Teacher's Guide

Ice cream Break with Nanoscience: Nucleation and Colloid Suspensions

Grade Level: Middle and high school; Undergraduate

Subject area(s): Physical science; chemistry

Time required: two 55 minute lab periods

Learning Objectives: Through observation and interaction students will: learn about colloids; nucleation; and crystal formation.

Summary: Though simple in ingredients, ice cream is actually a complex mixture that consists of multiple-phases. The structure of these phases and how they come together in a synergistic effect has a significant impact on the characteristics of ice cream and thus, the taste and enjoyment of ice cream. For this activity, liquid nitrogen is used to cool a mixture of cream, sugar, and vanilla flavoring at such a rapid rate that nano-sized ice crystals form. This method of making ice cream will be compared to both a traditional way of making ice cream in a freezer and with an ice cream ball by "mouthfeel."

Purpose: This exercise is designed to demonstrate how liquid nitrogen cools a mixture at such a rapid rate that it precipitates extremely fine ice crystals from a homogeneous mixture of cream and other ingredients. It is also designed to show how ice cream can be made smoother and creamier through nano-sized particles.

In this activity, ice cream will be created via three distinct methods and students will investigate how decreasing ice crystals affect the feel of ice cream in the mouth. Probably the most important step in ice cream making is the freezing step because it is the manufacturing step that affects the size of the crystals that develop throughout the ice cream mixture. Through this lab, students will learn about a colloid solution, which is where a substance is microscopically or nanoscopically dispersed throughout. In addition to exploring different production methods for a popular consumer good, they will also review concepts of thermodynamics, specifically freezing point depression and heat of fusion. They will also develop thinking skills for laboratory work, develop their ability to apply knowledge in practice, and improve their ability to conduct independent observations, frame a research problem, draw conclusions from their own observations, and generalize.

Pre-requisite Knowledge: Students should have an understanding of solutions, mixtures, and colloids as well as good lab techniques and measurement skills.

Background Information: Nanotechnology is the manipulation of matter at the atomic or molecular level. When methodologies and industrial processes are being developed, both low cost materials and methods are desired, while still allowing for the precise manipulation of matter. There have been countless breakthroughs in a wide variety of industries thanks to

Development and distribution funded by the National Science Foundation

nanotechnological advances, including medicine, electronics, biomaterials, energy production, optics, and even ice cream making! And while ice cream is something that has been enjoyed since 400 B.C., considerable changes in the manufacturing of ice cream have happened even in the last few years.

Traditionally, ice cream was made by freezing a homogeneous mixture of cream, sugar, and flavoring. While water isn't necessarily an obvious ingredient in this mixture, it does account for 80-90% of milk that the cream is derived from. As such, water comprises a large portion of the cream. So when cooling the mixture to sub-freezing levels to make ice cream, a person is literally making "iced cream," though this is easy to forget with the current commercially available ice cream. Upon freezing, water expands due to the hydrogen bond network (i.e. the extensive network of hydrogen-bonding that occurs intermolecularly). The slower the freezing happens, the more time that is allowed to have the hydrogen bonds to form and the larger the ice crystals that form. Figure 1 shows how a slower method of freezing (left) results in many more large ice crystals in an ice cream mixture than a more rapid freezing method (right). The ice crystals can actually be felt quite easily with the mouth and a reduction of ice crystals is desired to give ice cream that creamy "mouthfeel" that so many consumers prefer, whereas mouthfeel is a product's physical and chemical interaction in the mouth.

Ice crystallization has two distinct phases: first one is nucleation and the second is crystal growth. Nucleation is driven by both thermodynamics and kinetics. The thermodynamic piece of nucleation is twofold. The first is surface formation (i.e. "a seed" or "nuclei") and the second is volume transition (i.e. changing phases typically results in a change in volume). To produce smaller crystal sizes for a creamier texture, the rate of freezing must be increased significantly so that the extensive hydrogen bonding by the water molecules is avoided, which is the crystallization. It also promotes nuclei formation, which is a necessary step in nucleation and ice crystal growth happens as soon as nucleation has begun. The crystal formation in the creamy mixture that is ice cream, results in a colloid solution, a solution where solid particles are equally dispersed throughout.

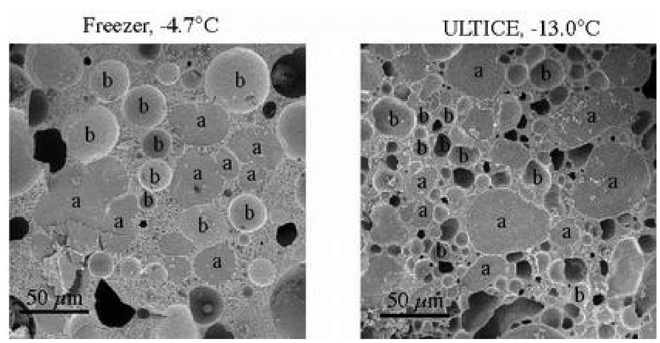

Figure 1: Cryo-SEM images of ice cream made by traditional freezing (left) and by a rapid freezing method called ULTICE (right). Air cells (a) and ice crystals (b) are labeled. Figure from Reference 6 (.

One way to increase the rate of freezing is to provide a lower temperature of freezing. The phenomenon is not unique to ice cream, rather anything that has water as a main constituent, like food products in general. This is one reason many freezer manufactures recommend setting the temperature of your freezer to the lowest possible setting: more rapid freezing results in smaller ice crystals being formed on your food. Many times making homemade ice cream in a personal freezer results in ice cream that is not preferred to commercially available ice cream because the cream mixture is cooled in a regular freezer and it happens very slowly. Homemade recipe directions offer a work around for this problem, which is mixing frequently, but this method can prove to be very tedious and very messy.

One method for creating an even lower temperature while mixing the cream mixture is placing the mixture in a container that is completely separated from an outer container that has a mixture of ice and sodium chloride. The salt is added to the ice because it has the ability to lower the freezing point of water, thus lowering the attainable temperature for the ice cream mixture than with just ice itself. This thermodynamic property is known as freezing point depression. The addition of salt can lower the freezing point of ice by ~20^{o}C with a 1:3 weight ratio of sodium chloride to ice. Subjecting the cream mixture to the ice mixture allows for quick cooling of the cream, however it is still not quite quick enough to prevent ice crystals from forming, albeit they are smaller than the freezer method when the mixture is continuously mixed while freezing. These smaller crystals can still be detected by the mouth of a consumer and provide a kind of "sandy" or "grittiness" to the ice cream.

Another method, which is employed commercially, is using liquid nitrogen to cool the cream mixture. Liquid nitrogen is an extremely cold temperature liquid (a "cryogenic") and boils at -196^{o}C (77 K). In some methods of ice cream production it is used in place of other cooling methods because it causes rapid freezing of anything it comes into contact with and is both colorless and tasteless. This freezing is so rapid, that it prevents hydrogen bonds from forming, resulting in extremely small crystal sizes and an even creamier texture than other methods. Liquid nitrogen cools the mixture so quickly that many nucleation points occur in the cream solution simultaneously. These nuclei initiate crystal growth and the crystals will not have the opportunity to grow very large. This yields a very creamy ice cream, which is preferred by most consumers.

Sources

1. The Nibble. "The History of Ice Cream & The Ice Cream Cone." (accessed July, 2014) http://www.thenibble.com/reviews/main/ice-cream/the-history-of-ice-cream8.asp
2. Demystifying Synthetic Organic Laboratory Technique. "Salt Ice Cooling Mixtures." *(accessed July, 2014). http://chem.chem.rochester.edu/~nvd/SaltIceCoolingMixtures.pdf*
3. C. Clarke. *The Science of Ice Cream.* Royal Society of Chemistry, 2012.
4. R.T. Marshall, D. Goff, R.W. Hartle. "Crystallization in Foods," *Ice Cream, 6th Edition. Spring Science & Business Media, 2003. pp. 259-265.*
5. K.L.K. Cook and R.W. Hartel "Mechanisms of Ice Crystallization in Ice Cream Production." *Comprehensive Reviews in Food Science and Food Safety*, Vol 9 (2), 2010, 213-222.
6. T. Althaus and E.J. Windhab. "Low temperature microstructuring of ice cream." (accessed at: https://www.researchgate.net/publication/243407777_Air_cell_microstructuring_in_a_high_viscous_ice_cream_matrix.

Materials sources:

Source/Website	Material
Industrial Revolution (http://www.industrialrev.com/yaylabs) Available on Amazon	**Ice Cream Ball, Pint-sized Cost ~$25-30 each**
Praxair (http://www. praxair.com) or your local industrial gas supplier	**5 L of liquid nitrogen**

Development and distribution funded by the **National Science Foundation**

Vocabulary and Definitions:
Colloid suspension **-** a solution which has microscopically or nanscopically dispersed, insoluble particles that are suspended throughout the solution.
Freezing Point Depression **-** a solution containing a nonvolatile solute has a lower freezing point than what is possible with just the pure solvent (i.e. by adding a solute to a solvent, the freezing point of the solvent is lowered).
Nuceli **-** a particle that acts as a nucleus for ice crystal formations.
Nucleation **-** a process of forming a nucleus. A necessary step in crystal formation.
Crystal growth **-** a solid material whose constituent atoms, molecules, or ions are arranged in an orderly repeating pattern in three dimensions.

Materials: for each group of 2 students

- Metal mixing bowl
- Measuring cup and spoons
- Two (2) Styrofoam bowls plus spoons for tasting
- Wooden or plastic spoon for mixing
- Spoons for tasting
- Small ice cream scoop
- Pint-sized Yay Labs Ice Cream Making Ball
- 50 mL dispensing syringe
- 1 pound of ice cream salt
- 2-3 pounds of ice cubes
- 1 pint of heavy cream
- 1 pint of half-and-half
- 2/3 cup plus 4 tablespoons sugar
- 2 tablespoons vanilla extract

Materials: per class of ~24

- 4.25 quart half-and-half
- 4.25 quart of heavy cream
- 2 cup sugar
- 16 Tbs vanilla
- 2-3 liters of liquid nitrogen
- 4 pounds of ice cream salt
- 1 large metal mixing bowl
- 1 small metal mixing bowl
- Electric hand mixer
- Wooden or plastic spoon for mixing
- Ice cream scoops
- Gloves
- Goggles
- Spoons, napkins, Styrofoam bowls for serving
- Towel
- Measuring cups and spoons

Development and distribution funded by the **National Science Foundation**

Safety Information: The ice-salt mixture used to make the ice cream by the student can be quite cold and if exposed to the mixture for an extended period of time can result in frost bite. The salt-ice mixture can be disposed of down the drain. Liquid nitrogen has a liquid to gas expansion ratio of 1:693 and so never work with it in a confined space, never ride with it in a passenger elevator, and handle it according to local and federal laws. If it comes into contact with skin, it will cause severe frostbite. Wear proper personal safety equipment. Print the MSDS for nitrogen.

Advance Preparation: Prepare traditional freezer ice cream prior to student activity *(requires access to a freezer so best to do at home)*

1. Combine 1.5 tablespoons of vanilla extract, 1/2 pint heavy cream, 1/2 pint half and half, and 1/3 cup plus 2 tablespoons of sugar in the mixing bowl. Mix with spoon.
2. Fill the large bowl about halfway with ice. Mix with 3/4 cup ice cream salt.
3. Nestle the smaller bowl in the ice/salt mixture. Try to get almost completely buried in the ice, but ensuring the salt/ice mixture does not get into the small bowl.
4. For 10 minutes, beat the cream mixture with a hand mixer. Half covering the bowl with a towel helps prevent spattering while mixing, but the smaller bowl must remain submerged in ice/salt mixture. This step aerates the cream mixture and chills it.
5. Cover the entire set of bowls with a towel and place in the freezer. Freeze for 45 minutes.
6. Remove the bowls from the freezer. Cream mixture should have consistency of watery pudding.
7. Mix the cream mixture again as before for 5 minutes. After this mixing, the cream mixture should have consistency of soft-serve ice cream.
8. Remove the small bowl from the large bowl. Cover the ice cream with plastic wrap, making sure the plastic wrap touches the surface of the cream mixture. Freeze for an additional two hours (or overnight) before serving.

Suggested Teaching Strategies:

Time	Activity	Goal
Day 1	The day before the lab	
30 min	Introduce students to the topic of nucleation, freezing point depression and ice cream science. Demonstrate freezing point depression by measuring the melting point of an ice/salt mixture.	To prepare students for the concepts behind the lab.
Day 2	The day of the student lab	
10 min	Students answer warm-up questions about freezing point depression and freezing on the molecular level.	To ensure students understand why the various ratios of salt to ice affect the freezing rates of the mixtures and that they understand what is happening at the intermolecular level.

5 min	Distribute *Student Worksheets* to students. Students follow procedures according to their group number.	To allow students to understand that this is an exploratory activity where the mouthfeel after different types of freezing and agitation are completed
15 min	Preparation of first cream mixtures and salt/ice for freezing with ice cream ball.	To prepare for the first part of the activity, freezing with ice/salt mixture in ice cream ball maker.
45 min	Making of ice cream with ice cream balls.	Producing ice cream with a salt and ice mixture.
15 min	Preparation of second cream mixtures and making of ice cream with liquid nitrogen.	To prepare for the second part of the activity, freezing with liquid nitrogen.
15 min	Clean up.	To prepare workspace for next class.

1. Procedure for the Activity:

1. Students will first mix the ingredients for their ball made ice cream and place in ice cream ball and hand tighten cap.
2. Assign a group number for each group. This group number will indicate which salt/ice ratio will be used and how the mixture in the ball will be agitated.
3. Students will then prepare their ice/salt mixtures by getting appropriate amounts of each, but not mixing them together.
4. They will then place the ice first into the ice cream ball and then the salt. They will then hand tighten the cap for this compartment.
5. For 10 minutes, the students will agitate the ice cream ball assigned to their group.
6. The ice cream compartment is opened first by the students in each group (may need to use plastic wrench), they will scrape the frozen mixture off of the walls with wooden spoons and mix the cream mixture thoroughly, then replace the cap, again hand tightening.
7. The ice compartment is then opened (may need to use plastic wrench), and they will replenish the ice and salt in the same ratio as before, then the cap is replaced and hand tightened.
8. They will return to agitating the ice cream mixture for at least another 30 minutes (more time may be required depending on their ice/salt mixture).
9. After the ice cream has been made for each group in the ice cream ball, have the groups make new mixtures of the cream, sugar, and vanilla in a metal mixing bowl.
10. Each group must obtain a Styrofoam bowl.
11. **INSTRUCTOR COMPLETES THIS STEP:** Fill their bowl with liquid nitrogen.
12. Each group of students will then suck up their ice cream mixture into a dispensing syringe.
13. Each group slowly dispenses cream mixture into liquid nitrogen. Refilling dispensing syringe and dispensing more until their mixture is gone.
14. Students will sample each different type of ice cream: traditional freezer ice cream the instructor prepared ahead of time, ice cream made with ball, and liquid nitrogen ice cream and observe and compare the different mouth feels that are experienced.

Cleanup: None of the materials in this lab are hazardous. The left-over ice cream and food products may be discarded down the drain or in the trash, which ever is easier. The liquid nitrogen will boil off at room temperature if dewer is left with cap off. Do this in a well ventilated area.

Assessment: Students should provide correct answers to the worksheets and demonstrate good laboratory procedures.

Optional: Activity extension, activity scaling, associated activities

1. Discuss with students the importance of nanotechnology in real life and what products have been enhanced by using nanotechnology or possible because of nanotechnology. You might want to direct students to Nanotechnology 101 at www.nano.gov.
2. Review the concepts of size and scale. In particular, focus on small particles like ice crystals.
3. Discuss the concept of a colloid suspension. What is it? What other food products or technologies use colloid suspensions? (you could use the Mixtures and Nanotechnology lesson at: http://nnci.net/educators-k-16)
4. Discuss the concept of freezing point depression and what affects it. Ask students for suggestions for other solutes that could be used instead of salt and the advantages/disadvantages of using them.
5. Ask students what happens when a mixture freezes. Emphasize the explanation needs to be on what happens on the molecular scale.
6. Discuss what factors affect the rate of freezing.
7. Discuss "mouthfeel" of other food products and how it affects a consumer's experience.
8. Discuss the concept of crystal growth and nucleation. Discuss what other food products have crystals.

Next Generation Science Standards:

HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
MS-PS1.B: Chemical reactions
MS-PS-2.B: Types of interactions
HS-PS1.A: Structure and properties of matter
HS-PS1.B: Chemical reactions
HS-PS2.B: Types of interactions

Contributors: Raeanne L. Napoleon, PhD, a faculty member at Santa Barbara City College, Santa Barbara, CA: rlnapoleon@sbcc.edu

Acknowledgements: The author thanks John Gomm, Marilyn Garza, Rano Sidhu, Wendy Ibsen, and William Elliot for their thoughtful guidance.

Supporting Programs – Research Experience for Teachers Program NSF # EEC-1200925; National Nanotechnology Coordinated Infrastructure NSF # ECCS 1626153

Name:________________________________Date:_______________Class:________________

Student Worksheet

Ice cream Break with Nanoscience: Nucleation and Colloid Suspensions

(with Answers in Red)

Safety

Frost bite is the biggest safety hazard in this activity. You will be making an ice-salt mixture today and using liquid nitrogen to make ice cream. Liquid nitrogen coming into contact with your skin can cause immediate and irreversible damage and prolonged exposure to the salt-ice can do the same. Be very careful not to touch either with bare hands and/or skin. Wear proper personal safety equipment.

Introduction

Ice cream is a complex food…
-H.D. Goff, Professor of Food Science
University of Guelph, Canada

Usually when we enjoy ice cream, we ignore all of the science behind it. Though simple in ingredients, ice cream is actually a complex mixture that consists of solids, liquids, and gases. It's not that we just simply enjoy ice cream, it's that the different phases and ingredients in ice cream come together in a delightful way. Without the right amount of each thing, ice cream wouldn't be as enjoyable. For this activity, we will be making our own ice cream in three different ways and studying our enjoyment of the ice cream as a function of the production method. The first way ice cream will be made for this investigation is using a traditional freezer and a mixture of cream, sugar, and vanilla flavoring, but the production was actually started last night because it takes such a long time for the mixture to freeze. A second way that you'll be doing today is using an ice cream ball maker with a mixture of salt and ice to cool a mixture of cream, ice, and vanilla flavoring. The last way we'll be producing ice cream, and probably the most exciting way, will be with liquid nitrogen! This very cold liquid will be used to cool our cream mixture at such a rapid rate that nano-sized ice crystals form. This method of making ice cream will be compared to both a traditional way of making ice cream in a freezer and with an ice cream ball by "mouthfeel," meaning we get to taste it all!
Nano-sized particles are really, really small particles and we'll be making them today. A nanosized particle is somewhere between 1 x 10^{-9} and 1 x 10^{-5} meters. It is the manipulation of matter at the atomic or molecular level that allows such small particles to be formed. There have been countless breakthroughs in a wide variety of industries thanks to nano-sized particles, including medicine, electronics, biomaterials, energy production, optics, and even ice cream making! And while ice cream is something that has been enjoyed since 400 B.C., considerable changes in the manufacturing of ice cream have happened even in the last few years. Traditionally, ice cream was made by freezing a mixture of cream, sugar, and flavoring. While water isn't necessarily an obvious ingredient in this mixture, it does account for 80-90% of milk that the cream is derived from. As such, water comprises a large portion of the cream. So when

Development and distribution funded by the **National Science Foundation**

cooling the mixture to sub-freezing levels to make ice cream, a person is literally making "iced cream," though this is easy to forget when enjoying ice cream today, as it is something so much more than just frozen cream. Upon freezing, water expands, which is easily observed when we freeze water in our freezers: we must always account for the increase in volume by leaving a little space in our vessel due to hydrogen bonding. As freezing of water occurs, the water actually creates small water crystals. The slower the freezing happens, the larger the ice crystals that form. The ice crystals in ice cream can actually be felt quite easily with the mouth and a reduction of ice crystals is desired to give ice cream that creamy "*mouthfeel*" that so many consumers prefer. To produce smaller crystal sizes for a creamier texture, the rate of freezing must be increased significantly so that the extensive hydrogen bonding by the water molecules is avoided, which is the crystallization. Figure 1 shows how a slower method of freezing (left) results in many more large ice crystals in an ice cream mixture than a more rapid freezing method (right). The crystal formation in the creamy mixture that is ice cream, results in a *colloid solution*, a solution where solid particles are equally mixed throughout.

One way to increase the rate of freezing is to provide a lower temperature of freezing. This is not unique to ice cream, rather food products in general. This is one reason many freezer manufactures recommend setting the temperature of your freezer to the lowest possible setting: more rapid freezing results in smaller ice crystals being formed on your food. Many times making homemade ice cream in a personal freezer results in ice cream that is not preferred to commercially available ice cream because the cream mixture is cooled in a regular freezer and it happens very slowly. Homemade recipe directions offer a work around for this problem, which is mixing frequently, but this method can prove to be very tedious and very messy. This procedure was initiated last night.

One method for creating an even lower temperature while mixing the cream mixture is placing the mixture in a container that is completely separated from an outer container that has a mixture of ice and sodium chloride. The salt is added to the ice because it has the ability to lower the freezing point of water, thus lowering the attainable temperature for the ice cream mixture than with just ice itself. This thermodynamic property is known as freezing point depression and it's the reason why salt is spread on some roads in the wintertime. The addition of salt can lower the freezing point of ice by ~20°C with a 1:3 weight ratio of sodium chloride to ice. Subjecting the cream mixture to the ice mixture allows for quick cooling of the cream, however it is still not quite quick enough to prevent ice crystals from forming, albeit they are smaller than the freezer method when the mixture is continuously mixed while freezing. These smaller crystals can still be detected by the mouth of a consumer and provide a kind of "sandy" or "grittiness" to the ice cream.

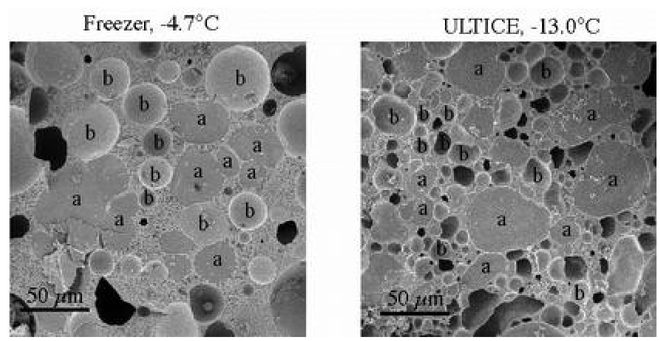

Figure 2: Cryo-SEM images of ice cream made by traditional freezing (left) and by a rapid freezing method called ULTICE (right). Air cells (a) and ice crystals (b) are labeled. Figure from Reference 6.

Another method, which is employed commercially, is using liquid nitrogen to cool the cream mixture. Liquid nitrogen is an extremely cold temperature liquid and boils at -196°C (77 K). In some methods of ice cream production it is used in place of other cooling methods because it causes rapid freezing of anything it comes into contact with and is both colorless and tasteless.

Development and distribution funded by the **National Science Foundation**

This freezing is so rapid, that it prevents hydrogen bonds from forming, resulting in extremely small crystal sizes and an even creamier texture than other methods, which is preferred by most consumers.
Question: What affects how creamy ice cream is when we taste it?

How fast it is cooled. The faster the cooling the smaller the crystal size. Smaller crystal size equates to a creamier texture.

Question: What are the three methods of ice cream making in this activity?

1. Traditional method in a commercial freezer 2. With ice and salt in an ice cream ball 3. With liquid nitrogen

Procedure:

Obtain a group number from your instructor. This group number will indicate which salt/ice ratio will be used and how the mixture in the ball will be agitated, so it's important to get it before you begin preparing your activity.

Materials per group of 2

- Metal mixing bowl
- (2) Styrofoam bowls
- Mixing spoon
- Small ice cream scoop
- Yay Labs Ice Cream Ball
- 50 mL dispensing syringe
- 1 lbs of ice cream salt
- 2-3 lbs of ice
- 1 pint of heavy cream
- 1 pint of half-and-half
- 2/3 cup plus 4 Tbs sugar
- 3 Tbs vanilla extract

1. Obtain a group number from your instructor. This group number will indicate which salt/ice ratio will be used and how the mixture in the ball will be agitated, so its important to get it before you begin the activity.
2. First combine 1/2pint heavy cream, ½ pint half-and-half, 1/3 cup and 2 tablespoons of sugar, and 1.5 tablespoons vanilla. Mix thoroughly with spoon.
3. Put your cream mixture into the ice cream compartment of your Ice Cream ball (it's the metal compartment). Tighten the cap with your hand (and not with the plastic wrench).
4. Prepare your ice/salt mixtures by getting appropriate amounts of each according to your group number and the chart below, but do not mix the salt and ice together yet!
5. First put your ice into the outer compartment of the ice cream ball and then add the salt. Some ice chunks may need to be broken up to fit, so crushing the ice first may be helpful. Hand-tighten the cap for this compartment (and again, do not use the plastic wrench).
6. For 10 minutes, agitate the ice cream ball in the way that is assigned by your group number.
7. After 10 minutes, open the ice cream compartment first, you may need to use plastic wrench to do this, then scrape the frozen mixture off of the walls with wooden spoon and mix the cream mixture thoroughly. Replace the cap, again by hand tightening only.
8. The ice compartment is then opened, again you may need to use plastic wrench for this, and replenish the ice and salt in the same ratio as before, then the cap is replaced and hand tighten.

Development and distribution funded by the **National Science Foundation**

9. Return to agitating the ice cream mixture in the fashion as before, for at least another 30 minutes (more time may be required depending on your ice/salt mixture).
10. Check the freezing of your cream mixture by removing the cap, scraping off the frozen cream mixture and mixing, as before. You want the consistency to be that of soft-serve ice cream. If not, replace cap and continue agitating your ice cream ball.
11. After the ice cream has been made for your group, keep the ice cream in your ball.
12. Make a new mixture by combining ½ pint heavy cream, ½ pint half-and-half, 1/3 cup and 2 tablespoons of sugar, and 1.5 tablespoons in your metal mixing bowl. Mix well.
13. Obtain a Styrofoam bowl for each member of your group.
14. Your instructor will then fill your bowls with liquid nitrogen. Make sure you do not touch the liquid nitrogen or spill it. Liquid nitrogen will cause immediate frost burns if it comes into contact with your skin!
15. Using a dispensing syringe, suck up your ice cream mixture and dispense into your liquid nitrogen. Stir your mixture immediately, being very careful not to spill the liquid nitrogen. Continue to slowly dispense your cream mixture into liquid nitrogen, making sure each person in your group gets an equal amount. Do so by refilling dispensing syringe and dispensing more until your mixture is gone.
16. Once all of the groups are finished, each group will sample each different type of ice cream by eating 1-2 tablespoons of each of the following: traditional freezer ice cream your instructor prepared ahead of time, your own ice cream made with ball, two other and different group's ice cream made with their ice cream ball, and liquid nitrogen ice cream. You will observe and compare the different mouth feels that are experienced. Rank the five different samples of ice cream that you enjoyed from "least creamy," which gets a score of 1, and "most creamy," which gets a score of 5.
17. Enjoy the remaining ice cream your group made from either method. Be sure to share with your partner.

Group Number	Amount of Salt	Agitation Method
1	¼ cup	Shake only
2	½ cup	Rolling only
3	1 cup	Shaking & Rolling
4	½ cup	Shake only
5	1 cup	Rolling only
6	¼ cup	Shaking & Rolling
7	1 cup	Shake only
8	¼ cup	Rolling only
9	½ cup	Shaking & Rolling

Development and distribution funded by the **National Science Foundation**

Observations & Analysis:

Example: Ranking of Mouthfeel

Ice Cream Production Type	Ranking of Creamiest (1 = least creamy, 5 = most creamy)	Other Observations
Traditional	1	Large ice crystals and rigid
Ice Cream Ball Group #2	4*	Feels gritty and soupy
Ice Cream Ball Group #4	3*	Feels gritty and soupy
Ice Cream Ball Group #7	2*	Feels gritty and soupy
Liquid Nitrogen	5	Very cold and very rigid

***Individual results may vary. It is not expected that there be consistent, discernable differences between the mouthfeel with respect to creaminess for ice cream made via the ball method.**

Development and distribution funded by the **National Science Foundation**

Draw Conclusions:

1. Which method of ice cream making provided the creamiest mouthfeel? And which method of ice cream making provided the least creamy mouthfeel?

    The liquid nitrogen method resulted in the most creamy ice cream. The traditional freezer method resulted in the least creamy ice cream.

2. For the ice cream production method that resulted in the creamiest mouthfeel, what do you conclude was the reason it was the creamiest?

    The liquid nitrogen method resulted in the most creamy ice cream because it was the method that allowed for the fastest freezing and therefore the smallest crystals. Answers may also include information on nucleation and bonding

3. Did you notice any difference between the creaminess of your ice cream made with your ice/salt mixture and agitation method and other group's ice cream made with their ice/salt mixture and agitation method? Explain.

    Answers will vary.

4. Suggest another way for freezing and ice cream mixture. You can provide a completely new way or your suggestion can combine or alter methods provided in this activity.

    Answers will vary.

5. What is the relationship between ice cream and nanoscale science? __Answers should *include that the particles that make up colloids are on the nanoscale and that the nucleation points are on the nanoscale*

Development and distribution funded by the **National Science Foundation**