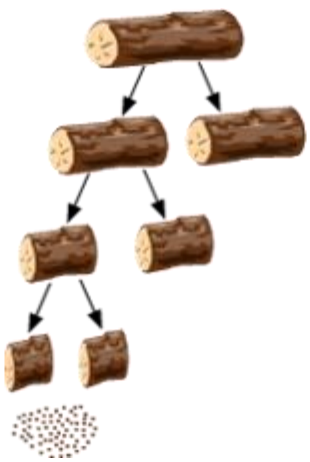
Structure of Atom

Dividing Matter



Matter cannot be divided infinite number of times.

For example, if we keep chopping a log of wood into smaller and smaller pieces, then we will reach a point when the wood will not be divisible any further. Minute particles of wood will remain and these will not be visible to the naked eye. This is true for all forms of matter. The same was believed by the early Indian and Greek philosophers.

In India, around 500 BC, an Indian philosopher named Maharishi Kanad called matter as padarth and these smallest particles (atoms) as ‘parmanu’. The word ‘atom’ is derived from the Greek word ‘atomos’ which means ‘indivisible’. It was the Greek philosopher Democritus who coined the term. However, for these ancient thinkers, the idea of the minute indivisible particle was a purely philosophical consideration.

By the end of the eighteenth century, scientists had begun to distinguish between elements and compounds. Two French chemists named Antoine Lavoisier and Joseph Proust observed that elements combine in definite proportions to form compounds. On the basis of this observation, each of them proposed an important law of chemical combination. The laws proposed by them helped Dalton formulate his atomic theory.

Dalton’s Atomic Theory

In the early nineteenth century, an English chemist named John Dalton proposed a theory about **atoms**. Known as ‘Dalton’s atomic theory’, it proved to be one of the most important theories of science. The various laws of chemical combination also supported Dalton’s theory. Dalton asserted that ‘atoms are the smallest particles of matter, which cannot be divided further’. He published his atomic theory in 1808 in his book *A New*

System of Chemical Philosophy. The postulates of Dalton's atomic theory are as follows:

- All matter is made up of very tiny particles. These particles are called atoms.
- An atom cannot be divided further, i.e., atoms are indivisible.
- Atoms can be neither created nor destroyed in a chemical reaction.
- All atoms of an **element** are identical in all respects, e.g. in terms of mass, chemical properties, etc.
- Atoms of different elements have different masses and chemical properties.
- Atoms of different elements combine in small whole-number ratios to form **compounds**.
- In a given compound, the relative numbers and types of atoms are constant.

Know Your Scientist

John Dalton (1766−1844) was born into the poor family of a weaver in Eaglesfield, England. He was colour-blind from childhood. He became a teacher when he was barely twelve years old. By the time he was nineteen, he had become the principal of a school. In 1793, Dalton left for Manchester to teach physics, chemistry and mathematics at a college.

Elected a member of the Manchester Literary and Philosophy Society in 1794, he became its president in 1817 and remained in that position until his death. During his early career, he identified the hereditary nature of red−green colour blindness.

In 1803, he postulated the law of partial pressures (known as Dalton's law of partial pressures). He was the first scientist to explain the behaviour of atoms in terms of relative atomic weight. He also proposed symbolic notations for various elements.

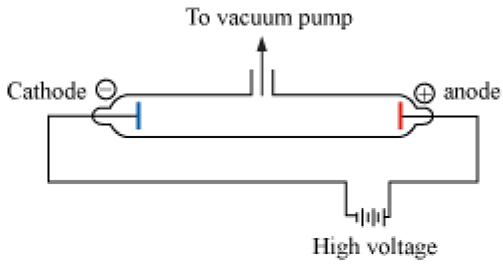
Subatomic Particles: Discovery and Characteristics

Subatomic Particles

Electrons, protons and neutrons are the three main subatomic particles that form an atom.

Discovery of Electron (Michael Faraday's Cathode Ray Discharge Tube Experiment)

Experimental Setup:



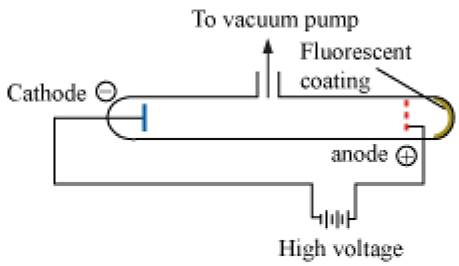
- Glass tube is partially evacuated (low pressure inside the tube).
- Very high voltage is applied across the electrodes.

Observation:

Stream of particles move from the cathode (−ve) to the anode (+ ve). These particles are known as cathode ray particles.

Results:

- Cathode rays move from the cathode to the anode.
- Cathode rays are not visible; they can be observed with the help of phosphorescent or fluorescent materials (such as zinc sulphide).



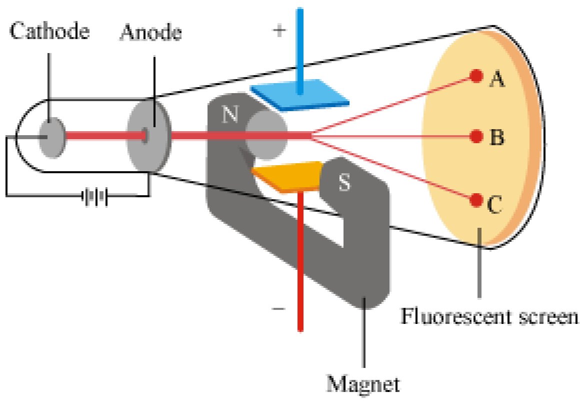
- These rays travel in a straight line in the absence of an electric or magnetic field.
- The behaviour of cathode rays is similar to that of the negatively charged particles (electrons) in the presence of an electrical or magnetic field.
- Characteristics of cathode rays do not depend upon the material of the electrodes and the nature of the gas present in the tube.

Conclusions:

- Cathode rays consist of electrons.
- Electrons are the basic units of all atoms.

Charge to Mass Ratio of Electrons (J. J. Thomson's Experiment)

- J. J. Thomson measured the ratio of charge (e) to the mass of an electron (m_e) by using the following apparatus.



- He determined $\frac{e}{m_e}$ by applying electric and magnetic fields perpendicular to each other as well as to the path of the electrons.
- The amount of deviation of the particles from their path in the presence of an electric or magnetic field depends upon:

1. the magnitude of the negative charge on the particle (greater the magnitude on the particle, greater the deflection)

2. the mass of the particle (lighter the particle, greater the deflection)

3. the strength of the electric or magnetic field (stronger the electric or magnetic field, greater the deflection)

Observations:

- When only electric field is applied, the electrons deviate to point A (as shown in the figure).
- When only magnetic field is applied, the electrons strike point C (as shown in the figure).

- On balancing the strength of electric and magnetic fields, the electrons hit the screen at point B (as shown in the figure) as in the absence of an electric or magnetic field.

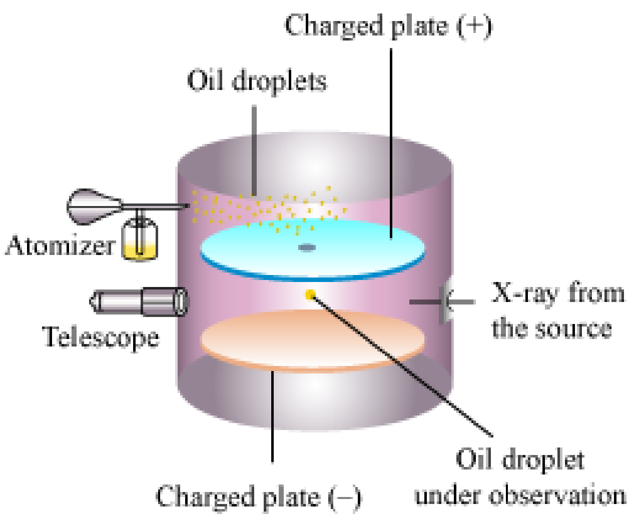
  Result:

  $$\frac{e}{m_e} = 1.758820 \times 10^{11}\,\mathrm{C\,kg^{-1}}$$

  To test your knowledge of **<u>this concept</u>**, solve the following puzzle.

  Charge on Electron (Millikan's Oil-Drop Experiment)

- **Millikan's Oil-Drop Apparatus**



- Atomiser forms oil droplets.
- The mass of the droplets is ascertained by calculating their falling rate.
- X-ray beam ionises the air.
- Oil droplets acquire charge by colliding with gaseous ions on passing through the ionised air.
- The falling rate of droplets can be controlled by controlling the voltage across the plate.
- Careful observation of the effects of electric field strength on the motion of droplets leads to the conclusion that $q = ne$. Here, q is the magnitude of electrical charge on the droplets, e is the electrical charge and n is 1, 2, 3,…

  Results:

Charge on an electron = -1.6022×10^{-19} C

Mass of an electron

$$(m_e) = \frac{e}{\frac{e}{m_e}}$$
$$= \frac{1.6022 \times 10^{-19}\ \text{C}}{1.758820 \times 10^{11}\ \text{C kg}^{-1}}$$
$$= 9.1094 \times 10^{-31}\ \text{kg}$$

Discovery of Proton

- Electric discharge carried out in a modified cathode ray tube led to the discovery of particles carrying positive charge; these are known as canal rays.
- These positively charged particles depend upon the nature of gas present in them.
- The behaviour of these positively charged particles is opposite to that of the electrons or cathode rays in the presence of an electric or magnetic field.
- The smallest and lightest positive ion is called a **proton** (obtained from hydrogen).

Discovery of Neutron

- Neutrons are electrically neutral.
- They were discovered by Chadwick, by bombarding a thin sheet of beryllium with alpha particles.

The given table lists the properties of these fundamental particles.

Name	Symbol	Absolute Charge/C	Relative Charge	Mass/kg	Mass/*u*	Approx. Mass/u
Electron	e	-1.6022×10^{-19}	−1	9.10939×10^{-31}	0.00054	0

Proton	p	$+1.6022 \times 10^{-19}$	+1	1.67262×10^{-27}	1.00727	1
Neutron	n	0	0	1.67493×10^{-27}	1.00867	1

Thomson's Atomic Model

Atom Is Divisible

Do you recall **Dalton's atomic theory**? Dalton postulated in his theory that an **atom is indivisible**. However, the later discoveries of **protons** and **electrons** proved this to be erroneous.

In 1886, while carrying out an experiment in a gas discharge tube, E. Goldstein discovered positively charged radiations which led to the discovery of the subatomic particles called protons. Later, in 1897, J. J.

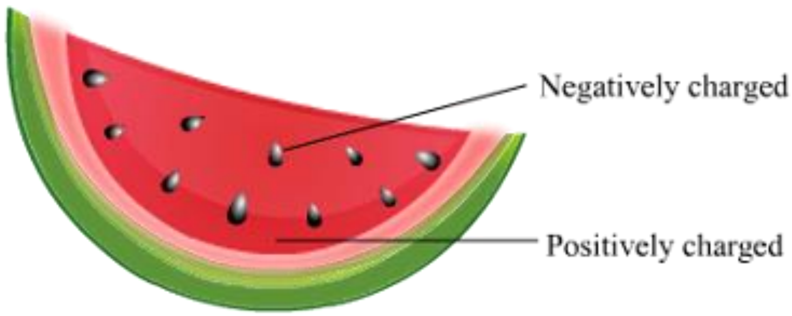
Thomson discovered another type of subatomic particle—the negatively charged electron. Consequent to these discoveries, an atom was no longer indivisible; rather, it became a sum total of differently charged subatomic particles.

We know that an atom is neutral. It is made up of an equal number of oppositely charged particles—protons and electrons. Now, the question that arises is this:

How are the subatomic particles arranged inside an atom?

Many scientists performed varied experiments to develop different models for the structure of an atom. The first such model was proposed by J. J. Thomson. His atomic model is compared to a plum pudding and a watermelon; hence, it is known by the names 'the plum-pudding model'.

The Plum-Pudding Model of an Atom

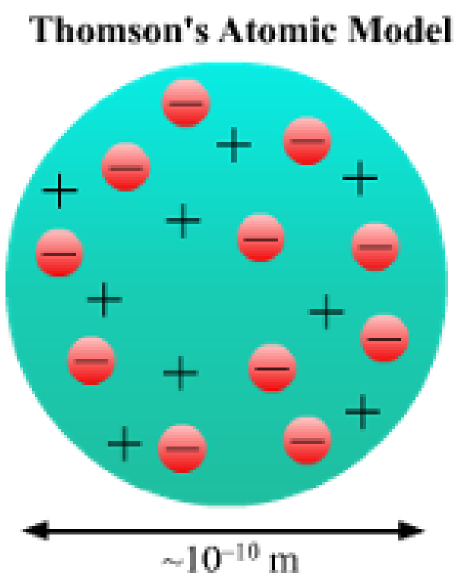


Let us understand Thomson's atomic model with the help of a slice of a watermelon. The slice consists of a red edible portion with embedded black seeds.

Now, if we liken this watermelon to an atom, then (as per Thomson's model) the positive charge in the atom is spread all over the red edible part; and the negatively charged particles, like the seeds, are embedded in this positively charged space.

In the same way, we can liken an atom to a plum pudding. In this case, the positive charge is spread all over the pudding, while the negatively charged particles are embedded like plums in this positively charged space.

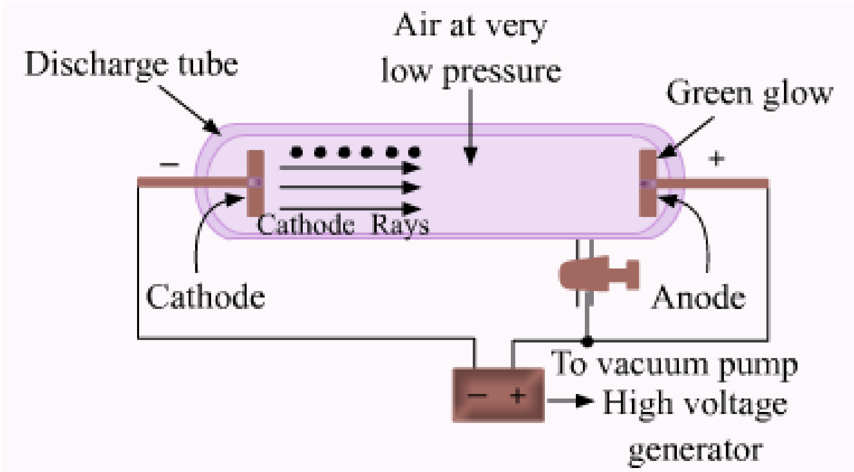
According to Thomson's atomic model:



1. An atom consists of a positively charged sphere with electrons embedded in it.

2. The negative and positive charges present inside an atom are equal in magnitude. Therefore, an atom as a whole is electrically neutral.

Cathode Rays



Production of Cathode Rays

J.J Thomson discovered that there are small particle present in the atom and that atom is divisible. J.J Thomson and his colleagues conducted experiments using discharge tube apparatus.

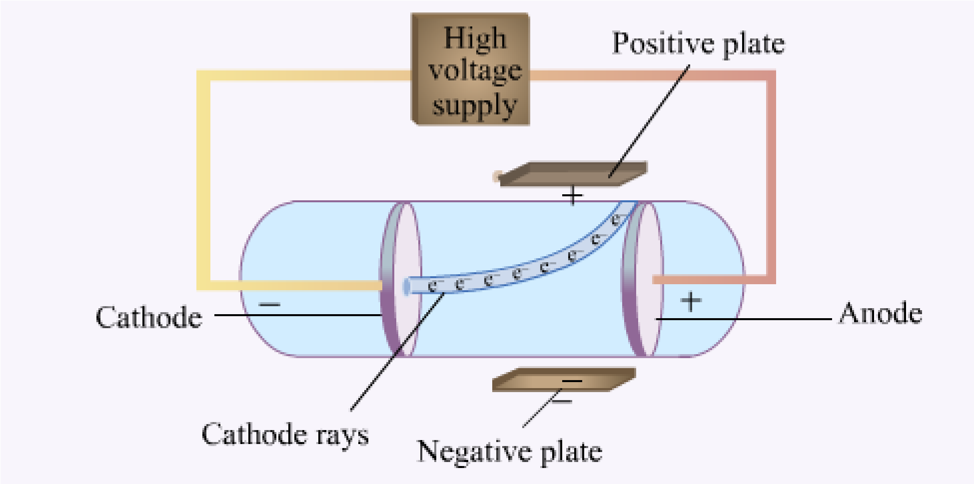
A discharge tube apparatus consists of a glass tube of about 15 cm length and 3 cm in diameter, filled with gas at low pressure. The tube is connected with the vacuum pump and two metal electrodes are fitted to the ends of the tube.

Low pressure was created inside the tube and high voltage was applied to the electrodes of the tube. This produced greenish glow at the anode end of the tube.

The greenish glow at anode was produced due to the emission of the streams of rays from the cathode. These rays are known as cathode rays. Cathode rays will emit with blue glow.

When J.J Thomson placed a light paddle wheel inside the tube in the path of the cathode rays, the wheel started rotating. This led him to conclude that cathode rays are particulate in nature.

Properties of Cathode Rays



Experiment to demonstrate properties of cathode rays

When J.J Thomson applied an electric field in the direction parallel to the path of cathode rays, he observed that the rays were deflected towards the anode.

This observation led to the conclusion that cathode rays are negatively charged.

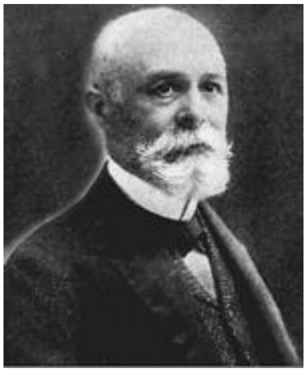
When the above experiment was conducted with different gases, same observation were made and he named these negatively charged particles as electrons.

An electron is lighter than hydrogen atom and has very small mass in comparison to the mass of an atom.

Thus, J.J Thomson's experiment and discovery of electron proved that atom is divisible and is made up of sub – atomic particles.

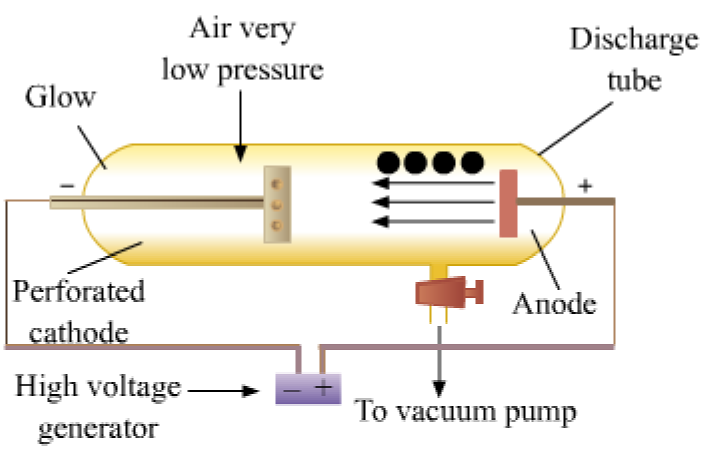
Know Your Scientist

Sir Joseph John Thomson (1856−1940) was a British physicist. He is known for the discovery of electrons and for his model of an atom, popularly known as 'the plum-pudding model'. He received the Nobel Prize in Physics in 1906 for discovering electrons and for his research on conduction in gases. In 1912, while working on the composition of canal rays, he and his colleague (F. W. Aston) found the first evidence for isotopes of neon.



Eugen Goldstein (1850−1930) was a German physicist. He is known for the discovery of canal rays which led to the discovery of protons. He also investigated comets using gas discharge tubes. His experiments established that a small object (like a ball) placed in the path of cathode rays produces emissions, flaring outward just like in case of a comet's tail.

Canal Rays



Production of anode rays

After J.J Thomson's discovery of atom another question arose that: if electrons are present inside the atom, then how is atom electrically neutral? Does this mean that there are positively charged particle also present inside the atom?

To find out the answers to such questions, Goldstein conducted an experiment similar to that of J.J Thomson's but with some modifications, for example he used perforated cathode in the discharge tube.

It was observed during the experiment that some rays were travelling in the direction opposite to that of cathode rays. Goldstein named these rays as anode rays.

When he applied an electric field in the direction parallel to that of the rays he observed that rays deflected towards cathode, thereby he concluded that anode rays are positively charged.

However, the deflection of anode rays in the discharge tube was found to be very less than that of cathode rays, because the emission of cathode rays was not dependent on the nature of the gas taken in the discharge tube. The deflection was seen highest for the hydrogen gas, when taken in the discharge tube.

The positive particles of hydrogen were found to be lightest and were named protons. Their mass is approximately equal to 1840 times that of electron. This mass is assumed as **1 atomic mass unit**. The charge on a proton (+1) is equal to charge on an electron in magnitude (-1).

Rutherford's Atomic Model

Why the Plum-Pudding Model Failed

The plum-pudding model of an atom was unable to explain the findings of Rutherford's experiment while studying radioactivity.

In an experiment with gold foil, Rutherford bombarded the gold foil with **alpha particles**. With Thomson's model as the basis, Rutherford expected small deviations; however, his findings were different from what was expected.

As we go further into this lesson, we will learn more about Rutherford's gold-foil experiment, his observations and his conclusions. We will also learn about the atomic model that he came up with on the basis of his conclusions.

Set up for Rutherford's experiment:

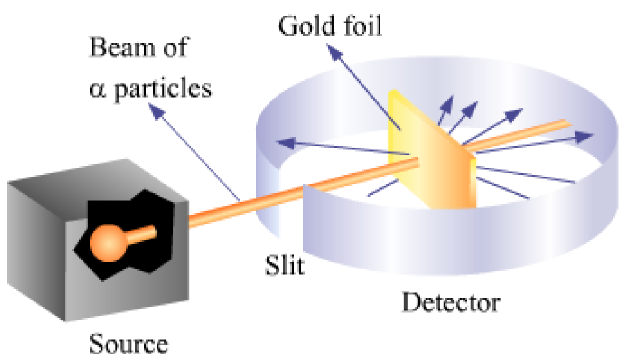
1. A thin gold foil, approximately 1000 atoms thick, was taken. Gold was chosen for its high malleability.

2. A detector screen with a small slit (for emission of radiation from the atom) was placed around the foil.

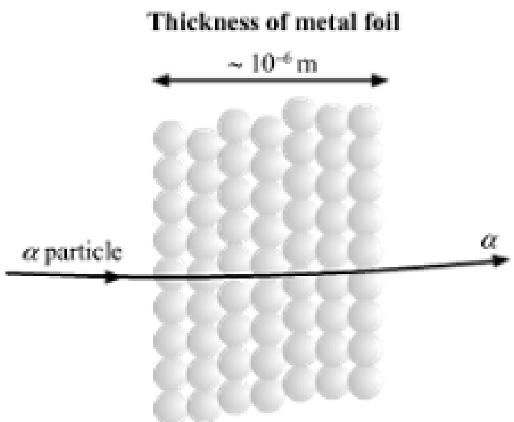
3. A source of alpha particles was kept in front of the foil.

4. The foil was bombarded with fast-moving alpha particles.

The set-up for Rutherford's gold-foil experiment is shown in the figure.



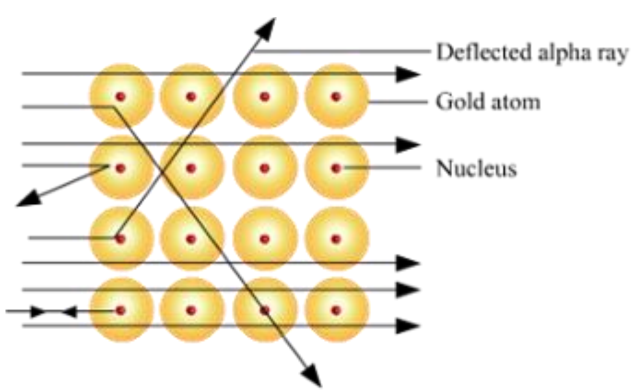
Rutherford's Expectations and Observations



What Rutherford expected?

Rutherford expected that the alpha particles would pass straight through the foil and only a small fraction of alpha particles would be deflected. This expectation was in compliance with Thomson's atomic model.

What Rutherford observed?



Rutherford's findings were contrary to his expectation. He observed that:

1. Most of the fast-moving alpha particles passed straight through the gold foil.

2. Some particles were deflected through the foil by small angles.

3. One out of every 12000 particles rebounded, i.e., they got deflected by an angle of 180°.

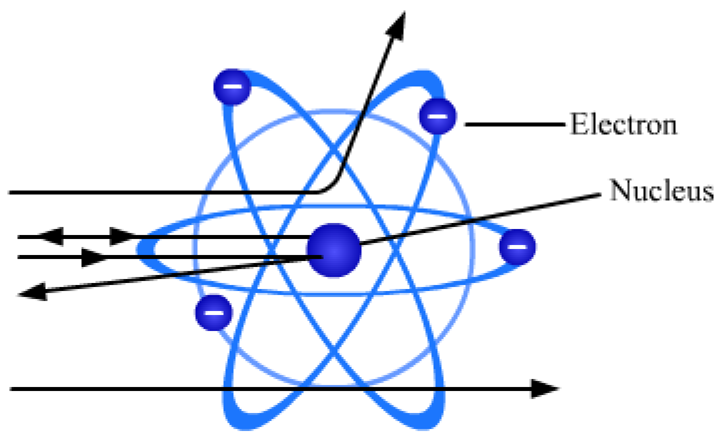
What Rutherford Concluded from His Observations

Rutherford then carefully studied his observations and made the following conclusions.

1. Most alpha particles passed through the gold foil without any deflection. This indicates that most of the space inside an atom is empty.

2. Very few particles suffered a deflection from their path. This means that positive charge occupies very little space inside an atom.

3. Only a small fraction of particles underwent a 180° deflection. This shows that the entire positive charge and mass of an atom are present within a very small volume inside the atom.



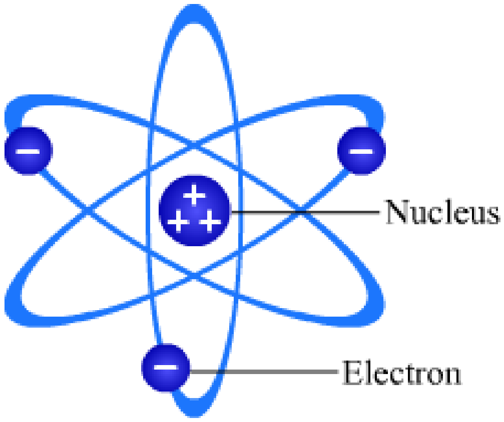
Rutherford's Atomic Model

Based on his conclusions in the gold-foil experiment, Rutherford devised his own atomic model. The major features of **Rutherford atomic model** or **the nuclear model of an atom** are as follows:

1. An atom consists of a nucleus at its centre and all the protons are present inside this nucleus.
2. Electrons reside outside the nucleus and revolve around the nucleus in well-defined orbits.

3. The size of the nucleus is very small as compared to the size of the atom. As per Rutherford's calculations, the nucleus is 10^5 times smaller than the atom.

4. Since the mass of the electrons is negligible as compared to the mass of the protons, almost all the mass of the atom is concentrated in its nucleus.



Know Your Scientist

Ernest Rutherford (1871−1937) was a British chemist and physicist. He is known as 'the father of nuclear physics'. He discovered radioactive half-life. He proved that alpha radiations are nothing but helium ions.

He was awarded the Nobel Prize in Chemistry in 1908 for his work on 'the disintegration of elements' and 'the chemistry of radioactive substances'. He was the first scientist to split an atom in a nuclear reaction. The element 'rutherfordium' (atomic number 104) is named after him.

Solved Examples

Hard

Example 1:

What would have been observed if neutrons had been used to bombard the gold foil?

1. **The observations of the experiment would have remained the same in spite of the change in the nature of the bombarding particles.**

2. **The neutrons would have suffered no deflection from the subatomic particles.**

3. **All the neutrons would have been absorbed by the gold atoms.**

4. **All the neutrons would have rebounded.**

Solution:

The correct answer is B.

Neutrons do not carry any charge; so, they do not suffer any repulsion. Hence, if neutrons had been used to bombard the gold foil, no deflection would have occurred. It is also possible that some neutrons would have been absorbed by the nucleus.

Medium

Example 2:

State whether the following statements are true (T) or false (F).

1. **Increasing the energy of the alpha particles will lead to more deflection.____**
2. **Speed of the alpha particles can be increased by increasing their energy.____**
3. **Use of aluminium sheet will lead to the same result as in case of gold foil.____**

Solution:

1. **T**: Increasing the energy of the alpha particles will cause them to strike closer to the nucleus. Consequently, they will suffer greater deflection.

2. **T**: The kinetic energy of the alpha particles is directly related to their velocity. So, increasing their energy will result in an increase in the speed of the particles.

3. **F**: The positive charge on the nucleus in case of an aluminium foil is much smaller as compared to that on the gold nucleus. So, the result will vary.

Easy

Example 3:

One of the postulates of Rutherford’s atomic model is that

1. **an atom consists of a positively charged sphere.**
2. **an atom has its mass concentrated in its nucleus.**
3. **the nucleus of an atom is composed of electrons and protons.**
4. **the mass of an atom is the sum of the masses of all electrons and protons.**

Solution:

The correct answer is B.

The postulates of Rutherford’s atomic model are as follows:

1. An atom consists of a nucleus at its centre and all the protons are present inside this nucleus.

2. Electrons reside outside the nucleus and revolve around the nucleus in well-defined orbits.

3. The size of the nucleus is very small as compared to the size of the atom. As per Rutherford’s calculations, the nucleus is 10^5 times smaller than the atom.

4. Since the mass of the electrons is negligible as compared to the mass of the protons, almost all the mass of the atom is concentrated in its nucleus.

Rutherford also noticed that the actual mass of the nucleus was much more higher than the sum of the masses of protons and electrons.

This lead him to predict that nucleus contains some kind of neutral particle whose mass must be equal to that of proton.

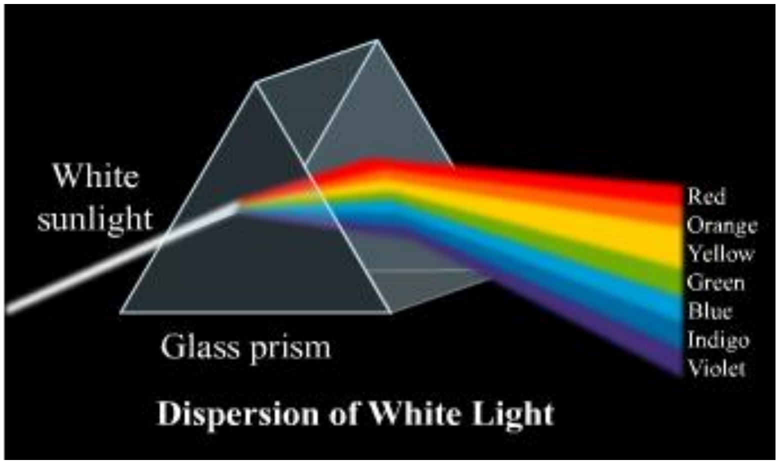
This was experimentally proved by James Chadwick in the year 1932. He proved that nucleus of atom contains an additional neutral particle and called them **neutrons.**

The mass of these neutrons is equal to that of protons.

Bohr's Atomic Model

The Shell Model of an Atom

In the late nineteenth century, scientists researched on the dispersal of white light into its constituent seven colours—known as the spectrum.

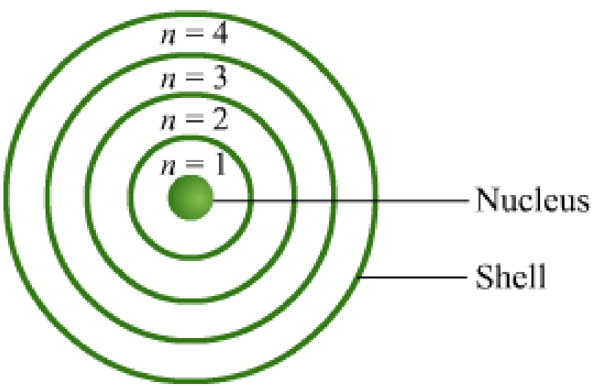


The spectrum was used for analyzing newly discovered elements. It was observed that this spectrum was different for different elements.

Now, the above observation could not be explained using Rutherford's model of an atom. Thus, Niels Bohr made some modifications to Rutherford's model. The modified atomic model of Niels Bohr is also known as **the shell model of an atom**.

Let us go through this lesson to learn more about this model.

Bohr's Model of an Atom



The postulates of Bohr's model of an atom are as follows:

1. Only certain special **orbits**, known as discrete orbits of electrons, are allowed inside the atom.

2. While revolving in the discrete orbits, the electrons do not radiate energy.

3. An electron can jump from one orbit to another by absorbing or emitting a fixed amount of energy in the form of radiation.

Bohr named these orbits as **energy levels**. These orbits (or shells) are represented by the letters **K, L, M, N**…, or the numbers n = 1, 2, 3, 4….

Bohr's model of an atom explains how:

- the electrons are arranged and distributed in the extra-nuclear space of the atom.
- the atom attains stability due to the presence of energy levels around the nucleus, in which the electrons revolve without radiating energy.
- each energy shell can accommodate only a fixed number of electrons.
- the filling of a shell begins only when the preceding shell has been completely filled.
- this gives the atom a shell-like structure.

Distribution of Electrons or Electronic Configuration

Let us see how the electrons are distributed in different orbits in an atom. Bohr, along with Charles R. Bury, suggested certain rules to show this electronic distribution. These rules (known as the Bohr−Bury scheme of electronic configuration) have to be followed while writing the **electronic configuration** of an atom.

1. The maximum number of electrons in a shell is given by the formula $2n^2$, where n is the orbit number or the energy level index (i.e., 1, 2, 3…).

Orbit numbers	**Names of the shells**	**Numbers of electrons in the shells**
1	K-shell	$2 \times (1)^2 = 2$
2	L-shell	$2 \times (2)^2 = 8$
3	M-shell	$2 \times (3)^2 = 18$
4	N-shell	$2 \times (4)^2 = 32$

2. The maximum number of electrons that can be accommodated in the outermost shell is 8.

3. The filling of the shells takes place in a stepwise manner. First, one shell is filled completely, then the next shell, and so on.

Solved Examples

Medium

Example 1:

Which of the following statements is true for Bohr's model of an atom?

1. **Electrons go around the nucleus based on the strength of the force of attraction extended by the nucleus.**
2. **Electrons lose energy while travelling in orbits around the nucleus.**
3. **The energy shells can accommodate only a fixed number of electrons.**
4. **The energy of the shells is continuous.**

Solution:

The correct answer is C.

According to Bohr's model of an atom:

- Only certain special orbits, known as discrete orbits of electrons, are allowed inside the atom.

- While revolving in the discrete orbits, the electrons do not radiate energy.

- The energy shells can accommodate only a fixed number of electrons.

- The energy of the shells is discrete, and not continuous.

Easy

Example 2:

An element has 12 electrons. How many energy shells does this element possess?

1. **1**
2. **2**
3. **3**
4. **4**

Solution:

The correct answer is C.

According to the Bohr−Bury scheme, each energy shell can accommodate $2n^2$ electrons, where n is the energy number. In case of any element, the electrons are distributed as shown in the table.

Shells	Energy numbers	Numbers of electrons in the shells

K	1	$2 \times (1)^2 = 2$
L	2	$2 \times (2)^2 = 8$
M	3	$2 \times (3)^2 = 18$

Now, the given element has 12 electrons. So, the K-shell fills first with 2 electrons. The remaining 10 electrons are divided among the L-shell and the M-shell as follows: 8 in the L-shell and 2 in the M-shell. Thus, the element has a total of 3 energy shells.

Hard

Example 3:

What is the electronic configuration for an element having 17 electrons?

1. **2, 8, 7**
2. **2, 6, 9**
3. **2, 10, 5**
4. **2, 7, 8**

Solution:

The correct answer is A.

According to the Bohr−Bury scheme, each energy shell can accommodate $2n^2$ electrons, where n is the energy number. In case of any element, the electrons are distributed as shown in the table.

Shells	**Energy numbers**	**Numbers of electrons in the shells**
K	1	$2 \times (1)^2 = 2$
L	2	$2 \times (2)^2 = 8$
M	3	$2 \times (3)^2 = 18$

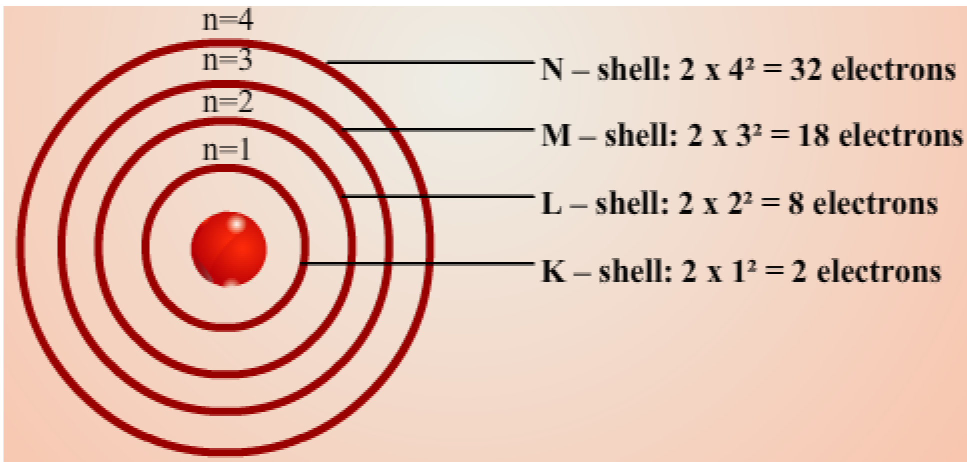
Now, the given element has 17 electrons. So, the K-shell fills first with 2 electrons. The remaining 15 electrons are divided among the L-shell and the M-shell as follows: 8 in the L-shell and 7 in the M-shell. Thus, the electronic configuration for the element is 2, 8, 7.

Electronic Configuration of Atoms

Bohr postulated that electrons can move from one shell to another by absorbing or emitting energy in the form of radiation. Let us understand this phenomenon.

As you know, in Bohr's atomic model, electrons are arranged in energy shells and each of these shells has a fixed amount of energy. The electrons residing in a particular shell possess the characteristic energy of the shell. The energy of an electron remains constant as long as it remains in a particular energy level.

In an atom, shells are arranged in order of increasing energy.



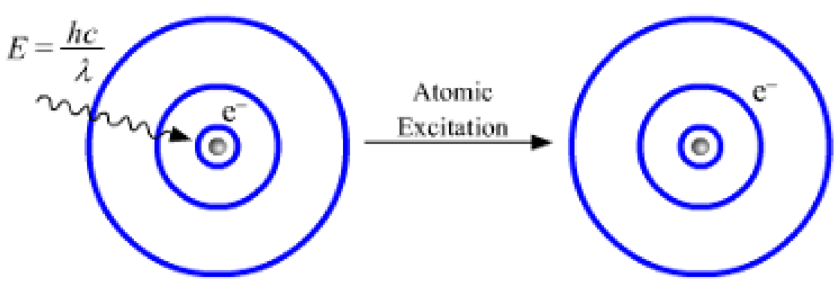
So, the shells in increasing order of energy are as follows:

K < L < M < N

Excitation and De-Excitation of Electrons

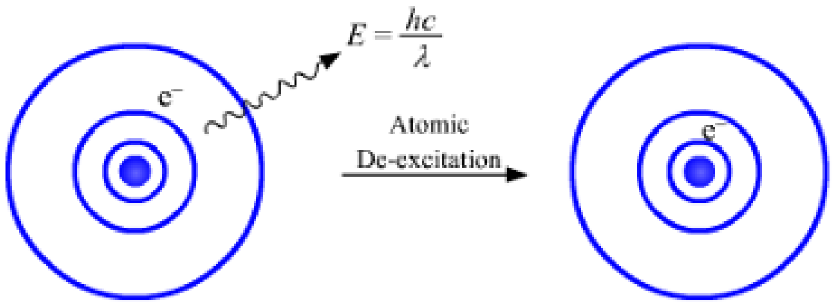
Excitation of electrons:

An electron lying in a lower energy shell absorbs energy from incident light to gain energy corresponding to that of the adjacent higher energy level. This is shown in the figure.



De-excitation of electrons:

An electron lying in a higher energy shell emits energy in the form of electromagnetic radiation to lose energy corresponding to that of the adjacent lower energy level. This is shown in the figure.



The emitted radiation may lie in any region of the electromagnetic spectrum, depending upon the frequency of the radiation.

Sub-Shells in an Atom and Discovery of Neutron

Sub-Shells in an Atom:

Further research on atomic structure indicated that the energy shells K, L, M, N, etc., are further divided into sub-shells of different shapes and energies. The division of shells into sub-shells is as follows:

Main energy levels	Sub-shell(s) in the main levels
K (1^{st})	s
L (2^{nd})	s, p
M (^{3rd})	s, p, d
N (4^{th})	s, p, d, f

In an atom, these sub-shells are arranged in order of increasing energy and are filled successively

Discovery of Neutrons:

- In 1932, J. Chadwick discovered the sub-atomic particles known as **neutrons**.
- Neutrons are present in all atomic nuclei, except that of hydrogen.
- The mass of a neutron was found to be 1.6749×10^{-27} kg, which is slightly more than that of a proton.
- Mass of an atom = Mass of all neutrons + Mass of all protons

Did You Know?

A hydrogen atom contains only one electron and one proton. It does not have any neutron in its nucleus. The removal of the electron from the atom leaves behind the single-proton-containing nucleus; so, H^+ is sometimes referred to as simply ‘proton’.

Know Your Scientist

Neils Bohr (1885−1962) was a Danish physicist. He made major contributions to the understanding of the atomic structure and quantum mechanics. He was awarded the Nobel Prize in Physics in 1922.

He is credited with developing the planetary model of an atom. While working on quantum mechanics, he postulated that electrons jump from one energy level to another by absorbing or emitting discrete amounts of energy. He also identified the uranium isotope U-238.

James Chadwick (1891−1974) was a British physicist. He is credited with the discovery of neutrons, for which he received the Nobel Prize in Physics in 1935. He was part of the Manhattan Project in the US and helped in the development of the atomic bombs that were dropped on Hiroshima and Nagasaki during the Second World War.

Atomic Number and Mass Number

In the 1830s, representation of elements and compounds was a major concern for chemists.

Many symbolic notations for elements were devised during this period. Gradually, the representations became standardized. Currently, the general symbolic notation for an element is:

${}_{Z}^{A}E$. Now, take for example the specific symbolic notations for oxygen and nitrogen.

Element	Symbolic notation
Oxygen	${}_{8}^{16}O$
Nitrogen	${}_{7}^{14}N$

Wondering what these symbolic notations represent? Go through this lesson to find out.

You know that the symbolic notation of oxygen is ${}_{8}^{16}O$. In this notation, the letter ‘O’ symbolises the element ‘oxygen’; the number ‘16’ represents the **mass number** of oxygen; and the number ‘8’ indicates the **atomic number** of oxygen.

Thus, in the general symbolic notation of an element $\left(\text{i.e., } {}_{Z}^{A}E\right)$, the letter ‘E’ is the symbol of the element, the letter ‘A’ is its mass number, and the letter ‘Z’ is its atomic number.

The **atomic number** is the number of protons present in the nucleus of an atom. It is denoted by **Z**.

The total number of the protons and the neutrons present in the nucleus of an atom is known as **mass number**. It is denoted by **A**.

Atomic Number and Mass Number

Symbolic Notations of Some Elements

Elements	Symbolic notations	Symbols	Atomic numbers	Mass numbers

Hydrogen	$^{1}_{1}H$	H	1	1
Helium	$^{4}_{2}He$	He	2	4
Lithium	$^{7}_{3}Li$	Li	3	**7**
Beryllium	$^{9}_{4}Be$	Be	4	9
Boron	$^{11}_{5}B$	B	5	11
Carbon	$^{12}_{6}C$	C	6	12
Nitrogen	$^{14}_{7}N$	N	7	14
Oxygen	$^{16}_{8}O$	O	8	16
Fluorine	$^{19}_{9}F$	F	9	19
Neon	$^{20}_{10}Ne$	Ne	10	20

Symbolic Notations of Some Elements

Elements	Symbolic notations	Symbols	Atomic numbers	Mass numbers
Sodium	${}^{23}_{11}Na$	Na	11	23
Magnesium	${}^{24}_{12}Mg$	Mg	12	24
Aluminium	${}^{27}_{13}Al$	Al	13	27
Silicon	${}^{28}_{14}Si$	Si	14	28
Phosphorus	${}^{31}_{15}P$	P	15	31
Sulphur	${}^{32}_{16}S$	S	16	32
Chlorine	${}^{35}_{17}Cl$	Cl	17	35
Argon	${}^{40}_{18}Ar$	Ar	18	40

Potassium	$^{39}_{19}K$	K	19	39
Calcium	$^{40}_{20}Ca$	Ca	20	40

Relation between Atomic Number and Mass Number

Mass number **(A)** of an atom = Number of protons + Number of neutrons

Therefore, Mass number **(A)** = Atomic number **(Z)** + Number of neutrons

Therefore, Number of neutrons = **A - Z**

Hence, the number of neutrons can be calculated if the atomic number and mass number of an element are known.

An atom of sodium contains 11 protons and 12 neutrons. **Can you calculate the mass number of a sodium atom?**

Now, mass number **(A)** = number of protons + number of neutrons

Therefore, mass number of sodium atom = 11 + 12 = 23

Hence, the mass number of sodium is 23.

An atom of carbon is represented as $^{12}_{6}C$. **Can you tell the number of neutrons and protons present in carbon atom?**

It is seen from the symbolic notation of carbon that the atomic number and mass number of carbon atom is 6 and 12 respectively.

Now, number of neutrons = mass number − atomic number = 12 − 6 = 6

Since the number of protons is equal to the atomic number of that element. Thus, the number of protons present in a carbon atom is 6.

Solved Examples

Easy

Example 1:

What is the symbol of the element sodium?

1. **Na**
2. **N**
3. **So**
4. **S**

Solution:

The correct answer is A.

The symbol of sodium is Na. It is derived from the Latin name for the element, i.e., ‘natrium’.

Example 2:

What is the atomic number of an element having five protons and six neutrons?

1. **11**
2. **9**
3. **6**
4. **5**

Solution:

The correct answer is D.

The atomic number of an element is the number of protons or electrons present in an atom of the element. Since an atom of the given element has five protons, its atomic number is 5.

Medium

Example 3:

What is the number of neutrons in an element having 39 protons and 89 as its mass number?

1. **45**
2. **50**
3. **55**

4. **60**

   Solution:

   The correct answer is B.

   We know that:

   Mass number = Number of protons + Number of neutrons

   In case of the given element:

   Mass number = 89

   Number of protons = 39

   So,

   89 = 39 + Number of neutrons

   => Number of neutrons = 89 -39 = 50

   Hard

   Example 4:

   What is the symbol of the element having 22 neutrons and 40 as its mass number?

1. **Al**
2. **Mg**
3. **Ar**
4. **Ca**

   Solution:

   The correct answer is C.

   The given element has:

   Mass number = 40

   Number of neutrons = 22

   We know that:

Mass number = Number of protons + Number of neutrons

So,

40 = Number of protons + 22

=> Number of protons = 40 - 22 = 18

Also,

Atomic number = Number of protons = 18

Argon is the element having 18 as its atomic number and 40 as its mass number. The symbol of argon is Ar.

Did You Know?

- Water is the major constituent of the human body. It is made up of two elements: hydrogen and oxygen.
- Almost all the mass of our body is made up of the following six elements.

1. Oxygen (65%)
2. Carbon (18%)
3. Hydrogen (10%)
4. Nitrogen (3%)
5. Calcium (1.5%)
6. Phosphorus (1%)

- Some of the other elements found in our body are:
- Sulphur (0.25%)
- Sodium (0.15%)
- Magnesium (0.05%)
- Zinc (0.7%)

Whiz Kid

The Periodic Table

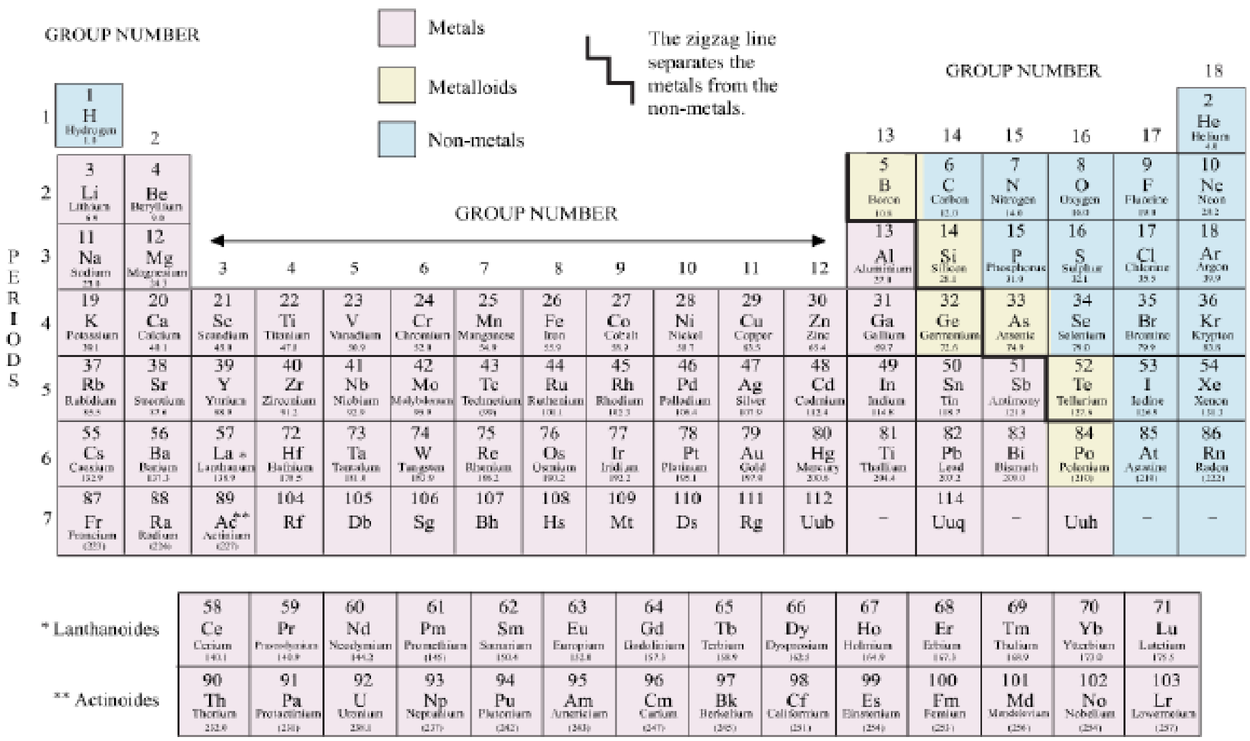
The periodic table is a table classifying all the known elements.

It is divided into 18 columns (called groups) and 7 rows (called periods).

The elements are arranged in the rows or periods by order of increasing atomic number.

The elements in the columns or groups display similar chemical and physical properties. This feature of the periodic table makes it easy to study the vast number of elements.

The periodic table is shown in the figure.



Valency:

We know that the outermost shell of an atom can hold a maximum of eight electrons. The elements, whose atoms have a completely filled outermost shell, have very little chemical activity. Such elements are said to have **zero combining capacity** or **valency**. For e.g., helium, neon, argon.

(The elements of the 18th group in the periodic table). These elements have either completely filled outermost shells or have 8 electrons in their outermost shell. Hence, their valency is zero. They are called **inert** or **noble gases**.

The combining capacity of atoms of the elements is their tendency to react with other atoms of the same or different molecules to attain a filled outermost shell. The outermost shell, which has eight electrons, is said to possess an **octet** and every atom tends to achieve an octet in its outermost shell.

This is done by gaining, losing, or sharing its electrons. **The number of electrons gained, lost, or shared by an atom to complete its octet is called the combining capacity or valency of that atom.**

Both hydrogen and sodium contain one electron each in their outermost shells. Thus, both can lose one electron. Hence, their valency is one.

It is not always true that the number of electrons present in the outermost shell of an atom represents its valency. For example, in fluorine, there are seven electrons in the outermost shell, but the valency of fluorine is one.

This is because it is energetically suitable for fluorine atom to accept one electron, rather than donating seven electrons. Hence, its valency is obtained by subtracting seven electrons from the octet.

Concept of valency

We know that the combining power or the combining capacity of an atom or an element is called its **valency**. The number of atoms of other elements with which one atom of an element combines is decided by the valency of that element.

For example, both hydrogen and chlorine have a valency of 1. Therefore, one atom of hydrogen reacts with one atom of chlorine to form one molecule of hydrogen chloride.

The valency of an ion is equal to the charge on it. The valencies of some common ions are given in the following table.

Name of ion	Symbol	Valency	Name of ion	Symbol	Valency
Aluminium	Al^{3+}	3	Sulphite	SO_3^{2-}	2
Ammonium	NH_4^+	1	Bromide	Br^-	1
Calcium	Ca^{2+}	2	Carbonate	CO_3^{2-}	2
Copper(II)	Cu^{2+}	2	Chloride	Cl^-	1
Hydrogen	H^+	1	Hydride	H^-	1
Iron(II)	Fe^{2+}	2	Hydrogen carbonate	HCO_3^-	1
Iron(III)	Fe^{3+}	3	Hydroxide	OH^-	1
Magnesium	Mg^{2+}	2	Nitrate	NO_3^-	1
Nickel	Ni^{2+}	2	Nitrite	NO_2^-	1
Potassium	K^+	1	Oxide	$O2-$	2
Silver	Ag^+	1	Phosphate	PO_4^{3-}	3
Sodium	Na^+	1	Sulphate	SO_4^{2-}	2

Zinc	Zn^{2+}	2	Sulphide	S^{2-}	2

Relationship Between Valency of Elements and Periodic Table

It is observed that valency of elements increases from 1 to 4 and then decreases to 1. For noble gases, the combining capacity or the valency is zero because of their inert nature.

Since we know, there are 118 elements which are classified with the help of a periodic table, which is divided into horizontal rows and vertical columns. These horizontal rows are called periods, whereas the vertical columns are called groups.

These groups are called IA, II, IIIA, IVA, VA, VIA, VIIA, and zero group.
The periods are numbered as 1, 2, 3, 4, 5, 6 and 7.

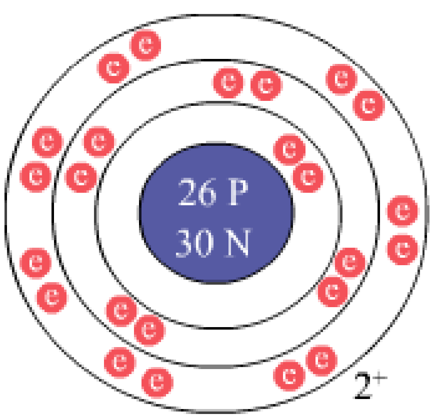
Elements present in the same group have same valency and it also corresponds to the group number up to IV.

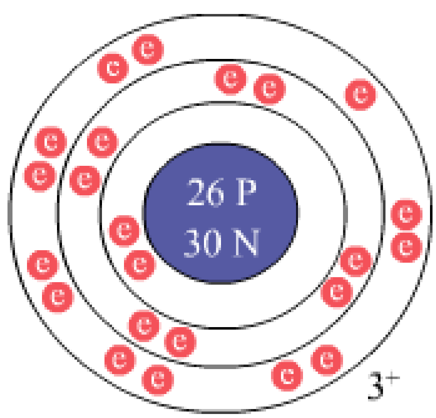
Valencies of elements present in group V, VI and VII are 3, 2, and 1, respectively. Hence, it is clear that metals or non-metals with same valency show similar properties.

Variable valency: - It has been found that certain elements exhibit more than one valency. In such a situation, the element is said to exhibit variable valency.

The **reason for variable valency** is that an atom of some element depending upon the conditions loses more electrons than are present in its outermost shell (valence shell) i.e., it loses some electrons from the shell next to the outermost shell.

Example: - An atom of iron has two electrons in its valence shell. On losing these electrons, it attains a valency of +2. However, sometimes it loses one more electron from its inner shell and hence attains a valency of +3.





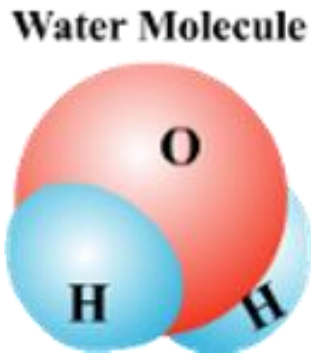
Molecules and Ions

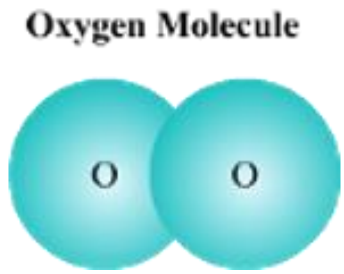
A Brief Introduction to Molecules and Ions

Most atoms are not stable in free state. So, they combine with other atoms to form molecules.

For example:

A water molecule is formed when two hydrogen atoms combine with one oxygen atom. An oxygen molecule is formed when two oxygen atoms combine with each other.





Some atoms are charged. Such charged atoms and molecules are called ions.

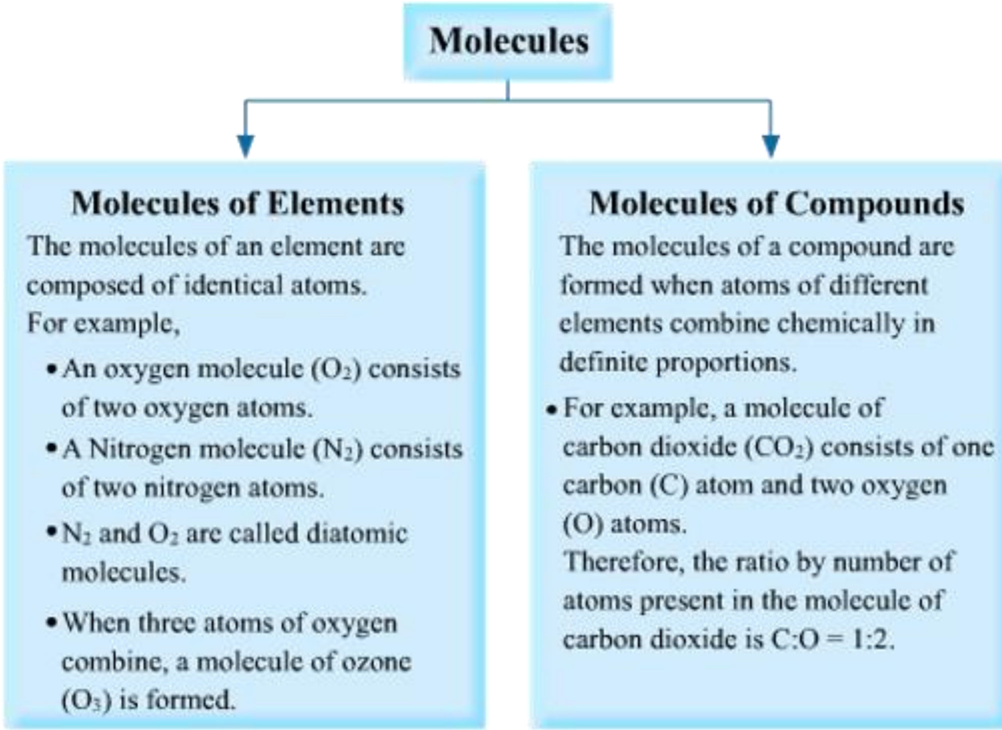
A positively charged ion is called **cation**.

A negatively charged ion is called **anion**.

In this lesson, we are going to study about:

- Molecules and molecular compounds
- Ions and ionic compounds

Molecules



Did You Know?

The term '**molecule'** originates from the French word '*molécule',* which means 'extremely minute particle'. It was coined by the French philosopher and mathematician Rene Descartes in the early seventeenth century.

In view of John Dalton's laws of definite and multiple proportions, the existence of molecules was accepted by many chemists since the early nineteenth century. However, it is the work of Jean Baptiste Perrin on the Brownian motion (1911) of particles of liquids and gases which is considered to be the final proof of the existence of molecules.

Atomicity of Molecules

The number of atoms constituting a molecule is known as its atomicity. The given table lists the atomicity of some common elements.

Elements	Atomicity
Helium (He), Neon (Ne), Argon (Ar)	Monoatomic (1 atom per molecule)

Oxygen (O_2), Hydrogen (H_2), Nitrogen (N_2) Chlorine (Cl_2), Fluorine (F_2)	Diatomic (2 atoms per molecule)
Phosphorus (P_4)	Tetratomic (4 atoms per molecule)
Sulphur (S_8)	Polyatomic (8 atoms per molecule)

Did You Know?

Buckminsterfullerene is an allotrope of carbon in which sixty carbon atoms are bonded together.

Ions

An ion is a charged atom or molecule. This charge arises because the number of electrons do not equal the number of protons in the atom or molecule. An ion is also known as **radical**. A positively charged ion is called **cation**; they are also called basic radicals. While a negatively charged ion is called **anion**. Such ions are called acid radicals.

There are many ions which are **polyatomic ions**.

The given table lists the symbols and atomicity of some common ions.

Cations	Symbols	Atomicity	Anions	Symbols	Atomicity
Aluminium	Al^{3+}	Monoatomic	Bromide	Br^-	Monoatomic
Ammonium	NH_4^+	Polyatomic	Carbonate	CO_3^{2-}	Tetra-atomic
Calcium	Ca^{2+}	Monoatomic	Chloride	Cl^-	Monoatomic
Cuprous ion	Cu^+	Monoatomic	Fluoride	F^-	Monoatomic
Cupric ion	Cu^{2+}	Monoatomic	Hydride	H^-	Monoatomic
Hydrogen	H^+	Monoatomic	Hydroxide	OH^-	Diatomic

Ions

The given table lists the symbols and atomicity of some other common ions.

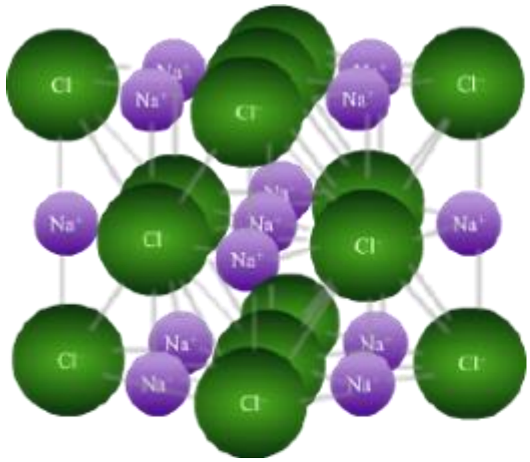
Cations	Symbols	Atomicity	Anions	Symbols	Atomicity
Ferric ion	Fe^{3+}	Monoatomic	Iodide	I^{-}	Monoatomic
Magnesium	Mg^{2+}	Monoatomic	Nitrate	NO_3^{-}	Tetra-atomic
Nickel	Ni^{2+}	Monoatomic	Nitride	N^{3-}	Monoatomic
Potassium	K^{+}	Monoatomic	Nitrite	NO−2NO2-	Tetra-atomic
Silver	Ag^{+}	Monoatomic	Oxide	O^{2-}	Monoatomic
Sodium	Na^{+}	Monoatomic	Phosphate	PO_4^{3-}	Polyatomic
Zinc	Zn^{2+}	Monoatomic	Sulphate	SO_4^{2-}	Polyatomic
Hydrogen carbonate	HCO−3HCO3-	Polyatomic	Sulphite	SO_3^{2-}	Tetra-atomic

Ionic Compounds

The compounds which are formed by the combination of cations and anions are known as **ionic compounds**.

For example:

- **Zinc oxide (ZnO)**: It is formed when a zinc ion (Zn^{2+}) combines with an oxide ion (O^{2-}).
- **Magnesium chloride ($MgCl_2$)**: It is formed when a magnesium ion (Mg^{2+}) combines with two chloride ions (Cl^{-}).
- **Potassium bromide (KBr)**: It is formed when a potassium ion (K^{+}) combines with a bromide ion (Br^{-}).
- **Sodium chloride (NaCl)**: It is formed when a sodium ion (Na^{+}) combines with a chloride ion (Cl^{-}). The structure of NaCl crystals is shown in the given figure. You can see that there is a group of Na^{+} and Cl^{-} ions combined with each other.



Solved Examples

Easy

Example 1:

Find the atomicity of each of the following ions.

i) S^{2-}

ii) SO_4^{2-}

iii) NH_4^+

iv) OH^-

Solution:

Ions	Atomicity
S^{2-}	1
SO_4^{2-}	5
NH_4^+	5
OH^-	2

Medium

Example 2:

Identify the anions and cations present in the following compounds.

Compounds	**Anions**	**Cations**
NaCl		
$KMnO_4$		
NaOH		
KBr		
NH_4OH		

Solution:

Compounds	**Anions**	**Cations**
NaCl	Cl^-	Na^+
$KMnO_4$	MnO_4^-	K^+
NaOH	OH^-	Na^+
KBr	Br^-	K^+
NH_4OH	OH^-	NH_4^+

Hard

Example 3:

Give the symbols and valence numbers for the following ions.

Ions	**Symbols**	**Valence numbers**
Ammonium		
Carbonate		
Sulphate		
Chloride		
Phosphate		

Solution:

Ions	Symbols	Valence numbers
Ammonium	NH_4^+	+1
Carbonate	CO_3^{2-}	−2
Sulphate	SO_4^{2-}	−2
Chloride	Cl^-	−1
Phosphate	PO_4^{3-}	−3