

**PHYSICAL PROPERTIES OF MINERALS
AND DETERMINATIVE TECHNIQUES**
An Introduction to Cooperative Learning

Ken Bladh
Wittenberg University
Springfield, Ohio 45501
KBLADH@Wittenberg.edu

How do you, as a student, make cooperative learning work ?

In a cooperative learning environment, you are responsible for others' learning as well as your own. I'm convinced that you don't really know something until you understand it well enough to teach someone else, a skeptical knowledgeable classmate, in this case. This learning strategy also reflects the reality that each of you has valuable insights and skills to contribute to the group. And by sharing, each of you will become better.

You will belong to one of several learning/teaching groups and assume part of that group's work load. Each group member accepts the responsibility of becoming an "expert" on part of the lab assignment. After completing your part of the assignment independently, you and "experts" on the same topic from other learning/teaching groups meet as an "expert group", to discuss your findings and to reach consensus. Upon returning to your respective learning/teaching group, each of you will teach (summarize and demonstrate on specimens) to your classmates what your expert group has concluded. The learning/teaching group has become a group (team) of different experts. Even though the original work was distributed, each student is responsible for all results. You are quizzed over all topics and those individual quiz scores become team scores by averaging. Each member receives the team score, so you have a vested interest in the performance of others in your learning/teaching group.

Some cautions: This environment only works when each of you puts a full effort into the small part of the total work assignment that is yours. Each member of an expert group must **critically review** the results of the other group members. **Expert group consensus must be based on proof - this week, by demonstrating a property on a specimen.** There is a tendency, in this week's lab particularly, to describe everything about your topic without critical analysis of just the most important aspects. In other words, don't simply regurgitate the text - which in this context does no one any good.

Instructions for this exercise

Read the appropriate sections of your text and the discussions in this handout. Use the reference specimens -- they should exhibit the behavior described in the text and this handout. If they don't, get help! Sometimes you may experience the limits and uncertainty associated with hand sample mineral identification; **don't hesitate to share examples of these uncertainties.** You will probably want to mention the location of good reference examples in your report to classmates. Text references are to Klein and Hurlbut (1993) *Manual of Mineralogy*, 21st edition (K&H).

→ Arrows mark demonstrations that you or a classmate will do and questions for which you must turn in answers.

Part A. Physical Properties Associated with Light

Read the explanations of **streak** and **luster** found on page 266 of K&H. Please take the time to study the reference specimens of those minerals cited as examples for luster types and use terms properly in your report to classmates.

Although sometimes obvious, **metallic** and **nonmetallic** lusters can be very difficult to distinguish from one another. Dark minerals (black, brown, deep green) appear to be opaque (metallic), although on their thin edges they are slightly transparent (and therefore nonmetallic!). You could ask the instructor to loan you a thin section of a seemingly-opaque, dark, nonmetallic mineral for which you have a handsample that shows the effect described above. Metallic minerals commonly develop a tarnished outer surface that masks the true luster, until scratched.

Luster is the appearance of the mineral's fresh surface in reflected white light. Although luster describes the reflected component of light, a quantitative relation exists between the **index of refraction (n)** (see K&H page 290) and the type of luster displayed by transparent or translucent minerals (see Figure 6.13, page 260 in K&H). An example of each species in italics below is available for your use as a reference. Non-metallic lusters:

adamantine splendent = $2.6 < n < 3.4$ (*orpiment, cinnabar, hematite*)
adamantine = $1.9 < n < 2.6$ (*diamond, cerussite, anglesite*)
vitreous = $1.3 < n < 1.9$ (*quartz, tourmaline, 70% of minerals*)
resinous = $1.9 < n < 2.6$ (*sphalerite, sulfur*)

Some non-metallic lusters are produced by physical optical effects:

pearly = mineral with internal microscopic separations parallel to its surface (often cleavage separations) - *talc*
greasy = mineral with a thin outer film of altered material of different n than the fresh material underneath. *nepheline* is the best example.
silky = mineral with parallel micro-fibers. *chrysotile, fibrous gypsum, malachite*.
play of colors - from optical interference. (see K&H pages 266-267)
opalescence (*opal*)
iridescence: *schiller*
labradorescence (*labradorite = plagioclase feldspar*)

Metallic lusters, usually are assigned to one of three subtypes - submetallic, metallic, or splendent. The percent reflectance of these mineral surfaces, as measured by sensitive photometers, provides quantitative measures of luster. "Metallic" surfaces range between "submetallic" (at low reflectance) and "splendent" (at high reflectance) lusters. Mineral examples for **submetallic** (8-20% reflectance) include: *magnetite, graphite, chromite*. Minerals with **metallic** luster (20-50% reflectance) include: *molybdenite, galena, chalcopyrite, bornite*. Minerals with **splendent metallic** luster (50-95% reflectance) include: *pyrite, marcasite, fresh copper or silver, gold, platinum*.

- For the samples provided, describe the **luster and streak**.
- For the samples provided, estimate the **% reflectance** by comparison to standards.

Part B. Breakage Behavior - Cleavage, Fracture and Parting (K&H pages 252-254)

Cleavage, fracture and parting describe the appearance of broken mineral surfaces. When a mineral breaks along flat planes, it has **cleavage** or **parting**; when the broken surface is irregular, the mineral displays **fracture**. Some minerals display cleavage and fracture, others have only one or the other. Fracture, cleavage and parting are detected by rotating the specimen so that it reflects light to the observer's eye and by simultaneously judging the flatness and perfection of the reflecting surface. Several terms describe the *quality of cleavage*:

perfect - it is difficult to break the mineral in any other direction. Cleavage surfaces are smooth and extensive. (*galena, calcite*)

good - breaks easily along cleavages but can also be broken in other directions. Cleavage surfaces are smooth but are interrupted by other fractures. (*enstatite, orthoclase*)

imperfect - breaks somewhat more easily along cleavage surfaces than along other surfaces.

Cleavage surfaces tend to be small and much interrupted. (*diopside, beryl {0001}*)

Fracture is described as **conchoidal, fibrous, splintery, hackly, irregular** or **uneven**.

Some hints for the careful observer: Breakage can be described only when individual crystals are large enough to be seen (many minerals occur as aggregates of tiny individuals). The description of breakage in minerals is also complicated when the observer must distinguish between broken surfaces and crystal faces. Crystal faces are perfectly smooth. Cleavage surfaces exhibit "sheeting" or "stepping" parallel to the cleavage plane. Transparent minerals show incipient cleavage breaks that look like flat ghosts, inside the mineral, parallel to the cleavage on the surface of the specimen. These incipient internal breaks are responsible for the "play of colors" seen when light reflects from the perfect cleavage surfaces of some minerals (cf. *calcite* and *fluorite* examples in the lab).

→ For the samples provided, record the "quality of cleavage" and "type of fracture."

Examine several samples of *corundum*. Note that some samples exhibit "cleavage" yet others do not. Therefore, this "false cleavage" (only present on some samples of a mineral) is an example of **parting** (cf. K&H Figure 6.5b).

In addition to recognizing the presence of cleavage, one should determine the number of **cleavage directions**. Each direction might be responsible for several parallel flat broken surfaces on a specimen. Alternatively, one could count the sets of parallel "cleavage traces" that intersect the specimen's surface. These traces are the intersections of breakage surfaces with the surface being viewed by the observer (cf. hornblende cross section, K&H page 490). When more than one direction of cleavage is present, one must describe the angle between the sets. The combined data about number of directions and angles between them can be expressed by the descriptive terms shown by Figure 6.4 in K&H (page 253) or by specifying them as follows: "2 directions intersecting at 56° and 124° to one another", for the amphibole example on page 490.

→ For the samples provided, record the **number of cleavage directions** and use a contact goniometer to measure the **angle** between directions.

Part C. Hardness (K&H pages 254-255)

Mineral **hardness** is usually described by comparison to the ten minerals in the Mohs scale of relative scratch hardness. Alternatively, hardness may be estimated for soft minerals by using a

steel probe ($H = 4.5$) or a knife blade ($H = 5$) and by noting the ease with which the mineral can be scratched. For harder minerals, one observes the ease with which a piece of glass ($H = 5.5$) is scratched by the mineral. You should be aware that the Mohs scale is not linear. Consequently, the difference in hardness between eight and nine is greater than between two and three.

- **Demonstrate to your group each of the following phenomena** that influence accurate scratch tests with specimens from the reference hardness sets:
1. Altered minerals are more easily scratched than their fresh equivalents (*garnets, feldspars, corundum, andalusite, etc.*).
 2. Minerals in granular aggregates appear to be scratched when in reality the grains have only torn apart or crushed.
 3. A relatively soft mineral may leave a faint white ridge on a harder surface which can be mistaken for a scratch if observed casually. Always rub a "scratch" to remove powder that may be obscuring the indentation on the softer surface -- the definitive proof of a real scratch !
 4. A mineral is often slightly scratched by the edge of another piece of the same species, even though they have the same hardness.
 5. As materials of more nearly equal hardness are used for the test, the difficulty of obtaining a scratch increases.
 6. The scratch should disfigure the specimen as little as possible !
- For the samples provided, record the **Mohs hardness**.

Somewhat related to hardness, **tenacity** describes the cohesiveness of a mineral. Although most minerals are "brittle", the descriptive terms for tenacity (K&H pages 255-256) are useful for minerals that are not brittle. Although used infrequently for mineral identification, this term, tenacity, can be very useful.

- Demonstrate the tenacity of chlorite (flexible) and muscovite (elastic) as an example of the utility of this observation.

Part D. Density (Specific Gravity) (K&H pages 256-257)

The **density** (weight per unit volume) of a mineral can be determined in several ways. The fastest and least accurate method is to pick up the specimen, heft it, make a judgment of its weight taking into account its size (volume) and purity, and then estimate the density by comparison to knowns. Water has a density of 1.0 g/cc, the average mineral is 2.8, and a heavy mineral has a density greater than 8.

- For the samples provided, record the **density** (low, average, or heavy) determined by hefting and comparison to knowns.
- Demonstration. Read the discussion about "Determination of Specific Gravity" (K&H pages 257-259) and obtain the equipment from your instructor to measure specific gravity. Outline a step-by-step procedure for measuring the data and calculating specific gravity with the equipment available to you. Follow your procedure for two samples provided by your instructor (one known and one unknown).

Part E. Miscellany - Some Chemical Properties and a Plea for Common Sense

Please do this last part individually.

Taste

Water-soluble minerals interact with the human tongue producing characteristic tastes. Halite, with its **saline** taste, is a good example of this phenomenon. Other minerals exhibit one of several common tastes (**astrigent, bitter, sour, alkaline, cooling**). However, great caution must be exercised when considering putting unknown materials in your mouth! Read the article "Toxic Minerals" by J. H. Puffer (Mineralogical Record, 1980, pages 5-11).

→ Then write brief responses to each of the following:

- List the names of all of the "suspected or proven toxins" (Table 1) that you have handled.
- Summarize Puffer's message about "dose", the levels of ingestion that are dangerous.
- Compare the expressed intent of the author (first sentence of the introduction) with the impact of the paper on you.
- Read Malcolm Ross' analysis of this paper copied from the MSA list server. Write your reaction to Ross' position (half page).

Odor

Most dry minerals do not produce odor. However, friction (hitting with a hammer), moistening with breath, heating, or reaction with acids may liberate a gas and its associated odor.

garlic = arsenic compounds (toxic)

horse-radish = selenium (toxic)

sulfurous = sulfide compounds

bituminous = hydrocarbons

fetid (rotten egg) = H_2S (toxic)

argillaceous = earthy materials

The last four examples on this list are most useful and least toxic. Try them on appropriate specimens as you learn the minerals this semester.

Other Properties

Read in K&H (pages 268-274) about other physical properties, even though, you will probably not use them in routine mineral identification. **Fluorescence** and **magnetism** will be of some use this term.

[What follows is a reply from one mineral scientist to an Internet request for references about mineral toxicity. Read Puffer's paper, this note and reach your own conclusions.]

Date: Tue, 21 Mar 1995 15:10:27 -0500 (EST)

From: Malcolm Ross, U.S. Geological Survey

Subject: Mineral Toxicity, a paper by J. H. Puffer, Mineralogical Record., Feb. 1980.

Pete Modreski recommended this paper as a reference on the subject of minerals and health. If those teaching mineralogy wish to scare the hell out of their students, let them read this paper. Afterward they'll probably change their major to something non-controversial like fly tying. Puffer's Table 1 lists nearly 200 minerals that are "analogous to minerals described by NIOSH (1977) as suspected or proven toxins." One is hard pressed to understand how most of these minerals got on the toxic list, except to note that the NIOSH people know nothing about mineralogy.

Barite, one of the most insoluble minerals, is ingested as a barite slurry for medical diagnostic purposes. **Corundum, native gold, beryl, brookite, and hematite** are extremely inert minerals and are in no way toxic unless, perhaps when ground up as sub micron particles and inhaled in large quantities. Did you know **calcite** is a toxic mineral? I'll bet not! This list is so ridiculous that it defies intelligent comment. One does not place minerals in their mouths, especially the soluble minerals, the same way one does not ingest reagent chemicals from your chem lab. All chemicals are poisonous when taken in sufficient amounts and all minerals dusts are dangerous in large quantities. **Hexavalent chromium salts** are dangerous in certain situations; **trivalent Cr** in minerals is unavailable biologically, the same way lead-bearing minerals in mine wastes are unavailable biologically. **Lead-bearing minerals** when ingested they go right through the digestive tract in a few hours before any significant dissolution takes place. Children in old lead mining towns, such as Leadville, CO, who played on lead-bearing mine tailings show blood lead levels that are no higher than the U.S. average. Yet the fear of lead in the environment of these towns has devastated real estate values. I could go on and on about this subject, but can only plea that mineralogists get a better understanding of health risks by very carefully reading the primary medical literature instead of relying on second hand literature promoted by fear mongers.

Comments to the Instructor

This laboratory exercise builds on learning from a prerequisite course (Physical Geology) and therefore works well early in my mineralogy course. I use it before crystallography, which explains why Miller indices and form names are not used to describe cleavage. Many of the students in my course have not yet had chemistry and are still developing basic skills in careful observation. Many are still learning the importance of quantitative ways of describing nature in contrast to the more qualitative ways that minerals and rocks are commonly handled in introductory geology courses. The topic is one about which they have some knowledge and are, therefore, in a comfort zone as they learn the "Jigsaw" cooperative learning strategies. This activity also demonstrates the limits and uncertainty associated with hand sample mineral identification as a context for the more quantitative techniques introduced later in the mineralogy course and later still in petrology, etc.

This laboratory is keyed to Klein and Hurlbut's Manual of Mineralogy (21st Edition, John Wiley & Sons). It could easily be adapted to another text of equal rigor and thoroughness. My syllabus explains the text's role as "... an excellent shelf reference on crystallography, crystal chemistry, and determinative mineralogy. Use it as such this semester. The text also provides a framework for advanced rock classifications you will encounter in geology courses. It is the primary data source you will need this semester for laboratory and homework exercises." Critical reading of the text by the student replaces lectures on some topics. Some of your students might benefit from reading excerpts from Bloss, F.D. (1971) Crystallography and Crystal Chemistry, an Introduction (Reprinted 1994, Mineralogical Society of America), Chapters 11 & 12 or Frye, K. (1993) Mineral Science an Introductory Survey (Macmillan), Chapter 4.

The "Jigsaw" pedagogy upon which this lab is based also provides the environment for four succeeding labs in which the students learn the megascopic characteristic properties, chemical composition, and a geologic significance for each of approximately 100 minerals. A good discussion of the technique appeared in *The Journal of Geological Education* (Constantopoulos, 1994, vol. 42, 261-3). See also Srogi and Baloché (this volume). I have used the technique three times and am convinced of its value. Every student is active and focused through the entire lab period, each improves his/her skills in oral presentation in small groups, each improves his/her skills in careful observation and analysis of specimens. The later benefit seems to be associated with a perception by the students that they can afford to be more careful and observant because each has less work to do than if they each completed the entire exercise individually. They also seem to understand and accept the responsibility each assumes for their classmates' learning. During the cooperative learning laboratory sessions, the instructor serves as arbitrator when members of an expert group can not agree or seem to be totally off track. Often I refer them back to the critical passage in the text rather than giving them "the answer". The instructor as ultimate authority (giver of truth) is replaced by the instructor as guide (which may require restraint on your part!).

One of the instructor's challenges is organizational, creating enough learning/teaching groups so that each of the four parts (A-D) of the exercise is completed by an expert group with between two to four students. Part B can be divided among two people yielding five topics (expert groups), if that number better accommodates your class. Consequently, this exercise accommodates between eight (2x4) and twenty(4x5) students. I commonly distribute students randomly among the topics until all have a task for the individual study phase and no topic (expert groups) has more than four students. There is no advantage to having all expert groups the same

size, so don't worry if unequal groups arise. However, you should divide groups larger than four into smaller expert groups with the same topic. You could drop the density part from the collaborative strategy (let every student do it) for sections with six students. Large lab sections with multiple expert groups on the same topic should be allowed extra time for those expert groups with the same topic to present their conclusions to one another before members return to their learning/teaching clusters. I use the performance of each student on this first, rather-straight-forward activity to guide my selections for the learning/teaching groups who will remain together throughout the next four to five labs on systematic mineralogy.

A second major challenge for the instructor is monitoring the pace of activities so that all expert groups finish in a timely manner and near the same time. There is a real advantage to giving time limits for the individual work (perhaps 30-45 minutes), the expert group conferences (30-45 minutes), and ample time for each expert to teach others in his or her learning/teaching group. This laboratory activity is designed for three hours. One could give the individual assignments a day or two before the lab sessions and expect the students to come to lab having read the appropriate portions of the text, thus saving some of the time allocated for individual work. Unless the instructor monitors the pace of work, the students tend to prolong each activity or drift toward social conversations in the group activities.

Each student is graded on the total lab report, his or her original work and that of classmates. If experts present wrong information, all who accept that data are penalized. This strategy reinforces the learner's responsibility to ask constructive questions of experts when the information doesn't make sense. Each student can also be graded individually on the portion of the exercise for which she was responsible. Once students accept their mutual dependence and stop competing with one another, the class room atmosphere becomes very supportive.

A list of the samples I use is included. There are enough of each so that each expert has representative material for demonstration during the final learning/teaching sessions. The lab room also contains sets of reference samples representative of the Mohs hardness, luster, fracture, cleavage and specific gravity examples mentioned in the lab instructions and text.

Many of the qualitative techniques upon which this exercise is based are supplemented later in the semester by more quantitative techniques. Most of my students don't develop the skills and self-confidence necessary for the quantitative methods until later in the semester. Which of the following techniques you may choose to include will certainly depend on equipment available and appropriate problems in subsequent lab exercises. There is real value in connecting topics between labs so that students can not compartmentalize their learning and avoid the connections among topics that we all strive to build into our syllabi.

Luster: measure indices of refraction in oils with polarizing light microscopes, measure reflectance by microscope photometry.

Cleavage: measure cleavage angles of several amphiboles and pyroxenes in thin section.

Hardness: measure microindentation hardness.

Specific gravity (heft): measure density by immersion or by pycnometer.

Color: determine quantitative color coordinates from spectral reflectance; compare to Munsell color charts.

Later in the semester, in the context of solid solution series, the students compare systematic variation of physical properties (density, color, index of refraction) and chemical composition for garnets and olivine group minerals. One could also include variability of cell edges if XRD analysis is an option. The chemical data is collected on a SEM-EDS system from the same samples used to determine density, color, and index of refraction in the earlier lab exercises. This solid solution lab also provides topics for homework problems on calculating theoretical density, crystal chemical rules for atomic substitutions, recasting chemical analyses to mineral formulae, and causes of color in minerals.

My choices for unknown specimens in this first Physical Properties lab:

Luster & Streak

black tourmaline crystal
sulfur - massive
barite crystal
calcite crystal
celestite crystal
bornite with covellite coating

% Reflectance

chalcocite
goethite
gold
ilmenite
wolframite

Density (heft)

feldspar (softball size)
galena (golf ball size or smaller)
celestite (golf ball size)
cerussite (golf ball size)
quartz (golf ball size)
lepidolite (silver dollar size)

Quality of Cleavage & Type of Fracture

chalcocite - massive
chalcopyrite - massive
quartz
copper
garnet - massive
garnet - with parting
galena
anthophyllite
tourmaline

Cleavage Directions & Angles

fluorite - cleavage octahedron
calcite - cleavage rhombohedron
gypsum (selenite)
mica
augite
stibnite
calcite (broken crystal with cleavage and crystal faces)
plagioclase
galena
hornblende
halite - cleavable
fluorite - intergrown coarse
sphalerite - cleavable
dolomite - cleavable

Scratch Hardness

quartz
apatite
gypsum
feldspar
pyrite
fluorite
calcite
corundum
talc
chalcopyrite

Physical properties reference sample sets are sold by:

D. J. Minerals, P.O. Box 761, Butte, Montana 59703-0761, (406-782-7339).

Omni Resources, 1004 S. Mebane Street, P.O. Box 2096, Burlington, North Carolina, 27216 (910-227-8300) (<http://www.omnimap.com>).

Watkin's Mineral Corp., 117 Pembroke Lane, Wichita Falls, Texas, 76301-2929.

Ward's (1-800-962-2660) (<http://www.wardsci.com>).

Other equipment: contact goniometers, equipment for measuring specific gravity.

