Table 5. Some ionic compounds.

Ionic compound	Constituting elements	Ratio by mass
Calcium oxide	Calcium and oxygen	5 : 2
Magnesium sulphide	Magnesium sulphur	3 : 4
Sodium chloride	Sodium chlorine	23 : 35.5

Thus, the formula of an ionic compound gives the simplest whole number ratio of ions present in it.

WRITING CHEMICAL FORMULAE

The chemical formulae of different compounds can by written easily by knowing the chemical symbols of the constituting atoms and the combining capacity of the elements.

The combining capacity** (or power) **of an element** is **known** as its **valency.

The fundamental reason for a particular atom having a particular valency or combining capacity will be understood in next chapter of Atomic Structure.

The valency of an atom may be used to find out how many atoms of one element will combine with other to form a chemical formula.

The valency of an atom of the element can be thought of as hands and arms of that atom. As we know, human beings have two hands while an octopus has eight hands. If one octopus has to catch hold of a few people

in such a manner that all the eight arms of octopus and two arms of all the humans are locked, how many humans do you think the octopus can hold? It can hold four humans.

Now represent humans with H and octopus with O, then we write the formula for this combination as OH_4. The subscript 4 indicates the number of humans held by the octopus.

It may be noted that besides atoms and ions having a valency sometimes groups of atoms behave as if they have a valency of their own. These are also called polyatomic ions.

The ions can be of two types :

(*i*) **Positively charged ions** and

(*ii*) **Negatively charged ions.**

The *positive ions* are also called **cations.** The *negative ions* are also called **anions.** For example, sodium chloride (NaCl) consists of positive sodium (Na^+) ion and negative chloride (Cl^-) ion.

The positive and negative ions may broadly be classified into two types :

(*i*) Simple or monoatomic ions, and

(*ii*) Compound or polyatomic ions.

(*i*) A **simple** or monoatomic ion contains only one atom. For example :

Sodium	: Na^+	Potassium	: K^+
Chloride	: Cl^-	Sulphide	: S^{2-}

(*ii*) A **compound ion** contains atoms of more than one atom and behaves as a single unit. These are also known as **polyatomic ions.** For example,

Ammonium	: NH_4^+	Sulphate	: SO_4^{2-}
Carbonate	: CO_3^{2-}	Nitrate	: NO_3^-

It may be noted that we generally find polyatomic ions under negative charge. Some common monoatomic ions are given in Tables 6 and 7 and polyatomic ions are given in Table 8.

Table 6. Some common monoatomic ions (positively charged)

+1 Charge	+2 Charge	+3 Charge	+4 Charge
Hydrogen H^+	Barium Ba^{2+}	Aluminium Al^{3+}	Lead (IV)
Sodium Na^+	Calcium Ca^{2+}	iron (III) or	or plumbic Pb^{4+}
Potassium K^+	Copper (II) or	Ferric Fe^{3+}	Platinum Pt^{4+}
Copper (I) or	cupric Cu^{2+}	Chromium Cr^{3+}	
cuprous Cu^+	Mercuric Hg^{2+}	Bismuth Bi^{3+}	
Mercurous Hg^+	Cobalt Co^{2+}		
Silver Ag^+	Nickel Ni^{2+}		
	Iron (II) or		
	or ferrous Fe^{2+}		
	Magnesium Mg^{2+}		
	Manganese Mn^{2+}		
	Zinc Zn^{2+}		
	Lead (II) or		
	Plumbous Pb^{2+}		

It may be noted that some metals like copper, mercury, iron, tin etc. form two types of ions having different charges or valencies. In these cases, Roman numerals in brackets are used to show their valencies. Alternatively, *–ous* is written after the name for lower valency and *–ic* is written after the name for higher valency.

For example, copper metal (Cu) forms two types of ions, Cu^{+} and Cu^{2+}. The Cu^{+} ion having 1 unit positive charge is written as copper (I) or it is written as cuprous ion (*–ous* after the name). Cu^{2+} ion having 2 unit positive charge is written as copper (II) or cupric ion (*–ic* after the name). Thus, Cu^{+} indicates valency of 1+ and is written as copper (I) ion or cuprous ion and Cu^{2+} indicates valency of 2+ and is written as copper (II) ion or cupric ion.

Similarly,

Mercury (Hg) forms two ions, Hg^{+} (valency 1+) and Hg^{2+} (valency 2+). These are named as :

Hg^{+} : Mercury (I) ion or mercurous ion

Hg^{2+} : Mercury (II) ion or mercuric ion

Iron (Fe) forms two ions, Fe^{2+} (valency 2+) and Fe^{3+} (valency 3+). These are named as :

Fe^{2+} : Iron (II) ion or ferrous ion

Fe^{3+} : Iron (III) ion or ferric ion

Lead (Pb) forms two ions, Pb^{2+} (valency 2+) and Pb^{4+} (valency 4+). These are named as :

Pb^{2+} : Lead (II) ion or plumbous ion

Pb^{4+} : Lead (IV) ion or plumbic ion.

Table 7. Some common monoatomic ions (negatively charged)

–1 Charge	–2 Charge	– 3 Charge
Fluoride F^{-}	Sulphide S^{2-}	Phosphide P^{3-}
Chloride Cl^{-}	Oxide O^{2-}	Nitride N^{3-}
Bromide Br^{-}		
Iodide I^{-}		
Hydride H^{-}		

The compound ions or polyatomic ions containing more than one elements are given in Table 8.

Table 8. Some common polyatomic ions

Positively charged		Negatively charged	
+1 Charge	– 1 Charge	– 2 Charge	– 3 Charge
Ammonium NH_4^{+}	Hydroxide OH^{-}	Carbonate CO_3^{2-}	Phosphate PO_4^{3-}
	Bicarbonate HCO_3^{-}	Sulphite SO_3^{2-}	Phosphite PO_3^{3-}
	Nitrate NO_3^{-}	Sulphate SO_4^{2-}	Borate BO_3^{3-}
	Acetate CH_3COO^{-}	Chromate CrO_4^{2-}	Phosphide P^{3-}
		Dichromate $Cr_2O_7^{2-}$	Nitride N^{3-}

Rules for Writing a Chemical Formula

The following general rules should be followed while, writing a chemical formula :

1. ***The valencies or charges of the ion must balance.*** For example, carbon has a valency 4. Therefore, it will combine with four atoms of an element, like hydrogen which has a valency of 1. Thus, the formula of methane having one carbon atom is CH_4.
2. ***When a compound consists of a metal and a non-metal, the symbol of the metal is written on the left hand side and that of the nonmetal is written on the right hand side.*** For example,

Sodium chloride : NaCl, Calcium oxide : CaO,

Iron sulphide : FeS, Copper oxide : CuO

Here sodium, calcium, iron and copper are metals and so are written on the left hand side while chlorine, oxygen and sulphur are non-metals and therefore, are written on the right hand side.

3. *In compounds with polyatomic ions, the ion is enclosed in a bracket before writing the number to indicate the ratio.* For example,

Calcium bicarbonate : $Ca(HCO_3)_2$, Ammonium sulphate : $(NH_4)_2SO_4$

Chemical formula for molecular compounds

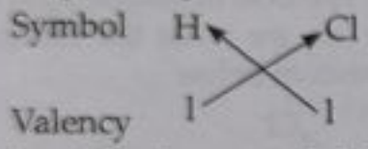
Compounds which donot have constituting ions are molecular compounds. We can write the chemical formula for molecular compounds in a simple way as shown below :

(*i*) Write the symbols of the constituent elements.

(*ii*) Write the valencies of the atoms below their symbols.

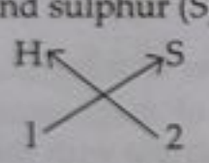
(*iii*) Cross over the valencies of the combining atoms *i.e.*, shift the valency numerals crosswise to the lower right corner of the symbols. Thus, we write the valency of second atom with first atom (as a subscript) and the valency of first atom with the second atom (as a subscript). For example,

(*i*) **Formula of hydrogen chloride.** The elements present are hydrogen (H) having valency 1 and chlorine (Cl) having valency 1.



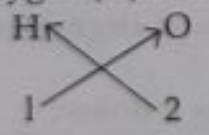
Formula : HCl

(*ii*) **Formula of hydrogen sulphide.** It contains element hydrogen (H) with valency 1 and sulphur (S) with valency 2.



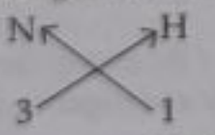
Formula : H_2S

(*iii*) **Formula of water.** The elements present are hydrogen (H) having valency 1 and oxygen (O) having valency 2.



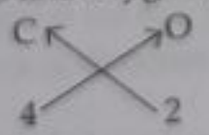
Formula : H_2O

(*iv*) **Formula of ammonia.** The elements present are hydrogen (H) having valency 1 and nitrogen (N) having valency 3.



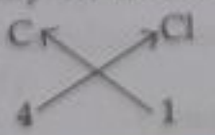
Formula : NH_3

(*v*) **Formula of carbon dioxide.** The elements present are carbon (C) having valency 4 and oxygen (O) having valency 2.



Formula : CO_2 (not C_2O_4)
(Dividing by common factor 2)

(*vi*) **Formula of carbon tetrachloride.** The elements present are carbon (C) having valency 4 and chlorine (Cl) having valency 1.



Formula : CCl_4

Writing the Formula of Ionic Compound

The knowledge of valencies of various radicals helps us to write the formulae of chemical compounds. The total positive charge on positive ions

(cations) is equal to the total negative charge on negative ions (anions) in a molecule. Therefore, in writing the formula of a compound, the positive and negative ions are adjusted in such a way that the total number of positive charges of positive ions (cations) becomes equal to the total number of negative charges of negative ions (anions). For example, let us try to write the formula of magnesium chloride. Magnesium chloride is made up of two ions : magnesium ion (Mg^{2+}) and chloride ion (Cl^-). We write the symbol of cation (Mg^{2+}) first followed by the symbol of anion (Cl^-) as

$$Mg^{2+} \qquad Cl^-$$

We find that magnesium ion has 2 unit of positive charge whereas chloride ion has one unit of negative charge. Since the positive and negative charges are to be made equal, we change the number of Cl^- ions to two. This means that one Mg^{2+} ion will react with $2Cl^-$ ions so that the charges become equal (+2 = –2). Thus, the formula of magnesium chloride is $MgCl_2$. It may be noted that the charges on the ions are not indicated in the formula.

There is another simple method for writing the formulae of ionic compounds. In this method, the valencies (or positive or negative charges) of the ions can be 'crossed over' to give subscripts. The purpose of crossing over of charges is to find the number of ions required to equalise the number of positive and negative charges. For example, we first write the symbols of magnesium ion and chloride ion. Below the symbol of magnesium ion we write the charge +2 and below chloride ion we write the charge –1 as shown below :

Ions	Mg^{2+}	Cl^-	$Mg_{\searrow}$	$_{\nearrow}Cl$
Charge	+2	–1	+2	–1

$= MgCl_2$ formula

Cross over charges

We now cross over the charges of magnesium and chloride ions. The cross over charges are written as subscripts with the ions (without positive or negative charges). So we get the formula $MgCl_2$ for magnesium chloride.

Thus, in magnesium chloride, there are two chloride (Cl^-) ions for each magnesium (Mg^{2+}) ion. The positive and negative charges are balanced and overall structure is neutral.

We can ckeck the charge balance as follows :

$$Mg^{2+} = 2 \qquad 2\,Cl^- = 2$$

The steps involved in writing the formula of a compound are summarized below :

Step 1. *Write the symbols of formulae of the ions of the compound side by side with positive ion on the left hand side and negative ion on right hand side.*

Step 2. *Enclose the polyatomic ion (containing atoms of more than one element e.g., CO_3^{2-}, NH_4^+, SO_4^{2-} etc.) in a bracket.*

Step 3. *Write the valency (or charge) of each ion below its symbol.*

Step 4. *Reduce the valency (or charge) numerals to a simple ratio by dividing with a common factor, if any.*

Step 5. *Cross the valencies (or charges) i.e., shift the charge (valency) numerals crosswise to the lower right corner of the ions. Do not write the charges positive or negative of the ions.*

Let us apply the above steps in order to write formula of **barium nitrate.**

Step 1. Writing the formulae of the ions :

$$Ba^{2+} \qquad NO_3^-$$

Step 2. Enclose the compound radical nitrate in bracket.

$$Ba^{2+} \qquad (NO_3)^-$$

Step 3. Write the valencies of both the ions :

Ba^{2+}	$(NO_3)^-$
2	1

Step 4. Not applicable, because ratio is already simple.

Step 5. Cross over the valencies.

Ba^{2+} ↔ NO_3^-
2 — 1

Thus, the formula of barium nitrate is $Ba(NO_3)_2$

(Generally the subscript 1 is not written)

We can check the charge balance as :

$Ba^{2+} = +2$

and $2(NO_3^-) = -2$

Let us write the formulae of more compounds.

Aluminium oxide

	Al^{3+}	O^{2-}
Symbol	Al	O
Charges	+ 3	− 2
Formula	Al_2O_3	

Calcium oxide

	Ca^{2+}	O^{2-}
Symbol	Ca	O
Charges	+ 2	− 2
Formula	CaO	

(The valencies are written in simple ratio so, the formula is not Ca_2O_2)

Calcium hydroxide

	Ca^{2+}	OH^-
Symbol	Ca	OH
Charges	+ 2	− 1
Formula	$Ca(OH)_2$	

(We use bracket when we have two or more atoms of the same ion *i.e.*, polyatomic ion so the formula is not $CaOH_2$).

Sodium carbonate

	Na^+	CO_3^{2-}
Symbol	Na	CO_3
Charges	+ 1	− 2
Formula	Na_2CO_3	

(Bracket is not needed if there is only one polyatomic ion)

Sodium nitrate

	Na^+	NO_3^-
Symbol	Na	NO_3
Charges	+ 1	− 1
Formula	$NaNO_3$	

Ammonium sulphate

	NH_4^+	SO_4^{2-}
Symbol	NH_4	SO_4
Charges	+ 1	− 2
Formula	$(NH_4)_2SO_4$	

Aluminium sulphate

Al^{3+} $(SO_4)^{2-}$
Al^{3+} ↔ SO_4^{2-}
3 — 2
$Al_2(SO_4)_3$

Barium carbonate

Ba^{2+} $(CO_3)^{2-}$
Ba^{2+} ↔ $(CO_3)^{2-}$
2 — 2
$BaCO_3$

Potassium carbonate

K^+ $(CO_3)^{2-}$
K^+ ↔ $(CO_3)^{2-}$
1 — 2
K_2CO_3

(valency numerals are reduced to simple numbers)

Magnesium hydroxide

Mg^{2+} $(OH)^-$
Mg^{2+} ↔ (OH^-)
2 — 1
$Mg(OH)_2$

Calcium chloride

Ca^{2+} Cl
Ca^{2+} ↔ Cl^-
2 — 1
$CaCl_2$

Sodium phosphate

Na^+ $(PO_4)^{3-}$
Na^+ ↔ PO_4^{3-}
1 — 3
Na_3PO_4

Ammonium chloride

$(NH_4)^+$ Cl^-

NH_4^+ Cl^-

1 1

NH_4Cl

Barium sulphide

Ba^{2+} S^{2-}

Ba^{2+} S^{2-}

2 2

BaS

Calcium carbonate

Ca^{2+} $(CO_3)^{2-}$

Ca^{2+} CO_3^{2-}

2 2

$CaCO_3$

(Bracket is not needed if there is only are polyatomic ion)

Some more examples are :

Magnesium bicarbonate	:	$Mg^{2+}(HCO_3)^-$	$Mg(HCO_3)_2$
Silver nitrate	:	$Ag^+(NO_3)^-$	$AgNO_3$
Lead phosphate	:	$Pb^{2+}(PO_4)^{3-}$	$Pb_3(PO_4)_2$
Magnesium nitrate	:	$Mg^{2+}(NO_3)^-$	$Mg(NO_3)_2$
Barium sulphate	:	$Ba^{2+}(SO_4)^{2-}$	$BaSO_4$
Chromium sulphate	:	$Cr^{3+}(SO_4)^{2-}$	$Cr_2(SO_4)_3$
Potassium nitrate	:	$K^+(NO_3)^-$	KNO_3
Sodium sulphide	:	Na^+S^{2-}	Na_2S
Ammonium carbonate	:	$(NH_4^+)\ (CO_3)^{2-}$	$(NH_4)_2CO_3$
Potassium iodide	:	K^+I^-	KI
Silver sulphide	:	$Ag^+\ S^{2-}$	Ag_2S
Calcium carbonate	:	$Ca^{2+}(CO_3)^{2-}$	$CaCO_3$

Examples

Write the chemical formulae of the npounds :

n oxide (*b*) aluminium chloride

Solution : (*i*) Silver oxide : $Ag^+\ O^{2-} = Ag_2O$

(*ii*) Copper (II) sulphide : $Cu^{2+}\ S^{2-} = CuS$

(*iii*) Iron (II) bromide : $Fe^{2+}\ Br^- = FeBr_2$