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89.325 – Geology for Engineers
Minerals

I. Minerals

Minerals are crystalline solids - the particles (atoms) that make-up the solid have a regular arrangement. In glasses, on the other hand, the atoms are not arranged in a regular way and the material is said to be amorphous. For example, in window glass the particles are randomly arranged and the glass can be viewed as a supercooled liquid. Over a period of time glass will actually flow, as can be noted by the thickening of the glass towards the bottom of an old window pane. On the other hand, the particles making up table salt (halite) are arranged in a regular cubic array, a fact which is reflected in the cubic appearance of table salt. a class of solids that are found in nature.

A **mineral** may be defined as *a naturally occurring substance with a characteristic internal structure and a chemical composition which is either fixed or varies within certain limits*. The mineral species is determined by the chemical composition and internal structure. For example, a substance that consists of sodium and chlorine in equal atomic proportions, and in which the atoms are arranged in a regular cubic array, is called *halite*. Another substance which consists of potassium and chlorine in equal proportions, and in which the atoms are arranged in a cubic array, would be called *sylvite*. In this case the two minerals differ in terms of their chemical constituents (sodium *vs* potassium). As another example, carbon atoms can be arranged in a cubic array (diamond) or a hexagonal array (graphite). In this case the chemistry has remained the same but the internal structure has changed. Minerals which have the same chemical composition, but different internal structures, are said to be *polymorphs*. Thus graphite and diamond are polymorphs of carbon.

II. Structure of Minerals

The arrangement of atoms in a crystal structure is determined by the relative size of the anions and cations. Because anions are almost always larger than cations, we usually determine how many anions can be arranged around a cation such that all the ions are touching. The larger the cation, relative to the anion, the greater the number of anions that can fit around the cation. In order to determine the coordination number (the number of anions around the cation) we need to calculate the radius ratio

Radius ratio = Size cation/Size anion

This ratio is then used to predict the coordination number (Fig. 1).

Table 1on the following page lists ionic radii for some common elements that are found in minerals. Note that the ionic radius does vary as a function of the coordination number.

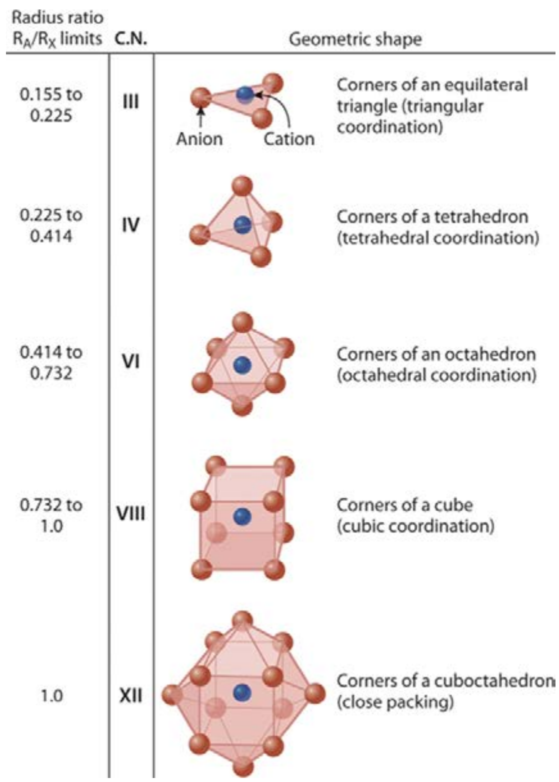

Figure 1. Coordination polyhedrons

Table 1. Ionic radii

Atomic #	Element	Ion	Radius as a function of coordination number III	IV	VI	VIII	XII
8	Oxygen	O^{2-}	1.22	1.24	1.26	1.28	
11	Sodium	Na^{+}		1.13	1.16	1.32	1.53
12	Magnesium	Mg^{2+}		0.71	0.86	1.03	
13	Aluminum	Al^{3+}		0.53	0.68		
14	Silicon	Si^{4+}		0.40	0.54		
17	Chlorine	Cl^{-}			1.67		
19	Potassium	K^{+}		1.51	1.52	1.65	1.78
20	Calcium	Ca^{2+}			1.14	1.26	1.48
26	Iron	Fe^{2+}		0.77	0.92	1.06	
		Fe^{3+}		0.63	0.78	0.92	

In order to answer the following questions you will need to refer to specific crystal models. The balls that make up the models are color coded. The color code is given in Table 2. For your calculations use the ionic radii for ions in VI coordination (Table 1)

Table 2. Color code for crystal models

Color	Element
Black	Si, Al
Red	O
Grey	Al, Mg, Fe, Ca
Robins egg blue	OH
Gold	K
Orange	Interlayer cations of H_2O

1. The chemical formula for ***olivine*** is Mg_2SiO_4. Calculate the coordination number for Mg and Si.

   Using the table, identify the positions of the Mg, Si, and O ions. Count the number of O ions around Mg and Si. Do your predicted values agree with the observed values. A note of caution: the models are accurate and the predicted values are not always correct. You do need to actually check the model for agreement.

2. The chemical formula for ***biotite*** is $K_2Mg_2AlSi_3O_{10}(OH)_2$. Calculate the coordinator number for K.

   Using the table identify the positions of the K and O ions. Does your predicted value agree with the number of O ions surrounding the K ion?

The major minerals in the earth's crust are the silicate minerals. The basic building block for the silicate minerals is the silica tetrahedron. The tetrahedrons can be arranged in different ways to create the various classes of silicate minerals (Fig. 2). For each of the crystal models listed below, place the model in the correct silicate structure group. Explain why you placed the structure in the particular group.

3. Olivine

4. Augite

5. Tremolite

6. Biotite

7. Sanidine

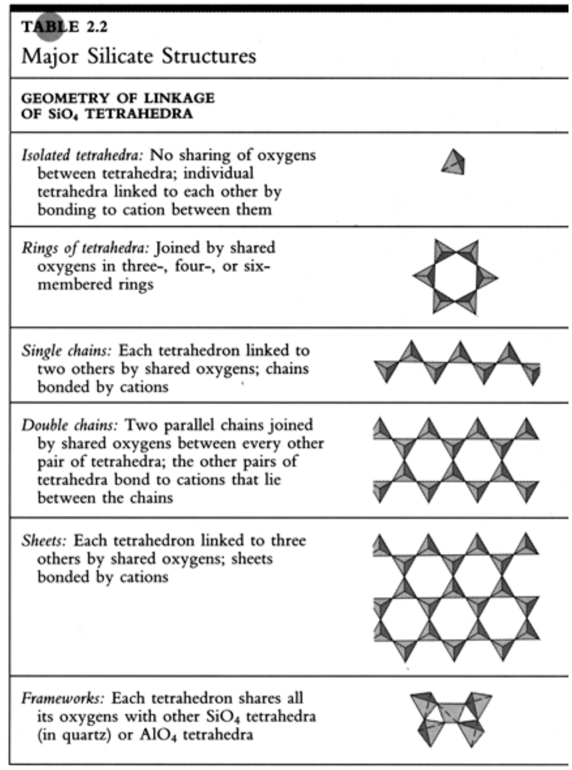

TABLE 2.2

Major Silicate Structures

GEOMETRY OF LINKAGE OF SiO_4 TETRAHEDRA
Isolated tetrahedra: No sharing of oxygens between tetrahedra; individual tetrahedra linked to each other by bonding to cation between them
Rings of tetrahedra: Joined by shared oxygens in three-, four-, or six-membered rings
Single chains: Each tetrahedron linked to two others by shared oxygens; chains bonded by cations
Double chains: Two parallel chains joined by shared oxygens between every other pair of tetrahedra; the other pairs of tetrahedra bond to cations that lie between the chains
Sheets: Each tetrahedron linked to three others by shared oxygens; sheets bonded by cations
Frameworks: Each tetrahedron shares all its oxygens with other SiO_4 tetrahedra (in quartz) or AlO_4 tetrahedra

Figure 2. Silicate structures

8. Two minerals of great interest in engineering applications are kaolinite and montmorillonite. Look at the structures of these two minerals. How are they the same? How are they different? Montmorillonite is and expandable clay. Based on your investigation of the two structures, what is the difference between the two structures that is responsible for the expandable behavior of montmorillonite?

III. Properties of Minerals

The chemical composition and internal structure of minerals are reflected in a wide range of physical and chemical properties. These properties are listed below.

Color. Color is the most obvious characteristic and may be an important property in the identification of minerals. Many minerals, however, exhibit a range in color due to slight variations in composition or impurities. In general it is best not to use color as a diagnostic property.

Streak. Streak is the color of the finely powdered mineral. It is produced by rubbing the mineral across an unglazed porcelain plate (streak plate). The streak produced by the powdered mineral may or may not have the same color as the massive mineral. In any event, the streak is less variable in color than the color of the bulk mineral and is consequently a better property to use for identification.

Luster. Luster refers to the way a mineral reflects light from its surface. The reflection of light is sensitive to the type of bond which holds the atoms together. In particular, minerals in which metallic bonding predominate are characterized by a metallic luster. Most of the terms used to describe luster are self-explanatory.

Types of luster:
- I. Metallic - looks like a metal
- II. Nonmetallic
  - A. Vitreous - like glass
  - B. Adamantine - brilliant like diamond
  - C. Resinous - luster like resin

Hardness. The hardness of a mineral is its resistance to scratching. A hard mineral can not be scratched by a soft mineral. Hardness should not be confused with toughness or brittleness. For example, window glass and a knife blade have about the same hardness since one will not scratch the other. There is no doubt, however, that the knife blade is tougher than the window glass.

Like other physical properties hardness is related to the atomic structure. In general, the hardness of a mineral is greater (1) the smaller the atoms, (2) the greater the valence charge and (3) the more tightly the atoms are packed.

In 1822 the Austrian mineralogist Mohs established a hardness scale consisting of ten common minerals of varying hardness. The first mineral is the softest known, the second is also soft but will scratch the first. The hardest mineral (number 10) is diamond and this mineral will scratch all the other minerals on the hardness scale. Your fingernail will scratch the first two minerals on the scale, but not the third. Therefore your fingernail has a hardness of 2.5. A knife blade (or glass) will scratch the first five minerals but not the sixth. A knife blade (or glass) has a hardness of 5.5.

The determination of hardness is simple, and is one of the best diagnostic properties for the identification of minerals. To get an idea of hardness, arrange the minerals in the *Mohs' Scale* in order from softest to hardest. Mohs' Scale is composed of the following minerals:

1 - talc	6 - orthoclase
2 - gypsum	7 - quartz
3 - calcite	8- topaz

4 - fluorite	9 - corundum
5 - apatite	10 - diamond

Cleavage. Cleavage is the tendency for a mineral to break along certain planes of weakness. Some minerals exhibit no cleavage, others break parallel to one plane, some parallel to two planes and some parallel to three or more planes. Cleavage is a reflection of the internal structure. It results from the fact that the atomic bonding is stronger is some directions than in others.

Fracture. If a mineral possesses no cleavage it will break along an irregular or curved surface. Fracture surfaces can be described as uneven, splintery or conchoidal. Conchoidal fractures are characteristically curved like the surface of a shell. Glass breaks in this manner.

Density. The density of a substance is its mass per unit volume. Practically one can determine relative density by comparing the weight of standard size, usually a cubic centimeter, minerals. Often the density is expressed as a number which tells you how many times heavier the mineral is than an equal volume of water (this is termed *specific gravity*). Most minerals are 2.5 to 3 times as heavy as water, but others are much heavier. Often a mineral's density is a clue to its identity. The density of a substance results from two factors, (1) the mass of the component atoms and (2) how closely the atoms are packed together.

Taste. Some minerals, such as halite (table salt), have a distinctive taste. ***Caution:*** do not taste any mineral with a metallic luster.

Magnetism. The mineral magnetite can readily be distinguished from other minerals since it is strongly attracted by a magnet.

Chemical Tests. Certain minerals react with acid. For example, when a drop of dilute acid is placed on a mineral containing carbonate (CO_3) a violent bubbling is produced. This results from the fact that CO_2 gas is produced by the chemical reaction between the mineral and the acid. This reaction proves that carbonate is present in the mineral. Two minerals, *calcite* ($CaCO_3$) and *dolomite* [$(Ca,Mg)CO_3$], which are very similar in their physical properties can be distinguished by this simple chemical test. If dilute acid is placed on dolomite a very weak, or no, bubbling occurs. If dilute acid is placed on calcite a violent bubbling is produced.

The same acid can be used to test for the presence of sulfur. Powder some of the mineral by rubbing it on an unglazed porcelain plate and then add a drop of acid. If you can detect the odor of hydrogen sulfide gas (H_2S - smells like rotten eggs) sulfur is present in the mineral.

IV. Mineral Identification

Identify the 10 minerals in your unknown mineral set. Determine the properties of these unknown minerals and then match these properties with standard descriptions to determine the mineral name. Complete the data sheet.

MINERAL IDENTIFICATION DATA SHEET

Mineral Name	Hardness	Color and Streak	Crystal Habit	Cleavage or Fracture	Other Properties