1

FUNDAMENTALS OF CHEMISTRY

This is a 15 days lesson

After completing this lesson, you will be able to:

- Change atomic mass, molecular mass and formula mass into gram atomic mass, gram molecular mass and gram formula mass.
- Differentiate between branches of chemistry.
- Differentiate between empirical and molecular formula.
- Differentiate among elements, compounds and mixtures.
- Differentiate between molecules and molecular ions
- Define ions, molecular ions, formula units and free radicals.
- Define atomic number, atomic mass, atomic mass unit.
- Define relative atomic mass based on C-12 scale.
- Distinguish between atoms and ions.
- Distinguish between ion and free radical. Classify the chemical species from given examples.
- Distinguish between matter and a substance.
- Describe how Avogadro's number is related to a mole of any substance. Distinguish among the terms gram atomic mass, gram molecular mass and gram formula mass.
- Identify the representative particles of elements and compounds.
- Identify and provide example of different branches of chemistry.
- Relate gram atomic mass, gram molecular mass and gram formula mass to mole.

Pre- Reading

What are the simplest components of wood, rocks and living organisms? This is an age-old question. Ancient Greek Philosophers believed that everything was made of an elemental substance. Some believed that substance to be water, other thought it was air. Some other believed that there were four elemental substances.

As 19th century began, John Dalton proposed an atomic theory. This theory led to rapid progress in chemistry. By the end of the century however, further observations exposed the need for a different atomic theory. 20th century led to a picture of an atom with a complex internal structure.

A major goal of this chapter is to acquaint you with the fundamental concepts about matter. In this chapter you will learn some basic definitions to understand matter. This knowledge will help you in grade XI.

Reading

1.1 BRANCHES OF CHEMISTRY

Chemistry is defined as the science that examines the materials of the universe and changes that these materials undergo.

The study of chemistry is commonly divided into eight major branches:

1. **Physical Chemistry**

   The branch of Chemistry that deals with laws and theories to understand the structure and changes of matter is called Physical Chemistry.

2. **Organic Chemistry:**

   The branch of Chemistry that deals with substances containing carbon (Except carbonates, bicarbonates, oxides and carbides.

3. **Inorganic Chemistry:**

   The branch of Chemistry that deals with elements and their compounds except organic compounds is called Inorganic Chemistry.

4. **Biochemistry:**

   The branch of Chemistry that deals with physical and chemical changes that occur in living organisms is called Biochemistry.

5. **Industrial Chemistry:**

   The branch of Chemistry that deals with the methods and use of technology in the large-scale production of useful substances is called industrial chemistry.

Do You Know?

Do you know the debate going on for centuries about the corpuscular nature of matter? An ancient Greek philosopher, Empedocles thought that all materials are made up of four things called elements:

1. Earth 2. Air 3. Water 4. Fire

Plato adopted Empedocles theory and coined the term element to describe these four substances. His successor, Aristotle also adopted the concept of four elements. He introduced the idea that elements can be differentiated on the basis of properties such as hot versus cold and wet versus dry. For example, heating clay in an oven could be thought of as driving of water and adding fire, transforming clay into a pot. Similarly water (cold & wet) falls from the sky as rain, when air (hot and wet) cools down. The Greek concept of four elements existed for more than two thousand years.

Society, Technology and Science

Archimedes was a Greek philosopher and mathematician and inventor of many war machines. Greek emperor gave him the task to determine whether his crown was made of pure gold or impure gold. Archimedes took the task and started thinking on it. He knew that the volume of an object determines the volume of the liquid it displaces, when submerged in the liquid. One day when he was taking bath, he observed that more water overflowed the bath tank as he sank deeper into the water. He also noticed that he felt weightless as he submerged deeper in the bath tank. From these observations he concluded that the loss in weight is equal to the weight of water overflowed. Thinking this he at once designed an experiment in his mind to check the purity of crown. He thought, he should weigh the crown and equal weight of the pure gold. Both should be dipped in water in separate containers, since every substance has different mass to volume ratio. If the crown was made of pure gold, it would displace same weight of water as an equal weight of pure gold. If the crown is impure, it would displace different mass of water than the pure gold. Thinking this, he was so excited that he ran from the bath shouting “Eureka” which means I have found it. Like Archimedes discovery, science developed through observations and experiments rather than by speculation alone.

Teacher’s Point

Teacher may give examples of branches of Chemistry applied in daily life.

6. Nuclear Chemistry:

The branch of Chemistry that deals with the changes that occur in atomic nuclei is called nuclear chemistry.

7. Environmental Chemistry:

The branch of Chemistry that deals with the chemicals and toxic substances that pollute the environment and their adverse effects on human beings is called environmental chemistry.

8. Analytical Chemistry:

The branch of Chemistry that deals with the methods and instruments for determining the composition of matter is called Analytical Chemistry.

1.1.1 Differentiation between Branches of Chemistry

Vinegar contains 5% acetic acid. Acetic acid (CH_3COOH) is a colourless liquid that has characteristic vinegar like smell. It is used to flavour food. Various types of studies on this compound can help you to differentiate between various branches of chemistry.

1. Explanation of its transformation into gaseous state or solid state, applications of laws and theories to understand its structure is **physical chemistry**.
2. Since this is a carbon compound, its method of preparations and study of its physical and chemical characteristics is **organic chemistry**.
3. But the study of its component elements, carbon, hydrogen and oxygen is **inorganic chemistry**. This is because inorganic chemistry deals with elements and their compounds except carbon compounds. However, some carbon compounds such as CO_2, CO, metal carbonates, hydrogen carbonates and carbides are studied in inorganic chemistry.
4. The study of chemical reactions that acetic acid undergoes in the bodies of human beings is **biochemistry**.

Society, Technology and Science

Theories are tentative. They may change if they do not adequately provide explanation of the observed facts. The work of scientists help to change existing theories of the time. In 1803, the British chemist John Dalton presented a scientific theory on the existence and nature of matter. This theory is called Dalton's atomic theory. Main postulates of his theory are as follows:

1. All elements are composed of tiny indivisible particles called atoms.
2. Atoms of a particular element are identical. They have same mass and same volume.
3. During chemical reaction atoms combine or separate or re-arrange. They combine in simple ratios.
4. Atoms can neither be created nor destroyed.

Dalton was able to explain quantitative results that scientists of his time had obtained in their experiments. He nicely explained the law of chemical combinations. His brilliant work became the main stimulus for the rapid progress of the chemistry during nineteenth century, However, series of experiment that were performed in 1850's and beginning of twentieth century clearly demonstrated that atom is divisible and consists of subatomic particles, electrons, protons and neutrons. Also the atoms of an element may differ in masses (such atoms are called isotopes). Thus some of the postulates of Dalton's atomic theory were found defective and were changed.

5. Use of technology and ways to obtain acetic acid on the large scale is **industrial chemistry**.
6. The study of the effect of radioactive radiations or neutron on this compound or its component elements is **nuclear chemistry**.
7. The study of any adverse effects of this compound or the compounds that are derived from it, on the humans is **environmental chemistry**.
8. The method and instruments used to determine its percentage composition, melting point, boiling point etc is **analytical chemistry**.

Example 1.1: Identifying examples of different branches of chemistry

Identify the branch of chemistry in each of the following examples:

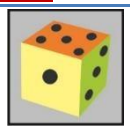
1. Photosynthesis produces glucose and oxygen from carbon dioxide and water in presence of chlorophyll and sunlight.
2. Plantation helps in overcoming green house effect.
3. Haber's process converts large quantities of hydrogen and nitrogen into ammonia $\left(NH_3\right)$.
4. Ammonia is a colourless gas with pungent irritating odour. It is highly soluble in water.
5. A chemist performed an experiment to check the percentage purity of a sample of glucose $\left(C_6H_{12}O_6\right)$.
6. An analyst determines that NO_2 is responsible for acid rain.
7. Chlorofluorocarbon compounds are responsible for the depletion of ozone layer.
8. α-particles (He^{++}) when bombard on nitrogen atom, a proton is emitted.

Problem Solving strategy:

Concentrate on the basic definition of each branch of chemistry and identify branch of chemistry in each example.

Solution:

1. Biochemistry, since photosynthesis is a chemical reaction that occurs in plants (living organism).
2. Environmental chemistry, since green house effect is an environmental problem.
3. Industrial chemistry, since large scale production of any substance is the subject of industrial chemistry.
4. Inorganic chemistry, since it deals with properties of inorganic compounds.
5. Analytical chemistry, since it deals with analysis of a compound, whether organic or inorganic in nature.
6. Environmental chemistry, since acid rain is an environmental problem.
7. Environmental chemistry, since depletion of ozone layer is environmental problem.
8. Nuclear chemistry, since nuclear change can emit protons.



Self-Assessment Exercise 1.1

Identify the branch of chemistry that is related to the following information:

1. Hair contain a special class of proteins called keratins, which are present in nails and wool. Proteins contain chains of C-atoms.
2. Acetylene is the simplest hydrocarbon that contains carbon-carbon triple bond. Hydrocarbons are the compounds of carbon and hydrogen.
3. White lead is a pigment used by artists for centuries, the metal Pb in the compound is extracted from its ore, galena (PbS).
4. Sulphuric acid (H_2SO_4) is extremely corrosive to skin.
5. Gases can be compressed by applying pressure.
6. Meat, Milk and eggs contain long chains of carbon compounds.
7. Element radium decays by emitting α-particles and is converted into another element radon.
8. Calorimeter is a device that measures the amount of heat, a substance absorbs on heating or emits on cooling.

Society, Technology and Science
Molecularity of the physical world

World is composed of a few more than a hundred elements. Elements are building blocks of all the substances that make up all living and non-living things. This means elements are building blocks for everything in the universe. The same elements that make up earth also make up moon. A careful observation of the physical world reveals that matter usually occurs as mixtures. Most of the components of these mixtures are elements and compounds that exist as molecules. Only noble gases exist as monoatomic molecules, other substances exist as polyatomic molecules. Air consists of many elements and compounds all existing in molecular form. For instance O_2, N_2, CO_2, H_2O and the noble gases. Water a molecular substance cover 70% of the earth's crust. It also fills the empty under the earth. Rocks and earth are mixtures of numerous compounds. Clay and sand consists of long chains of atoms called giant molecules. Petroleum and coal that are complex mixtures also contain hundreds of thousands of molecular compounds. Living things contain thousands of different substances such as carbohydrates, proteins, fats, lipids, DNA, RNA etc. All these substances are molecular in nature.

Reading

1.2 BASIC DEFINITIONS

Some of the important definitions used to understand matter are given below:

1.2.1 Elements, Compounds and Mixtures

Anything that occupies space and has mass is called matter. Any matter that has a particular set of characteristics that differ from the characteristics of another kind of matter is called a substance. For instance, oxygen, water, carbon dioxide, urea, glucose, common salt etc are different substances.

A substance that cannot be converted to other simpler substances is called an element. For example substances like oxygen, hydrogen, iron, copper, aluminium etc are elements. An element is now defined as a substance whose all the atoms have the same atomic number.

A compound is a pure substance that consists of two or more elements held together in fixed proportions by natural forces called chemical bonds. The properties of compounds are different from the properties of the elements from which they are formed. For example, water, carbon dioxide, copper sulphate, sodium chloride etc are compounds. Elements and compounds have uniform composition throughout.

An impure substance that contains two or more pure substances that retain their individual chemical characteristics is called a mixture. A mixture can be converted into two or more pure substances by a physical method. Examples of mixture are air, water containing dissolved oxygen, table salt dissolved in water, salt + sand etc. A mixture that consists of two or more visibly different components is called a heterogeneous mixture. For example sand + salt, oil floating on water etc. A mixture that consists of only one phase is called a homogeneous mixture. For example, sugar mixed in water, salt dissolved in water. Homogeneous mixtures also have uniform composition throughout.

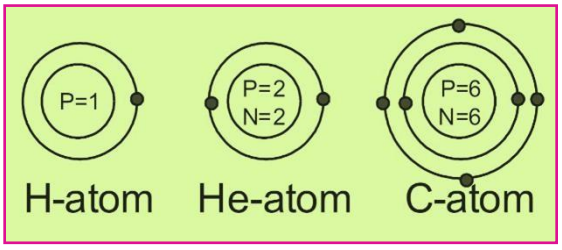
Science Tit Bits

Bad breath may be good for you. The chemistry of garlic is not simple. Garlic contains more than 200 compounds. People who eat a lot of garlic have a lower chance of getting stomach cancer, suffering from heart disease or having a stroke than people who eat little or no garlic.

In fact the entire physical world is made up of mixture of elements and compounds. Most of its components are made up of molecules.

1.2.2 Atomic Number, Mass Number

The number of protons in the nucleus of an atom is known as its atomic number. For example, there is only one proton in the nucleus of H-atom; therefore its atomic number is 1. All the atoms of a given element have the same number of protons and therefore the same atomic number. Do you think atomic number of He is 2? What is the mass number of C-atom? **The total number of protons and neutrons in an atom is known as its mass number.**



Some atoms of an element have different number of neutrons, such atoms are called isotopes. We will discuss isotopes in section 2.2.

No. of neutrons = mass number – atomic number

Example 1.2: Determining the number of protons and neutrons in an atom

Atomic number of an element is 17 and mass number is 35. How many protons and neutrons are in the nucleus of an atom of this element?

Problem Solving Strategy:

Number of protons are equal to atomic number and

Number of neutrons = mass number – atomic number

Solution:

Number of protons = atomic number = 17

Number of neutrons = mass number – atomic number

= 35-17 = 18

1.2.3 Relative Atomic Mass and Atomic Mass Unit

The first quantitative information about atomic masses came from the work of Dalton, Gay Lussac, Lavoisier, Avogadro and Berzelius. By observing the proportions in which elements combine to form various compounds, nineteenth century chemists calculated relative atomic masses. An atom is extremely small particle; therefore we cannot determine the mass of a single atom. However, it is possible to determine the mass of one atom of an element relative to another experimentally. This can be done by assigning a value to the mass of one atom of a given element, so that it can be used as standard. By international agreement in 1961, light isotope of carbon C-12 has been chosen as a standard. This isotope of carbon(C-12) has been assigned a mass of exactly 12 atomic mass unit. This value has been determined accurately using mass spectrometer. The mass of atoms of all other elements are compared to the mass C-12. Thus **"the mass of an atom of an element relative to the mass of an atom of C-12 is called its relative atomic mass"**.

One atomic mass unit (amu) is defined as a mass exactly equal to one-twelfth the mass of one C-12 atom.

Mass of one C-12 atom = 12 amu

$$1\text{amu} = \frac{\text{mass of one C-12 atom}}{12}$$

A hydrogen atom is 8.40% as massive as the standard C-12 atom. Therefore, relative atomic mass of hydrogen.

$$= \frac{8.40}{100} \text{ x } 12 \text{ amu}$$

$$= 1.008 \text{ amu}$$

Similarly, relative atomic masses of O, Na, Al are 15.9994 amu, 22.9898 amu, 26.9815 amu respectively. Table 1.1 shows the relative atomic masses of some elements.

Table 1.1 relative atomic masses of some elements

Element	Relative atomic mass	Element	Relative atomic mass
H	1.008 amu	Al	26.9815 amu
N	14.0067amu	S	32.06 amu
O	15.9994amu	Cl	35.453 amu
Na	22.9898 amu	Fe	55.847 amu

1.2.4 Empirical Formula, Molecular Formula

Recall that the chemical formula of a compound tells us which elements are present in it and the whole number ratio of their atoms. In a chemical formula element's symbol and numerical subscripts show the type and the number of each atom in a compound. There are several types of chemical formulas for a compound. Here you will learn about two types of chemical formulas.

1. Empirical Formula

The empirical formula of a compound is the chemical formula that gives the simplest whole-number ratio of atoms of each element. For example in compound hydrogen peroxide there is one H atom for every O atom. Therefore, simplest ratio of hydrogen to oxygen is 1: 1. So the empirical formula of hydrogen peroxide is written as **HO.**

The simplest ratio between C, H and O atoms in glucose is 1 : 2 : 1. What is the empirical formula of glucose?

2. Molecular Formula

A molecular formula gives the actual whole number ratio of atoms of each element present in a compound. For example there are actually two H atoms and two O atoms in each molecule of hydrogen peroxide. Therefore, actual ratio of hydrogen to oxygen atoms is 2 : 2. So molecular formula of hydrogen peroxide is $\mathbf{H_2O_2}$.

The actual ratio between C, H and O atoms in a glucose molecule is 6 : 12 : 6. What is the molecular formula of glucose?

An empirical formula shows the simplest number of atoms of each element in a compound whereas the molecular formula shows the actual number of aotms of each element in the molecule of a compound.

Benzene is a compound of carbon and hydrogen. It contains one C atom for every H atom. There are actually six C atoms and six hydrogen atoms in each molecule of benzene. Identify empirical and molecular formula for benzene from the following formulas.

$\mathbf{C_6H_6}$, **CH**

Molecular formulas for water and carbon dioxide are H_2O and CO_2 respectively. What are empirical formulas for these compounds?

Self-Assessment Exercise 1.2

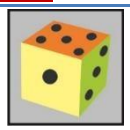
Write the empirical formulas for the compound containing carbon to hydrogen in the following ratios:

(a) 1:4 (b) 2:6 (c) 2:2 (d) 6:6

For many compounds, empirical and molecular formulas are same. For example water (H_2O), carbon dioxide (CO_2) ammonia (NH_3), methane (CH_4), sulphur dioxide (SO_2) etc. Can you show it why?

Teacher's Point

A teacher may give numerical example to determine E.F of a Compound.



Self-Assessment Exercise 1.3

1. Aspirin is used as a mild pain killer. There are nine carbon atoms, eight hydrogen atoms and four oxygen atoms, in this compound. Write its empirical and molecular formulas.
2. Vinegar is 5% acetic acid. It contains 2 carbon atoms, four hydrogen atoms and 2 oxygen atoms. Write its empirical and molecular formulas.
3. Caffeine $(C_8H_{10}N_4O_2)$ is found in tea and coffee. Write the empirical formula for caffeine.

Reading

1.2.5 Molecular Mass and Formula Mass

Molecular mass is the sum of atomic masses of all the atoms present in the molecule. All you have to do is to add up the atomic masses of all the atoms in the compound. For example,

Molecular mass of water H_2O = 2(atomic mass of H) + atomic mass of oxygen

= 2(1.008) + 16.00

= 2.016 + 16.00

= 18.016amu

Example 1.3: Determining molecular mass

1. Determine the molecular mass of glucose $C_6H_{12}O_6$ which is also known as blood sugar.
2. Determine the molecular mass of naphthalene $C_{10}H_8$, which is used in mothballs.

Problem solving strategy:

Multiply atomic masses of carbon, hydrogen and oxygen by their subscripts and add.

Solution:

1. Molecular mass of $C_6H_{12}O_6$ = 6(12.00) + 12(1.008) + 6(16.00)

   =180.096 amu
2. Molecular mass of $C_{10}H_8$ = 12 x 10 + 1 x 8

   = 120 + 8 = 128 amu

The term molecular mass is used for molecular compounds. Whereas, the term formula mass is used for ionic compounds. Ionic compounds consist of arrays of oppositely charged ions rather than separate molecules. So we represent an ionic compound by its formula unit. A formula unit indicates the simplest ratio between cations and anions in an ionic compound. For example, the common salt consists of Na^+ and Cl^- ions. It has one Na^+ ion for every Cl^- ion. So formula unit for common salt is NaCl.

The sum of the atomic masses of all the atoms in the formula unit of a substance is called formula mass.

Example 1.4: Determining formula mass

1. Sodium Chloride, also called as table salt is used to flavour food, preserve meat, and in the preparation of large number of compounds. Determine its formula mass.
2. Milk of magnesia which contains $Mg(OH)_2$, is used to treat acidity. Determine its formula mass.

Problem solving strategy:

Add the atomic masses of all the atoms in the formula unit.

Solution:

1. Formula mass of NaCl = 1 x Atomic mass of Na + 1 x Atomic mass of Cl
   = 1 x 23 + 1 x 35.5
   = 58.5amu
2. Formula mass of $Mg(OH)_2$ = 24 + 16x2 + 1x2
   = 24 + 32 + 2
   = 58 amu

Self-Assessment Exercise 1.4

1. Potassium Chlorate $(KClO_3)$ is used commonly for the laboratory preparation of oxygen gas. Calculate its formula mass.
2. When baking soda, $NaHCO_3$ is heated carbon dioxide is released, which is responsible for the rising of cookies and bread. Determine the formula masses of baking soda and carbon dioxide.
3. Following compounds are used as fertilizers. Determine their formula masses.
   - Urea, $(NH_2)_2CO$
   - Ammonium nitrate, NH_4NO_3.

Important information

Many scientists regarded atom as merely a convenient mental construct and nothing more. This is because atom is so small that it cannot be seen with the naked eye. Today, however, we have sophisticated instruments to weigh atoms and even visualize them. Figure 1.1 shows an image of gold atoms on the surface.

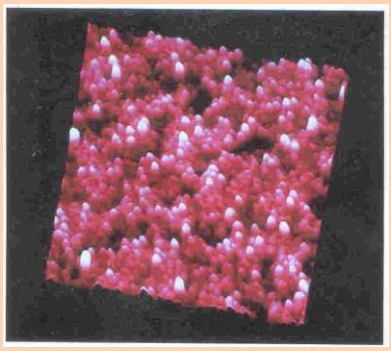


Figure 1.1 view of surface atoms of gold

The image has been drawn by computer from signal sent to it by an instrument called a scanning tunneling microscope. The computer has drawn gold atoms as topped peaks.

Reading

1.3 CHEMICAL SPECIES

Most of the matter is composed of molecules or ions, formed by atoms.

1.3.1 Ions (Cation, Anions), Molecular Ions and Free Radicals

Atom is the smallest particle of an element that cannot exist in free state. It is electrically neutral. On the other hand an ion is a charged species formed from an atom or chemically bonded groups of atoms by adding or removing electrons. **Positively charged ions are called cations, whereas, the negatively charged ions are called anions.** An ionic compound contains anions and cations in such number that the compound is electrically neutral. Metal atoms generally lose one or more electrons and form cations. For example Na forms Na^+ by losing one electron, Ca forms Ca^{+2} by losing two electrons. The Non-metal atoms usually gain one or more electrons and form anions. For example a chlorine atom gains one electron and forms Cl^- ion. An O-atom gains two electrons and forms O^{-2} ion.

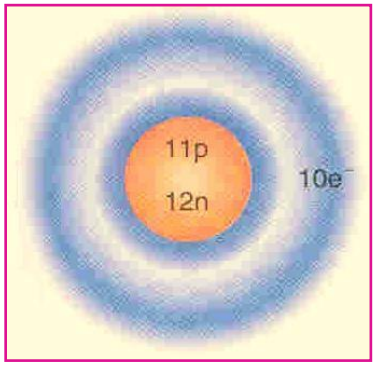


Fig.1.2 Na^+ ion

Let us understand why an ion acquires a net positive or negative charge. Consider the formation of Na^+ ion.

Figure 1.2 shows the sodium ion. Note that sodium has a nucleus of 11 protons and 12 neutrons. Thus its nucleus has a total charge of +11. Around the nucleus, there are 10 electrons, with a total charge of -10. The charge on the ion is +11 + (-10) = +1

Self-Assessment Exercise 1.5

Explain Why?

1. An oxide ion O^{-2} has –2 charge.
2. Magnesium ion, Mg^{+2} has +2 charge.
3. Sulphide ion, S^{-2} has –2 charge.

Reading

Molecular Ion

When a molecule loses or gains one or more electrons, the resulting species is called a molecular ion. For example O_2 when loses one electron it forms O_2^+ ion, but when it absorbs an electrons it forms O_2^- ion. These ions are called molecular ions. Similarly N_2^-, N_2^+ etc are examples of molecular ions. These are short lived species and only exist at high temperature. Molecular ions do not form ionic compounds.

Free Radicals

A free radical is an atom which has an unpaired electron and bears no electrical charge. For example

are free radicals

When substances like halogens are exposed to sun light, their molecules split up into free radicals.

Difference between Ion and Free Radical

Chlorine free radical

Chloride ion

Which species has even number of electrons? Which species has odd number of electrons?

A free radical has an unpaired electron, so it has odd number of electrons. A free radical is an electrically neutral species. Whereas an ion has even number of electrons, so it has no unpaired electrons.

Dot (.) indicates an unpaired electron.

Self-Assessment Exercise 1.6

Identify ions, molecular ions and free radicals from the following species.

$$CN^{-},\ \dot{C}N,\ He^{+2},\ N^{-3},\ CH_4^{+}$$

Reading

1.3.2 Representiative Particles of Elements and Compounds

The term representative particles refer to species present in a substance. These species are atoms, molecules or formula units. For instance water exists as molecules, carbon exists as atoms.

Example 1.5: Identifying representative particles of elements and compounds

Figure 1.3 shows some molecules. Identify particles of elements and compounds.

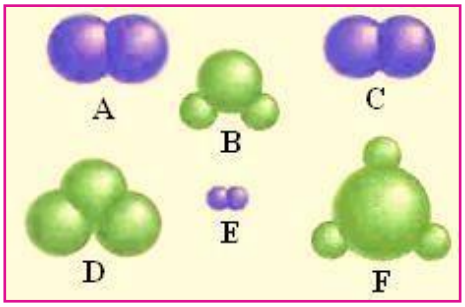


Fig 1.3 Some common molecules

Problem Solving Strategy:

Elements have atoms of same sizes and compounds have atoms of different sizes.

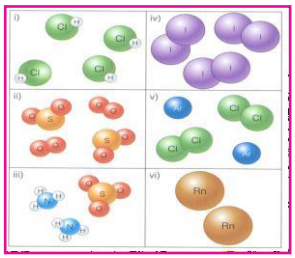
Solution:

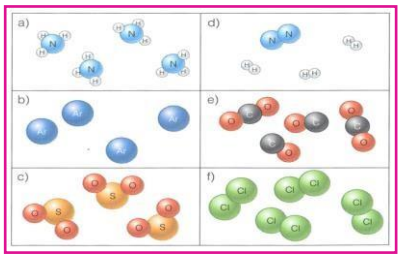
Particles of elements are A, C, D and E. Particles of compounds are B and F.

Molecules can also be classified as monoatomic or polyatomic. Inert gases consist of monoatomic molecules such as He, Ne, Ar, Kr, Rn. **A molecule that contains only one atom is called monoatomic. Molecules that contain two or more similar or different atoms are called polyatomic molecules.** For example, H_2, O_2, HCl, NH_3 etc are polyatomic molecules.

Self-Assessment Exercise 1.7

1. **Observe the given figure and identify the diagrams that represents the particles of :**
   a) An element whose particles are atoms.
   b) An element whose particles are molecules.
   c) A compound.
   d) A mixture of an element and a compound.
   e) A mixture of two elements.
   f) A mixture of two compounds.
2. **Observe the given figure and decide which diagram represents particles in an element, a compound or a mixture.**





Reading

1.4 AVOGADRO'S NUMBER AND MOLE

How do you count shoes? As shoes come in pairs, so you would most likely count them by pairs rather than individually. Similarly eggs, oranges etc. are counted in dozens, but paper by ream. Thus, the counting unit depends on what you are counting.

Society, Technology and Science

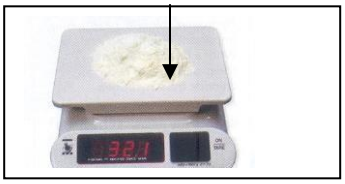
During 600 – 1600 AD, Chemical history was dominated by a pseudo-science called alchemy. Earlier alchemists were obsessed with the idea of turning cheap metals into gold. They searched for ways to change less valued metals such as lead into gold. They could not succeed and wasted their time and money. Therefore, the works of earlier alchemists handicapped progress of science. However, during that period they discovered many new processes such as distillation, sublimation and extraction. These processes are still in use today. Such processes are contributing a lot in the progress of science. This means the works of different scientists at the same time handicap or promote the growth of science.

Chemists also use a practical unit for counting atoms, molecules and ions. They use a counting unit called mole to measure the amount of a substance.

A mole is an amount of a substance that contains 6.022 x 10^{23} particles of that substance. This experimentally determined number is known as Avogadro's number. It is represented by $\mathbf{N_A}$. Just as a dozen eggs represent twelve eggs, a ream of paper represent 500 papers, a mole of a substance represents 6.022 x 10^{23} representative particles of a substance..

For example a mole of carbon is 6.022 x 10^{23} atoms. A mole of sulphur is 6.022 x 10^{23} atoms. A mole of water is 6.022 x 10^{23} molecules.

A mole of S-atoms (6.022 x 10^{23} S-atoms)



A mole of C-atoms (6.022 x 10^{23} C-atoms)

A pair of Shoes & a dozen eggs

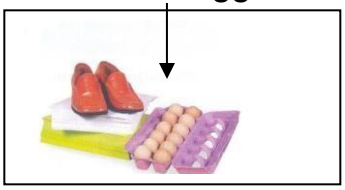


Figure 1.4 A mole of S-atoms, a mole of C-atoms & pair of Shoes & a dozen eggs

What is the mass of one mole C-atoms?
How many atoms are there in 32.1 g of S-atoms?
Does a dozen eggs have same mass as a dozen bananas? Does a mole of carbon atoms have a different mass than a mole of sulphur atoms?

Society, Technology and Science
Size of the Mole

Entire population cannot count 1 mole of coins in a year. They need about one million year to count them. So, when counting a pile of coins, it would not be convenient to count them one by one. The concept of mole has given a very simple method to count large number of items. Mole is not only a number but also represents definite amount of a substance. Just as 6.02 x 10^{23} carbon atoms weigh 12 g, 6.02 x 10^{23} coins will also have a definite mass. So an easy way is to weigh them. If you know the mass of one coin, you can count them by weighing.

The mass of one mole of substance is called as molar mass. What are the molar masses of carbon and sulphur? The term representative particles in a substance are atoms, molecules, formula units or ions. For instance water exists as molecules, therefore, one mole of water contains 6.022 x 10^{23} molecules of water. Hydrogen exists as H_2 molecules, so one mole of hydrogen contain 6.022 x 10^{23} molecules. Carbon exists as atoms so 1 mole of carbon contains 6.022 x 10^{23}atoms.

1.4.3 Gram Atomic Mass, Gram Molecular Mass and Gram Formula Mass

A mole of S-atoms (6.022 x 10^{23} S-atoms)

What is the mass of 6.022 x 10^{23} S-atoms?
Is this mass of S-atoms equal to its atomic mass?

A mole of C- atoms (6.022 x 10^{23} C-atoms)

What is the mass of one mole of C-atoms?
Is this mass of C-atoms equal to its atomic mass?

Teacher's Point

Teacher may give more examples of mole.

Atomic mass of an element expressed in grams is called gram atomic mass.

Is the gram atomic mass of C-atoms 12 g?

What is the gram atomic mass of S-atoms?

If each of the carbon and sulphur sample shown above contains one mole of atoms, why do the samples have different masses?

Atomic mass of C = 12amu ∴gram atomic mass of C = 12g

Atomic mass of Na = 23amu ∴gram atomic mass of C = 23g

Atomic mass of Zn = 63.54amu ∴gram atomic mass of C = 63.54g

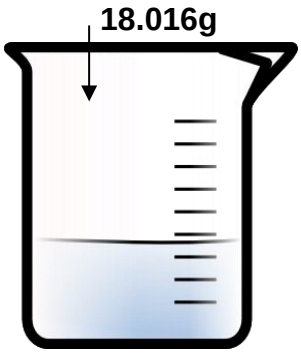
Gram atomic mass of an element contains 1 mole of atoms.
Therefore,

Mass of 1 mole of C-atoms = 12g

Mass of 1 mole of Na-atoms = 23g

Mass of 1 mole of Zn-atoms = 63.54g

A mole of H_2O -molecules
(6.022×10^{23} H_2O-molecules)



What is the mass of one mole of water molecules?
Is this mass of water molecules equal to molecular mass of water?

A mole of $C_6H_{12}O_6$ – molecules
(6.022×10^{23} $C_6H_{12}O_6$ -molecules)

what is the mass of 6.022×10^{23} molecules of glucose?
is this mass of glucose molecules equal to molecular mass of glucose?

Molecular mass of a substance expressed in grams is called gram molecular mass.

Molecular mass of **H_2O** = 2 x 1.008 + 16

= 18.016amu

So, gram molecular mass of **H_2O** = 18.016g

Molecular mass of $C_6H_{12}O_6$ = 6 x 12 + 12 x 1.008 + 16 x 6

= 180.096amu

So, gram molecular mass of $C_6H_{12}O_6$ = 180.096g

Formula mass of a substance expressed in gram is called gram formula mass.

An ionic compound is represented by the formula unit that represents the simplest ratio between the ions of a compound. For example NaCl, KCl, $CuSO_4$ etc.

Formula mass of NaCl = 23 + 35.5
= 58.5amu

Therefore, gram formula mass of NaCl = 58.5g = mole of NaCl formula units.

Formula mass of KCl = 39 + 35.5
= 74.5amu

So, gram formula mass of KCl = 74.5g

Difference between the Terms Gram Atomic Mass, Gram Molecular Mass And Gram Formula Mass

(i) Gram atomic mass represents one mole of atoms of an element, gram molecular mass represents one mole of molecules of a compound or an element that exists in molecular state whereas gram formula mass represents one mole of ionic formula units of a compound.

(ii) Gram atomic mass contains 6.022×10^{23} atoms, gram molecular mass contains 6.022×10^{23} molecules whereas gram formula mass contain 6.022×10^{23} formula units.

(iii) All of these quantities represent molar mass. Mass of one mole of a substance expressed in grams is called molar mass. **"Therefore, mole can be defined as atomic mass, molecular mass or formula mass expressed in grams"**.

1.5 CHEMICAL CALCULATIONS

In this section, you will learn about the chemical calculations based on the concept of mole and Avogadro's number.

1.5.1 Mole-Mass Calculations

Example 1.5: Calculating mass of one mole of a substance

Calculate the molar masses of (a) Na (b) Nitrogen (c) Surcose $C_{12}H_{22}O_{11}$

Problem solving strategy:

If an element is a metal then its molar mass is its atomic mass expressed in grams (gram atomic mass). If an element exists as molecule, its molar mass is its molecular mass expressed in grams (gram molecular mass).

Solution:

a) 1 mole of Na = 23g

b) Nitrogen occurs as diatomic molecules.

Molecular mass of N_2 = 14 x 2
= 28amu

Therefore, mass of 1 mole of N_2 = 28 g

c) Molecular mass of $C_{12}H_{22}O_{11}$ = 12x12 + 1x22 + 16x11

= 144 + 22 + 176

Therefore, mass of 1mole of sucrose = 342g

Self-Assessment Exercise 1.8

Calculate the mass of one mole of (a) Copper (b) Iodine (c) Potassium (d) Oxygen

Example 1.5(a): Calculating the mass of a given number of moles of a substance

Oxygen is converted to ozone (O_3) during thunder storms. Calculate the mass of ozone if 9.05 moles of ozone is formed in a storm?

Problem solving strategy:

Ozone is a molecular substance. Determine its molar mass and use it to convert moles to mass in grams.

9.05 moles of O_3 ↓↓ ? g of O_3

Solution:

1 mole of O_3 = 16 x 3

= 48 g

1 mole of O_3 = 48 g

So, 9.05 moles of O_3 = 48 g x 9.05

= 434.4g of O_3

Example 1.6: When natural gas burns CO_2 is formed. If 0.25 moles of CO_2 is formed, what mass of CO_2 is produced?

Problem solving strategy:

Carbon dioxide is a molecular substance. Determine its molar mass and use it to convert moles to mass in grams

0.25 moles of CO_2 ↓↓ ? g of CO_2

Solution:

Molar mass of CO_2 = 12 + 16 x 2

= 44g

1 mole of CO_2 = 44g of CO_2

So, 0.25 moles of CO_2 = 44 x 0.25

= 11g of CO_2

Example 1.7: Converting grams to moles

How many moles of each of the following substance are present?

(a) A balloon filled with 5g of hydrogen.

(b) A block of ice that weighs 100g.

Problem solving strategy:

Hydrogen and ice both are molecular substances. Determine their molar masses. Use the molar mass of each to convert masses in grams to moles.

mass ↓↓→ ? moles

Solution:

a) Molar mass of H_2 = 1.008 x 2

= 2.016g

1 mole of H_2 = 2.016g

So, 2.016g of H_2 = 1 mole of H_2

1g of H_2 = $\frac{1}{2.016}$ moles of H_2

5g of H_2 = $\frac{1}{2.016}$ x5 moles of H_2

= 2.48 moles of H_2O

b) 1 mole of H_2O = 2 x 1.008 + 16

= 2.016 + 16

= 18.016g

1 mole of H_2O = 18.016g

So, 18.016g of H_2O = 1 mole

1g of H_2O = $\frac{1}{18.016}$ moles

100g of H_2O = $\frac{1}{18.016}$ x100 moles

= 5.55 moles of H_2O

Self-Assessment Exercise 1.9

1. The molecular formula of a compound used for bleaching hair is H_2O_2. Calculate (a) Mass of this compound that would contain 2.5 moles. (b) No. of moles of this compound that would exactly weigh 30g.
2. A spoon of table salt, NaCl contains 12.5grams of this salt. Calculate the number of moles it contains.
3. Before the digestive systems X-rayed, people are required to swallow suspensions of barium sulphate $BaSO_4$ Calculate mass of one mole of $BaSO_4$.

Teacher's Point

A teacher may in courage students solve self- assessment exercise themselves.

Reading

1.5.2 Mole-Particles Calculations

Example 1.8: Calculating the number of atoms in given moles

1. Zn is a silvery metal that is used to galvanize steel to prevent corrosion. How many atoms are there in 1.25 moles of Zn.
2. A thin foil of aluminium (Al) is used as wrapper in food industries. How many atoms are present in a foil that contains 0.2 moles of aluminium?

Problem solving strategy:

Remember that symbols Zn and Al stand for one mole of Zn and Al atoms respectively.

Solution:

1. 1 mole of Zn contains $= 6.022 \times 10^{23}$ atoms
   1.25 moles of Zn contain $= 6.022 \times 10^{23} \times 1.25$
   $= 7.53 \times 10^{23}$ Zn atoms
2. 1 mole of Al contains $= 6.022 \times 10^{23}$ atoms
   So 0.2 moles of Al will contain $= 6.022 \times 10^{23} \times 0.2$
   $= 1.2044 \times 10^{23}$ atoms

Example 1.9: Calculating the number of molecules in given moles of a substance

1. Methane (CH_4) is the major component of natural gas. How many molecules are present in 0.5 moles of a pure sample of methane?
2. At high temperature hydrogen sulphide (H_2S) gas given off by a volcano is oxidized by air to sulphur dioxide (SO_2). Sulphur dioxide reacts with water to form acid rain. How many molecules are there in 0.25 moles of SO_2.

Problem solving strategy:

Remember that CH_4 is a molecular compound, thus 1 mole of methane will have 6.022×10^{23} molecules. Similarly, SO_2 is a molecular compound, its one mole will also have 6.022×10^{23} molecules.

Solution:

1. 1 mole of CH_4 contains $= 6.022 \times 10^{23}$ molecules
   So, 0.5 moles of CH_4 will contain $= 6.022 \times 10^{23} \times 0.5$
   $= 3.011 \times 10^{23}$ molecules
2. 1 mole of SO_2 contains $= 6.022 \times 10^{23}$ molecules
   So, 0.25 moles of SO_2 will contain $= 6.022 \times 10^{23} \times 0.25$
   $= 1.5055 \times 10^{23}$ molecules

Example 1.10: Calculating the number of moles in the given number of atoms

Titanium is corrosion resistant metal that is used in rockets, aircrafts and jet engines. Calculate the number of moles of this metal in a sample containing 3.011×10^{23} Ti-atoms.

Problem solving strategy:

Remember that 1 mole of an element contains 6.022×10^{23} atoms.

Thus,

6.022×10^{23} atoms = 1 mole

3.011×10^{23} atoms $\longrightarrow$? moles

Solution:

6.022×10^{23} Ti atoms = 1 mole of Ti

$$1 \text{ Ti atom} = \frac{1}{6.022 \times 10^{23}} \text{ moles of Ti}$$

$$3.011 \times 10^{23} \text{ Ti atoms} = \frac{1}{6.022 \times 10^{23}} \times 3.011 \times 10^{23} \text{ moles of Ti}$$

$$= 0.5 \text{ moles of Ti}$$

Example 1.11: Calculating number of moles in the given number of molecules

Formaldehyde is used to preserve dead animals. Its molecular formula is CH_2O. Calculate the number of moles that would contain 3.011×10^{22} molecules of this compound.

Problem Solving Strategy:

Remember that 1 mole of any compound contains 6.022×10^{23} molecules.

Thus,

6.022×10^{23} molecules = 1 mole of compound

3.011×10^{22} molecules $\downarrow\downarrow$? moles

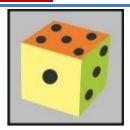
Solution:

6.022×10^{23} molecules = 1 mole of formaldehyde

$$1 \text{ molecule} = \frac{1}{6.022 \times 10^{23}} \text{ moles of formaldehyde}$$

$$3.011 \times 10^{22} \text{ molecules} = \frac{1}{6.022 \times 10^{23}} \times 3.011 \times 10^{22} \text{ moles of formaldehyde}$$

$$= 0.05 \text{ moles of formaldehyde}$$



Self-Assessment Exercise 1.10

1. Aspirin is a compound that contains carbon, hydrogen and oxygen. It is used as a painkiller. An aspirin tablet contains 1.25 x 10^{30} molecules. How many moles of this compound are present in the tablet?
2. A method used to prevent rusting in ships and underground pipelines involves connecting the iron to a block of a more active metal such as magnesium. This method is called cathodic protection. How many moles of magnesium are present in 1 billion (1 x 10^{9}) atoms of magnesium.

Key Points

- Chemistry is the science of materials of the universe.
- The branch of Chemistry that deals with laws and theories to understand the structure and changes of matter is called Physical Chemistry.
  Organic chemistry deals with carbon compounds (except bicarbonates carbonates oxides and carbides.
- The branch of Chemistry that deals with elements and their compounds except organic compounds is called Inorganic Chemistry.
- Physical and chemical changes that occur in living organisms are studied in biochemistry.
- Industrial chemistry is concerned with the large scale production of chemical substances.
- An element is a substance all the atoms of which have the same atomic number.
- A compound consists of two or more elements held together in fixed proportions by chemical bonds.
- An impure substance that contains two or more pure substances that retain their individual chemical characteristics is called a mixture.
- The number of protons in the nucleus of an atom is known as its atomic number.
- The total number of protons and neutrons in an atom is called its mass number.
- Atoms of an element that have different number of neutrons are called isotopes.
- The mass of an atom of an element relative to the mass of an atom of C-12 is called relative atomic mass.
- One atomic mass unit is defined as the mass exactly equal to one-twelfth the mass of one C-12 atom.
- Chemical formula of a compound that gives the simplest whole-number ratio between atoms is called empirical formula.
- Molecular formula of a compound gives the exact number of atoms present in a molecule.
- Molecular mass is the sum of atomic masses of all the atoms present in the molecule.
- Positively charged ions are called cations and negatively charged ions are called anions.
- When a molecule loses or gains electrons, the resulting species is called molecular ion.

- Free radical is an atom or group of atoms that contains an unpaired electron.
- The number of representative particles in one mole of the substance is known as Avogadro's number.
- The amount of matter that contains as many atoms, ions or molecules as the number of atoms in exactly 12g of C-12 is called mole. Mole can also be defined as atomic mass, molecular mass or formula mass expressed in grams.
- Atomic mass of an element expressed in grams is called gram atomic mass.
- Molecular mass of an element or a compound expressed in grams is its gram molecular mass.
- Gram formula mass is the formula mass of a substance in grams.

REFERENCES FOR ADDITIONAL INFORMATION

- Zumdahl, Introductory Chemistry.
- Raymond Chang, Essential Chemistry.

Activity

Take two balloons. Fill one balloon full of air and other half. Then weigh both and compare the masses of both. It confirms that masses of gases increase with increase in number of molecules in it.

Review Questions

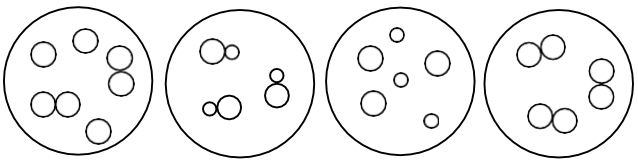
1. Encircle the correct answer:

(i) Which of the following lists contains only elements?

(a) Air, water, oxygen (b) Hydrogen, oxygen, brass

(c) Air, water, fire, earth (d) Calcium, sulphur, carbon

(ii) The diagrams below represent particles in four substances, which box represent the particles in nitrogen.



a. b. c. d.

(iii) What is the formula mass of $CuSO_4.5H_2O$. (Atomic masses: Cu=63.5, S=32, O=16, H=1)

(a) 159.5 (b) 185.5 (c) 249.5 (d) 149.5

(iv) A compound with chemical formula Na_2CX_3 has formula mass 106amu. Atomic mass of the element X is

(a) 106 (b) 23 (c) 12 (d) 16

(v) How many moles of molecules are there in 16g oxygen.

(a) 1 (b) 0.5 (c) 0.1 (d) 0.05

(vi) What is the mass of 4 moles of hydrogen gas.

(a) 8.064g (b) 4.032g (c) 1g (d) 1.008g

(vii) What is the mass of carbon present in 44g of carbon dioxide.
(a) 12g (b) 6g (c) 24g (d) 44g

(viii) The electron configuration of an element is $1s^2 2s^2$. An atom of this element will form an ion that will have charge.
(a) +1 (b) +2 (c) +3 (d) -1

(ix) Which term is the same for one mole of oxygen and one mole of water?
(a) volume (b) (c) mass (d) atoms (e) molecules

(x) If one mole of carbon contains *x* atoms, what is the number of atoms contained in 12g of Mg.
(a) *x* (b) 0.5*x* (c) 2*x* (d) 1.5*x*

2. Give short answers.

(i) Differentiate between an ion and a free radical
(ii) What do you know about corpuscular nature of matter?
(iii) Differentiate between analytical chemistry and environmental chemistry.
(iv) What is mole?
(v) Differentiate between empirical formula and molecular formula.
(vi) What is the number of molecules in 9.0 g of steam?
(vii) What are the molar masses of uranium -238 and uranium -235?
(viii) Why one mole of hydrogen molecules and one mole of H-atoms have different masses?

3. Define ion, molecular ion, formula unit, free radical, atomic number, mass number, atomic mass unit.

4. Differentiate between (a) atom and ion (b) molecular ion and free radical.

5. Describe how Avogadro's number is related to a mole of any substance.

6. Calculate the number of moles of each substance in samples with the following masses:
(a) 2.4 g of He (b) 250mg of carbon (c) 15g of sodium chloride
(d) 40g of sulphur (e) 1.5kg of MgO

7. Calculate the mass in grams of each of the following samples:
(a) 1.2 moles of K (b) 75moles of H_2 (c) 0.25 moles of steam
(d) 1.05 moles of $CuSO_4.5H_2O$ (e) 0.15moles of H_2SO_4

8. Calculate the number of molecules present in each of the following samples:
(a) 2.5 moles of carbon dioxide (b) 3.4 moles of ammonia, NH_3
(c) 1.09 moles of benzene, C_6H_6 (d) 0.01 moles of acetic acid, CH_3COOH

9. Decide whether or not each of the following is an example of empirical formula:
(a) Al_2Cl_6 (b) Hg_2Cl_2 (c) NaCl (d) C_2H_6O

10. TNT or trinitrotoluene is an explosive compound used in bombs. It contains 7 C-atoms, 5 H-atoms, 3 -N atoms and 6 O-atoms. Write its empirical formula.

11. A molecule contains four phosphorus atoms and ten oxygen atoms. Write the empirical formula of this compound. Also determine the molar mass of this molecule.

12. **Indigo $(C_{16}H_{10}N_2O_2)$, the dye used to colour blue jeans is derived from a compound known as indoxyl (C_8H_7ON). Calculate the molar masses of these compounds. Also write their empirical formulas.**

13. **Identify the substance that has formula mass of 133.5amu.**

(a) $MgCl_2$ (b) S_2Cl_2 (c) BCl_3 (d) $AlCl_3$

14. **Calculate the number of atoms in each of the following samples:**

(a) 3.4 moles of nitrogen atoms (b) 23g of Na (d) 5g of H atoms

15. **Calculate the mass of the following:**

(a) 3.24×10^{18} atoms of iron (b) 2×10^{10} molecules of nitrogen gas

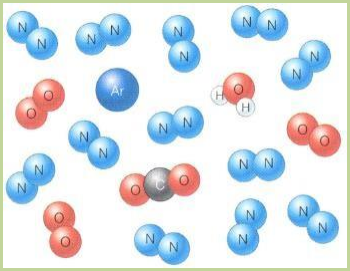
(c) 1×10^{25} molecules of water (d) 3×10^{6} atoms of Al

16. **Identify the branch of chemistry that deals with the following examples:**

1. A cornstalk grows from a seed.
2. Dynamite $(C_3H_5N_3O_9)$ explodes to form a mixture of gases.
3. Purple iodine vapour appears when solid iodine is warmed.
4. Gasoline (a mixture of hydrocarbons) fumes are ignited in an auto mobile engine.
5. A silver article tarnishes in air.
6. Ice floats on water.
7. Sulphur dioxide is the major source of acid rain.
8. Many other light chlorinated hydrocarbons in drinking water are carcinogens.
9. In Pakistan most of the factories use wet process for the production of cement.
10. Carbon-14 is continuously produced in the atmosphere when high energy neutrons from space collide with nitrogen-14.

Think-Tank

1. What mass of sodium metal contains the same number of atoms as 12.00g of carbon.
2. What mass of oxygen contains the same number of molecules as 42g of nitrogen.
3. Calculate the mass of one hydrogen atom in grams.
4. Observe the given figure. It shows particles in a sample of air.
   a) Count the substances shown in the sample
   b) Is air a mixture or pure substance? Explain?
   c) Identify the formula of each substance in air.
   d) Argue whether each substance in air is an element or a compound.
   e) What is the most common substance in air?



5. Calculate the number of H-atoms present in 18g H_2O .
6. Calculate the total number of atoms present in18g H_2O .