Chapter-4

Chemical Bond and Chemical Equation

4.1 Symbol

The chemical names of elements are represented by a minimum number of alphabet. Initially the names of the elements were derived from their place of extraction or their specific colour. For example 'Gold' has its origin from its colour and 'Copper' from the place of its original extraction 'Cyprus'. Dalton was the first scientist to use a symbol to denote a definite amount i.e. an atom of an element.

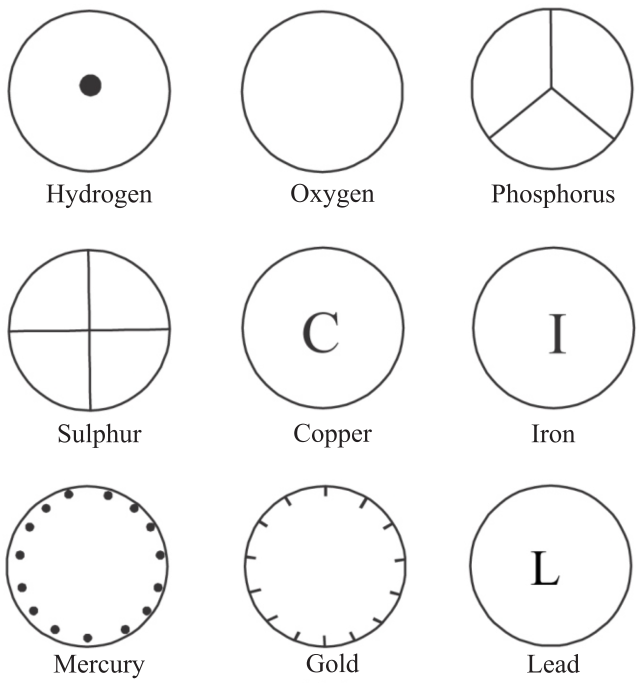


Fig. 4.1 Symbols for elements provided by Dalton

Berzelius developed a novel system of the symbols for elements, in which one or two alphabets of the name of the elements were used. Even IUPAC gives acceptance to the symbol of element on this basis. [IUPAC = International Union of Pure and Applied Chemistry.] According to this :

4.1.1 Element is expressed by the first alphabet of its English name :

Hydrogen	H
Oxygen	O
Carbon	C
Nitrogen	N

4.1.2 In cases where names of many elements initiate with the same alphabet, the first alphabet is used for one element while for others the first two alphabets are made use of. The first is written in capitals while the second in small letter.

For example :

Boron	B
Beryllium	Be
Barium	Ba
Bismuth	Bi
Carbon	C
Calcium	Ca
Cobalt	Co
Chlorine	Cl
Chromium	Cr

4.1.3 The symbols of certain elements have been obtained from their latin names. For example :

Sodium	Natrium	Na
Silver	Argentum	Ag
Gold	Aurum	Au
Copper	Cuprum	Cu
Potassium	Kallium	K
Iron	Ferrium	Fe

4.1.4 The symbols for elements with atomic number more than hundred have been taken from their numeric names and are composed of three alphabets.

For example :

Elements are named using the numeric roots of their atomic numbers.

Number	1	2	3	4	5	6	7	8	9	0
Numeric roots	un	bi	tri	quad	pent	hex	sept	oct	enn	nil

Element is named by putting together the roots, in order of the digits of their atomic number and adding 'ium' in the end. The symbol consists of the initial letter of the numerical roots that form the name.

Atomic number	Name	Symbol
101	Un-nil-unium	Unu
102	Un-nil-bium	Unb
103	Un-nil-trium	Unt
104	Un-nil-quadium	Unq

4.2 Ion

Atoms are electrically neutral because of the presence of equal number of the negatively charged particles : electrons and positively charged particles : protons.

An atom gets charged by giving up or accepting electron in its outermost orbit. These charged particles are known as ions. On the basis of the nature of charge, ions can be

(1) Positive ions (2) Negative ions

4.2.1 Cation

Cation is formed by the removal of an electron from the valence shell of the isolated gaseous atom of the element. In this process, energy is absorbed.

$$A_{(g)} + \text{Energy} \rightarrow A^{+} + e^{-}$$

Metal atom → positive ion

The energy required to remove electron from the isolated gaseous atom is known as ionization enthalpy.

The size of the cation is always smaller than that of its compliant atom because when electron is removed from the outermost shell, the force of attraction between the nucleus and the electrons increases, thus reducing its size. Normally only metal atoms form cations. The metal atoms form uni-valent, bi-valent, tri-valent, quadri-valent and penta-valent cations.

4.2.2 Anions

Anions are the negatively charged particles formed by the addition of one or more electrons in the outermost valence shell of the gaseous atom of the isolated element. The energy released on addition of the first electrons to an atom is known as electron affinity enthalpy. The size of an anion is always greater than that of its compliant atom since the electron cloud spreads because of the increase in repulsion between the electrons. Normally, non-metallic atoms form anion.

4.3 Radical :

Ionic substances, acids and bases dissolve in water and dissociate into ions which participates in reactions as a unit. They are termed as **Radical**. Radicals are of two types

(1) Simple Radical : Which are made up of only one type of atoms.

Example - Na^{+}, Mg^{2+}, Cl^{-} Br^{-} etc.

(2) Compound Radical : Group of two or more type of atoms having a definite charge is known as a Compound Radical

Example : NO_3^{-}, NH_4^{+} etc.

4.3.1 Radical can be classified into two types on the basis of the charge present :

(1) Basic radical : These are metallic cation or positively charged radicals. They are also known as ash - radical because they are obtained from metallic ashes.

Example : Na^{+}, Mg^{2}, NH_4^{+} etc.

(2) Acidic radical : Non-metallic anions and negatively charged radicals are known as Acidic Radical

Example : Cl^{-}, Br^{-}, NH_3^{-} etc.

Mono-atomic cations :

Uni-valent	Bi-valent
Sodium Na^{+}	Barium Ba^{2+}
Potassium K^{+}	Calcium Ca^{2+}
Silver Ag^{+}	Magnesium Mg^{2+}
Cuprous Cu^{+}	Zinc Zn^{2+}
Mercurous Hg_2^{+2}	Manganese Mn^{2+}
	Ferrous Fe^{2+}
	Cupric Cu^{2+}
	Mercuric Hg^{2+}
	Stannous Sn^{2+}
	Lead Pb^{2+}

Tri valent	Poly valent
Aluminium Al^{3+}	Stannic Sn^{4+}
Chromium Cr^{3+}	Arsenic As^{5+}
Ferric Fe^{3+}	

Mono-atomic Anions

Uni valent	Bi valent	Tri valent
Chloride Cl^{-}	Oxide O^{2-}	Nitride N^{3-}
Bromide Br^{-}	Sulphide S^{2-}	Phosphide P^{3-}
Iodide I^{-}		
Floride F^{-}		

Poly-atomic anions

Uni valent	Bi valent	Tri valent
Hydroxide OH^{-}	Carbonate CO_3^{2-}	Phosphate PO_4^{3-}

Cyanide CN^-	Sulphate SO_4^{2-}
Nitrate NO_3^-	Sulphite SO_3^{2-}
Permanganate MnO_4^-	
Acetate CH_3COO^-	

* The charge present on the ion represent its valency.
* Usually 'ate', 'ite' and 'ide' are used as suffix, in anions.
* In case of variable valencies the ion with lesser charge ends with 'ous' and 'ic' is used for those with greater charge.

4.4 Valency :

According to Bohr's Atomic Model there are a maximum of eight electrons in the outer most orbit of an atom. The outermost shells of the noble elements of Group 18 are completely filled and commonly they are chemically inactive. In other words their combining ability is zero.

The tendency of atoms of active elements to form molecules, with atoms of other elements, is considered to be an effort to fill the eight electrons in its outermost shell. In 1916 Corcel-Lewis formulated the "**Octet rule**", according to which "There is transfer or sharing of electrons between two atoms to complete the octet in the outermost (valence) shell of atom and thus the two atoms combine with each other."

The atoms of each element has a definite combining capacity, which is known as its valency. The number of electrons shared or transferred by an atom to complete the octet in its outermost shell is known as its combining capacity or valency. For example there are 1, 2 and 3 electrons in the outermost shell of sodium, magnesium and aluminium respectively, which is lost by them easily in order to achieve the octet in the outermost orbit. Therefore their valency is 1, 2 and 3 respectively.

The number of electrons in the outermost shell of oxygen and fluorine is 6 and 7, respectively. It is easy for them to gain 2 and 1 electrons in order to complete their octet in the outermost shell. Therefore their valency is calculated by subtracting 6 and 7 from eight. Hence, the valency of oxygen is 2 and that of fluorine is 1. In some exceptions the octet rule is not followed, which will be studied in higher classes.

4.4.1 Variable Valency : In some elements the valency is not specific, instead they have more than one valency. This is known as **variable valency**. The variable valency of certain elements is as under :

Element	Symbol	Valency
Copper	Cu	1 and 2
Mercury	Hg	1and 2
Tin	Sn	2 and 4
Iron	Fe	2 and 3
Phosphorous	P	2 and 5
Lead	Pb	2 and 4

4.5 Molecular Formula :

Molecule is a group of two or more than two atoms which are bound to each other by chemical bonds. Molecule is the smallest particle of an element or a compound which exhibits all of their properties and which can exist independently.

The combination of the symbols of elements which represent the molecule of an element or a compound is known as its molecular formula.

We can get the following facts from the molecular formula :

(1) The chemical name of the substance is known, for example Potassium Chloride.

(2) Details of the component elements of the compound can be known, for example in H_2O there are two elements : hydrogen and oxygen.

(3) The information about the total number of atoms in the molecule is obtained, for example in H_2SO_4 there are two atoms of hydrogen, one of sulphur and four atoms of oxygen.

(4) The molecular weight can be determined if the atomic weight is known.

Molecular formulae of Simple Compounds :

Often, the molecular formulae of the simplest binary inorganic compounds are known by the symbols of their constituent elements and their valencies.

When an element combines with other elements, they do so in the reverse proportion of their respective valencies. Therefore while writing the molecular formula, first the positive radicals are written on left side and the negative radicals on the right side along with their valencies superscripted. Then after, their valencies are written as crossover subscript to get the molecular formula. In case of need, the valencies are written in simple proportions.

The formula for poly-atomic ions are written within the brackets and their number is subscripted outside.

For example $Al_2(SO_4)_3$

4.5.1 Compounds having mono-atomic ions:

1. The formula for hydrogen flouride is obtained as under

   Valency 1 1

   Symbol H F

Therefore the molecular formula will be HF.

2. Hydrogen sulphide

   Valency 1 2

   Symbol H S

Therefore the molecular formula will be H_2S.

3. Calcium chloride :f

   Valency 2 1

   Symbol Ca Cl

Therefore the molecular formula will be $CaCl_2$.

4. Calcium oxide :

   Valency 2 2

   Symbol Ca O

Here the molecular formula will be CaO instead of Ca_2O_2.

When the valencies are the same, the simplified formula is written in a simple ratio.

4.5.2 Compounds having poly atomic ions

1. Barium Sulphate

   Valency 2 2

   Symbol Ba SO_4

   Therefore the molecular formula will be $BaSO_4$.

2. Calcium hydroxide

   Valency 2 1

   Symbol Ca OH

   Therefore the molecular formula will be $Ca(OH)_2$.

3. Aluminium sulphate

   Valency 3 2

   Symbol Al SO_4

   Therefore the molecular formula will be $Al_2(SO_4)_3$.

4. Ammonium carbonate

   Valency 1 2

   Symbol NH_4 CO_3

   Therefore the molecular formula will be $(NH_4)_2CO_3$.

4.6 Chemical Bond :

Chemical bond is the force of attraction present between the component particles (ions, atoms etc.) of a molecule which binds them together.

Atoms share or transfer electrons to complete their octet arrangement. In doing so, the atoms combine with each other forming molecules. After bond formation, the total energy of the molecule is less than the total of the energy of the independent atoms. This decrease in the energy of the molecule increases its stability as compared to that of the atoms. In other words, lesser the energy more stable will be the molecule. Chemical bonds are of many types; like ionic bond, covalent bond, co-ordinate bond, metallic bond etc.

4.6.1 Ionic bond : The electronic configuration of the cationic shell has one electron which can be easily removed by supplying energy. This energy is known as **ionisation enthalpy**.

$Na_{(g)}$ + ionisation enthalpy $\rightarrow$ $Na^+ + e^-$

(2, 8, 1) (2, 8)

On the other hand, an electron can be added to the outermost shell (valence shell) of chlorine (2, 8, 7) to obtain the stable configuration (2, 8, 8). The energy released in doing so is known as the **electron gain enthalpy**.

$Cl + e^-$ $\rightarrow$ Cl^- + electron gain enthalpy

(2, 8, 7) (2, 8, 8)

When sodium atom reacts with chlorine, it donates one electron and the chlorine atoms accepts one electron. Thus two oppositely charged ions are obtained because of the transfer of electron. The mutual electrostatic force of attraction between the two, keeps, them together. As a result, a chemical bond is built between the two ions. **Ionic bond** is the force of electrostatic attraction that develops between the oppositely charged ions. It is also known as the **electro valent bond**.

The compounds having ionic bonds are known as ionic compounds.

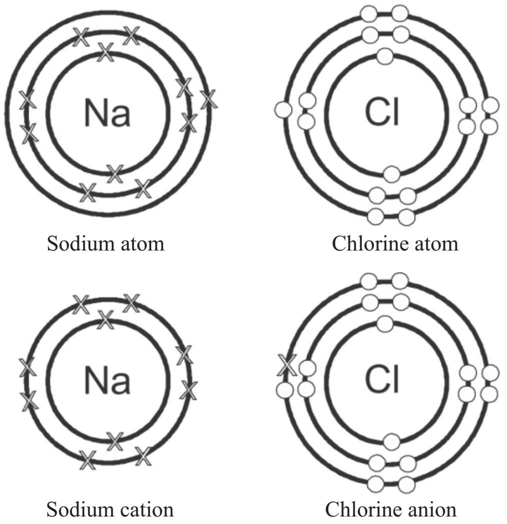
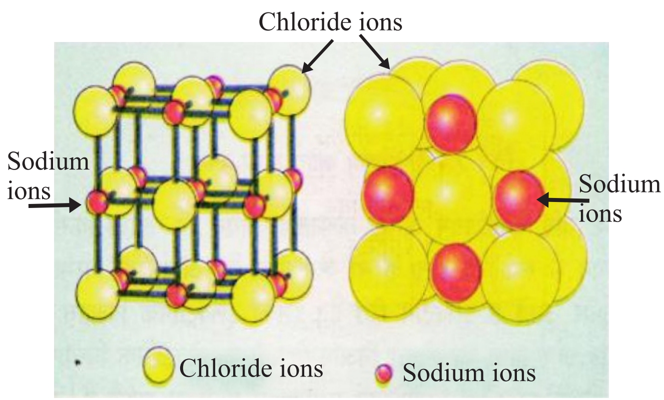


Fig. 4.2 Formation of NaCl molecule by the ionic bond between one sodium and one chlorine atom.

In the crystals of ionic compounds the ions are arranged in such a manner that each cation is surrounded by a definite number of anions and vice versa, as a result a clustered shape is formed. Like, in sodium chloride crystal, each sodium cation (Na^+) is surrounded by six chloride ions (Cl^-) and each chloride anion is surrounded by six sodium ions. The force of attraction responsible for binding these ions together is absolutely and completely the electrostatic force. The crystal is electrically neutral because of the presence of equal number of cations and anions.



4.3 Arrangement of ions in sodium chloride

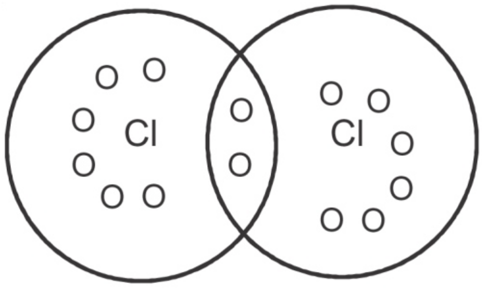
Properties of ionic compounds :

1. **Nature :** Ionic compounds are usually crystalline solid, hard and brittle.
2. **Melting point and Boiling point :** More energy is required to break the ionic crystal because of the presence of strong force of attraction between the charged ions. Therefore their melting point and boiling point is high.
3. **Solubility :** Ionic compounds are soluble in polar solvents (like water) and are insoluble in non-polar solvents (like benzene ether etc.)
4. **Conductivity :** Ionic compounds are good conductors of heat and exhibit electric conductivity in molten state.
5. Ionic compounds exhibit ionic reactions which occur at high rate.

4.6.2 Covalent bond : Besides ionic compounds there are compounds whose molecules do not have ions. For example, water.

Similarly, ionic bonds are not present in the molecules of non-metallic elements also. A covalent bond is formed by the sharing of one or more than one valence electrons between the binding atoms. Single bond is formed by the sharing of one-one electrons from each atom, a double-bond by sharing two-two electrons while the three-three electron sharing, result in the formation of triple bond. When two or more than two atoms bind together, electrons of the valence shell are shared, forming electron pairs to get octet. This type of bond is known as covalent bond. The compounds having covalent bonds are known as covalent compounds.

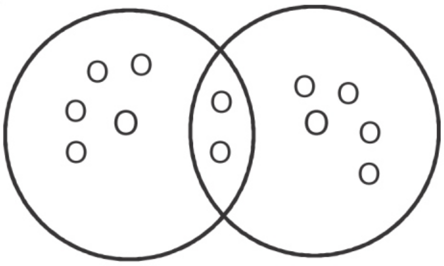
(i) Single Bond : The electronic configuration of chlorine is 2, 8, 7. The chlorine atom has a tendency to accept electron easily. Two chlorine atoms can



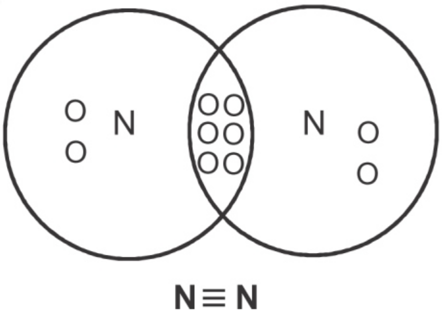
Cl–Cl

complete their octet by sharing one electron from the valence shell of each atom. The electron pair obtained by sharing is present in the middle of the nuclei of the two chlorine atoms and is under the combined effect of both the nuclei.

(ii) Double Bond : When there is sharing of two pairs of electrons between the two atoms, a double bond is said to be formed. For example : This type of bonding occurs between oxygen atoms.



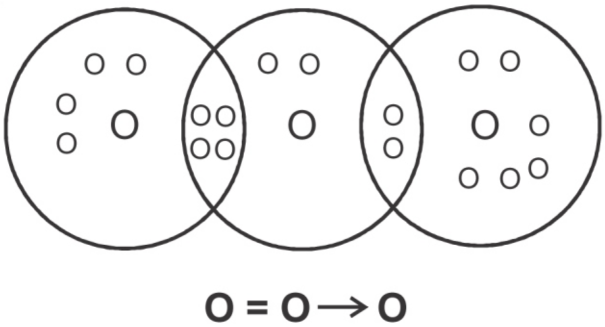
(iii) Triple Bond : If three-three electrons from each atom are shared between the two atoms, a triple bond is formed. For example in nitrogen this type of bond is formed.



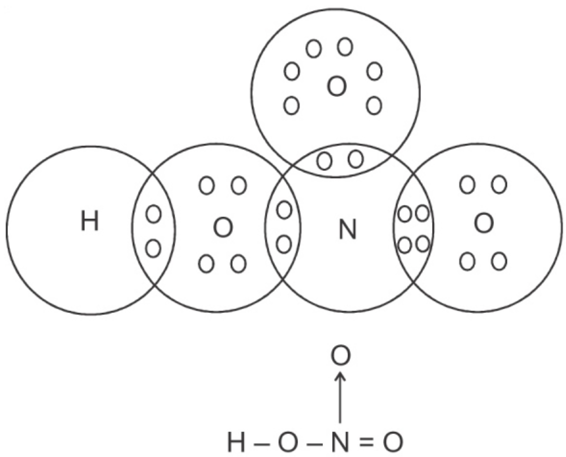
Properties of Covalent Compounds :

1. **Physical state :** These compounds are present in all three states : solid, liquid and gas. Generally they are soft; diamond and sand being the exceptions.
2. **Melting point and boiling point :** Generally, their melting and boiling points are low.
3. **Solubility :** They are soluble in non-polar and carbonic solvents.
4. **Conductivity :** They are bad conductors of electricity and heat. (exception : graphite)
5. The covalent compounds generally exhibit atomic reactions which takes place at slow rate.

4.6.3 Coordinate bond : Coordinate bonds are a type of covalent bond in which the electron pair for the bond formation is provided by only one atom but sharing is between both the atoms. For example in case of ozone molecule.



Nitric acid molecule



Prerequisite conditions for formation of coordinate bond :

1. The atom must have at least one lonely electron pair after the completion of its octet.
2. The other atom must have a deficiency of at least one electron pair.

4.7 Chemical Equation :

Representation of any reaction in the form of molecular formulae and symbols is known as chemical equation. For example the reaction of calcium oxide (lime) with water, resulting in the formation of calcium hydroxide, is expressed as :

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Reactants Product

The substance taking part in a reaction is known as reactant or substrate and the substance formed as a result of reaction is known as the product.

4.7.1 Writing the chemical equation :

1. In a chemical equation the reactants are written on the left hand side of an arrow, which points towards the products, written towards its right hand side.
2. If there are more than one reactant or product, a plus sign is written between them. Like in the above reaction $CaO+H_2O$ has been written.
3. The number of each type of atom present in the reactants and products are made equal on both sides of the arrow by increasing or decreasing the number of molecules. This process is known as balancing of the equation.

4.7.2 Characteristics of Chemical Equation:

The following information is provided by the chemical equation of any reaction.

1. The reactants and products of the reaction.
2. If the reaction is balanced, the number of molecules of the reactants participating in the reaction and the number of molecules of the product formed.
3. Reaction shows the equivalent quantities of the substances.
4. If the reactants or products are in gaseous state their volume is known.

4.7.3 Limitations of the chemical equations:

1. The physical state of reactants and products cannot be known by the equation.
2. Information regarding the concentration of reactants and products is not provided.
3. Reversibility or irreversibility of the reaction is not known.
4. Exothermic or Endothermic nature of reaction is not known.
5. No information about the temperature and pressure at which the reaction takes place.
6. The information regarding completeness of reaction is not made available.

These drawbacks can be overcome by the following means :

1. For representing the physical state, (s) is mentioned for solid, (*l*) for liquid and (g) for gas. For example:
   $CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$
2. Simple arrow is replaced by $\rightleftharpoons$ to represent reversible reaction.
3. The amount of energy is written as product. When the reaction is exothermic a positive sign is used while when it is an endothermic reaction a negative sign is made use of.
   $SO_{2(g)} + O_{2(g)} \rightarrow SO_{3(g)} + 694.6\,kJ$
   $H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)} - 53.6\,kJ$
4. The temperature and pressure at which the reaction occurs is written on the arrow.
   $$N_2 + 3H_2 \underset{200\,atm}{\overset{723°K}{\rightleftharpoons}} 2NH_2$$
5. Information regarding catalyst is given by writing above or below the arrow.

Important Points

1. Berzillius developed a new system for the symbols of elements.
2. The Latin name for sodium is Natrium.
3. The actual number of atoms of different elements present in a molecule of a compound is known by the molecular formula.
4. The force of attraction between two ions is known as IonicBond.
5. Ionic compounds are solid and brittle.
6. Covalent Bond is formed by sharing electrons in equal number, by two atoms.
7. The Co-ordinate Bond is represented by an arrow.
8. Covalent bond is represented by a dash (–).

Questions

Objective type :

1. The symbol for sodium is
   (a) S (b) Si
   (c) Na (d) Ni
2. The formula for carbonate radical is
   (a) CO_3 (b) CO_3^{2-}
   (c) CO_3^{-1} (d) CO
3. The name of the bond present in sodium chloride is :
   (a) Ionic bond (b) Covalent bond
   (c) Metallic bond (d) Hydrogen bond
4. The element exhibiting variable valency is :
   (a) Na (b) Ca
   (c) K (d) Cu
5. The formula for calcium oxide is
   (a) Ca_2O_2 (b) CaO_2
   (c) CaO (d) Ca_2O
6. The generator of the modern system of symbols for elements was :
   (a) Berzillius (b) John Dalton
   (c) Rutherford (d) Neil Bohr
7. The molecule with covalent bond is :
   (a) H_2O (b) NaCl
   (c) CaO (d) $CaCO_3$
8. Fe is the symbol for :
   (a) Iron (b) Copper
   (c) Gold (d) Silver

Very short answer type questions :

9. What are radicals?
10. Define ionic bond.
11. Write the symbol and Latin name of Potassium.
12. Define Molecular formula.
13. Write the formula for calcium carbonate.
14. Write the formula of a tri valent acidic radical.
15. What are anions?
16. What is valency?

Short answer type questions :

17. "The size of cation is smaller than the total size of the atoms that make it." Explain.
18. Explain variable valency with the help of an example.
19. What is a co-ordinate bond? Give an example.
20. Explain the energy of ionization.
21. Explain double and triple bond with the help of examples.

Essay type Questions :

22. Differentiate between covalent and ionic bonds.
23. Write the molecular formula of the following :
    (i) Sodium carbonate
    (ii) Zinc sulphide
    (iii) Aluminium oxide
    (iv) Ferric sulphate
    (v) Barium chloride
    (vi) Magnesium carbonate
24. Balance the following reactions :
    (i) $KClO_3 \rightarrow KCl + O_2$
    (ii) $BaCl_2 + AgNO_3 \rightarrow AgCl + Ba(NO_3)_2$
    (iii) $Mg + HCl \rightarrow MgCl_2 + H_2$
    (iv) $NaOH + Cl_2 \rightarrow NaCl + NaOCl + H_2O$

Answer Key

1. (c) 2. (b) 3. (a) 4. (d) 5. (c)
6. (a) 7. (a) 8. (a)