GY 302: Crystallography & Mineralogy

Lecture 1: Introduction to Crystallography

Instructor: Dr. Douglas Haywick
Today’s Agenda

1. Basics of Crystallography
2. Symmetry Operations
What is Crystallography?
What is Crystallography?

The science of crystallization, crystal form, structure and symmetry.
What is Crystallography?

The science of crystallization, crystal form, structure and symmetry.

Math + Chemistry + Physics = 😞
Why do Crystallography?

• At last count, there are well over 4500 distinct “minerals” in our solar system
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• They are composed of 90+ elements, as well as more complex ions like $\text{CO}_3^{2-}$, $\text{SO}_4^{2-}$, $\text{PO}_4^{3-}$ etc.
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• Minerals are assembled according to exact chemical “blueprints”...

... and those blue prints are controlled by mathematical and physical laws.
Chemical Considerations:

As a bare minimum, this class requires you to understand basic chemistry (CH 131 level) e.g., the elements, their behavior, feasible substitutes:

\[ 2e^- + \pi = 2024 \]

Na \rightarrow Na^+ \quad \quad \quad + \quad \quad \quad Cl^- 

K \rightarrow K^+
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**Analcime**

\[ \text{Na}[\text{H}_2\text{O}]\text{AlSi}_2\text{O}_6 \]
And how electrons fill shells and sub-shells according to quantum mechanics.

<table>
<thead>
<tr>
<th>Principle Quantum Number</th>
<th>Angular Momentum Quantum Number</th>
<th>Magnetic Quantum #</th>
<th>Spin Quantum Number</th>
<th>Number of electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Shell</td>
<td>l</td>
<td>subshell</td>
<td>m₁</td>
</tr>
<tr>
<td>1</td>
<td>K</td>
<td>0</td>
<td>S</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>0</td>
<td>S</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>P</td>
<td>-1</td>
<td>+½</td>
<td>6</td>
</tr>
<tr>
<td>0</td>
<td>+½</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>-½</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chemical Considerations:

Orbital Orientation

$S$ (1 lobe)

$p$ (2 lobes)

$d$ (4 lobes)
Chemical Considerations:

Hydrogen: $1S^1$

Helium: $1S^2$

Uranium: $[\text{Rn}] 5f^3 6d^1 7s^2$
## Chemical Considerations:

<table>
<thead>
<tr>
<th>Bond</th>
<th>Mineral properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic</td>
<td>- strong bond</td>
</tr>
<tr>
<td></td>
<td>- high melting points</td>
</tr>
<tr>
<td></td>
<td>- vitreous lusters</td>
</tr>
<tr>
<td></td>
<td>- higher solubility</td>
</tr>
<tr>
<td>Covalent</td>
<td>- strong bonds</td>
</tr>
<tr>
<td></td>
<td>- hard minerals</td>
</tr>
<tr>
<td></td>
<td>- very high melting points</td>
</tr>
<tr>
<td></td>
<td>- vitreous – adamantine lusters</td>
</tr>
<tr>
<td>Metallic</td>
<td>- weak bonds</td>
</tr>
<tr>
<td></td>
<td>- low to high melting points</td>
</tr>
<tr>
<td></td>
<td>- metallic lusters</td>
</tr>
<tr>
<td></td>
<td>- electrically conductive</td>
</tr>
</tbody>
</table>

**Ionic Bond**
- 

**Covalent Bond**
- 

**Metallic Bond**
-
Crystallography:
Crystallography:
Crystal Systems
Crystal Systems

- Crystals are classified according to the lengths and angles between crystallographic axes.
Crystal Systems

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3 axes are the same length:

- All axes are at 90° to one another:
  
  \[ a = b = c; \]
  
  \[ \alpha = \beta = \gamma = 90^\circ \]
Crystal Systems

- Crystals are classified according to the lengths and angles between crystallographic axes.

  3 axes are the same length

  All axes are at 90° to one another

  \[ a = b = c; \]

  \[ \alpha = \beta = \gamma = 90° \]

This defines the Cubic or Isometric Crystal System.
# Crystal Systems

## The 6 (or 7) Crystal Systems.

<table>
<thead>
<tr>
<th>Crystal System</th>
<th>Axes</th>
<th>Angles between axes</th>
<th>Mineral examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cubic</td>
<td>$a = b = c$</td>
<td>$\alpha = \beta = \gamma = 90^\circ$</td>
<td>Halite, Galena, Pyrite</td>
</tr>
<tr>
<td>2 Tetragonal</td>
<td>$a = b \neq c$</td>
<td>$\alpha = \beta = \gamma = 90^\circ$</td>
<td>Zircon</td>
</tr>
<tr>
<td>3a Hexagonal</td>
<td>$a_1 = a_2 = a_3 \neq c$</td>
<td>$\alpha = \beta = 120^\circ, \gamma = 90^\circ$</td>
<td>Apatite</td>
</tr>
<tr>
<td>3b Trigonal</td>
<td>$a_1 = a_2 = b \neq c$</td>
<td>$\alpha = \beta = 120^\circ, \gamma = 90^\circ$</td>
<td>Quartz, Calcite</td>
</tr>
<tr>
<td>4 Orthorhombic</td>
<td>$a \neq b \neq c$</td>
<td>$\alpha = \beta = \gamma = 90^\circ$</td>
<td>Aragonite, Staurolite</td>
</tr>
<tr>
<td>5 Monoclinic</td>
<td>$a \neq b \neq c$</td>
<td>$\alpha = \beta = 90^\circ, \gamma \neq 90^\circ$</td>
<td>Gypsum, Orthoclase</td>
</tr>
<tr>
<td>6 Triclinic</td>
<td>$a \neq b \neq c$</td>
<td>$\alpha \neq \beta \neq \gamma \neq 90^\circ$</td>
<td>Plagioclase</td>
</tr>
</tbody>
</table>

![Isometric Crystal](image1.png)  ![Tetragonal Crystal](image2.png)  ![Hexagonal Crystal](image3.png)  ![Orthorhombic Crystal](image4.png)  ![Monoclinic Crystal](image5.png)
Crystal Systems

There are also subdivisions of each system that we will get to in time.
Crystal
Systems

First Lab next week
Symmetry
Symmetry

... is the hardest thing for students to appreciate, understand or visualize.
Symmetry

1) Reflection symmetry (mirror planes)
Symmetry

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Isometric crystals have up to 9 mirror planes
Symmetry

1) Reflection symmetry (mirror planes)
Symmetry

2) Rotational symmetry
Symmetry

2) Rotational symmetry
2) Rotational symmetry

4 fold rotational axis
2) Rotational symmetry
2) Rotational symmetry: usually three 4 fold rotational axes defines the isometric system (highest order)
2) Rotational symmetry: but there are also 4 x 3-fold rotational axes at the corners*

* there is more to the 3-fold axis story to be revealed in an upcoming lecture
2) Rotational symmetry and 6 x 2-fold rotational axes at the edges
2) Rotational symmetry
Crystal Systems

Symmetry operations:

1) Reflection (mirror planes)
Crystal Systems

Symmetry operations:

1) Reflection (mirror planes)
2) Rotation (2, 3, 4, 6 fold axes)
Crystal Systems

Symmetry operations:

1) Reflection (mirror planes)
2) Rotation (2, 3, 4, 6 fold axes)
3) Inversion
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Symmetry operations:

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3) Inversion
4) Translation (We will consider this next time)
Crystal Systems

1) Reflection (mirror planes)
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3) Inversion
4) Translation

Basic symmetry operations
Crystal Systems

1) Reflection (mirror planes)
2) Rotation (2, 3, 4, 6 fold axes)
3) Inversion
4) Translation

Basic symmetry operations

5) Screw Rotation
6) Glide Rotation
7) Rotoinversion

Compound symmetry operations
Today’s Lecture Homework

1. Online Lecture: nothing this week
2. Purchase a hand lens, the GY 302 Mineral notebook and one big 3 ring binder* and decent art supplies (e.g., eraser, ink pens)

Thursday

1. Plane and Bravais Lattices (Lecture 2)
2. Lab: Group Activity: Symmetry recognition

*for your notes, syllabus, assignments, quizzes etc.
Your First Lab Assignment

Examine 4 wooden models from the isometric and hexagonal crystal systems (2 from each group)

A) sketch the crystal
B) identify all mirror planes
C) Identify the highest rotational symmetry
D) identify all other rotational axes
E) Identify the point group of the mineral

Due Date

1. Aug 31st by 12:00 pm (followed by a quiz)