General Chemistry 1

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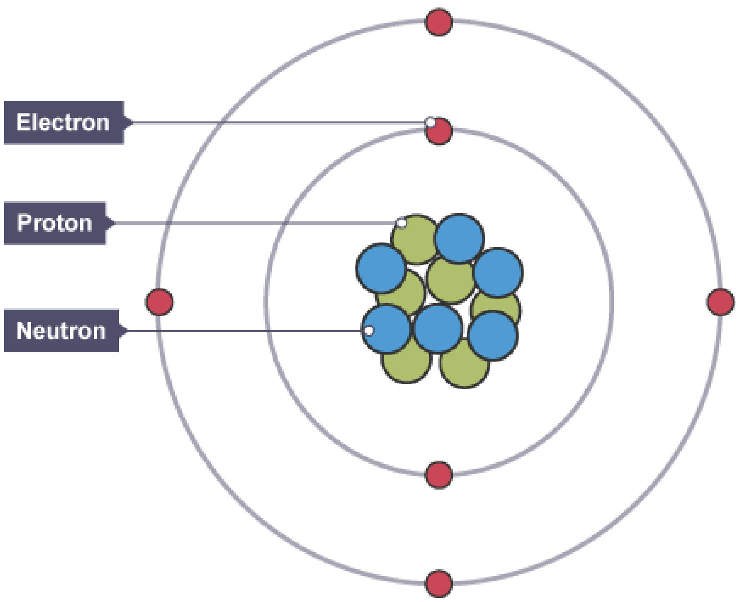
General Chemistry

Atomic structure

What is Atomic Structure?

The atomic structure of an element refers to the constitution of its nucleus and the arrangement of the electrons around it. Primarily, the atomic structure of matter is made up of **protons**, **electrons** and **neutrons.**



The **protons and neutrons** make up the nucleus of the atom, which is surrounded by the electrons belonging to the atom. The **atomic number** of an element describes the total number of protons in its nucleus.

Neutral atoms have equal numbers of protons and electrons. However, atoms may gain or lose electrons in order to increase their stability and the resulting charged entity is called an **ion**.

Atoms of different elements have different atomic structures because they contain different numbers of **protons and electrons**. This is the reason for the unique characteristics of different elements.

Atomic Models

In the 18th and 19th centuries, many scientists attempted to explain the structure of the atom with the help of atomic models. Each of these models had their own merits and demerits and were pivotal to the development of the **modern atomic model**. The most notable contributions to the field were by the scientists John Dalton, J.J. Thomson, Ernest Rutherford and Niels Bohr.

Dalton's Atomic Theory

The English chemist **John Dalton** suggested that all matter is made up of atoms, which were indivisible and indestructible. He also stated that all the atoms of an element were exactly the same, but the atoms of different elements differ in size and mass.

Chemical reactions, according to Dalton's atomic theory, involve a rearrangement of atoms to form products. According to the postulates proposed by Dalton, the atomic structure comprised atoms, the smallest particle responsible for the **chemical reactions** to occur.

The following are the postulates of his theory:

- Every matter is made up of atoms.
- Atoms are indivisible.
- Specific elements have only one type of atoms in them.
- Each atom has its own constant mass that varies from element to element.

- Atoms undergo rearrangement during a chemical reaction.
- Atoms can neither be created nor be destroyed but can be transformed from one form to another.

Demerits of Dalton's Atomic Theory

- The theory was unable to explain the existence of isotopes.
- Nothing about the structure of atom was appropriately explained.
- Later, the scientists discovered particles inside the atom that proved, the atoms are divisible.

The discovery of particles inside atoms led to a better understanding of chemical species, these particles inside the atoms are called subatomic particles. The discovery of various subatomic particles is as follows:

Thomson Atomic Model

The English chemist Sir Joseph John Thomson put forth his model describing the atomic structure in the early 1900s.

He was later awarded the Nobel prize for the **discovery of "electrons"**. His work is based on an experiment called cathode ray experiment.

Based on conclusions from his cathode ray experiment, Thomson described the atomic structure as a positively charged sphere into which negatively charged electrons were embedded.

Thomson's atomic structure described atoms as electrically neutral, i.e. the positive and the negative charges were of equal magnitude.

Limitations of Thomson's Atomic Structure: Thomson's atomic model does not clearly explain the stability of an atom. Also, further discoveries of other subatomic particles, couldn't be placed inside his atomic model.

Rutherford Atomic Theory

Rutherford, a student of J. J. Thomson modified the atomic structure with the discovery of another **subatomic particle called "Nucleus"**. His atomic model is based on the Alpha ray scattering experiment.

Alpha Ray Scattering Experiment

Construction:

- A very thin gold foil of 1000 atoms thick is taken.
- Alpha rays (doubly charged Helium He^{2+}) were made to bombard the gold foil.
- ZnS screen is placed behind the gold foil.

Observations:

- Most of the rays just went through the gold foil making scintillations (bright spots) in the **ZnS** screen.
- A few rays got reflected after hitting the gold foil.
- One in 1000 rays got reflected by an angle of 180° (retraced path) after hitting the gold foil.

Conclusions:

- Since most rays passed through, Rutherford concluded that most of the space inside the atom is empty.
- Few rays got reflected because of the repulsion of its positive with some other positive charge inside the atom.
- 1/1000th of rays got strongly deflected because of a very strong positive charge in the center of the atom. He called this strong positive charge as "nucleus".
- He said most of the charge and mass of the atom resides in the Nucleus.

Rutherford’s Structure of Atom

Based on the above observations and conclusions, Rutherford proposed his own atomic structure which is as follows.

- The nucleus is at the center of an atom, where most of the charge and mass are concentrated.
- Atomic structure is spherical.
- Electrons revolve around the nucleus in a circular orbit, similar to the way planets orbit the sun.

Limitations of Rutherford Atomic Model

- If electrons have to revolve around the nucleus, they will spend energy and that too against the strong force of attraction from the nucleus, a lot of energy will be spent by the electrons and eventually, they will lose all their energy and will fall into the nucleus so the stability of atom is not explained.
- If electrons continuously revolve around the ‘nucleus, the type of spectrum expected is a continuous spectrum. But in reality, what we see is a line spectrum.

Subatomic Particles

Protons

- Protons are positively charged subatomic particles. The charge of a proton is +1e, which corresponds to approximately 1.602×10^{-19}
- The mass of a proton is approximately 1.672×10^{-24}
- Protons are over 1800 times heavier than electrons.
- The total number of protons in the atoms of an element is always equal to the atomic number of the element.

Neutrons

- The mass of a neutron is almost the same as that of a proton i.e. 1.674×10^{-24}
- Neutrons are electrically neutral particles and carry no charge.
- Different isotopes of an element have the same number of protons but vary in the number of neutrons present in their respective nuclei.

Electrons

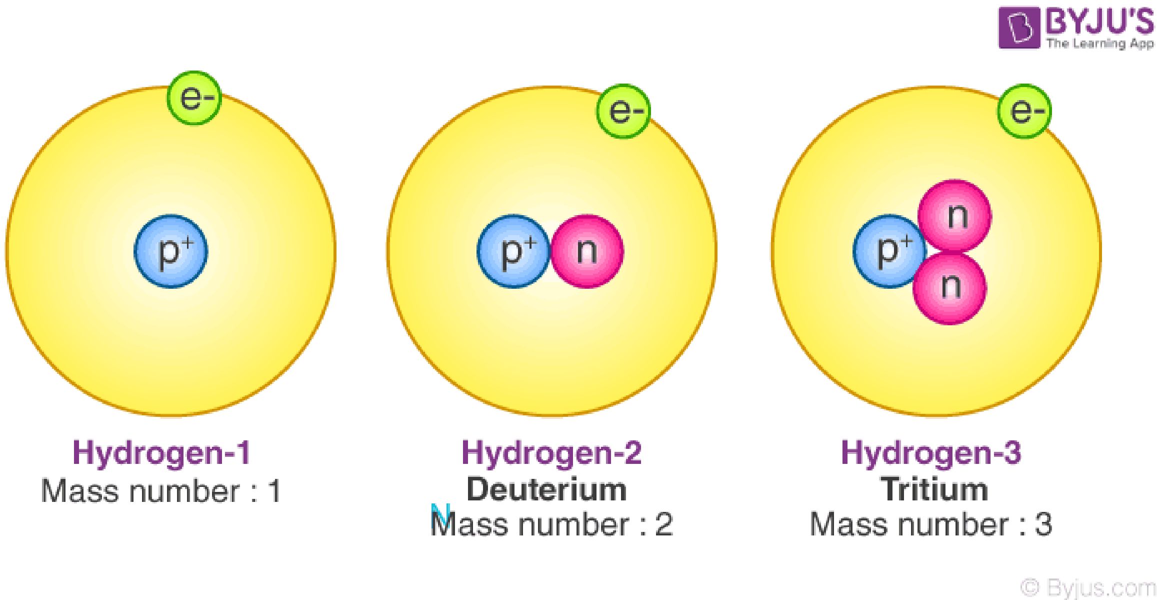
- The charge of an electron is -1e, which approximates to -1.602×10^{-19}
- The mass of an electron is approximately 9.1×10^{-31}.
- Due to the relatively negligible mass of electrons, they are ignored when calculating the mass of an atom.

Atomic Structure of Isotopes

Nucleons are the components of the nucleus of an atom. A nucleon can either be a proton or a neutron. Each element has a unique number of protons in it, which is described by its unique atomic number. However, several atomic structures of an element can exist, which differ in the total number of nucleons.

These variants of elements having a different nucleon number (also known as the mass number) are called isotopes of the element. Therefore, the isotopes of an element have the same number of protons but differ in the number of neutrons.

The atomic structure of an isotope is described with the help of the chemical symbol of the element, the atomic number of the element, and the mass number of the isotope. For example, there exist three known naturally occurring isotopes of hydrogen, namely, protium, deuterium, and tritium. The atomic structures of these hydrogen isotopes are illustrated below.



Bohr's Atomic Theory

Neils Bohr put forth his model of the atom in the year 1915. This is the most widely used atomic model to describe the atomic structure of an element which is based on Planck's theory of quantization.

Postulates:

- The electrons inside atoms are placed in discrete orbits called "stationery orbits".
- The energy levels of these shells can be represented via quantum numbers.
- Electrons can jump to higher levels by absorbing energy and move to lower energy levels by losing or emitting its energy.
- As longs as, an electron stays in its own stationery, there will be no absorption or emission of energy.

- Electrons revolve around the nucleus in these stationery orbits only.
- The energy of the stationary orbits is quantized.

Limitations of Bohr's Atomic Theory:

- Bohr's atomic structure works only for single electron species such as H, He^{+}, Li^{2+}, Be^{3+}, ….
- When the emission spectrum of hydrogen was observed under a more accurate spectrometer, each line spectrum was seen to be a combination of no of smaller discrete lines.
- Both Stark and Zeeman effects couldn't be explain using Bohr's theory.

Quantum Numbers

- **Principal Quantum number (n):** It denotes the orbital number or shell number of electron.
- **Azimuthal Quantum numbers (*l*):** It denotes the orbital (sub-orbit) of the electron.
- **Magnetic Quantum number: (*ml*)** It denotes the number of energy states in each orbit.
- **Spin Quantum number(s):** It denotes the direction of spin, S = -½ = Anticlockwise and ½ = Clockwise.

Electronic Configuration of an Atom

The electrons have to be filled in the s, p, d, f in accordance with the following rule.

1. Aufbau's principle: The filling of electrons should take place in accordance with the ascending order of energy of orbitals:

- Lower energy orbital should be filled first and higher energy levels.
- The energy of orbital **α(p + l)** value it two orbitals have same (n + *l*) value, E α n
- Ascending order of energy 1s, 2s, 2p, 3s, 3p, 4s, 3d, . . .

2. Pauli's exclusion principle: No two electrons can have all the four quantum numbers to be the same or, if two electrons have to placed in an energy state they should be placed with opposite spies.

3. Hund's rule of maximum multiplicity: In case of filling degenerate (same energy) orbitals, all the degenerate orbitals have to be singly filled first and then only pairing has to happen.