2.2 Atomic Structure and Bonding

Achievement Indicators

Upon completion of this sub-strand, students will be able to:

- ✓ Examine and present the electron configuration/arrangement of the first 20 elements.
- ✓ Explore and discuss the properties of elements in terms of their position in the periodic table.
- ✓ Investigate and explain the properties of any isotope.
- ✓ Evaluate and describe the stability of noble gases.
- ✓ Research and present on the findings of Dimitri Mendeleev in relation to the periodic table and John Dalton on atoms.
- ✓ Draw and explain the electron diagram illustrating the formation of ions and name them.
- ✓ Discover and write names and formula of ions.
- ✓ Describe and draw the formation of stable pairs and octets in bonding.
- ✓ Confirm by carrying out experiments on some general properties of ionic and covalent substances.

Elements & Their Symbols

There are approximately 118 discovered and known elements. An element may be defined as 'a pure substance made up of only one type of atom'. For example, the element copper is made up of only copper atoms, and sulphur is made up of only sulphur atoms. Elements are distinguishable from each other by their atomic number, which is the number of protons in its nucleus.

The Periodic Table is a table of all the known elements. In the table, the elements are represented by their symbols. The symbol may consist of:

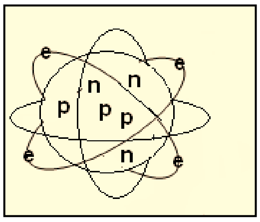
1. A single capital letter e.g. N for nitrogen and F for fluorine; OR
2. Two letters, one capital letter and one small lowercase letter e.g. Mg for magnesium and Pb for lead.

Exercise 2.2.1

Identify the first twenty elements of the Periodic table, including the common elements of bromine, iodine, iron, copper, iron, zinc, silver, barium and lead. Learn the symbols of these elements.

Hint: Create an acronym to help you remember the order and symbols of the first twenty elements.

Elements are made up of tiny particles called **atoms.** An atom is the smallest particle of matter. Atoms are made up of a central core called the nucleus and three subatomic particles:



1. **Protons** – They are positively charged particles and are found within the nucleus.
2. **Neutrons** - They have no charge, are neutral particles and found within the nucleus.
3. **Electrons** - They are negatively charged particles that are orbiting the nucleus.

All atoms are neutral because they contain the same number of protons (positive charge) as the number of electrons (negative charge).

On the Periodic Table, an element X appears as: ${}^{A}_{Z}X$

Where:

X: Represents the symbol of the element

Z: Represents the **Atomic Number** (it is always the smaller number.
It is equal to the number of protons and is equal to the number of electrons.

A: Represents the **Atomic mass** (or Mass number) and it is the sum of number of protons and neutrons.

Example

The atomic structure of an aluminium atom may be written as:

27
Al
13

Symbol:	Al
Atomic Number:	13
Mass Number:	27
Number of protons:	13
Number of electrons:	13
Number of neutrons:	14

Isotopes

The atoms that make up an element all have the same number of protons. However, some elements have atoms whose number of neutrons differs. Therefore, these atoms have atomic masses that differ.

Atoms of the same element that have the same atomic number but different mass numbers are called **isotopes**.

An example is the isotopes of carbon as given in table given below:

Isotope	${}^{12}_{6}C$	${}^{13}_{6}C$	${}^{14}_{6}C$
Mass Number	12	13	14
Atomic Number	6	6	6
Number of Neutrons	6	7	8

Exercise 2.2.2

1. The nucleus of an atom contains 9 protons and 10 neutrons.

   i. What is its atomic number?
   ii. What is its atomic mass?
   iii. Name the element and give its symbol.

2. What are isotopes?

3. Isotopes of the same element should have the same number of

   A. neutrons.
   B. protons.
   C. nucleus.
   D. both neutrons and protons

4. Isotopes of the same element should have different numbers of

   A. neutrons.
   B. protons.
   C. electrons.
   D. both protons and electrons.

5. Consider the isotopes of chlorine given below and answer questions that follow:

$$^{35}_{17}Cl \quad ^{36}_{17}Cl \quad ^{37}_{17}Cl$$

   i. How many protons, electrons and neutrons are found in each isotope?
   ii. What structural characteristics do all the isotopes above have in common?
   iii. How does one isotope of chlorine differ from another isotope of chlorine?

6. Complete the paragraph below.

   The _________ number of an atom is the total number of _________and protons present.

   Atoms of an ___________with __________ numbers of neutrons are called____________.

7. Consider the three atoms, $^{1}_{1}H$, $^{2}_{1}D$ and $^{3}_{1}T$, where D stands for deuterium and T stands for tritium. What is the relationship between these atoms? Give as much information as you know about the relationship between these atoms. Which of the atoms do not have any neutron?

8. Briefly explain why the atoms of $^{14}_{6}C$ and $^{14}_{7}N$ have the same mass.

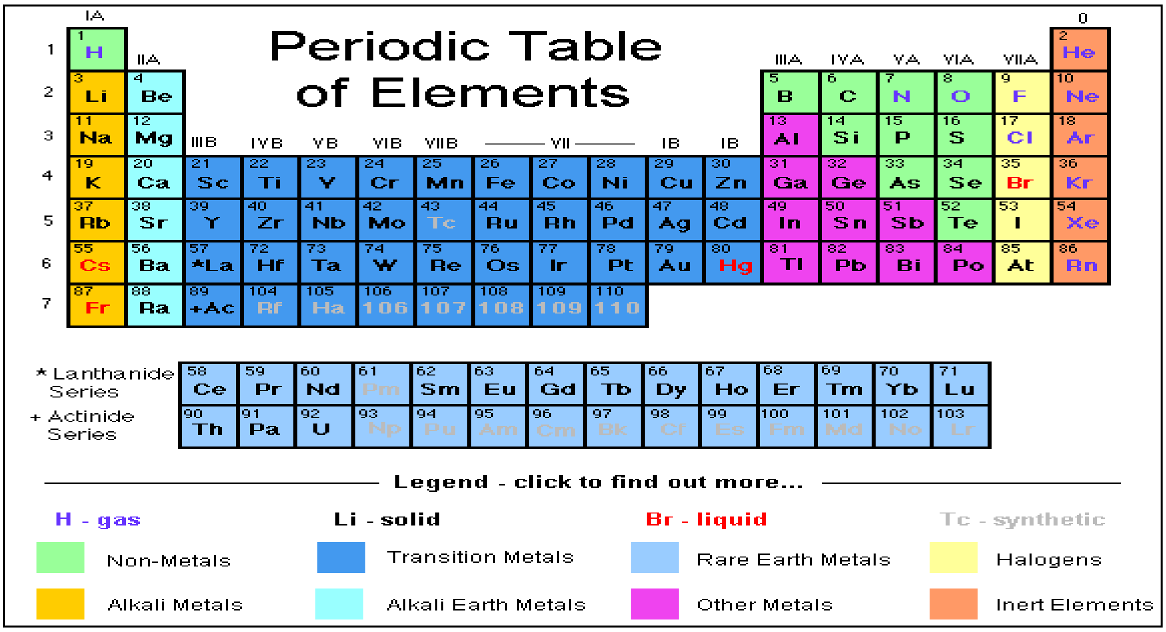
The Periodic Table

The Periodic table is a table of all the known elements. Dmitri Mendeleev (1834-1907) was a Russian scientist who presented the elements in a table. He recognized that there was a pattern in the characteristics and behaviour of elements and that this pattern and behaviour was regularly repeated. Anything that is repeated regularly is said to be *periodic*. Mendeleev was able to place the elements into a table where the pattern the elements exhibited could be grouped. The modern Periodic Table shows this.

Sections of the Periodic Table

The Periodic Table has eight groups, symbolized but roman numerals (Group I to Group VIII). The **groups** are the vertical columns on the table. The horizontal rows are called **periods.** For example, the second row elements are from Li to Ne.

Between Group II elements and Group III elements is a block of ten elements called the **transition** elements. Generally the metals are found on the left hand side of the periodic table, and the non-metals are on the right-hand side of the periodic table. The **metalloids** are found between the metals and non-metals. The Group VII elements are called the **halogens** or the salt-makers and the Group VIII elements are the **noble** or inert gases.



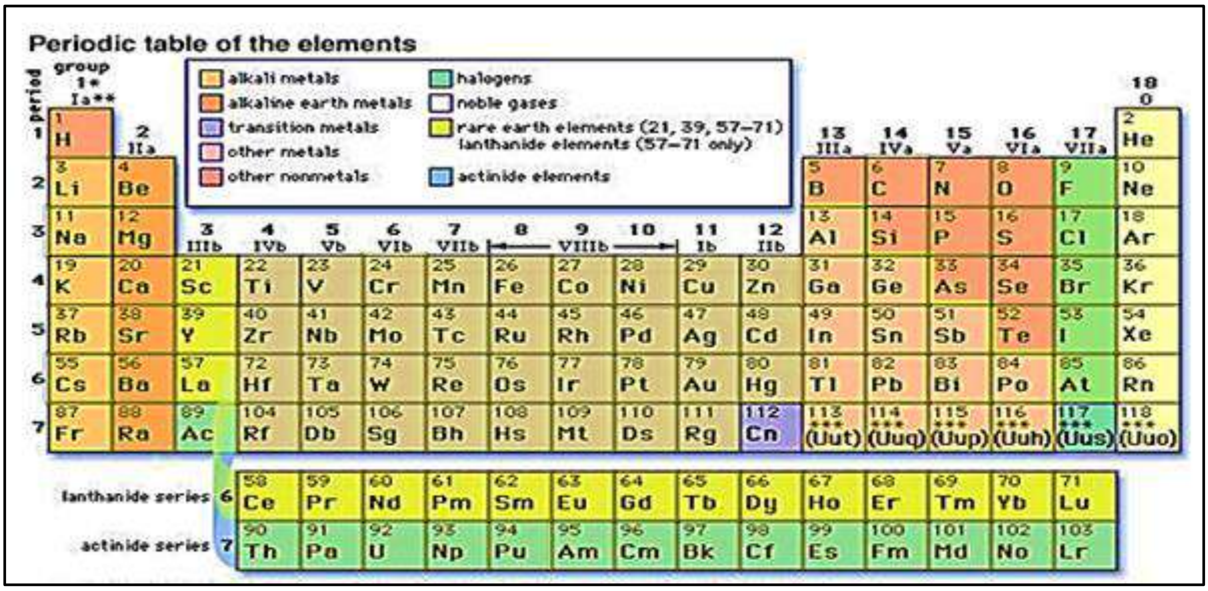
Source: paphysicalscience.wikispaces.com

The elements in the Periodic Table are arranged in increasing order of their atomic number. In this way, some trends that have emerged in relation to the electron arrangement in the atoms of these elements are:

- All the elements in a group have the same number of electrons in their outermost (or valence) shell or the highest energy level. These valence electrons correspond to their group number. For example, lithium, sodium and potassium are Group I elements. In their outermost shells, they all have one electron. Beryllium, magnesium and calcium are Group II elements. They all have two electrons in their valence shells.

- All the elements in the same row or period have the same number of electron shells. For example, sodium with 11 electrons will have 3 electron shells, so will magnesium and aluminium. This is because all of them belong to Period 3.

The modern version of the periodic table of the elements.



Source: http://islam4jesus.org

Summary

Horizontal rows are called **Periods.**

Vertical columns are called **Groups.**

Metals are generally on the left side of the periodic able

Non-metals are generally on the right side of the periodic table.

Metalloids which have properties of both metals and non-metals are found between the metal and non-metal blocks.

Transition metals are found in the centre of the table.

Group VII elements are the **halogens** or **salt –makers**

Group VIII elements are the **noble** or **inert** gases

Trends in the Periodic Table

There are some trends seen in the physical properties of elements in their arrangement in the Periodic table.

- **Physical State** - Across the period, the state changes from solid to liquid to gas. All Group I elements are solid while all Group VIII elements are gases.
- **Melting point** - Is the temperature at which the elements change from solid to liquid. It is expressed in degrees Celsius and is shown the table below.

H																	He
-259																	-272
Li	Be											B	C	N	O	F	Ne
181	128											2300	3550	-209	-218	-219	-248
Na	Mg											Al	Si	P	S	Cl	Ar
97.8	649											660.3	1410	44.09	112.8	-100	-189
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
63.3	839	1539	1660	1890	1857	1244	1535	1495	1453	1083	420	29.78	937	817	217	-7.2	-156

Source: http://www.chemix-chemistry-software.com

Exercise 2.2.3

1. What trend or pattern can you see in the melting points of the elements:
   a) Across the period?
   b) Down the group?
2. What would be the cause of such trend?

- **Boiling point** – is the temperature at which the element changes from liquid to gas.

H																	He
-252																	-268
Li	Be											B	C	N	O	F	Ne
1342	2970											2550	4827	-195	-182	-188	-246
Na	Mg											Al	Si	P	S	Cl	Ar
882.9	1090											2467	2355	280	444.6	-34.5	-185
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
759.9	1484	2832	3287	3380	2672	1962	2750	2870	2732	2567	907	2403	2830	613	684.9	58.8	-152

It is expressed in degrees Celsius as shown in the table below.

Source: http://www.chemix-chemistry-software.com

Exercise 2.2.4

1. What trend or pattern you can see in the boiling points of the elements:
   a) Across the period?
   b) Down the group?
2. What would be the cause of such trend?

- **Electrical conductivity** - it measures the elements ability to conduct an electric current. It is expressed in x 10^6/cm Ω.

Electricla Conductivity																	
H																	He
0																	0
Li	Be											B	C	N	O	F	Ne
0.108	0.313											0	0	0	0	0	0
Na	Mg											Al	Si	P	S	Cl	Ar
0.21	0.226											0.377	0	0	0	0	0
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
0.139	0.298	0.017	0.02	0.05	0.08	0.01	0.09	0.17	0.14	0.6	0.1	0.067	0	0.034	0	0	0

Source: http://www.chemix-chemistry-software.com

Electron Arrangement

The electrons that are orbiting around the nucleus are in electron shells or energy levels. The **electron arrangement** (or configuration) describes the arrangement of electrons in shells or energy levels.

The table below shows the maximum number of electrons that can be accommodated by an electron shell.

Electron Shell (Energy level)	Maximum number of electrons that can be accommodated
1	2
2	8
3	8
4	18

Example

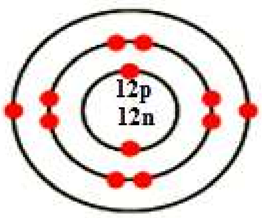
Write the electron configuration for magnesium and potassium.

a. Magnesium has 12 electrons:

1st level:	2 electrons
2nd level:	8 electrons
3rd level:	2 electrons
Total	12 electrons

Electron configuration: **Mg (2, 8, 2)**

Electron structure diagram

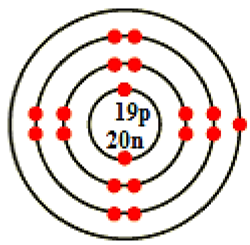


b. Potassium has 19 electrons:

1st level:	2 electrons
2nd level:	8 electrons
3rd level:	8 electrons
4th level:	1 electron
Total	19 electrons

Electron configuration: **K (2, 8, 8, 1)**

Electron structure diagram



Valence Electrons

The electrons in the outermost shell have the highest energy. They are called the **valence electrons**. In our examples of magnesium and calcium, magnesium has 2 valence electrons and potassium has 1 valence electron.

The valence electrons can be represented in an electron dot diagram.

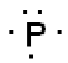
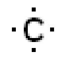
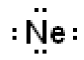
Example

Chlorine: Electron configuration: Cl (2, 8, 7)

Number of valence electrons: 7

Lewis structure diagram:

Other examples: Phosphorus Carbon Neon

Note: At this stage, only the first twenty elements are of concern. Thus the biggest number of valence electrons is 8 i.e. 4 pairs of electrons around the central symbol.

Ions

An ion is formed when an atom loses or gains electrons in order to become more stable. Ions are charged particles and are found in ionic compounds. For example, the ions present in potassium chloride (KCl) are Na^+ and Cl^-. The electrons that 'lost or gained' are the valence electrons. An atom is said to be stable when its electron shell is fully filled. Thus in the case of the first shell, if there are two electrons present, it is fully filled because that is the maximum number of electrons that the first shell can hold. If the second shell is holding 8 electrons, then it is fully filled because 8 is the maximum number of electrons that it can hold.

So what happens if an electron shell does not have the maximum number of electrons?

Example Sodium atom: Na (2,8,1) Chlorine atom: Cl (2,8,7)

The sodium atom has only one valence electron in the third shell, and the chlorine atom has seven electrons in the third shell.

In this case, to achieve stability, the sodium atom must give away (lose) the valence electron and for chlorine to achieve stability, it must gain an electron.

For the neutral sodium atom: Na (2, 8, 1) protons: +11

electrons: -11

Overall charge: 0

When sodium gives away an electron to become stable, then it becomes an ion:

Na^+ protons: +11

electrons: -10

Overall charge: +1

Thus when sodium gives away an electron to become stable, it becomes a positive ion, Na^+. Positive ions are called **cations**, and are formed when atoms give away electrons.

For the neutral chlorine atom: Cl (2, 8, 7) protons: +17

electrons: -17

Overall charge: 0

When chlorine gains an electron to become stable, it becomes an ion:

Cl^- protons: +17

electrons: -18

Overall charge: -1

Thus when chlorine gains an electron to become stable, it becomes a negative ion, Cl^-.

Negative ions are called **anions**, and are formed when atoms gain electrons.

The table below shows some common metal and non-metal ions:

Name of Ion	Symbol	Name of Ion	Symbol
Bromide	Br^-	Barium	Ba^{2+}
Iodide	I^-	Sodium	Na^+
Iron	Fe^{2+} , Fe^{3+}	Chloride	Cl^-
Copper	Cu^+ , Cu^{2+}	Fluoride	F^-
Zinc	Zn^{2+}	Magnesium	Mg^{2+}
Lead	Pb^{2+}	Calcium	Ca^{2+}
Oxygen	O^{2-}	Potassium	K^+
Lithium	Li^+	Aluminium	Al^{3+}

Monoatomic ions have only one type of atom. For example: Na^+, Mg^{2+} and Cl^-. Polyatomic ions have two of more different type of atoms in the ion. For example: NH_4^+ (ammonium ion) and OH^- (hydroxide ion).

Bonding

When atoms gain electrons, these gained electrons must come from another atom. When atoms lose electrons, these lost electrons must go to another atom. In the case of losing or gaining, the electrons are *transferred* to another atom or shared between the two atoms.

Ionic Bonding

Consider the substance sodium chloride, NaCl:

Na (11): 2,8, 1 Cl (17): 2,8,7

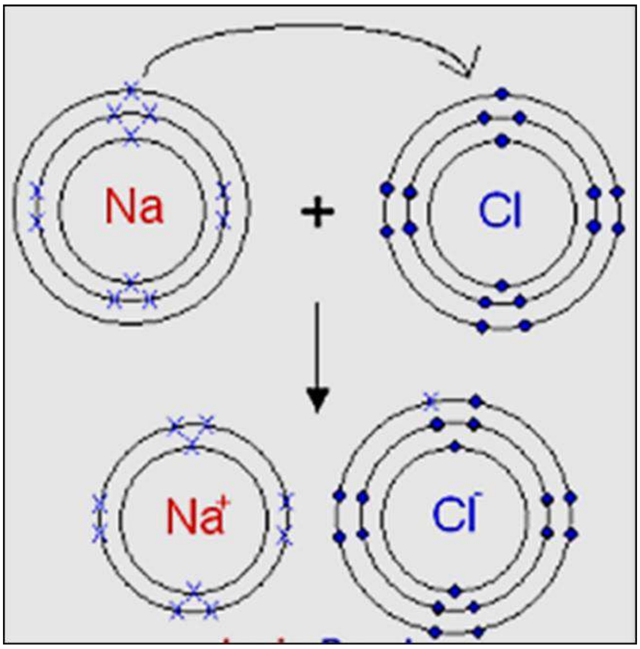
In the above example, in order for sodium (Na) to be stable, it must give away the 1 electron in its valence shell and in order for chlorine (Cl) to be stable; it needs 1 electron to have a fully filled valence shell.

Thus, the electron that sodium gives away will go to chlorine.

When sodium gives away its electron it will become Na^+ (sodium ion) while chlorine becomes a chloride ion (Cl^-) upon receiving that electron.

In this case, the electron is **transferred** entirely from the sodium to the chlorine, and there is no sharing of electrons.

The force of attraction between positive and negatively charged particles or ions is called an **electrostatic force**. The bond that forms between positive and negative ions is called an **ionic bond**. There is a *transfer* of electrons during the formation of an ionic bond. Ionic bonds form between metals and non-metals.



Source: http://www.gcsescience.com

Summary

In ionic bonding, there is transfer of electrons and it occurs between metals and non-metals.

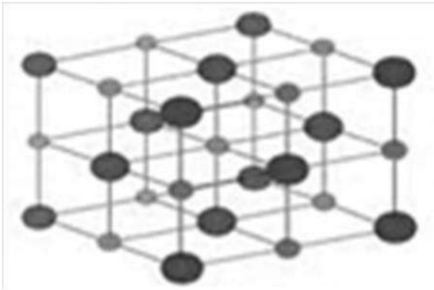
Properties of Ionic Compounds

It is not difficult to identify ionic compounds because they are compounds that consist of a metal and a non-metal. Ionic compounds are compounds held together by ionic bonds.

Some properties of ionic compounds include:

1. They usually have a solid crystal structure. A crystal is an organised network of particles, having organised shapes where each ion that makes up the crystal is attached to another ion with the opposite charge.

   The figure on the right shows a small portion of a sodium chloride crystal. Since ions are bound together by ionic bonds, the crystal is a very strong structure.



An ionic crystal

2. Due to the strong crystal structure of ionic compounds, they have very high melting and boiling points. This is because a lot of energy is needed to break the strong electrostatic force of attraction that holds the ions together.

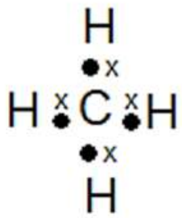
3. The formula of the ionic compound is sometimes referred to as an **empirical formula.** It is a formula that gives the simplest ratio of positive ions to negative ions in the crystal. Empirical formulas are needed for ionic salts because there are millions of positive and negative ions and these cannot be represented in the formula. Thus, the formula NaCl means that for every sodium ion, there is a chloride ion.

Covalent Bonding

Consider the compound methane, CH_4.

C (2,4)

H (1)



Structure of CH_4

In ionic compounds, ions are formed first then bonds form because oppositely charged particles are attracted to each other. Some elements like carbon and silicon do not form ions very easily as they have half-filled shells. Thus in order to fill their valence shells, these atoms must form **covalent bonds** where electrons in the valence shell are **shared**.

The structure of methane above shows the covalent bonds that form between the hydrogen and carbon atoms in the methane molecule. Carbon has four electrons in its valence shell and in order to become stable, it must *share* these electrons with four hydrogen atoms, each one having an electron and needing one more to become stable. This sharing of electrons results in the carbon and all the hydrogen atoms having fully filled shells.

Compounds like methane that have covalent bonds are called **molecules** or **molecular compounds**. Covalent bonds form between non-metals.

Summary

In covalent bonding there is sharing of electrons and it occurs between non-metals.

Properties of Covalent Substance

1. Covalent bonding exists in solids, liquid and gases at room temperature.
2. Do not conduct electricity as they are made up of neutral particles.
3. The melting and boiling points are lower than those of ionic solids.
4. Lower solubility in water than ionic solids.

Exercise 2.2.5

1. Silicon and carbon are in the same Group of the periodic table. This is best explained by the fact that both:

   A. are non-metals.
   B. are in Period 1 of the periodic table.
   C. have the same number of valence electrons.
   D. form ionic bonds.

2. An element has the electron configuration: 2,8,8,1. The element is
   A. an alkali earth metal.
   B. an alkali metal.
   C. a transition metal.
   D. a halogen.

3. The same number of electrons are present in each of:

   A. an ion of Na, an ion of Mg and an ion of Ne.
   B. an atom of Ar, an ion of Ca and an ion of Cl.
   C. an atom of S, an ion of Ar and an ion of Ca.
   D. an atom of S, an ion of O and an atom of H.

4. Complete the Concept map below.