Notes on Atoms, Elements and Minerals

Vince Cronin's lecture section of introductory physical geology

revised 12 September 2015 at 8:45 PM

Around 98.5% of Earth's crust is composed of just 8 elements. Oxygen is the most abundant (~47%), so about half of any mountain you see is composed of oxygen. Silicon is next most abundant (~28%), and bonds with oxygen to form silicates. Aluminum is the third most abundant (~8%), and bonds with oxygen and silicon to produced alumino-silicates. Hence, it is obvious why most of Earth's crust is composed of silicate or alumino-silicate minerals.

The physical/chemical properties of minerals are a manifestation of their chemical composition and lattice structure. Some of the more easily observed physical properties are color, streak (the color of a fine powder of a mineral), luster, diaphaneity (opaque, translucent, transparent), how the mineral fractures and whether it displays cleavage, chemical reactivity, and the shape in which a mineral grows if it is free to grow unimpeded by other minerals (mineral habit).

Minerals are made of atoms bonded together in a regular 3-dimensional lattice structure. For example, the common mineral *quartz* is composed of two atoms of the element *oxygen* for every one atom of the element *silicon* (SiO_2), arranged in a complex "network" lattice.

An atom is a very small bit of matter that has a nucleus surrounded by an electron cloud. (Words like "surrounded by" and "cloud" are convenient for the purpose of discussion, as the simplistic illustrations in your book help you to gain an impression of atoms; however, the world at the atomic and sub-atomic level is substantially different from the world at our usual scale of observation. So a nucleus is really not a cluster of red and green balls, and electrons do not "orbit" in regular spheres around the nucleus. We simplify this very strange, tiny world in order to extract the bits that we need to understand chemical bonding, lattice structure, and the behavior of isotopes.)

The nucleus of an atom contains very little of the atom's volume, but virtually all of its mass. The nucleus includes protons (massive particles that are each associated with a +1 charge) and neutrons (massive particles with no charge).

The electrons associated with a given nucleus can be thought of as existing (more often than not) within an electron cloud around the nucleus. The electron cloud represents nearly all of an atom's volume, but very very little of its mass. Each electron is associated with a -1 charge.

For purposes of understanding chemical bonding, it is convenient to think of the electrons around a nucleus as being organized into shells. The "innermost" shell has space for two electrons, and each successive shell has space for eight electrons. Shells are "filled" with electrons from the innermost shell out, so the outermost shell is the only one that might not be entirely filled with its full compliment of electrons. The electrons in an unfilled outermost shell are called *valence electrons*, and these are the electrons that form chemical bonds.

There are 92 naturally occurring elements. Each element is distinguished from every other element by the number of protons in its nucleus. For example, every atom of the element *hydrogen* has one proton, and every atom of the element *carbon* has six protons.

Each element has a number of different isotopes. Isotopes are varieties of an element that differ from one another in the number of neutrons in their nuclei. For example, each atom of the element hydrogen has 1 proton in its nucleus, and there are isotopes of hydrogen that have 0, 1 or 2 neutrons in their nuclei. (Nerd factiod -- The isotope *hydrogen-1*, with 1 proton and 0 neutron, is called "protium;" *hydrogen-2* with 1 proton and 1 neutron is called "deuterium;" and *hydrogen-3* with 1 proton and 2 neutrons is called "tritium." Hydrogen-3 through hydrogen-7 are very unstable isotopes with half-lives of a very very small fraction of a second.)

Carbon has 6 protons. The most common isotope of carbon is carbon-12, which comprises around 98% of all carbon on/in Earth. Carbon-12 has 6 neutrons: 6 protons + 6 neutrons = 12. About 98.9% of carbon is the stable isotope carbon-12, and about 1.1% is the stable isotope carbon-13 (6 protons + 7 neutrons = 13). A trace amount is the unstable isotope carbon-14 (6 + 8 = 14), which decays with a half-life of 5730 years.

How do atoms bond together to form molecules or lattices?

Octet rule: Atoms tend to gain, lose or share electrons until they are surrounded by eight valence electrons in their outermost shell.

A single atom of sodium has 11 protons and 11 electrons: 11 positive charged particles + 11 negative charged particles to yield a neutral atom. This neutral atom has just one electron in its outer valence shell – a bonding opportunity.

A single atom of chlorine has 17 protons and 17 electrons, and 7 of those electrons are in the outer valence shell. Chlorine needs another electron to complete its outer valence shell.

Sodium and chlorine bond in such a way that sodium loans its extra valence electron to chlorine, resulting in an electrically neutral combination in which both atoms have filled outer valence shells.

Sodium without its outer valence electron has 11 protons and 10 electrons, resulting in it being a charged particle -- an ***ion*** -- with a net charge of +1. Charged atoms or molecules with an overall positive charge are called ***cations***.

Chlorine with the extra electron contributed by sodium has 17 protons and 18 electrons, resulting in it being an ion with a net charge of -1. A negatively charged ion is called an ***anion***.

A positive ion (a cation) has more protons than electrons. A negative ion (an anion) has more electrons than protons.

The sodium cation Na^{+1} is ***ionically bonded*** to the chlorine anion Cl^{-1} to form *sodium chloride* – the fundamental compound in the mineral ***halite*** and in common table salt.

An ***ionic bond*** can be thought of as a bond in which a valence electron from one atom is transferred to another atom to fill a valence shell.

In a ***covalent bond***, one or more valence electrons are shared by two or more atomic nuclei to fill valence shells. A ***metallic bond*** is a type of covalent bond in which the valence electrons freely pass from one nucleus to another. This type of bonding enables our use of copper wire to transmit electricity.

Van der Waals forces are weak attractions between surfaces that arise when one surface has a positive net charge and another surface has a negative net charge. Bugs can climb on walls and across ceilings without falling off because their weight is small relative to the Van der Waals forces. The sheets of carbon in the mineral *graphite* are held together with Van der Waals forces.

Chemical composition alone does not fully explain the physical properties of minerals. The chemical composition of diamond (the hardest naturally occurring mineral) is identical to that of graphite (a very soft mineral) – both are composed entirely of carbon. ***The physical properties of minerals are a function of chemical composition and the structure of their crystalline lattice.***

Each mineral has a characteristic growth form or ***habit***: the shape in which it develops if its growth is not impeded by other crystals. Some minerals have multiple crystal habits that depend on the pressure-temperature-time-chemical conditions under which they crystallize. Pyrite, for example, can crystallize into cubes or into 12-sided forms.

When a mineral grain is hit with a hammer, it fractures. If some or all of those fractures are along planes, the mineral is said to have ***cleavage***. Cleavage is found in minerals that have one or more plane of weakness within their crystal lattices. Types of minerals that lack such a structural plane of weakness in their lattices (e.g., quartz, olivine, pyrite, etc.) fracture in a more chaotic manner.

Different types of minerals have …
• no cleavage (quartz, olivine, pyrite, …),
• one direction of cleavage (mica minerals (biotite, muscovite, chlorite, lepidolite) graphite, …),
• two directions of cleavage (feldspars, amphiboles, pyroxenes, …),
• three directions of cleavage (halite, calcite, …),
• four directions of cleavage (fluorite), or
• six directions of cleavage (sphalerite).
A cube created by cleaving halite displays three directions of cleavage at right angles to each other: top/bottom sides, right/left sides, and front/back sides.

Missing from these notes to this point: hardness, color, streak, diaphaneity, luster (metallic, earthy, fibrous, silky, etc.), chemical reactivity, magnetism, fluorescence and phosphorescence, density/specific gravity, silicate structure, other chemical classes of minerals (carbonates, halides, oxides, sulfides, sulfates, native elements)