Chemical Bonding Syllabus Learning Objectives / Notes

3.1 Ionic Bonding

(a) describe the formation of ions by electron loss/gain and that these ions usually have the electronic configuration of a noble gas
(b) describe, including the use of 'dot-and-cross' diagrams, the formation of ionic bonds between metals and non-metals, e.g. NaCl; $MgCl_2$
(c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. NaCl (students will not be required to draw diagrams of ionic lattices) (d) relate the physical properties (including electrical property) of ionic compounds to their lattice structure (see also 3.4(g))

3.2 Covalent Bonding

(a) describe the formation of a covalent bond by the sharing of a pair of electrons and that the atoms in the molecules usually have the electronic configuration of a noble gas (b) describe, using 'dot-and-cross' diagrams, the formation of covalent bonds between non metallic elements, e.g. H_2; O_2; H_2O; CH_4; CO_2
(c) deduce the arrangement of electrons in other covalent molecules
(d) relate the physical properties (including electrical property) of covalent substances to their structure and bonding (see also 3.4(g))

3.3 Metallic Bonding

(a) describe metals as a lattice of positive ions in a 'sea of electrons'
(b) describe the general physical properties of metals as solids having high melting and boiling points, malleable, good conductors of heat and electricity in terms of their structure (see also 3.4(g))

3.4 Structure and Properties of Materials

(b) describe an alloy as a mixture of a metal with another element, e.g. brass; stainless steel (c) identify representations of metals and alloys from diagrams of structures (d) explain why alloys have different physical properties to their constituent elements (e) compare the structures of the following substances in order to deduce their properties: (i) simple molecular substances, e.g. methane, iodine
(ii) macromolecules, e.g. poly(ethene)
(iii) giant covalent substances, e.g. sand (silicon dioxide), diamond, graphite (see also 3.4(g))
(f) compare the bonding and structures of diamond and graphite in order to deduce their

properties such as electrical conductivity, lubricating or cutting action (students will not be required to draw the structures)

(g) deduce the physical and chemical properties of substances from their structures and bonding and vice versa (see also 3.1(d), 3.2(d), 3.3(b) and 3.4(e))

4.1 Formulae and Equation Writing

(a) state the symbols of the elements and formulae of the compounds mentioned in the syllabus (c) deduce the formulae of simple compounds from the relative numbers of atoms present and vice versa

(d) deduce the formulae of ionic compounds from the charges on the ions present and vice versa

Ionic Bonding

1. Formation of Ions
Big idea 1: The Stable Electronic Configuration of a Noble Gas

1. The elements found in Group 0 of the Periodic Table are known as noble gases. Some examples of the noble gases are helium, neon, argon, krypton, xenon and radon.

2. Noble gases are stable and unreactive. They are monatomic and exist as single atoms.

3. Noble gases are stable because they have fully filled outer shells. Helium has a duplet configuration while all other noble gases have an octet configuration. (thus are inert and do not react with other atoms.)

4. Atoms of other elements are reactive because their outer shells are not fully filled. These atoms lose, gain or share outer electrons to achieve complete valence shell configuration (the stable noble gas configuration).

2. Why atoms form ions?
Big idea 2: Atoms form ions to achieve stable electronic structure with full electron shells.

1. To achieve the stable electronic structure,

(a) atoms of metals lose electrons to form positive ions (cations);

(b) atoms of non-metals gain electron to form negative ions (anions). 2. Ions

with two or more covalently bonded atoms are called polyatomic ions.

Examples of such ions are the ammonium ion (NH_4^+), carbonate ion (CO_3^{2-}) and the sulfate ion (SO_4^{2-}) (Note: structure of polyatomic ions is not required).

3. Formation of Ionic Bond: Transferring Electrons

1. Ionic bonds are formed between metals and non-metals.

Fluorine, chlorine, oxygen, sulfur

Examples of metals: Sodium, potassium, calcium, magnesium

Examples of non-metals:

2. In the formation of an ionic bond, the metal atom transfers electrons to the non-metal atom to form positive ions (cations) and negative ions (anions).

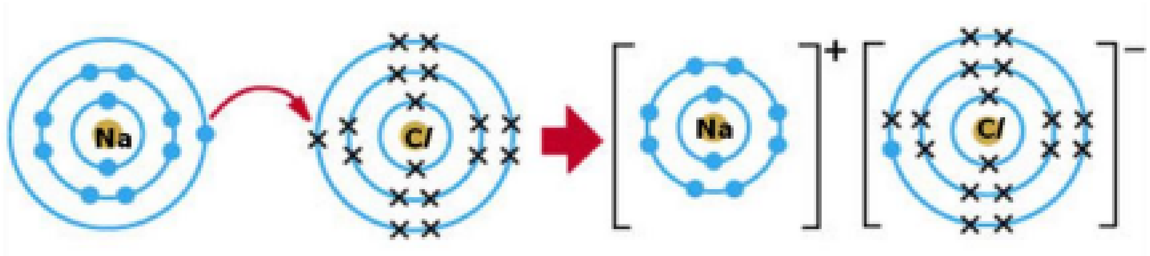
3. The oppositely-charged ions are held together by strong electrostatic forces of attraction called ionic bonds.

Example 1: In the formation of sodium chloride.

(a) sodium atom (2.8.1) loses 1 electron to form Na^+ion, achieving stable electronic structure (2.8).

(b) chlorine atom (2.8.7) gains 1 electron to form Cl^-, achieving stable electronic structure (2.8.8).

(c) There is a transfer of electrons from sodium to chlorine to form sodium chloride.



Formula	Na	Cl	Na^+	Cl^-
Name	Sodium atom	Chlorine atom	Sodium ion	Chloride ion
Electronic configuration	2, 8, 1	2, 8, 7	2, 8	2, 8, 8

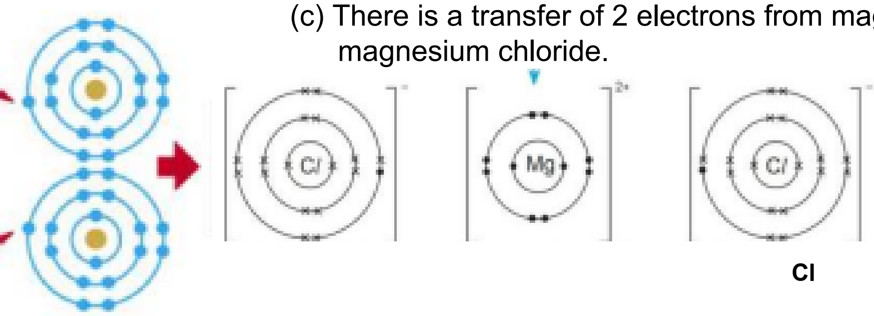
(d) The formula of the compound formed is NaCl.

<u>Example 2: In the formation of magnesium chloride,</u>

(a) magnesium atom (2.8.2) loses 2 electrons to form Mg^{2+}, achieving stable electronic structure.

(b) chlorine atom (2.8.7) gains 1 electron to form Cl^-, achieving stable electronic structure (2.8.8).

(c) There is a transfer of 2 electrons from magnesium to two chlorine atoms, forming magnesium chloride.



Cl

Mg

Cl

Formula	Mg	Cl	Cl^-	Mg^{2+}	Cl^-
Name	Magnesium atom	Chlorine atom	Chloride ion	Magnesium ion	Chloride ion
Electronic configuration	2, 8, 2	2, 8, 7	2, 8, 8	2, 8	2, 8, 8

(d) The formula of the compound formed is $MgCl_2$.

4. Physical Properties of Ionic compounds

Property	**Explanation** *(Specify the identity of the ions where applicable.)*
Have very high melting and boiling points (for reference: m.p. ~ few hundred to few thousand degrees Celsius).	An ionic compound has a giant ionic crystal lattice structure. A large amount of energy is required to overcome the strong forces of electrostatic forces of attraction between the negative and positive ions. (Ionic compounds are usually solid at room temperature due to the same reason.)
Usually soluble in water but insoluble in organic solvents. Dissolve to form a solution (aqueous state and the symbol is (aq)).	Not required to explain
Conduct electricity in the aqueous and molten states but not in the solid state.	In **solid** state, the ions are held in fixed positions by strong electrostatic forces of attraction between the positive and negative ions. As there are no free mobile ions to carry charges, ionic compounds cannot conduct electricity in the solid state. In **molten** or **aqueous states,** the strong electrostatic forces of attraction have been overcome, hence there are mobile ions to carry charges.
Hard and strong	A large amount of energy is required to overcome the strong forces of electrostatic forces of attraction between the negative and positive ions.

5. Chemical Formulae of Ionic Compounds

1. The name of the non-metal ion usually ends with –ide (mostly monatomic), –ite (polyatomic) or –ate (polyatomic)

2. Name and formulae of complex (polyatomic) ions **[need to remember the formula]**

Name	**Formula**
hydroxide	OH^-

sulfate	SO_4^{2-}
nitrate	NO_3^-
carbonate	CO_3^{2-}
ammonium	NH_4^+
phosphate	PO_4^{3-}

3. Some examples of chemical formulae of ionic compounds:

Chemical formula	**Name**
$NaCl$	sodium chloride
CaO	calcium oxide
NH_4F	ammonium fluoride
$Ca(OH)_2$	magnesium hydroxide
BaS	barium sulfide
Zn_3N_2	zinc nitride
K_2S	potassium sulfide
$BaSO_4$	barium sulfate

4. To determine the ratio of positive to negative ions:

(a) The charges must be balanced for the compound to be stable (i.e. overall charge must be 0).
(b) For inorganic compounds, the symbol of the metallic element will go first. (c) More than one ion can be involved in forming the compound. The number of each ion is indicated by a subscript number after the chemical symbol of the ion. The ratio should be the simplest ratio. “1” is by default and does not need to be indicated in the chemical formula.
(d) Polyatomic ions cannot be split up and should be considered as a whole. Brackets are required to group them.

5. Some common acids and their chemical formulae:

Substance	**Chemical formula**
Hydrochloric acid	HCl

Nitric acid	HNO_3
Sulfuric acid	H_2SO_4
Phosphoric acid	H_3PO_4

Covalent Bonding

1. Covalent Bond: Sharing Electrons

1. Covalent bonding involves the sharing of electrons with no transfer or movement of electrons between two atoms. Molecules are formed, not ions.

2. This type of bonding occurs when non-metal atoms bond together so as to achieve the stable electronic configuration of a noble gas with full electron shells.

3. Covalent compounds can be categorised into simple molecules (simple molecular structure) and giant molecules (giant molecular structure).

   (a) Example of simple molecules: chlorine, methane, carbon dioxide and water (b) Example of giant molecules: diamond, graphite and silicon dioxide

2. Simple Molecules

1. Simple covalent compounds exist as simple, discrete molecules.
2. Atoms are held together by strong covalent bonds.
3. Molecules are held together by weak intermolecular forces of attraction.

Weak intermolecular forces of attraction between molecules

Strong covalent bond between atoms in molecules

3. Simple Molecules: Description for Formation of Covalent

Bonds Example 1

Chlorine gas

(a) Chlorine atom has electronic configuration of 2.8.7.
(b) Each chlorine atom has <u>seven</u> outer electrons.
(c) A chlorine atom shares <u>one</u> valence electron with another chlorine atom to achieve the complete valence shell.
(d) <u>A single C*l* – C*l*</u> bond is formed.

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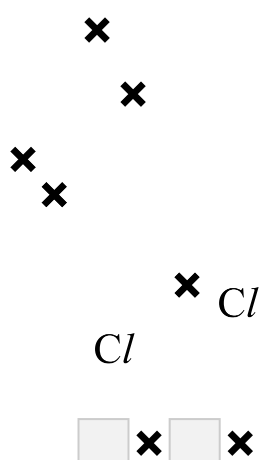
<u>Example 2</u>

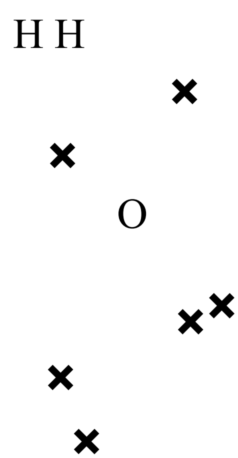
Carbon dioxide gas

(a) Carbon atom has electronic configuration of 2.4.
(b) Oxygen atom has electronic configuration of 2.6.
(c) A carbon atom shares <u>four</u> valence electrons with <u>two</u> oxygen atoms to achieve the complete valence shell.
(d) <u>Two double C = O</u> bonds are formed.

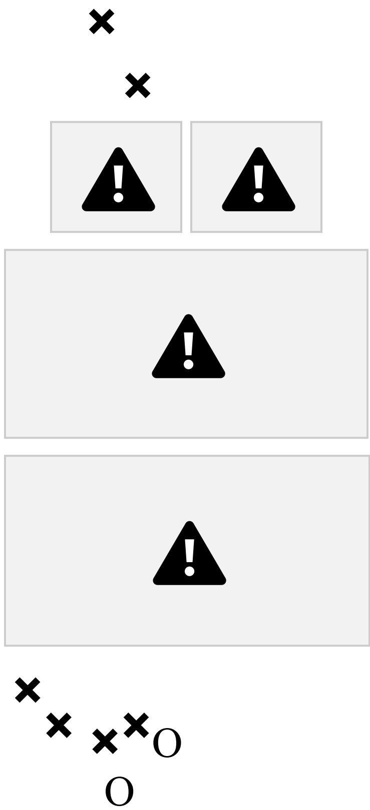
4. Simple Molecules: Drawing of Electronic Structures

Note: Shared pair of electrons are to be drawn <u>inside</u> the overlap of circles only!

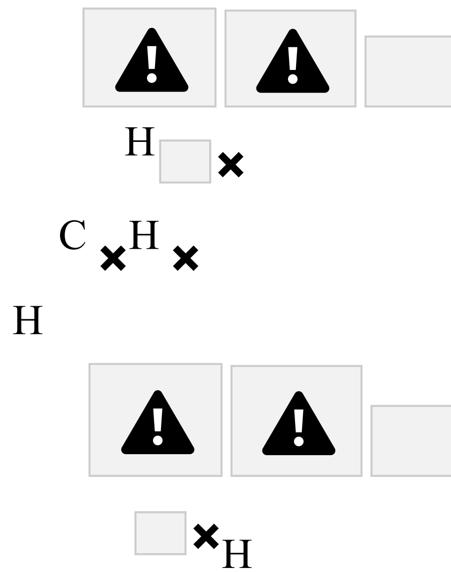
<table>
<tr><th>Molecules of elements</th><th>Molecules of compounds</th></tr>
<tr><td>

Name: Chlorine
Chemical formula: Cl_2
Structural formula: Cl – Cl
– : single covalent bond
– : 2 shared electrons
*Cl_2 has 1 single covalent bond</td><td>

Name: Water
Chemical formula: H_2O
Structural formula: H – O – H
*H_2O has 2 single covalent bonds</td></tr>
</table>

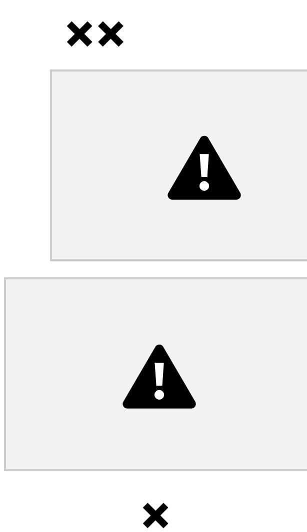


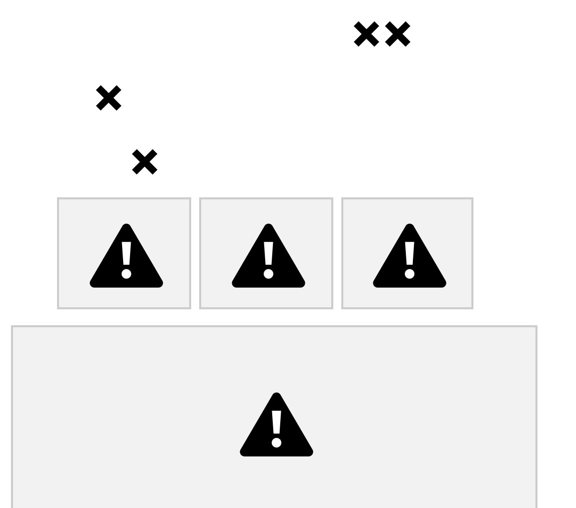
Name: Oxygen
Chemical formula: O_2
Structural formula: O = O
= : double covalent bond
= : 4 shared electrons
**O_2 has 2 double covalent bonds*

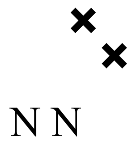
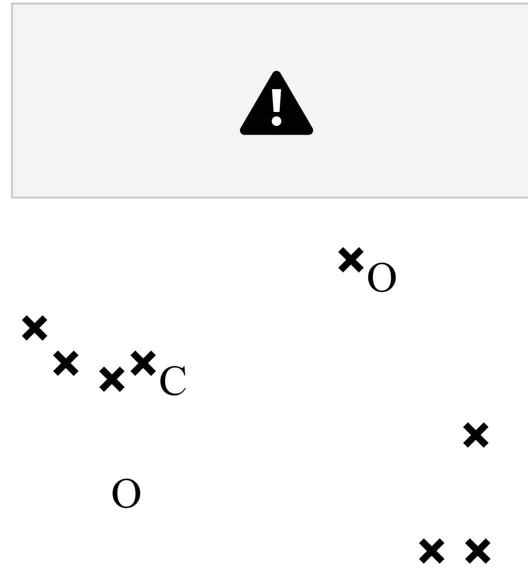


Name: Methane
Chemical formula: CH_4
Structural formula:

**CH_4 has 4 single covalent bonds*





 **Name:** Nitrogen **Chemical formula:** N_2 **Structural formula:** N ≡ N ≡ : triple covalent bond ≡ : 6 shared electrons **N_2 has 1 triple covalent bond*	 **Name:** Carbon dioxide **Chemical formula:** CO_2 **Structural formula:** O = C = O **CO_2 has 2 double covalent bonds*

5. Simple Molecules: Physical Properties

Property	**Explanation** *(Specify the identity of the atoms / molecules where applicable.)*
Have low melting and boiling points	A simple molecule has simple molecular structure. Little energy is needed to overcome the weak intermolecular forces of attraction between the molecules. (Covalent molecules are usually liquids or gases at room temperature due to the same reason.)
Poor conductors of electricity in all physical states.	The molecules do not have mobile particles to carry charges.
Usually insoluble in water but soluble in organic solvents such as alcohol, methylated spirits or petrol. Exceptions: hydrochloric acid, sulfuric acid and nitric acid which are soluble in water.	Not required to explain

6. Giant Molecules: Physical Properties of Diamond

strong covalent bond

carbon atom

carbon atom

1. Diamond is an allotrope of carbon.

Allotrope: Different structural forms of the same element, as the atoms are arranged differently. They can have different physical properties and chemical properties.

Property	**Explanation** *(Specify the identity of the atoms / molecules where applicable.)*
Very hard and has high melting and boiling points.	Diamond has a giant molecular structure. Each carbon atom is covalently bonded to 4 other carbon atoms by strong covalent bonds. A large energy is needed to break the strong bonds.
Poor conductors of electricity in all physical states.	Each carbon atom shares all four of their valence electrons with 4 other carbon atoms. Hence, there are no mobile electrons to carry charges.

7. Giant Molecules: Physical Properties of Graphite

1. Graphite is another allotrope of carbon.

strong covalent bond

carbon atom

weak intermolecular forces of attraction

Property	Explanation *(Specify the identity of the atoms / molecules where applicable.)*
Have low melting and boiling points	Graphite has a giant molecular structure. Each carbon atom is covalently bonded to 3 other carbon atoms by strong covalent bonds. A large energy is needed to break the strong bonds.
Can conduct electricity	Each carbon atoms shares three of their valence electrons with 3 other carbon atoms. Hence there is one valence electron that is not used to form covalent bonds and these mobile electrons can carry charges.
Soft and slippery	There are weak intermolecular forces of attraction between hexagonal layers of carbon atoms. A small energy is needed to overcome them so they can slide over each other easily.

3. Giant Molecules: Physical Properties of Silicon Dioxide

silicon atom

oxygen atom

strong covalent bond

1. Silicon dioxide, also known as silica, can be found in sand, SiO_2

Property	Explanation *(Specify the identity of the atoms / molecules where applicable.)*
Very hard and has high melting and boiling points.	Silicon dioxide has a giant molecular structure. Each silicon atom is covalently bonded to 4 other oxygen atoms and each oxygen atom is bonded to 2 other silicon atoms by strong covalent bonds. A large energy is needed to break the strong bonds.
Poor conductors of electricity in all physical states.	All the valence electrons of the oxygen and silicon atoms are used for bonding. Hence, there are no free mobile electrons to carry charges.

Metallic Bonding

1. Metallic Bond

positive ion

mobile electron

1. In metals, each atom loses its valence electrons to form a positive ion.

2. These electrons are mobile to form a "sea of mobile electrons".

3. The electrostatic forces of attraction between the positive metal ions and the 'sea of mobile electrons' forms the metallic bond.

2. Metals: Physical Properties

	Property	**Meaning**	**Explanation**
1	**Malleable**	Metals can be hammered or beaten into thin sheets without breaking.	Metal atoms are of the same size and are arranged in orderly layers by strong metallic bonds. When a force is applied, the layers can slide past one another.
2	**Ductile**	Metals can stretched into thin wires.	

3	**High Density (except Group I metals)**	Metals have high densities.	The atoms are closely-packed together in orderly layers by strong metallic bonds. Hence, there are more atoms per unit volume and the mass is higher per unit volume.
4	**Good conductor of electricity and heat**	Metals are good conductors of electricity and heat.	The positive ions of the metal are surrounded by a 'sea of mobile electrons'. **Mobile electrons** allow metals to conduct heat and electricity.
5	**High melting and boiling point (except Group I metals)**	Metals have high melting and boiling points.	There is a strong electrostatic forces of attraction between the positive metal ions and the 'sea of mobile electrons' which requires a large energy to overcome.
6	**Shiny**		

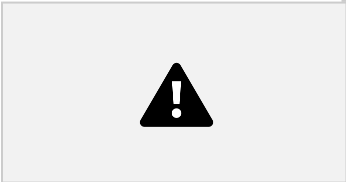
3. Alloys

Definition: It is a mixture of a metal with one or a few other elements.

1. Alloys have many advantages over pure metal. Alloys can be made to:
   - Be harder and stronger
   - Have better appearance
   - Be more resistant to corrosion
   - Have a lower melting point

Examples of alloys	Element	Properties
Steel	iron + carbon	It makes metals harder and stronger.
Stainless Steel	iron + carbon + nickel + chromium	It makes the metal more resistant to corrosion (rusting) – see later part of notes.
Bronze	copper + tin	It makes metals harder and stronger.
Brass	copper + zinc	It makes metals harder and stronger.

2. Pure metal vs Alloy



**** Common Qns: Why are alloys harder and stronger than pure metals?**

Different sized atom of another element disrupts the orderly arrangement of atoms, making it more difficult for the layers of atoms to slide past one another easily.

Difference	Pure Metal	Alloy (eg. brass)
Structure	Atoms are of the same size. They are orderly arranged in regular rows.	Atoms are of different sizes. The orderly arrangement of atoms is disrupted.
Properties	When force is applied, the layers of atoms slide over each other easily. Thus, pure metal is soft.	When force is applied, the layers of atoms cannot slide over each other easily.

Summary

	Metals	**Ionic Compounds**	**Covaler**	
Bonding	Metallic bond	Ionic bond	Cova	
Elements involved	Metals only	Metals* and non metals	Non-metals	
Bond formation	Losing of valence electrons	Transfer of electrons	Sharing	
Structure	Giant metallic lattice structure	Giant ionic crystal lattice structure	**Simple Molecular Structure**	
Bonds	strong electrostatic forces of attraction between the positive ions and the 'sea of mobile electrons'	strong electrostatic forces of attraction between positive and negative ions	strong covalent bonds between atoms in the molecule weak intermolecular forces of attraction between molecules	stro

Examples	Iron, Copper, Zinc	Sodium chloride, ammonium nitrate	Water, ammonia, hydrogen	D silic
Melting and Boiling Points	High	High	Low	
	strong electrostatic forces of attraction	strong electrostatic forces of attraction	weak intermolecular forces of attraction	stro
Electrical conductivity	Conducts electricity in solid and molten states	Conducts electricity in aqueous and molten state, not in solid state	Does not conduct electricity in any state	I elec
	Presence of mobile electrons in all states	Mobile ions are present only in aqueous and molten states, ions are fixed in positions in solid state	No free mobile ions or electrons	No f ions

Solubility in water	Insoluble	Soluble	Insoluble	I
Solubility in organic solvent	Insoluble	Insoluble	Soluble	I
Others	Malleable, ductile, high density	Hard	May dissolve in water to form ions@	

*Ammonium cation is an exception, #r.t.p refers to room temperature and pressure,
^Mercury is an exception, @See chapter 11 on acids