3 Isotopes, Isobars and Isotones

CHAPTER

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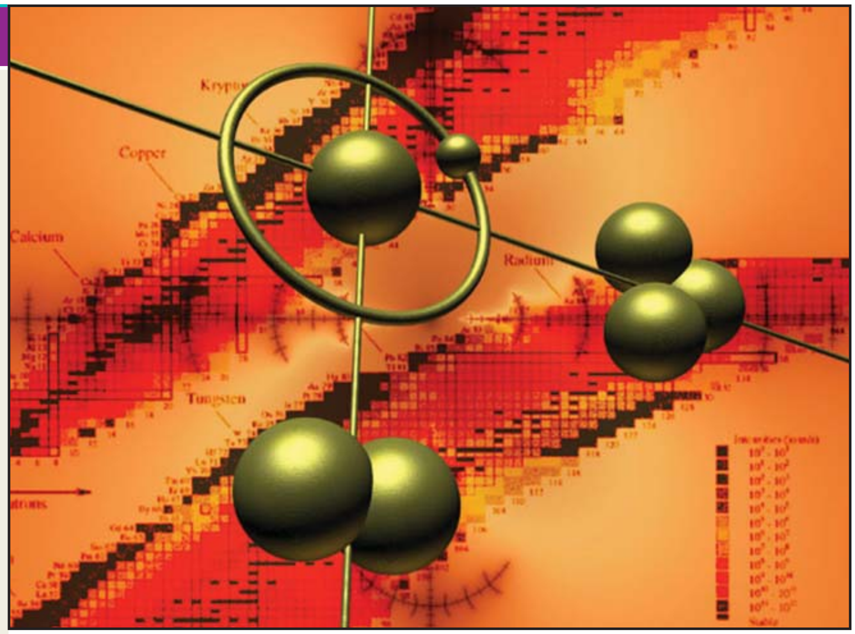


WHAT ARE ISOTOPES?

Contrary to Dalton's Atomic theory, all atoms of a given element are not necessarily identical. In fact, most elements have been shown to be composed of two or more types of atoms mixed in a fixed proportion.

(1) The different atoms of such an element contain equal number of protons and, therefore, have the same atomic number.

(2) The atoms which vary from one another have different number of neutrons in the nucleus. Thus they have different atomic masses.

The atoms of an element which have the same number of protons and different number of neutrons are called Isotopes.

Alternatively, isotopes may be defined as :

The atoms of an element which have the same atomic number but different atomic masses or mass numbers.

The name 'isotope' was assigned to them by Soddy because they have the same atomic number and hence occupied the same place in the periodic table (Greek, *isos* = same; *topos* = place). Isotopes have similar chemical properties as they have the same electronic configuration. However, they differ in respect of physical properties which depend on atomic mass.

SYMBOLIC REPRESENTATION OF ISOTOPES

In denoting particular isotopes of an element, the following notation has been internationally adopted. **The symbol of the element is written with atomic mass at the head and atomic number at the bottom.** Alternatively, the name of the element is followed by the atomic mass with a hyphen (-) in between. Thus the isotopes of carbon (atomic number 6) having atomic masses 12 and 14 may be written as

$$^{12}_{6}C \quad \text{or} \quad ^{12}C \quad \text{or} \quad \text{Carbon-12}$$

$$^{14}_{6}C \quad \text{or} \quad ^{14}C \quad \text{or} \quad \text{Carbon-14}$$

^{12}C or Carbon-12 reads 'carbon twelve', meaning isotope of carbon with a mass of approximately 12 amu.

IDENTIFICATION OF ISOTOPES

The positive rays produced in a discharge tube consist of nuclei of atoms. The deflection of positive rays in an electric and magnetic field is proportional to *e/m*, the charge on the particle divided by its mass. The nuclei obtained from an element consisting of a mixture of isotopes will have the same positive charge and, therefore, **their deflection will be inversely proportional to their masses.** Thus with a suitable application of electric and magnetic field, we can identify the isotopes present in a given element.

(1) Aston's Mass Spectrograph

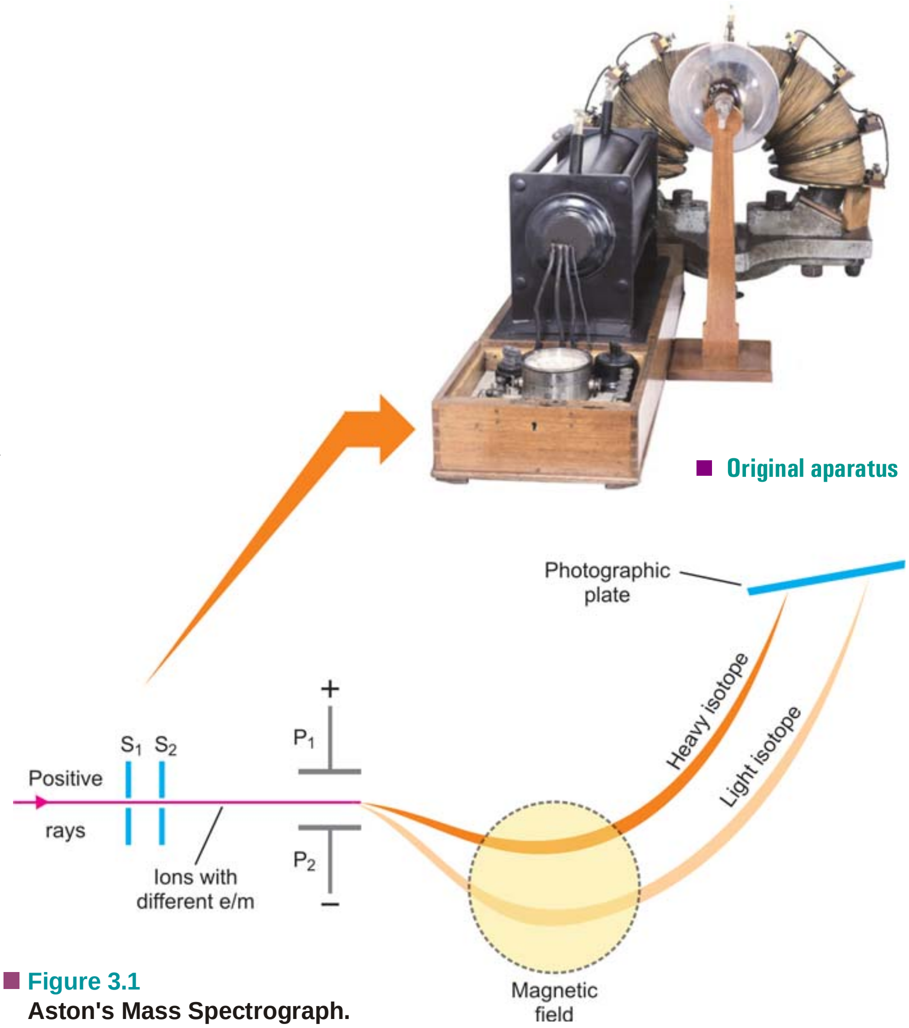
In 1919 F.W. Aston developed an instrument known as the *Mass Spectrograph* which can accurately sort out the positive ions of different isotopes of an element and determine their masses (Fig. 3.1).

In this apparatus a beam of positive rays obtained from a gaseous element in the discharge tube, is rendered into a fine ribbon by passing through slits S_1 and S_2. The fine beam consisting of positive ions of the various isotopes of the element is then sent between the electrostatically charged plates P_1 and P_2. Here the beam of positive ions is deflected down toward the negative plate. The slow moving ions of the same isotope are deflected more than the faster ones which causes a broadening of the beam. Also, the heavier particles are deflected more (being slower) than the lighter ones and this brings about a separation of the various isotopes. The broadened beam of ions is then subjected to a magnetic field (shown by dashed circle) at right angles to the plane of the charged plates and is thus sent in a direction opposite to that caused by the electrostatic field, slower particles again being deflected most. By adjustment of the two fields all ions of the same mass come to focus on the same point on the photographic plate where a sharp line is obtained. Thus each line recorded on the photographic plate shows the existence of separate isotope. Further, the intensity of the line in comparison with the lines of other isotopes, gives the relative abundance of this particular isotope.

The mass of a particle corresponding to a line produced on the photographic plate is determined by comparing with a standard line produced by a particle of known mass (say, $O^+ = 16$). For example, the examination of a sample of neon and chlorine by Aston's Mass Spectrograph showed that they were made of Ne-20, Ne-22 and Cl-35, Cl-37 respectively. The intensities of their lines showed that the relative abundance was

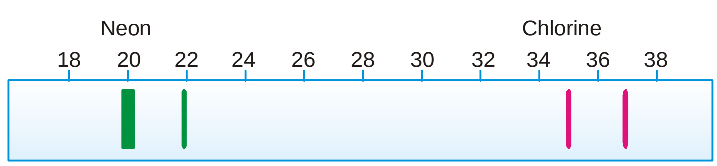
$$^{20}Ne : {}^{22}Ne \quad \text{as} \quad 9:1$$

$$^{35}Cl : {}^{37}Cl \quad \text{as} \quad 3:1$$



■ **Figure 3.1**
Aston's Mass Spectrograph.

Thus Aston's Mass spectrograph not only helped in identifying the isotopes present in an element but also helped in determining the average atomic mass of a given element.



■ **Figure 3.2**
Mass spectrographs of Neon and Chlorine.

SOLVED PROBLEM. A Sample of neon is found to consist of ^{20}Ne, ^{21}Ne and ^{22}Ne in the following percentages :

^{20}Ne	90.92
^{21}Ne	0.26
^{22}Ne	8.82

Calculate the atomic mass of neon.

SOLUTION

The atomic mass of an ordinary isotopic mixture is the average of the determined atomic masses of individual isotopes. Thus :

$$20 \times 0.9092 = 18.18$$
$$21 \times 0.0026 = 0.055$$
$$22 \times 0.0882 = 1.94$$
$$20.18$$

The atomic mass of neon is **20.18.**

(2) Dempster's Mass Spectrograph

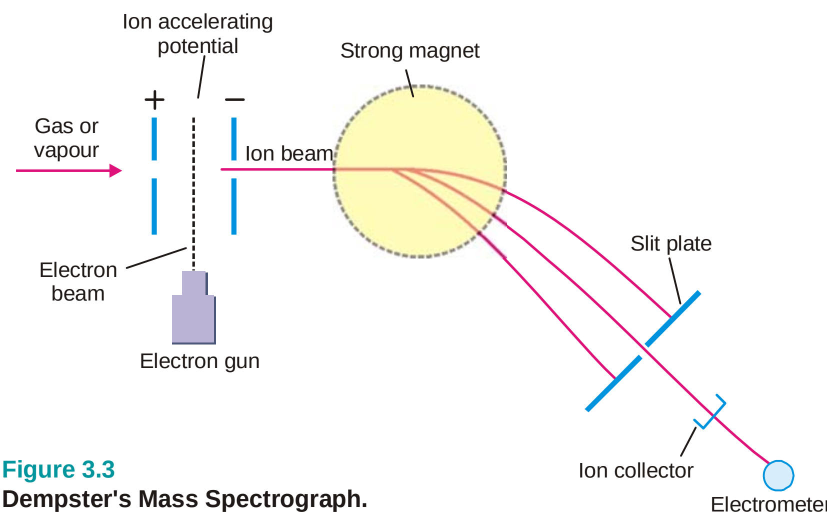


Figure 3.3
Dempster's Mass Spectrograph.

In this apparatus (Fig. 3.3) a slow stream of gas or vapour of the sample under examination is passed in between two perforated plates. Here it is bombarded by high-energy electrons shot out from an *electron gun*. The gas atoms are thus stripped of an electron and are converted to mono-positive ions (atom – e = ion $^{1+}$). When a potential of 500 to 2000 volts is applied between the perforated accelerating plates, the positive ions are strongly attracted to the negative plate. The beam of positive ions moving with accelerated speed then enters the magnetic field at right angles to its path and is thus made to move in a circular path.

If V is the potential applied across the accelerating plates and e the charge on each positive particle, the electrical energy is Ve. This is imparted to the particles as kinetic energy, $1/2\ mv^2$. Thus,

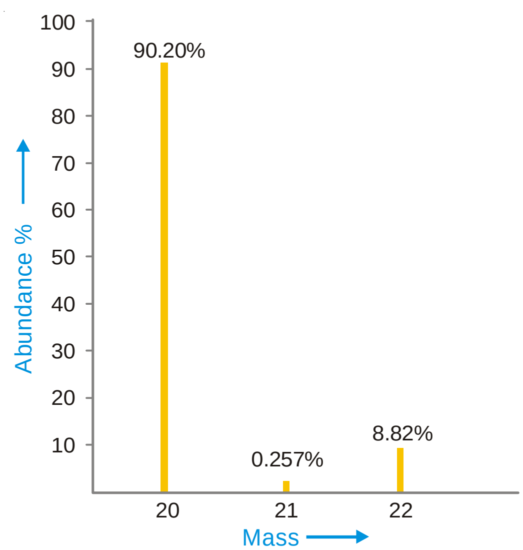


Figure 3.4
A computer-plotted graph showing relative abundances of the three isotopes of neon against mass number.

$$Ve = \frac{1}{2}mv^2 \quad ...(1)$$

In the magnetic field of strength *H*, the magnetic force on the particle *Hev*, exactly balances the centrifugal force, mv^2/r, *r* being the radius of the circular path. Thus,

$$\frac{mv^2}{r} = Hev \quad ...(2)$$

Eliminating *v* between (1) and (2), we have

$$r = \sqrt{\frac{2Vm}{H^2e}}$$

or

$$\frac{m}{e} = \frac{H^2r^2}{2V} \quad ...(3)$$

e, being the unit electrical charge, and *r* (depending on particular apparatus) are constant. If during an experiment magnetic field *H* is kept the same, from (3) it follows that

$$m \propto \frac{1}{V}$$

Thus by adjusting the accelerating potential (*V*), particles of mass *m* can be made to fall on the collector plate. Each ion sets up a minute electric current which passes to the electrometer. **The strength of the current thus measured, gives the relative abundance of the particles of mass *m*.** Similarly, the particles of the other isotopes having different masses are made to fall on the collector and current strength measured. The current strength in each case gives the relative abundance of the individual isotopes. By comparing the current strengths with an experiment performed with C-12 ion, the mass numbers of the various isotopes can be determined.

In the modern mass spectrographs, each ion strikes a detector, the ion current is amplified and fed to a recorder. The recorder makes a graph showing relative abundance plotted against mass number. A computer-plotted graph of neon isotopes is shown in Fig. 3.4.

SEPARATION OF ISOTOPES

Since isotopes have exactly similar chemical properties, their separation by chemical means is out of question. **Their difference in those physical properties which depend on the mass of the atom has been utilised to effect their separation.** The methods commonly employed for the purpose are:

(1) Gaseous Diffusion

The rate of diffusion of a gas is inversely proportional to the square root of the molecular weight (*Graham*'s *Law of Diffusion*).

$$\text{Rate of Diffusion} \propto \sqrt{\frac{1}{\text{Molecular weight}}}$$

Thus when a mixture of two gaseous isotopes is allowed to diffuse through a porous partition, **the lighter isotope passes through more rapidly than the heavier one.** The isotopes of neon (^{20}Ne, ^{22}Ne) and oxygen (^{16}O, ^{18}O) were separated by this method. The mixture of gaseous isotopes is passed through a porous tube sealed in an outer jacket (see Fig. 3.5). The lighter isotopes passes into the jacket, while the residual gas becomes richer in the heavier isotope. In actual practice a cascade of many 'Diffusion units' is used to achieve an appreciable separation. This process has been recently used for the separation of the gaseous fluorides $^{235}UF_6$ and $^{238}UF_6$. It provides a procedure for effective separation of the isotopes of uranium, namely, U-238 and U-235 (needed for atomic energy).

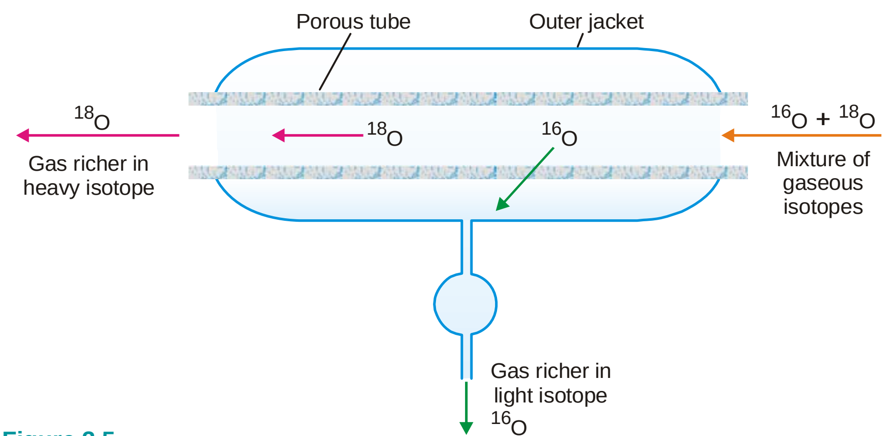


Figure 3.5
A unit of the 'diffusion cascade' for the separation of gaseous isotopes (^{16}O,^{18}O).

(2) Thermal Diffusion

A long vertical tube with an electrical heated wire running down its axis is used. When a mixture of gaseous isotopes is introduced into the tube, **the lighter particles diffuse more rapidly to the central hot region.** Here they are carried upwards by convection currents. The heavier particles, on the other hand, travel to the cooler inner surface of the tube and sink to the bottom. Thus the lighter isotope collects at the top and the heavier one at the bottom. The isotopes of chlorine Cl-35 and Cl-37, have been separated by this process. The fluorides of uranium have also been separated by thermal diffusion.

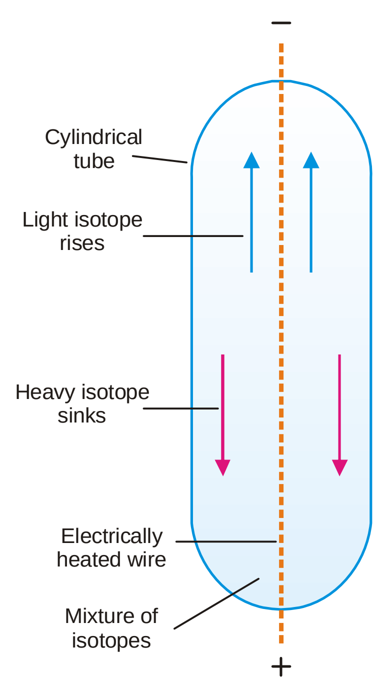


Figure 3.6
Separation of isotopes by thermal diffusion.

(3) Distillation

The lighter isotope will be distilled over first, leaving the heavier one behind. The isotopes of mercury were separated by this method. The frozen mercury from the cooled surface is removed, melted and evaporated under vacuum again. The whole process is repeated several times to separate the isotopes of mercury.

(4) Ultracentrifuge

The mixture of isotopes is rotated in a high speed centrifuge. The heavier isotope is concentrated at the periphery. The separation depends essentially on the molecular mass and not its square root, causing better separation. The gaseous fluorides of U-235 and U-238 have been separated by this method.

(5) Electromagnetic Separation

This method uses the principle of the Mass Spectrograph (Dempster). For example, the beam of ions of the isotopes of neon (Ne-20, Ne-21, Ne-22) as obtained in the mass spectrograph, is then passed between the poles of a magnet. **The different isotopes are deflected to different extents and are collected in cooled chambers placed in appropriate positions.** Although the quantities obtained by this method are very small indeed, the separation is complete.

(6) Fractional Electrolysis

Here the principle is that the rates of liberation of the isotopes of an element at an electrode during electrolysis are different. This is so because **the ions of the heavier isotope move slower, while those of the lighter isotope move faster to the opposite electrode.**

Urey (1931) separated the two isotopes of hydrogen, H-1 and H-2, by the electrolysis of acidified water. H-1 (protium) is liberated five times as rapidly as H-2 (deuterium) at the cathode. The residual water becomes richer in heavy water or deuterium oxide ^2H_2O or D_2O which upon further electrolysis yields gas richer in deuterium.

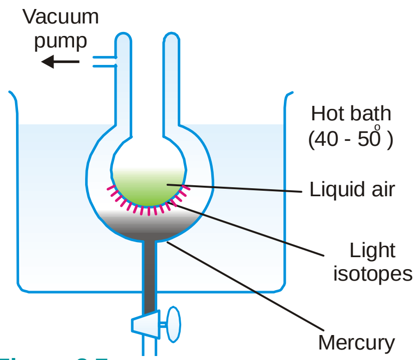


Figure 3.7
The separation of the isotopes of mercury by vacuum distillation.

(7) Laser Separation

A laser is a very fine beam of electromagnetic radiation which consists of photons corresponding to a single wavelength, frequency or energy. All the waves in the beam are in phase with all troughs and peaks moving through space together.

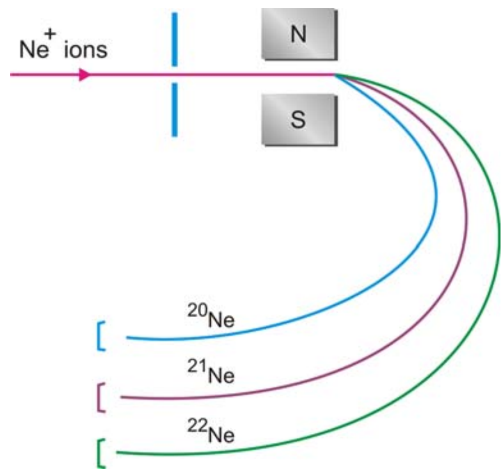


Figure 3.8
Separation of isotopes of Neon by using the principle of the Dempster's Mass Spectrograph.

In recent years, the development of lasers has been used for the separation of isotopes. If the laser light is of the appropriate wavelength, one isotope will absorb the energy, while another isotope will not. **The slight difference in absorption spectra of the two isotopes thus produced has been used to separate the more energetic isotope from the other.**

The laser method has been used successfully for the separation of isotopes of chlorine and sulphur. Potentially, laser isotope separation of uranium is 1000 times more efficient than gaseous diffusion separation.

EXAMPLES OF ISOTOPES

Since isotopes of an element have the same atomic number, each of these contains equal number of protons. They have different atomic masses which is accounted for by the different number of neutrons present in the nucleus. Thus **the isotopes of an element are characterised by different number of neutrons in the nucleus.**

The atomic structure of an isotope with atomic number Z and mass number A (atomic mass in amu) can be given as follows :

(1) The number of extranuclear electrons = Z

(2) The number of protons in the nucleus = Z

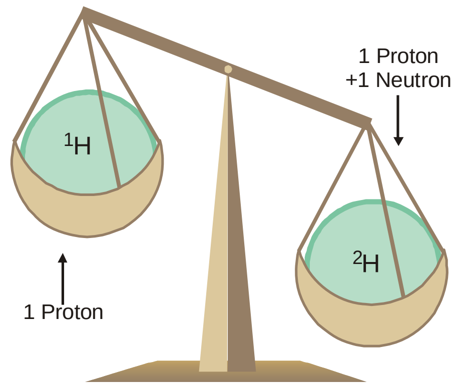
(3) The mass number A is equal to the total number of protons (Z) and neutrons (N) in the nucleus. That is,

$$A = Z + N$$

$$\therefore \quad N = A - Z$$

Isotopes of Hydrogen

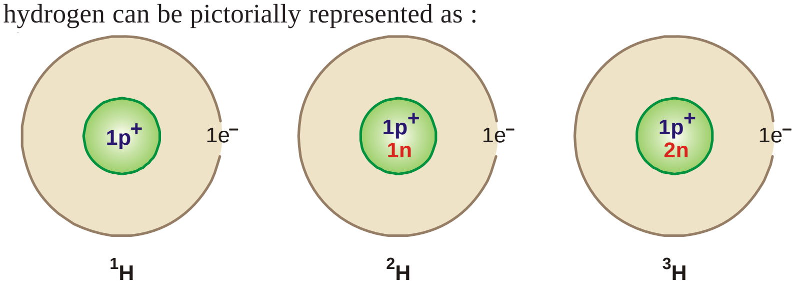
There are three isotopes of hydrogen : *protium* $\left({}^1_1\text{H}\right)$, *deuterium* $\left({}^2_1\text{H or D}\right)$, and *tritium* $\left({}^3_1\text{H or T}\right)$. Protium is by far the most abundant in natural hydrogen, deuterium about 0.015% and tritium only one out of 10,000,000 hydrogen atoms.



■ Two isotopes of hydrogen

Structure

The atomic number of the three isotopes of hydrogen is 1, while their mass numbers are : protium 1, deuterium 2, and tritium 3. Therefore each of the three isotopes has one extranuclear electron and one proton in the nucleus. The nucleus of protium is made of one proton only, while the number of neutrons ($A - Z$) present in deuterium is 2 – 1 = 1, and in tritium 3 – 1 = 2. The structure of the three isotopes of hydrogen can be pictorially represented as :



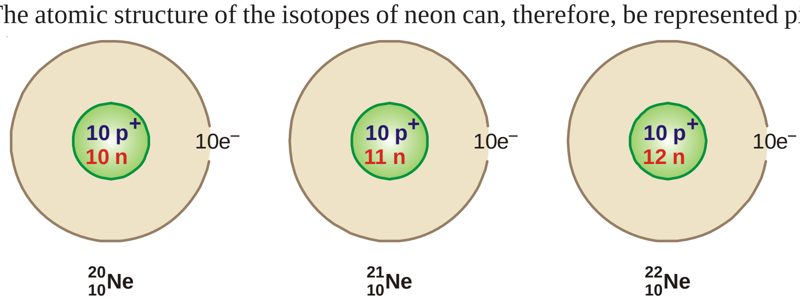
Isotopes of Neon

Neon has been found to consist of three isotopes : ${}^{20}_{10}\text{Ne}$, ${}^{21}_{10}\text{Ne}$ and ${}^{22}_{10}\text{Ne}$. Their percentage abundance is

^{20}Ne	^{21}Ne	^{22}Ne
90.92%	0.257%	8.82%

Structure

The atomic number of the three isotopes of neon is 10, while their mass numbers are 20, 21 and 22 respectively. Therefore each of these isotopes has ten extranuclear electrons and ten protons in the nucleus. The number of neutrons ($A - Z$) are : ^{20}Ne, 20 – 10 = 10 ; ^{21}Ne, 21 – 10 = 11 ; ^{22}Ne, 22 – 10 = 12. The atomic structure of the isotopes of neon can, therefore, be represented pictorially as:



Isotopes of Oxygen

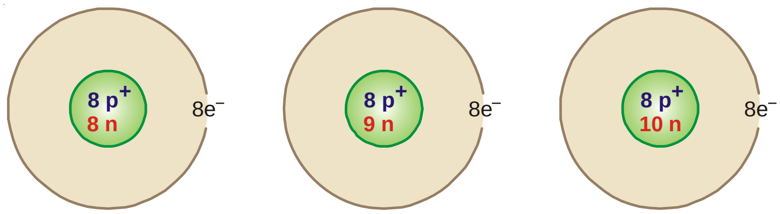
Oxygen has three isotopes : ${}^{16}_{8}O$, ${}^{17}_{8}O$ and ${}^{18}_{8}O$. These are found with the relative abundances of 99.759, 0.037 and 0.204 respectively.

Structure

The atomic number of the above three isotopes of oxygen is 8 while their mass numbers are 16, 17 and 18. Therefore each isotope has 8 extranuclear electrons and 8 protons in the nucleus. The number of neutrons ($A - Z$) in the three isotopes is :

${}^{16}O$	16 – 8 = 8 neutrons
${}^{17}O$	17 – 8 = 9 neutrons
${}^{18}O$	18 – 8 = 10 neutrons

The complete atomic structure of the isotopes of oxygen can be pictorially represented as :



${}^{16}O$ ${}^{17}O$ ${}^{18}O$

Isotopes of Chlorine

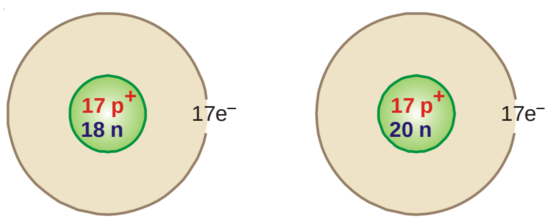
Chlorine is a mixture of two isotopes : ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$. Their percentage abundance is 75.53 and 24.47 respectively.

Structure

The atomic number of the two isotopes of chlorine is 17 while their mass numbers are 35 and 37. Therefore each isotopes has 17 extranuclear electrons and 17 protons in the nucleus. The number of neutrons ($A - Z$) in these isotopes is :

${}^{35}Cl$	35 – 17 = 18 neutrons
${}^{37}Cl$	37 – 17 = 20 neutrons

The atomic structure of the isotopes of chlorine can be pictorially represented as :



${}^{35}Cl$ ${}^{37}Cl$

Isotopes of Uranium

There are three isotopes of uranium :

$${}^{238}_{92}U, \quad {}^{235}_{92}U \quad \text{and} \quad {}^{234}_{92}U$$

Natural uranium consists almost entirely of ^{238}U, with about 0.72% of ^{235}U and 0.006% of ^{234}U. These isotopes are particularly important in atomic energy.

Structure

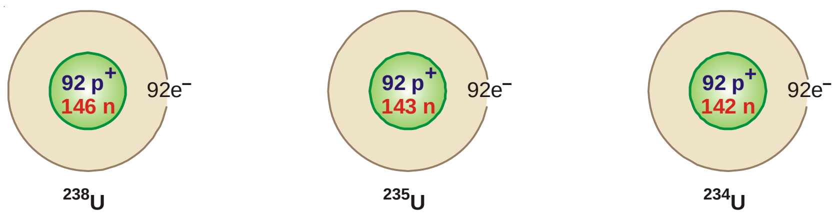
The atomic number of the three isotopes of uranium is 92 and their mass numbers are 238, 235 and 234. Thus each isotope has 92 extranuclear electrons and 92 protons. The number of neutrons ($A - Z$) in these isotopes is :

^{238}U $238 - 92 = 146$ neutrons

^{235}U $235 - 92 = 143$ neutrons

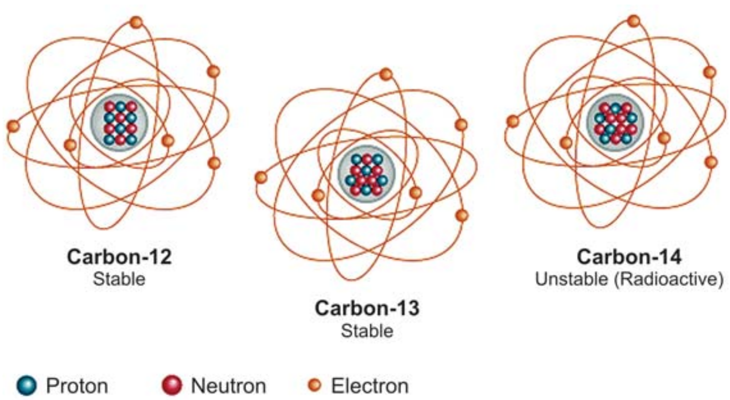
^{234}U $234 - 92 = 142$ neutrons

The atomic structure of the three isotopes of uranium may be represented as :



Almost every element in nature exists as a mixture of isotopes. The isotopes of the elements with atomic numbers 1 to 10, and their structure is listed in Table 3.1. It may be noted that some elements *e.g.*, fluorine, are **monoisotopic.** These are found in nature only as a single isotope. About 20 elements are monoisotopic.

ISOTOPES OF CARBON



Isotopes of an element are atoms of the element that have different numbers of neutrons in their nuclei. Carbon has three naturally occurring isotopes. The isotopes of carbon are carbon-12, which constitutes 98.89 of all carbon atoms and serves as the standard for the atomic mass scale; carbon-13, which is the only magnetic isotope, making it very important for structural studies of compounds containing carbon; and carbon-14, which is produced by cosmic rays bombarding the atmosphere. Carbon-14 is radioactive, with a half-life of 5760 years. The amount of carbon-14 remaining in historical artifacts can be used to estimate their age.

ISOTOPIC EFFECTS

Although in many respects the chemistry of the isotopes of an element is the same, there are significant differences between them due to difference in masses. Thus the physical properties of the compounds of each isotope of an element are distinctly different from those of others. Similarly, reaction rates of the individual isotopes are also different.

TABLE 3.1. THE NATURALLY OCCURRING ISOTOPES OF ELEMENTS WITH ATOMIC NUMBERS 1 TO 10

Isotope	Atomic No. (Z)	Mass No. (A)	Protons (= Z)	Neutrons (= A – Z)	Electronic configuration			
Hydrogen–1	1	1	1	0	1	$1s^1$		
Hydrogen–2	1	2	1	1	1	$1s^1$		
Hydrogen–3	1	3	1	2	1	$1s^1$		
Helium–3	2	3	2	1	2	$1s^2$		
Helium–4	2	4	2	2	2	$1s^2$		
Lithium–6	3	6	3	3	2, 1	$1s^2$	$2s^1$	
Lithium–7	3	7	3	4	2, 1	$1s^2$	$2s^1$	
Beryllium–9	4	9	4	5	2, 2	$1s^2$	$2s^2$	
Boron–10	5	10	5	5	2, 3	$1s^2$	$2s^2$	$2p^1$
Boron–11	5	11	5	6	2, 3	$1s^2$	$2s^2$	$2p^1$
Carbon–12	6	12	6	6	2, 4	$1s^2$	$2s^2$	$2p^2$
Carbon–13	6	13	6	7	2, 4	$1s^2$	$2s^2$	$2p^2$
Carbon–14	6	14	6	8	2, 4	$1s^2$	$2s^2$	$2p^2$
Nitrogen–13	7	13	7	6	2, 5	$1s^2$	$2s^2$	$2p^3$
Nitrogen–14	7	14	7	7	2, 5	$1s^2$	$2s^2$	$2p^3$
Nitrogen–16	7	16	7	9	2, 5	$1s^2$	$2s^2$	$2p^3$
Oxygen–16	8	16	8	8	2, 6	$1s^2$	$2s^2$	$2p^4$
Oxygen–17	8	17	8	9	2, 6	$1s^2$	$2s^2$	$2p^4$
Oxygen–18	8	18	8	10	2, 6	$1s^2$	$2s^2$	$2p^4$
Fluorine–19	9	19	9	10	2, 7	$1s^2$	$2s^2$	$2p^5$
Neon–20	10	20	10	10	2, 8	$1s^2$	$2s^2$	$2p^6$
Neon–21	10	21	10	11	2, 8	$1s^2$	$2s^2$	$2p^6$
Neon–22	10	22	10	12	2, 8	$1s^2$	$2s^2$	$2p^6$

The differences in isotopes due to mass differences are termed Isotopic Effects.

The isotopic effects show up clearly in the isotopes of hydrogen $^{1}_{1}H$ and $^{2}_{1}H(D)$. The differences in the physical properties of water from ordinary hydrogen $^{1}_{1}H$ and heavy hydrogen D are listed in Table 3.2.

TABLE 3.2. PHYSICAL PROPERTIES OF H_2O AND D_2O

	H_2O	D_2O
Molecular weight	18.02	20.03
Density at 0°C, g cm^{-3}	1.000	1.105
Melting point, 0°C	0.00	3.82
Boiling point, 0°C	100.00	101.42

The isotopic effects are also exhibited by the difference in the reaction rates of the two isotopes of hydrogen. Under similar conditions, the reaction of the heavy isotopes with chlorine is about six times slower than that of light isotope.

$$Cl\,(g) + D_2\,(g) \longrightarrow DCl\,(g) + D\,(g) \qquad \textit{SLOWER}$$
$$Cl\,(g) + H_2\,(g) \longrightarrow HCl\,(g) + H\,(g) \qquad \textit{FASTER}$$

This difference in reaction rates is explained by the fact that the covalent bond formed by deuterium is slightly stronger than the corresponding bond with ordinary hydrogen. Hence a reaction that breaks a deuterium covalent bond is slower than the same reaction involving bond to light hydrogen.

There are several useful applications of isotopic effects. One method of separation of isotopes of hydrogen depends on the fact that the electrolysis of heavy water (D_2O) is slower than the electrolysis of normal water. Pure heavy water is a valuable by-product of the electrolysis of water, since large quantities are required in nuclear reactors to moderate the rate of the uranium fission reaction.

WHAT ARE ISOBARS?

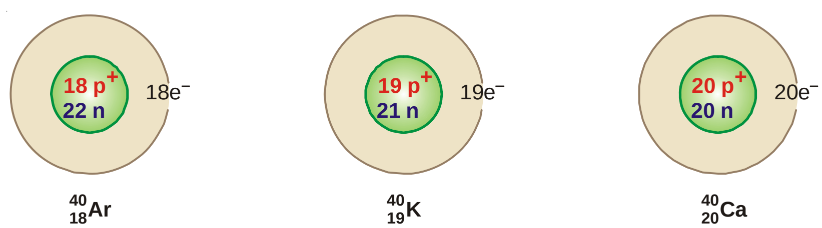
The atoms which have the same mass number but different atomic numbers are called isobars.

Isobars

The word isobar meaning 'equally heavy' is taken from the Greek *isos* = equal, and *barys* = heavy. For example, ${}^{40}_{18}Ar$, ${}^{40}_{19}K$, and ${}^{40}_{20}Ca$ are isobaric atoms. Similarly, ${}^{235}_{92}U$, ${}^{235}_{93}Np$, and ${}^{235}_{94}Pu$ are isobars.

Structure

Since isobars have the same mass number, the number of protons plus neutrons in the nucleus in each of these is equal. The number of protons being given by atomic number (Z), the number of neutrons is, therefore, ($A – Z$) where A is the mass number. The number of extranuclear electrons is equal to (Z). Thus the atomic structure of the isobars ${}^{40}_{18}Ar$, ${}^{40}_{19}K$ and ${}^{40}_{20}Ca$ is shown below :

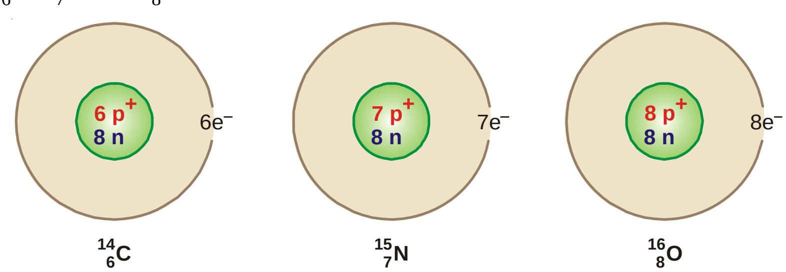


WHAT ARE ISOTONES?

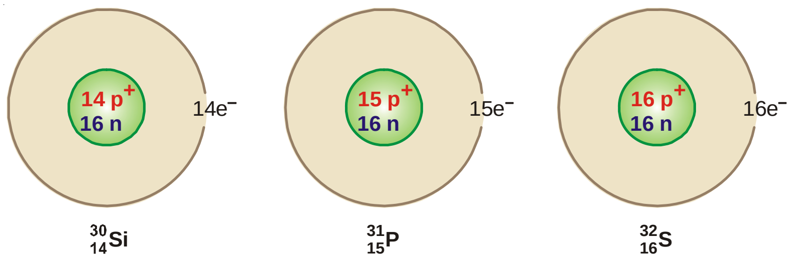
Atoms which have different atomic number and different atomic masses but the same number of neutrons are called Isotones.

Examples of isotones

(1) ${}^{14}_{6}C$, ${}^{15}_{7}N$ and ${}^{16}_{8}O$ are isotones since each contains eight neutrons.



(2) $^{30}_{14}Si$, $^{31}_{15}P$ and $^{32}_{16}S$ are isotones. Each contains sixteen neutrons.



Isotones are different elements having entirely different atomic structure. They have different physical and chemical properties.

Some other examples of isotones are :

$$^{5}_{3}Li \text{ and } ^{6}_{4}Be$$

$$^{5}_{2}He \text{ and } ^{6}_{3}Li$$

$$^{6}_{2}He,\ ^{7}_{3}Li \text{ and } ^{8}_{4}Be$$

EXAMINATION QUESTIONS

1. Define or explain the following terms :
   (*a*) Isotopes (*b*) Rate of diffusion
   (*c*) Isobars (*d*) Isotones
2. (*a*) What are isotopes and isobars? Illustrate your answer with suitable examples.
   (*b*) Discuss the construction and working of Dempster's mass spectrograph.
3. How is Aston's mass spectrograph used to detect the presence of an isotope? Describe briefly two methods of separation of isotopes.
4. What are Isotopes and Isobars? Discuss the method by which isotopes can be separated from one another.
5. (*a*) What do you understand by isotopes and isobars?
   (*b*) Describe the working of Dempster's Mass Spectrograph.
6. Write three isotopes of hydrogen and draw their structure.
7. Discuss the construction, working and advantages of Aston's Mass Spectrograph.
8. Describe the construction, working and the use of Dempster's Mass Spectrograph.
9. Give the principle of the diffusion method for the separation of isotopes.
10. Magnesium has naturally occurring isotopes with the following masses and abundances.

Isotope	*Atomic mass (amu)*	*Fractional abundance*
$_{12}Mg^{24}$	23.985	0.7870
$_{12}Mg^{25}$	24.986	0.1013
$_{12}Mg^{26}$	25.983	0.1117

Calculate the atomic mass of magnesium.

Answer. 24.31 amu

11. Calculate the fractional abundances for the two naturally occurring isotopes of copper. The masses of isotopes are 62.9298 and 64.9278 amu. The atomic mass of copper is 63.546 amu.

Answer. 0.692; 0.308 (*Delhi BSc, 2000*)

12. Calculate the atomic mass of boron, B, from the following data :

Isotope	*Atomic mass (amu)*	*Fractional abundance*
${}_5B^{10}$	10.013	0.1978
${}_5B^{11}$	11.009	0.8022

Answer. 10.8119 amu (*Bundelkhand BSc, 2001*)

13. Naturally occurring boron consists of two isotopes whose atomic masses are 10.01 and 11.01. The atomic mass of naturally occurring boron is 10.81. Calculate the percentage of each isotope in natural boron.

Answer. Percentage of isotope with atomic mass 10.01 = 20 (*Dibrugarh BSc, 2002*)

Percentage of isotope with atomic mass 11.01 = 80

14. Describe in brief any two methods of separation of isotopes. (*Arunachal BSc, 2003*)

15. Discuss the detection and separation of isotopes. (*Madras BSc, 2003*)

16. What are isotones and nuclear isomerism? Give examples. (*Kerala BSc, 2003*)

17. Define the terms : Isotope and Isobar. Give one example of each. (*Kerala BSc, 2004*)

18. (*a*) How are nuclear masses determined with a mass spectrometer? Explain.

(*b*) Calculate the relative atomic mass of an element which consists of the following isotopes with the indicated relative abundance.

Isotope	*Isotopic mass*	*Natural abundance*
1	28.0	92.0
2	29.0	5.0
3	30.0	3.0

(*Baroda BSc, 2005*)

Answer. (*b*) 28.11

19. Silver has two naturally occurring isotopes with atomic masses 106.91 and 108.90 amu. The atomic mass of silver is 107.87 amu. Calculate the fractional abundances for these two isotopes.

Answer. 0.518; 0.482 (*North Eastern Hill BSc, 2006*)

MULTIPLE CHOICE QUESTIONS

1. The atoms of an element which have the same number of protons and different number of neutrons are called

(*a*) isotopes (*b*) isobars
(*c*) isotones (*d*) isomers

Answer. (*a*)

2. Isotopes of an element have _______ atomic number but _______ mass numbers.

(*a*) same, same (*b*) different, same
(*c*) same, different (*d*) different, different

Answer. (*c*)

3. _____occupy the same place in the periodic table.

(*a*) isobars (*b*) isotopes
(*c*) isotones (*d*) none of these

Answer. (*b*)

4. Isotopes have _______ chemical properties.

(*a*) same (*b*) similar

(*c*) different (*d*) none of these

Answer. (*b*)

5. The electronic configuration of isotopes of an element is _______.

(*a*) same (*b*) similar

(*c*) different (*d*) none of these

Answer. (*a*)

6. The physical properties of the isotopes which depend on the _______ of the atoms are used to separate them.

(*a*) electronic configuration (*b*) mass

(*c*) velocity (*d*) valence electrons

Answer. (*b*)

7. The mass number *A* is given by (*Z* is atomic number and *N* is number of neutrons)

(*a*) $A = Z - N$ (*b*) $A = Z + N$

(*c*) $A = N - Z$ (*d*) $A = 2(Z + N)$

Answer. (*b*)

8. An atom of _______ contains no neutrons.

(*a*) hydrogen (*b*) deuterium

(*c*) tritium (*d*) none of these

Answer. (*a*)

9. The difference between the number of neutrons and the protons is positive for

(*a*) hydrogen atom (*b*) deuterium atom

(*c*) tritium atom (*d*) none of these

Answer. (*c*)

10. An element with atomic number equal to one, exists in three isotopes namely $_1H^1$, $_1H^2$ and $_1H^3$. Which out of these has only one electron in its outermost shell.

(*a*) $_1H^1$ (*b*) $_1H^2$

(*c*) $_1H^3$ (*d*) all the three

Answer. (*d*)

11. In which isotope of oxygen out of O^{16}, O^{17} and O^{18} there are equal number of protons, electrons and neutrons.

(*a*) O^{16} (*b*) O^{17}

(*c*) O^{18} (*d*) none of these

Answer. (*a*)

12. Which isotope of chlorine out of $_{17}Cl^{35}$ and $_{17}Cl^{37}$ has greater number of neutrons than the protons?

(*a*) $_{17}Cl^{35}$ (*b*) $_{17}Cl^{37}$

(*c*) neither of the two (*d*) both

Answer. (*d*)

13. The reaction rates of the individual isotopes are

(*a*) the same (*b*) different

(*c*) sometimes the same, sometimes different (*d*) none of these

Answer. (*b*)

14. The atoms which have the same mass number but different atomic numbers are called

(*a*) isobars (*b*) isotopes

(*c*) isotones (*d*) isomers

Answer. (*a*)

15. Which is true about the isobars?

(*a*) they have same mass number and same atomic number

(*b*) they have same mass number and different atomic number

(*c*) they have different mass number and same atomic number

(*d*) they have different mass number and different atomic number

Answer. (*b*)

16. Which of the following statements holds good for $^{40}_{18}Ar$, $^{40}_{19}K$ and $^{40}_{20}Ca$

(*a*) they have equal number of protons and electrons

(*b*) they have equal number of protons and neutrons taken together

(*c*) they have equal number of neutrons in their respective nuclei
(*d*) none of the above
Answer. (*b*)

17. Atoms which have different atomic numbers, different mass numbers but the same number of neutrons are called
(*a*) isotopes (*b*) isobars
(*c*) isotones (*d*) isomers
Answer. (*c*)

18. Which of the following statement is true for $^{14}_{6}C$, $^{15}_{7}N$ and $^{16}_{8}O$.
(*a*) they have equal number of protons (*b*) they have equal number of electrons
(*c*) they have equal number of neutrons (*d*) they have equal mass number
Answer. (*c*)

19. Which of the following pairs represents isotones?
(*a*) $_1H^1$ and $_1H^2$ (*b*) $^{40}_{18}Ar$ and $^{40}_{19}K$
(*c*) $^{14}_{6}C$ and $^{16}_{8}O$ (*d*) $^{22}_{10}Ne$ and $^{23}_{11}Na$
Answer. (*c*)

20. Which of the following pairs represents isobars?
(*a*) $^{17}_{8}O$ and $^{18}_{8}O$ (*b*) $^{40}_{19}K$ and $^{40}_{20}Ca$
(*c*) $^{15}_{7}N$ and $^{16}_{8}O$ (*d*) $^{235}_{92}U$ and $^{238}_{92}U$
Answer. (*b*)

21. An isotone of $^{14}_{6}C$ is
(*a*) $^{16}_{8}O$ (*b*) $^{13}_{6}C$
(*c*) $^{17}_{8}O$ (*d*) $^{16}_{7}N$
Answer. (*a*)

22. Which of the following is isoelectronic with Cl^{-1}?
(*a*) S^{2-} (*b*) P^{3-}
(*c*) K^{+} (*d*) All
Answer. (*d*)

23. Two nuclei A and B are isotonic with mass numbers 15 and 16 respectively. If A contains 7 protons, then the number of protons in B would be
(*a*) 7 (*b*) 8
(*c*) 9 (*d*) 10
Answer. (*b*)

24. $^{76}_{32}Ge$ is isotonic with
(*a*) $^{77}_{32}Ge$ (*b*) $^{78}_{33}As$
(*c*) $^{78}_{32}Ge$ (*d*) $^{77}_{33}As$
Answer. (*d*)

25. Which of the following atoms contains the largest number of neutrons?
(*a*) $^{210}_{83}Bi$ (*b*) $^{208}_{83}Bi$
(*c*) $^{209}_{84}Pb$ (*d*) $^{208}_{84}Pb$
Answer. (*a*)

26. The number of neutrons present in $^{239}_{93}Np$ is
(*a*) 93 (*b*) 146
(*c*) 239 (*d*) 332
Answer. (*b*)

27. Which of the following properties of the element is a whole number?
(*a*) atomic mass (*b*) atomic volume
(*c*) atomic radius (*d*) atomic number
Answer. (*d*)

28. Which of the following is false about ${}^{16}_{8}O$ and ${}^{17}_{8}O$?

(*a*) both have eight protons
(*b*) both have eight electrons
(*c*) both have eight neutrons
(*d*) they have different rates of diffusion

Answer. (*c*)

29. What is the relationship between ${}^{27}_{13}Al^{3+}$ and ${}^{23}_{11}Na^{+}$?

(*a*) they are isotopes
(*b*) they are isobars
(*c*) they are isotones
(*d*) they are isoelectronic

Answer. (*d*)

30. ${}^{24}_{11}Na$ and ${}^{24}_{12}Mg$ are related to each other as

(*a*) isotopes
(*b*) isobars
(*c*) isotones
(*d*) isoelectronic

Answer. (*b*)

31. The *n*/*p* ratio for ${}^{16}_{8}O$ is the same as for

(*a*) ${}^{12}_{6}C$
(*b*) ${}^{14}_{7}N$
(*c*) both
(*d*) none of these

Answer. (*c*)

32. In the nucleus of ${}^{40}_{18}Ar$, the difference between the number of neutrons and protons is

(*a*) 4
(*b*) 18
(*c*) 22
(*d*) 40

Answer. (*a*)

33. Amongst the three isotopes of Neon - ${}^{20}_{10}Ne$, ${}^{21}_{10}Ne$ and ${}^{22}_{10}Ne$ the nucleus with lowest *n*/*p* ratio is

(*a*) ${}^{22}_{10}Ne$
(*b*) ${}^{21}_{10}Ne$
(*c*) ${}^{20}_{10}Ne$
(*d*) all of these

Answer. (*c*)

34. The number of neutrons is greatest in

(*a*) ${}^{235}_{92}U$
(*b*) ${}^{236}_{92}U$
(*c*) ${}^{237}_{92}U$
(*d*) ${}^{238}_{92}U$

Answer. (*d*)

35. Calcium atom and Ca^{2+} ions have

(*a*) the same number of electrons
(*b*) the same number of neutrons
(*c*) different number of protons
(*d*) different number of neutrons

Answer. (*b*)

36. The set of isoelectronic species is

(*a*) Na^{+} Ne Mg^{+}
(*b*) Na^{+} Mg^{2+} Al^{3+}
(*c*) Na^{+} K^{+} Ne
(*d*) Ne Cl^{-} Na

Answer. (*b*)

37. An atom of ${}^{94}_{36}Kr$ contains

(*a*) 36 protons, 36 electrons and 36 neutrons
(*b*) 94 protons, 94 electrons and 94 neutrons
(*c*) 36 protons, 58 electrons and 36 neutrons
(*d*) 36 protons, 36 electrons and 58 neutrons

Answer. (*d*)

38. In ${}^{10}_{5}B$, the *n*/*p* ratio is

(*a*) 1.0
(*b*) 1.25
(*c*) 1.50
(*d*) 2.0

Answer. (*a*)

39. The nuclei ${}_{52}Te^{130}$, ${}_{54}Xe^{130}$ and ${}_{56}Ba^{130}$ are isobars as they have

(*a*) different number of protons
(*b*) different number of neutrons
(*c*) same mass number
(*d*) different mass number

Answer. (*c*)

40. Isotones have different physical and chemical properties as they have
(*a*) same number of neutrons
(*b*) different number of protons (or electrons)
(*c*) same mass numbers
(*d*) different mass numbers
Answer. (*b*)

41. An element M has an atomic mass 19 and atomic number 9, its ion is represented by
(*a*) M^+
(*b*) M^{2+}
(*c*) M^-
(*d*) M^{2-}
Answer. (*c*)

42. The nuclei, which are not identical but have the same number of nucleons, are called
(*a*) isotopes
(*b*) isobars
(*c*) isotones
(*d*) isoelectronic
Answer. (*b*)

43. Which of the following are isotopes?
(*a*) 17 p + 18 n and 17 p + 20 n
(*b*) 19 p + 20 n and 20 p + 21 n
(*c*) 18 p + 20 n and 19 p + 21 n
(*d*) 20 p + 20 n and 19 p + 22 n
Answer. (*a*)

44. In which of the species the number of neutrons is equal to the number of electrons?
(*a*) ${}_6C^{12}$
(*b*) ${}_7N^{15}$
(*c*) ${}_8O^{17}$
(*d*) ${}_9F^{19}$
Answer. (*a*)

45. The triad of nuclei that is isotonic is
(*a*) ${}_1H^1$ and ${}_1H^2$ and ${}_1H^3$
(*b*) ${}^{235}_{92}U$, ${}^{237}_{92}U$ and ${}^{238}_{92}U$
(*c*) ${}^{40}_{18}Ar$, ${}^{40}_{19}K$ and ${}^{40}_{20}Ca$
(*d*) ${}^{14}_{6}C$, ${}^{15}_{7}N$ and ${}^{16}_{8}O$
Answer. (*d*)

46. ${}^{24}_{12}Mg^{2+}$ is isoelectronic with
(*a*) ${}^{23}_{11}Na$
(*b*) ${}^{27}_{13}Al$
(*c*) ${}^{23}_{11}Na^+$
(*d*) ${}^{24}_{12}Mg$
Answer. (*c*)

47. In the nucleus of ${}_{42}Mo^{96}$ the number of nucleons is
(*a*) 42
(*b*) 54
(*c*) 96
(*d*) 138
Answer. (*c*)

48. The atomic mass of an element is not a whole number because
(*a*) nucleons are present in the nucleus
(*b*) the number of protons is different from the neutrons
(*c*) of the presence of isobars
(*d*) of the presence of isotopes
Answer. (*d*)

49. ${}_{88}Ra^{236}$ contains _______ neutrons in its nucleus.
(*a*) 88
(*b*) 236
(*c*) 148
(*d*) 324
Answer. (*c*)

50. An element has atomic number 20. Its cation has 2 units positive charge. The number of electrons and protons in its cation are
(*a*) 18 e and 20 p
(*b*) 20 e and 18 p
(*c*) 20 e and 20 p
(*d*) 18 e and 18 p
Answer. (*a*)