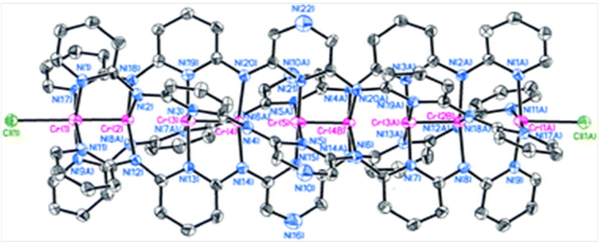
10.3 - 10.5 - Structures of Solids and Metallic Bonding



Types of Soilds

Two broad categories of solids exist:
Crystalline Solids: have highly regular arrangement of components.
Amorphous Solids: have considerable disorder in their structures.

A **lattice** is a three dimensional system of points designating positions of components (atoms, ions, or molecules) making up the substance.

A **Unit Cell** is the smallest repeating unit of a lattice. A particular lattice can be generated by replicating the unit cell in all three dimensions to form the extended structure.

Introduction to Crystal Types

Mineralogists study the myriad configurations that lattices can display.
In this class, we will only look briefly at one type: the cubic crystal.

A cube is a geometric shape consisting of six square facets meeting such that eight corner points arise.
In terms of atomic packing, however, a cube can take on three distinct packing modes:

Simple Cubic

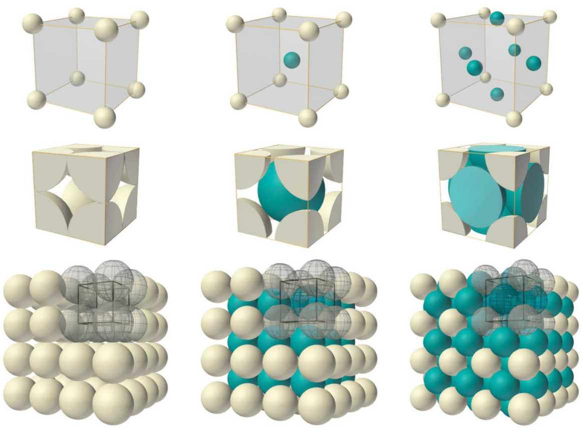
Body-Centered Cubic

Face-Centered Cubic

Cubic Configurations

Simple Cubic: atoms are at the corners of a cube. A single atom occupies a lattice.
Body-Centered Cubic: atoms are at the corners, and one more in the space between corners. Two atoms occupy a lattice.
Face-Centered Cubic: highest atomic density - atoms wedge diagonally in between corners, and four atoms occupy a lattice.

Cubic Configuration Graphic



(a) Simple cubic (b) Body-centered cubic (c) Face-centered cubic

Types of Crystalline Solids

Three types of crystalline solids exist, their type defined by the bonds that hold particles together.

Ionic Solids: composed of an alternating network of positive and negative ions. Ionic compounds which dissolve in water are called **electrolytes**, and will allow electric current to pass through the solution.

Molecular Solids: are composed of covalently bonded molecules, and are held together by intermolecular forces (such as hydrogen bonding or dipole-dipole forces). Solutions made from molecular solids do not conduct an electric current.

Crystalline Solids (Continued)

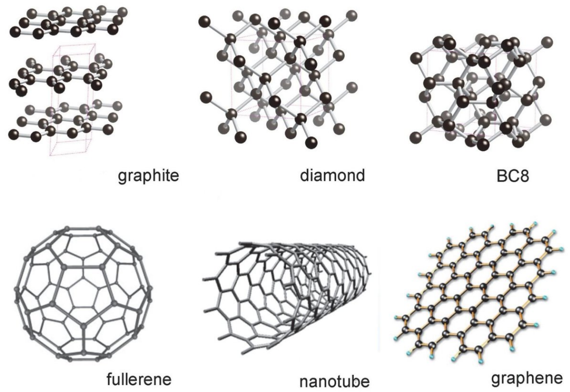
Atomic Solids: are represented by elements in their atomic state. Depending on the element, there are three types of solids that form, each with its own type of connective forces:

Metals: delocalized covalent bonds (more on that later) hold atoms in their lattice.

Noble gases: held together only by London forces.

Crystalline Solids (Continued)

Non-Metals: directional covalent bonds lead to giant molecules.
Example: carbon forms graphite, diamond, or fullerenes - each a potentially huge lattice of atoms.



Structure and Bonding in Metals

Metals have high thermal and electrical conductivity, which can be traced to the nondirectional covalent bonding that holds their atoms together.

As you saw in the cubic examples earlier, metallic solids are composed of spherical atoms that employs **closest packing** theory: atoms are packed as tighly together as geometric (and bonding) constraints allow.

In a cubic arrangement, the closest packing configuration is face-centered, which holds exactly four complete atoms.
A simple cubic configuration holds one complete atom, and a body-centered holds two complete atoms.

1. Density Example

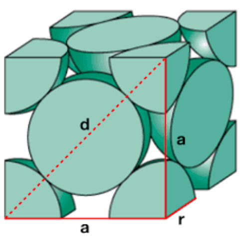
Silver crystallizes in a cubic closest packed structure. The radius of a silver atom is 144 pm. Calculate the density of solid silver (g/cm^3).
Hint - closest packing means that this crystal is face-centered.

1. Density Answer

Density is mass per volume, so we need to determine the mass of the atoms that occupy the lattice, and calculate the volume of a lattice.

Since there are four complete atoms in this configuration, the mass becomes:

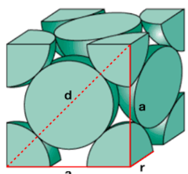
$$4\,atoms \bullet 107.9\,g/mol \bullet \frac{1\,mol}{6.02\,E23\,atoms} = 7.16\,E-22\,g$$



1. Density Answer

Using the diagram of a face-centered crystal, and the radial data, Pythagorean theorem determines the length of an edge of the cube.
Diagonal line = 4r.
Edge:

$$a^2 + b^2 = c^2$$
$$2a^2 = c^2$$
$$a = \sqrt{\frac{(4r)^2}{2}} = \sqrt{8r^2} = \sqrt{8 \bullet (144\,pm)^2} = 407\,pm$$



$$= 407E-12\,m \bullet \frac{100\,cm}{1\,m} = 4.07\,E-8\,cm$$

Volume:

$$side^3 = (4.07\,E-8\,cm)^3 = 6.74\,E-23\,cm^3$$

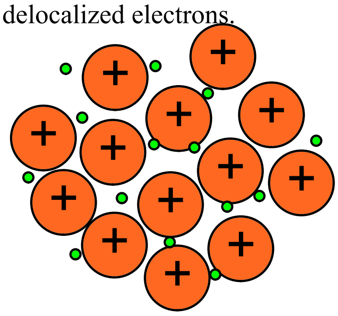
Finally, density:

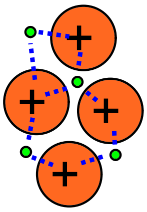
$$\sigma = \frac{m}{v} = \frac{7.16\,E-22\,g}{6.74\,E-23\,cm^3} = \boxed{10.6\,g/cm^3}$$

Bonding Models for Metals

'Electron Sea' Model - metal atoms have delocalized valence electrons that are free to move from atom to atom, leaving behind a positively charged metal center

Metallic Bond - attraction of metal centers to delocalized electrons.

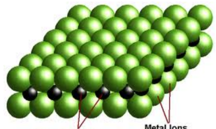




Metallic Bonds

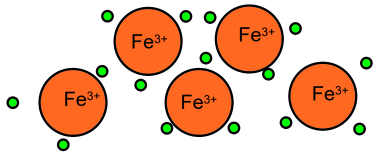
Metal Structure

Form lattices - a repeating structure between atoms.



The valence electrons a metal center can have equals its maximum charge (use your ions list).

Ex. Iron has a +3 ion, so it can have 3 valence electrons.



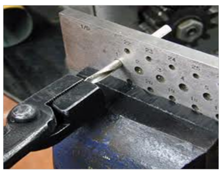
Properties of Metals

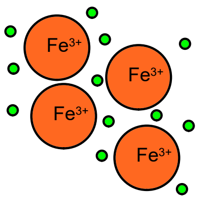
Delocalized electrons act as a lubricant, letting metal centers to slide past each other when force is applied.
Metals are shiny, and:
Malleable – can be hammered flat,

Durable – will bend without breaking,

Ductile – can be drawn into wire.

Draw plate for making wire.

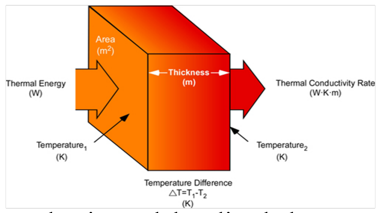




Ionic compounds, in comparison, with fixed charges, do NOT bend much before breaking, and will shatter if a hammer hits them.

More Properties

Thermally conductive – transfer heat well



Electrically conductive – delocalized electrons move when electric potential (voltage) applied.

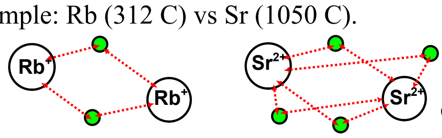
Melting & Boiling Points

Generally, metals have relatively high melting and boiling temperatures.

The more valence electrons a metal has, the higher the temperature: electrons in metallic bonds are attracted to metal centers (like little grappling hooks).

The more bonds there are, the more energy is needed to break them.

Example: Rb (312 C) vs Sr (1050 C).

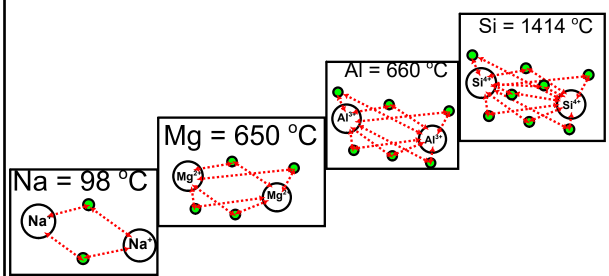


More Connections

2. Melting Point Example

Order these elements by increasing melting point:

Si Al Na Mg



Alloys

Metals form alloys – mixtures of elements with metallic properties.

Brass: Cu and Zn

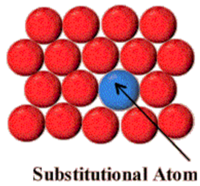
Bronze Statue: Cu and Sn

Steel: Fe and C with other metals

Types of Alloys

Substitutional – Some metal atoms replaced with atoms of similar size.

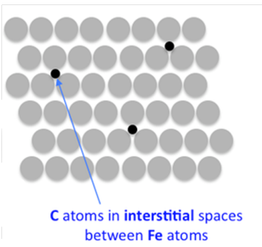
Example: Sterling silver → Silver (92%) mixed with Copper (8%).



Types of alloys

Interstitial – small holes in a lattice filled with small atoms.

Example = carbon steel. Carbon fits between iron atoms.

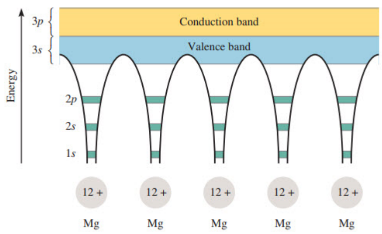


More on Electrical Conduction

The availability of vacant spaces in the valence shells of metals is what allows for delocalization.

This picture summarizes the concept well, in that the core electrons are unable to move, but those in the valence band can enter the conduction band and move around.

Figure 20.9 *Formation of conduction bands in magnesium. The electrons in the 1s, 2s, and 2p orbitals are localized on each Mg atom. However, the 3s and 3p orbitals overlap to form delocalized molecular orbitals. Electrons in these orbitals can travel throughout the metal, and this accounts for the electrical conductivity of the metal.*



Carbon and Silicon: Network Solids

Network Solids: Form when atoms of one non-metallic element form directional covalent bonds with each other, essentially forming tremendous molecules. These compounds are typically brittle, and won't conduct heat of electricity.

Carbon and silicon are two of these. Read pages 471 to 476 to learn more, or please research these two elements on the internet.

Also, continuing on to pages 477-478 provide useful information as to how semiconductors work. Please research this topic as well, if you've not got a textbook.

Homework

Preview 10.6 - 10.9

10.3 - 10.5 Problems in your Booklet
Due: Next Class