ALETHEIA
The Alpha Chi Journal of Undergraduate Scholarship

Volume 1 | Issue 1 | 2016

Sweet Chemistry:
A Study of the Intermolecular Forces in Candy Dye Molecules

Kara E. Paden

Cumberland University
Tennessee Lambda Chapter

Sarah S. Pierce, PhD.

Vol. 1(1) 2016
Article Title: Sweet Chemistry: A Study of the Intermolecular Forces in Candy Dye Molecules
DOI: 10.21081/ax0015
ISSN: 2381-800X
Key Words: Carnuba Wax, Dye Molecules, Food Chemistry, Intermolecular Forces, Solvent Interactions
This work is licensed under a Creative Commons Attribution 4.0 International License.
Author contact information is available from the Editor at editor@alphachihonor.org.

Aletheia—The Alpha Chi Journal of Undergraduate Scholarship

- This publication is an online, peer-reviewed, interdisciplinary undergraduate journal, whose mission is to promote high quality research and scholarship among undergraduates by showcasing exemplary work.
- Submissions can be in any basic or applied field of study, including the physical and life sciences, the social sciences, the humanities, education, engineering, and the arts.
- Publication in *Aletheia* will recognize students who excel academically and foster mentor/mentee relationships between faculty and students.
- In keeping with the strong tradition of student involvement in all levels of Alpha Chi, the journal will also provide a forum for students to become actively involved in the writing, peer review, and publication process.
- More information and instructions for authors is available under the publications tab at www.AlphaChiHonor.org. Questions to the editor may be directed to editor@alphachihonor.org.

Alpha Chi is a national college honor society that admits students from all academic disciplines, with membership limited to the top 10 percent of an institution's juniors, seniors, and graduate students. Invitation to membership comes only through an institutional chapter. A college seeking a chapter must grant baccalaureate degrees and be regionally accredited. Some 300 chapters, located in almost every state, induct approximately 12,000 members annually. Alpha Chi members have been "making scholarship effective for good" since 1922.

Volume 1 | Issue 1 | Spring 2016

Article Title: Sweet Chemistry: A Study of the Intermolecular Forces in Candy Dye Molecules
DOI: 10.21081/ax0015
ISSN: 2381-800X

ALETHEIA
The Alpha Chi
Journal of
Undergraduate
Scholarship

Sweet Chemistry:
A Study of the Intermolecular Forces in Candy Dye Molecules

By Kara E. Paden
and Sarah S. Pierce, PhD.

Abstract

Different temperatures and solvents were used to test the interactions of candy coatings using Everlasting Gobstoppers®, M&M's®, and Skittles®. The carnauba wax that coats the Gobstoppers® and Skittles® did not play a significant role in the dissolving rates of the candy dyes. Furthermore, the different dyes from the candy coating did not mix over time but formed layers. When the food dyes alone (not on candy) were tested in water, they mixed over time. Different solvents were used to test the intermolecular forces of the dye molecules. Nonpolar and polar aprotic solvents had no effect on the candy coating dyes, but polar protic solvents caused the dyes to dissolve off the candies and form layers, while still not mixing. Ethanol, however, was a polar protic solvent that had no effect on the candy coating due to the higher pH value. When salt water was used as the solvent, the formation of micelles was observed.

Key words: Carnuba Wax, Dye Molecules, Food Chemistry, Intermolecular Forces, Solvent Interactions

Steve Spangler has become famous doing hundreds of different science experiments, making science fun for all ages. One of his more well-known experiments is done by dissolving four different colored Gobstoppers® in a petri dish (Spangler, 2015). When the colors dissolve of each Gobstopper®, the colors do not mix with the water but settle to the bottom. The color dyes also do not mix together, but form barriers between one another within the dish (Figure 1). However, Spangler gives little explanation about why the colors do not mix. The purpose of this paper is to investigate why the colors do not mix over time.

Figure 1: Steve Spangler's Color Mixing Gobstoppers® experiment

Intermolecular forces are the attractions or repulsions between neighboring molecules. London dispersion forces are the weakest of all the intermolecular forces of attraction (Brown, et al., 2012). These attractions occur when two nonpolar molecules form temporary dipoles between molecules. The larger the molecule, the more electrons the molecule will have to form London dispersion attractions. The more London dispersion forces present, the higher the melting point will be (Campbell & Farrell, 2012). Dipole-dipole interactions are another type of intermolecular force between two partially charged particles. A specific type of dipole-dipole interaction is hydrogen bonding. Hydrogen bonds occur between hydrogen molecules and molecules of either oxygen, fluorine, or nitrogen. The last of the intermolecular forces is ion-dipole bonds, which occur between an ion and a molecule with a dipole (Ebbing & Gammon, 2009). The strongest intermolecular force is ion-dipole bonds, followed by hydrogen bonds, dipole-dipole bonds, and London dispersion (Bruice, 2014).

These different intermolecular forces play a role in the properties of different solvents. Polar solvents contain components that have different electronegativities (such as oxygen and hydrogen), meaning they have partial charges (Ebbing & Gammon, 2009). Following the "like dissolves like" rule for chemistry, polar solvents will only dissolve other polar molecules such as salts including the food dyes (Brown, et al., 2012). There are two different types of polar solvents, protic and aprotic. Aprotic solvents are solvents that do not have hydrogen bonds while protic solvents can participate in hydrogen bonding (Campbell & Farrell, 2012).

Carnauba wax comes from the leaves of the *Copernicia prunifera* palm tree grown exclusively in Brazil. Carnauba wax is nearly insoluble, with a high melting point of 187°F (86.1°C) (Milanovic, J., Manojlovic, V., Levic, S., Rajic, N., Nedovic, V., & Bugarski, B., 2010). This wax is a nonpolar substance, meaning that the main force of attraction is London dispersion forces (Milanovic, J., Manojlovic, V., Levic, S., Rajic, N., Nedovic, V., & Bugarski, B., 2010). It consists of cinnamic acid based mono- and di-esters, free wax acids, free wax alcohols, lactides, hydrocarbons, and resins (Endlein & Peleikis, 2011). Carnauba wax is a non-toxic, renewable resource. It is used for many household items, such as mascara, lipstick, deodorant, and furniture polish. Among these, carnauba wax is also the coating that goes on many candies such as Nerds®, Skittles®, Everlasting Gobstoppers®, and Double Bubble® gum to keep the color coating from melting in people's hands. Underneath the carnauba wax are the synthetic dyes that give the candies' color. The dyes that are used to coat the Everlasting Gobstoppers®, M&M's®, and Skittles® are Blue 1, Blue 2 Lake, Red 40 Lake, Yellow 5, Yellow 5 Lake, and Yellow 6 (Kobylewski, S., & Jacobson, M. F., 2010).

Some food dyes used in this experiment are water soluble salts. They each contain a sulfonic acid group that has been neutralized which is what makes each dye easily dissolvable in water. The lake dyes, however, are water insoluble. These types of dyes (lake dyes) are made by combining dyes and salts to get an insoluble compound that is much more stable and versatile (Field, 2008). The primary intermolecular forces of the color dyes used in this experiment are ionic bonds and hydrogen bonds (Rohrig, 2015). The lake dyes contain fewer ionic and hydrogen bonds, and contain more nonpolar interactions than the water soluble dyes. The purpose of these experiments was to determine if carnauba wax was responsible for the segregation of dye color and to gain a better understanding of the intermolecular forces involved in candy coating.

Experimental Procedures

Temperature Variance:

To begin testing the chemical composition of the candy coating on Gobstoppers®, the five different colored candies were submerged in mini petri dishes in room temperature distilled water (30.0mL at 13.3°C). This experiment was repeated with water at 43.3°C, 71.1°C, and 100°C. Each experiment was repeated three times.

Table 1: Average time the color on each Gobstopper® took to dissolve

	13.3° C	**43.3° C**	**71.1° C**	**100° C**
Purple	277 sec.	72 sec.	29 sec.	29 sec.
Red	323 sec.	157 sec.	39 sec.	46 sec.
Yellow	334 sec.	121 sec.	43 sec.	41 sec.
Orange	395 sec.	161 sec.	52 sec.	67 sec.
Green	710 sec.	190 sec.	68 sec.	59 sec.

An experiment was conducted to determine how the dyes would react when dissolved in the same dish together. The five different Gobstoppers® were submerged in 85.0 mL of room temperature (13.3°C) distilled water in a large petri dish. The candies were placed equidistance apart at the edges of the dish. This experiment was repeated with different water temperatures of 43.3°C, 71.1°C, and 100°C.

Effects of carnauba wax:

Experiments were performed on Skittles® and M&M's® to compare the effects of carnauba wax versus no wax. For this experiment, 60.0 mL of room temperature distilled water was used to submerge the five different colored candies of each in separate, large petri dishes. Observations were made over a 20 minute period, and three consecutive trials were done. After each candy had been tested, a separate trial was done following this same manner using regular food dyes of red, green, yellow, and blue.

Solvent effects:

After testing the effects of candy coating in water (polar protic solvent), the effects of different solvents (nonpolar, polar aprotic, and polar protic) were tested. The same procedures were followed as before using hexane, acetone, ethanol (95% denatured with isopropyl alcohol and methanol), acetic acid (17.4 M) and salt water. All of the solvents used were obtained from Flinn Scientific. The salt water composition was made by dissolving 8.0 grams of NaCl into 80.0 mL of room temperature distilled water. Each of the three candies was tested by submerging the five different colored candies within the same petri dish over a 20 minute period. The pH was taken of each of the polar protic solvents (Table 2).

Table 2: pH of polar protic solvents

Solvent	pH
Deionized water	4.5
Acetic acid	2.5
Ethanol	5.5

Results and Discussion

To determine the effect of carnauba wax, several experiments using different temperatures and solvents were performed. The melting point of carnauba wax is 187°F (86.1°C) (Milanovic, J., Manojlovic, V., Levic, S., Rajic, N., Nedovic, V., & Bugarski, B., 2010). That, combined with the fact that molecules move faster at higher temperatures, led to the hypothesis that if the wax were the cause of the colors not mixing, the colors would mix at higher temperatures. In each trial with the individual Gobstoppers® submerged at different temperatures, the results of how quickly each color dissolved generally followed the same pattern (Figures 2 through 6). Each time, the purple colored Gobstopper® dissolved the fastest. Yellow and red both dissolved around the same time, while the yellow Gobstopper® averaged a faster dissolving rate the more the temperature was increased (Figures 2 and 4). The green Gobstopper® took the longest to dissolve until the last trial with the temperature right at boiling. The orange took the longest to dissolve in this trial with just over one minute (Table 1). As the color dye dissolved off of each Gobstopper®, the dye settled to the bottom and formed an immiscible layer that did not mix.

Figure 2: Dissolving rates of the red Gobstopper® over four different temperatures.

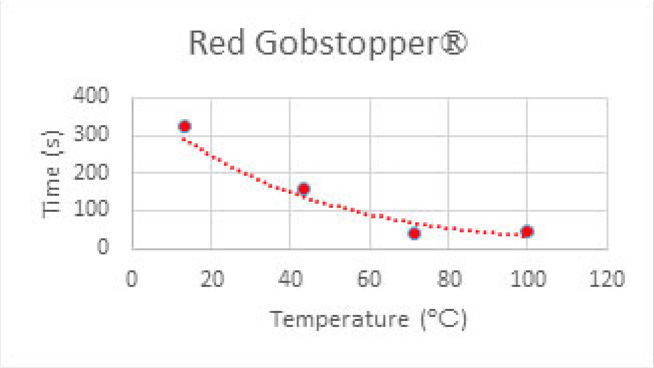


Figure 3: Dissolving rates of the orange Gobstopper® over four different temperatures.

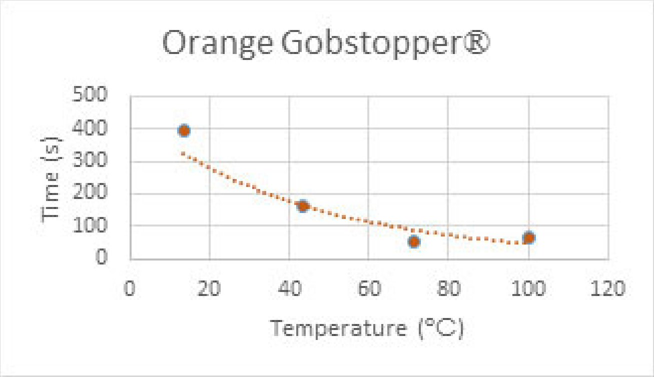


Figure 4: Dissolving rates of the yellow Gobstopper® at four different temperatures.

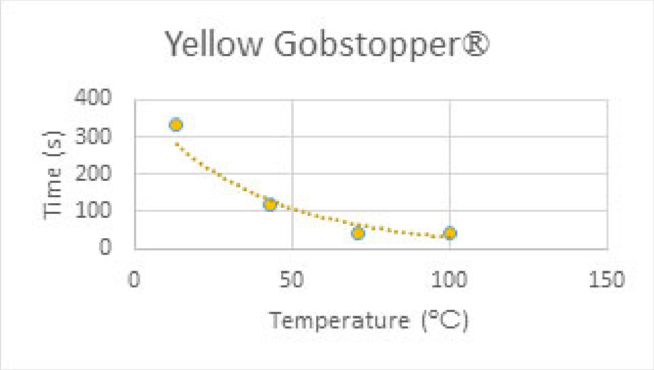


Figure 5: Dissolving rates of the green Gobstopper® at four different temperatures.

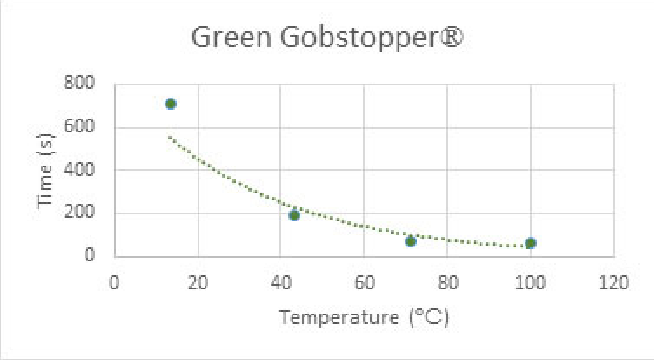
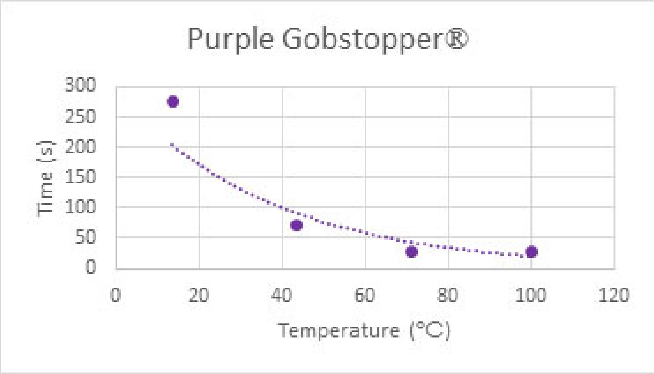


Figure 6: Dissolving rates of the purple Gobstopper® at four different temperatures.



The results for the temperatures at 71.1°C and 100°C were very similar in the rates that each Gobstopper® dissolved, with red desolving at 39s and 46s, yellow at 43s and 41s, orange at 52s and 67s, green at 68s and 59s, and purple at 29s for each of the two trials of 71.1°C and 100°C, respectively. A few of the candies (red and orange) even increased their time in how fast the color coat dissolved, with red increasing from 39s to 46s and orange increasing from 52s to 67s (Figures 2 and 3). This result was not as expected and did not support the original hypothesis that the carnauba wax played a key role in the dissolving rates of the dyes. The melting point of carnauba wax is 86.1°C, which falls almost exactly between 71.1°C and 100°C (Endlein & Peleikis, 2011). If carnauba wax played a large role in the temperature effect of how quickly the dyes dissolved, then there should have been a difference in the dissolving rates of each candy after 86.1°C had been reached. Instead, the results remained relatively similar between the trials at 71.1°C and 100°C.

The components of the wax, combined with the bonds and intermolecular forces of the sugars and dyes, could have contributed to this similarity in the results of the two temperatures, 71.1°C and 100°C. Sugar readily dissolves in water, and most of the dyes used were water soluble. The combination of these two components having the ability to dissolve in water could have led to the breakdown of the carnauba wax as well. The intermolecular forces of the water binding with the dyes and sugars (dipole-dipole) could have been stronger than the forces holding the wax together (London dispersion). This could have led to the breakdown of the wax, causing the two sets of results to be similar.

When the trials were completed with the five Gobstopper® candies in a single petri dish at different temperatures, the results did not support the claim that over time the colored dyes would mix together. At room temperature, the color had completely dissolved off of each candy after 10 minutes. As the temperature was increased in each trial, it took less time for the dyes to dissolve off of the candies, with all the color dissolving in the first minute for the candies put in water at 100°C. As each color coating dissolved, they formed separate “pie pieces” around the dish, similar to Steve Spangler’s experiment. As time continued, the dyes broke their color barriers and bled over onto each other. However, as the barriers were broken, the dyes still formed layers one on top of the other instead of mixing together as to be expected. Even as the temperature was increased throughout the different trials, the layering of the colors was still observed.

Another phenomenon noticed in each of these experiments was that the dyes settled to the bottom of the dish. The food dyes are water soluble, so they would be expected to mix with the water. One theory was that a partial insolubility occurred. The wax was insoluble, but most of the dyes were water soluble. Combined together they could have led to a partial solubility where the dyes dissolved off the candy, but did not mix with the water. However, this same experience was observed in the M&M's®, which do not have carnauba wax on them. Therefore, carnauba wax does not seem to affect how the dyes mix. Instead, the lake dyes used may play a role in the insolubility of the dyes. Even though a large percentage of the dyes were soluble in water, the lake dyes, such as Blue 2 Lake, Red 40 Lake, and Yellow 5 Lake, were insoluble and which could have contributed to the overall insolubility of the substances (Field, 2008). The lake dyes could also have contributed to the different colored dyes not mixing together but instead forming layers.

As the temperature of the solvent increased, the candy center of the gobstopper began to dissolve. With the trials done at 100°C, the entire sugar center dissolved. The more sugar that dissolved, the wider the band of dye became in the immiscible layer underneath the water. The top of the dish still contained the pure water that had not been mixed, but the bottom layer of dyes became thicker and had less vibrant color as the sugar content increased. This could be due in part to the binding properties of each dye as they mixed with the sugar. As the sugar content in the water increased, the hydrogen bonds between the water and dyes seemed to increase, causing the band of dye to expand. The dyes began to form intermolecular bonds with the sugar water, and the colors were not as vibrant, but the higher sugar concentration stayed settled to the bottom of the dish. From this observation, it would seem that sugar acts as a type of medium by disrupting the bonds between the dye molecules themselves and forming new ones between the dye and the water. Even after being stirred with a glass stirring rod, the colors did not mix together nor form new color combinations.

In the trials comparing the Skittles® (which were coated in carnauba wax) with the M&M's® (which contained no wax), much of the same phenomena was observed as with the Gobstoppers®. As the coating dissolved off of the candies, both the Skittles® and M&M's® formed barriers between each color instead of mixing. Similar to the Gobstoppers®, the dyes in each did not mix to form new colors but formed layers on top of each other. This indicates that the carnauba wax is not responsible for the separation of colors.

Both candies also formed an immiscible layer on the bottom of the dish separate from the water. With the Skittles®, the dye dissolved to the bottom and formed rays while the M&M's® dissolved to the bottom in an evenly distributed layer (Figure 7). As the dyes of the Skittles® dissolved, the sugar center also began to disintegrate slightly. This, along with the carnauba wax, could contribute to the different pattern of dissolving in the M&M's® and the Skittles®. The Skittles® have a sugar center and are coated in carnauba wax. Carnauba wax is insoluble in water while sugar can dissolve. These two components would contribute to the dissolving pattern of the dyes on each skittle and could lead to the formation of the ray pattern. M&M's®, however, have a chocolate center and are not coated with carnauba wax. Chocolate would not dissolve in water, and without the carnauba wax playing a factor, the dyes could dissolve into an evenly distributed layer along the bottom of the dish.

Figure 7: Left-M&M's® and Right-Skittles® submerged in distilled water at 13.3°C

To test if the separation of color was due to the shape of the petri dish, water soluble food dyes were investigated. When the water-soluble color dyes were dropped into a petri dish together, the colors quickly mixed. These dyes also mixed with the water. These results were conclusive with what was to be expected, as all these dyes were water soluble with no other factors playing a role such as sugar or wax. This also indicates that the shape of the petri dish was not responsible for the separation of colors observed in the candy experiments.

The next part of the experiment tested different solvents with each of the three candies. A non-polar solvent (hexane), polar aprotic (acetone), and polar protic (acetic acid and ethanol) solvents were tested. When hexane, acetone, and ethanol were used to submerge the three candies, no reaction occurred, as expected. No reaction was expected with hexane, a non-polar solvent, because neither dipole-dipole nor hydrogen bonding could take place. This also explains why acetone, a polar aprotic solvent, resulted with no reaction when the candies were placed in the solvent even though the dyes are polar. Because it was a polar aprotic solvent, no hydrogen bonds could take place. From this, it can be concluded that hydrogen bonding is necessary for the candy coating to dissolve off the candies. When acetic acid was used, the candy dissolved similarly to the experiments in water. Water, like acetic acid, is also a polar protic solvent. Acetic acid dissolved the candy coating off the candies because it contained all of the same necessary components as water to form the necessary bonds (hydrogen bonds) to dissolve the coating. Following this hypothesis, ethanol should have reacted the same way as the acetic acid since it is also a polar protic solvent. Instead, ethanol showed no reaction with the candies and no coating was dissolved. This could be due to the fact that ethanol had a higher pH than the other polar protic solvents used, acetic acid and water. Acetic acid had a pH of 2.5, water had a pH of 4.5, and ethanol was the least acidic with a pH of 5.5 (Table 2). The pKa of the dyes used was approximately 5 (Levitan, 1977). In relation to the pH of the polar protic solvents used, acetic acid and water both had a pH that was less than the pKa value of the dyes. This indicates that the water and acetic acid used were more acidic than the dyes, and the dyes were still present in their acidic state. Ethanol was the only polar protic solvent used that had a pH higher than the pKa of the dyes. When the pH is one unit higher than the pKa value, the ratio of the conjugate base to the conjugate acid is 10:1. Ethanol was 0.5 units higher than the pKa of the dye, indicating that the base to acid ratio was 3.16 with more base present than the other solvents used (Campbell & Farrell, 2012). This means that the ethanol would not have dissociated the polar components of the candies and their dyes.

The last experiment tested the effects of adding sodium chloride (NaCl) to the water solution in which the candies were placed. With the M&M's®, the dyes dissolved just as before in the water. The colors settled to the bottom, and little mixing occurred between the color barriers. The Gobstoppers® and Skittles® initially dissolved similarly to the previous trials with the pure water, forming barriers between each color and all the dyes settling at the bottom of the dish. However, grainy dye particles began to float on the surface of the water of both candy dishes as time passed (Figure 8). The phenomenon that occurred appeared to be similar to the structure of micelles. Micelles are spherical structures that have a polar head on the outside acting as a barrier, which can come into contact with the water (or polar) solvent. The nonpolar portion of the structure is sequestered in the interior of the particle (Campbell & Farrell, 2012). Since the carnauba wax that coats the Gobstoppers® and Skittles® is nonpolar and insoluble in water, the micelle can attach to these molecules and force the hydrophobic portion inward while the hydrophilic portion of the micelle will come into contact with the water (Bruice, 2014). The main function of the dyes in this reaction (since they are water soluble) was to make this process visible.

Figure 8: Micelle formation

Conclusion

The higher the temperature of the solvent, the faster the candy coating dissolved, regardless of whether the carnauba wax was present. Carnauba wax played a small role in the dissolving patterns of the coatings. However, the dyes of the candies separated regardless of the carnauba wax content. Therefore, carnauba wax is not responsible for the color separation. The different colors of the dyes did not mix together and form new colors over time.

When different solvents were tested, no effects were observed with hexane (nonpolar) and acetone (polar aprotic), but acetic acid (polar protic) dissolved the dyes similar to that of water. This was to be expected because polar protic solvents are the only solvents to have both dipole-dipole and hydrogen bonds, which are needed to dissolve the food dyes. However, ethanol (a polar protic) showed no reaction with the dyes due to the higher pH level. Micelles were observed when candies were placed in salt water if carnauba wax was present. From Steve Spangler's experiment of watching Gobstoppers® dissolve to dissolving candies in different solvents, a better understanding of the intermolecular forces in the dyes of candy coating was obtained through these experiments.

Works Cited

Brown, Lemay, J., Bursten, Murphy, Woodward, & Stoltzfus. (2012). *Chemistry The Central Science* (13th ed.). Pearson.

Bruice, P. Y. (2014). *Organic Chemistry* (7th ed.). Pearson.

Campbell, M. K., & Farrell, S. O. (2012). *Biochemistry* (8th ed.). Cengage Learning.

Ebbing, & Gammon. (2009). *General Chemistry* (9th ed.). Houghton Mifflin Company.

Endlein, E., & Peleikis, K. (2011). Natural Waxes- Properties, Compositions, and Applications. *SOFW- Journal*.

Field, S. Q. (2008). Why There's Antifreeze in Your Toothpaste. Chicago: Chicago Review Press, Incorporated.

Kobylewski, S. &. (2010). *Food Dyes: A Rainbow of Risks.* Center for Science in the Public Interest.

Spangler, S. (2015, October). *Color Mixing Gobstoppers- Candy Science.* Retrieved from Steve Spangler Science: http://www.stevespanglerscience.com/lab/experiments/gobstopper-science/

Milanovic, Manojlovic, Levic, Rajic, Nedovic, & Bugarski*. (2010). *Microencapsulation of Flavors in Carnauba Wax.* Sensors.

Rohrig, Brian. (2015). *Eating with Your Eyes: The Chemistry of Food Colorings*. ChemMatters. October 2015. American Chemical Society.

Levitan, Herbert. (1977). Food, drug, and cosmetic dyes: *Biological effects related to lipid solubility.* Cell Biology. Proc. Natl. Acad. Sd. USA