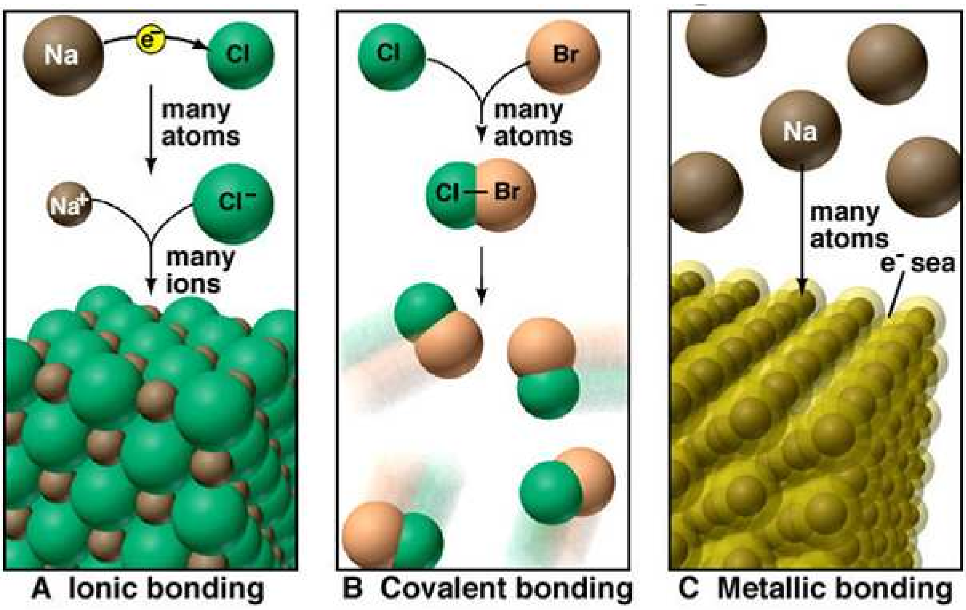
Chemical Bonding

What is a chemical bond? If a system has a lower energy when the atoms are close together than when apart, then bonds exist between those atoms. A bond is an electrostatic force that holds the atoms of elements together in a compound.

There are three types of bonding:



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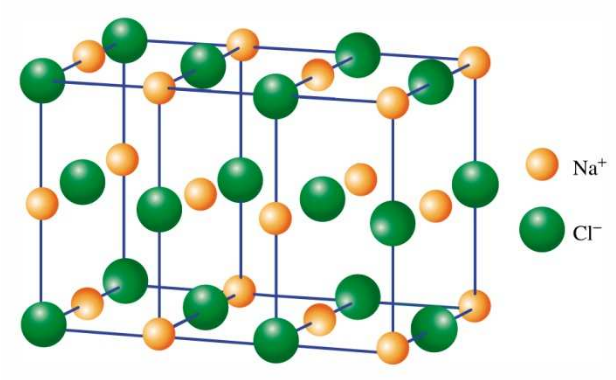
Ionic Bonding



The structure of an ionic compound is a three-dimensional lattice (e.g. cubic, tetrahedral, octahedral) and depends on the radii of the ions and the stoichiometry.

- Electrons are transferred to form cations (positively charged ions) and anions (negatively charged ions).
- An ionic bond is the electrostatic attraction between oppositely charged ions.
- The magnitude of the attraction depends on the size and charge of the ions involved (charge density).
- The interactions are *isotropic - i.e.* non-directional.
- Electronegativity differences >2 generally result in ionic bonds. So, compounds formed between elements of Groups 1 and 2 and elements of Groups 16 and 17 are expected to be ionic.

The *lattice energy* of a compound represents the strength of the ionic attraction and properties (*e.g.*, melting point, hardness, solubility). It is the energy change required to separate one mole of ionic solid into the gaseous ions.

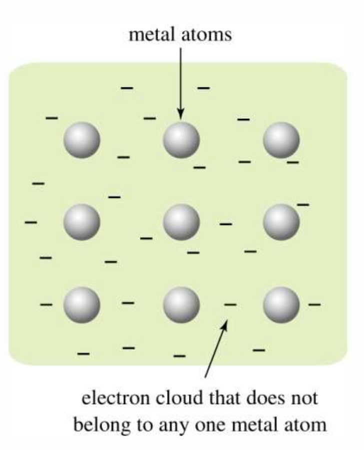
e.g. $NaCl(s) \rightarrow Na^{+}(g) + Cl^{-}(g)$ LE = +788 kJ mol^{-1}
e.g. $Na_2O(s) \rightarrow 2Na^{+}(g) + O^{2-}(g)$ LE = +2488 kJ mol^{-1}
e.g. $MgO(s) \rightarrow Mg^{2+}(g) + O^{2-}(g)$ LE = +3800 kJ mol^{-1}

Typically ionic compounds show the following properties:

- Solids are hard, crystalline, brittle and have a high melting point.
- The solid does *not* conduct electricity.
- An ionic compound does conduct electricity as a molten liquid, or in solution for soluble compounds, when ions are released to carry the current.

Metallic Bonding

If elements have relatively low ionization energies then the valence electrons become mobile giving rise to a “sea of electrons” or metallic bonding, e.g. Fe(s).

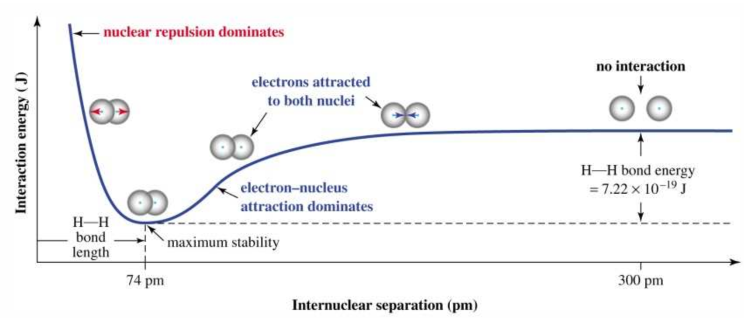


Typically metals show the following properties:

- Good electrical conductivity in solid and molten state as a result of the mobile electrons.
- Metals are malleable and ductile –atoms are able to slide past each other in a sea of electrons.
- Melting point – variable but often low as attraction between nuclei and mobile electrons not really broken when melted.
- Boiling point – typically high due to need to overcome attraction between nuclei and mobile electrons.

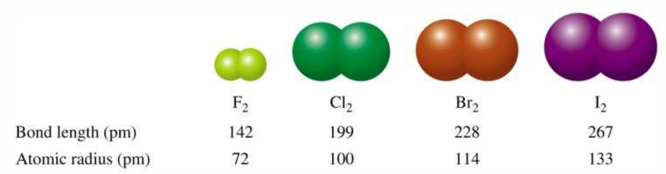
Covalent Bonding

In a covalent bond electrons are shared between two atoms.

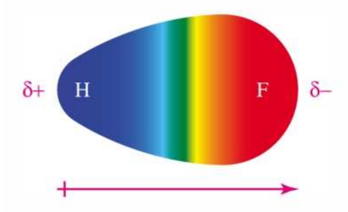


There is a specific distance between the bonding nuclei at which the energy of the molecule is minimized. This distance is called the bond length of a covalent bond.

- A single covalent bond is made up of a pair of electrons. Some atoms can share more than one pair of electrons at a time. Such sharing results in a double bond (for sharing two electron pairs) or a triple bond (for sharing three pairs).



- Pairs of electrons in the valence shell of an atom, but which do not take part in bonding (i.e. are not shared) are called lone pairs or non-bonding pairs of electrons.
- If a bond is formed between two different atoms, the electron pair of the bond will be attracted towards the atom with the higher electronegativity (EN). This results in the atom with the higher EN having a partial negative charge relative to the atom of lower EN. The bond is termed polar.



- There is a broad inverse correlation between the strength of a bond and its length

Bond	Energy (kJ mol^{-1})	Bond length (pm)
H-H	432	74
C-H	413	109
Cl-Cl	239	199
Br-Br	193	228
C-C	347	154
C=C	614	134
C≡C	839	121

- Electronegativity differences <2 generally result in covalent bonds. So, compounds formed between non-metals are predicted to be covalent.

Two types of covalent solid with very different properties:

- Network covalent solids, e.g. diamond – very hard, high mp, (infinite network of covalent bonds, much energy to break), non conducting (electrons not mobile, no ions in melt)
- Molecular covalent, e.g. I_2, CO_2 – soft, low mp (small molecules with only weak forces between them), non conducting (electrons not mobile, no ions in melt)

Lewis Structures

Lewis structures are a means of determining stable electron arrangements in molecules. It considers the valence electrons of an atom only. A stable arrangement is one in which each atom has achieved a Noble gas electron configuration by distribution of the electrons as bond pairs or lone pairs (non-bonded pairs). A Noble gas electron configuration is 2 for hydrogen and 8 for C, N, O and F. This is sometimes called *The Octet Rule*.

Covalent compounds of Be and B may have fewer than 8 electrons associated with these atoms. They are referred to as 'electron deficient compounds'.

Covalent compounds involving elements from the 3rd Period or higher (typically S, Cl, Br, I) may show 8, 10 or 12 electrons associated with these elements. This expanded valence is possible because of the availability of *d*-orbitals.

To draw a *Lewis Structure* you need to know which atoms are bonded to which. Then:

1. Add up the total number of valence electrons present, add or subtract electrons to account for any charge.
2. Join the appropriate atoms using one electron pair for each bond.
3. Distribute the remaining electrons to result in an octet of electrons on each atom (except hydrogen that always has two electrons associated with it).
4. If there are too few electrons to give every atom an octet, move non-bonded pairs between atoms to give multiple bonds.
5. If there are electrons left over after forming octets, place them on the central atom.
6. Indicate the overall charge.

Question: Draw the Lewis structures of: CH_4, NH_3, NH_4^+, H_2O, O_2 and N_2

σ-Bonds

The first bond between any pair of atoms arises from end on overlap of orbitals, e.g. H_2, and is called a σ-bond. "Single bonds are always sigma bonds".

π-Bonds

The second and third bonds between any pair of atoms arise from side on overlap of *p*-atomic orbitals, e.g. N_2, and are called a π-bonds. So a double bond is composed of one sigma and one pi bond and a triple bond is composed of one sigma and two pi bonds.

Question: Draw the Lewis structures of PCl_3, PCl_5, SF_4 and ICl_4^-

Where more than one structure may be drawn, *resonance* occurs where the actual structure is a weighted combination of all possible structures and the electrons are *delocalised* in the molecule/ion.

Question: Draw the Lewis structures of O_3, HCO_2^-, NO_3^- and SO_4^{2-}