion have kinetic energy. Particles that make up substances are objects. Particles are always moving. Therefore, the particles that make up the hot cocoa and the cold milk have kinetic energy.

Cold milk being poured into hot cocoa

The amount of energy a particle has depends on how fast it is moving. Faster-moving particles have more energy. Slower-moving particles have less energy.

The particles in hot substances have more kinetic energy than the particles in cold substances. The simple rule is that the more kinetic energy the particles have, the hotter the substance is.

After mixing, the cup of cocoa is warm throughout. It is cooler than the hot cocoa and hotter than the cold milk. It seems as if the hot cocoa gets colder and the cold milk gets hotter. The new temperature is between the starting temperatures of the cocoa and the milk.

How does that happen?

This is important. Kinetic energy of particles is directly related to heat.

Changing Kinetic Energy

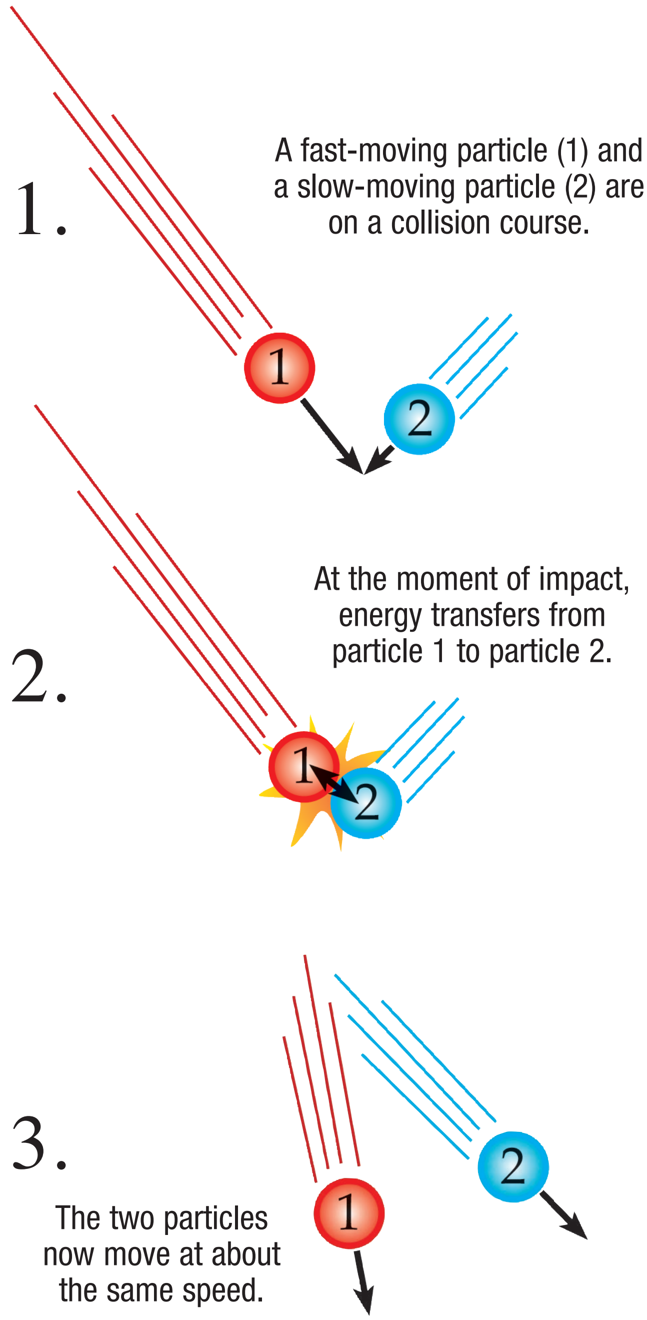
Energy is **conserved**. That simply means that energy is never destroyed or created during interactions. The amount of energy in a system is always the same, but it can move from place to place. When energy moves from one place to another, it is called an **energy transfer**.

Energy transfer happens when particles collide. When a fast-moving particle hits a slow-moving particle, the slow-moving particle speeds up. The fast-moving particle slows down. When a particle speeds up, it has more kinetic energy. When a particle slows down, it has less kinetic energy. Energy transfers from a fast-moving particle to a slow-moving particle at the moment of impact. Visualize this situation.

1. Fast-moving particle 1 is on a collision course with slow-moving particle 2.
2. The particles collide. At the moment of impact, energy transfers from particle 1 to particle 2. As a result, particle 1 has less kinetic energy, and particle 2 has more kinetic energy.
3. The two particles are now moving at about the same speed. Energy transferred from particle 1 to particle 2 at the moment of impact.

If you add up the kinetic energy of the two particles before the collision, it is exactly the same as the kinetic energy of the two particles after the collision. No kinetic energy is created or lost as a result of the collision. The energy of the two-particle system is conserved.

But something did change. As a result of the collision, particle 1 has less kinetic energy, and particle 2 has more kinetic energy. The collision resulted in an energy transfer. Energy transferred from particle 1 to particle 2.



Energy Transfer in Cocoa

The kinetic energy of the particles in hot cocoa is high. They are all moving fast. The kinetic energy of the particles in cold milk is low. They are all moving slowly.

When you pour cold milk into hot cocoa, the milk and cocoa particles start to collide. When a high-energy cocoa particle hits a low-energy milk particle, energy transfers. The cocoa particles slow down, and the cup of cocoa cools down.

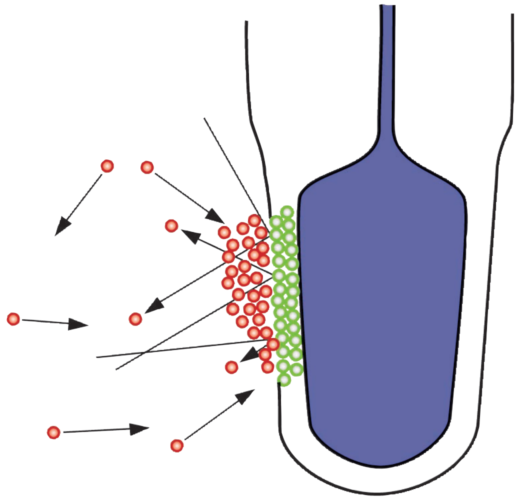
Look at the illustration on page 33. Can you tell which of the particles represents a cocoa particle and which represents a milk particle? And can you see how the energy transfer reduced the speed of the cocoa particle? Remember, reduced particle speed means less kinetic energy. Lower kinetic energy means lower temperature.

Using a Thermometer

You can use a thermometer to find out if your cocoa is too hot. When you dip a thermometer in that cup of hot cocoa, it reads 90°C. Whoa, too hot. Need to add some cold milk. Move the thermometer over to the cold milk, and the thermometer reads 10°C. That should do the job. But how does the thermometer "know" that the cocoa is 90°C and the milk is 10°C?

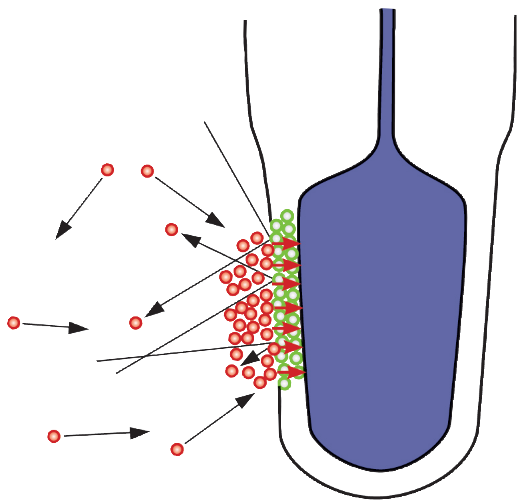
Kinetic energy. The thermometer reports the **average kinetic energy** of the particles in a substance. That's what temperature is: average kinetic energy of particles.

How exactly does the thermometer work? Now that we have an idea of how energy transfer takes place, let's put the thermometer into the 90°C cocoa. The cocoa particles collide with the glass particles on the outside of the thermometer stem.

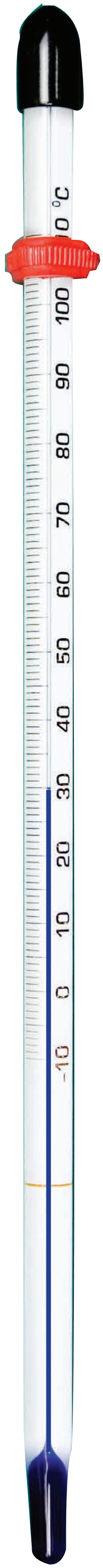


Energy transfers from cocoa particles to glass particles.

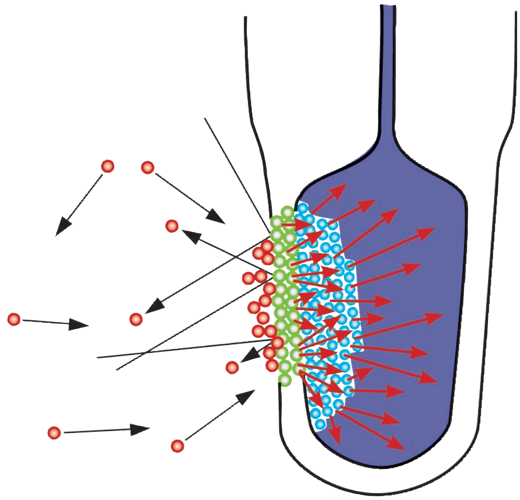
The glass particles gain kinetic energy and start vibrating more rapidly. The glass particles transfer energy to their neighbors, and those transfer energy to their neighbors. Transfer of energy from particle to particle by contact is called **conduction**. Pretty soon the whole glass stem is at 90°C.



Energy transfers through the glass by conduction.

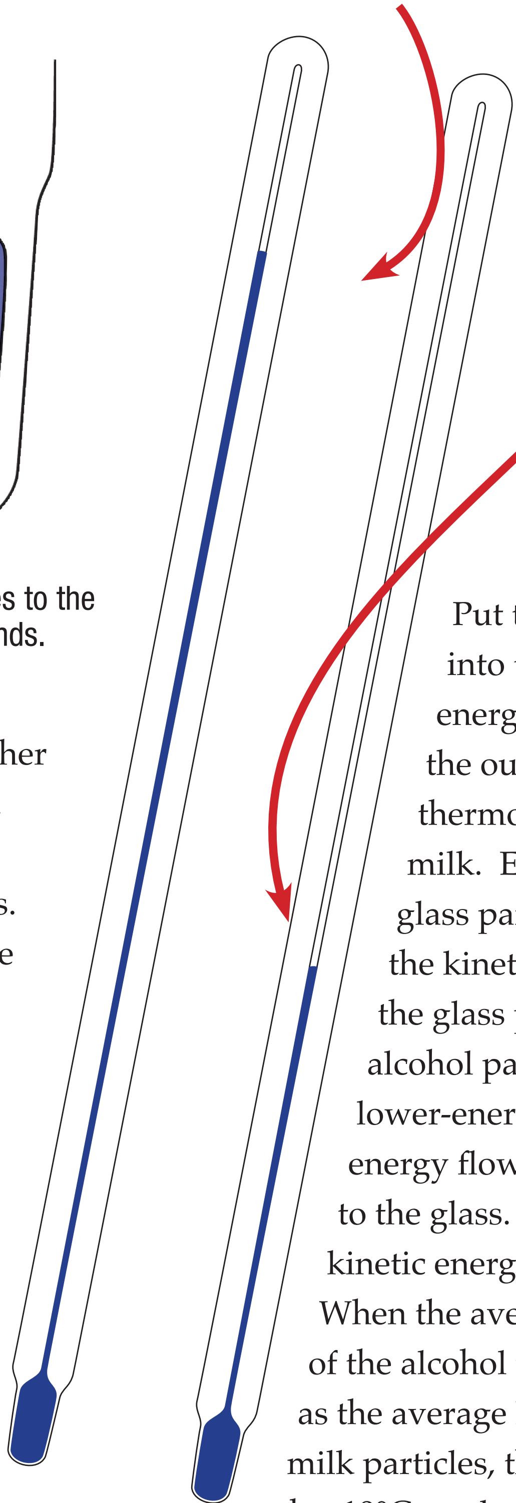


The rapidly vibrating glass particles that are in contact with the alcohol inside the thermometer stem transfer kinetic energy to the alcohol particles. Kinetic energy is conducted from alcohol particle to alcohol particle.



Energy transfers from the glass particles to the alcohol particles. The alcohol expands.

Soon all the alcohol particles are moving faster, pushing on each other more often and with greater force. The distance between particles increases, and the alcohol expands. As the alcohol expands, its volume increases. Alcohol pushes up the stem of the thermometer. The greater the kinetic energy of the alcohol particles, the more the alcohol expands. Energy transfers to the alcohol until the average kinetic energy of the alcohol particles is the same as the average kinetic energy of the cocoa particles. When this happens, the top of the alcohol is at the 90°C mark.



Put the thermometer into the 10°C milk. Now energy transfers from the outside of the glass thermometer stem to the milk. Energy transfers from glass particles, lowering the kinetic energy of all the glass particles. When alcohol particles collide with lower-energy glass particles, energy flows from the alcohol to the glass. The alcohol loses kinetic energy and contracts. When the average kinetic energy of the alcohol particles is the same as the average kinetic energy of the milk particles, the alcohol level is at the 10°C mark.

Energy Flows from High to Low

When two particles collide, is it possible for the fast-moving particle to end up going even faster? Can energy transfer from a lower-energy particle to a higher-energy particle?

No. It never happens. Energy *always* transfers from a faster-moving particle to a slower-moving particle. As a result of an energy-transfer collision, the particle that was going faster before the collision will always be going slower after the collision. And the particle that was going slower before the collision will be going faster after the collision. Always.

It is sometimes useful to think of energy as flowing. Energy always flows from higher to lower, from hot to less hot (cold).

When Does Energy Stop Flowing?

When you pour cold milk into the hot cocoa, the high-energy cocoa particles and low-energy milk particles instantly mix with one another. They collide with each other billions of times every second. The energy flows from the high-energy cocoa particles to the low-energy milk particles.

Almost instantly the average kinetic energy of the milk particles is the same as the average kinetic energy of the cocoa particles. The kinetic-energy level is uniform throughout—lower than the cocoa and higher than the milk.

Has energy stopped flowing? Has energy transfer between particles stopped? No, not really. Even when the average kinetic energy of the mixture stays steady, there are still individual particles that have high energy, and there are particles that have low energy. But the number of high-energy particles is the same as the number of low-energy particles.

When the temperature is constant, the system is in a condition called **equilibrium**. At equilibrium, there is no change of temperature. When a mixture of hot cocoa and cold milk has reached equilibrium, you can use a thermometer to measure the equilibrium temperature. The equilibrium temperature is a measure of the average kinetic energy of all the particles in the system. This includes the cup, the mixture of cocoa and milk, and the thermometer.

So, has energy stopped flowing? Think about this. The phone rings and you talk to a friend for 20 minutes. Now the cup of cocoa is cold. Why? The room is cooler than the cocoa. Particles of air collide with the cup and the surface of the cocoa. Energy transfers from the cup of cocoa to the air. Energy continues to transfer to the air until the average kinetic energy of the cocoa is the same as the average kinetic energy of the air. We say the cocoa is room temperature. The cocoa is at equilibrium with everything else in the room.

Energy Transfer Summary

All matter is made of tiny particles that are too small to see. The particles are in constant motion.

Objects in motion have kinetic energy. Particles are objects in motion, so they have kinetic energy. The faster a particle moves, the more kinetic energy it has.

Kinetic energy is related to heat. The faster the particles in a substance move, the hotter it is.

Energy can move, or transfer, from one particle to another when particles collide. Energy always transfers from a higher-energy particle to a lower-energy particle. The transfer of kinetic energy from particle to particle as a result of contact is called conduction.

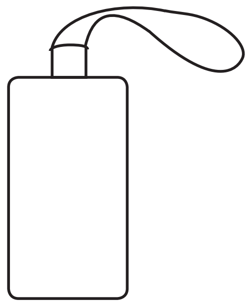
Temperature is a measure of the average kinetic energy of the particles in a mass.

Matter heats up and cools down because of energy transfer at the particle level.

Review Questions

1. Explain how cold milk cools hot cocoa.
2. Why do you think an ice cube feels cold when you hold it in your hand?
3. What will happen to the balloon stretched over the mouth of this "empty" bottle when the bottle is placed in hot water? Explain all the energy transfers.

Wait!



4. When does energy flow from a cold object to a hot object?
5. What does a thermometer measure, and how does it do it?

Before you answer this question, look back in your notebook at your observations from when you did this in class to remember what happened. Then, think about the energy transfers that took place.