Heat Transfer

What is heat, and how is it different from temperature?

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. 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.

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.**

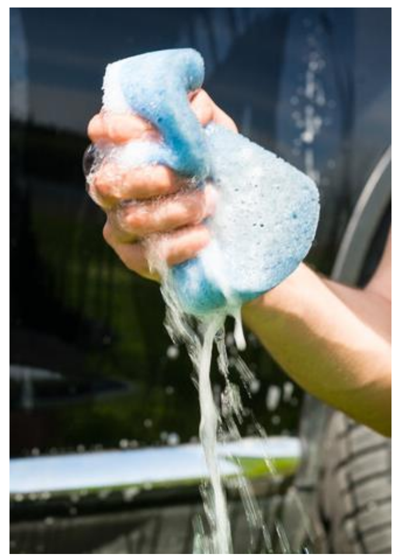
The ice cube receives heat from your lemonade. Your lemonade gives heat to the ice cube. Heat can only move from an object of higher temperature to an object of lower temperature.

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?!?!"* We're going to take a look at one of the ways heat can move while the thermometer doesn't.

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.

One key distinction is that objects don't contain heat, but they contain energy. **Heat is the transfer of energy from one object to another**, or from one system to another, like a hot cup of coffee to the cool ambient air. Heat can change the temperature of objects when it transfers the energy. In the example with the coffee cup, it lowered the temperature of the coffee.



Imagine putting a 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 how much heat an object can absorb before it increases in temperature. It's often used interchangeably with "specific heat capacity", but in reality, it's a little different.

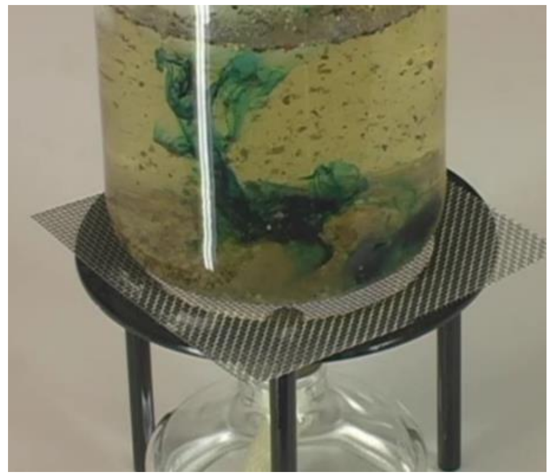
Heat can also change the state of matter. When an ice cube melts into a liquid puddle, it remains at the same temperature until the phase change is complete, and only then does the temperature begin to rise, even though heat was added throughout the entire process. The thermometer reading will stay on the same temperature reading until the ice is completely melted.

Methods of Heat Transfer

Heat can be transferred in three different ways: conduction, convection and radiation.

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, fire...) begin moving faster (that is, their temperature increases).



Sugar water with pepper flakes heated over open flame, and then food dye drops added.

Convection is a little more difficult to understand than conduction. Heat is transferred by convection by moving currents of a gas or a liquid. Have you ever heard: "Hot air rises and cold air sinks"? It turns out that hot liquid rises and cold liquid sinks as well!

Room heaters generally work by convection. The heater heats up the air next to it which makes the air rise. As the air rises it pulls more air in to take its place which then heats up that air and makes it rise as well. As the air get close to the ceiling it may cool. The cooler air sinks to the ground and gets pulled back near the heat source. There it heats up again and rises back up.

This movement of heating and cooling air is convection and it can eventually heat an entire room or a pot of soup. If you watch a hot pot of soup (something with little flakes or spices in it), you'll see the hot water rising in some areas of the pot and cold water sinking in other areas. This rising and sinking transferred heat through all the water causing the water in the pot to increase in temperature.

Ice cubes on white and black paper, left in the sun to be heated by radiation.

Hot water rising in some areas of the pot and cold water sinking in other areas of the pot carried the pepper and food coloring throughout the pot. This rising and sinking transferred heat through all the water causing the water in the pot to increase in temperature.

Heat is transferred by **radiation** through electromagnetic waves. Energy is vibrating particles that can move by waves over distances, and if those vibrating particles hit something and cause those particles to vibrate (causing them to move faster and increasing their temperature) then heat is being transferred by waves. The type of electromagnetic waves that transfer heat are infra-red waves. The Sun transfers heat to the Earth through radiation.

If you hold your hand near a heat source (without touching it), you can feel heat on your hand. You'll be able to understand how light can travel like a wave. This type of heat transfer is called *radiation*.

Now don't panic! This is not a bad kind of radiation like you get from x-rays. It's infra-red radiation. Imagine putting your hand near an incandescent light bulb. Heat was transferred from the light bulb to your hand. The energy from the light bulb resonated the molecules in your hand. Since the molecules in your hand are now moving faster, they have increased in temperature. Heat has been transferred! In fact, an incandescent light bulb gives off more energy in heat then it does in light. They are not very energy efficient, which is why most have been replaced by LED and fluorescent lights today.

HEAT TRANSFER LABS: For the labs, please get out your math journal and watch the videos, and write down everything as I am demonstrating it to you. I'll explain each of the problems in detail as well as working out the solution. Due to the complexity of these problems, we're going to everything on the videos together.

> IMPORTANT: Part 4 is a hands-on lab in energy from a peanut. If you have a chemistry kit with test tubes and a burner, please watch the second part of the video. If not, use the first part which uses simple household items ("Kitchen Chemistry"). Both labs demonstrate the same thing!
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> NOTE: Two labs are following this page, the first is the *Kitchen Chemistry* version, and the second is appropriate if you have a *Chemistry Lab* kit. Again, both are the *same* experiment, just using two different sets of supplies.

Do Plants Store Energy?

Overview: Put your safety goggles on for today's lab, because we're working with fire! You'll be measuring how much energy a peanut holds by setting it aflame.

What to Learn: All our energy needs on earth come from somewhere. We cannot make our own food, but plants can. We are all connected to the plants and soils that they grow in because they provide our very basic needs, as well as some of our more modern needs.

Materials

- Goggles
- 2 shelled peanuts
- Small pair of pliers
- Match or lighter
- Sink
- Timer

Lab Time

1. Today we're working with fire, so follow all special instructions about working with flames today.
2. Close the drain with a sink stopper, and fill the sink with around an inch of water.
3. Put on safety goggles. Using a small pair of pliers, hold the peanut over the sink and ask your adult helper to light the peanut with the lighter until it catches fire. Have your data recorder ready with the timer.
4. Upon ignition (when the peanut is burning by itself and doesn't need the lighter), start the timer and run it until the peanut stops burning. Record the time on the worksheet. The adult remains present for the entire duration that the peanut is one fire.
5. Drop the peanut into the sink once finished to ensure all flames are out. Allow it to cool as you record additional observations in the worksheet and complete the exercises.

Do Plants Store Energy? Data and Observations

Peanut	Time burned (write in seconds):
1 2	

Observations:

Does the peanut burn with a clean flame or a sooty flame?

What color is the flame? What color does the peanut turn when it burns?

Did the size of the peanut change after it had burned for several minutes?

Reading

A peanut is not a nut, but actually a seed. In addition to containing protein, a peanut is rich in fats and carbohydrates. Fats and carbohydrates are the major sources of energy for plants and animals.

The energy contained in the peanut actually came from the sun. Green plants absorb solar energy and use it in photosynthesis. During photosynthesis, carbon dioxide and water are combined to make glucose. Glucose is a simple sugar that is a type of carbohydrate. Oxygen gas is also made during photosynthesis.

The glucose made during photosynthesis is used by plants to make other important chemical substances needed for living and growing. Some of the chemical substances made from glucose include fats, carbohydrates (such as various sugars, starch, and cellulose), and proteins.

Photosynthesis is the way in which green plants make their food, and ultimately all the food available on earth. All animals and non-green plants (such as fungi and bacteria) depend on the stored energy of green plants to live. Photosynthesis is the most important way animals obtain energy from the sun.

Oil squeezed from nuts and seeds is a potential source of fuel. In some parts of the world, oil squeezed from seeds--particularly sunflower seeds--is burned as a motor fuel in some farm equipment. In the United States and elsewhere, some people have modified diesel cars and trucks to run on vegetable oils.

Fuels from vegetable oils are particularly attractive because, unlike fossil fuels, these fuels are renewable. They come from plants that can be grown in a reasonable amount of time. Fossil fuels are nonrenewable fuels because they are formed over a long period of time.

Exercises Answer the questions below:

1. What is the process called where plants get food from the sun?
    a. Osteoporosis
    b. Photosynthesis
    c. Chlorophyll
    d. Metamorphosis
2. Where does all life on the planet get its food?

3. List two ways that we could use the energy in a peanut:
    a.

    b.

Answers to Exercises: Do Plants Store Energy:

1. What is the process called in which plants get food from the sun? (photosynthesis)
2. Where does all life on the planet get its food? (plants, and the sun)
3. What can people use a peanut's energy for? (fuel for cars, food)

Peanut Energy

Overview: Put your safety goggles on for today's lab –we'll be looking at fire again. You'll be measuring how much energy a peanut holds by setting it on fire and measuring an increase in water temperature.

What to Learn: All our energy needs on earth come from somewhere. We cannot make our own food, but plants can. We are all connected to the plants and soils that they grow in because they provide our very basic needs, as well as some of our more modern needs.

Materials

- Goggles
- 2 shelled peanuts
- Small pair of pliers
- Match or lighter
- Test tube in wire test tube holders (these look like pliers that are designed to hold a test tube)
- Scale
- Thermometer

Lab Time

1. Today we're working with fire, so follow all special instructions provided about working with fire today.
2. Measure your test tube on the scale when it's empty: ______________________ grams
3. Fill up your test tube with about 10 grams of water and weigh it again: ______________________ grams
4. Measure the initial temperature of the water: __________________________ ^{o}C
5. Put on safety goggles.
6. Using a small pair of pliers, hold the peanut and ask an adult to light the peanut with the lighter until it catches fire.
7. Upon ignition (when the peanut is burning by itself and doesn't need the lighter), hold the peanut under the water close to the bottom of the test tube until the peanut stops burning.
8. Quickly measure the final temperature of the water: __________________________ ^{o}C
9. Record your results on the worksheet.
10. Allow the peanut to cool as you record your observations and complete the data tables.

Let's take an example measurement. Suppose you measured a temperature increase from 20 °C to 100 °C for 10 grams of water, and boiled off 2 grams. We need to break this problem down into two parts - the first part deals with the temperature increase, and the second deals with the water escaping as vapor.

The first basic heat equation is this: $Q = m\ c\ T$

Q is the heat flow (in calories)
m is the mass of the water (in grams)
c is the specific heat of water (which is 1 degree per calorie per gram)
and T is the temperature change (in degrees)

So our equation becomes: $Q = 10 * 1 * 80 = 800$ calories.

If you measured that we boiled off 2 grams of water, your equation would look like this for heat energy: $Q = L\ m$

L is the latent heat of vaporization of water (L= 540 calories per gram)
m is the mass of the water (in grams)

So our equation becomes: $Q = 540 * 2 = 1080$ calories.

The total energy needed is the sum of these two:

Q = 800 calories + 1080 calories = **1880 calories.**

Reading

Did you know that eating a single peanut will power your brain for 30 minutes? The energy in a peanut also produces a large amount of energy when burned in a flame, which can be used to boil water and measure energy.

Peanuts are part of the bean family, and actually grow underground (not from trees like almonds or walnuts). In addition to your lunchtime sandwich, peanuts are also used in woman's cosmetics, certain plastics, paint dyes, and also when making nitroglycerin.

What makes up a peanut? Inside you'll find a lot of fats (most of them unsaturated) and antioxidants (as much as found in berries). And more than half of all the peanuts Americans eat are produced in Alabama. We're going to learn how to release the energy inside a peanut and how to measure it.

There's chemical energy stored inside a peanut, which gets transformed into heat energy when you ignite it. This heat flows to raise the water temperature, which you can measure with a thermometer. You should find that your peanut contains 1500-2100 calories of energy! Now don't panic - this isn't the same as the number of calories you're allowed to eat in a day. The average person aims to eat around 2,000 Calories (with a capital "C"). 1 Calorie = 1,000 calories. So each peanut contains 1.5-2.1 Calories of energy (the kind you eat in a day). Do you see the difference?

So did all the energy from the peanut go straight to the water, or did it leak somewhere else, too? The heat actually warmed up the nearby air, too, but we weren't able to measure that. If you were a food scientist, you'd use a nifty little device known as a *bomb calorimeter* to measure calorie content. It's basically a well-insulated, well-sealed device that catches nearly ***all*** the energy and flows it to the water, so you get a much more accurate temperature reading. (Using a bomb calorimeter, you'd get 6.1-6.8 Calories of energy from one peanut!)

Peanut Energy Data and Observations

Trial #	Mass of Water (grams)	Temperature Increase (^oC)	Heat Energy 1 (calories)
Sample	*10 grams*	*80 ^oC*	*= (10 grams) x (1 degree per cal per gram) x 80 (^oC) = 800 calories*

Trial #	Mass of Water Boiled Off (grams)	Heat Energy 2 (calories)
Sample	*2 grams*	*=542calories per gram x 2 grams = 1080 calories*

Trial #	Heat Energy 1 (calories)	Heat Energy 2 (calories)	Total Energy Produced (calories)
Sample	*800 cal*	*1080 cal*	*1880 Calories*