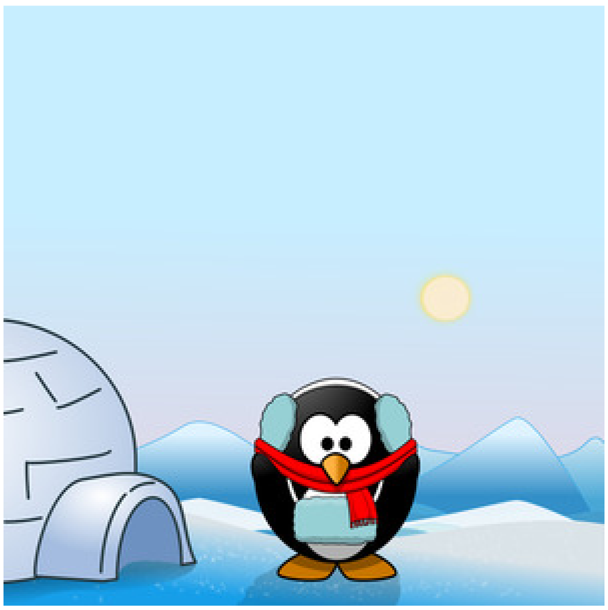
Hi!

My name is Mac, and I am a penguin. It is cold where I live. Because it is so cold where I live, I am going to tell you about my favorite topic, heat.

The study of heat and how it flows is called *Thermodynamics*.



Like Sir Isaac Newton's three laws, thermodynamics has its own set of laws. There are four laws of thermodynamics, and I will share these laws with you. Along the way, I will introduce several famous scientists to you, and perhaps a famous engineer or two to round things out.

So, sit back and let's take a look at things, shall we?
Maybe you can help me to raise some money so my girlfriend and I can vacation somewhere warm? You can do this by completing the labs below.

Tell students they can help Mac by doing the labs set forth in their student modules.

Objective

Students will be able to have a conceptual understanding of the four laws of thermodynamics.

Target audience:

This curriculum is geared toward middle school aged students.

Idaho State Standards:

PS3-MS-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

PS3-MS-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

PS3.A: Definitions of Energy

PS3.B: Conservation of Energy and Energy Transfer

The First Law of Thermodynamics

The First Law of thermodynamics states that energy cannot be created or destroyed by ordinary means, but can merely be transformed from one form to another. The first law also goes by another name. When you take chemistry, your teacher will refer to this as the *Law of Conservation of Energy*.

Mathematically, it is stated as $Q - W = \Delta E$ which says,
heat – work = change in energy.

So, let's explore the three major forms of heat transfer, shall we?

The three forms of heat transfer are convection, conduction and radiation.

In convection, thermal energy is circulated by a fluid sitting in a gravity field.
In conduction, thermal energy is being transferred through a solid.
Finally, in radiation, thermal energy is transferred via electromagnetic waves.

Teachers do the first two investigations as demonstrations.
Students can do the third investigation on their own, or perhaps in lab groups.

Convection

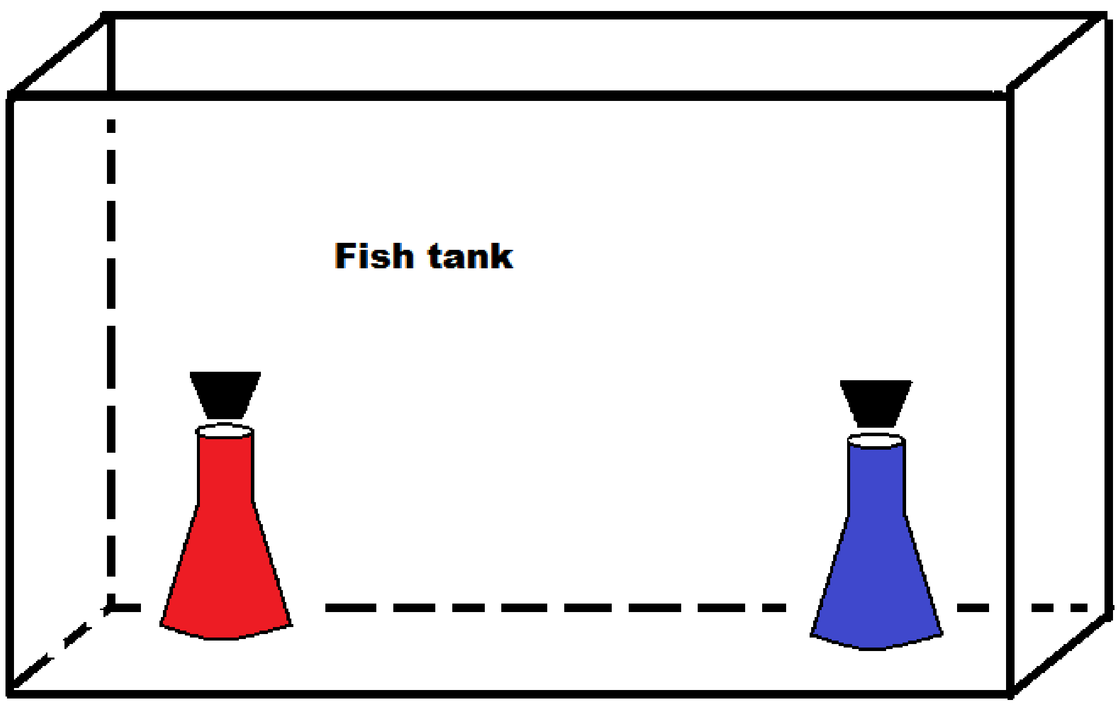
(teacher demonstration)

Take small fish tank and fill it mostly full of water.

Take two matching Erlenmeyer flasks and place a lab mass in the bottom of the flask. If you are unable to obtain a pair of lab masses, pebbles, pennies or sand will work. Fill one Erlenmeyer flask with hot water and fill the other with ice water. Place a rubber stopper in the top of each flask.

Place one of the Erlenmeyer flasks at the right side of the fish tank and the other at the left side.

Add a drop or two of food coloring to the water, immediately above the ice water, and observe the pattern the food coloring makes in the water.



So, what happened to the food coloring?

The food coloring is circulating in the tank.

Why is it swirling?

When heated, water will become less dense, and when cooled, water will become more dense, causing it to circulate in the tank.

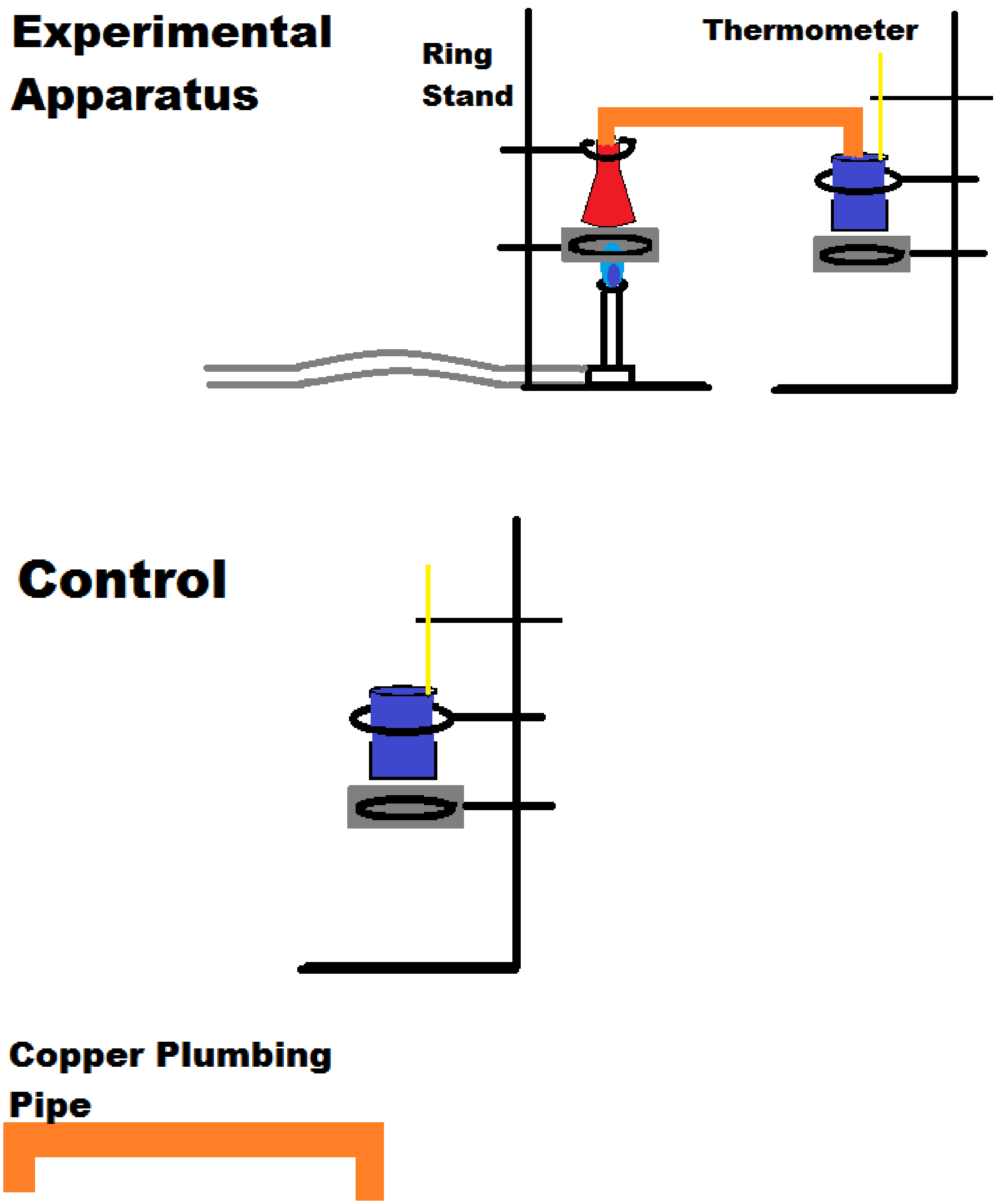
Will this happen indefinitely?

No.

Why, or why not?
Please defend your answer to the question above.

The water will circulate until all of the water in the fish tank reaches thermal equilibrium.

Conduction


Experimental
Apparatus
Ring
Stand
Thermometer
Control
Copper Plumbing
Pipe

Place a kilogram of ice in each beaker.
Have a student volunteer note the time it takes for each block of ice to melt.
Help students calculate the rate of energy transfer as each block of ice melts.

Rate = Energy/time
Joules/second = watts

Convert melting time to seconds.
Do this for both blocks of ice.
The heat transferred through the pipe will be expressed as the time differential between the two blocks of ice as they melt.

The metric unit for energy is called a joule. This unit is named after the famous British physicist James Prescott Joule. It takes a whopping 333,550 joules of energy to melt a kilogram of ice. The rate at which energy is expended is called a watt. A watt is a joule of energy expended in a second.

Your teacher has placed a kilogram of ice in each beaker.
Will the ice in beaker with the copper pipe in it melt faster? If so, how much faster?

Yes, it will melt faster.

Why is this so?

The difference in melting time of the two blocks of ice is due to the heat being transferred through the pipe.

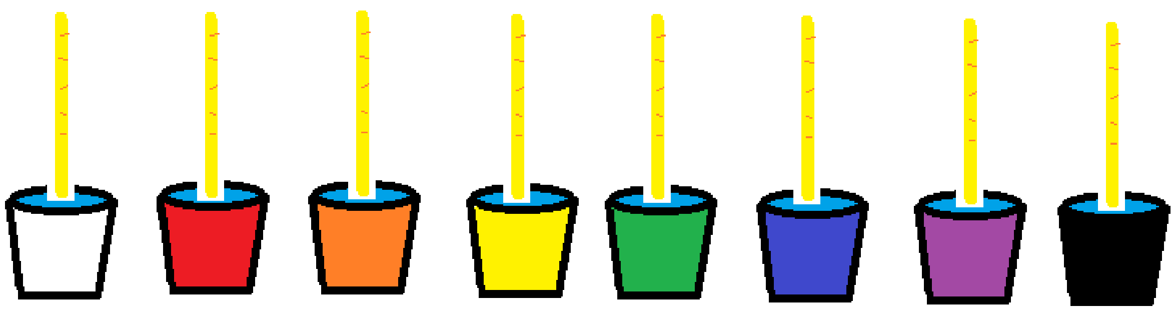
Is the thermal energy being transferred through the pipe?
Hint: Take the time of the test sample and subtract it from the control.

Yes, thermal energy is being transferred through the pipe.

Radiation

Take eight identical Styrofoam coffee cups, or other small plastic cups.

Spray paint one white, spray paint six of the cups the colors of the rainbow, and spray paint the last cup black. Place a lab thermometer in each cup, and fill each cup with equal amounts of water, say, 25 mL.
Alcohol lab thermometer will work, and digital thermometers will work better.



Place the cups side by side in a sunny window, or outdoors (and out of the wind) in the sun on a warm sunny day. Or, the thermometers can be placed side by side under a pair of heat lamps.

Take the temperature of the water in each cup every five minutes and record your data. After 30 minutes, remove the cups from under their heat source and place the coffee cups side by side on an empty lab table. Place a thermometer next to the coffee cups, hanging off of a thermometer clamp that has been attached to a ring stand.

Continue to take the temperature of each cup of water every five minutes until the water in each cup reaches room temperature.

Make two lists, ranking each cup
The first list should rank the cups by temperature, with the highest temperature first on the list, and the second list should rank the cups by the time they took to cool back to room temperature, with the first cup that cools back to room temperature, first on the list.

Do the lists match? Yes
The black painted cup will heat the fastest, but it will also cool the fastest.
The white painted cup will heat the slowest and will cool off the slowest.

If so, why? Hint: Look up a guy named Boltzman (and the Steffan Boltzman Law)

Work

Work is the “W” term in the First Law equation.

Work is done on an object by a force that
moves it. A force is equal to mass being accelerated, and work is equal to force multiplied by a distance. In math speak, **F**=m**a** and W = **F**xd.

The metric unit for a force is a Newton.
A Newton is equal to the mass of one kilogram being accelerated at a rate of one meter per second squared.
Once again, 1N = 1kg x 1m/s^2.

The Earth’s gravity field imparts an acceleration of 9.81 m/s^2 at the surface of the Earth. So, a kilogram mass will have a force 9.81 Newtons.
F = 1 kg x 9.81m/s^2 = 9.81Newtons and
1 kilogram = 1000 grams.

(~~102 grams~~) x ($\frac{1kg}{\cancel{1000g}}$) x 9.81m/$s^2$ = 1.00062 kg*m/s^2 = (to three significant digits)
1.00 kg*m/s^2 = 1.00 Newtons

You need to figure how many grams you would need to have a force of 1 Newton. After you do this, check this with your teacher and hold this in your hand. This is what a Newton feels like.

Next, once you have done this, you need to figure how to done one Joule of work.

Hint: Work is equal to mass x gravity x height.
Place your newly minted Newton on the floor and pick it up.

Work = force x distance.
1 Newton x 1 meter = 1N*m = 1 Joule

Have students pick up their Newtons off of the floor and lift them 1 meter into the air. Students will do one Joule of work by lifting their Newton off the floor a distance of one meter.

The Second Law of Thermodynamics

The second law of thermo deals with a phenomena in nature called *entropy.* Entropy is the measure of the state of disorder in a system. The Second Law of Thermodynamics states that all systems with the universe will tend to go from a state of order to a state of disorder.

So, what is the natural state of your bedroom? Ordered, you say? nope. To create order in your bedroom, and to avoid being yelled at by your folks, you have to clean your room, which takes time and energy. The natural state of your bedroom is messy, not tidy. In fact, the natural state of everybody's bedroom is messy.

Another example would be your lawn. To make your lawn nice and pretty, you have to mow the grass. And a few days later, the grass has grown back, and you have to mow the grass again!

Shiny new cars will, over time, become old clunkers. People eventually get old. The second law is a fact of life.

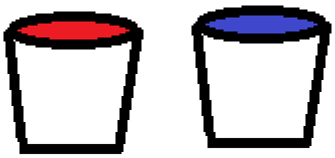
Another consequence the second law is the second law is the fact that no machine can ever be 100 percent efficient. Some of the energy used to run a machine will be wasted, usually as waste heat. That is why cars have radiators. If a car did not have a radiator, then the car's engine will overheat and the engine will overheat and will be ruined. Bad (and expensive) plan indeed!

Ok, so time to do a little lab investigation.

Step 0
Don safety glasses.
Even though dealing with Styrofoam coffee cups full of tap water is not a particularly dangerous undertaking, you need to make it a habit of using your safety glasses whenever you do a lab.

Step 1
Obtain three Styrofoam coffee cups, two small cups and a larger cup. Small beakers will work here too.

Take the two small Styrofoam coffee cups and fill both with tapwater. Add a few drops of red food coloring to one cup, and add a few drops of blue food coloring to the other cup.

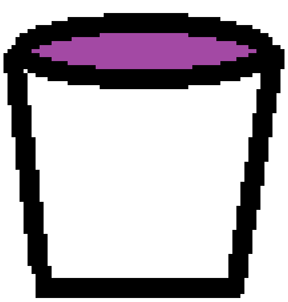


Step 2
Predict what will happen when you mix the contents of the two cups into the larger coffee cup.

We predict:

Student answers will vary

Now pour the contents of both of the small coffee cups into the larger cup.



Does what your observe match your prediction? yes or no circle one

Now, devise a way to unmix the contents of the larger coffee cup and return the two samples back into their original colors.

Answer below

This cannot be done due to the second law of thermodynamics.

Teacher might lead student discussion of the implications of the *Second Law of Thermodynamics.*

The Third Law of Thermodynamics

The *Third Law of Thermodynamics* states that a perfect crystal will have a zero entropy level at absolute zero.

Now, good luck finding a perfect crystal and good luck getting all the way down to absolute zero. To go all the way down to absolute zero would violate the second law of thermodynamics. This would mean you would be able to make a machine that is100% efficient, which is not possible.

But since you have been studying the laws of thermo, and since crystals are now being discussed, perhaps we can make (and study) some rock candy.

First of all, NEVER do this with lab glassware. Doing so, could lead to disastrous consequences.

Step 0
Remember your safety glasses?

Step 1

Take a short piece of string and tie a small stainless steel nut to the bottom of the string. Do not use galvanized steel. Tie the other end of the string around a pencil, and set the pencil aside for the moment.

Step 2

Measure out two cups (475 mL) of distilled water into a sauce pan and heat the water until it begins to boil.

When the water begins to boil stir in 4 cups (960 grams) of sugar into the boiling water in ½ cup (120 gram) increments, making sure the sugar dissolves completely before adding the additional sugar. Stir the sugar water mixture until all of the sugar is dissolved.

At this point, you can add a couple of drops of food coloring, flavoring, or perhaps some Kool Aid™.

Step 3

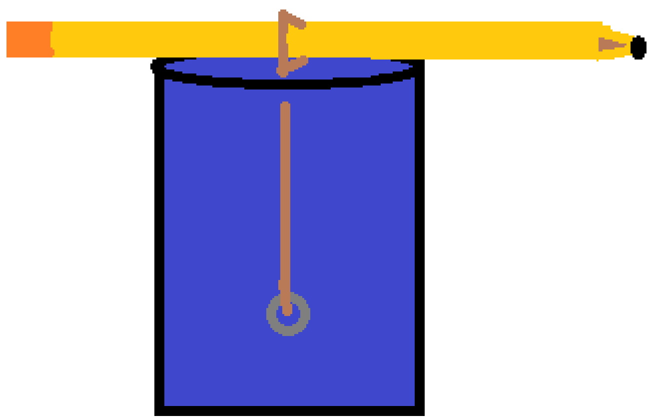
Pour your solution into an old mason jar. Make sure the jar is thoroughly clean. You do not want stray dust particles providing a surface on which crystals are likely to form.

Step 4

Hang the string from the pencil so that the nut sits near the bottom of the Mason jar, but not touching it. Cover the top of the Mason jar with a piece of paper towel and place it cool dark place.

Wait one week and then look at the Mason jar.
The string should be covered with sugar crystals.

This is the one time you will be allowed to eat the results of a lab, so enjoy!



While you are waiting for your rock candy to crystallize, perhaps you can explore absolute temperature scales.

There are four temperature scales on planet Earth, two metric temperature scales, and two US (called Imperial) temperature scales.

The metric scales are called the Celsius scale and the Kelvin scale.
The US measure scales are called the Fahrenheit scale and the Rankine scale.
No worries, the Kelvin scale is merely the absolute version of the Celsius scale and the Rankine scale is merely the absolute version of the Fahrenheit scale.

The Fahrenheit and Celsius temperature scales describe the kind of temperatures we experience in our everyday world. For example, if you live in a metric country and the weather forecast calls for tomorrow's high to be 40°C, you instinctively know that it is time to head to the beach. If you live in the United States, and your weather forecaster tells you that tomorrow's high temperature will be 20°F, better grab your coat!

But why an absolute scale?

Both the Rankin and Kelvin scales use absolute zero as their starting points. Absolute zero, as you have just learned, is the coldest possible temperature in the universe, and it is the point at which atoms and molecules have no thermal energy at all!

Absolute temperature scales are very useful for both scientists and engineers.
They are used to describe what happens to gasses, say, when heated, or compressed.
These relationships are called gas laws. Absolute temperature scales are also used to describe really low temperatures. It is much easier to say that helium becomes a liquid at 4K, then at -269°C.

Before we go on, one thing needs to be mentioned: When using the metric absolute scale, the Kelvin scale, it is not appropriate to say "degrees Kelvin." The appropriate term is "Kelvins," and similarly, the degree symbol ° is dropped. One is supposed to do this with the absolute US scale, but more often than not, this rule is generally ignored.

So, while you are waiting for your rock candy to set up, let's practice doing some conversions, shall we?

Please convert the following temperature from degrees Celsius to Kelvins
Hint: Add 273 to your temperature
For example: Propane has a boiling point of -42°C

-42°C + 273 = 231
Propane becomes a liquid at -42°C or 231K

Oxygen	-183°C	90K
Water	100°C	373K
Tar	300°C	573K
Nitrogen	-196°C	77K
Helium	-269°C	4K
Hydrogen	-253°C	20K
Ammonia	-35.5°C	237.5K
Argon	-186°C	87K
Chlorine	-34.4°C	238.6K
Ethyl Alcohol	78.4°C	351.4K

Please convert the following absolute temperatures to degrees Celsius
Hint: Now you subtract 273 from your temperature
For example: Neon boils at 27K
27 – 273 = -246°C

Fluorine	87K	-186°C
Krypton	120K	-153°C
Xenon	165K	-108°C
Methyl Alcohol	338K	65°C
Rubbing Alcohol	356K	83°C
Butane	272K	-1°C
Propane	231K	-42°C
Methane	111K	-162°C
Bromine	332K	59°C
Room Temperature	298K	25°C

Thank you!

Thermodynamics

To begin our study of thermodynamics, we must learn the four laws that comprise the subject.

The four laws are the zeroth law of thermodynamics, the first law of thermodynamics, the second law of thermodynamics, and the third law.

But why the zeroth law?

By the late 19th century, scientists had worked out the first, second and third laws, but they realized that something was missing. The first three laws lacked an underpinning, so scientists came up with the zeroth law.

The zeroth law basically states that if two places, say, place A and place B, are in thermal equilibrium with one another, and place B is in thermal equilibrium with place C, then place A will also be in thermal equilibrium with place C.

In algebra class, this would be called the transitive property of equality.

Also, the zeroth law postulates that if two places are in thermal equilibrium with one another, no energy will flow between them.

So, how does one determine whether two regions are in thermal equilibrium?
We start with the humble thermometer.

So, why are there two different measuring systems on Planet Earth?

In 1724 a Swedish physicist, named Daniel Gabriel Fahrenheit created the world's first accurate thermometer. He used a mixture of ice and salt for his zero point and the boiling point of water at sea level for his upper fixed point.
The freezing point of water in the Fahrenheit scale is 32 degrees and the boiling point of water at sea level is 212 degrees.

In 1742 the Swedish astronomer, Anders Celsius invented the Celsius temperature scale. The Celsius scale is the metric temperature scale. In the Celsius temperature scale, water freezes at 0 degrees and boils, at sea level, at 100 degrees. Occasionally, you will hear an old timer science teacher refer to this scale as the centigrade scale.

So, to help Mac earn the money so he and his girlfriend escape his frigid homeland, and to begin our study of thermodynamics, let's begin by building a thermometer.

Building a homemade thermometer

Items needed:

one small jar (a baby food jar will work, as well as a small peanut butter jar)

plastic tubing 2 feet (61 cm)

dowel rod

epoxy

drill

drill bit

balloon

rubber band

distilled water or deionized water

table salt

triple beam balance

beaker

food coloring

clothes pin

1 commercial thermometer

2 large bowls

ice water

hot water

And, of course, safety glasses

Step 0

Don safety glasses

Safety first!
Failure to wear proper protection is both unwise and majorly uncool!
How could you???

Step 1

Drill a small hole in the center of the lid of the peanut butter jar, large enough to slip the plastic tubing through

Drill a second hole next to the first hole and slip the dowel rod through the hole so that it sits on the bottom of the jar

Step 2

Slip the plastic tubing through the hole and tie it to the dowel rod with a bunch of rubber bands

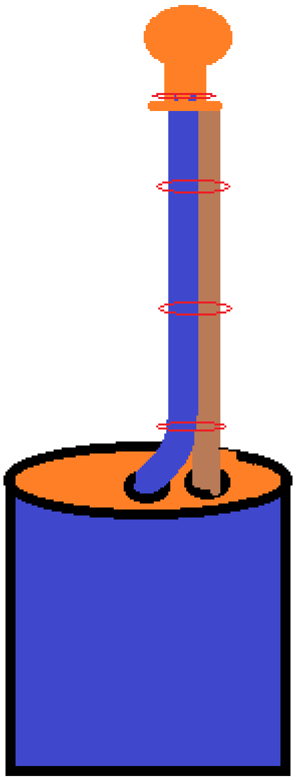
Step 3

Place a folded piece of paper or cardboard at the bottom of the baby food jar and screw on the cap of the baby food jar with the glass tubing sticking out of the hole, with the other end of the tubing resting on the cardboard

Step 4

Seal up the hole around the glass tubing using the epoxy

Let the epoxy set up over night



Day two

Step 0

I know, I know. Safety glasses…

Step 1

Mix two liters or so, of a 27% salt water solution. This is called the “eutectic” point for a salt water solution. The eutectic point for a solution is the lowest point at which a solution will freeze at.

1a) To mix a percent solution, a crazy little formula is used.
The formula goes as follows: $(x + y) = 1$, or $(x + y) = 100\%$.
So, you are going huh?

Suppose $x = 15\%$. Then x, when converted to a decimal, would be 0.15.
Since $(x + y) = 1$, then y would be equal to $(1 – x)$. Y would then be equal to $(1 – 0.15)$, or 0.85.

Since pure water has a mass of 1 gram per milliliter (at 4°C), then one liter of pure water would have a mass of 1000 grams, or 1 kilogram.

To make 100 mL of a 27% salt water solution, you would need 27grams of salt and (100 – 27) grams of water. So, you would need 27 grams of salt and you would need 73 grams of water. Since pure water has a mass of 1 gram per mL, then you would need 73 milliliters of pure water.

To check your work you can set up a fraction:

$$\frac{27}{(27+73)} * 100\% = 27\%$$

1b) To make 1 liter of this solution, two relationships would be used.
The first says that 1 liter of a liquid = 1000 milliliters.
So, 1L = 1000 mL.

The second relationship involves the volume of water you are using.
Since you are using 100 mL of water, then 100 mL * x = 1000 mL.

From your algebra class, you remember to divide both sides by 100.
Since the rules for algebra do not change, the same can be done here.

$$\frac{100mL}{100mL} * x = \frac{1000mL}{100mL}$$

Solving for x

$$\frac{\cancel{100mL}}{\cancel{100mL}} * x = \frac{1000mL}{100mL}$$

X = 10

So, you would need to multiply everything by 10.

You would need 270 grams of table salt and (1000 – 270) grams of water.
Since pure water has a mass of 1 gram per milliliter, you would need 270 grams of water dissolved into 720 milliliters of water.

Step 2

Fill the peanut butter jar full of water and screw the lid onto the jar.
Turn the jar over and let some of the water run up into the plastic tubing.
Momentarily pinch off the plastic tubing with a clothes pin.

Refill the peanut butter jar with your salt water solution until it is once again, full, and then add a drop or two, of food coloring.

Screw the lid back onto the jar and release the clothes pin.
The salt water should stay in the tubing.

Step 3

To calibrate your thermometer, take a large bowl and fill it full of ice water. Place your thermometer in the ice water until the liquid in the plastic tubing quits moving downward. When the water quits moving downward, mark a line on your dowel rod. This is your lower fixed point. If you want a US measure (Fahrenheit) thermometer, this mark represents 32°F.

If you want your thermometer to be a metric thermometer, this mark represents 0°C.

Now pull your thermometer out of the ice water bath, and place it into a bowl of hot tap water. Place your commercial thermometer next to your homemade thermometer and note the reading. Wait until the water quits rising in the plastic tubing of your homemade thermometer. Mark a second line on your dowel rod and note the temperature.

Finally, let your thermometer sit in your classroom, next to the commercial thermometer and record this temperature on your dowel rod.

Now, make the following solutions:

5% salt water solution

10% salt water solution

15% salt water solution

20% salt water solution

Place all of these solutions in the freezer and leave them in the freezer overnight.

The next day, observe the temperatures at which the solutions begin to melt.

Plot these temperatures on a graph.

Does the plot form a straight line?

Finally, since there are two everyday temperature scales, one metric and one US measure, lets practice converting between the two temperature scales.

To convert from degrees Celsius to degrees Fahrenheit you start with your metric temperature and multiply this by 9. You then divide your answer by 5.
Finally, you just add the number 32 to your answer. Its as easy as that!

So, please convert °C to °F

$°F = \frac{9}{5}°C + 32$

For example 25°C to °F

25°C x 9 / 5 + 32 = 77°F

So, you get to practice a little bit on this.

30°C	86°F
21°C	69.8°F
-40°C	-40°F
37°C	98.6°F
45°C	113°F
0°C	32°F
100°C	212°F
4°C	39.2°F
18°C	64.4°F
40°C	104°F

Now, see if you can convert US temperature to metric temperature
To do this, you simply reverse the process!
You begin by taking your US temperature and subtracting 32 from it.
After you receive your answer, you multiply your answer by 5 and then you divide by 9! Once again, easy!

$°C = (°F – 32) \times \frac{5}{9}$

For example

100°F to °C

(100°F – 32) x 5/9 = 37.7°C

Now, you get to practice a little bit.

104°F	40°C
32°F	0°C
120°F	48.9°C
-40°F	-40°C
212°F	100°C
60°F	15.6°C
0°F	-17.8°C
50°F	10°C
40°F	4.4°C
118°F	47.8°C