Chocolate Experiment

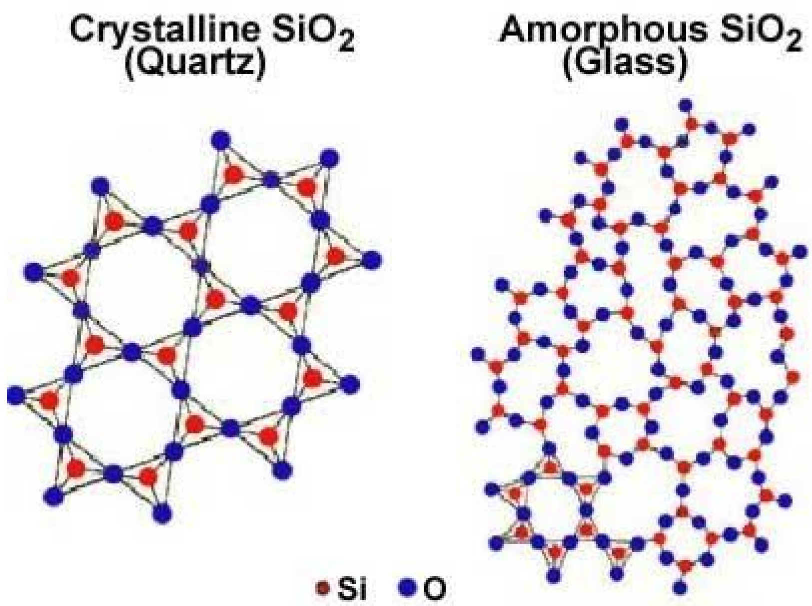
Learning goals:

1. Phase diagrams and melting temperature
2. Polymorphisms
   Tempered chocolate vs. non-tempered chocolate
3. Hydrophilicity vs. Hydrophobicity and emulsion
   Seized chocolate – Water in oil vs. un-seize chocolate – oil in water

Backgrounds:

Chocolate is probably one of the most popular food types in the world! What makes it so special? Is it the glossy, shiny look? Or the crisp snap when bitten into? Or is it the smooth texture we feel when the chocolate is melting in our mouths? Let's learn more about the science of chocolate today!

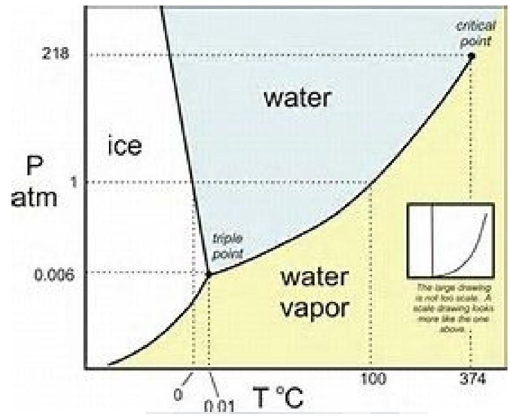
Chocolate is one of a few unique crystalline solids that we eat. Crystalline solids, or crystals, have molecules, atoms, or ions pack together in an ordered structure. In contrast, amorphous solids have molecules, atoms, or ions are random. Some other crystalline solids that we eat are ice, sugar, salt, and butter or margarine.



Difference in molecular packing between crystalline solid (Quartz) and amorphous solid (Glass) demonstrated by SiO_2

Have you ever wondered why chocolate only melts in your mouth but not your hands? In order to answer these questions, we first need to talk about different phase diagrams for different materials.

We know that as temperature decreases, water goes from gas phase (water vapor), to liquid, to solid as shown in the diagram below. We can think about it as if the temperature is the level of energy of these water molecules. In the gas phase, they have a lot of energy and are just running around away from each other in random directions. However, as they lose energy and getting more tired, they don't move as fast or freely from each other anymore. They are now staying closer together. In the solid phase, they are even more tired and don't want to fight each other anymore so they just pack closely together into a more structured form. At our atmospheric pressure, the water becomes water vapor at 100°C; whereas ice becomes water at 0°C. This is why if we leave the ice cube out at room temperature (around 25°C), the ice cube will start to melt into liquid water.



(Image from Google)

Similarly, in chocolate, the cocoa butter or fat molecules also undergo phase changes as the temperature changes. The melting point for fat molecules in chocolate is about 36°C, which is very close to body temperature of 37°C. Thus, at temperature below 36°C like our hand temperature, which is measured to be around 27-32°C, chocolate still stays solid. However, above 36°C, like in our body, the chocolate will melt.

Quick experiment: Does all chocolate have the same melting temperature?

Materials:

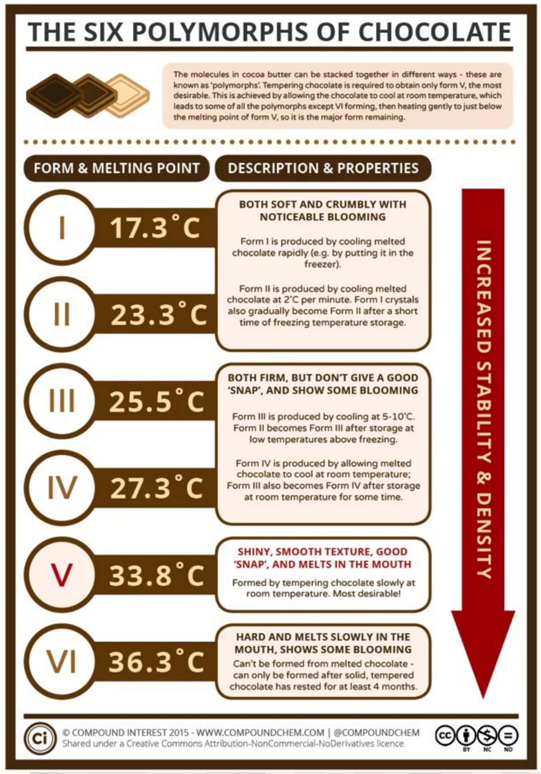
- ¼ bar of chocolates of different % cacao
- Small bowls
- A baking tray filled half way with water
- Timer
- Ranger

Experiments:

1. Predict the trend of melting of the chocolate samples
2. Acquire ¼ of a bar of chocolate- keep the size and weight the same for all samples as much as possible.
3. Transfer chocolate to a small bowl and label.
4. Place the bowls in water tray and start heating the tray
5. Start the timer and record the time it takes to full melt the chocolate samples.
6. Compare your results and hypothesis.

Although chocolate also undergoes phase changes as temperature changes, similarly to water or any other substances; chocolate undergoes a more complex transition. If you remember from our previous blog post, cocoa butter is polymorphic and can exist in six crystalline forms. This is why the art of making chocolate is simply the art of forming the desirable crystals, which is polymorph V (five), the finest type of cocoa butter.

Why is making chocolate an art? Let's think about making ice cubes for a second. When we make ice cubes, we don't think about what crystalline we are forming, since there is only one solid phase- according to the water phase diagram. As long as we leave the ice-tray in the freezer for a few hours, we will get the same kind of ice no matter what. It is more complicated for chocolate, since each of the polymorph has a different melting point as shown below.



In order to produce the smooth, glossy, free of blemishes or bubbles bar of chocolate that gives a crisp snap when broken or bitten into; the chocolatiers would need to go through the process of tempering- manipulating the temperature of the chocolate during the cooking process to control the crystallization of the cocoa butter.

Experiment 1: Becoming a chocolatier!
In this experiment, we will act as a chocolate maker to recreate the smooth, glossy appearance and most importantly, the crisp snap when being broken/bitten.
Materials:

- Dark chocolate bar
- Thermometer
- Cutting board and knife
- Small bowls
- Microwave
- Parchment paper
- Optional: LEGO pieces, ice cubes, hair dryer

Experiments
Sample 1: Tempered chocolate

1. Chop up ¼ of the chocolate bar into small pieces
2. Transfer half the amount into a small bowl

3. Heat the chocolate bowl in the microwave in 5-10 seconds intervals (depends on the power of the microwave, small intervals is recommended). Stir the mixture as needed.
4. Once the chocolate is melted (around 110°F), add the other half of the chopped chocolate to the bowl. Mix well. The addition of the solid chocolate should brings the temperature down to around 93°F)
5. Reheat the chocolate bowl again, for another 5 seconds until all the chocolate is melted.
6. Spread the chocolate onto the parchment paper and let solidify

Sample 2: Non-tempered chocolate

1. Chop up ¼ of the chocolate bar into small pieces
2. Transfer the chocolate into a small bowl
3. Heat the chocolate bowl in the microwave in 5-10 seconds intervals (depends on the power of the microwave, small intervals is recommended). Stir the mixture as needed.
4. Once the chocolate is melted, spread the chocolate onto the parchment paper and let solidify.

Observations

- Sample 1 has smooth texture and is shiny. It became harden pretty quickly and does not melt when touch with hand. It has a crisp snap when broken.
- Sample 2 took longer to become solid. It is still pretty smooth and shiny when solidified; however, it becomes dull after a while. This piece of chocolate is soft and flexible. It does not make a clean snap when broken. As time goes on, notice chocolate blooms- white spots on the chocolate surface. This is when the fat recrystallizes on the surface.

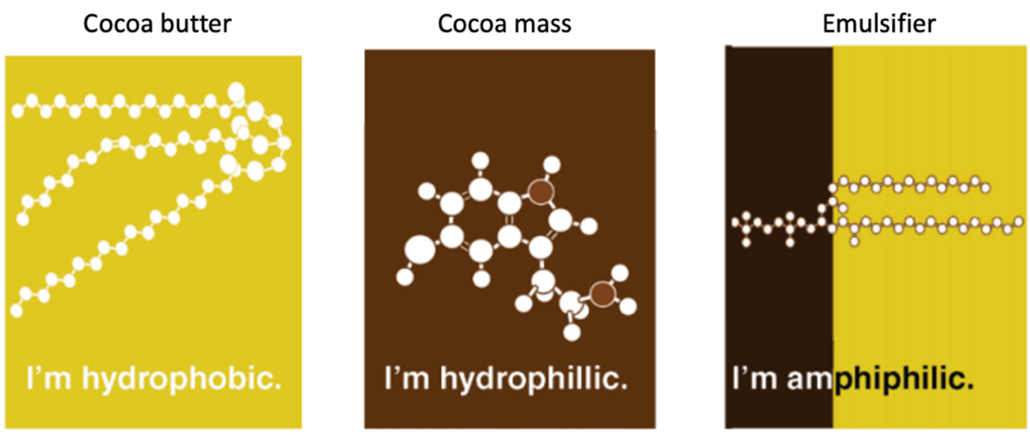
Explanation

- Once the chocolate is melted, sample 2 is allowed to solidify forming any of the 6 polymorphs of cocoa butter; whereas, in sample 1, the chocolate mixture is let cool down to solidify into form V. Moreover, the additional added solid chocolate acts as "seed" crystals, providing template for new crystals to form. The mixture is then gently heated again, melting any other polymorphs resulting in "tempered chocolate," containing mostly form V crystals. (Illustration in PPT)
- **Take a closer look**
  1. **Stack some ice cubes on LEGO pieces- this acts as the untampered chocolate crystal- where ice cubes are undesirable polymorphs and LEGO are desirable form V**
  2. **Use a hair dryer to blow at the structure- the ice starts to melt away- this is when we heated the chocolate mixture a second time**
  3. **Once the ice cubes melt away, the LEGO pieces can be stack together, forming a stable structure- this is when we formed tempered chocolate.**

Main takeaways:

- Cocoa butter in chocolate can stack in different ways leading to different crystalline forms.
- Form V is most desirable inn chocolate making, which can be achieved by manipulating temperature at which the chocolate liquor is cooled- the process of tempering- to form good chocolate with smooth, shiny texture and especially gives a crisp snap when bitten into.

Why does chocolate feel smooth in your mouth?
The major components of a typical chocolate bar are cocoa beans or mass, sugar, cocoa butter, and soy lecithin (an emulsifier). For simplicity's sake, we will represent cocoa mass as a serotonin molecule, a component of cocoa that is largely hydrophilic- water loving; cocoa butter as a triglyceride (fat) molecule, a component of cocoa butter that is largely hydrophobic- water repelling; and the emulsifier as lecithin that is amphiphilic- having both a water loving and a water repelling component.



Quick experiment: hydrophilic vs hydrophobic?
Materials:
- Cocoa powder
- Oil
- Water

Experiment
1. Place ¼ cup of water in one glass and ¼ cup of oil in another glass
2. Place 1 teaspoon of cocoa powder in each glass, mix
3. Observe to see which glass the cocoa powder dissolves in and answer if cocoa powder is hydrophilic- water loving or hydrophobic- water repelling

We see that cocoa powder is indeed hydrophilic, so why doesn't the chocolate stay clumpy or grainy but gives a smooth texture in our mouth? That is when the emulsifier comes in to save the day! Emulsifiers are amphiphilic- meaning they have a water-loving component as well as a water-repelling component- allowing them to form an emulsion. An emulsifier protects the hydrophilic component of the mixture from the hydrophobic continuous phase or the hydrophobic component of the mixture from the hydrophilic continuous phase forming what's called an emulsion. The emulsifier allows the mixture of components that normally don't mix.

Quick experiment: Forming an emulsion
Materials:
- Oil
- Water
- Soap (egg yolk as alternative)
- Emptied water bottle with a cap

Experiment

1. Place some water in the glass
2. Add oil to the water
3. Shake the bottle to mix the two layers
4. Observe if the two layers mix?
5. Add some soap to the bottle
6. Shake the bottle to mix
7. Observe if the two layers mix?
8. The two layers are now not two layers anymore- you have formed an emulsion

Experiment 2: Rescuing seized chocolate!

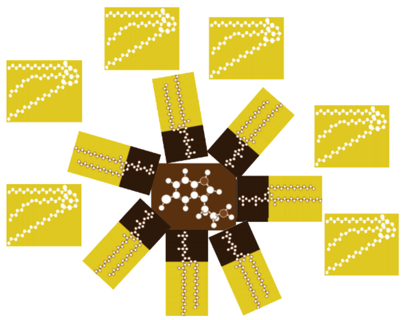
In this experiment, we will learn about hydrophobicity, hydrophilicity, and emulsion through the adventure of rescuing seized chocolate.

1. Chop up ¼ of the chocolate bar into small pieces
2. Transfer the chocolate into the small bowl
3. Heat the chocolate bowl in the microwave in 5-10 seconds (depends on the power of the microwave) Stir the mixture as needed.
4. Once the chocolate is melted (around 110°F), sprinkle a few drops of water into the mixture and continue stirring.
   - What is your observation? Is the chocolate losing its shine, becoming grainy and hard to stir? THE CHOCOLATE IS SEIZED!
5. Time to rescue the seized chocolate! Add 1/8 teaspoon of water at a time while continuing stirring the mixture. The mixture will become shiny again. Although you can't turn this chocolate to the state it was before, you can still use this chocolate for dipping and it does not have to go to waste.

   Observations:
   - The smooth, shiny chocolate mixture turns grainy, loose its shine and becomes thickened once drops of water is added; however, the mixture is loosened and gain back its shine when additional water is added.

   Explanation:
   - Chocolate has a smooth texture when melted due to the presence of an emulsifier, keeping the sugar (hydrophilic- water loving) dispersed in cocoa butter (continuous oil phase- hydrophobic- water repelling). The emulsifier builds a protecting layer around the sugar particles so that they don't separate from the cocoa butter.
   - When a small amount of water is added to the melted chocolate, the water molecules form small droplets to avoid mixing with the cocoa butter. Just like how water does not like to mix with oil. On the other hand, cocoa mass and water likes to mingle, resulting in something similar to the "sugar bowl effect" where the sugar particles become wet and lumps together (agglomerate). This agglomeration leads to the grainy texture we observe. At this point, the emulsifier is no longer capable of stabilizing such large amounts of hydrophilic constituents, causing the chocolate to seize.

No water added

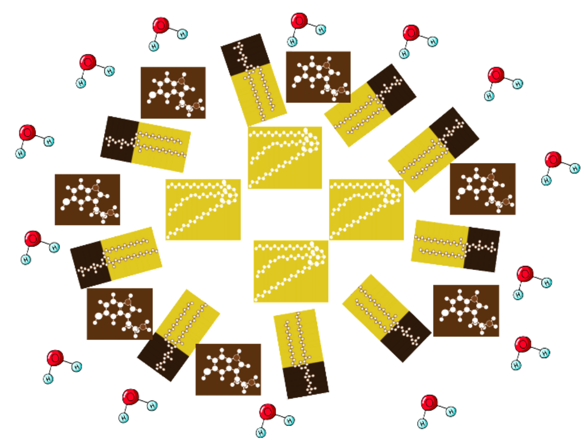


Small amount of water added

- Although the seized chocolate cannot be reverted back to the original chocolate mixture, the smooth texture can be gained back by adding more water to the mixture. It is because the emulsion is now inverted. The cocoa butter, which was the continuous oil phase, is now dispersed in the continuous water phase.

Small amount of water added

Large amount of water added



Main takeaways:

- Hydrophilic substances dissolves in water, while hydrophobic substances do not dissolve in water. Example: water does not mix with oil.
- Hydrophobic and hydrophilic substances can be mixed together in presence of a surfactant, forming what is called an emulsion. Example: mayonnaise is an emulsion of oil phase dispersed in a continuous water phase.

FOR FUN:
OPTICAL CHOCOLATE - NEED TO ADD INSTRUCTIONS AND ORDER GRATING FILMS.

Citation

- *Journal of Chemical Education* article by A.C. Rowat, et al. (2011): The Science of Chocolate: Interactive Activities on Phase Transitions, Emulsificaiton, and Nucleation. (for ages 6 and up)