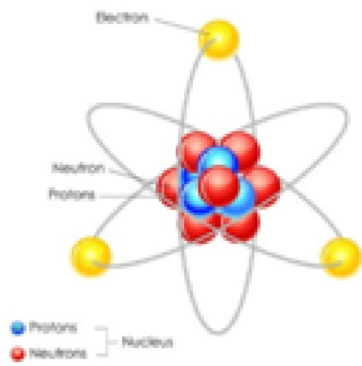
The Nucleus

Group 1

May 2024

1 Atom and its discovery



Structure of an atom- Every atom has these particles except the smallest isotope of hydrogen which has no any neutron.

The atom is the smallest unit of matter made of three sub-atomic particles: the proton, neutron, and electron. Protons and neutrons form the nucleus, while electrons are found in the electron cloud around it. Democritus, a Greek philosopher, coined the term 'atom' from atomos, meaning indivisible. Aristotle disagreed with the idea of indivisible particles, but in 1803 John Dalton presented a new theory based on experimental evidence, earning him the title of the father of modern atomic theory.

Dalton's Atomic Theory: John Dalton proposed that elements composed of tiny, indivisible particles called atoms. These atoms combine in simple ratios to form compounds.

Democritus: An ancient Greek philosopher who first proposed the idea of atoms as the building blocks of the universe.

Aristotle: A Greek philosopher who believed in aether as the fifth element in addition to earth, water, fire, and air. His views on atoms differed from those of Democritus.

Rutherford: Ernest Rutherford discovered the nucleus of an atom through his gold foil experiment. He proposed that electrons orbit the nucleus like planets around the sun.

In modern definition, all matter is composed of atoms. Atoms themselves are composed of protons, neutrons, and electrons. Also,protons and neutrons are composite particles,which are composed of quarks. Currently,the Standard Model has a defined number of key particles: elementary and composite. Elementary particles are quarks, leptons and bosons.

2 Isotopes

Isotopes are distinct nuclear species (or nuclides) of the same chemical element. They have the same atomic number (number of protons in their nuclei) and position in the periodic table (and hence belong to the same chemical element), but differ in nucleon numbers (mass numbers) due to different numbers of neutrons in their nuclei. While all isotopes of a given element have similar chemical properties, they have different atomic masses and physical properties.

The term isotope is derived from the Greek roots isos (”equal”) and topos (”place”), meaning ”the same place”; thus, the meaning behind the name is that different isotopes of a single element occupy the same position on the periodic table.It was coined by Scottish doctor and writer Margaret Todd in 1913 suggestion to the British chemist Frederick Soddy, who popularized the term.

For example, carbon-12, carbon-13, and carbon-14 are three isotopes of the element carbon with mass numbers 12, 13, and 14, respectively. The atomic number of carbon is 6, which means that every carbon atom has 6 protons so that the neutron numbers of these isotopes are 6, 7, and 8 respectively.

3 Discovery of the Constituent Particles

Subatomic particles are self-contained units of matter or energy. The atom consists of electrons surrounding a nucleus with protons and neutrons. Nucleus composed of even smaller particles called quarks and leptons. Bosons transmit forces. Over 200 subatomic particles detected with corresponding antiparticles.

Discovery of Electrons

Electrons were amongst the first subatomic particles to be discovered. Here's how it happened.

- In the 1850s, Faraday began to study electricaldischarge in partially evacuated tubes, known as cathode ray discharge tubes.
- His work was carried further by J. J. Thompson. He was the first to discover an electron.
- A cathode ray tube is made of glass having two thin pieces of metal, called electrodes, sealed in it.
- The electrical discharge through the gases could be observed only at very low pressure and at very high voltage.
- The pressure of different gases can be adjusted by evacuation
- When sufficient High voltage is applied on the electrodes, current starts flowing through a stream of particles moving in the tube from the negative electrode

(cathode) to the positive electrode (anode).

- These streams of particles were called cathode rays or cathode ray particles.

Discovery of Protons

- In 1815, the English Chemist William Prout proposed that all atoms are made up of the same fundamental hydrogen atoms.
- In 1886, German physicist Eugen Goldstein observed the canal rays which showed that the charge-to-mass ratio of the hydrogen ion was the highest amongst all gases.
- In the year 1917, Ernest Rutherford conducted an experiment using a modified cathode ray tube.
- Ernest Rutherford observed that when a beam of alpha particles was shot into the air, the scintillation detectors detected hydrogen nuclei.
- Rutherford investigated further and found that the nitrogen atoms present in the air produced hydrogen nuclei.
- So he fired alpha particle beams into pure nitrogen gas and observed that the hydrogen nuclei produced increased in number.
- Thus it was concluded that the hydrogen nuclei originated from the nitrogen atom. Hence, the nitrogen gas must be made of hydrogen fundamental particles. Hydrogen should also be a part of all other atoms.
- The hydrogen nucleus was later named 'proton' and recognized as one of the building blocks of the atomic nucleus.

Discovery of Neutrons

- When the alpha particles emitted by heavy elements like polonium were made incident on relatively light elements like lithium, beryllium, and boron, penetrating radiation was observed.
- This radiation was unaffected by electric fields and was, therefore, assumed be gamma radiation was unaffected by electric fields and was, therefore, assumed to be gamma radiation.
- This radiation had high energy about 5MeV. Hence, Italian physicist Ettore Majorana suggested the existence of a neutral particle.
- Rutherford also suggested the existence of a neutral after his alpha scattering experiment.
- Sir James Chadwick studied this radiation. When electrically neutral particles had a mass slightly greater than that of the protons was emitted. He named these particles neutrons.

4 Constituent Particles of the Atom and Bohr's Model of the Atom

The constituents of the atom are protons, neutrons and electrons. The protons and neutrons (nucleons) are found in the nucleus of atoms. The nucleus of an atom is surrounded by empty space in which there are electrons.

Bohr's Model of the Atom

Bohr's model consists of a small nucleus (positively charged) surrounded by negative electrons moving around the nucleus in orbits where he found out that an electron located away from the nucleus has more energy as compared to electrons close to the nucleus.

Bohr's model of an atom consists of three sub-atomic particles – protons, electrons, and neutrons. Protons are positively charged particles found in atomic nuclei, while electrons move around the nucleus in energy levels. Neutrons are neutral particles with a slightly greater mass than protons. The formula for the maximum number of electrons in each energy level is $2n^2$.

Each energy level is associated with a fixed amount of energy and there is no change in the energy of the electrons as long as they keep revolving in the same energy level, and the atom remains stable.

Postulates of Bohr's Model of an Atom Electrons revolve around the nucleus in orbits or shells, each with fixed energy levels represented by quantum numbers. Electrons move to higher energy levels when gaining energy and to lower levels when losing energy.

Limitations of Bohr's Model of Atom:-It failed to explain the Zeeman Effect. In the presence of a static magnetic field, the Zeeman effect causes a spectral line to break into numerous components. It's similar to the Stark effect. It also failed to explain the Stark effect. The Stark effect is the splitting of a spectral line into several components in the presence of an electric field. It violated the Heisenberg Uncertainty Principle and couldn't explain the spectra of bigger atoms. This concept asserts that an object's position and velocity cannot be determined precisely at the same time.

5 Quantum Numbers and Rules

Physical characteristics that are quantized—such as energy, charge, and angular momentum—are of such importance that names and symbols are given to them. The values of quantized entities are expressed in terms of quantum numbers, and the rules governing them are of the utmost importance in determining what nature is and does. This section covers some of the more important quantum numbers and rules—all of which apply in chemistry, material science, and far beyond the realm of atomic physics, where they were first discovered. Once again, we see how physics makes discoveries which enable other fields to grow.

The energy states of bound systems are quantized, because the particle wavelength can fit into the bounds of the system in only certain ways. This was elaborated for the hydrogen atom, for which the allowed energies are expressed as En1/n2, where n =1,2,3, We define n to be the principal quantum number that labels the basic states of a system. The lowest-energy state has n = 1, the first excited state has n = 2, and so on. Thus the allowed values for the principal quantum number are n = 1,2,3,

This is more than just a numbering scheme, since the energy of the system, such as the hydrogen atom, can be expressed as some function of n, as can other characteristics (such as the orbital radii of the hydrogen atom). The fact that the magnitude of angular momentum is quantized was first recognized by Bohr in relation to the hydrogen atom; it is now known to be true in general. With the development of quantum mechanics, it was found that the magnitude of angular momentum L can have only the values

$\mathrm{L} = \sqrt{l(l+1)}\mathrm{h}/2\pi$

where l is defined to be the angular momentum quantum number. The rule for l in atoms is given in the parentheses. Given n, the value of l can be any integer from zero up to n1. For example, if n=4, then l can be 0, 1, 2, or 3.

Note that for n=1, l can only be zero. This means that the ground-state angular momentum for hydrogen is actually zero, not $\frac{h}{2\pi}$ as Bohr proposed. The picture of circular orbits is not valid, because there would be angular momentum for any circular orbit. A more valid picture is the cloud of probability shown for the ground state of hydrogen. The electron actually spends time in and near the nucleus. The reason the electron does not remain in the nucleus is related to Heisenberg's uncertainty principle—the electron's energy would have to be much too large to be confined to the small space of the nucleus. Now the first excited state of hydrogen has n=2, so that l can be either 0 or 1, according to the rule in L = $\sqrt{l(l+1)}$h/2π. Similarly, for n=3, l can be 0, 1, or 2. It is often most convenient to state the value of l, a simple integer, rather than calculating the value of L from L = $\sqrt{l(l+1)}$h/2π.

6 The Strong and Weak Nuclear Forces

The Big Bang Theory explains that in the first second of the Universe, all matter was broken down into sub-atomic particles. The strong nuclear force formed protons and neutrons in the nucleus of atoms and enabled the creation of stars, galaxies, and planets. Without these forces, our Universe would not exist as it does today.

Strong Nuclear Force: Two positive charges repel each other because of the electromagnetic force, so the strong nuclear force lives up to its name by overcoming the intense repulsion between similarly charged particles that coexist in the nucleus of atoms. When the strong nuclear force that binds protons and neutrons in an atom is broken, extreme high-energy photons are released in the process.

Weak Nuclear Force: The weak nuclear force can change a neutron into a proton in a process called nuclear decay. When the weak nuclear force converts a neutrally charged neutron into a positively charged proton, sub-atomic particles are released near the speed of light.

When the nuclei of atoms smash together or break apart, they often change their mass in the process. This gain or loss of mass corresponds to a loss or gain of energy, as well. The strong and weak nuclear forces are what enable fission and fusion energy to create the devastating power of nuclear weapons, as well as powering the core of stars.

7 Binding Energy

In physics and chemistry, binding energy is the smallest amount of energy required to remove a particle from a system of particles or to disassemble a system of particles into individual parts.In the former meaning the term is predominantly used in condensed matter physics, atomic physics, and chemistry, whereas in nuclear physics the term separation energy is used. A bound system is typically at a lower energy level than its unbound constituents. According to relativity theory, a E decrease in the total energy of a system is accompanied by a decrease m in the total mass, where mc^2. = E.

Binding also can refer to two particles connecting together, such as phagocytosis and pathogen binding (connecting) together so that the phagocytosis destroys the pathogen.

Types of Binding Energy

- Electron Binding Energy

– Ionisation Energy.

- Atomic Binding Energy.

- Nuclear Binding Energy.

- Bond Dissociation Energy or Bond Energy.

- Gravitational Binding Energy.

- Binding energy curve indications.

Binding energy depends on the following aspects: Atomic number:-Inversely proportional to the distance from the nucleus, Asymmetry between the number of protons and neutrons.

8 Nuclear Stability

A nucleus is stable if it cannot be transformed into another configuration without adding energy from the outside. Of the thousands of nuclides that exist, about 250 are stable. The band of stability is a narrow region where stable isotopes fall on a plot of neutrons versus protons. Lighter stable nuclei generally have equal numbers of protons and neutrons, while heavier stable nuclei have more neutrons than protons. This is due to the larger proton-proton repulsions in larger nuclei, which require more neutrons to overcome and hold the nucleus together. Nuclear stability is governed by a combination of quantum mechanical rules, nuclear forces, and electrostatic charge. When these are violated, the nucleus is unstable. An unstable nucleus will decay to another isotope. table nuclei generally have even numbers of both protons and neutrons and a neutron-to-proton ratio of at least 1. Nuclei that contain magic numbers of protons and neutrons are often especially stable. Superheavy elements, with atomic numbers near 126, may even be stable enough to exist in nature.