SUPERCHARGED SCIENCE

Unit 13: Thermodynamics

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Appropriate for Grades:
K-12 (see notes on each project)
Duration: 5-15 hours, depending on how many activities you do!

Objects whose molecules are moving very quickly are said to have high thermal energy or high temperature. The higher the temperature, the faster the molecules are moving. Temperature is just a speedometer for molecules.

We are also going to learn what heat is and how it moves from place to place. Believe it or not, the concept of heat is really a bit tricky. What we call heat in common language, is really not what heat is as far as physics goes. Heat, in a way, doesn't exist. Nothing has heat. Things can have a temperature. They can have a thermal energy but they can't have heat. Heat is really the transfer of thermal energy. Or, in other words, the movement of thermal energy from one object to another. Ready to start?

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Materials for Experiments

We've broken the materials down in this list by project, so you'll find overlap between the different projects. Most projects take a bit of time to do – they're not like the quick 5-minute activities you have seen so far.

NOTE: This material list is for the entire Experiment section online.

Temperature Experiments

2 water or soda bottles

food dye

index card

pot, stove

pepper

ice cubes

black paper, white paper

aluminum foil

rubbing alcohol

dime, penny, and/or nickel

gum wrapper (must be metallic on one side)

index card

six 7-9" balloons

cooking oil (about a cup of the cheap kind)

OPTIONAL:

1 quart whole milk (do not substitute, unless your child has a milk allergy, then use soy or almond milk)

1 pint heavy cream (do not substitute, unless your child has a milk allergy, then skip)

1 cup sugar (or other sweetener)

1 tsp vanilla (use non-alcohol kind)

rock salt (use table salt if you can't find it)

lots of ice

freezer-grade zipper-style bags (you'll need quart and gallon sizes)

Heat & Thermodynamics Experiments

clear plastic (needle-less) syringe, 5– 20mL

can of soda (leave unopened)

four votive candles or tealights

large glass jar (like a clean empty pickle jar)

matches with adult help

aluminum pie plate or cookie sheet

liquid crystal sheet

silver highlighter marker or aluminum foil block of foam (any scrap piece will work)

1/4-1/8” diameter x 12” metal tube (copper)

thermometer

bathtub

stopwatch, ruler, tape, scissors

drinking bird

black paint and silver (or white) paint

mug of hot water

For Grades 9-12:

fresh peanuts

test tubes and test tube clamp

large paper clips

Key Vocabulary

Changing from a liquid to a gas is called **boiling**, evaporating, or vaporizing. Boiling point is the temperature at which a material changes from liquid to gas. Objects absorb heat as they evaporate.

Changing from a gas to a liquid is called **condensation**. Condensation point is the temperature at which a material changes from gas to liquid. Objects release heat as they condense.

Conduction is the wiggle and bump method of heat transfer. Faster moving molecules bump into slower moving molecules speeding them up. Those molecules then bump into other molecules speeding them up and so on increasing the temperature of the object.

Convection is heat being transferred by currents of moving gas or liquid caused by hot air/liquid rising and cold air/liquid falling.

Changing from a liquid to a solid is called **freezing**. Freezing point is the temperature at which a material changes from liquid to gas. Objects release heat as they freeze.

Energy is the ability to do work. Energy can be transferred, in other words it can be changed from one form to another and from one object to another.

Gases have no bonds between the molecules.

Heat is the movement of thermal energy from one object to another. Heat can only flow from an object of a higher temperature to an object of a lower temperature. Heat can be transferred from one object to another through conduction, convection and radiation.

Heat capacity is how much heat an object can absorb before its temperature increases. Heat capacity is influenced by the specific heat of the material and/or the amount of the material. A larger amount of something will have a higher heat capacity then a smaller amount of something. (Water has a very high heat capacity.)

Liquids have loose, stringy bonds between molecules that hold molecules together but allow them some flexibility.

Changing from a solid to a liquid is called **melting**. Melting point is the temperature at which a material changes from solid to liquid. Objects absorb heat as they melt.

Plasma is similar to gas but the molecules are very highly energized.

Radiation is the transfer of heat by electromagnetic radiation, specifically infra-red radiation.

Solids have strong, stiff bonds between molecules that hold the molecules in place.

Specific heat is how much heat energy a mass of a material must absorb before it increases 1°C. Each material has its own specific heat. The higher a material's specific heat is, the more heat it must absorb before its temperature increases.

There are four **states of matter**: Solid, liquid, gas and plasma. (The fifth state, BEC, is found only in a lab, so we'll disregard it for now.)

Materials change from one **state** to another depending on the temperature and these bonds. All materials have given points at which they change from state to state. As objects change state they do not change temperature. The heat that goes into something as it's changing phases is used to change the "bonds" between molecules. Freezing points, melting points, boiling points and condensation points are the "speed limits" of the phases. Once the molecules reach that speed they must change state.

Temperature is basically a speedometer for molecules. The faster they are wiggling and jiggling, the higher the temperature and the higher the thermal energy that object has. Your skin, mouth and tongue are antennas which can sense thermal energy. When an object absorbs heat it does not necessarily change temperature.

There are three different **temperature scales** for measuring temperature. Fahrenheit, Celsius and Kelvin. (The fourth scale, Rankine, the absolute scale for Fahrenheit, is usually reserved for college engineering students and NASA engineers.)

The terms hot, cold, warm etc. describe what physicists call **thermal energy**. Thermal energy is how much the molecules are moving inside an object. The faster molecules move, the more thermal energy that object has.

Unit Description

If you put an ice cube in a glass of lemonade, the ice cube melts. The thermal energy from your lemonade moves to the ice cube. Increasing the temperature of the ice cube and decreasing the temperature of your lemonade. The movement of thermal energy is called heat. The ice cube receives heat from your lemonade. Your lemonade gives heat to the ice cube.

Heat can only move from an object of higher temperature to an object of lower temperature. We're going to learn about temperature, heat energy, atoms, matter, phase changes, and more in our unit on Thermodynamics.

Objectives

Lesson 1: Temperature

Objects whose molecules are moving very quickly are said to have high thermal energy or high temperature. The higher the temperature, the faster the molecules are moving. You may remember that temperature is just a speedometer for molecules.

You may have asked yourself the question, "So, if everything is made of molecules, and these molecules are often speeding up and slowing down...what happens to the stuff these molecules are made of if they change speed a lot? Will my kitchen table start vibrating across the room if the table somehow gets too hot?" No, it's pretty unlikely that your table will begin jumping around the room, no matter how hot it gets. However, some interesting things do happen when molecules change speeds.

Highlights:

- The terms hot, cold, warm etc. describe what physicists call thermal energy.
- Thermal energy is how much the molecules are moving inside an object.
- The faster molecules move, the more thermal energy that object has.
- There are three different scales for measuring temperature. Fahrenheit, Celsius and Kelvin.
- Temperature is basically a speedometer for molecules. The faster they are wiggling and jiggling, the higher the temperature and the higher the thermal energy that object has.
- Your skin, mouth and tongue are antennas which can sense thermal energy.
- There are four states of matter: Solid, liquid, gas and plasma.
- Solids have strong, stiff bonds between molecules that hold the molecules in place.
- Liquids have loose, stringy bonds between molecules that hold molecules together but allow them some flexibility.
- Gasses have no bonds between the molecules.
- Plasma is similar to gas but the molecules are very highly energized.
- Materials change from one state to another depending on the temperature and these bonds.

- Changing from a solid to a liquid is called melting.
- Changing from a liquid to a gas is called boiling, evaporating, or vaporizing.
- Changing from a gas to a liquid is called condensation.
- Changing from a liquid to a solid is called freezing.
- All materials have given points at which they change from state to state.
- Melting point is the temperature at which a material changes from solid to liquid.
- Boiling point is the temperature at which a material changes from liquid to gas.
- Condensation point is the temperature at which a material changes from gas to liquid.
- Freezing point is the temperature at which a material changes from liquid to gas.

Objectives

Lesson 2: Heat

Believe it or not, the concept of heat is really a bit tricky. What we call heat in common language, is really not what heat is as far as physics goes. Heat, in a way, doesn't exist. Nothing has heat. Things can have a temperature. They can have a thermal energy but they can't have heat. Heat is really the transfer of thermal energy. Or, in other words, the movement of thermal energy from one object to another. Confused yet?

Highlights:

- Heat is the movement of thermal energy from one object to another.
- Heat can only flow from an object of a higher temperature to an object of a lower temperature.
- Heat can be transferred from one object to another through conduction, convection and radiation.
- Conduction is the wiggle and bump method of heat transfer. Faster moving molecules bump into slower moving molecules speeding them up. Those molecules then bump into other molecules speeding them up and so on increasing the temperature of the object.
- Convection is heat being transferred by currents of moving gas or liquid caused by hot air/liquid rising and cold air/liquid falling.
- Radiation is the transfer of heat by electromagnetic radiation, specifically infra-red radiation.
- Heat is movement of thermal energy from one object to another.
- When an object absorbs heat it does not necessarily change temperature.
- As objects change state they do not change temperature.
- The heat that goes into something as it's changing phases is used to change the "bonds" between molecules.
- Objects release heat as they freeze and condense.
- Objects absorb heat as they evaporate and melt.
- Freezing points, melting points, boiling points and condensation points are the "speed limits" of the phases. Once the molecules reach that speed they must change state.

- Heat capacity is how much heat an object can absorb before its temperature increases.
- Specific heat is how much heat energy a mass of a material must absorb before it increases 1°C.
- Heat capacity is influenced by the specific heat of the material and/or the amount of the material.
- Each material has its own specific heat. The higher a material's specific heat is, the more heat it must absorb before its temperature increases.
- A larger amount of something will have a higher heat capacity then a smaller amount of something.
- Water has a very high heat capacity.

Textbook Reading

"I'm too cold. Get me a sweater!"

"This soup's too hot!"

"Phew, I'm sweating."

"Yowtch, that pan handle burned me!"

If you've ever made any of the above comments, then you were talking about thermal energy. Very clever of you, don't you think?

Thermal energy is basically the energy of the molecules moving inside something. The faster the molecules are moving, the more thermal energy that something has. The slower they are moving, the less thermal energy that something has.

I'm sure at some point you've said, *"Wow, my internal thermal energy is way high! I need a liquid with a low thermal energy."*

What...you've never said that?! Oh, wait. I bet it sounded like this when you said it, *"Wow, I'm hot! I need a cool drink."* Whenever we talk about the temperature of something we are talking about its thermal energy.

Temperature

Temperature is a way of talking about, measuring, and comparing the thermal energy of objects. We use three different kinds of scales to measure temperature. Fahrenheit, Celsius, and Kelvin. (The fourth, Rankine, which is the absolute scale for Fahrenheit, is the one you'll learn about in college.)

Mr. Fahrenheit, way back when (18th century) created a scale using a mercury thermometer to measure temperature. He marked 0° as the temperature ice melts in a tub of salt. (Ice melts at lower temperatures when it sits in salt. This is why we salt our driveways to get rid of ice). To standardize the higher point of his scale, he used the body temperature of his wife, 96°.

As you can tell, this wasn't the most precise or useful measuring device. I can just imagine Mr. Fahrenheit, *"Hmmm, something cold...something cold. I got it! Ice in salt. Good, okay there's zero, excellent. Now, for something hot. Ummm, my wife! She always feels warm. Perfect, 96°. "* I hope he never tried to make a thermometer when she had a fever.

Just kidding, I'm sure he was very precise and careful, but it does seem kind of weird. Over time, the scale was made more precise and today body temperature is usually around 98.6°F.

Later, (still 18th century) Mr. Celsius came along and created his scale. He decided that he was going to use water as his standard. He chose the temperature that water freezes at as his 0° mark. He chose the temperature that water boils at as his 100° mark. From there, he put in 100 evenly spaced lines and a thermometer was born.

Last but not least Mr. Kelvin came along and wanted to create another scale. He said, I want my zero to be ZERO! So he chose absolute zero to be the zero on his scale.

Absolute zero is the theoretical temperature where molecules and atoms stop moving. They do not vibrate, jiggle or anything at absolute zero. In Celsius, absolute zero is -273 ° C. In Fahrenheit, absolute zero is -459°F (or 0°R). It doesn't get colder than that!

As you can see, creating the temperature scales was really rather arbitrary:

"I think 0° is when water freezes with salt."
"I think it's just when water freezes."
"Oh, yea, well I think it's when atoms stop!"

Many of our measuring systems started rather arbitrarily and then, due to standardization over time, became the systems we use today.

What is Temperature Measuring?

So that's how temperature is measured, but what is temperature measuring? Temperature is measuring thermal energy which is how fast the molecules in something are vibrating and moving.

The higher the temperature something has, the faster the molecules are moving. Water at 34°F has molecules moving much more slowly than water at 150°F. Temperature is really a molecular speedometer. This demonstration may make this clearer.

Sensing Temperature

When something feels hot to you, the molecules in that something are moving very fast. When something feels cool to you, the molecules in that object aren't moving quite so fast.

Believe it or not, your body perceives how fast molecules are moving by how hot or cold something feels. Your body has a variety of antennae to detect energy. Your eyes perceive certain frequencies of electromagnetic waves as light. Your ears perceive certain frequencies of longitudinal waves as sound. Your skin, mouth and tongue can perceive thermal energy as hot or cold. What a magnificent energy sensing instrument you are!

Thermal Energy

Objects whose molecules are moving very quickly are said to have high thermal energy or high temperature. The higher the temperature, the faster the molecules are moving. You may remember that temperature is just a speedometer for molecules.

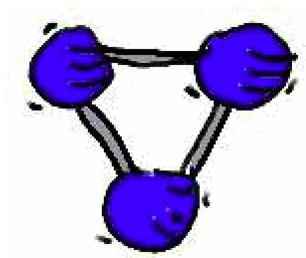
You may have asked yourself the question, *"So, if everything is made of molecules, and these molecules are often speeding up and slowing down...what happens to the stuff these molecules are made of if they change speed a lot? Will my kitchen table start vibrating across the room if the table somehow gets too hot?"*

No, it's pretty unlikely that your table will begin jumping around the room, no matter how hot it gets. However, some interesting things do happen when molecules change speeds.

Changes of State

Matter has a tendency to hang out in fairly stable states under normal temperatures. There are three common states of matter; solid, liquid, and gas.

There is another state of matter called plasma but it is not common on Earth. Plasma is a highly energized gas. It is used in florescent lights. I'm going to assume you know a bit about solids, liquids and gasses so I won't go into much detail about them here (see Unit 3 and 8 for more information).



What I do want to talk about is what happens as temperatures change in a substance. Let's take one of the neatest substances on the Earth, water. Water is quite special since it can be in its solid, liquid and gas state at relatively "normal" temperatures. It's quite special for a variety of other reasons too, but we'll leave it at that for now.

Pretend we have an ice cube on a frying pan (poor ice cube). Right now the water is in a solid state. It's holding its shape. The molecules in the water are held together by strong, stiff bonds. These bonds hold the water molecules in a tight, very specific pattern called a matrix.

This matrix holds the water molecules in a crystalline pattern and the solid water holds its shape. Now, let's turn on the heat. The heat is transferred from the stove to the frying pan to the ice cube. (We'll talk about heat transfer a bit later.)

As the ice cube absorbs the heat the molecules begin to vibrate faster (the temperature is increasing).

When the molecules vibrate at a certain speed (gain enough thermal energy) they stretch those strong, stiff bonds enough that the bonds become more like rubber bands or springs.

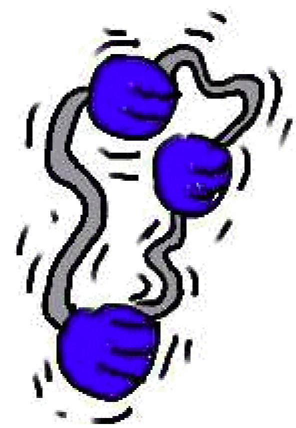
When the bonds loosen up, the water loosens up and becomes liquid. There are still bonds between the molecules, but they are a bit loose, allowing the molecules to move and flow around each other.

The act of changing from a solid to a liquid is called melting. The temperature at which a substance changes from a solid to a liquid is called its melting point. For water, that point is 32° F or 0° C.

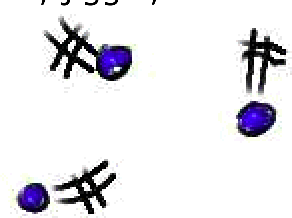
Now we will watch carefully as our ice cube continues to melt (little is more exciting than watching an ice cube melt - golf maybe). A bit after we see our ice cube go from solid to completely liquid, we notice bubbling.

What's going on now? If we were able to see the molecules of water at this point we'd be quite amazed at the fantastic scene before us.

At 212° F or 100° C water goes from a liquid state to a gaseous state. This means that the loosey goosey bonds that connected the molecules before have been stretched as far as they go, can't hold on any longer and "POW!" they snap.



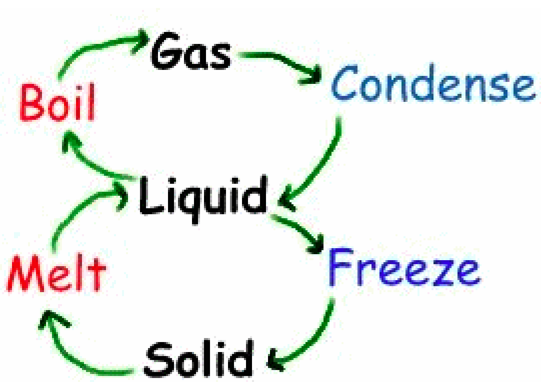
Those water molecules no longer have any bonds and are free to roam aimlessly around the room. Gas molecules move at very quick speeds as they bounce, jiggle, crash and zip around any container they are in. The act of changing from a liquid to a gas is called evaporation or boiling and the temperature at which a substance changes from a liquid to a gas is called its boiling point.



I don't know about you, but I think it's getting a bit hot in here. Let's turn the heat down a bit and see what happens. If our gaseous water molecules get close to something cool, they will combine and turn from gaseous to liquid state.

This is what happens to your bathroom mirror during a shower or bath. The gaseous water molecules that are having fun bouncing and jiggling around the bathroom get close to the mirror. The mirror is colder than the air. As the gas molecules get close they slow down due to loss of temperature. If they slow enough, they form loosey goosey bonds with other gas molecules and change from gas to liquid state.

The act of changing from gas to liquid is called condensation. The temperature at which molecules change from a gas to a liquid is called the condensation point. Clouds are made of hundreds of billions of tiny little droplets of liquid water that have condensed onto particles of some sort of dust.



Now let's turn the heat down a bit more and see what happens. As the temperature drops and the molecules continue to slow, the bonds between the molecules can pull them together tighter and tighter.

Eventually the molecules will fall into a matrix, a pattern, and stick together quite tightly. This would be the solid state. The act of changing from a liquid to a solid is called freezing and the temperature at which it changes is called (say it with me now) freezing point.

Think about this for a second - is the freezing point and melting point of an object at the same temperature? Does something go from solid to liquid or from liquid to solid at the same temperature?

If you said yes, you're right! The freezing point of water and the melting point of water are both 32° F or 0° C. The temperature is the same. It just depends on whether it is getting hotter or colder as to whether the water is freezing or melting.

The boiling and condensation point is also the same point. Now I'm going to mess things up a little bit. Substances can change state at temperatures other than their different freezing or boiling points. Many liquids change from liquid to gas and from gas to liquid relatively easily at room temperatures.

And, believe it or not, solids can change to liquids and even gases and vice versa at temperatures other than the usual melting, freezing, or boiling points. So what's the point of the points?

At a substance's boiling, freezing, etc, points, all of the substance must change to the next state. The condition of the bonds cannot remain the same at that temperature. For example, at 100° C water must change from a liquid to a gas. That is the speed limit of liquid water molecules. At 100° C the liquid bonds can no longer hold on and all the molecules convert to gas.

Heat Transfer

The heat is on! Now we are going to learn what heat is and how it moves from place to place. You know how they say, *"If you can't stand the heat, get out of the kitchen."*?

Well after this lesson you'll know exactly what it is that you can't stand!

Heat

Believe it or not, the concept of heat is really a bit tricky. What we call heat in common language, is really not what heat is as far as physics goes.

Heat, in a way, doesn't exist. Nothing has heat. Things can have a temperature. They can have a thermal energy but they can't have heat. **Heat is really the transfer of thermal energy.** Or, in other words, the movement of thermal energy from one object to another.

If you put an ice cube in a glass of lemonade, the ice cube melts. The thermal energy from your lemonade moves to the ice cube. Increasing the temperature of the ice cube and decreasing the temperature of your lemonade.

The movement of thermal energy is called heat. The ice cube receives heat from your lemonade. Your lemonade gives heat to the ice cube.

Heat can only move from an object of higher temperature to an object of lower temperature. **Heat goes from hot to cold.** Coffee cools down and ice water heats up. That's one of the laws of thermodynamics.

Do you remember what temperature is? Temperature measures how fast molecules are moving, right?

Well, when heat transfers (moves) from one object to another, the movement of the molecules in the higher temperature object slow down and the movement of the molecules in the lower temperature object speed up.

In our example of the ice and the lemonade, it would work like this. The lemonade has a higher temperature than the ice. (The molecules are moving faster than the ice molecules.)

The faster moving molecules of the lemonade would transfer heat to the ice causing the ice molecules to move faster (increase temperature) and eventually change from solid to liquid.

In turn, since the faster moving molecules of the lemonade moves energy (transfers heat) to the ice, they slow down. This causes the temperature of your drink to decrease and that is what makes your lemonade nice and cold. Heat can be transferred in three different ways: conduction, convection and radiation.

Conduction

Let’s start with conduction. Heat is transferred through conduction the same way pool balls are scattered around a table in the opening break. On a pool table, one ball crashes into another ball which crashes into another ball speeding the balls up and moving them around the table.

Heat transferred from one object to another through conduction does the same thing. The molecules near the heat source (candle, stove, etc.) begin moving faster (their temperature increases).

As they move faster they crash into other molecules around them which cause them to move faster. As those molecules move faster they crash into more molecules...etc, etc. Thus the molecules in the object are all moving faster.

Heat has been transferred by conduction and the temperature of the object is higher. This experiment may make this clearer.

Radiation

Heat is transferred by radiation through electromagnetic waves. Remember, when we talked about waves and energy in Unit 9? Well, heat can be transferred by electromagnetic waves.

Energy is vibrating particles that can move by waves over distances right? Well, if those vibrating particles hit something and cause those particles to vibrate (causing them to move faster/increasing their temperature) then heat is being transferred by waves.

The type of electromagnetic wave that transfer heat are infra-red (IR) waves. The Sun transfers heat to the Earth through radiation. (There's nothing between the Earth and the sun to conduct through or convent with.)

Now let's take explore how, even though heat can move from one object to another, it doesn't necessarily mean that the temperature of the objects will change. You may ask, *"What? Heat can move from one object to another without temperature changing one little bit?!?!"*

Yea...confusing huh? In this lesson we're going to take a look at one of the ways heat can move while the thermometer doesn't.

Changing Phases

When things change phase (change from solid to liquid or liquid to gas or...well, you get the picture) the temperature of those objects don't change. If you were able to take the temperature of water as it changed from a solid (ice) to a liquid you would notice that the temperature of that piece of ice will stay at about 32° F until that piece of ice was completely melted. The temperature would not increase at all.

Even if that ice was in an oven, the temperature would stay the same. Once all the solid ice had disappeared, then you would see the temperature of the puddle of water increase.

(By the way, as the ice is melting, from where is heat being transferred? Heat is being transferred, by conduction, from the air.)

Heat Capacity

Think of a dry sponge. Now imagine putting that sponge under a slowly running faucet. The sponge would continue to fill with water until it reached a certain point and then water started to drip from it. You could say that the sponge had a water capacity. It could hold so much water before it couldn't hold any more and the water started dripping out.

Heat capacity is similar. Heat capacity is how much heat an object can absorb before it increases in temperature. This is also referred to as specific heat. Specific heat is how much heat energy a mass of a material must absorb before it increases 1°C.

Each material has its own specific heat. The higher a material's specific heat, the more heat it must absorb before it increases in temperature.

Water is unique in that it has a very large specific heat. Liquid water's specific heat is over 4 which is very high. In comparison, granite is 0.8, aluminum is 0.9, rubbing alcohol is 2.4 and gold is 0.1.

To get the same amount of rubbing alcohol and liquid water to increase the same amount of temperature, you would need to pump about twice the amount of heat into the water.

To get the same amount of gold and liquid water to increase the same amount of temperature, you would need to pump 40 times the amount of heat into the water!

In other words, it takes more energy to heat water then it does to heat alcohol, gold, or for that matter most other things.

Activities, Experiments, Projects

Note: This section is an abbreviated overview of the experiments online.

Experiment: Homemade Thermostat

If you can remember thermostats before they went 'digital', then you may know about bi-metallic strips – a piece of material made from of two strips of different metals which expand at different rates as they are heated (usually steel and copper). The result is that the flat strip bends one way if heated, and in the opposite direction if cooled.

1. Normally, it takes serious skill and a red-hot torch to stick two different metals together, but here's a homemade version of this concept that your kids can make using your freezer. Here what you do:
2. Tape a gum wrapper (one side must be metallic) so it stands upright on an index card. Place a piece of tape on each side.
3. Insert into the freezer for an hour.
4. Open freezer – your gum wrapper should be curled up!

Since gum wrappers are paper on one side and foil on the other, you can use one to make your own bi-metallic strip. Flatten out the wrapper into a sheet and find a way fasten the wrapper so it sits upright on an index card (we used the bubble gum itself as the adhesive). Stick it in the freezer overnight and check it in the morning! Where can you place it to flex the other direction?

How does that work? A bimetallic strip is a stack of two metals stuck together. The metal with the higher expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled. The bi-metallic strip was invented by the eighteenth century clockmaker John Harrison to compensate for temperature-induced changes his clock springs.

Experiment: Fire-Water Balloon

If you've ever had a shot, you know how cold your arm feels when the nurse swipes it with a pad of alcohol. What happened there? Well, alcohol is a liquid with a fairly low boiling point. In other words, it goes from liquid to gas at a fairly low temperature. The heat from your body is more than enough to make the alcohol evaporate.

As the alcohol went from liquid to gas it sucked heat out of your body. For things to evaporate, they must suck in heat from their surroundings to change state. As the alcohol evaporated you felt cold where the alcohol was. This is because the alcohol was sucking the heat energy out of that part of your body (heat was being transferred by conduction) and causing that part of your body to decrease in temperature.

As things condense (go from gas to liquid state) the opposite happens. Things release heat as they change to a liquid state. The water gas that condenses on your mirror actually increases the temperature of that mirror. This is why steam can be quite dangerous. Not only is it hot to begin with, but if it condenses on your skin it releases even more heat which can give you severe burns. Objects absorb heat when they melt and evaporate/boil. Objects release heat when they freeze and condense.

Do you remember when I said that heat and temperature are two different things? Heat is energy - it is thermal energy. It can be transferred from one object to another by conduction, convection, and radiation. We're now going to explore heat capacity and specific heat.

Here’s what you need:

- Balloon
- Water
- Sink
- Matches, candle, and adult help

1. Put the balloon under the faucet and fill the balloon with some water.

2. Now blow up the balloon and tie it, leaving the water in the balloon. You should have an inflated balloon with a tablespoon or two of water at the bottom of it.

3. Carefully light the match or the lighter and hold it under the part of the balloon where there is water.

4. Feel free to hold it there for a couple of seconds. You might want to do this over a sink or outside just in case!

So why didn’t the balloon pop? The water absorbed the heat! The water actually absorbed the heat coming from the match so that the rubber of the balloon couldn’t heat up enough to melt and pop the balloon. Water is very good at absorbing heat without increasing in temperature which is why it is used in car radiators and nuclear power plants. Whenever someone wants to keep something from getting too hot, they will often use water to absorb the heat.

Think of a dry sponge. Now imagine putting that sponge under a slowly running faucet. The sponge would continue to fill with water until it reached a certain point and then water started to drip from it. You could say that the sponge had a water capacity. It could hold so much water before it couldn't hold any more and the water started dripping out. Heat capacity is similar. Heat capacity is how much heat an object can absorb before it increases in temperature. This is also referred to as specific heat. Specific heat is how much heat energy a mass of a material must absorb before it increases 1°C.

Exercises

Temperature Exercises

1. What is thermal energy?

2. What does temperature measure?

3. What are the three different scales used to measure temperature?

4. What is absolute zero?

5. If something is hot, what are its molecules doing?

6. In our "Spread It Around" experiment why did the food coloring spread out faster in the hot bowl than in the cold bowl?

7. In which parts of your body do you have your thermal energy antenna?

8. What are the four states of matter (ignoring BEC)?

9. Which states have no bonds between the molecules?

10. Which state has bonds that hold the molecules in a tight matrix?

11. As the temperature increases, what happens to the bonds that allow a substance to go from solid to liquid?

12. What happens to the bonds as a substance reaches its boiling point?

13. What happens to the bonds as a substance reaches its freezing point?

Exercises

Heat Exercises

1. What is heat?

2. Does heat flow from higher to lower temperature, from lower to higher temperature or does it matter?

3. When I first turn on the shower the shower curtain keeps blowing into my legs. Is this an example of conduction, convection or radiation?

4. When I bite into a pizza, the heat is transferred painfully to the roof of my mouth. Is this an example of convection, conduction or radiation?

5. Someone sits a little too close to me on a bus and I can feel the heat coming off of them. Is this an example of convection, conduction or radiation?

6. My daughter holds my hand as we walk across the street. I can feel heat coming from her hand to mine. Is this an example of convection, conduction or radiation?

7. It's a hot sunny day outside. Am I better off wearing a dark shirt or a light shirt if I want to stay cool?

8. An object's temperature always drops when it loses heat. True or false?

9. What happens to molecules as they change from one state to another?

10. When objects evaporate do they absorb heat or release heat?

11. Why do we sweat when we’re hot?

12. Why doesn’t temperature change when things are changing state?

13. What is heat capacity?

14. Which would cool down faster, a bottle of maple syrup or a teaspoon of maple syrup?

15. Owww!! I just burned my mouth on a piece of pizza! The strange thing is the crust is just warm. What happened?

16. When I eat at a fast food restaurant I always eat my fries before the burger since the fries get cold so much faster. Which has a higher heat capacity, the fries or the burger?

17. Why do I fill a hot water bottle with hot water and not just hot air?

Answers to Temperature Exercises

1. Thermal energy is basically the energy of the molecules moving inside something. The faster the molecules are moving the more thermal energy that something has. The slower they are moving the less thermal energy that something has.

2. Temperature measures thermal energy. In other words, temperature measures the amount that the molecules are moving. Thermometers are speedometers for molecules.

3. Fahrenheit, Celsius, and Kelvin.

4. Absolute zero is a theoretical temperature where molecules and atoms stop moving. This temperature has never been reached in the laboratory but they have come close.

5. Its molecules are moving very quickly.

6. In the hot bowl, the molecules are moving very fast. Since they are moving quickly, they bump into the food coloring molecules more and harder spreading them out faster than in the cold water.

7. Skin.

8. Solid, liquid, gas, plasma

9. Gases and plasma

10. Solid

11. The bonds are forced to stretch and loosen up since the molecules are moving at greater speeds.

12. As a substance reaches its boiling point it changes from a liquid to a gas. As this happens the bonds that are holding the molecules together break allowing the molecules to wander off on their own as a gas.

13. As a substance reaches its freezing point it turns from a liquid to a solid. The bonds tighten up, pulling the molecules into a matrix and forming a nice solid substance.

Answers to Heat Exercises

1. Heat is the movement of thermal energy from one object to another.

2. Heat can only flow from a higher temperature object to a lower temperature object.

3. Convection. The heat from the hot water in the shower heats up the air in the shower. The heated air rises. As the heated air rises, it creates a convection current. Which draws air into the shower and blows the shower curtain into my legs. Many of the winds on the Earth are caused by hot air rising and cold air sinking.

4. This is conduction. The fast moving molecules of the pizza bombard my poor mouth molecules. This, in turn, creates sound energy as I scream "OUCH!".

5. This is radiation. Humans can transfer heat by radiation. The fellow sitting next to me was giving off infra-red radiation.

6. This time it's primarily conduction. The molecules in her little hand are vibrating quickly and causing my molecules to vibrate quicker as well. There is probably some radiation going on as well, but since our hands are touching her molecules can directly affect my molecules.

7. A light colored shirt reflects more infra-red radiation so I'll stay cooler.

8. False.

9. The "bonds" between molecules change. They can either tighten up or loosen up depending on whether the energy is increasing or decreasing.

10. They absorb heat.

11. The sweat absorbs excess heat from the body as it evaporates and cools us off.

12. The energy that's entering the object is being used to change the bonds between the molecules. The molecules have reached their "speed limit". They can't go any faster or slower without changing state.

13. Heat capacity is how much heat an object can absorb before its temperature increases.

14. The teaspoon. The smaller the amount the less heat capacity it has.

15. The cheese has a much higher heat capacity then the crust. So the cheese stays hot much longer.

16. The burger holds onto its heat longer then the fries. The burger has a higher heat capacity.

17. Water has a higher heat capacity so it cools much more slowly than air. A hot air bottle will be cool in a matter of seconds. Hot water will take many minutes to cool down.

