

Unit 1, Lesson 06: Introduction to Metallic Bonding (page 170- 171)

The vast majority of elements are metals. These elements are located to the left of the staircase line on the periodic table.

The properties of the individual metals vary widely. Mercury, with a melting point of -39°C , is a liquid at room temperature while tungsten melts at 3968°C . Lithium is soft and light (density 0.53 g/cm^3) while osmium is hard and dense (22.6 g/cm^3).

Regardless of the individual variation in properties, metals do have a number of characteristics in common. Metals:

- have lustre (are shiny)
- are solid at SATP (except mercury)
- are silver-coloured (except gold and copper)
- are good conductors of heat and of electricity
- are malleable and ductile

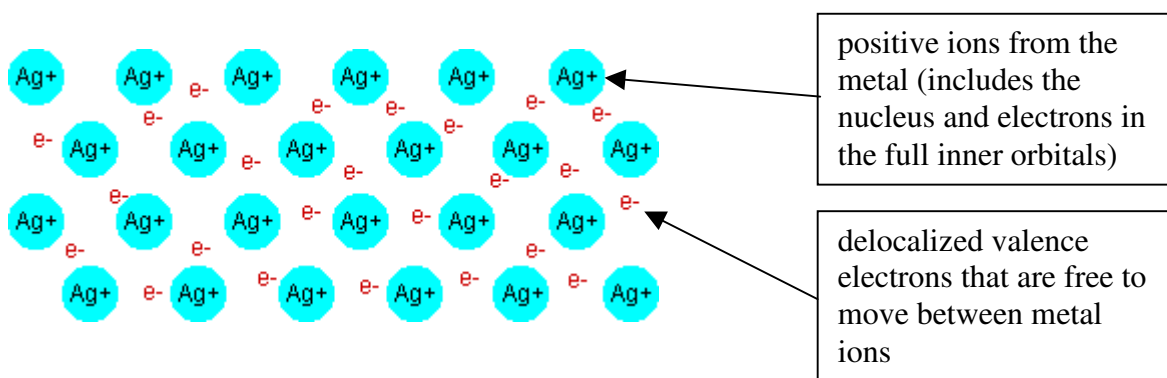
Because metals are solid (or liquid) at SATP, something must be holding the atoms together. It is a type of bonding called metallic bonding. Without metallic bonding, metal atoms would remain as separate, individual atoms, like the Noble gases.

Metallic bonding is defined as the force of attraction between metal atoms due to pooling of their valence electrons to form a delocalized “sea” of electrons.

So, how does metallic bonding work?

Recall that metals have low ionization energy and low electronegativity. The valence electrons in metals are only loosely held to the nucleus, so they are relatively free to move.

In metallic bonding, the positive metal cations are packed closely together, something like marbles in a box. The valence electrons are not associated with a single atom, but are “delocalized” and free to move from atom to atom. That is, the positive metal ions are surrounded by a “sea” or “cloud” of delocalized electrons. This is called the “free-electron” or “electron sea” model of metallic bonding.



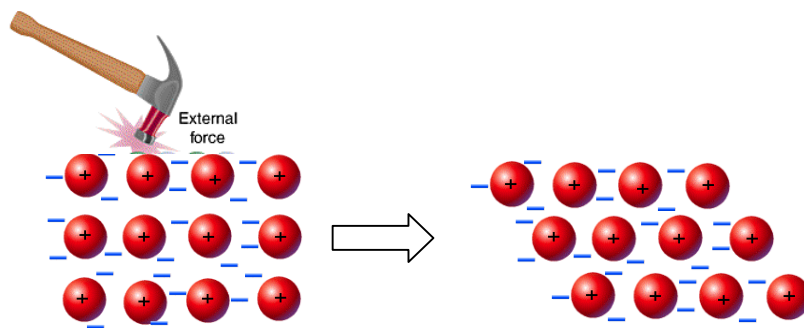
Animation showing electron motion in metallic bonding:

www.dur.ac.uk/.../01_metallic_bonding.htm

The electron sea model of metallic bonding explains many of the observed properties of metals:

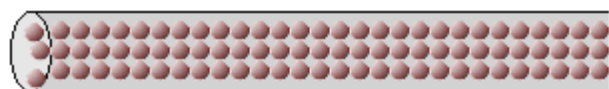
1. Metals are malleable and ductile

Malleable refers to the ability to pound a piece of metal into a thin sheet. Ductile refers to the ability to draw a piece of metal into a thin wire. When a piece of metal is hammered or stretched, the atoms slide or roll past one another. The metal atoms rearrange themselves within the “electron sea” to assume the new shape without breaking their metallic bonds.



2. Metals are good conductors of electricity

When an electric current (a stream of electrons) is passed through a metal, the electrons are free to move from metal ion to metal ion. The more freely they move through the metal, the better conductor it is.



unheated metal: atoms in an orderly arrangement, vibrating in place



added heat causes atoms to vibrate faster, colliding with their neighbours, which then vibrate faster within the electron sea

3. Metals are good conductors of heat

Heat is due to the motion of particles. If energy is added to a metal, the metal ions and electrons move faster. As these particles vibrate and move, they collide with their neighbours, which transmits the heat through the piece of metal.

4. Metals have lustre

When light hits the surface of a metal, the free valence electrons on the surface absorb and then re-emit the light energy, which makes the surface of the metal appear shiny.

The electron sea model of metallic bonding also explains the variation in the properties of metals:

1. Hardness and Melting Points

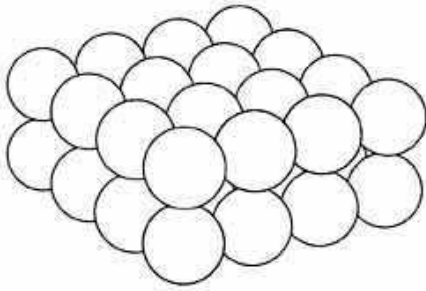
The hardness and melting point of a metal depend to a large extent on how many valence electrons the metal has to participate in metallic bonding. The greater the number of valence electrons, the more firmly the metal ions are held in place. This increases both the hardness and melting point of the metal. Alkali metals (Li, Na, K) have only one valence electron so they are very soft metals with low melting points. Alkaline Earth (Mg, Ca, Sr) have two valence electrons, so they are harder than the Alkali metals and have higher melting points. Moving left to right across a period, the hardness and melting points of metals generally increases as the number of valence electrons available for metallic bonding increases.

2. Density

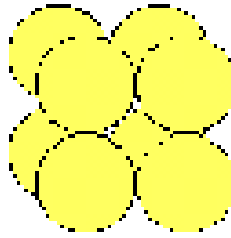
The density of metals depends on the average atomic mass of the atoms, and also on how the metal ions are packed together to form its crystal structure. Metal atoms arrange themselves so that they are as close together as possible (lowest possible potential energy), while minimizing the repulsion between their nuclei. Each metal has a characteristic, lowest energy arrangement of atoms which is called its “crystal structure”. This is indicated on the back of the periodic table.

Common Crystal Arrangements

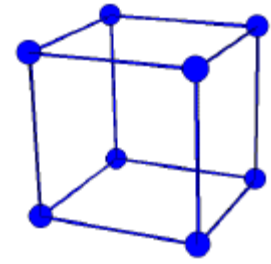
1. **Simple cubic packing**- the layers of atoms are arranged directly over one another. This is the most uncommon and least dense arrangement of atoms. It leaves large spaces between the atoms.



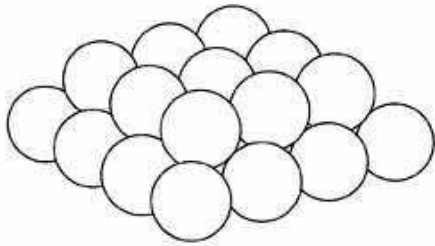
or



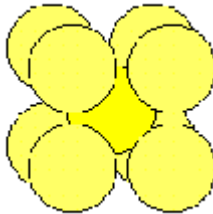
drawn



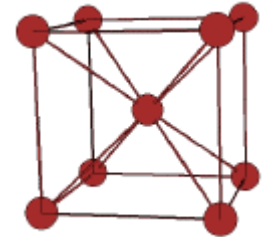
2. **Body-centred cubic packing**- the second layer fits into the spaces over the first layer. The third layer fits into the spaces over the second layer and is directly above the first layer. This is the most dense arrangement of atoms.



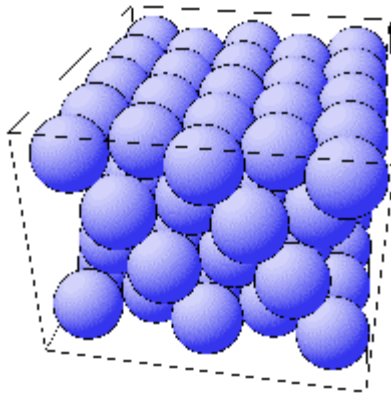
or



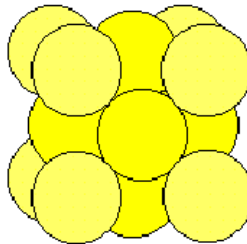
drawn



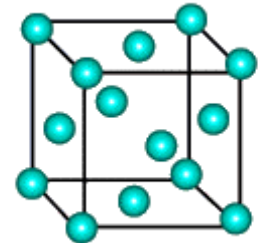
3. **Face-centred cubic packing**- the second layer has four atoms while the layers above and below it have five atoms. This is the second most dense arrangement of atoms.



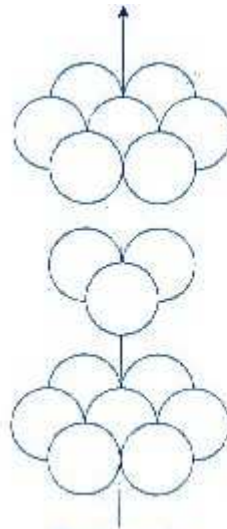
or



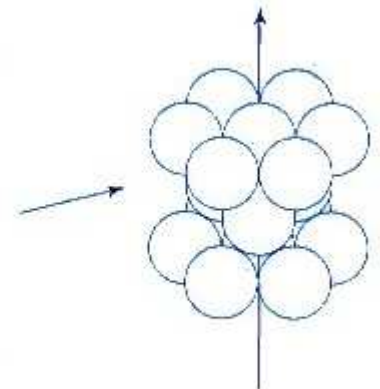
drawn



4. **Hexagonal packing**: the atoms form a three-dimensional hexagonal shape. The second layer has six atoms arranged in a hexagon around a single central atom, while the layers above and below it have three atoms that fit into the spaces above and below the central layer.



Exploded view.



Hexagonal close-packed structure

Metallic Bonding in Alloys

An **alloy** is a homogeneous mixture (solution) of a base metal with other elements (other metals or non-metals such as carbon or silicon). The base metal is the metal which is present in the largest concentration. The elements are mixed when they are molten and form metallic bonds as they solidify to form an alloy.

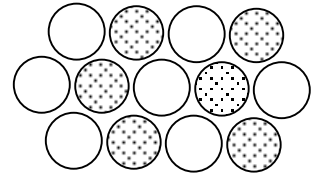
eg. sterling silver is an alloy of 92.5% silver and 7.5% copper, by weight. Silver is the base metal.

eg. bronze is an alloy of (about) 75% copper and 25% tin. Copper is the base metal.

If the added metal atoms are about the same size as the base metal atoms (within about 15%), then the added atoms just mix evenly through the alloy and the crystal structure remains similar. This is called a “substitutional alloy”.

eg. brass, made of copper ($Z = 29$) and zinc ($Z = 30$)

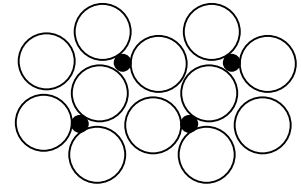
eg. stainless steel, made of iron ($Z = 26$), chromium ($Z = 24$)
and nickel ($Z = 28$)



If the added atoms are much smaller than the base metal atoms (more than about 15% smaller), they can fit into the spaces between the base metal atoms. This is called an “interstitial alloy”.

eg. high-carbon steel, made of iron ($Z = 26$) and carbon ($Z = 6$)

eg. an alloy containing tungsten ($Z = 74$) and cobalt ($Z = 27$)



Both types of alloys are usually much harder and stronger than pure metals because of **TWO** factors:

1. The added metal may provide additional valence electrons which will increase the strength of the metallic bonding
2. The different size of the added atoms will interfere with how easily the metal atoms can slide past one another, making the metal stronger and less malleable