

**JoVE: Science Education**  
**Physical Properties of Minerals: Crystal Form and Cleavage**  
--Manuscript Draft--

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## **Earth Science Education Title: Physical Properties of Minerals: Crystal Form and Cleavage**

### **Overview**

The physical properties of minerals include various measurable and discernible attributes, including color, streak, magnetic properties, hardness, crystal growth form, and crystal cleavage. Each of these properties are mineral-specific, and they are fundamentally related to a particular mineral's chemical make-up and atomic structure.

This video examines two properties that stem primarily from symmetric repetition of fundamental structural atomic groupings, called unit cells, within a crystal lattice- crystal growth form and crystal cleavage.

Crystal growth form is the macroscopic expression of atomic-level symmetry, generated by the natural growth process of adding unit cells (the molecular building blocks of minerals) to a growing crystal lattice. Zones of rapid unit-cell-addition become the edges between the planar surfaces, i.e. faces, of the crystal (figure 1).

It is important to recognize that rocks are aggregates of mineral grains. Most rocks are polymineralic (multiple kinds of mineral grains) but some are effectively monomineralic (composed of a single mineral). Because rocks are combinations of minerals, we do not refer to rocks as having crystal form. In some cases, geologists will refer to rocks as having a general sort of cleavage, but here the term is simply used to refer to repetitive breaking surfaces, and is not a reflection of atomic crystal structure. So in general, the terms crystal form and crystal cleavage are used in reference to mineral samples, and not for rock samples.

### **Principles**

All minerals possess physical properties, but specific and easily recognizable features associated with the properties are not always expressed in an individual crystal. For example, quartz crystals have a characteristic hexagonal shape, but if crystal growth occurs in an environment where other minerals block or impinge the natural growth shape (which is commonly the case in most rocks) then the hexagonal shape does not form. So with this in mind, it's important to carefully select a suitable group of samples for either crystal growth or crystal cleavage analysis, as not all samples will show these key features.

Furthermore, although crystal cleavage is relatively easy to test—by breaking a sample with a hammer—different minerals will demonstrate a range of cleavage quality, such that the planar surfaces generated by breaking may be ragged and rough (termed “poor-cleavage”) or extremely smooth (termed “good-” or “excellent-cleavage”). In some cases (e.g. quartz, see below) crystallographic bond strengths are uniform in all directions, and this results in a mineral with a lack of recognizable cleavage planes.

## PROCEDURE

1) Establish a group of mineral samples. Include as many of the following as you can: Quartz, Halite, Calcite, Garnet, Biotite and/or Muscovite.

Some are chosen for crystal growth features, and others for crystal cleavage features.

2) Observing and Analyzing Crystal Form.

2.1 Place a sample onto the observation surface.

2.2 Rotate in order to observe all sides. Look for crystal faces, crystal edges (lines where faces meet), and crystal vertices (points where edges meet).

2.3 Where possible, measure the interfacial angles using the goniometer. This is done by simply laying one side of the goniometer on a particular crystal face, and the other side of the goniometer on an adjoining face, then reading the angle.

2.4 Compare to the set of characteristic crystalline polyhedra.

2.5. Repeat steps 2.1- 2.4 for Quartz (note hexagonal dipyramidal form (figure 2)), for Calcite (note scalenohedron form (figure 3)), for Halite (note cubic crystal form (figure 4)), Garnet (note dodecahedron form (figure 5)), and for Biotite (note pseudo-hexagonal form (figure 6)).

3) Observing and Analyzing Cleavage.

3.1. Put on eye protection

3.2 Place a piece of Quartz on breaking surface.

3.3. Using hammer, break the piece of Quartz in half.

3.4 Using hand lens, observe broken piece of Quartz for cleavage surfaces. Notice that Quartz has none. Quartz exhibits conchoidal fracture but no well-defined cleavage surfaces. This is a consequence of the fact that the unit cells in the quartz

crystal lattice (SiO<sub>4</sub> groups, called silica tetrahedral) have comparably equal bond strengths in all directions. This uniformity of bond strengths results in a crystal that has no preferred breaking planes.

3.5. Repeat steps 3.2 – 3.4 for specimens Calcite (should display rhombohedral cleavage (figure 7)), Halite (should display cubic cleavage (figure 8)), Biotite and/or Muscovite (should each display planar cleavage (figure 9)).

4) Use hand lens to evaluate different cleavage qualities. Cleavage can occur at a variety of levels. When there is a dramatic difference in bond strengths in a particular orientation, such as between sheets of SiO<sub>4</sub> groupings in the case of mica, a nearly perfect cleavage is generated between these sheets. As noted above, quartz exhibits a nearly total lack of cleavage. In between these extremes (of perfect cleavage and lack of cleavage) we have minerals that have good cleavage (e.g. feldspar) and poor cleavage (certain faces on amphibole crystals)

## APPLICATION

Historically, evaluating the physical properties of minerals has been a key first step in mineral identification. Even today, when lacking microscopic and modern analytical instrumentation (e.g. petrographic microscopy, x-ray diffraction, x-ray fluorescence, and electron microprobe techniques), observed physical properties are still quite useful as diagnostic tools for mineral identification. This is particularly the case in field geologic studies.

Evaluating and observing the physical properties of minerals is an excellent means to demonstrate the critical dependence of macroscopic features on atomic-level structure and arrangement.

Lastly, and as previously discussed and noted, the key physical properties of minerals are not always expressed in specific samples. Therefore, actually being able to recognize and use these properties as diagnostic tools requires a combination of science, experience, and craft. Often, the geologist must utilize a hand-lens to evaluate relatively small mineral crystals or grains, within the matrix of a larger rock. In such cases, it can become a distinct challenge to identify the useful aspects of crystal form and crystal cleavage.

## Legend:

**Comment [AK1]:** What we really want from these applications is specific examples of how the method discussed in the manuscript/video is used to achieve something that a geologist might set out to do whether or not we're talking about an academic or industrial application. I'm not getting much from this section that I couldn't infer from the rest of the manuscript. By the time I get to this part of the submission, I already know that that looking at physical properties is used to identify minerals. The fact that we are covering this topic in SciEd period pretty much makes it obvious that the concepts here are important for application.

Really, we want context for mineral analysis using the techniques covered in the video. Why and when are geologists or mineral analysis experts doing these methods?

**Comment [ml2]:** Well,, here's the scoop-- Both academic and industry geologists use the hand lens and this whole business of "hand-sample mineral ID" in relatively few circumstances.

The NOTABLE exception is in field work. In the field, the geologist is often tasked to do rock/mineral ID. This can only be accomplished in a crude fashion, and IF the rock exhibits mineral grains that are 1) visible to naked eye or with hand lens,,, and 2) exhibit diagnostic features such as cleavage/color/xtal form that can be used to establish a "proposed" ID (i.e.—a hypothesis regarding mineral content of the rock,,, only "provable" with more advanced microscopic and chemical techniques)

HENCE—I fee that my last paragraph is really important and central to this whole video. The idea is that mineral/rock ID is HARD to do...and even under good conditions (meaning the rock exhibits large enough xtals, with clear-cut properties), a geologist has to be quite skilled.

**Comment [DM3]:** Figures 2-9 can be obtained at the actual shoot.

### **Fig 1 Schematic illustration of why crystals have smooth faces**

(taken from: <http://en.wikipedia.org/wiki/Crystal>)

The rough edges have a lot of dangling bonds, which new atoms can easily bond to as the crystal grows. The smooth planes (with low surface energy and usually low Miller index) have fewer dangling bonds, and new atoms cannot easily attach, so these planes grow outwards more slowly. Eventually you end up with the whole surface being smooth planes. This cartoon is supposed to represent of cross-section of halite: Purple circles are sodium ions, green circles are chloride ions. Image is inspired by a similar one at <http://www.its.caltech.edu/~atomic/snowcrystals/faceting/faceting.htm>

### **Figure 2: Quartz displaying hexagonal dipyramidal form**

### **Figure 3: Calcite displaying scalenohedron form**

Note how several crystal faces intersect to form crystal edges and also the combination of edges to form points known as “vertices.” Symmetric crystal growth forms are generated by repetition of fundamental atomic structures (unit cells) within the crystal lattice. In this case, calcite crystal growth generates the specific polyhedron known as a scalenohedron.

### **Figure 4: Halite displaying cubic crystal form**

### **Figure 5: Garnet displaying dodecahedron form**

### **Figure 6: Biotite displaying pseudo-hexagonal form**

### **Figure 7: Calcite displaying rhombohedral cleavage**

Symmetric breaking and fracture surfaces are generated by zones of relative weakness in atomic bonding within the crystal lattice. Calcite cleavage results in the specific polyhedron known as rhombohedron.

### **Figure 8: Halite displaying cubic cleavage**

### **Figure 9: Biotite/or Muscovite (depending on what sample is at the shoot) displaying planar cleavage**

#### **Materials:**

- hand lens for examination of growth surfaces and cleavage surfaces
- goniometer for measuring interfacial angles on the crystal surface

- A set of wooden models showing basic polyhedral forms that are expressed by common minerals. If wooden models are not available you can alternatively access any number of online polyhedron charts.
- observation surface (can be the same as your breaking surface)
- hammer and breaking surface preparations (platform and eye-protection)

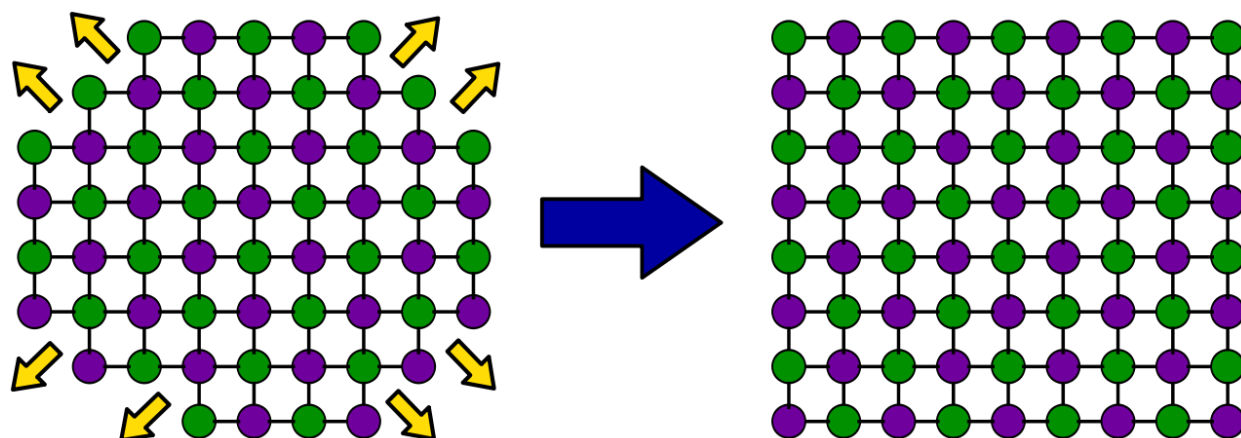


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The key physical properties of minerals are not always expressed in specific samples. Therefore, actually being able to recognize and use these properties as diagnostic tools requires a combination of science, experience, and craft. Often, the geologist must utilize a hand lens to evaluate relatively small mineral crystals or grains within the matrix of a larger rock. In such cases, it can become a distinct challenge to identify the useful aspects of crystal form and crystal cleavage.

In the academic or teaching setting, the evaluation of minerals via hand sample analysis is an exercise that demonstrates how repetitive patterns and

characteristics are imposed by the physical chemistry of natural materials. -In other words, for any specific mineral, there are certain crystallographic features (e.g. crystal morphology) and physical properties (e.g. color, hardness, streak) that are imposed by chemical composition and atomic structure.

2) In the realm of mineral resources and exploration geology, the identification of minerals via hand sample is a key component of field work, aimed at locating potential ores and economically useful deposits. -For example, the identification of various metal sulfides (pyrite, sphalerite, galena) in association with hydrothermal iron oxy-hydroxides (hematite, goethite, limonite) can be indicative of potential Au- and Ag-rich veins and regions.

3) In the context of historical geology (deciphering the deep temporal history of a region), mineral identification can set the stage for interpretations of ancient conditions. - For example, certain metamorphic minerals (e.g. the  $Al_2SiO_5$  polymorphs, kyanite, andalusite, and sillimanite) are markers of particular pressure and temperature conditions in the ancient crust.

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