GEO 310 -- Mineralogy
Laboratory #2   9/4/08

Crystallography and Symmetry

The purpose of this exercise is to develop the ability to describe crystal forms in consistent ways that relate to their internal atomic arrangement: their symmetry. The tools gained in this lab combined with those from Lab #1 to form the basis for rational study minerals both by optical (petrographic) methods and in hand specimen. Chapter 6 in Klein will provide useful background for portions of this lab. If you are particularly intrigued, Chapters 7-9 go further into symmetry on levels we do not need to consider for the present course.

Keeping in mind the definition of the word *mineral*, these come in the form of crystals, although individuals may commonly be too tiny to discern without aid. *Symmetry* is the outward manifestation of internal order that all crystals possess. Symmetry is generally quantified relative to faces, edges and corners of crystals. Minerals may possess high symmetry (abundant distinct symmetrical elements) or low symmetry (few symmetrical operations possible) -- due to the orderly 3D arrangement of atoms in their structures all minerals are symmetrical to some extent.

<u>Symmetry operations</u>:

- **rotation axis -** imaginary line about which a crystal face may be rotated so as to repeat itself once or multiple times (2, 3, 4, 6) during a 360^{o} rotation [there is also something called a *rotoinversion axis*, which is not key to applying symmetry to unknown samples, so we will not discuss it]
- **mirror plane -** planes that reflect a specific crystal face onto its mirror image
- **center of symmetry -** relation between a specific crystal face and an equivalent face through inversion through a point

Based on all permutations of symmetry operations to natural polyhedra, six *crystal systems* can be recognized (or seven, depending on how you count them). These can be further subdivided into the 32 fundamental crystal classes, but we will concentrate only on determining crystal systems for unknowns.

<u>Identifying criteria (symmetry required) for the six crystal systems</u>:

- **triclinic -** 1-fold axis
- **monoclinic -** one 2-fold axis *or* one mirror plane
- **orthorhombic** – three perpendicular 2-fold axes *and/or* mirror planes
- **tetragonal -** one 4-fold axis
- **hexagonal** – one 6-fold axis and **hexagonal (trigonal)** – one 3-fold axis
- **isometric** – four 3-fold axes

We have dealt with mineral *habit*, which relates to appearance in nature. In crystallography the crystal *form* relates to the geometry of the *faces* of well-formed crystals. Several common forms are recognized that appear in samples from most of the crystal systems, so it is important to understand these.

The combination of faces involved in each form may either enclose space (closed) or not (open). Because of their high symmetry, isometric crystals have 15 distinct forms possible, all of which are closed. Most non-isometric crystals display a combination of forms (e.g., prism and pinacoid, or prism and pyramid).

<u>Prominent non-isometric crystal forms (see Klein p.137-141)</u>:

open forms - pedion, pinacoid, dihedra (dome and sphenoid), prism, pyramid
closed forms - dipyramid, trapezohedron, scalenohedron, rhombohedron, tetrahedron

<u>Miller Indices</u>

We use an inverse system to describe the arrangement of crystal faces in space, such that planar features are assigned a *Miller index* (hkl). See Klein p. 133-134 for reference. This notation references the atomic lattice spacing of features, and as such is not something that you measure directly off a crystal unless you have additional data about the crystal structure of the mineral. The general rules that we can apply to Miller indices are as follows:

(1) they must always be whole numbers--no fractions;
(2) they are least common multiples (so the index (224) would automatically reduce to (112) and (002) reduces to (001));
(3) major and minor faces of most crystals will have low numbers in their indices--seldom will a number above 6 be seen for common faces.

It is important to note that an infinite number of planes *parallel* to a face defined with a particular Miller index will share the same index.

Note: Miller indices can be used to describe lines (square brackets [hkl] are used) and the index of a crystal form (described below) uses curly bracket {hkl}.

Why are Miller indices important? They allow us to communicate about minerals in a very simple and direct way. For example, (001) refers to faces that define the “top” and “bottom” of a crystal that lacks a pyramidal or similarly slanted termination. Similarly, the index (100) refers to prism faces. Crystal forms are denoted by the Miller index of the most prominent symmetrically-relatable face {hkl}. Thus, a {111} form (note the curly brackets) refers to the faces of an octahedron -- do you see why this is?

Exercises

(1) Symmetry and crystal forms of ideal samples

The point of this station is to make you consider, for ideal crystal forms, what symmetry operations exist, because with this information the crystal system can be determined. If you can identify the crystal system, it is a key clue to the identity of an unknown mineral. Choose one block from each group and fill out the sheet with the appropriate information. The “evidence” to cite is based on the identifying criteria from above. Use Klein p. 185-207 to cite one mineral example for the block you have chosen.

Note 1: isometric models from this set show just one form -- use Klein p.141-142 to identify these forms; non-isometric crystals typically present multiple forms.

Note 2: use of the *contact goniometer* for measuring interfacial angles on the non-perpendicular samples is recommended (see Klein fig.8.9).

model #	# faces	forms present (open/closed)	crystal system	evidence/example

(2) Symmetry and crystal forms of natural samples

The sad truth about symmetry as a tool for mineral identification is that in practice few minerals will display forms that allow this kind of analysis. However, general forms are common and many are diagnostic. Also, many rock forming minerals commonly crystallize in *euhedral* shapes (e.g., garnet, pyrite).

At this station there are natural mineral samples for you to examine. Some are very small and some are rather delicate. TREAT THEM CAREFULLY. Use the binocular microscope to your advantage.

a. Assess for each crystal any symmetry elements or forms you can identify.

b. For each sample, state your assessment of the crystal system and give your evidence of this. It may be acceptable to state that you cannot determine the system, as long as you can give appropriate support.

(3) Miller index examples

a. For the three ideal crystal models which show the orientations of crystallographic axes, estimate the Miller indices of the indicated faces.

b. Complete the Miller index problem in Figure 1. This example is of a single plane lattice -- for problems such as this it is critical to identify what axis is *missing* and how that affects your calculations.

c. Determine the Miller index of planes **m** through **w** on the attached example plane lattice Figure 2.

These exercises are due at the end of today's lab period.
Symmetry & Miller index blocks will be available throughout the week.