

## LECTURE 2.

### 2.0 ELEMENTS OF CRYSTALLOGRAPHY AND MINERALOGY

#### 2.1 INTRODUCTION

Welcome to Lecture 2. In the previous lecture we defined the science of geology and broadly discussed the theories advanced for the origin of our planet earth. We also noted how scientists using the science of seismology and other techniques have been able to understand the internal structure and composition of the earth. We established that the Earth is not homogenous but consists of three main shells – the **core**, **mantle** and the **crust**. The Earth's crust is composed mainly of granitic and basaltic rocks. Rocks by nature are so common that people often don't notice them. What most people don't realize is that rocks and minerals are the building blocks or essential bones of our planet. In order to find out the economic uses these rocks, we must first find out the nature of the crystalline materials constituting these rocks. Hence an introduction to the study of **crystallography** and **mineralogy** - which deals with crystalline materials - will form the present lecture topic.



### OBJECTIVES

At the end of this lecture, you should be able to:

- a). Define crystals and the study of crystallography.
- b). Give examples of properties influenced by crystallography.
- c). Explain the formation of crystals
- e). Outline the classification of crystals
- d). Describe and illustrate the various properties of crystals – symmetry elements, crystal systems, parametral plane, axial length, axial ratios, miller indices and crystal faces

## 2.2 WHAT IS CRYSTALLOGRAPHY?

Crystallography is the study of crystals and the crystalline state. Crystallography is the key in understanding the structures of crystalline materials. Hence it forms the natural introduction to the study of rocks and minerals since they are all predominantly crystalline materials.

The crystal structure along with the chemical composition determines all properties of crystalline materials. It is these properties that dictate the uses to which the materials can be put into use. Examples of properties that are influenced by crystal structure are:

- Density or specific gravity of materials
- How a material breaks (fractures or cleavage).
- The optical properties of minerals under the microscope.
- Thermal and electromagnetic properties of minerals.

## 2.3 CRYSTALS, CRYSTALLINE SOLIDS AND THEIR FORMATION



### What is a Crystal?

A **crystal** by definition is a solid body bounded by natural planar surfaces generally called crystal faces that are the external expression of a regular internal arrangement of constituent atoms or ions. The term **crystalline** is applied to any material having a regular internal arrangement of its constituent atoms or ions i.e., crystalline material may or may not be bounded by crystal faces. Minerals by definition are crystalline solids.

Natural crystals may grow whenever:

- Their constituent atoms and ions are free to come together in the correct proportions
- The existing conditions are such that growth will take place at a reasonably slow and steady state

- The external surface of the growing crystal is not constrained physically.

## 2.4. PROPERTIES OF CRYSTALS

### 2.4.1 The Interfacial Angle

The Interfacial angle in crystals is the angle between the normal to two faces as indicated in the diagram Figure 2.1. The instrument used to measure the angles is called a Goniometer.

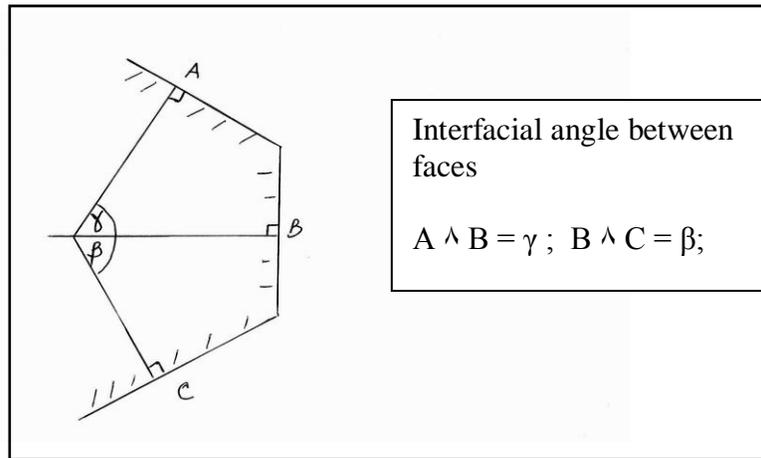


Figure 2.1 Diagram to illustrate the measurement of the interfacial angles.

### 2.4.2 Symmetry Elements

- **Plane of Symmetry** – This is defined as a plane along which the crystal may be cut into exactly similar half each of which is a mirror image of the other. As an example, Figure 2.2 shows the nine symmetry planes of a cube.
- **Symmetry Axis** – This is a line about which the crystal may be rotated so as to show the same view of the crystal more than once per revolution, e.g. a cube. Alternatively it can be defined as a line along which the crystal may be rotated such that the crystal assumes a position of congruence i.e. the crystal presents the same appearance to

a fixed observer. If a position of congruence occurs after every 180 degrees of rotation, the axis is said to be DIAD symmetry axis. Other axes may be called TRIAD, TETRAD or HEXAD depending on whether congruence is attained every 120, 90, or 60 degrees respectively.

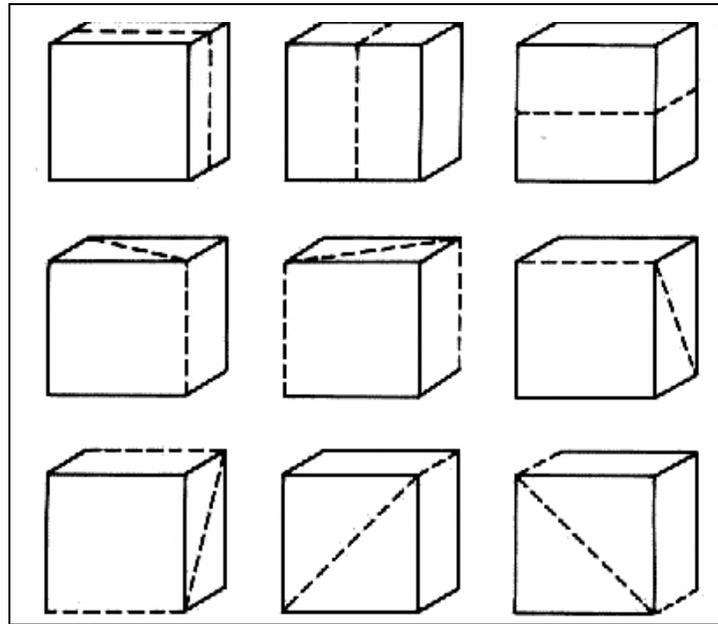


Fig. 2.2. The nine symmetry planes of the cube.

- **Center of Symmetry** – Center of symmetry is the point from which all similar faces are equidistant.

### 2.4.3 Crystallographic Axes

The morphology of crystals can be usefully treated as a type of analytical geometry in three dimensions and it is therefore necessary to have axes to which planes (i.e. faces) may be referred. These reference axes are known as **crystallographic axes** (Figure 2.3) and should not be confused with symmetry axes although they coincide with them to some extent.

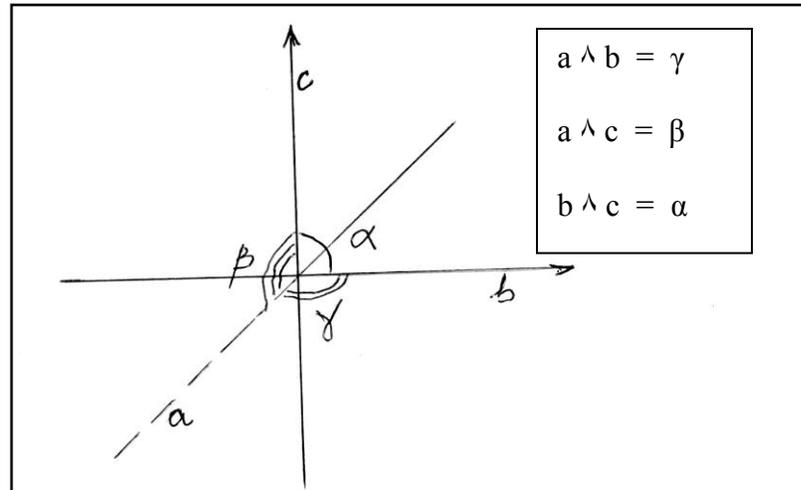


Figure 2.3 The crystallographic axes a, b, and c.

Important things to note regarding the crystallographic axes:

- The axes are perpendicular to the main crystal faces.
- Crystallographic axes are always labeled a, b, and c but for the purpose of this unit course, the letter **a** shall be used to denote axis of equal length.
- Length of an axis is the distance from the central intersection of the three axis to the point where the axis cuts the face of the crystal.

#### 2.4.4 Equivalence of Crystals

Consider the diagram in Figure 2.4 below:

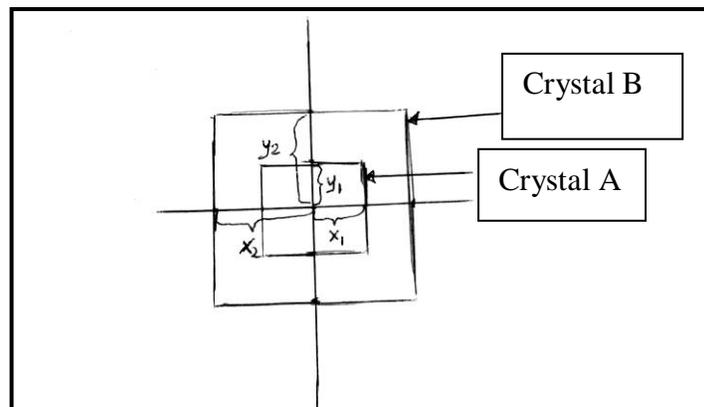


Figure 2.4 Equivalence of Crystals

Consider Crystal A : The ratio of axial length  $c:b$  is equivalent to  $Y_1 = X_1$

Crystal B: The ratio of axial length  $c:b$  is equivalent to  $Y_2 = X_2$ .

If the ratios of the intercepts are equal then crystal A and B are crystallographically equivalent i.e. the size is not important. It's the ratio of the intercepts and the angles between the reference axis that matters i.e. there could be an infinite number of crystals larger or smaller than A and B but as long as the intercept ratios and angles are equal, all these crystals are crystallographically equivalent.



### ACTIVITY

**How many Kinds of Crystals Are There?**

## 2.5 CLASSIFICATION OF CRYSTALS

There is an infinite variety of crystals, but the varying numbers and orientation of the various symmetry elements (Table 2.1) produces only six fundamental crystal systems, namely **Cubic, Tetragonal, Orthorhombic, Monoclinic, Triclinic, Hexagonal (or Trigonal)**. These crystal systems can be represented by three reference axes referred to as the crystallographic axes as follows:

**Cubic or isometric system** – three equal axes at right angles

**Tetragonal system** – three axes at right angles, two of which are equal

**Orthorhombic system** – three unequal axes at right angles

**Monoclinic system** – three unequal axes with one oblique intersection

**Triclinic** – three unequal axes intersecting at oblique angles

**Hexagonal system** – four axes, three in a plane at  $60^\circ$ , one normal to that plane.

The resultant arrangement of these axes in the six crystal systems is presented in Figure 2.5.

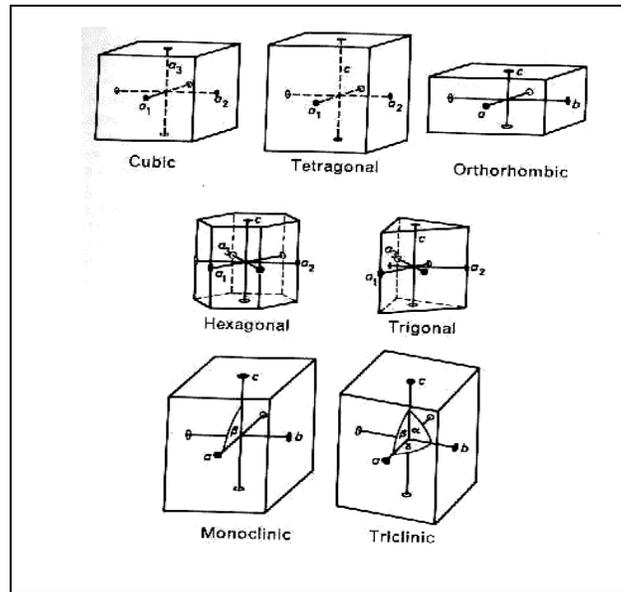


Figure 2.5 Crystallographic axes in the seven crystal systems.

Table 2.1 The symmetry elements of the various crystal systems.

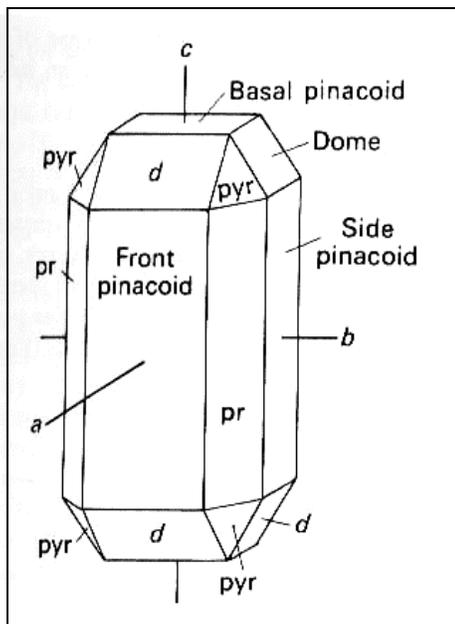
CRYSTAL SYSTEMS	AXIAL LENGTHS	AXIAL ANGLES	MINERAL EXAMPLES
CUBIC	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	Rock Salt Garnet Flourite Pyrite
TETRAGONAL	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	Idocrase Zircon Chalcopyrite
ORTHORHOMBIC	$a \neq b \neq c$ $c > b > a$	$\alpha = \beta = \gamma = 90^\circ$	Natrolite Orthopyroxene Olivine Sillimanite
MONOCLINIC	$a \neq b \neq c$ $b > a$	$\alpha = \gamma = 90^\circ$ $\beta \neq 90^\circ$	Gypsum Feldspar Hornblende
TRICLINIC	$a \neq b \neq c$ $b > a$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	Microcline Feldspar Albite Kyanite
HEXAGONAL (TRIGONAL)	$a_1 = a_2 = a_3 \neq c$	$a_1 \wedge a_2 \wedge a_3 = 60^\circ$ $a \wedge c = 90^\circ$	Corundum Calcite Quartz Beryl

## 2.6 THE CRYSTAL FACES

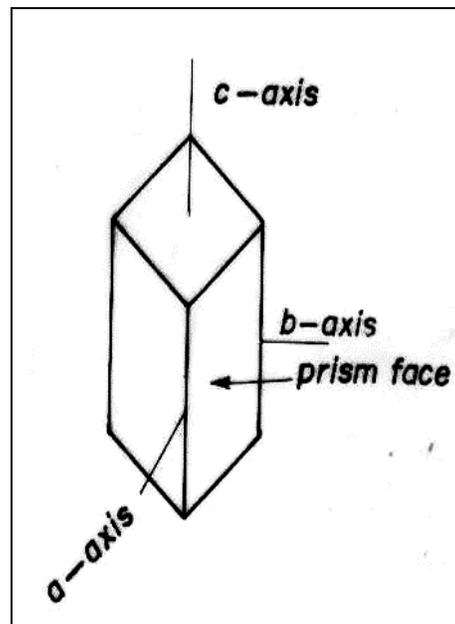
In the orthorhombic, triclinic and monoclinic systems where the axes are all unequal, the faces are named as follows:

- a). A face which when produced cuts all the three axes is called a **Pyramid face**.
- b). A face which cuts two lateral axes and is parallel to the third axis is known as a **Prism face**.
- d). A **Pinacoid face** is one that cuts any one axis and is parallel to the other two axes.
- e). A **Dome face** cuts two axes and is parallel to the third axis which is not seen.

An illustration of some of the crystal faces – pinacoid, dome, pyramid and prism – are given in Figures 2.6 (a) and (b) here below.



(a).



(b).

Figure 2.6 (a) and (b). Illustration of the crystal axes and faces. pr = prism, d = dome, pyr = pyramid.

### 2.6.1 Parametral Planes

In any given crystal type there will always be a unique pyramidal face that makes an intercept on the three crystallographic axis that are as nearly equal as possible. This then is the **Parametral Plane** of that crystal. There are probably other pyramidal faces but the ratios of their intercepts will not be nearly equal to each other as those of the parametral plane.

Let us consider the two pyramidal faces ABC and A B' C' represented in Figure 2.7.

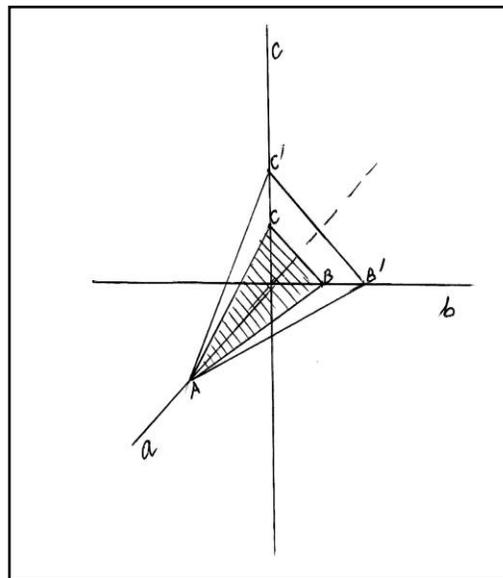


Figure 2.7 Parametral plane represented by pyramidal face ABC.

Their intercept ratios on the three crystallographic axes are:

$$A:B:C = 1:0.9:1 \text{ ; AND } A:B':C' = 1:2:1.7 .$$

Comparing the relative ratios, the shaded triangle ABC gives the parametral plane.

## 2.7 AXIAL LENGTHS AND AXIAL RATIOS

The axial lengths of a crystal are the intercepts of the parametral plane on the three crystallographic axes. If the axial lengths are expressed relative to the b axial length such that  $b=1$ , then  $a/b = \mathbf{n}_1$  and  $c/b = \mathbf{n}_2$ . In this case  $\mathbf{n}_1$  and  $\mathbf{n}_2$  are the axial ratios of that crystal. The axial ratios are specific to the crystal and are usually determined by the inclination of the crystal faces.

## 2.8 MILLER INDICES

We can use axial ratios to designate any individual crystal face. For example let us consider Figure 2.8 to illustrate how miller indices are derived.

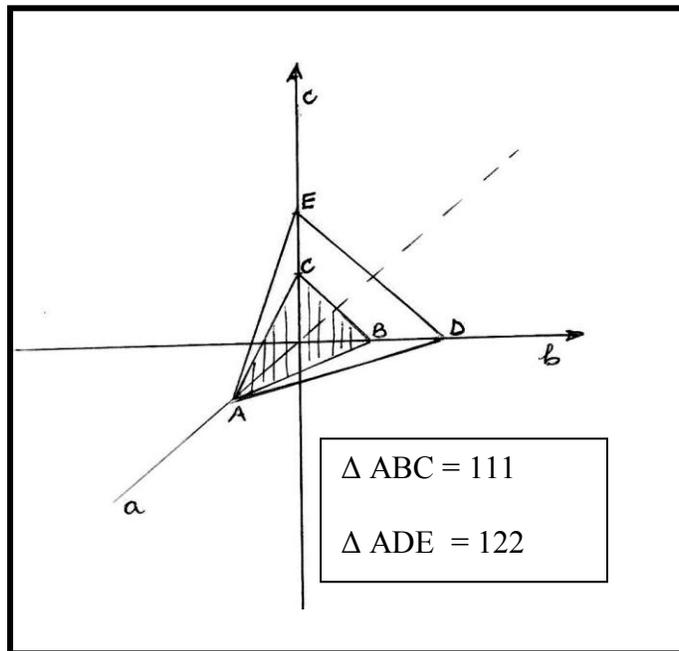


Figure 2.8. The parametral plane ABC in relation to the miller indices.

Method.

1. Select the reference pyramidal plane -which is usually the parametral plane.
2. Let ABC be the chosen plane with intercept lengths of: A1 on the crystallographic a-axis, B1 on b-axis, and C1 on the c-axis.

3. Construct a second pyramidal plane ADE where the intercept are : A1 on the a-axis, D on the b-axis, and E on the c-axis where  $D = 2 \times B1$  and  $E = 2 \times C1$ . Therefore the reference plane  $ABC = 111$  and  $ADE = 122$ . In other words, ADE is 122 with reference to the reference plane and therefore ADE is defined by 122. However using this notation, a face parallel to an axis would theoretically meet that axis at infinity and this concept becomes difficult to use. As a result, the reciprocal of the intercepts are the ones that are used, such that  $1/\infty = 0$ . The reciprocals values are the **miller indices**. The miller indices are usually expressed as full integers and not as fractions.

Table 2. Examples of miller Indices: their derivation.

INTERCEPT RELATIVE TO PARAMETRAL PLANE	RECIPROCAL	MILLER INDICES
$\frac{1}{2} a, \frac{1}{2} b, 1c$	2 2 1	2 2 1
1a, 1b, 2c	1 1 $\frac{1}{2}$	2 2 1
$\frac{1}{2}a, 1b, \infty$	2 1 0	2 1 0
1a, $\frac{3}{4} b, \frac{1}{2} c$	1 $\frac{4}{3}$ 2	3 4 6
2a, $\infty, 1c$	?	?
$\frac{1}{2} a, 1b, \frac{1}{4} c$	?	?



### ACTIVITY

Calculate the reciprocal and miller indices for faces with intercepts at  $2a, \infty, 1c$  and  $\frac{1}{2} a, 1b, \frac{1}{4} c$  on the a, b, c crystallographic axes as shown in Table 2 above.

### 2.8.1 Unit Type Faces

These are crystal faces that have only one's (1's) and zero's (0) in their miller indices i.e. the simple basic faces of the crystal.

### 2.8.2 General Symbols For Miller Indices

These are the h, k, l on the a, b, c crystallographic axes. Therefore the miller indices  $1\ 2\ 0 = h\ k\ 0$  and  $0\ 2\ 1 = 0\ k\ l$ . These values gives a rough immediate indication of the face position.

### 2.8.3 Miller-Bravais Indices

The miller indices discussed above are three digit symbols used in those crystal systems which have three crystallographic axes. In the Trigonal and hexagonal systems where four crystallographic axes are employed, four-digit symbols known as **Miller- Bravais** indices are used.



## Summary

1. A crystal is the natural form of a mineral bounded by smooth surfaces that is the “external expression of an orderly internal atomic arrangement.”
2. Crystals exhibit external regularities of shape, constancy of interfacial angles, and symmetry relations that allow them to be divided or classified into 6 crystal systems, namely: Cubic or isometric, Hexagonal, Tetragonal, Orthorhombic, Monoclinic, and Triclinic.

**References.**

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