Edible Glass

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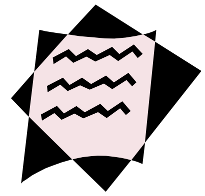
By Josh Pomeroy

Abstract



Students learn the principles of edible glass by making a supersaturated sugar solution.

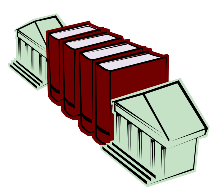
Equipment

1. Hot plate
2. Heavy pot with lid
3. Water
4. Thermometer
5. Watch or Clock with seconds place
6. Balance or scale
7. Oven mitts
8. Hot pad
9. 2 cups sugar
10. ¾ cup light corn syrup
11. 1 tablespoon unsalted butter
12. Plate
13. Long wooden spoon
14. Drinking Glass
15. Food Coloring
16. Flavoring
17. Cookie Sheet greased with vegetable oil
18. Sturdy Toothpicks
19. Aluminum Foil

Grade Level

This activity is suitable for Late Elementary, Middle and High School Students.

State Standards Met.



Standard 1 – Analysis, Inquiry, and Design
Standard 4 – Physical Setting and Living Environment
Standard 7 – Interdisciplinary Problem Solving

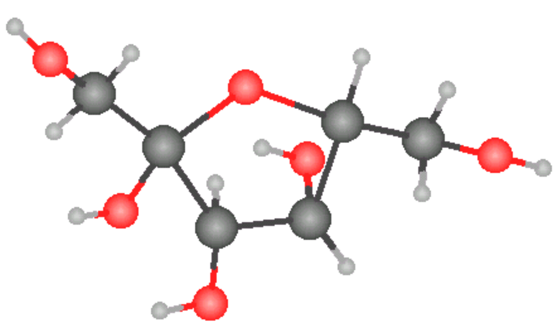
Introduction

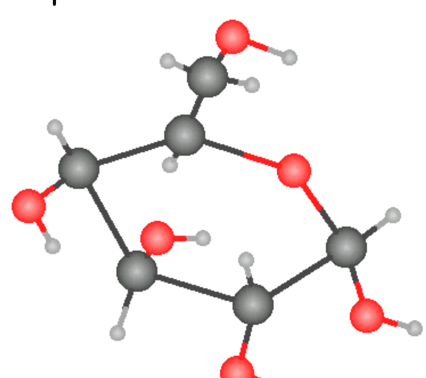
The goal of the following lab is to provide an interesting experiment which students of many different levels can perform, and to provide information to present the experiment from several different perspectives. The lab will begin with an introduction to common sugars and will include some discussion of temperature and thermometry, some basic thermodynamics, and the experimental procedure to make the candy glass. Finally I have provided some sample questions to encourage thought and to further develop an understanding of how one uses measurements to determine science.

Sugars – From Glucose to Cellulose

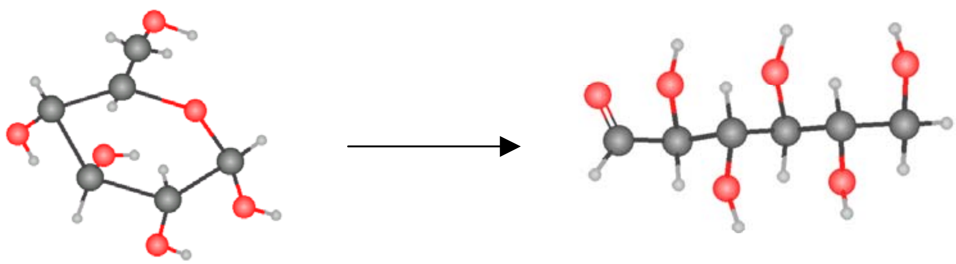
Glucose? Cellulose? Huh? You may never have heard of these names before, but they are all around you and in the food you eat. Glucose is the simplest type of sugar, the fuel your cells burn to give you energy. Cellulose is the stringy material that holds plants together. Have you noticed when you eat an apple the little stringy bits that stick between your teeth. Or have you gotten a piece of toilet paper wet and had it come apart into little stringy pieces? Those strings are both examples of cellulose.

In general, sugars are one of the classes of chemicals composed of carbon, hydrogen, and oxygen. The simplest sugars like glucose and fructose are composed of 6 carbons, 12 hydrogens, and 6 oxygens, (written as $C_6H_{12}O_6$). Plants form these basic sugars like glucose photosynthesis, using energy from sunlight, along with carbon dioxide (CO_2) from the atmosphere, and water (H_2O) from the soil to form sugars: $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$. So you might also see why people say plants produce oxygen, they release the oxygen from its bond with carbon. Now, you might think that once you have been given a chemical formula, you know all you need to know about that chemical. Well, have a look at the molecules in the picture below :

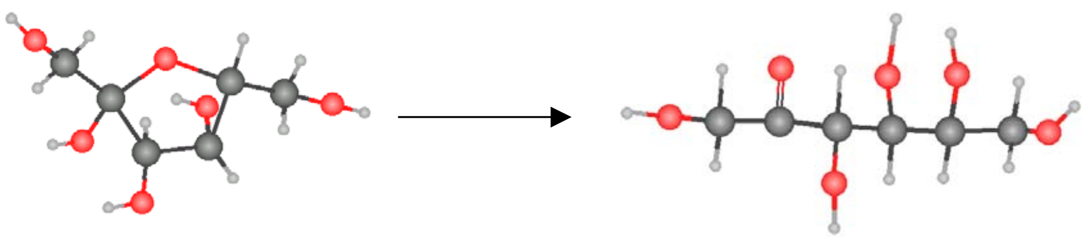




Both molecules are $C_6H_{12}O_6$ (the gray atoms are Carbon, the red are oxygen, and the smallest, light-gray atoms are hydrogen), but they look very different. When molecules of the same chemical formula can have different shapes, the shapes are called "conformations." In this case, the molecule on the left is the most common form of fructose (notice the ring is formed with five atoms), and the one on the right is the most common form of glucose (the ring is formed by six atoms.) Each of these molecules are $C_6H_{12}O_6$ molecules and are called monosaccharides since they only have one group of $C_6H_{12}O_6$. When these molecules are put in water, or "in solution", they can exist either as the rings shown above, or they can open to form chains, or polymers, as shown below :

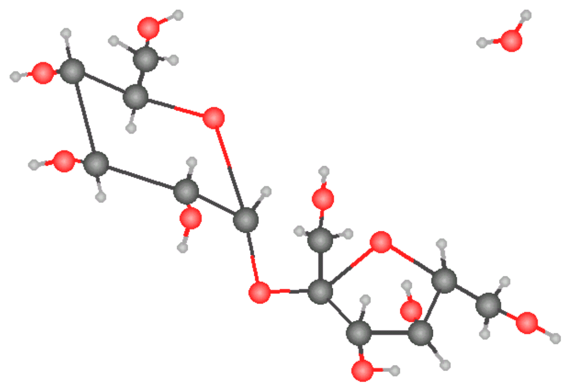


When sucrose opens to form a chain, notice the Carbon/Oxygen double bond is on the very left of the chain, whereas …



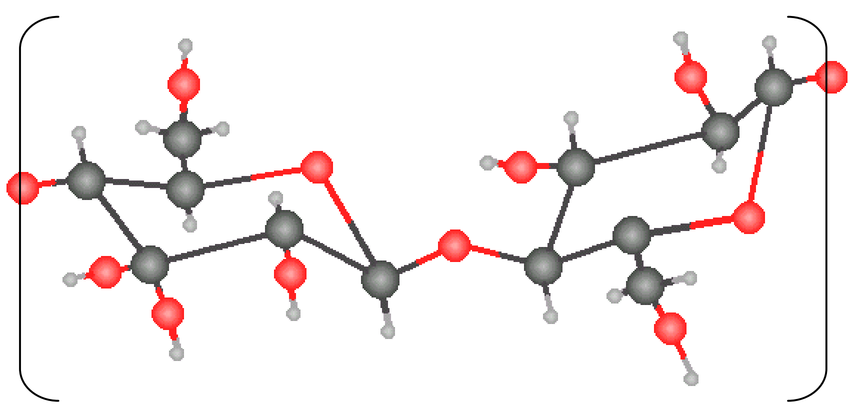
… fructose has a Carbon/Oxygen double bond on the second atom from the left, this is one way which you can tell the difference. When molecules like these are in solution, they continually open and close. Occasionally they collide with each other joining to form a larger molecule.

In the picture below, you can see the ring of six atoms on the left, and the ring of five atoms on the right connected by an oxygen atom. If you look above at the glucose ring, you can find the same oxygen atom on the lower right of the ring with a hydrogen attached to it. Now, look at the fructose ring above.   The left most carbon in the ring is where the bond is formed. In the picture above, an oxygen and a hydrogen atom are where the bond is below. The extra hydrogen on the glucose, combined with these two atoms add up to one water molecule (H_2O). If you look in the upper right corner of the picture below, you will see the water molecule formed from these three atoms. This reaction is known as a condensation reaction, since in addition to the large resulting molecule, water was also "condensed."

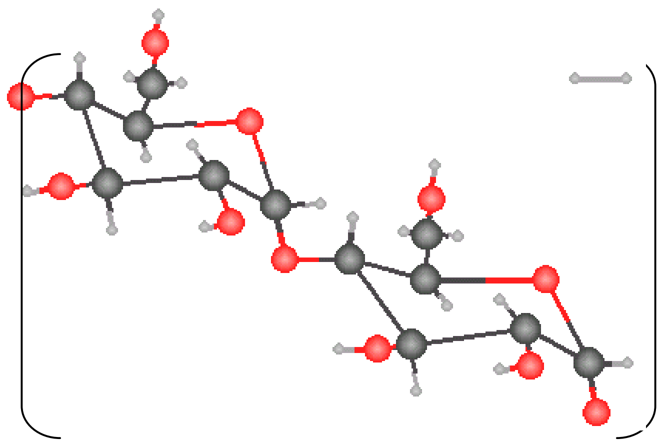


This new large molecule is sucrose, which is just common table sugar. Since it is formed from two monosaccharides, it is called a disaccharide. When this molecule is dissolved in water, it can "hydrolyze," or reverse the condensation and take in a water molecule to form glucose and fructose again. As a result of this, humidity in candy factories is carefully controlled.

More complex molecules like cellulose or starch are formed many, many monosaccharides strung together from groups of two to form "polysaccharides," which are often many hundreds or thousands of monosaccharides long. Let's look at cellulose first, where you can see the oxygen molecules hanging out on either side that would connect to more of the chain:



This is a base unit of cellulose, which is formed from two glucose molecules with a slightly different conformation than the one shown at the beginning of this section. The change is from a hydrogen and an OH group switching positions, but it makes a big difference in the properties of the molecule. To understand what some of those differences are, let's first look at starch, which is made from one of the glucose molecules we saw at the beginning of this section (a-D-glucose), and one of the molecules of the type which makes the cellulose (b-D-glucose).



That little difference in the molecules causes starch to form with an almost ninety degree angle where the two molecules join, where in cellulose the molecules form with a very wide angle, almost 180 degrees. Still not much of a difference you might say! Well, this difference is enough that most animals can digest starch (including humans). We make enzymes that break the bonds joining the monosaccharides and get the glucose back to burn in our cells. Only some bacteria, and a few insects have the ability to break down cellulose, which is why we cannot eat grass. Cows and other animals which eat grass have a bacteria which lives in their digestive organs which can break down cellulose for them.

You might still wonder, how do we digest starch? Well, as I mentioned earlier, many of these sugars dissolve in water, like sucrose. Starch is digested by enzymes in our saliva which break the oxygen bonds so that water can recombine with the sugar molecule to form glucose. Then the glucose is absorbed into bloodstream by our small intestine, passing into our cell walls along with O_2 from our lungs. Another kind of enzyme in our cells triggers a reaction exactly the opposite of photosynthesis. A sugar molecule and six oxygen molecules form carbon dioxide and water ($C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$). The carbon dioxide is expelled through our lungs, and the water is removed from our blood by our kidneys. The energy from sunlight that was originally stored in the sugar by the plant is used to keep our bodies functioning.

Heat, Temperature, and Thermometers

What is temperature? You think it is how hot or cold something is? Well, what does it mean to be hot or cold? Hot and cold are words comparing one thing to another, they have no set value. You can probably guess from the title temperature has something to do with heat, but what is heat? Ok, enough questions.

Heat is a form of energy. You may be familiar with potential energy, where some object is at some height, and when you drop the object, it converts that energy to kinetic energy. Kinetic energy is associated with something that has mass and is moving, kind of like momentum. If you think about a reservoir, the dam builds the water up very high, then drops it over the edge so that the water is moving quickly, converting potential energy the water had to kinetic. Hydroelectric dams then use that kinetic energy from the falling water to turn turbines making electricity.

Anything having mass and moving has some kinetic energy, even atoms which have very small masses. Heat refers to energy stored in atoms, or in the motion of the atoms. When you add heat to a system, like water, you increase the average speed at which the atoms or molecule in that system are moving. Since you have increased their speed and their mass has stayed the same, you have increased their kinetic energy. If you think about a whole bunch of molecules, like water in a pot, and you add heat, some molecules will get more heat than others. Temperature then is just the average amount of kinetic energy each molecule in your pot has, since some may be moving more quickly than others. Be careful not to confuse this with the energy stored in the molecule’s chemical bonds.

You can also ask how the molecules in the top of your pot get hot when the molecules in bottom of the pot get more heat than those at the top. As the molecules in the bottom begin to move faster, they collide with the molecules in the top and send them flying off faster too. How quickly a material transfers heat through it through having molecules (or atoms) collide with each other is called thermal conductivity.

You might also notice when you boil a pot of water the water seems to push up in the center and curl down on the edges. As the molecules on the bottom get more heat and begin to move faster, they expand and become more buoyant, pushing up to the surface. The cooler molecules at the top fall down to the bottom on the edges, and it starts moving in a circle. This process is called convection, and is how heat moves through a room. Air is a terrible thermal conductor, which we use to our advantage in down coats. The down in the coat traps the air into little pockets where it cannot start moving with convection. So the air insulates you and you can stay warm even though the air outside the coat is cold. When birds fluff up their feathers in the winter, they are trapping the air in their feathers to keep themselves warm. A room is large enough that convection can move the heat around and it doesn't matter that air is a poor thermal conductor.

Let's take a minute to recap important points, and to catch our breath:

- Heat is energy an atom or molecule has from moving around.
- Temperature is the average of this energy per atom.
- The thermal conductivity is how quickly a material can distribute this energy through itself.

But how can you possibly measure any of this? You can't exactly time how fast a molecule moves across your pot. So, how does a thermometer work, and what do the marks on it mean?

Let's think about the second part of that question first. The Fahrenheit scale was developed in the 1700s and was actually based on an even earlier scale called the Roemer scale. Olaus Roemer was a Danish astronomer who used a wine thermometer and chose 0 to be the temperature of a mixture of equal parts ice, salt, and water. Roemer then set 60 to be the boiling point of water, which meant the freezing point of fresh water fell at 7 ½ degrees. G. Daniel Fahrenheit had a notable dislike for fractions, so when he built his version of the mercury thermometer, he multiplied the units by four. That made the freezing point of fresh water 32 F, but since the mercury thermometer is more accurate than Roemer's wine thermometer, fresh water boiled at 212 F.

The Celsius (or Centigrade) scale today is actually exactly the opposite of the way in which Anders Celsius proposed it. Celsius also used a mercury thermometer, but selected 0 to be the boiling point of water, and 100 to be the freezing point. People liked the idea of having 100 degrees between the freezing point and the boiling point, but thought that the temperature should go *up* when something got hotter! So, after Anders Celsius died the scale was reversed to the way it is today: at 0 C water freezes, and at 100 C water boils.

Both the Fahrenheit and Celsius scales have negative numbers, but another scale used by scientists you may not know does not. It is possible to cool something until the atoms stop moving entirely. If you do that for all known substances, you will find the atoms of all the substances stop moving at the same temperature. This point is called "absolute zero," and the Kelvin temperature scale sets that point at 0 K. The atoms essentially have no energy at absolute zero, so this scale has no negative temperatures. Absolute zero is colder than the dark side of the moon, in fact the coldest temperature recorded on earth is still about 200 K. The increments, or size of a degree, on the Kelvin scale are the same as on the Celsius scale. Water freezes at 273 K, and boils at 373 K, leaving a 100 K difference, but the zero has been shifted to absolute zero.

The really hard question has still been avoided: how does a thermometer work? It measures temperature, which is the average amount of heat per atom or molecule in your pot, but how? Well, imagine you shrink yourself a billion times smaller than your current size and stand in your pot. The hotter the molecules in the pot, the faster they are zipping around you. If one runs into you, the faster it is moving when it hits you, the farther you will be thrown. When you recoil, the atom or molecule has transferred energy to you, and after only a couple of collisions, you will have the same energy as the other molecules, flying around at the same speed. When you have gained or lost energy until you have the same energy as the other molecules you have come into thermal equilibrium.

When you put a thermometer into your pot, the molecules collide into the glass transferring energy. The mercury (or alcohol if it is red) in the thermometer can then come into thermal equilibrium with the stuff in your pot. As the mercury warms up to come into thermal equilibrium, it expands and rises up inside of the glass. You can then use the marks on the outside to compare the height of the mercury to the temperature scale you are using.

Over time people have come up with many ways of measuring temperature, but somehow the mercury and alcohol thermometers are the method with which most people are familiar. Another common method using in many household thermometers takes advantage of the thermal expansion of metals. Imagine you have a strip of metal 20 cm long (about 8 inches). If you heat it up, it will expand and get longer. But now what if you take the same piece of metal and wrap it around itself so it is coiled like a snake, and then heated it? If you said it would still expand, but now so it wrapped farther around itself, you'd be right! You can imagine attaching a needle to this, and calibrating it (putting marks for known temperatures) so you have the kind of thermometer you see with the big orange needles at the hardware store. The switches in electric ranges are made in a similar way, except those switches compare how fast one metal expands compared to another for temperature. This way the metal will move to close the circuit and allow electricity to flow, then as it heats, it will expand and break the circuit. One other common way is to take two different kinds of metals and make an electrical contact between them. Taking advantage of chemical differences, you can then measure the voltage between the two metals to determine temperature. Special types of metals have especially high voltages which makes these measurements very accurate. This is called the thermoelectric effect and is how temperature is measured in most assembly lines, on the space shuttle, and many other places where the temperature needs to be known to $1/10^{th}$ of a degree.

Some Conceptual Thermodynamics

Thermodynamics refers to how things change with temperature, or more specifically, how things change as you add or remove heat. Start by thinking about your pot of water again. As you add heat, the temperature slowly increases. Imagine you have a burner that provides a constant amount of heat, then you would expect the temperature to rise at the same rate the entire time you add heat. The amount of heat (or energy) the water requires to increase the temperature one degree of temperature is the water's heat capacity. But now suppose we have added enough heat to get our water pot to 100 C. What happens to the temperature now, as the water begins to boil? Well, the temperature remains at 100 C even though you continue to add heat! This is because the water is changing from water to steam, or going through a "phase transition." But since the properties of water and steam are very different, it takes a lot of energy to just change the phase of the water, without any change in temperature. The amount of energy it takes to take a gram of 100 C water to 100 C steam is called the "latent heat of vaporization." That amount of energy is actually more than it takes to heat 1 gram of 0 C water to 100 C!

The same thing happens with water at 0 C when it changes to ice, or ice changes to water, except this is the "latent heat of solidification." Again, the amount of energy required to change 1 gram of 0 C ice to water at 0 C is more than to heat the 0 C water to 100 C. This is why when you put ice cubes into warm soda, the soda will cool to nearly 0 C and stay cold without melting all the ice!

All materials can be solids, liquids, and gases, but the heat required to change the temperature and the phases of the materials can be very different. The properties help determine where, and how they can be used when building products. For example, common glass requires relatively little heat to change its temperature, especially when compared with water. But the glass transfers the heat through it very well, keeping the temperature pretty even throughout it. This is also why you have two panes of glass in your windows separated by air. The glass transfers heat very well, but the air does not, so the air between the panes keeps the window from passing heat through it.

Some materials, like the candy in the lab, have many different complex phases, not just simple solid, liquid, and gas. As you do the experiment, you will be asked to watch the properties of the candy as it gets hotter and hotter. You can also look at the diagram* of sugar phases:

Temperature C (F)	Moisture (%)	Physical Characteristics	Application
102 (215)	20-25	Pulls to threads	Candied Fruit
102 (222)	15-20	Pulls to pearly tough threads	Jams, marmalade, jelly syrups
110 (230)	12-13	Pearly balls and flakes	Grained sugar candy sweets
118 (240)	9-10	Forms soft balls in cold water	Gumdrops, fondants, fudge
119.5 (245)	8-9	Between soft and hard	Soft caramel
121	7-8	Forms hard balls in cold water	Nougat, soft toffee, marshmallows
129	5	A hard tearing layer in cold water	Toffee, non-grained candy
143	3-5	Yellowish and glassy hard	Hard toffee
150 (302)	2-3	Glassy and yellow	Butterscotch, boiled sweets, fruit drops, brittles
180 (356)	< 2	Glassy and caramel brown	Spun sugar, toffee apples, hard caramel
> 180	0	Darkens, loses sweetness as it becomes carbon	Caramel

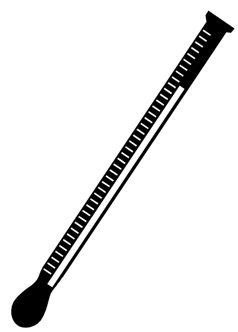
***From The Chemistry of Cooking, p.42.**

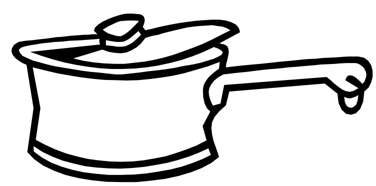
Science Lab - Making Edible Glass

Hopefully by now you are thinking about sugar, water, and heat a little bit differently. See if you can observe some of the things discussed above, and if by taking some simple measurements, you can use the results of those measurements to learn some valuable information about the candy glass.
(You should probably halve the amount listed below.)

Equipment:

- hot plate
- heavy pot with a lid
- water
- thermometer
- watch or clock with seconds place
- balance (or scale)
- oven mitts
- hot pad (something to place hot pot on)
- 2 cups sugar
- 3/4 cup light corn syrup
- 1 tablespoon unsalted butter
- plate
- long wooden spoon
- drinking glass
- food coloring
- flavoring
- cookie sheet greased with vegetable oil
- sturdy toothpicks
- aluminum foil





Instructions:

1. Without adding anything to your pot, and without the lid, measure the mass of your pot, measuring spoon, and the hot pad. (You will find it easier to use metric if you can!)

Mass of Pot ________________________

Mass of Hot Pad ________________________

Mass of Spoon _______________________

2. Add about as close as you can get to two cups of water to the pot.
   Measure the mass of the water and pot combined.

Mass of Pot + Water ______________________

What is the mass of just the water?

Mass of Water _______________________

Mass/Cup ______________________

3. Measure the starting temperature of your water.

Start temperature of water ______________________

4. With the burner still off, look on the label and write down the rated power (e.g. 1500 W). Cover the burner with aluminum foil (if electric), and turn on the burner to about 75% of it maximum value, and allow it to heat. Be sure not to change the setting after this point, since you are calibrating the burner at this setting.

5. Cover and put the pot on the burner after it is hot and mark the time to the second.

Start time on burner _____________________

6. Bring the water to a boil. As soon as the water begins to boil, mark the time down (again to the second.) If you have waited 10 min, turn the burner up to maximum, and start over with only one cup of water.

Boil Time ______________________

7. You are now going to calibrate your thermometer. Hold thermometer in center of boiling water until the temperature has not moved for 20

seconds. Try not to let the thermometer touch the bottom of the pot. Be careful, steam burns, use a mitt. Check the temperature of the thermometer while in the boiling water.

Record the temperature: ________________ C.

What temperature should the thermometer read? ____________ C.

How many degrees do you need to add or subtract to correct the thermometer's reading? _____________ C.

When doing the experiment, add or subtract it to the temperatures given to determine what your thermometer should read at each step.

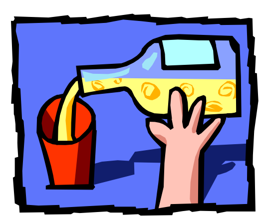
Using the heat capacity of water as 4.186 J/g C, calculate the power of the burner (i.e. the heat provided per second.) 1 oz = 28.35 g

Power J/s = Heat Capacity J/g C * Water Mass g * D Temp. C / Time s

Power _________________

(J/s is a Joule per second, Joules are units of energy. 1 Watt = 1 Joule/second)

Is this close to 75% of the number you wrote down from the label on the burner above? If not, maybe you should check your math!



8. Place the hot pad on the scale. Remove the pot to the hot pad on the scale. Carefully measure out 1 cup of hot water, and then place the pot with water on the hot pad on the scale. Note this mass. Now add the sugar, corn syrup, and butter to the boiling water. Measure the mass of the whole mixture and replace the pot on the heat. Stir until the ingredients dissolve.

Mass of Pot + Water + Hot pad _______________

Mass of Mixture ________________

9. Heat mixture to a boil without stirring. Record the temperature as soon as it begins to boil.

    Boiling Point of Mixture _____________ C

10. Cover and cook for three minutes. From now on, record the temperature every two minutes (a table is included in step 14), and record the mass as indicated in step 14.

11. Remove syrup from heat. Each time you take a sample you need to measure the mass before and after, so you know how much you removed. Scoop up a spoon of syrup and pour it onto the plate. What happened to the syrup?

12. Scoop another spoonful of hot syrup into a glass of cool water. What happened to the syrup? Put $\frac{1}{4}$ teaspoon onto the graph paper and measure how far it spreads out.

13. Return syrup to heat without stirring and repeat steps 11 and 12 at the following temperatures: 112 C, 118 C, 121 C, and 132 C. Complete the chart below:

Temperature		Area	Mass	Observation of the syrup
Temp	Temp (Corrected)		Before	11 –
			After	12 –
Step 11			Before	11 –
			After	12 –
112 C			Before	11 –
			After	12 –
118 C			Before	11 –

			After	12 -
121 C			Before	11 -
			After	12 -
132 C			Before	11 -
			After	12 -

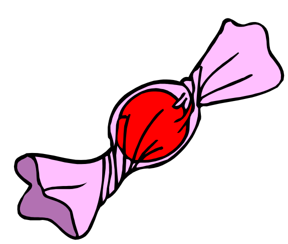
Time	**Temp**	**Time**	**Temp**	**Time**	**Temp**

14. When syrup reaches 149 C, remove from heat. Cool to 71 C. This will take about 15 minutes. Be sure to record the final mass :

Mass of candy ______________________

15. Stir in color and flavor.

16. Set toothpicks on oiled cookie sheet. Pour a small amount of syrup around each.



17. Remove lollipops from cookie sheet as soon as they are firm. You have just made edible glass.

18. (OPTIONAL) As the candy cools, try pulling out thread of it like you might do to make fiber optics. Using a HeNe laser, see if you can get light to pass down the fiber.

Questions:

1. Plot temperature vs. time on the graph below. Be sure to label the axis, and mark off the increments. Remember the independent variable goes on the horizontal axis (the variable you cannot control.)

2. Now, plot mass vs. temperature on the plot below. Once you have that graph, go back to the graph above, and in a different color, plot mass vs. time.

3. Now, plot area vs. temperature on the plot below. Can you fit the dots to a curve of some kind? Why do you think this trend exists physically?

4. What happened to the particles in the syrup as it was cooled? Once it has solidified, how is it similar to or different from other solids.

<u>Metals –</u>

<u>Plastics –</u>

Window Glass –

5. As you performed the experiment, much of the water was lost to steam. Using the mass measurements above, calculate how much mass was lost (Mass in Step 8 – Mass in Step 14) and be sure to correct your measurement in Step 14 for the candy you sampled in doing steps 11 and 12:

   Lost Mass ______________________

6. If the only mass lost was water, you should be able to find the latent heat (the amount of heat needed to change the water to steam).

   Latent Heat J/g = Power of Burner J/s * Total Time s / Mass Lost g

   Latent Heat __________________

   Compare with the accepted value 2256 J/g

7. Compare the mass of the water added (step 8) to the mass lost. If more mass was lost than the water added, is the assumption in Question 5 still a good assumption? Explain your finding, and your answer.

8. What happened to the sugars in the syrup as it was heated up? Using your plots above, and your information about the mass, can you say anything about whether the sugars condensed into chains? Why or why not?

9. If some of the sugars condensed, estimate how many bonds were made if 1 water molecule = 3×10^{-23} g. (Take the difference in starting mass of the water and the lost mass, then divide by the mass/molecule.

   Number of bonds made ____________________

10. Using your value for the latent heat, calculate the amount of time needed to vaporize the water added at the beginning.

   Time to vaporization ____________________

   Does anything interesting happen in your temperature vs. time graph at that time? Explain.

11. Using the difference in the time from Question 9 and the final finishing time along with the power of the burner, estimate the heat capacity of the candy.

   Candy Heat Capacity __________________

   Is this more or less than water? Does this answer make sense? How will heat lost to the air, etc. affect this measurement?

12. How does the condensation of the sugars affect the properties you observed? At what temperature would it be easiest to make candy optical fibers? How does the bonding of the sugars change these properties? Explain.

13. What physical properties does your glass share with window glass? How well would it work as a fiber optic?

14. What could you do to improve any of the measurements you made above? How accurate do you think your results are?