3. ATOMS AND MOLECULES

■ Introduction

18^{th} century marked the recognition of difference between compounds and elements and scientists started thinking about combining & reactions of elements.

The smallest unit is called atom Democritus called these indivisible particles, atoms.

Antoine L. Lavoisier laid the foundation of chemical sciences by establishing two important laws of chemical combination.

■ Laws of chemical combination

By studying the result of quantitative measurement of many reactions it was observed that whenever substances react, they follow certain laws. These laws are called the laws of chemical combination.

(a) Law of conservation of mass.

(b) Law of constant proportion.

■ Law of conservation of mass

This law of conservation of mass is given by the French chemist **A. Lavoisier** in 1774.

"The mass can neither be created nor destroyed in a chemical reaction".

The total mass of the products of a chemical reaction is equal to the total mass of the reactants that have combined. This law is also known as **the law of indestructibility of matter**.

For example- In a reaction, 5.3 g of sodium carbonate reacted with 6 g of ethanoic acid. The products were 2.2 g of carbon dioxide, 0.9 g water and 8.2 g of sodium ethanoate. Show that these observations are in agreement with the law of conservation of mass.

Sodium carbonate reacts with ethanoic acid converted into sodium ethanoate, carbon dioxide, and water.

Sodium carbonate + ethanoic acid $\longrightarrow$ sodium ethanoate + carbon dioxide + water

5.3g 6g 8.2g 2.2g 0.9g

(5.3+6)g = 11.3g $\longrightarrow$ (8.2+2.2+0.9)g = 11.3g

$\therefore$ Total mass before the reaction = Total mass after the reaction

Hence, the given observations are in agreement with the law of conservation of mass.

■ Law of constant proportions

This law was stated by **Joseph Proust** and **A.L. Lavosier** as "In a chemical substance the elements are always present in definite proportions by mass".

For example-Water obtained from any source like river, rain or tap etc & from any country is always made up of the same elements i.e. hydrogen & oxygen combined together in the same fixed proportion i.e. 1 : 8 by mass.

Similarly carbon dioxide always contains C & O in the ratio of 3 : 8. If a sample of H_2O contains 3g of hydrogen then it is compulsory that is has 24 g oxygen.

This is calculated as $\frac{1}{8}=\frac{3}{x}$ $x = \frac{3\times 8}{1}$ = 24 g

■ Law of multiple proportions (John Dalton 1804)

According to this law, when two elements A and B combine together to form more than one chemical compound then different weights of A, which combine with a fixed weight of B, are in a proportion of simple whole numbers.

The law is fully illustrated by the following example.

Nitrogen forms as many as five stable oxides.

That combines are in the ratio 16 : 32 : 48 : 64 : 90 : i.e. 1 : 2 : 3 : 4 : 5 in N_2O, NO, N_2O_3, N_2O_4 and N_2O_5 respectively

Example: Tin combines with oxygen to form two compounds having the following composition:

	% of Tin	% of oxygen
Compound A	78.77	21.23
Compound B	88.12	11:88

Show that the above data illustrate the law of multiple proportion.

Solution: In compound A:

21.23 part of oxygen combines with 78.77 part of tin

1 part of oxygen combines with 78.77/21.23 part of tin = 3.7

In compound B:

11.88 part of oxygen combines with 88.12 parts of tin

1 part of oxygen combines with 88.12/11.88 part of tin = 7.4

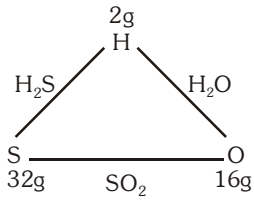
Thus weight ratio of tin for its combination with one part of oxygen are 3.7 : 7.4 *i.e.* 1 : 2. This is a simple ratio and this data illustrate the law of multiple proportion.

■ Law of equivalent proportion or law of reciprocal proportion: [Ritcher 1792-94]

The weights of the two or more substances which separately react with same weight of a third substance are also the weights of these substances which react with each other or simple multiple of them. The law can be illustrated as below:

- Hydrogen combines with sulphur forming hydrogen sulphide (H_2S); 2 gm of hydrogen reacts with 32 gm of sulphur.
- Hydrogen combines with oxygen forming water (H_2O); 2 gm of hydrogen reacts with 16 gm of oxygen.
- Sulphur combines with oxygen to form SO_2; 32 gm of sulphur reacts with 32 gm of oxygen i.e. in the ratio 32 : 32. This ratio is double of the ratio of weights of these elements which combine with 2 gm of hydrogen.

32/16: 32/32 = 2 : 1



■ Dalton's atomic theory

British chemist John Dalton provided a theory about the nature of matter in 1808.

● Postulates of Dalton's atomic theory

The important features of the Dalton's Atomic theory are listed,

- Every matter is made up of very small particles known as **atoms**.
- Atoms are the ultimate particles of matter which cannot be created or destroyed in a chemical reaction & cannot be further subdivided into smaller particles.
- All atoms of a particular element are identical in all respects. This means that they have same mass, size & also same chemical properties
- Atoms of different elements have different masses, sizes and also chemical properties.
- Atoms are the smallest particles of matter which can take part in chemical combination.
- Atoms of the same or different elements combine in small whole number ratios to form molecules of a compound.
- The relative number & kinds of atoms are constant in a given compound.

- **Drawbacks of Dalton's atomic theory**

Some of the drawbacks of the Dalton's atomic theory of matter are given below

- According to Dalton's atomic theory, atoms were thought to be indivisible. But is now known that atoms can be further divided into still smaller particles called **electrons**, **protons** & **neutrons**.
- Dalton's atomic theory said that all the atoms of an element have exactly the same mass. But it is now known that atoms of the same element can have slightly different masses, as in case of **isotopes**.
- Dalton's atomic theory said that atoms of different elements have different masses. But it is now known that even atoms of different elements can have the same mass as in case of **isobars**.
- The ratio in which the different atoms combine to form compound may be fixed and integral but not be simple. For example, sugar (sucrose) molecule ($C_{12}H_{22}O_{11}$) contains C, H & O in the ratio 12 : 22 : 11 which is integral and fixed but not simple.

The modifications, as given above, are called the postulates of **"modern atomic theory".**

Atom

An atom is defined as the smallest particle of an element which may or may not be capable of free existence. However, it is the smallest particle that takes part in a chemical reaction. An atom maintains its identity in all physical changes and chemical reactions. For example, He, Ne, H_2, O_2.

Atomic size

The size of an atom is extremely small. The radius of an atom of hydrogen is only 10^{-10}m.
Recently a highly sophisticated microscope known as **scanning tunneling microscope** (STM), has bean devised which has made it possible to take photographs of atoms. As atoms are considered to be spherical, their size is expressed in terms of their radii, called atomic radii. The atoms are so small in size that their radii are usually expressed in **nanometre** (nm).

Relative Radii (in m)	Example
10^{-10}	Atom of hydrogen
10^{-9}	Molecule of water
10^{-8}	Molecule of haemoglobin
10^{-4}	Grain of sand
10^{-2}	Ant
10^{-1}	Watermelon

Modern symbols

Modern symbols for the elements were introduced by **J.J. Berzelius**. These are also known as chemical symbols. The symbol of an element are generally either the first letter or the first two letter or the first and the third letters of the name of the element. For example the symbol of the following elements are the first letter of the name of that element.

S.No.	Element	Symbol
1	Hydrogen	H
2	Carbon	C
3	Nitrogen	N
4	Oxygen	O
5	Fluorine	F

Some symbols derived from the first two letters of the names of the element

S.No.	Element	Symbol
1	Aluminium	Al
2	Barium	Ba
3	Lithium	Li
4	Neon	Ne
5	Calcium	Ca

Some symbols are derived from the first and the third letter of the name of the elements.

S.No.	Element	Symbol
1	Arsenic	As
2	Magnesium	Mg
3	Chlorine	Cl
4	Zinc	Zn
5	Chromium	Cr

Atomicity

The number of atoms in a molecule of the elementary substance is called its atomicity.

For example- Atomicity of sulphur-8

Atomic mass

It was suggested that the mass of an atom should be expressed as the relative mass. It could be done by fixing the mass of some atom of a particular element as the standard mass. The masses of the other atoms could be compared relative to it. In the beginning, hydrogen was chosen to be standard element because it happens to be the lightest of all the elements. Later, it was found that hydrogen gas in its natural state has three isotopes.

However, using hydrogen as the reference, the masses of atoms of other elements came out to be fractional. Hence, the reference was changed to oxygen taken as 16. In other words , $1/16^{th}$ of the mass of an atom of naturally occurring oxygen was taken as one unit.

However, a difficulty arouse when it was found that naturally occurring oxygen is a mixture of atoms of slightly different masses (called "isotopes").

- **Carbon-12 as standard reference**

It was found that the atomic mass of the most common isotope of carbon, ^{12}C is a whole number 12. Thus, the mass of 1/12 of ^{12}C is equivalent to 1 atomic mass unit (a.m.u.) or unified atomic mass.

Atomic masses of some common elements (in amu or u)

Element	Symbol	Atomic mass
Hydrogen	H	1
Carbon	C	12
Lithium	Li	7
Nitrogen	N	14
Oxygen	O	16
Fluorine	F	19
Neon	Ne	20
Sodium	Na	23
Magnesium	Mg	24
Phosphorous	P	31
Sulphur	S	32
Chlorine	Cl	35.5
Calcium	Ca	40

Molecule

Molecule represents a group of two or more atoms (same or different) chemically bonded to each other and held tightly by strong attractive forces. Molecules are of two types :

- **Molecules of elements**

Type of Element	Name	Atomicity
Non-Metal	Argon	Monoatomic
Non-Metal	Helium	Monoatomic
Non-Metal	Oxygen	Diatomic
Non-Metal	Hydrogen	Diatomic
Non-Metal	Nitrogen	Diatomic
Non-Metal	Chlorine	Diatomic
Non-Metal	Phosphorus	Tetra-atomic
Non-Metal	Sulphur	Poly-atomic

- **Molecules of compounds**

Molecules of some compounds		
Compound	**Combining Elements**	**Ratio by Mass**
Water	Hydrogen, Oxygen	1 : 8
Ammonia	Nitrogen, Hydrogen	14 : 3
Carbon dioxide	Carbon, Oxygen	3 : 8

■ Ion

An ion is a species carrying either positive or negative charge.

Classification of ion :-

1. On the bases of number of atoms.

(a) monoatomic ions, for e.g.- Cu^{+},Cl^{-} **(b) polyatomic ion**. for e.g.-NH_4^{+}, CO_3^{2-}

2. On the basis of nature of charge

The ions carrying positive charge are called **cations** for e.g.-Na^{+},NH_4^{+}, Ca^{+2} while ions that carrying negative charge are called **anions** for e.g.-Cl^{-},SO_4^{2-},NO_3^{-}

3. On the basis of number (amount) of charges.

(a) monovalent ions, for e.g.- Na^{+},Cl^{-} **(b) divalent ions,** for e.g.-Mg^{+2}, Ca^{+2} **(c) trivalent ions**. for e.g.-N^{3-}, Al^{+3} **(d) polyvalent ions,** for e.g.-C^{4-},Sn^{4+}

Naming of ionic compounds : Cation is always named 1st followed by the anion. The number of cations and anions are not written in the name. Eg. $Al_2(SO_4)_3$ is called aluminium sulphate and not dialuminium trisulphate.

Some Ionic Compounds :

S.No.	Ionic compound	Cations	Anions
1	Sodium chloride	Sodium ion (Na^{+})	Chloride ion (Cl^{-})
2	Potassium sulphide	Potassium ion (K^{+})	Sulphide ion (S^{2-})
3	Calcium sulphate	Calcium ion (Ca^{2+})	Sulphate ion (SO_4^{2-})

■ Writing chemical formula

We represent the atoms with the help of symbols. In the same way, the molecules can also be represented by the symbols of the constituent atoms. This is known as the **chemical formula** of the molecule, or in other words we can say, chemical formula of a molecular compound represents the actual number & kind of atoms of different elements present in one molecule of the compound, e.g. H_2O.

Some ionic compounds		
Ionic Compound	**Constituting Elements**	**Ratio by Mass**
Calcium oxide	Calcium and oxygen	5 : 2
Magnesium sulphide	Magnesium and sulphur	3 : 4
Sodium chloride	Sodium and chlorine	23 : 35.5

Chemical formula of an ionic compound simply represents the ratio of the cations & anions present in the structure of the compound, eg. : NaCl. However, in both cases, the writing of chemical formula is based on the concept of "**Valency**".

Valency of an element is defined as the combining capacity of the element.

Examples

Ammonia	Methane	Carbon dioxide
N H 3 1	C H 4 1	C O 4 2
NH_3	CH_4	C_2O_4 or CO_2

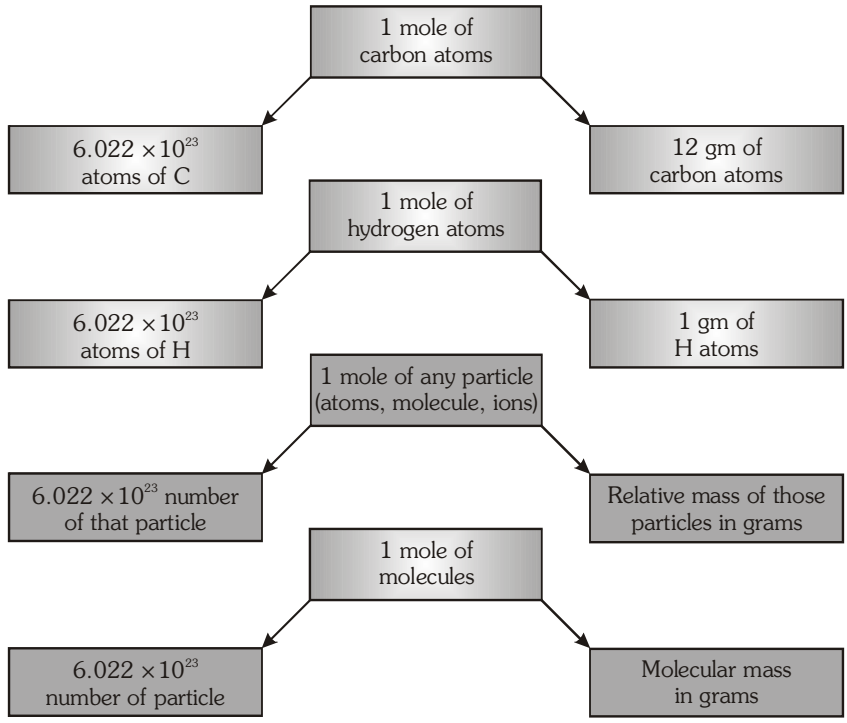
■ Molecular mass

We have studied that the mass of the atom of an element is known as its atomic mass. In the same way, the mass of a molecule of a chemical compound is known as the molecular mass.

■ Mole concept

A mole represents 6.022×10^{23} particles. They may be atoms, molecules, ions, electrons, protons etc. This 6.022×10^{23} is known as Avogadro's number or Avogadro's constant & is denoted by either 'N_0' or 'N_A'. A mole denotes Avogadro's number of particles.

Memory chart



Relationship between mole, Avogadro number and mass.

1. When 20 g of $BaCl_2$ is mixed with 10.6 g of H_2SO_4 it produces 8.2 g of HCl and some amount of $BaSO_4$ The mass of $BaSO_4$ is equal to

(1) 20.4 g (2) 22.4 g

(3) 11.2 g (4) 18.5 g

2. The percentage of hydrogen in water is

(1) 1.11% (2) 11.11%

(3) 8.89% (4) 88.9%

3. The percentage by weight of oxygen in $CaSO_4$ (O = 16u, S = 32u, Ca = 40u) is

(1) 64 (2) 28.2

(3) 47.2 (4) 16.2

4. **Statement-I :** When 10 g of $CaCO_3$ is decomposed, 5.6 g of residue is left and 4.4 g of CO_2 escapes.

Statement-II : Law of constant proportions is being followed.

(1) Statement I and II are true and Statement II is the correct explanation of Statement I.

(2) Statement I and II are true but Statement II is not the correct explanation of Statement I.

(3) Statement I is true but Statement II is false.

(4) Statement I is false but Statement II is true.

5. For the reaction-

$Na_2CO_3 + 2CH_3COOH \rightarrow 2CH_3COONa + H_2O + CO_2$

Where, atomic masses of

Na = 23 u, C = 12 u, O = 16 u, H = 1u, how many grams of Na_2CO_3 would be required if 82 g of CH_3COONa is formed ?

(1) 106 (2) 100

(3) 86 (4) 53

6. The oxides of carbon, CO and CO_2 must have which of the following carbon-oxygen mass ratios

(1) 12 : 12 and 12 : 24

(2) 6 : 12 and 6 : 24

(3) 12 : 8 and 12: 16

(4) 12 : 16 and 12 : 32

7. A metal M and Cl_2 combine in different proportions to form two compounds, A and B. The mass ratio M : Cl is 0.89 : 1 in A and 1.791 : 1 in B. This example explains the

(1) Law of reciprocal proportions

(2) Law of definite proportions

(3) Law of partial pressure

(4) Law of multiple proportions

8. In carbon disulphide (CS_2), the mass of sulphur in combination with 3.0 g of carbon is

(1) 4.0 g (2) 6.0 g

(3) 64.0 g (4) 16.0 g

9. Two gaseous samples were analysed. One contained 1.2 g of carbon and 3.2 g of oxygen. The other contained 27.3 % carbon and 72.7% oxygen. The experimental data are in accordance with

(1) Law of conservation of mass

(2) Law of definite proportions

(3) Law of reciprocal proportions

(4) Law of multiple proportions

10. The simple formula of the compound containing hydrogen, carbon, oxygen and nitrogen in the mass ratio 1 : 3 : 4 : 7 is

(1) $C_3HO_4N_7$

(2) CH_2ON

(3) CH_4ON_2

(4) $C_2H_8ON_2$

11. Which among the following is not a postulate of Dalton's atomic theory ?

(1) Atoms cannot be created nor destroyed.

(2) Atoms of different elements have different sizes, masses and chemical properties.

(3) Atoms of same elements can combine in only one ratio to produce more than one compound.

(4) Atoms are very small tiny particles which cannot be divided further.

12. Which of the following statements is not true about an atom ?

(1) Atoms may or may not be able to exist independently.

(2) Atom can be created and destroyed.

(3) Atoms are always neutral in nature.

(4) Atoms aggregate in large numbers to form the matter that we can see, feel or touch.

13. Modern atomic symbols are based on the method proposed by

(1) Dalton (2) Berzilius

(3) Bohr (4) Mendeleev

14. Natrium is the latin name of

(1) Calcium (2) Potassium

(3) Sodium (4) Nickel

15. The atomicity of $K_2Cr_2O_7$ is

(1) 9 (2) 11

(3) 10 (4) 12

16. A particle which maintains its chemical identity even after physical and chemical changes is

(1) Atom (2) Molecule

(3) Compound (4) None of these

17. Which one of the following statements is incorrect?

(1) One gram atom of carbon –12 contains Avogadro's number of atoms.

(2) One gram molecule of oxygen gas contains Avogadro's number of molecules.

(3) One mole hydrogen gas contains Avogadro's number of atoms.

(4) One mole of electron stands for 6.02×10^{23} electrons.

18. 'Ion' is a three-letter word. It means

(1) A mixture of iodine, oxygen and nitrogen

(2) An alloy of iron

(3) A charged particle

(4) A form of light

19. Which of the following represents a polyatomic ion?

(1) Sulphide (2) Chloride

(3) Sulphate (4) Nitride

20. A cation has a positive charge because

(1) there are more protons than neutrons.

(2) the neutrons in the nucleus are charged.

(3) there are fewer electrons than protons.

(4) there are more electrons than protons.

21. In which of the following the valency of each of the consituent elements is equal to the total number of atoms in one molecule of the compound ?

(1) HCl (2) H_2S

(3) CaO (4) $MgCl_2$

22. The formula of chloride of a metal M is MCl_3, then the formula of the phosphate of metal M will be

(1) MPO_4 (2) M_2PO_4

(3) M_3PO_4 (4) $M_2(PO_4)_3$

23. The hydrogen phosphate of a metal is $MHPO_4$. The formula of its metal chloride and metal sulphate is

(1) MCl and M_2SO_4

(2) M_2Cl and MSO_4

(3) MCl_2 and MSO_4

(4) MCl_3 and $M_3(SO_4)_2$

24. Formula of Calcium phosphate is

(1) $CaPO_4$ (2) $Ca_2(PO_4)_3$

(3) $Ca(PO_4)_2$ (4) $Ca_3(PO_4)_2$

25. The molecule P_2O_5 means

(1) A molecule contains 2 atoms of P and 5 atoms of O

(2) The ratio of the mass of P to the mass of O in the molecule is 2 : 5

(3) There are twice as many P atoms in the molecule as there are O atoms

(4) The ratio of the mass of P to the mass of O in the molecule is 5 : 2

26. Formula of chromic acid is H_2CrO_4. Formula of divalent metal chromate is

(1) $MCrO_4$

(2) M_2CrO_4

(3) $M_2(CrO_4)_3$

(4) M_3CrO_4

27. The formula of a compound when a positive radical with valency 2 and negative radical with valency 1 combine is_____.

(1) B_2A (2) A_2B

(3) AB_2 (4) AB

28. **Statement-I :** Molecular weight of oxygen is 16

Statement-II : Atomic wieight of oxygen is 16

(1) Statement I is True, Statement II is true, Statement-2 is a correct explanation for statement I

(2) Statement I is True, Statement II is true, Statement-2 is not correct explanation for statement I

(3) Statement I is true but Statement II is false.

(4) Statement I is false but Statement II is true.

29. The amount of a substance is measured in

(1) Mole (2) Kilogram

(3) Seconds (4) Gram

30. Which one of the following pair of gases contains the same number of molecules ?

(1) 16 g of O_2 and 14 g of N_2

(2) 8 g of O_2 and 22 g of CO_2

(3) 28 g of O_2 and 22 g of CO_2

(4) 32 g of O_2 and 32 g of N_2

31. How many gram of H_2SO_4 are present in 0.25 mole of H_2SO_4 ?

(1) 2.45 g (2) 24.5 g

(3) 0.245 g (4) 0.25 g

32. A sample of phosphorous trichloride (PCl_3) contains 1.4 moles of the substance. How many atoms are there in the sample ?

(1) 4 (2) 8.4×10^{23}

(3) 3.372×10^{24} (4) 5.6

33. How many gram of O is present in 50 g of $CaCO_3$?

(1) 50 g (2) 150 g

(3) 48 g (4) 24 g

34. 3.42 g of sucrose are dissolved in 18 g of water in beaker. The number of oxygen atoms in the solution are.

(1) 6.68×10^{23} (2) 6.09×10^{22}

(3) 6.022×10^{23} (4) 6.022×10^{21}

35. Rahul was told by his teacher to Calculate the mass of the following

(I) 0.5 mole of N_2 gas

(II) 0.5 mole of atoms of N

(III) 3.011×10^{23} number of N atoms

(IV) 6.023×10^{23} N_2 molecules

He calculated the mass as I = x g, II = y g, III = zg, IV = wg Which relation is correct among these ?

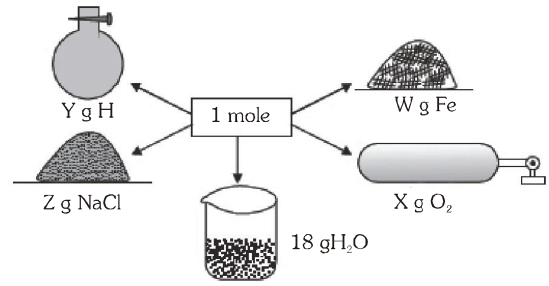
(1) x = y = z = w

(2) x/2 = y = z = w/4

(3) x = 2y = z = 4w

(4) x = y = z/2 = w/4

36. Observe the given figure carefully and select the correct option.



(1) W = 55.8, X = 16, Y = 2.016, Z = 58.5

(2) W = 55.8, X = 32, Y = 1.008, Z = 58.5

(3) W = 55.8, X = 16, Y = 1.008, Z = 58.5

(4) W = 55.8, X = 32, Y = 2.016, Z = 58.5

37. Calculate the no. of gram atoms and gram molecules present in 12.4g of phosphorus ?

(1) 0.1 gram atoms,0.1 gram molecules

(2) 0.2gram atoms,0.1gram molecules

(3) 0.1 gram atoms,0.4 gram molecules

(4) 0.4 gram atoms,0.1 gram molecules

38. The number of atoms in 4.25 g of NH_3 is approximately

(1) 1×10^{23}

(2) 2×10^{23}

(3) 4×10^{23}

(4) 6×10^{23}

39. Which of the following has largest number of particles

(1) 8g of CH_4

(2) 4.4g of CO_2

(3) 34.2g of $C_{12}H_{22}O_{11}$

(4) 2g of H_2

40. 25.4 g of Iodine and 14.2g of chlorine are made to react completely to yield a mixture of ICl and ICl_3. Calculate the ratio of moles of ICl and ICl_3?

(1) 1 : 1

(2) 2 : 1

(3) 3 : 1

(4) 1 : 2

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	2	2	3	3	4	4	4	4	2	1	3	2	2	3	2	1	3	3	3	3
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	3	1	3	4	1	1	3	4	1	1	2	3	4	1	2	2	4	4	4	1