

STRUCTURE OF ATOM



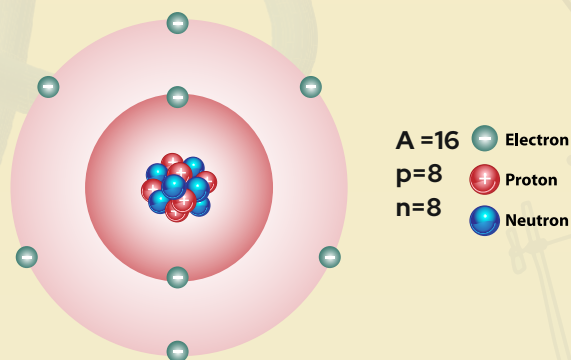
KEY POINTS

Introduction

- Indians to be proud of that in 600B.C. Kanad - Indian philosopher and saint conceived of matter as being composed of smallest individual discrete particles. He called them "parmanu".
- The concept that atoms are the fundamental building blocks of matter dates to very ancient times. However, the ideas regarding atoms of those times had no experimental evidence and remained as mere speculation.
- Therefore, these ideas had to lay dormant for a long period until John Dalton (1810) proposed his atomic theory on the basis of certain observations and experimental results.

Structure of atom

- Atom is made up of a number of particles out of which the most important are electrons, protons and neutrons.
- The electrons are negatively charged and move around very quickly in electron shells or energy levels.
- The electrons are held within the atom by an electrostatic force of attraction between themselves and the positive charge of the protons in the nucleus.
- About 1837 electrons are equal in mass to the mass of one proton. Because of their identical charges, electrons repel each other.

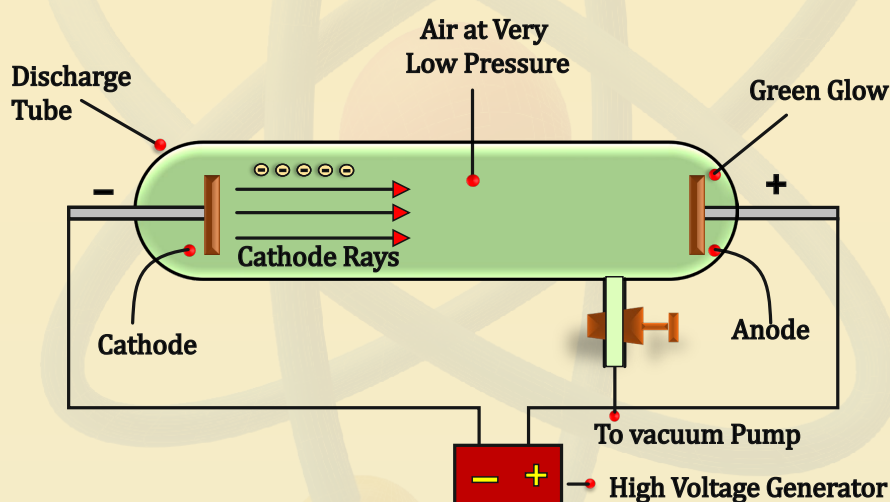


Pictorial representation of oxygen atom



Discovery of electrons (cathode or negative rays)

- In 1878, an English physicist named William Crookes showed that when a high voltage charge of 10,000 or more volts is applied from an induction coil to tubes filled with air or any other gases at very low pressure of about 0.0001 mm of Hg, the gases (which are ordinarily poor conductors of electricity) become good conductors of electricity which begin to flow in the form of rays.
- A greenish glow is observed on the walls of the discharge tube behind the anode. This is because of the electrons produced by the electrical energy after knocking off some electrons from the atoms of the gases. These rays of electrons which travel from the cathode to the anode are called cathode rays.

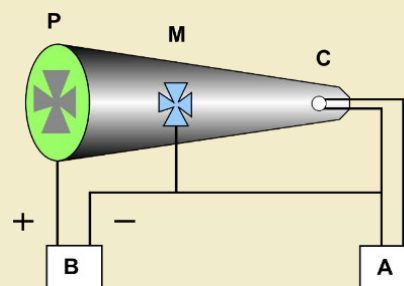


Equipment setup for cathode rays

◆ Properties of cathode rays

1 These rays travel in straight line away from cathode with very high velocity nearly equal to the speed of light.

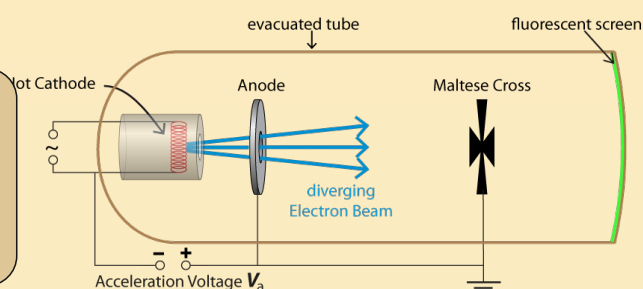
2 A shadow of metallic object placed in the path is casted on the wall opposite to cathode.



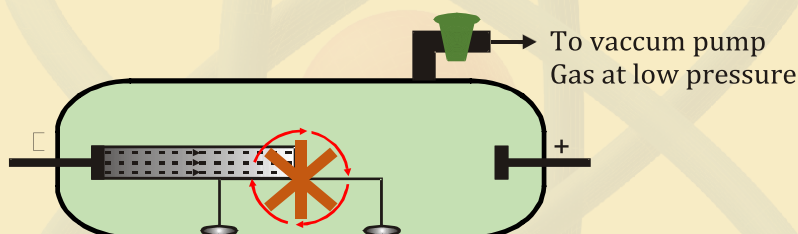
Cathode ray casted shadow of metallic object



- 3** Cathode rays cause green fluorescence on glass surface, i.e the glass surface on which the cathode rays strike show a coloured shine.

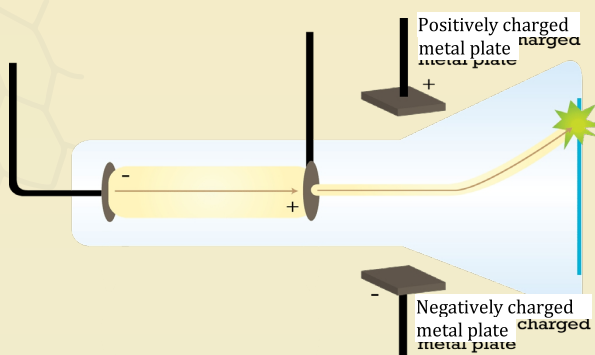


- 4** Cathode rays consist of matter particles, and possess energy by the virtue of their mass and velocity. Cathode rays set a paddle wheel into motion when it is placed in the path of these rays. This is due to the impact of the particles of the cathode rays on the blades of the paddle wheel.

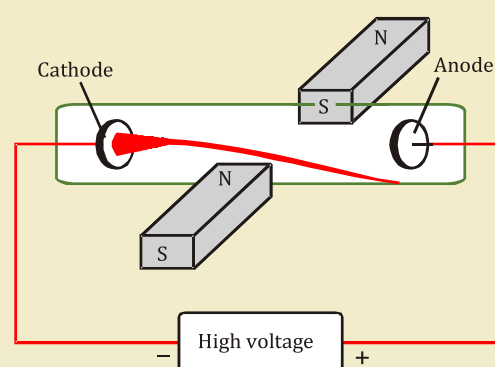


Cathode ray particles strike the blades of the paddle wheel and set it into motion.

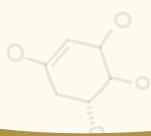
- 5** These rays are deflected by the electric or magnetic fields when the rays are passed between two electrically charged plates, these are deflected towards the positively charged plates. It shows that cathode rays carry negative charge. These particles carrying negative charge were called negatrons by Thomson. The name negatron was changed to "Electron" by Stoney.



Deflection of cathode ray towards positive plate of the electric field



Deflection of cathode ray in the magnetic field



- 6 These rays produce heat energy when they collide with the matter. It shows that cathode rays possess kinetic energy which is converted into heat energy when stopped by matter.
- 7 These rays affect the photographic plate.
- 8 Cathode rays can penetrate the thin foil of solid materials.
- 9 Cathode rays can ionize the gases through which they pass.
- 10 The nature of cathode rays is independent of
 - (a) The nature of cathode.
 - (b) The gas in discharge tube.

Mass Of Electron Relative To Hydrogen Atom

The mass of the electron (9.1×10^{-28} g) is approximately $\frac{1}{1837}$ th the mass of a hydrogen atom as shown below. However, the mass of the electron is so small that for all practical purposes, its value is considered negligible.

$$\text{Mass of an electron} = \frac{1}{1837} \times \text{Mass of one atom of hydrogen}$$

Determination Of Avogadro's Number

We know, 1 Faraday = 96500 coulombs or 9.65×10^4 coulombs.

1 Faraday is a charge carried by 1 mole of e^-

Charge on one electron = 1.60×10^{-19} coulombs

$$N_0 = \text{Avogadro's number} = \frac{9.65 \times 10^4}{1.60 \times 10^{-19}} = 6.02 \times 10^{23} \text{ electrons}$$





So, from the above discussed experiments, we conclude,

- ▶ All atoms contain electrons.
- ▶ An electron is a subatomic particle which carries a negative charge of 1.6×10^{-19} C.
- ▶ The mass of an electron is 9.1×10^{-28} g or 9.1×10^{-31} kg.
- ▶ Mass of an electron is $1/1837$ of the mass of one hydrogen atom.
- ▶ Electrons from all sources (solid, liquid or gas) are alike, having identical mass.

Discovery of protons (anode or positive rays)

- The presence of positively charged particles in an atom has been predicted by Goldstein on the electrical neutrality of an atom.
- The discovery of proton by Goldstein was done on the basis of the cathode ray experiment conducted by using a perforated cathode.
- Cathode rays are stream of electron and are created because of emission of electron from atom and thus for each element, electron charge is 1.6×10^{-19} coulomb and mass is 9.1×10^{-28} gm.
- This ratio is constant, but in case of proton rays these rays are stream of +ve ions which were produced because of knock out of electron from atom's valence shells and as mass of atom is different for different elements thus e/m is never constant for positive radiation

For example,

He^{+1} ion charge is 1 coulomb mass is 4 amu and $= \frac{e}{m} = \frac{1}{23}$

Na^{+1} ion charge is 1 coulomb mass is 23 amu $= \frac{e}{m} = \frac{1}{23}$



◆ Characteristics of anode rays

1 Anode rays travel in straight lines. These rays rotate the light paddle wheel placed in their path. Anode rays are deflected by magnetic or electric field. In electric field they deflect towards negatively charged plate. This indicates that these rays are positively charged.

2 The nature of anode rays depends upon the type of gas used. The charge (e) to mass (m) ratio (e/m) of anode rays particle is different for different gases. The value of e/m is maximum for hydrogen gas.

3 The positive rays obtained from hydrogen are made up of some type of positive particles. These particles are known as protons.

4 Mass of proton is 1.67×10^{-27} kg
Mass of 1 H atom = $1837 \times (\text{Mass of } 1e^-)$

5 The anode rays affect photographic plate.

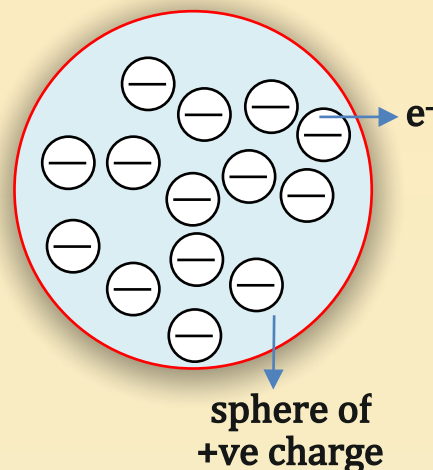
Fundamental particles

Sr. No.	Particle	Symbol	Relative charge (electronic unit)	Mass (a.m.u.)	Mass in grams
1.	Electron	e^- or ${}_1^0e$	-1	1/1837	9.1×10^{-28}
2.	Proton	${}_1^1H$ or p^+	+1	1	1.6×10^{-24}
3.	Neutron	${}_0^1n$ or n	0	1	1.6×10^{-24}



Thomson's Model of Atom [1898]

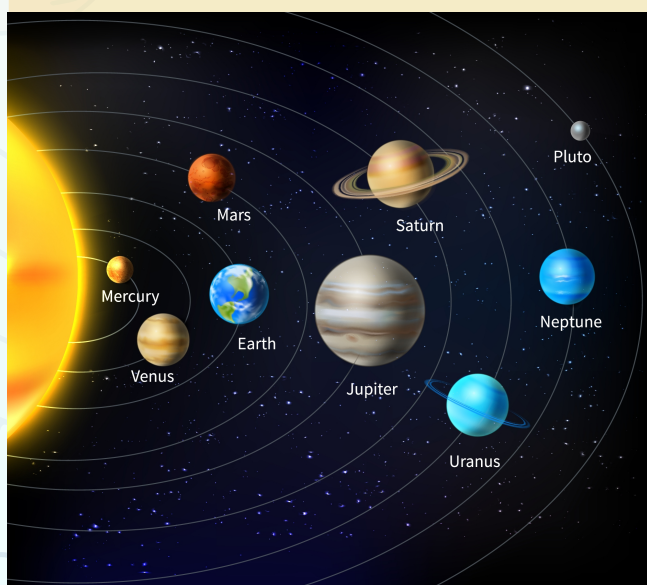
- Thomson was the first to propose a detailed model of an atom.
- Thomson proposed that an atom consists of a uniform sphere of positive charge in which the electrons are distributed more or less uniformly.
- This model of atom is known as "Plum-Pudding model" or "Raisin Pudding Model" or "Water Melon Model".



◆ Drawbacks of Thomson's Model

- An important drawback of this model is that the mass of the atoms is considered to be evenly spread over that atom.
- It is a static model. It does not reflect the movement of electron.
- It did not have any experimental support.

Rutherford's atomic model

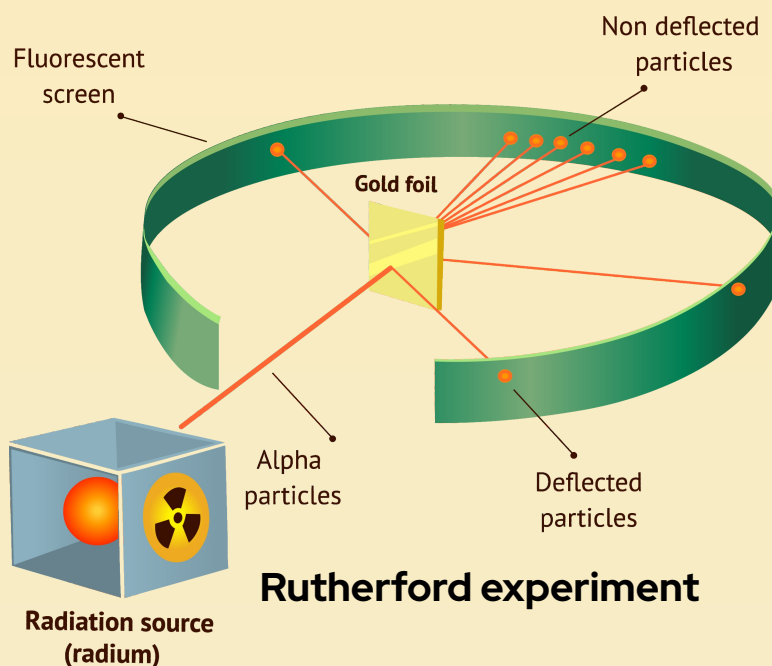


Solar system resembles with Rutherford's model

- According to Rutherford, the atom is mostly composed of empty space. The entire positive charge and mass of the atom is concentrated in small central part known as nucleus.
- The size of the nucleus is so small that its diameter is 10^{-5} times less than that of an atom. The electrons present outside the nucleus revolve around the nucleus with high velocities. Nuclear force counter balances the electrostatic forces of attraction between protons and electrons.



→ Rutherford's atomic model resembles the planetary motion in solar system. Therefore, Rutherford's model of an atom is also called planetary model.



One of the early model of the atom was the plum pudding model, in which the electrons were pictured as embedded in a positively charged spherical cloud, much as raisins are distributed in an old-fashioned plum pudding.

Particle are charged particles having 2 units of positive charge and 4 units of mass, that is particles (${}^4_2\text{He}^{+2}$) are doubly charged helium atoms (He^{+2}).

He selected a thin foil of a heavy gold metal because it was only 1000 atoms thick. He bombarded the same with high speed alpha particles.

Note: Rutherford selected a gold foil because he wanted as thin a layer as possible.

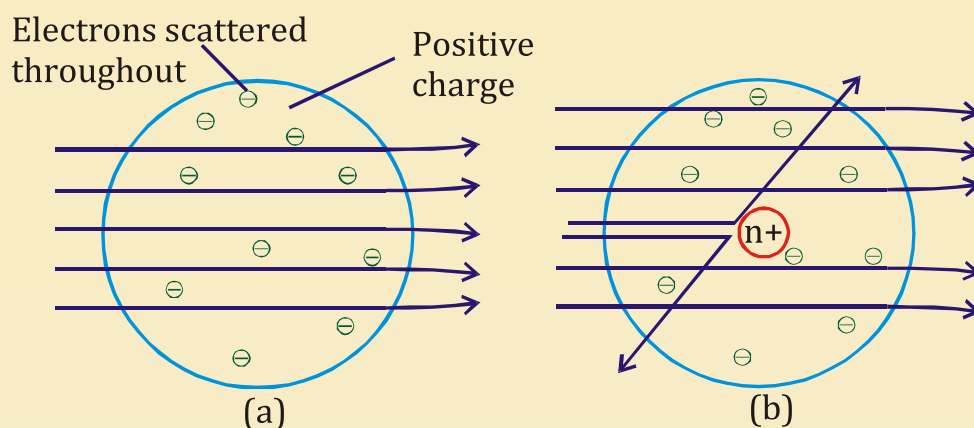
1. Most of the fast moving α -particles passed straight through the gold foil, without any deflection from their original path.
2. Some of the α -particles were deflected by the foil by small angles.
3. A very few alpha particles got completely rebound on hitting the gold foil and turned back on their path.



Conclusion of Rutherford experiment

Rutherford concluded from the α -particle scattering experiment that-

1. Most of the space inside the atom is empty because most of the particles passed through the gold foil without getting deflected.
2. As a few alpha particles suffered minor deflections and a very few major deflections, this means that these must have met with some obstruction in their path.



- (a) The results that the metal foil experiment would have yielded if the plum pudding model had been correct
 (b) Actual results.

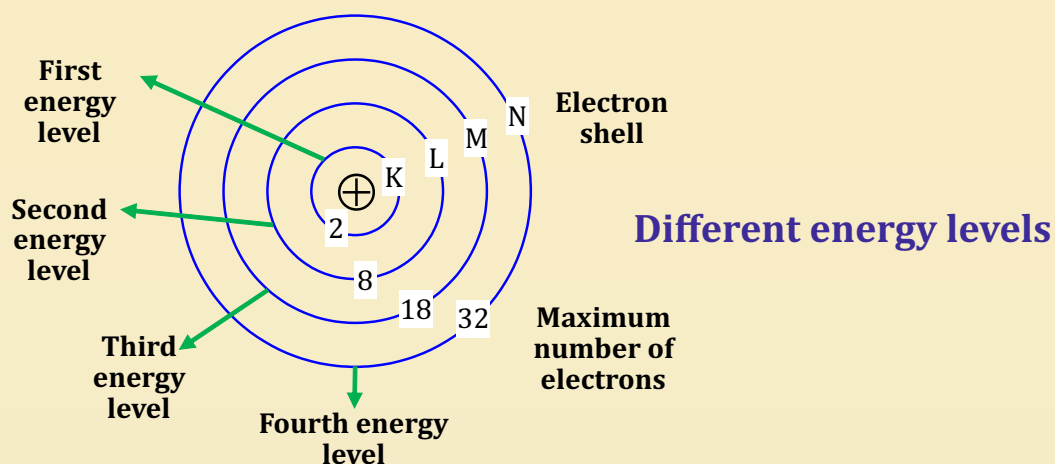
◆ Drawbacks of Rutherford model of atom

- According to Maxwell's Radiation theory, any charged particle moving in circular orbits with fast speed emit energy in the form of radiations.
- Since electrons are also fast moving charged particles, they must release energy continuously in the form of radiations. With reduced energy, they must be drawn closer to the nucleus.
- Since the loss of energy is a continuous process, the electrons must come closer and closer to the nucleus of the atom.
- Ultimately, they must fall into the nucleus or become its part. In other words, the atom should collapse. However, this actually does not happen and the atom is quite stable.



Bohr's model of an atom

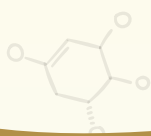
- Electrons revolve around the nucleus in specified circular paths called orbits or shells. Each orbit or shell is associated with a definite amount of energy. Hence these are also called energy levels and are designated K, L, M, N respectively.
- The energy associated with a certain energy level increases with the increase of its distance from the nucleus. Hence, if the energy associated with the K, L, M, N shells are E_1, E_2, E_3 respectively, then $E_1 < E_2 < E_3$ etc.
- As long as the electron revolves in a particular orbit, the electron does not lose its energy. Therefore, these orbits are called stationary orbits and the electrons are said to be in stationary energy states.



- The outermost shell (also called valence shell) cannot have more than 8 electrons.
- It is not necessary for a given shell to complete itself, before another shell starts forming. As a rule, a new shell is formed as soon as the shell attains 8 electrons.

Discovery of neutrons

- In 1920, Rutherford found that except for hydrogen atom, the atomic masses of no other elements could be explained by electrons and protons only.
- According to ${}_1\text{H}^1$ mass of protium will depend on protons but if we see ${}_2\text{He}^4$ the mass of He is not equal to number of P. So, definitely an another particle is present, then neutron is discovered.



Valency of element

- The valency of element is either equal to the number of valence electron in its atom or equal to number of electrons required to complete the octet in valence shell.
- The combining capacity of an element with atoms of other elements in order to acquire 8 electrons (2 in some exceptional cases) is called the valency of an element.

The valency of the element can be calculated as,

(a) The atoms having 1, 2, 3 or 4 valence electrons normally lose these to the combining atoms and they show valencies of 1, 2, 3 or 4 respectively.

(b) The atoms having 5, 6 or 7 valence electrons generally take up 3, 2 or 1 electrons respectively from the atoms of the other elements and show valencies of 3, 2 or 1 respectively.

Formation of ions

- The species carrying charge are called ions. The charge on the ions is equal to the number of electrons lost or gained by the atom and represents the valency of an element.

Positive ions or cations: A positive ion is formed in case atom of an element loses one or more electrons.

Negative ions or anions: A negative ion gets formed in case atom of an element gains one or more electrons.

Atomic number and mass number

Atomic number (Z)

Protons are present in the nucleus of an atom. It is the number of protons of an atom, which determines its atomic number.

It is denoted by 'Z'. Thus, atomic number = No. of protons = No. of electrons

Therefore, the atomic number is defined as the total number of protons present in the nucleus of an atom.



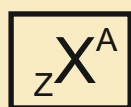


Mass number (A)

The mass number of an atom is defined as the sum of the total number of protons and neutrons present in the nucleus of an atom.

Mass number: Number of protons + number of neutrons.

The notation for an atom: The atomic number, mass number and symbol of the element are to be written as follows.



X → element, A → Mass No., Z → Atomic No.

Distribution of electrons in different orbits (shells)

- We know that atoms of different elements differ in their atomic numbers and hence have different number of electrons. These are distributed in the various energy shells which were given by Bohr i.e. K, L, M, N etc.
- The distribution or arrangement of the electrons in the different shells of the atom is called the electronic configuration of the element. It is based on certain guidelines or rules given by Bohr and Bury. This is known as Bohr-Bury Scheme. According to this scheme,

(i) The maximum number of electrons which can be present in a particular energy shell of an atom is given by $2n^2$. Here 'n' is the number of the energy shell or energy level. Hence the maximum number of electrons in different shells are as follows.

First orbit (K-shell) = $2 \times 1^2 = 2$

Second orbit (L-shell) = $2 \times 2^2 = 8$

Third orbit (M-shell) = $2 \times 3^2 = 18$

Fourth orbit (N-shell) = $2 \times 4^2 = 32$

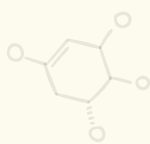
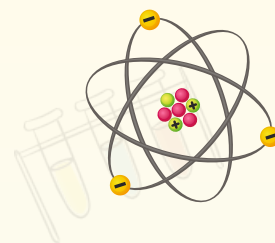
(ii) The maximum number of electrons that can be accommodated in the outermost orbit is 8. The outermost energy shell in an atom cannot have more than eight electrons even if it has a capacity to take up more electrons.

(iii) Electrons do not enter into a new shell unless the inner shells are completely filled. In other words, the shells are filled in a step-wise manner.



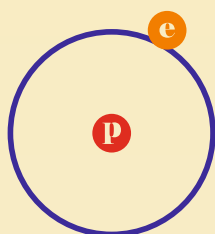
Atomic parameter of first 20 elements

Name and Symbol	Atomic no. (Z)	Mass no. (A)	Sub Atomic Particles	Electronic configuration				Valency	Metal/Non-metal or Noble gases and Nature of element
				K	L	M	N		
Hydrogen (H)	1	1	p=1, e=1, n=0	1				±1	Metal as well as Non-Metal (Gas)
Helium (He)	2	4	p=2, e=2, n=2	2				0	Noble gas (Gas)
Lithium (Li)	3	7	p=3, e=3, n=4	2	1			1	Metal (Solid)
Beryllium (Be)	4	9	p=4, e=4, n=5	2	2			2	Metal (Solid)
Boron (B)	5	11	p=5, e=5, n=6	2	3			3	Metalloid (Solid)
Carbon (C)	6	12	p=6, e=6, n=6	2	4			4	Non-metal (Solid)
Nitrogen (N)	7	14	p=7, e=7, n=7	2	5			-3	Non-metal (Gas)
Oxygen (O)	8	16	p=8, e=8, n=8	2	6			-2	Non-metal (Gas)
Fluorine (F)	9	19	p=9, e=9, n=10	2	7			-1	Non-Metal (Gas)
Neon (Ne)	10	20	p=10, e=10, n=10	2	8			0	Noble Gas (Gas)
Sodium (Na)	11	23	p=11, e=11, n=12	2	8	1		1	Metal (Solid)
Magnesium (Mg)	12	24	p=12, e=12, n=12	2	8	2		2	Metal (Solid)
Aluminium (Al)	13	27	p=13, e=13, n=14	2	8	3		3	Metal (Solid)
Silicon (Si)	14	28	p=14, e=14, n=14	2	8	4		4	Non-Metal (Solid)
Phosphorus (P)	15	31	p=15, e=15, n=16	2	8	5		-3	Non-Metal (Solid)
Sulphur (S)	16	32	p=16, e=16, n=16	2	8	6		-2	Non-Metal (Solid)
Chlorine (Cl)	17	35	p=17, e=17, n=18	2	8	7		-1	Non-Metal (Gas)
Argon (Ar)	18	40	p=18, e=18, n=22	2	8	8		0	Noble gas (Gas)
Potassium (K)	19	39	p=19, e=19, n=20	2	8	8	1	1	Metal (Solid)
Calcium (Ca)	20	40	p=20, e=20, n=20	2	8	8	2	2	Metal (Solid)

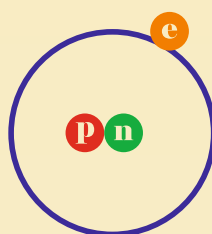


Isotopes

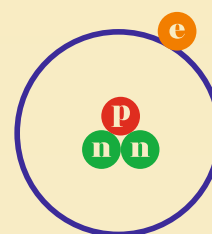
- Isotopes are atoms of the same element, having the same atomic number but different mass number.
- For example, isotopes of hydrogen atom, namely protium (${}_1\text{H}^1$), deuterium (${}_1\text{H}^2$), tritium (${}_1\text{H}^3$). The atomic number of each one is 1, but the mass number is 1, 2, and 3 respectively.



Protium



Deuterium



Tritium

Isotopes of hydrogen.

Applications of Isotopes

- Since the chemical properties of all isotopes of an element are the same but some isotopes have special properties which find them useful in various fields. Some of them are.

${}_{27}^{60}\text{Co}$ for treatment of cancer.

${}_{11}^{24}\text{Na}$ for circulation of blood.

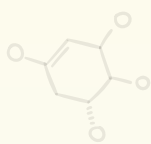
${}_{53}^{131}\text{I}$ for thyroid.

${}_{92}^{235}\text{U}$ is used as a fuel in nuclear reactors.

${}_6^{14}\text{C}$ is used in dating of fossil samples known as carbon dating.

${}_{15}^{32}\text{P}$ is used in the treatment of blood cancer.





Isobars

Atoms of different elements with different atomic number which have the same mass number, are known as isobars. Chemical properties of isobars are different.

For example,

Calcium and argon ${}_{20}^{40}\text{Ca}$ ${}_{18}^{40}\text{Ar}$ The atomic number of argon is 18, calcium is 20 but the mass number of these elements is same.

Carbon Isotopes	${}_{6}^{12}\text{C}$	${}_{6}^{14}\text{C}$
Atomic number	6	6
No. of protons	6	6
No. of electrons	6	6
No. of neutrons	6	8
Mass number	12	14

Average atomic mass

The atomic mass of an element is the weighted arithmetic mean of the atomic masses of its isotopes present in the sample of the element.

Fractional atomic masses indicate average mass of all the isotopes taken together with respect to their relative abundance in environment.

Let us consider a sample of an element X containing its two isotopes X_1 and X_2 .

Average atomic mass of the element

$$X = \frac{\% \text{ of } X_1 \times \text{Atomic mass of } X_1 + \% \text{ of } X_2 \times \text{Atomic mass of } X_2}{100}$$

