Experiencing Supercooled Crystallization

P3-1020, P3-1025

INSTRUCTIONAL GUIDE

Contents

Experiencing Supercooled Crystallization Classroom kit: (P3-1020)

- 12 Small Heat Pads (3" x 3")
- 1 Large Heat Pad (7.5" x 7.5")
- 600 g sodium acetate

- OR -

Experiencing Supercooled Crystallization Activity Set: (P3-1025)

- 1 Small Heat Pad (3" x 3")
- 50 g sodium acetate

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Introduction

This classroom kit utilizes a commercially available product to illustrate scientific concepts. In fact, a well-known chemical principle has been "harnessed" to become a useful consumer product. This improved packaging makes it possible to explain to the student the difficult concepts upon which it is based! This is a rather unique science education.

Some of the more difficult scientific concepts to explain to students are the concepts of conservation of energy and latent heat. It is very easy to see the effects of adding heat to matter, such as boiling water. It is much more difficult to feel the effects of the release of the latent heat of condensation when the water molecules that boiled out of the pot condense to form water droplets. The release of latent heat of crystallization, the principle of this demonstration, is analogous to the latent heat of condensation. This lesson package should provide you with the material to make these concepts understandable to students of all ages. This classroom kit, has been used with 5th and 6th grade students with excellent results. It is an excellent teaching tool for grades 5 through 12.

This instruction guide will provide enough background to use in almost any classroom setting.

Chemical Facts

This kit contains a chemical called **sodium acetate trihydrate**. Sodium acetate is a salt whose unique solubility properties have been known for a long time. Commercial applications date back to the early 1900s, including medical applications during World War I as a heat supply. Today, sodium acetate is used as a food preservative and in other industrial applications.

The solubility of sodium acetate is strongly influenced by the temperature as shown by the data and graph on the next page. Above +58°C (+136°F) sodium acetate trihydrate is always a liquid; below about -10°C (+14°F) it is a solid. Normally, the salt would crystallize as it cools below +58°C, except under special conditions such as in the Heat Packs. Thus, it can easily exist at room temperature as a **supercooled liquid**. The trigger button is the mechanism for producing the seed crystals that initiate the phase change.

A high yield of sodium acetate trihydrate crystals can be obtained by cooling a saturated feed solution. This is the basis for the lab demonstrations as well as the commercial applications such as in the heat pads.

Sodium Acetate (anhydrous): $NaC_2H_3O_2$
Molecular Weight:
82 grams/mole

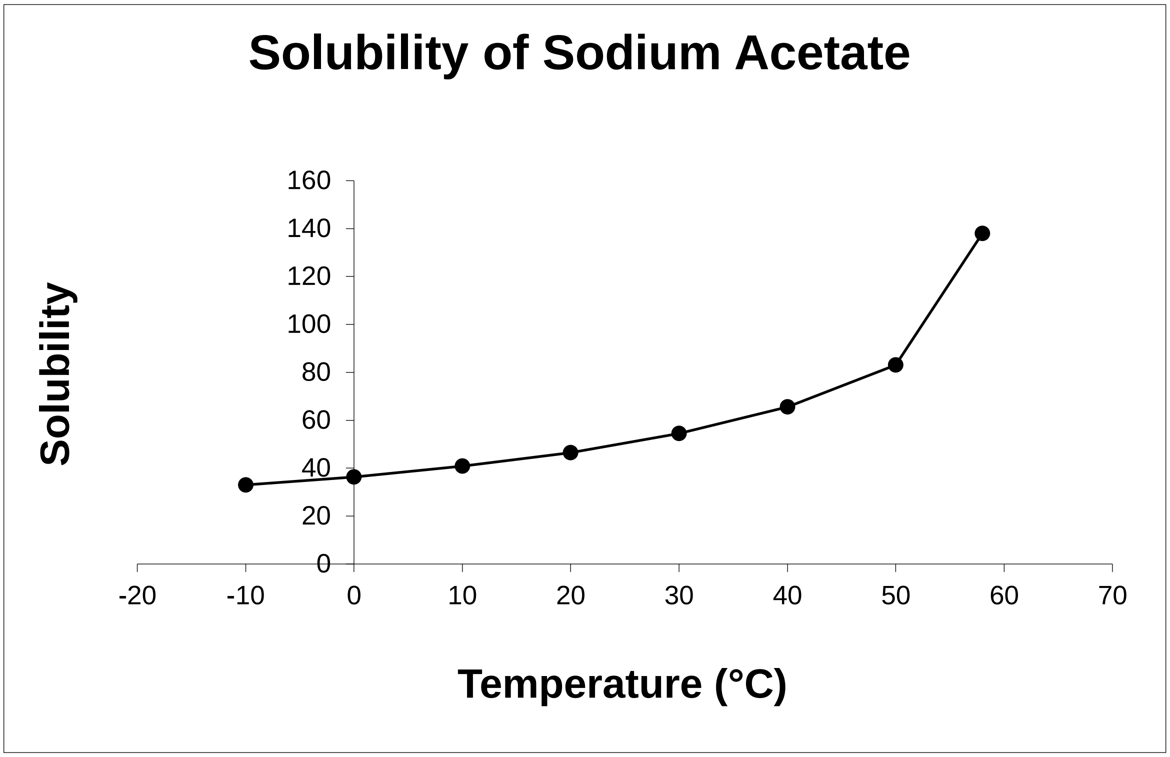
Sodium Acetate Trihydrate: $NaC_2H_3O_2 \bullet 3H_2O$
Molecular Weight:
136 grams/mole

The phase change reaction in the Heat Packs:

$Na^+ + C_2H_30_2^- + 3H_20 \rightarrow NaC_2H_3O_2 \bullet 3H_2O$ (solid) + 4 Kilocalories/mole

This is a reversible reaction. Just add heat to solubilize.

In comparison, the solubility of salt (that is, table salt or sodium chloride, NaCl) does not change appreciably with temperature, varying by only 1.5 grams over the same temperature range (0° to 60°C).



Solubility Data	
Temperature (°C)	Grams Sodium Acetate per 100 Grams of Water
-10	33
0	36.3
10	40.8
20	46.5
30	54.5
40	65.5
50	83
58	138

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The Hydrological Cycle

The hydrological or water cycle is usually described in the following manner. The sun heats the Earth, warming the oceans, lakes, rivers, etc. Liquid water molecules evaporate from the surface of the water bodies and become a gas. Another source of water is transpiration from living material, primarily vegetation, but also animals. This water vapor rises and cools, condensing into cloud droplets or ice crystals. Eventually, these droplets or crystals become large enough and fall back to the surface of the earth as rain or snow, replenishing the bodies of water – and the cycle continues.

Besides distributing water over a larger area of the Earth (although not very evenly as we can see by the existence of rain forests and deserts), the water cycle is a method for redistributing the heat and energy that we receive from the sun. Here is the background for this:

The Atmosphere is Heated from Below!

We know that the atmosphere is transparent to most of the light (energy) from the sun. Indeed, the only portion of the incoming solar radiation that is absorbed directly by the atmosphere is a small, yet significant, amount in the ultraviolet range. Today, this is much in the news because of the "hole" in the ozone layer. The ozone layer in the stratosphere protects life on Earth from the damaging effects of this ultraviolet radiation. The only portion of the atmosphere that is directly heated by the sun is the ozone layer. The ozone layer ranges from 12 to 30 miles (20 to 50 kilometers) above the surface of the earth. This is the same region as the stratosphere.

The troposphere is the lowest layer of the atmosphere. This is the region from the surface up to about 12 miles and this is where all the weather occurs. The troposphere is heated from below. The incoming solar radiation heats the water and the lad. These warm surfaces come into contact with the air that is immediately adjacent. During the day, the lowest layer of air becomes warm enough to be buoyant and rise. As this buoyant parcel of air rises, it loses its heat (energy) to the surrounding atmosphere. Conduction and convection heat the atmosphere. At night, the reverse process occurs. The surface emits radiation and cools (actually, the surface always emits radiation; it is just that at night there is a net loss of radiation from the surface as there is no incoming solar radiation). The cool surface cools the air immediately in contact with it. Cool air, however, does not rise, so the cooling of the next layer must be by conduction.

Water is a major source of heating for the atmosphere. First, we know that water covers most of the Earth. Secondly, we know that it takes one calorie to raise the temperature of 1 gram (or milliliter) of water one degree Celsius, say from 15°C to 16°C. However, it takes about 600 calories to vaporize a gram of water! This is a tremendous amount of energy. Likewise, 600 calories/gram are released to the atmosphere when this water vapor condenses. In a similar manner, 80 calories/gram are required for the phase change from water to ice or ice to water.

The basic physical principle that we must now observe is conservation of energy. It is the basis for the phase change discussion. If 600 calories/gram is added to the water in one location, then 600 calories/gram must be released in some other location. Thus, when water changes from a gas or vapor to a liquid, or cloud drop, a tremendous amount of energy is released, heating the atmosphere. This energy is called the **latent heat of condensation** and is a major source of heating for the atmosphere. Similarly, when water changes to ice or snow, a solid, heat is released, although much less during condensation. *This is the heat or energy source for storms.*

Latent heat is a concept that is hard to visualize. While students have no problem understanding adding heat to a substance to liquefy or vaporize it, it is much harder to comprehend the release of heat when the substance condenses or freezes. The Heat Packs provides a dramatic example that all students will appreciate and enjoy. What you observe in the Heat Packs is actually the release of latent heat of crystallization, but this is analogous to the release of latent heat of condensation or solidification (freezing).

The foregoing is a brief discussion of latent heat and its importance in the atmosphere. More detailed explanations should be found in standard college texts on meteorology.

Supercooled Liquids

Understanding supercooled liquids is very important for meteorology, especially for aviation weather and thunderstorms. The basic problem is to understand that liquids can be cooled below their normal freezing temperatures under certain special conditions.

Water, which usually freezes at 32°F (0°C), can be found in a liquid state as low as -40°F (-40°C) or more. This supercooled water usually exists as cloud droplets that are very small. In fact, in order for snow or ice particles to form in a cloud, the temperature must be well below freezing because all freezing depends on *ice forming nuclei*. Many different substances, such as dust, bacteria, other ice particles, and silver iodide, may serve as ice-forming nuclei. Most of these ice forming nuclei are active in the range from -10°C to -20°C, although silver iodide, which is used in cloud seeding, is active as warm as -4°C.

If cold clouds contain large amounts of supercooled water, that is, they are "young clouds," and not all ice particles, we can see that these clouds can be especially dangerous to aircraft. An airplane flying through the cloud where the temperature is -15°C to -20°C will encounter a great deal of supercooled water. The airplane surfaces, being well below freezing, provide excellent locations for supercooled water to freeze and attach. This is called aircraft icing, and can be quite severe under certain circumstances. All modern large aircraft have de-icing equipment that take care of most icing situations. Additionally, the area of greatest amount of supercooled water usually is found between 15,000 and 25,000 feet, especially in springtime. Most large aircraft fly above these altitudes, but they pass through while ascending or descending. On the other hand, small aircraft generally fly below 18,000 feet, so they are usually only subject to icing during cold winter storms.

Hail is one of the more dangerous forms of precipitation, with large hailstones (up to 6" in diameter) known to kill both plants and animals. Hailstones begin as very small ice particles, but in a cloud with large amounts of supercooled water, these ice particles will collide with many droplets, quickly becoming sizeable hailstones. When the hail is large enough (heavy enough), it will fall. It may, however, run into even stronger cloud updrafts that will bring it back into the supercooled portion of the cloud where it can grow even larger before falling out of the cloud.

The Heat Packs provide a very dramatic example of supercooled liquid. The freezing temperature of the sodium acetate solution is about 130°F, yet it exists at room temperature, say 70°F. The Heat Packs can be cooled down to 14°F under some conditions, at which point it will freeze.

Measuring Latent Heat

Subject: Chemistry

Objectives: Students will be able to define, describe and measure latent heat. Students will be able to apply this knowledge to discussions of related topics such as weather, the hydrologic cycle, including hail formation and airplane icing.

Background Information

The heat produced from the 3 x 3" heat pad is about 1.4 kilocalories. This can be measured by submerging it in 300 milliliters of water in a dewar or another insulated container, such as styrofoam or thermos. This should produce a 5°C rise in temperature.

The package weighs about 56 grams. The packaging and the trigger mechanism weigh about 7 grams. Thus, the solution weighs about 49 grams or 0.36 moles (49 divided by 136). The heat released should be the number of moles times the calories per mole (0.36 mole times 4 Kcal/Mole = 1.44 KiloCalories, which is close to the observed).

A kilocalorie is defined as the amount of heat needed to raise the temperature of one liter of water by one degree Celsius (this is defined in the range of 15° to 20°C, which is close to room temperature). Thus, 0.3 liters of water rising 5°C yields 1.5 kilocalories (0.3 times 5). If you use a liter of water (about a quart), the temperature rise would be about 1.5 degrees, which, although you can still measure it, does not give you a very dramatic demonstration or good accuracy, since most commonly available thermometers are hard to read to the nearest tenth of a degree.

Equipment Required

1. 3 x 3" heat pad
2. Insulated container to hold heat pad and 300 milliliters of water
3. Thermometer

Procedure

1. Place 300 milliliters of water in the insulated container.
2. Place the small Heat Pack in the container and allow the system to come to equilibrium. Water and heat pad should be at room temperature.
3. Activate the Heat Pack according to instructions. After 10 to 15 seconds, maximum temperature will be attained. Return the Heat Pack to the container and cover.
4. Measure temperature of water at regular intervals. You should get about a 5°C rise.

Crystallization

The Pillar of Salt

Subject: Chemistry
Objectives: Students will observe the rapid freezing and solidification of a supercooled liquid. Students will be able to apply this to the related topics of weather, the hydrologic cycle and icing of airplanes.

The following demonstration is a dramatic display of the crystallization process. The concepts involved are **supersaturation**, **supercooling**, and **crystallization.**

Caution:

Please practice this demonstration before presenting it to your students. And remember, **SAFETY FIRST**. Be careful of burners or other heating devices as well as the hot containers themselves. As you need to warm the liquid to up to 180° to 212°F, this can still scald or cause minor burns if splashed directly on the skin. However, this should be no more difficult than making a cup of coffee.

Equipment Required

1. 50 grams of Sodium Acetate Trihydrate
2. 5 milliliters of Water
3. 125 milliliter Erlenmeyer flask
4. Laboratory burner
5. Burner stand
6. Wire gauze
7. Tongs
8. Gloves

Procedure

Place sodium acetate and water in flask and heat over low flame with the wire gauze between the flame and the flask. Wear gloves and use tongs to hold and swirl the flask until the crystals dissolve. If any crystals remain on the sides of the flask, quickly wash down the sides with a small amount of water. Remove the flask from the heat and *cover tightly* with a clean piece of foil. Let cool to near room temperature (the cover will keep dust out which may trigger crystallization).

Note: The solution and flask must be free of all traces of crystals, otherwise crystallization will occur as the solution cools. If too much water is used, a watery matrix will result, but you can then boil off the excess water and proceed.

To Crystallize

Place a few sodium acetate crystals on the lab bench or tabletop and slowly and steadily pour solution on them. Crystallization will begin immediately and continued pouring will give a tall column of crystals. If done properly, the crystal column will extend into the flask and be strong enough to support the flask (obviously, the flask should not be that far off the tabletop as there isn't very much of the solution).

A considerable amount of heat is released during the crystallization. This can be felt by touching the crystals. It is most noticeable if your reference point is the temperature of the flask just before you pour the liquid. The flask should be at room temperature, while the crystals will warm to about 130°F.

Another demonstration is simply to drop a crystal into the cooled solution in the flask. The crystals will grow rapidly in all directions from the seed.

The sample can be dissolved and used again, but be sure there is no debris, as it will cause premature crystallization.

Alternate Procedure

If you do not have access to all the proper chemistry lab equipment, you can use substitutes. Items that are commonly available are:

- PYREX glassware such as measuring cups and baking dishes
- Any heat source such as an electric burner
- You can use a double boiler method by immersing the container in boiling water
- Metric liquid measurements are available on measuring cups
- 50 grams is between 1.5 and 2 oz, so try using a kitchen scale
- 5 milliliters is only a teaspoon or so of liquid

Remember, the liquid does not need to be boiled. You can use hot water from a coffeemaker to do this experiment![1]

[1] References:

Hiegel, G.A. (1980). Crystallization of Sodium Acetate. *Journal of Chemical Education*, **57**(2), 152

Farrel, K. and Dowde, E. (February, 1988). Tracking Temperature with Your Computer. *The Science Teacher*, **55**(2), 42-43.

NOTE: "Tracking Temperatures with Your Computer" uses a personal computer to demonstrate supercooling. Phenyl salicylate is used for this experiment.

Teacher-Directed

Instructional Sequence

Subjects: Chemistry
Physical Science
Geography
Weather and Climate

Objective: Students will be able to describe phase change, supercooled liquids, supersaturated solutions, release of latent heat and conservation of energy as they apply to commonly observed phenomena.

I. Specific Objectives

Students will be able to define the following terms and apply them to commonly observed phenomena:

a) Supersaturated Solution
b) Supercooled Liquid
c) Phase Change: Solid, Liquid, Gas (or Vapor)
d) Latent Heat
e) Specific Heat
f) Release of Latent Heat of Crystallization
g) Release of Latent Heat of Condensation
h) Conservation of Energy

II. Value to Students in Achieving the Objective

Studying the above concepts will help the students to understand natural and applied physics. In the natural realm, the most common application is the weather and the precipitation cycle (see supplement on Weather). In the practical area, students receive an introduction to the application of physical properties to commercial and consumer products.

III. Initial Instructional Activity to Teach Objective to Students

Explain basic theory of particular subject matter, e.g., weather or crystallization or latent and specific heat along with related kinetic theory. Use visual aids to reinforce theory portion of presentation (see graph supplement). Students will perform an experiment to illustrate the theory.

IV. Guided Group Practice

Qualitative Demonstration. If Supercooled Crystallization Classroom Set is available, distribute one packet to each student if possible. Instruct class on procedure for activating Heat Packs. Observe (see and feel) what happens.

If you only have one Heat Pack, gather students around you to afford the best view, and let them feel the packet so they know it is at room temperature. Activate as everyone watches. After 10 seconds, the Heat Pack will reach maximum temperature, at which point you can pass the packet around the classroom. The Heat Pack will stay warm for at least 5 minutes, so all students should have ample opportunity to touch it.

Quantitative Demonstration. Use procedures as outlined in supplement Quantitative Lab Demonstration.

V. Independent Practice or Activity

Answer the following questions after investigation is completed (as appropriate)

1. What happened to the packet?
2. What happened to the temperature of the packet?
3. How does this relate to the weather?
4. How does this relate to heating and air conditioning a building? (Think about steam and radiators.)
5. What are some practical applications of the HEAT PACK?
6. How does this relate to airplane safety?

VI. Provision for Individual Differences in Ways of Learning

a. **Remediation or Alternate Activities**
   Peer tutoring or group discussion can be utilized so that students can help each other and share ideas.
b. **Enrichment or Supplemental Activities**
   There are several related topics and experiments in this package.

Related products

Sodium Acetate Trihydrate 500 g (P3-1015-05) Experiment with creating your own heat pack. Sodium Acetate Trihydrate is the active ingredient commonly found in heating pads and hand warmers.

Acknowledgement

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