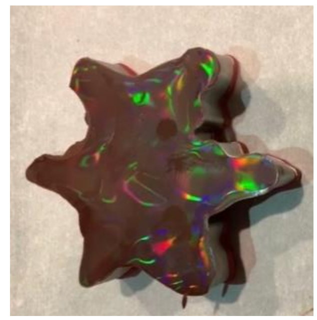
Nano at Home

Chocolate Experiment

Science concepts you will learn about in these experiments:

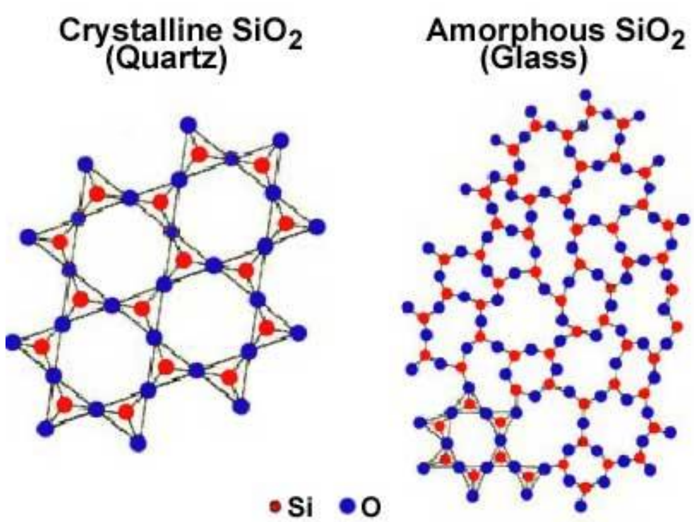


1. Phase diagrams and melting point
2. Polymorphisms
3. Hydrophilicity vs. hydrophobicity and emulsion
4. Diffraction of light

Safety: Adult supervision needed for any heating of chocolate!

Background:
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 melts in our mouths? Let’s learn more about the science of chocolate!

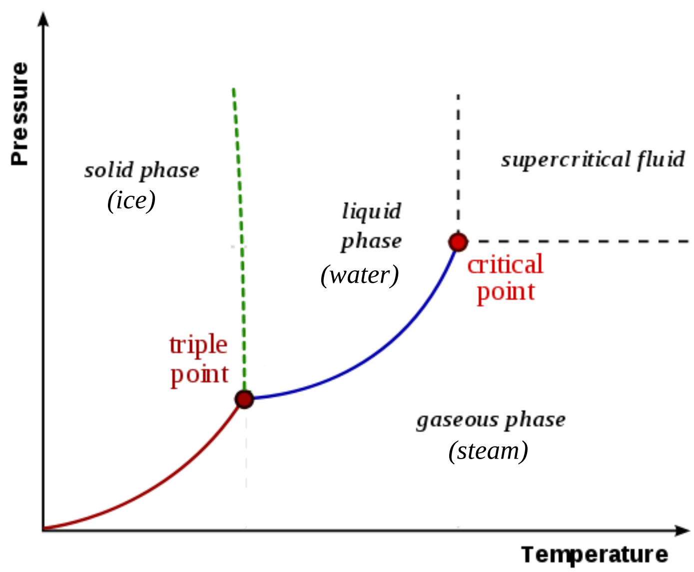
Chocolate is one of the few crystalline solids that we eat. Usually when we think of crystalline solids we think of things like gemstones, but a crystal can be made of many different materials. Crystals have molecules, atoms, or ions packed together in an ordered structure. In contrast, amorphous solids have molecules, atoms, or ions that 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), both made of molecules of silicon dioxide (SiO_2) [from physicsopenlab.org]

Have you ever wondered why chocolate melts faster in your mouth than in your hands? In order to explain why, we first need to talk about *phase diagrams* for different materials.

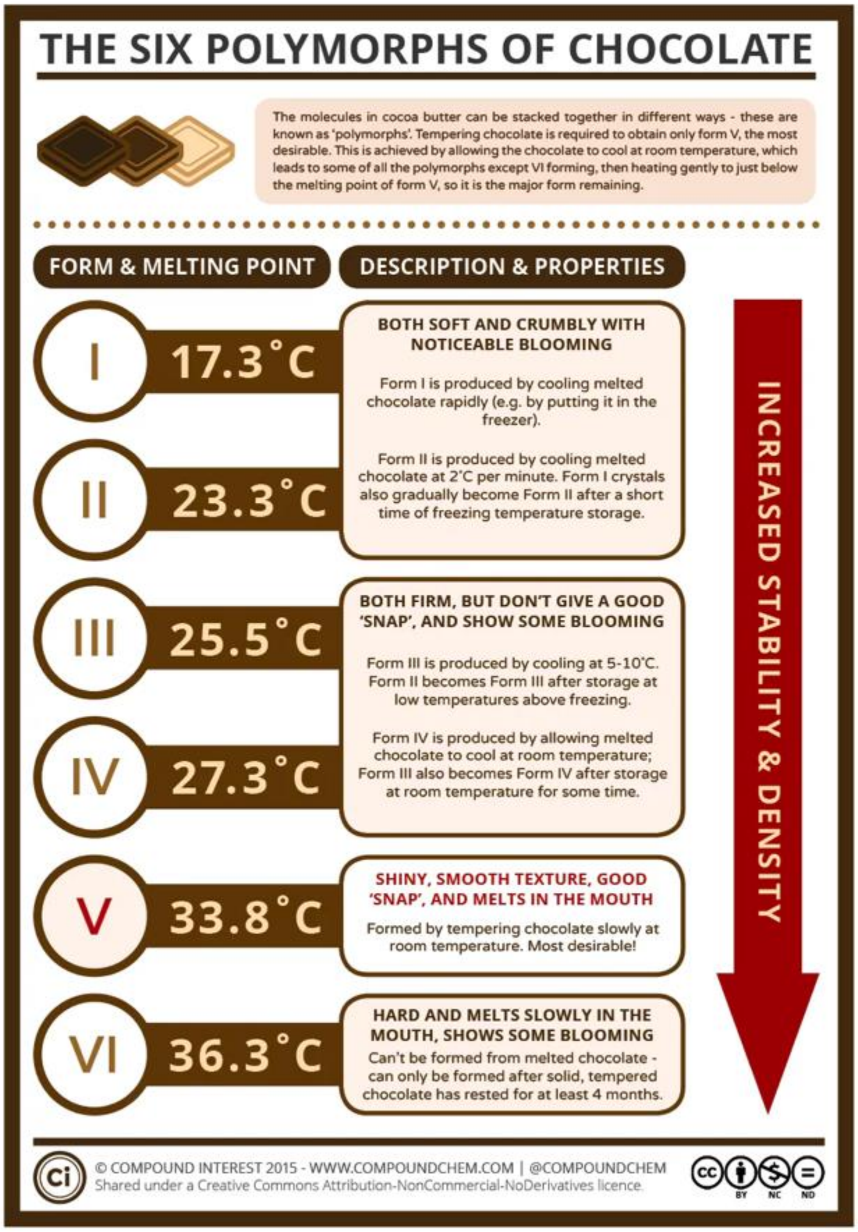
We know that as temperature gets cooler, water goes from gas phase (steam), to liquid (water), to solid (ice). The phase diagram below shows these changes. One way to understand *why* these changes happens is to think about temperature as the energy level of water molecules. In the gas phase, water molecules have a lot of energy and are just randomly running around each other. However, as they lose energy and get more tired, they don't move as fast or as freely. They now stay 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 structured form. Pressure also plays a role: at regular atmospheric pressure, water becomes water vapor (steam) when heated to 100°C (boiling point), and solidifies to ice when cooled to 0°C (freezing point). This is why, if we leave an ice cube out at room temperature, (around 25°C), the ice cube will start to melt into liquid water.



Phase diagram for water [adapted from chemistnate.com]

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 our body temperature of 37°C. Thus, at temperature below 36°C (like your hand, which is around 27-32°C) chocolate still stays solid. However, above 36°C (like inside your mouth) the chocolate will melt.

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 crystal 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, as each the polymorph has a different melting point, as shown below.



Polymorphs of chocolate and their melting points [from compoundchem.com]

Although chocolate also undergo the phase changes as temperature changes, similarly to water or any other substance, chocolate undergoes a more complex transition. Cocoa butter is polymorphic and can exist in six crystalline forms, which you can read more about in our blog post at susnano.wisc.edu/chocolateblog. 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. In order to produce a smooth, glossy, blemish-free and bubble-free bar of chocolate that gives a crisp snap when broken or bitten into, chocolatiers 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! (Ages 5+)

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 (>70% cacao works best; chocolate chips do not work very well)
- Candy/cooking thermometer (if you don't have one, this experiment may not work as well)
- Cutting board and knife
- Small microwave-safe bowls
- Microwave
- Parchment paper

Directions:

Be careful when handling hot chocolate!

Sample 1: Non-tempered chocolate

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

Sample 2: Tempered chocolate

1. Chop up about ¼ of the chocolate bar into small pieces.
2. Transfer half of the chopped amount into a small bowl
3. Heat the chocolate bowl in the microwave in intervals of 5-10 seconds (depends on the power of the microwave). 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 bring the temperature down to around 93°F.
5. Reheat the chocolate bowl again for another 5 seconds and mix until all the chocolate is melted.
6. Spread the chocolate onto the parchment paper and let it solidify

Observations: What happened when you tried this experiment?

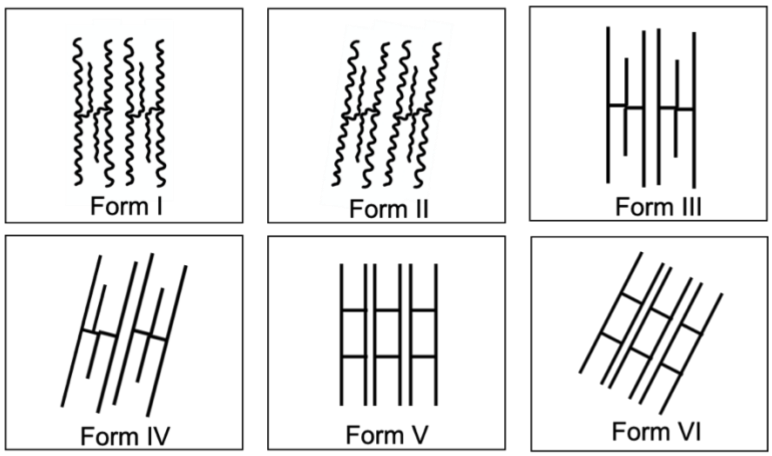
Take a picture and tag us at @SustainableNano on Twitter or Instagram!

Here is what we observed; did you see the same thing?

- Sample 1 (non-tempered) 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
- Sample 2 (tempered) has smooth texture and is shiny. It hardened pretty quickly and does not melt when touched with your hand. It has a crisp snap when broken.

Explanation

Once the chocolate is melted, sample 1 solidifies, forming any of the 6 polymorphs of cocoa butter:



In sample 2, on the other hand, the added solid chocolate acts as “seeds,” a template for the chocolate to solidify into form V, the most orderly crystal structure. The mixture is then gently heated again, melting any other polymorphs resulting in “tempered chocolate”:

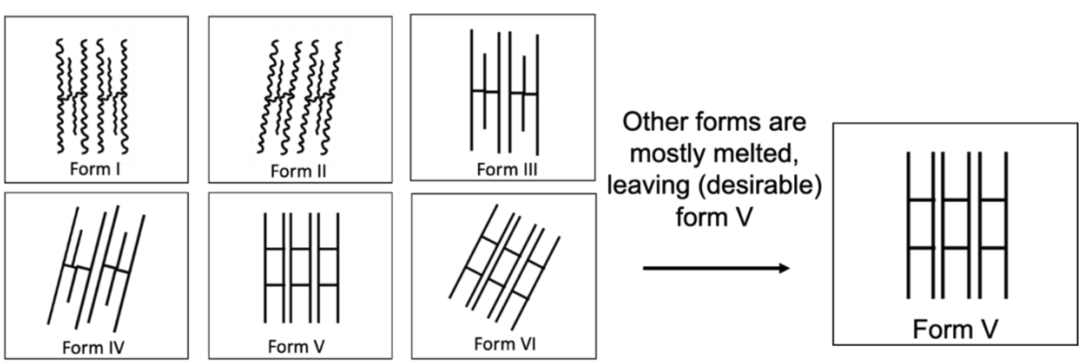


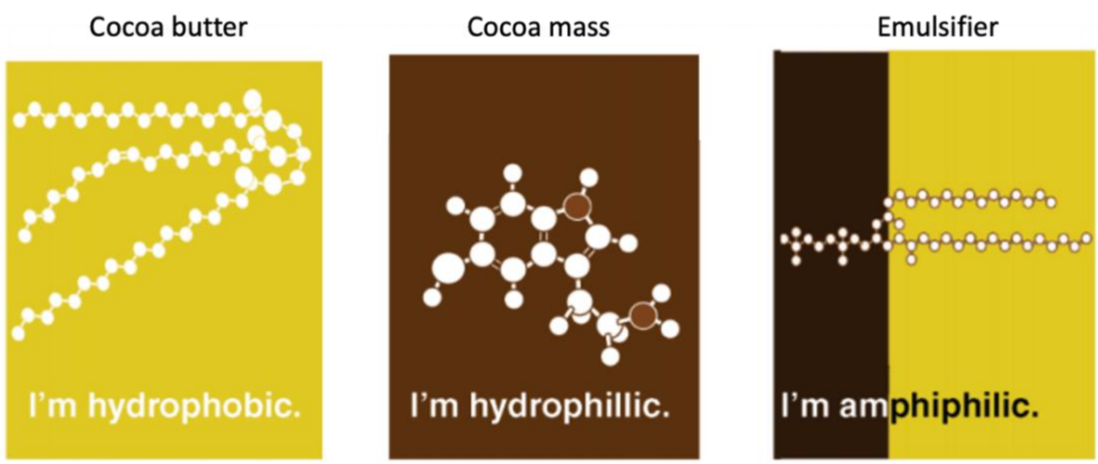
Illustration of different cocoa butter polymorphs (not exact)

Take a closer look:
Check out the YouTube video at https://youtu.be/p5_kheJtQO4 for a great tutorial about tempering chocolate. From 1:50-2:20, they show another demonstration using LEGO bricks and ice cubes.

Main takeaways:

- Cocoa butter in chocolate can stack in different ways leading to different crystalline forms.
- Form V is most desirable in chocolate making, which can be achieved by manipulating temperature at which the melted chocolate is cooled—the process of tempering—to form good chocolate with a 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 in the figure below, we represent cocoa butter as a triglyceride (fat) molecule, which is largely hydrophobic (water-repelling); cocoa mass as a mixture of a serotonin molecule, which is largely hydrophilic (or water-loving); and the emulsifier as lecithin, which is amphiphilic (has both water-loving and water-repelling parts).



Major ingredients in chocolate presented in molecular forms showing their affinity for water [image from Rowat, A.C., J. Chem. Educ., 2011, 88, 1, 29-33, used with permission from the American Chemical Society]

The cocoa powder we use for baking is indeed hydrophobic, so why doesn't chocolate stay clumpy or grainy but instead has a smooth texture in our mouth? That is when the emulsifier comes in to save the day! Because an emulsifier has both hydrophobic and hydrophilic parts, it can protect the hydrophilic molecules of the mixture from the hydrophobic phase and the hydrophobic molecules of the mixture from the hydrophilic phase, forming what's called an emulsion. The emulsifier allows us to mix components that normally don't mix, which leads us to our next experiment.

Experiment 2: Forming an emulsion (Age 3+)

Materials:

- Oil
- Water
- Soap (or egg yolk as an alternative)
- Emptied water bottle with a cap

Directions:

1. Place some water in the bottle.
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 or egg yolk to the bottle.
6. Shake the bottle to mix.
7. Observe if the two layers mix.

Observations: What happened when you tried this experiment?

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Here is what we observed; did you see the same thing?

- We observed that the two layers are now not two layers anymore — we have formed an emulsion!

Explanation:

- In this experiment, oil is hydrophobic, so by itself it does not mix with water. But soap or egg yolk is an emulsifier, so when combined with the oil it allows the oil and water to mix!

Experiment 3: Rescuing seized chocolate!

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

Materials:

- Dark chocolate bar (>70% cacao works best; chocolate chips do not work very well)
- Candy/cooking thermometer (if you don't have one, just make sure the chocolate is thoroughly melted)
- Cutting board and knife
- Small microwave-safe bowls
- Microwave

Directions:

1. Chop up about 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 intervals of 5-10 seconds (depends on the power of 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.

Observations: What happened?

Here is what we observed: We saw that 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 to stir the mixture. The mixture will become shiny again. Although you can't return 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. (Note: you might have to add more water than you think! Just keep slowly adding more until the chocolate gets shiny again.)

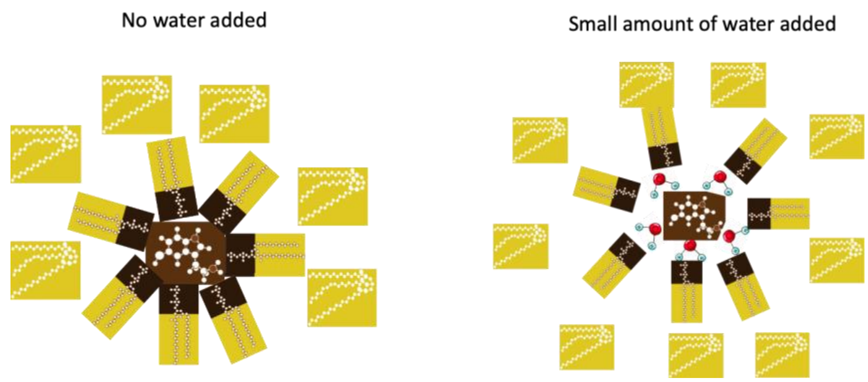
Observations: What happened when you tried this experiment?

Here is what we observed; did you see the same thing?

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

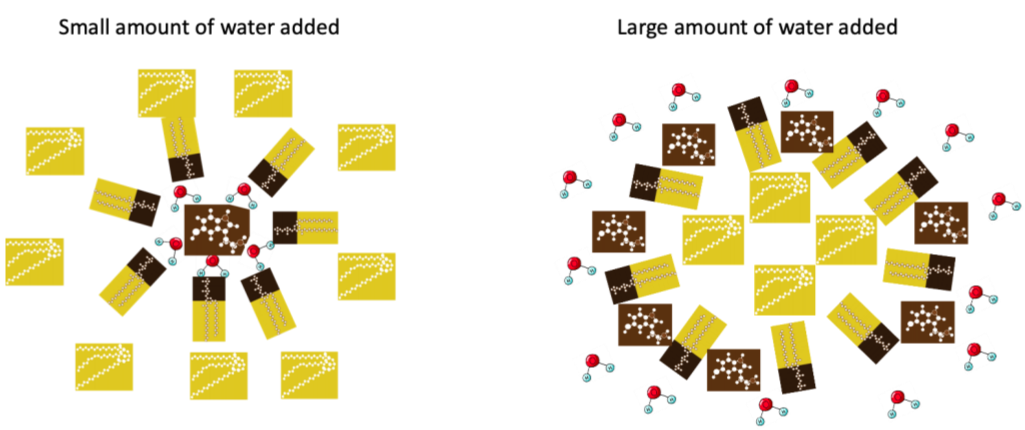
Explanation:

- Chocolate has a smooth texture when melted due to the presence of an emulsifier, keeping the sugar (hydrophilic or water-loving) dispersed in cocoa butter (continuous oil phase, hydrophobic or 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 like to mingle, resulting in something similar to the "sugar bowl effect" in which the sugar granules lump together when they get wet. 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.



Chocolate that is not seized (left) and after it has seized (right) [image adapted from Rowat, A.C., J. Chem. Educ., 2011, 88, 1, 29-33, used with permission from the American Chemical Society]

Although the seized chocolate cannot be returned to its original state, the smooth texture can be gained back by adding more water. That's because the emulsion is now inverted: the cocoa butter, which was the continuous oil phase, is now dispersed in the continuous water phase instead of the other way around.



Seized chocolate (left) and rescued chocolate (right) [image adapted from Rowat, A.C., J. Chem. Educ., 2011, 88, 1, 29-33, used with permission from the American Chemical Society]

Main takeaways:

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

Experiment 4: Holographic chocolate (Ages 5+)

In this experiment we will make some edible art! Use the same materials and procedure the for making tempered chocolate (experiment 2), but this time you will recrystallize the chocolate on diffraction grating films instead of parchment paper.

Diffraction grating is a plastic or glass sheet with very close parallel ridges or ruling. For example, we used a film with 13,500 lines per inch, which costs about $10 for a 6-by-12-inch sheet.* You only need a piece big enough for spreading your melted chocolate!

Directions:

1. Cut the grating film into any shape and size that you want your chocolate to be.
2. Place the grating film onto the parchment paper with the "grooved" side facing up. (To figure out which side contains the grooves, scratch each side gently with your fingernail. If you hear a high-pitched noise, that's the side with the grooves.)

Repeat the process of tempering chocolate (see experiment 2):

3. Chop up ¼ of the chocolate bar into small pieces
4. Transfer half of the chopped amount into a small bowl
5. Heat the chocolate bowl in the microwave in 5-10 seconds intervals (depends on the power of the microwave, small intervals are recommended). Stir the mixture as needed.
6. 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 bring the temperature down to around 93°F)
7. Reheat the chocolate bowl again, for another 5 seconds until all the chocolate is melted.
8. Spread the chocolate onto the grating film on top of the parchment paper and let solidify.
9. Peel off grating and see how your chocolate diffracts light!

Observations: What happened when you tried this experiment?

Take a picture and tag us at @sustainablenano on twitter or Instagram!

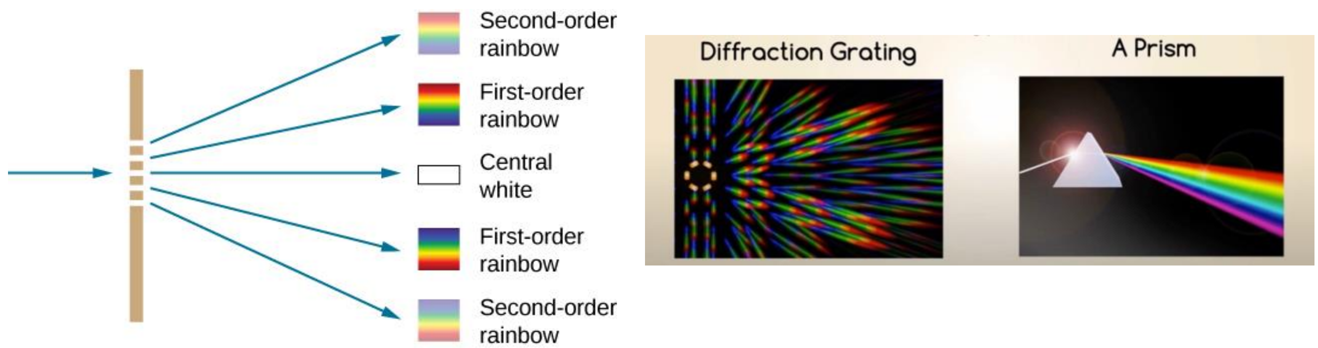
* https://www.amazon.com/gp/product/B00SK3S6BY/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&th=1

Here is what we observed; did you see the same thing?

- Once the chocolate solidifies, you should now have shiny and colorful chocolate that is still just as tasty as before!

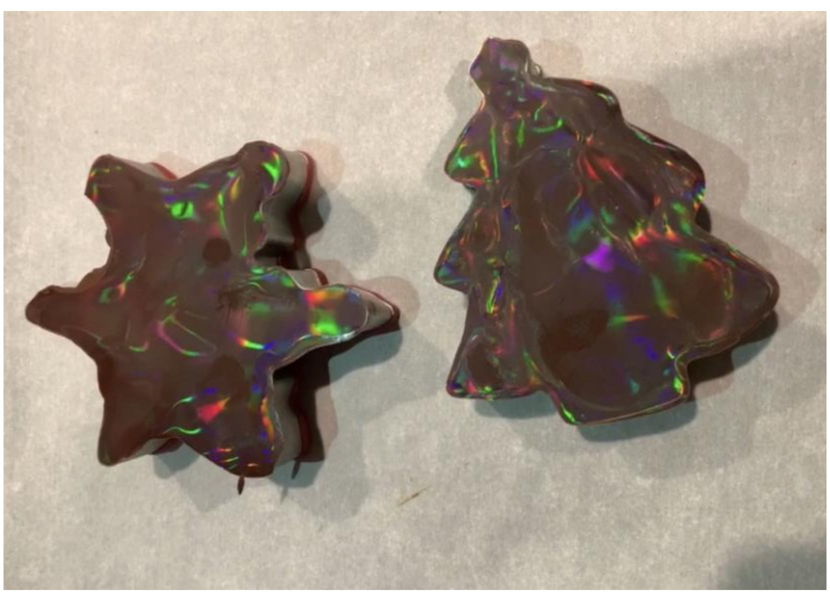
Explanation:

- The holographic effects come from the tiny grooves from the grating film that get imprinted onto the chocolate as it solidifies. This roughness bends the light at many different angles as it bounces off the surface – this is known as diffraction.



White light passing through diffraction grating/prism and the obtain pattern [lightforminc.com]

The angle at which the light bends is proportional the wavelength of light, hence violet light will bend more than red light because, in the visible wavelengths of the electromagnetic spectrum, red has the longest wavelength and violet has the shortest wavelength. The different amount of bending caused by the roughed surface gives the chocolate holographic colors.



Holographic chocolate using 1/2 bar of chocolate and molded with cookie cutters

Do you still have chocolate left over or other types of chocolate in the house? Here's one more experiment you can do:

Experiment 5: Does all chocolate have the same melting temperature?

Materials:

- Two or more ¼ bars of chocolate of different % cacao
- Small oven-safe bowls
- A baking tray filled halfway with water
- Timer
- Stovetop or oven

Directions:

1. Predict (make a hypothesis) based on what you have learned about chocolate science: do you think chocolate with different percentages of cacao will melt faster or slower? Why?

Prediction:

2. Use ¼ of a bar of chocolate for each type - keep the size and weight the same for all samples as much as possible.
3. Transfer chocolate to small bowls and label % of cacao for each sample (make a chart if you're worried about your labels burning!)
4. Place the bowls in the water tray and start heating the tray (oven or stovetop can work; the goal is to melt all the chocolate evenly)
5. Start the timer and record the time it takes to fully melt the chocolate samples.
6. Compare your results and hypothesis.

Observations: What happened when you tried this experiment?

Here is what we observed; did you see the same thing?

- Our darker chocolate melted faster than our lighter chocolate.

Explanation:

- Having a higher content of fat (cocoa butter) will make chocolate melt faster, so chocolate with a higher percent of cacao generally melts faster. But if white chocolate or milk chocolate are added to the mix, it is hard to predict which will melt faster.