SECTION 4

CHEMICAL BONDS

In most matter atoms exist close together in aggregates. The inner electrons are held tightly by the nucleus, (i.e. they have very high ionisation energies), but the valence electrons can be attracted to the nuclei of two or more atoms simultaneously. It is this electrostatic attraction of the valence electrons to two or more nuclei that provides the forces which hold atoms together and is the basis of the chemical bond. This section defines different classes of bonds and the language of depicting them on paper.

Chemical bonds: The forces holding atoms together in matter.

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Covalent bond: A pair of electrons shared between two atoms (nuclei) in a molecule or polyatomic ion.

Single bond: One pair of shared bonding electrons; represented by a line [e.g. H-H in H_2].

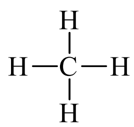
Double bond: Two pairs of shared bonding electrons; represented by a double line [e.g. O=C=O in CO_2].

Triple bond: Three pairs of shared bonding electrons; represented by a triple line [e.g. N≡N in N_2].

The chemical behaviour of different elements can be understood by considering the number and arrangement of valence electrons in their atoms.

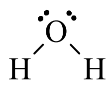
With the exception of metals, almost all atoms in stable substances have 2 (H, He), 8, 18, or an even number between 8 or 18 electrons in their outermost shell. (High temperatures and low pressures change this.) An octet (8) of electrons in the third shell (which can accommodate 18) is common.

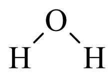
Now we can understand the formulae and properties of some simple compounds that we have met in previous sections.

<u>Methane</u>, CH_4. The carbon nucleus (atom) is surrounded by four hydrogen nuclei. Number of valence electrons = 4(C) + 4 x 1(H) = 8. These 8 are in four pairs around C and each H has one pair. We represent methane by the **Lewis structure** 

Lewis structure: A chemical formula (diagram) which shows the arrangement of the atoms and valence electrons in the species.

Water, H_2O. The oxygen nucleus has two H nuclei attached. Again there are 8 valence electrons, 6(O) + 2 x 1 (H). Lewis structure:

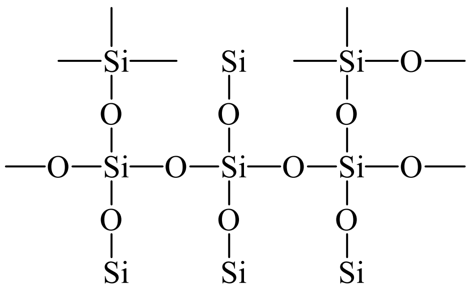




The two pairs of dots represent the two **non-bonding electron pairs** in the valence shell of the O atom. However, these are not always shown as their existence can be inferred. The inner shell electrons which we can consider belonging exclusively to the one nucleus are never shown in Lewis structures.

Dinitrogen, N_2. 10 valence electron, 2 x 5 (N). The Lewis structure: :N≡N: Each N nucleus is surrounded by 8 valence electrons, 3 pairs of electrons being attracted simultaneously to two N nuclei. Dinitrogen contains a triple bond .

Carbon dioxide, CO_2, and silicon dioxide, SiO_2. In CO_2 and an SiO_2 unit there are 16 valence electrons 4 (C) or (Si) + 2 x 6 (O). Carbon dioxide exists as discrete CO_2 molecules. We can rationalise this by the Lewis structure O=C=O where each atom has 8 valence electrons and the molecule has two double bonds. Silicon dioxide (quartz) is a solid. We can rationalise this by writing the Lewis structure for a small part of the compound:



Again each atom is surrounded (tetrahedrally) by 8 valence electrons, each Si with 4 bonding pairs, and each O with two single bonds and two non-bonding electron pairs.

CO_2 and SiO_2 have different structures. The explanation for this is beyond the scope of this document. The existence of discrete molecules of CO_2 implies the energy of CO_2 in this form is lower than that of a polymeric structure.

Sodium chloride, NaCl, is an ionic solid composed of Na^+ ions surrounded by Cl^- ions and vice-versa. Each Na^+ and Cl^- ion has eight electrons in its outermost shell. (The valence electrons are all located on the Cl^- ion.) **Ionic bonds** hold the structure together.

Ionic bonds: The electrostatic attraction between cations and anions. The bonding electrons are localised on the anions.

<u>Calcium phosphate</u>, $Ca_3(PO_4)_2$ consists of Ca^{2+} cations surrounded by PO_4^{3-} anions and vice-versa and is therefore also an ionic compound, the cations and anions being held together by electrostatic attraction. However the bonds holding the P and O nuclei together in the phosphate anion are covalent. The same is true of the bonds in a sulfate anion or a carbonate anion, etc.

Metallic bonds: The bonds holding atoms of a metal together. The simplest picture is that of cations in a sea of valence electrons spread out or "delocalised" over the whole structure.

Polar bond: A covalent bond in which the bonding electrons are not evenly shared, the electrons being attracted more to the more **electronegative** atom [e.g. H-Cl, which has a polar bond with H partially positive and Cl partially negative].
Electronegativity: A measure of the ability of an atom to attract electrons to itself in a compound. The order of electronegativity is:

$$F > O > Cl > N > Br > I > S > C > H > P > B > Si$$

Polar molecule: A molecule with a positive side and a negative side [e.g. H-Cl, (δ+)H-Cl(δ-) where δ means slightly; H_2O with O slightly negative and the H's slightly positive].

Bond length: The average distance between the nuclei of the two atoms bonded together. (Average because the nuclei are vibrating).

Bond strength: The energy needed to break a chemical bond with the bonding electrons being equally divided between the two fragments. (see *section 11*)

Intramolecular bonds: Bonds between atoms in a molecule. [e.g. H-O bonds of water]

Intermolecular bonds: Bonds or attractive forces between different molecules. [e.g. **hydrogen** and **Van der Waals bonds**]

Hydrogen bond: A weak bond between fluorine, oxygen or nitrogen in one molecule or ion and a hydrogen atom bonded to a fluorine, oxygen or nitrogen atom in another molecule or ion or in the same molecule. Properties of water and the structure of many biological substances [e.g .proteins and DNA] are explained in terms of hydrogen bonds.

Van der Waals bonds (forces): The intermolecular forces which hold molecules together in liquids and solids. In vaporisation and sublimation these bonds are broken, and in condensation and deposition they are made.

EXERCISES

Show the polarity of the following bonds:

1. *Example*: C-Cl

   Answer: (δ+)C-Cl(δ-) Chlorine more electronegative than carbon

2. C-O 3. Si-F 4. Cl-P 5. H-C 6. H-N

State whether the following molecules are polar and if so show the polarity:

7. Hydrogen fluoride, HF 8. Boron trifluoride, BF_3, a planar triangular molecule

9. Carbon dioxide, CO_2, a linear molecule 10. Sulfur dioxide, SO_2, a bent molecule

11. Ammonia, NH_3, a pyramidal molecule

12. Methane, CH_4, the carbon atom is tetrahedrally surrounded by the 4 hydrogens