

CRYSTALS - A HANDBOOK FOR SCHOOL TEACHERS

Elizabeth A. Wood, 1972

Written for the Commission on Crystallographic Teaching of the
International Union of Crystallography

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Contents

I	Preface to the 2002 Edition	4
II	Introduction	5
III	Equipment and Materials	9
IV	Crystals in Classroom and Home	10
A	Growing Crystals from Solution	10
1	Salt (table salt, sodium chloride, NaCl)	10
2	Borax ($Na_2B_4O_7 \cdot 10H_2O$) in water	15
3	Sugar (sucrose or saccharose, $C_{12}H_{22}O_{11}$) in water	17
4	Alum [ammonium alum, $NH_4Al(SO_4)_2 \cdot 12H_2O$ or potassium alum, $KAl(SO_4)_2 \cdot 12H_2O$] in water	18
5	Copper sulfate (blue vitriol, $CuSO_4 \cdot 5H_2O$) in water	19
6	Epsom Salt ($MgSO_4 \cdot 7H_2O$) in water	20
7	What else?	22
B	Crystals from the Melt	22
1	Ice (solid water, H_2O)	22
2	Salol (phenyl salicylate, $HOC_6H_4COOC_6H_5$)	25
3	Bismuth (metallic element, Bi)	27
C	Crystals from the Vapor	28
1	Ice	28
2	Naphthalene (moth flakes, $C_{10}H_8$)	29
D	Experiments with Polarized Light	30
1	The Nature of Polarized Light and the Means for Producing It	30
2	Crystals between Crossed Polarizers	31
3	Ice and mica	33
4	Sugar solutions	33
V	Crystals Outside of Home and Classroom	34
A	In Museums	34
1	Displays of Rocks and Minerals	34
2	The Museum Staff (suggestions for field trips)	34
B	Out of Doors	34
C	At the Big Stores and Small Shops	36
1	Decoration of buildings and counters	36
2	Jewelry stores	37

CONTENTS **3**

3	Drug stores (apothecaries, chemists' shops)	37
VI	References for Further Reading	38
VII	References	39
VIII	Acknowledgement	39

I Preface to the 2002 Edition

The text of this edition is largely unchanged from that of the original 1972 edition; there has been a small amount of editing where materials are no longer considered safe for general use, *e.g.* the use of benzene as a solvent is no longer advocated due to its toxic and carcinogenic properties.

Readers outside the USA and Canada should be aware that the measurements (*e.g.* cup) used in the practical sections are based on American cooking measures, which are not quite the same as the equivalents used in British or other Commonwealth kitchens!

Users of “U.K.” or “British” English should be warned that spellings and usage in this document are “American” (*e.g.* “color” rather than “colour”, ‘Crystals Outside of Home’ rather than “Crystals Outside the Home”).

The original guide is available as an HTML document on the IUCr’s website (<http://www.iucr.org/iucr-top/comm/cteach/pamphlets/20/index.html>); there are translations (by native speakers) into several languages (currently (*i.e.* Autumn 2002) Arabic, Czech, Polish, Russian and Spanish).

Harry Powell
Cambridge, UK
November 2002

II Introduction

To the Teachers of Young Children Everywhere:

This booklet was produced for the Commission on Teaching of the International Union of Crystallography, which is an organization for the benefit of the science of crystallography throughout the World. It is not a trade union, but a group of people of all nations interested in crystals. Many teachers have found that children are interested in crystals. There are good reasons for the teacher to encourage this interest. Children can perform simple experiments with crystals and so get the feel of doing science themselves, the experience of watching something happen in their own experiments. Crystals are of interest to chemists, physicists, geologists, biologists and mathematicians. To study crystals is to be part of all these fields and to become aware that Nature is not separated into chemistry, physics, geology, and biology. Most teachers at the present time (the 1970s) did not learn about crystals when they were in school and college. The purpose of this booklet is to give them some background of understanding of crystals so that they can enjoy working with children who are interested in crystals. It is not a systematic course in crystallography. This would not be suitable. Those students who want to know that much about crystallography will take courses in crystallography at the university. It is a handbook for your enjoyment.

In this booklet, technical terms are avoided as much as possible, not to make it easier, but to avoid the pitfall of substituting **learning names** for **thinking** about what is going on. Children think they know why an apple falls because they have learned the word 'gravity', but our most competent scientists are puzzled by the way in which an apple and the Earth are drawn toward each other.

Most books on crystallography, the subject that deals with the study of crystals, emphasize the importance of symmetry in the classification of crystals. However, many of the crystals that children can grow themselves, or find in nature, have shapes that do not exhibit perfect symmetry, because the growing conditions were not the same all around the crystal. It takes a mature imagination and experience with some perfectly symmetrical crystals to imagine what such a crystal would have looked like if the growing conditions had been uniform.

Unless students can be convinced from their own observations that symmetry is really useful in classifying crystals, there is no merit in having them memorize the symmetry terms, since they have no meaning for them. The

essence of science is observation and wonder, curiosity and the effort to satisfy that curiosity. Learning what others have found out is part of learning about science, but first we must see how scientists learn what they know about nature so that we may be convinced that their results are based on repeatable experiments.

For these reasons this booklet does not deal with systematic crystallography, the classification of crystals according to their symmetry. It seeks to lay a firm foundation for later study of crystallography by encouraging observation and experimentation. Over a period of time, the students' observations will probably lead them to conclusions such as the following:

1. Under suitable conditions some kinds of solid matter form in shapes called **crystals**.

2. Crystals grow bigger by adding more layers of solid matter around their outsides.

3. Crystals form from solution when the solvent evaporates. Crystals form from the molten state when the liquid cools. Crystals form from warm invisible vapor when that vapor meets a cooler surface.

4. Crystals of different substances have different forms.

5. Crystals of different substances have different properties; that is, some are colored and some are not; some grow nicely and some do not; some have cleavage (to be discussed later) and some do not; some look bright between crossed polarizers (see section III-D) and some do not.

6. (for older students) There must be something orderly about the way a crystal forms that is responsible for its flat faces, its characteristic shape, and the way it affects light. This orderliness must be different for different substances.

If your students have some conviction about such conclusions from their own observations, they will have a good foundation in the science of crystallography.

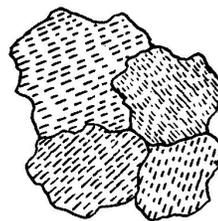
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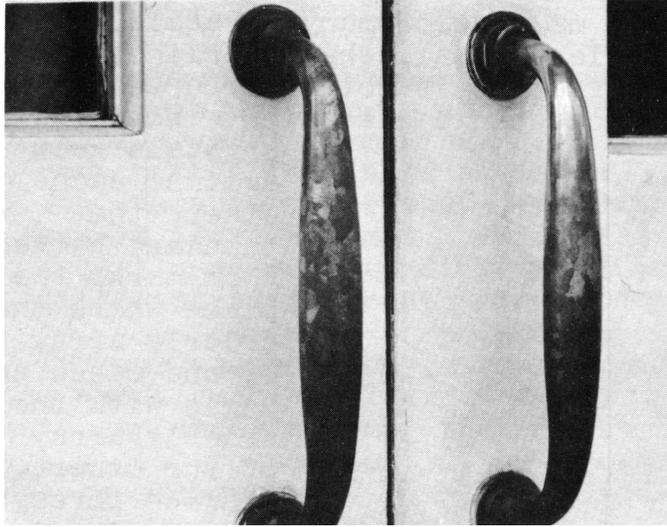
A crystal of a given substance or material shows plane faces always at the same angles to each other and has its other orderly properties because

it is made up of atoms, ions, or molecules arranged in a very orderly way. This orderliness of structure is found in almost all solid matter, though some substances have a more orderly arrangement than others. Even in wood the molecules are arranged in good order along the fibers, though there is not much orderliness from one fiber to the next. Is wood, then, a crystal? It doesn't show shiny faces. Some crystallographers (people who study crystals) would say its fibers are crystals; some would not.

A substance that is made up of crystals is called a crystalline substance. Sometimes the word **polycrystalline** is used to indicate a substance made up of many crystals. In a single crystal, the orderliness of rows of atoms is not interrupted and does not change direction. When two crystals grow against each other, the boundary between them marks the place where the orderly array of one makes an angle with the orderly array of the other. A slice through four crystals with such boundaries is crudely suggested by this sketch. The solid lines represent boundaries between crystals (sometimes called grain boundaries). The dotted lines represent layers of atoms, ions, or molecules.

Many substances that we are familiar with are made of very orderly crystals that do not show their bright faces because neighboring crystals have grown against each other with irregular boundaries. Nearly all rocks are made up of crystals and the different kinds of crystals in a rock can often be distinguished from each other. Metal objects are made up of interlocking crystals. Sometimes their boundaries can be seen, as in the zinc coating on galvanized iron often used for pails (buckets) and garbage cans. Sometimes a brass door handle shows the boundaries between the crystals of which it is composed. A substance in which the atoms or ions or molecules are not arranged in orderly rows is called a glass. Window glass is a familiar example. Volcanic glass, and some volcanic ash, is also glassy - not crystalline. There is a glassy kind of candy that is very brittle, usually made with nuts in it. It is made by cooling the melted sugar very quickly so that crystals do not have time to grow before the fluid gets too stiff to allow the molecules to move about and take their proper positions to make a crystal. This suggests that other glasses may be formed by quick cooling. This is so of volcanic glass and of some manufactured glass too, although glass manufacturers have learned to produce mixtures that can be cooled at a convenient rate without crystallizing. In some very old glass, made before the art was well developed, crystals





have begun to form as, over the years, the atoms have slowly migrated into orderly positions, drawn by their attraction for each other. There are no very old volcanic glasses, geologically speaking. In hundreds of thousands of years, the atoms have had time to get together to form crystals.

Young people learn best by doing, not by being told. The best way for a child to learn about crystals is by experience, not by having someone tell him about them. Let him observe and wonder and ask questions. Then perhaps you can help him seek answers to them. We will not even try to define the word **crystal** until we have had some experience with crystals. It is essential that you, the teacher, have these experiences yourself so that you can enjoy the discoveries with your students.

The rest of this handbook will be written as though for the students. If it teaches something that you already know, remember that it was written for all schools, everywhere in the World.

III Equipment and Materials

A. Essential

Materials	Equipment
Salt (table salt, sodium chloride, NaCl)	Cup, glass or other container
Sugar (sucrose or saccharose, $C_{12}H_{22}O_{11}$)	Measuring cup (8 ounce; about 235 cm ³)
Water	Teaspoon
	Thread or thin string

B. Desirable

Materials	Equipment
Borax ($Na_2B_4O_7 \cdot 7H_2O$)	Magnifying glass
Alum (ammonium alum $NH_4Al(SO_4)_2 \cdot 12H_2O$ or potassium alum, $KAl(SO_4)_2 \cdot 12H_2O$)	Tweezers or forceps
	Microscope slides (glass). The bottom of an overturned drinking glass can be used.
Copper sulfate (blue vitriol, $CuSO_4 \cdot 5H_2O$)	Candle or match flame
	Source of heat to boil water
Epsom salt ($MgSO_4 \cdot 7H_2O$)	Refrigerator or temperature below 0°C
Salol (phenyl salicylate, $HOC_6H_4COOC_6H_5$)	Two pieces of polarizing film, such as Polaroid
Bismuth (Bi)	
Naphthalene (moth flakes, $C_{10}H_8$)	

IV Crystals in Classroom and Home

A Growing Crystals from Solution

1 Salt (table salt, sodium chloride, NaCl)

We will begin with salt because everybody has it. While the salt experiment is going on, you can be getting together the materials for the later experiments.

a. Growing the crystals and observing their growth

Put 3 teaspoonfuls of salt into 1/3 cup of water.¹ Stir well. Most of the salt will dissolve, forming a solution of salt in water, but some will remain in the bottom of the container and the solution may appear cloudy. (Some producers of salt coat the salt grains with a harmless insoluble substance so that they will not stick together in damp weather. The following procedure is used to separate this and the undissolved salt, if any, from the salt solution.) Let the mixture stand over night. Next morning, the solution will appear clear. Pour the clear solution into a shallow glass or cup, being careful not to stir up any of the material from the bottom. (This process of separating a liquid from a solid, simply by pouring the liquid off, is called decanting.)

Discard the solid material. Let the clear solution stand, uncovered, for a few days. To keep the dust out, it may be well to place an overturned box over it.

A given amount of any **solvent**, such as water, can hold in solution just a certain amount of a particular substance. When it has this amount in solution, it is said to be a **saturated solution** of that substance. If it has less than that amount, it is **undersaturated**. In some cases, substances seem to need a nucleus - a tiny bit of crystal of their own kind - to cause the beginning of crystallization of the solid from the solution. In such cases, as a saturated solution stands, and the solvent evaporates, it may become **super-saturated**, containing in solution more than it would if it were in contact with crystalline material of the substance that it has in solution. In such cases, addition of the tiniest fragment of the **solute** (the dissolved substance) will cause **precipitation** of the excess solute in the bottom of the vessel.

¹ In a chemical laboratory, amounts would be given in grams. Here we use the measuring cup and the measuring teaspoon familiar to all cooks. An American cup holds 8 fluid ounces or approximately 236 milliliters; a British cup holds 10 fluid ounces or 284 milliliters. Both American and British teaspoons are closely equivalent to 5 milliliters.

When the first solid particles appear in the bottom of your salt solution, examine them with a magnifier. Try to pay attention to one particular particle and watch it change from day to day. If the vessel containing the solution is glass, you can place it over a piece of paper on which a marked circle helps you locate the particle you are watching. (A white crust may form at the edge of the solution, where evaporation is rapid. We will discuss that later.) You may find that a strong light from the side helps your observations.

The particles gradually forming from solution are salt crystals. If you will watch the very early stages of their formation you will find that they look square. If you look at them from the side, you will see that they also look square, or perhaps rectangular. Their sides are very precisely at right angles to each other and stay that way as they grow.

Think about this! Out of that formless solution come these perfectly formed solid shapes, whether you are evaporating the solution in Spain or in Siberia, in Africa, America, or Australia, in a submarine or in an airplane. Dependably, the solid that comes out of salt solution forms little crystals with bright, shiny faces at right angles to each other. How do you suppose it does this?

Take one of the little crystals out of the container, with tweezers if you have them, and dry it off. You can put it in a box and keep it. It will not change, unless the weather is **very** damp. With extreme dampness, water from the air may gather on the crystal and dissolve it. Those left in the container continue to grow larger because, as the water evaporates, the salt that you dissolved in it has to come out of solution and it is added to the tiny salt crystals, making them bigger. As layer after layer is added, like layers of paint on a box, each flat face just progresses outward, staying precisely at right angles to its neighbors.

What happens when two crystals that are growing next to each other meet? Watch carefully and see. In most cases they grow together, irregularly, while their beautifully flat faces continue to grow outward on the free sides where they are not in contact with each other. When they have grown together for a while, pick them up with the tweezers. Can you tell where one crystal ends and the other begins? In some cases this is easy, in other cases not. Can you pull them apart?

As your solution evaporates further, many crystals will grow together in the bottom of the container. The white crust at the side is formed of just such crystals grown together but they are very very small. Where the evaporation was very rapid, many crystals started to grow at the same time and quickly met neighboring crystals so that none could grow large.

In the very small spaces between some of these crystals and between this crust of crystals and your container capillary action causes the solution to be drawn up the side of the container where it then evaporates rapidly and more white crust is formed.

How could you grow a bigger crystal that still had its perfect shape because it had not come in contact with a neighboring crystal? Try to answer this before reading further.

Here are two methods to try:

1. Since rapid evaporation caused many crystals to start growing at the same time, close to each other, perhaps we could cause fewer crystals to grow, farther apart, by preventing rapid evaporation. We could put a cover on the container - not a tight cover, that would stop the evaporation completely, but more of a cover than the overturned box. A piece of paper or cloth could be fastened over the top of the container with a rubber band to let evaporation proceed slowly.

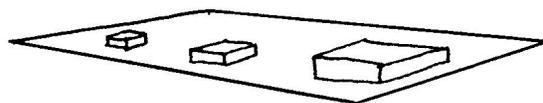
2. We could take one good little crystal out, transfer the saturated solution to another container, and put that crystal back in again. Maybe it would be the only one to grow. A crystal used in this way is called a seed crystal. (Remember that any solution, clinging to the crystal you take out or to the tweezers or your fingers, is saturated. As it evaporates little crystals will grow rapidly in it and form additional seeds that will compete for material with the one that you want to grow. For this reason you should dry your crystal quickly on cleansing tissue or a clean handkerchief, and wash and dry the tweezers and your fingers.)

When a crystal grows, resting on a surface, the part next to the surface is deprived of additional material and cannot develop. To let a crystal develop on all sides, we must hang it from a thread in the solution. Tying a thread around a very small crystal is not easy. An alternative method is to cement the thread to the crystal with a tiny bit of the kind of cement that is used for mending plates. Let it dry over night before hanging the crystal in the saturated solution.

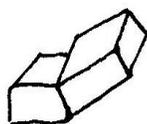
b. What to do with the crystals

1. An instructive exhibit could be made by taking out a series of crystals (with tweezers) at various stages of growth, and mounting them with a very small bit of glue or cement on a card or paper (perhaps black or dark colored). The sequence, from small to large, will show how the crystals keep the same shape as they grow larger.

Try to avoid choosing a piece made up of more than one crystal, since



this makes observation of the shape and comparison of the sizes more difficult.



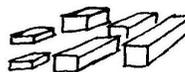
Two crystals

2. Break them. Tap a crystal lightly with a small hammer or the heavy handle of a knife or screwdriver or the bowl of a spoon. It will break along plane surfaces parallel to the plane faces that form the outside surface.

These may be broken into still smaller pieces, again with plane surfaces (that shine brightly in a strong light) parallel to the original ones. They may be broken anywhere at all. The surfaces will still be parallel to each other.



This may break into... these



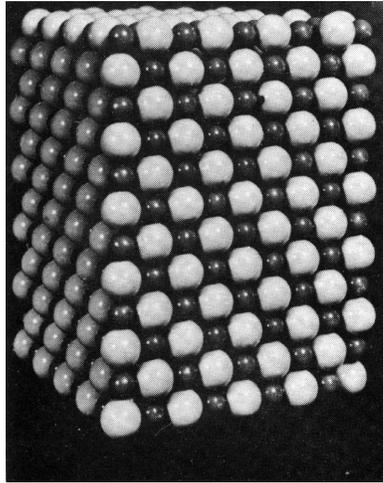
This tendency of a crystal to come apart along plane surfaces of a particular orientation is known as **cleavage**. Not all crystals show cleavage. Some just break like a piece of glass.

In salt, the cleavage planes are parallel to the growth faces, the faces that form the outer surfaces as the crystal grows. In crystals of some other substances, the cleavage planes are not parallel to the growth faces.

What is it that makes sodium chloride crystals grow in rectangular shapes and come apart along planes at right angles to each other? Crystallographers wondered and speculated about such questions for many years. Only in the twentieth century has the use of x-ray diffraction enabled us to find out how the arrangement of atoms and ions and molecules in crystals accounts for the way they grow and can be cleaved and for many other properties. The x rays do not cast shadows of the atoms as they do of the bones

of the body. The atoms are too small for that. The x rays are scattered by the atoms, and by studying the directions in which they are scattered crystallographers learn how the crystals are put together.

In sodium chloride, common table salt, they find that the sodium and chlorine ions alternate with each other, like this.



It would take 10^{17} blocks like this to make one cubic grain of salt 1 mm on each edge. That is 100,000,000,000,000,000. That's a hundred million times a thousand million. You would expect such an arrangement to build rectangular crystals. You might also expect that it would come apart most easily along those layers of sodium and chlorine ions.

Each crystal has its own characteristic arrangement of atoms, ions, or molecules which accounts for the shape in which it grows and for its other properties.

3. Keep a few of the best crystals in a small box or jar or envelope, for use in later experiments. (See experiments with polarized light, Section III-D.)

4. Place a crystal on a glass slide or other clean surface and place a large drop of water on it, watching it with a magnifier as it dissolves in the water. The corners get rounded quickly because they have three faces exposed to the solvent. The edges get rounded somewhat less quickly because they have only two faces exposed to the solvent. If the crystal is rescued before it has dissolved completely, is dried with cleansing tissue or a clean handkerchief, and then placed again in the saturated salt solution, it will start to grow

again, filling out the edges and corners and regaining its original shape!

5. You can use any of your crystals as seed crystals, to grow bigger crystals from a saturated solution of the same substance, but the smaller ones are better.

6. Use your crystals as source material to start over again from the beginning. They are now pure salt, without any insoluble coating.

c. Lessons from this section

An important lesson to be learned from this section is that a salt crystal grows by adding salt to itself from the water solution of salt that surrounds it and that it grows with flat shiny faces which are at right angles to each other, provided its growth is not obstructed. The fact that these crystals have cleavage indicates that, **within the crystal**, one direction is not like every other. The kind and arrangement of atoms, ions, or molecules in a crystal determine its shape and other properties.

Decanting has been used as a method of separating liquid from solid. Seeding has been used as a method of growing larger single crystals.

The fact that crystals growing from closely spaced nuclei cannot grow very large was observed in the growth of the white crust at the edge of the solution, a crust which spread as the solution crept up through it and under it by capillary action.

The manner in which solution of a cube-shaped solid progresses was observed.

2 Borax ($Na_2B_4O_7 \cdot 10H_2O$) in water

Although the third substance, sugar, is more readily available than borax, borax is placed second because it forms beautiful crystals so quickly. Borax is used as a cleaning agent, in washing clothes, and is sold in paper boxes, just as powdered soap is. It is harmful, if swallowed.

Borax is much more soluble in hot water than in cold water. This is not true of everything. Salt, for instance, is about as soluble in cold water as it is in hot water.

a. Growing the crystals and observing their growth

Add one teaspoonful of borax to 1/2 cup of very hot water, stirring the mixture until the borax has dissolved completely. After this has cooled, many beautiful little crystals will grow.

b. What to do with the crystals

The activities suggested for using the sodium chloride (salt) crystals are also suitable for the borax. Similar growth-stage exhibits could be made. It could be tested for cleavage. One crystal could be taken from the solution, dried, tied with a thread, and used for a seed to be suspended in a saturated solution. A solution with which growing crystals are in contact is certainly saturated. Otherwise they would dissolve. Therefore if such a solution is poured into another container, at the same temperature, (taken away from the several little crystals growing in it) it will deposit borax on a borax seed hung in it.

It is best to have the seed near the bottom of the container. The reason for this is as follows. The density of a saturated solution of almost anything is greater than that of an unsaturated solution. As borax is deposited on the crystal, the solution from which it is deposited becomes less dense and rises. The denser, saturated solution (weighing more, per unit volume) flows in to take its place and bring more material to the seed crystal. If the seed is close to the top of the solution, the less dense, unsaturated solution surrounds its upper end. Of course, right at the surface, where the solution is in contact with the air, evaporation results in crystallization. Seeds often form there, but can only develop on one side and are always, therefore, distorted in form.

Compare the shape of the borax crystals with that of the salt crystals.

Look at very small salt crystals and very small borax crystals between crossed polarizers (see section III-D), using a magnifier. The effect may be less obvious with large crystals having bright faces or inclusions which reflect the light.

Water molecules are among the invisible particles of which borax crystals are made. If borax crystals are kept in a warm dry place for a long time, some of the water will escape into the air. That part of the crystal that has lost water falls apart into a powder. The little particles of the powder scatter the light and therefore look white. This process of losing water is called **dehydration**.

c. Lessons from this section

Some crystals, such as borax, grow faces that do not meet at right angles. Borax and salt have different shapes. Borax and salt have different effects on light, as indicated by their appearance between crossed polarizers. The two substances could be distinguished from each other by the **properties** which have been observed. They differ in solubility, crystal form, cleavage,

and effect on light. It is clear, therefore, that when borax comes out of solution, it builds borax crystals in a different way from that in which the salt builds salt crystals when it comes out of solution.

3 Sugar (sucrose or saccharose, $C_{12}H_{22}O_{11}$) in water

a. Growing the crystals and observing their growth

Good sugar crystals are difficult to grow. Sugar in water forms a very viscous (thick, syrupy) liquid and the sugar molecules cannot move rapidly through it to join the other sugar molecules in the orderly arrangement that we call a crystal.

The secret of success is to keep the solution warm enough to promote the mobility of the molecules, but, at the same time, not to cause rapid evaporation at the surface that would cause the formation of a surface crust. To achieve these two results, proceed as follows.

Heat one cup of sugar and one-half cup of water gently, with constant stirring, until all the sugar dissolves and the solution is clear. Put this in a jar of the sort used for jams and jellies and put a cover on the jar, but do not screw it down tightly. The jar must be kept very warm for many days. It could be placed over the pilot light of a gas stove. Water evaporating from the surface condenses on the lid and drops back onto the surface, preventing the formation of a crust. A little water escapes, all the time, because the lid is not tight. Eventually crystals will grow with the beautiful form characteristic of table-sugar crystals. The growth continues slowly for a very long time.

The sugar solution has the interesting property that it rotates the plane of polarized light (see section III-D). This rotation is different for different colors of light. When you hold the jar of sugar solution between crossed polarizers and look through it and the polarizers toward a white light, you will find that it does not look black, as the salt solution does, but colored. As you rotate either of the polarizers (in its own plane, as the hands of the clock rotate), keeping the other still, the color changes.

b. What to do with the crystals

All of the suggestions made under the headings of salt and borax are also applicable here. In addition, you can now compare the shape of a sugar crystal with that of a borax crystal and a salt crystal.

c. Lessons from this section

Sugar crystals differ in shape and ease of growth from salt, the other familiar substance on our dinner table. They also differ in shape and ease of growth from borax. When sugar comes out of solution, it must build the sugar crystal in a different way from that in which the salt crystals are built or that in which the borax crystals are built. Each substance has its own way of arranging the particles of the substance to form a crystal.

The particles that form a crystal must be free to move if they are to get together to form a crystal. The sugar solution is so viscous (thick, syrupy) that it slows down this motion and therefore sugar crystals are harder to grow than salt or borax crystals.

A water solution of sugar, unlike a water solution of salt or borax, rotates the plane of polarized light (see section III-D).

4 Alum [ammonium alum, $NH_4Al(SO_4)_2 \cdot 12H_2O$ or potassium alum, $KAl(SO_4)_2 \cdot 12H_2O$] in water

Alum crystals are easier to grow than salt crystals and much easier than sugar crystals. They have brightly reflecting faces and the smaller crystals sparkle attractively. Powdered alum is available in most drug stores (chemists', pharmacists'). It is used as an astringent and to reduce bleeding from small cuts.

a. Growing the crystals and observing their growth

Put 4 teaspoonfuls of alum powder in half a cup of hot water. Stir to aid solution. After some time, all of the powder will go into solution, which will then be clear.

Put a light cover, such as a piece of paper, over the container, to keep the dust out. As the water evaporates, beautiful alum crystals will appear.

Observe the crystals carefully and compare their shapes with those of other crystals. Are these clearer or less clear than the salt crystals? Note that alum, like borax, contains water (H_2O) as part of the composition of the crystal. It may be of interest to compare the appearance and ease of growth from water solution of those crystals that do contain water molecules in their composition and those that do not.

b. What to do with the crystals

1. Arrange a growth sequence exhibit, as in the salt case.
2. Break them. You will discover that, unlike salt, but like sugar, alum has no cleavage planes.

3. Keep some in a box or envelope, appropriately labeled, for use in later experiments.

4. Partially dissolve and regrow an alum crystal, as in b,4 of the salt experiment.

5. Hang a perfect little alum seed crystal in a saturated alum solution and grow a beauty.

6. Look at an alum crystal between crossed polarizers (section III-D2).

c. Lessons from this section

Alum crystals are unlike either salt crystals or sugar crystals in several ways. They grow large more quickly. They have a shape that differs from both salt and sugar. Like sugar crystals, but not like salt crystals, they do not show cleavage, but break irregularly. Like salt crystals, but not like sugar or borax crystals, they look dark between crossed polarizers.

5 Copper sulfate (blue vitriol, $CuSO_4 \cdot 5H_2O$) in water

POISONOUS

You may be able to get copper sulfate from a drug store (chemists', pharmacists'). It is used in some swimming pools to prevent plant growth, but is somewhat poisonous. Students should not be allowed to take any of it home. Wash your hands thoroughly after handling copper sulfate powder, solution, or crystals. (The powder is also made of very small crystals, but is mostly of the anhydrous copper sulfate, copper sulfate without water as part of its composition.)

a. Growing the crystals and observing their growth

Put 4 teaspoonfuls of copper sulfate powder into half a cup of hot water and stir until the solid has dissolved. As the solution evaporates, a crust of copper sulfate will creep up the side of the container and over the edge. Copper sulfate is even worse in this respect than the salt solution, so it would be a good idea to have the container standing on a dish or saucer.

When the solution has evaporated enough, bright blue crystals will start to grow. Study their shapes and watch them develop, day by day.

A very beautiful experiment can be performed by mixing alum powder and copper sulfate powder and dissolving the mixture (2 teaspoonfuls of each in half a cup of water, for example). The result is that the alum crystals grow as they did before, colorless, with their characteristic shape; and the copper sulfate crystals grow as they did before, bright blue, with their characteristic shape. They may meet and stick to each other; one may

grow around another; but they don't **mix**. The orderly array in alum is not the same as the orderly array in copper sulfate and each substance builds its own kind of crystal.

b. What to do with the crystals

REMEMBER THAT COPPER SULFATE IS POISONOUS. It should not be given to young children. Older children should be repeatedly warned to wash their hands after handling it.

1. Crystals of various sizes may be mounted for display as previously grown crystals were.

2. Examine their shapes and compare them with the shapes of the alum, sugar, borax, and salt crystals.

3. Try to draw the edge-out-lines of each crystal grown so far. Drawing aids observation.

4. Try to cleave them. (Copper sulfate does not show cleavage.)

5. If kept for a very long time in a warm dry place, copper sulfate, like alum and borax, may become dehydrated.

6. The crust that forms on the side of the vessel consists mostly of the anhydrous form of copper sulfate. It can be collected and dissolved, just as the original powder was.

c. Lessons from this section

Again the comparison of the new crystals with the other crystals grown shows that each substance has its own form and properties, and this time a new property has been added - color.

If the mixture of alum and copper sulfate is tried, the added observation has been made that each substance adds on to its own crystals those particles that belong to the crystal that is being built and does not accept other particles that may be present that do not belong in the structure of that crystal.

6 Epsom Salt ($MgSO_4 \cdot 7H_2O$) in water

Epsom Salt is sold as a laxative and also for making a wet dressing to use on bruises, sprains, and insect bites. It is sold by nearly all drug stores (chemists', pharmacists').

a. Growing the crystals and observing them

Epsom salt is very soluble in water. You can dissolve about 6 teaspoonfuls in a quarter of a cup of hot water. Stir the solution for several minutes.