# Modern Physics

## For Lower Secondary School

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# Part I: Atomic Models

**Introduction to Modern Physics**

Modern physics is a branch of physics that deals with the study of matter and energy on a small scale, such as atoms and subatomic particles; it explores the behavior of particles like electrons, protons, and neutrons and the forces that hold them within atoms.

Before the $20^{th}$ century, scientists like Isaac Newton, Galileo Galilei, Johannes Kepler, and others focused on events that were visible to the naked eye, most of these were to do with motion and energy, i.e. observation of large objects (much larger than the atom) moving at slower speeds (much smaller than the speed of light). This is now termed, classical physics.

By the early 1900s, the technology to probe into smaller realms was developing rapidly just as the number of physics scholars & researchers was rising; physicists such as Max Planck, Albert Einstein, Niels Bohr, (the list is endless) were able to study and explore phenomena dealing with atoms and sub-atomic particles; this was the birth of a new era in physics – modern physics.

This shift in focus from classical to modern physics has broadened our understanding of the universe, leading to groundbreaking technologies and insights into the fundamental nature of matter and energy across different scales and conditions.

## The Atom

An atom is the basic unit of matter, consisting of a nucleus (which contains protons and neutrons) surrounded by electrons.

The word atom (*atomos* in Greek) was coined by Greek philosopher around 400 BC to mean something that is '*uncuttable*'.

As of today, we understand quite a lot about atoms and their structure, but this was not always the case, our modern understanding of the atom is based on different models developed over a period of time; each building upon the other; Each model of the atom represents a step forward in our understanding, incorporating new experimental data, theoretical frameworks, and mathematical equations. The fact that we have different of models of atomic structures also demonstrates the dynamic nature of scientific exploration and the continuous search for deeper insights into the nature of matter.

Before we look at the current modern structure of the atom, let's journey through a few of the popular models developed between the early 1800s and early 1900s.

### Dalton's Model (1803)

This was developed by John Dalton in 1803, Dalton proposed that atoms are *'indivisible spheres'* and have no internal structure.

This model simply looked at atoms as spherical balls that cannot be broken down any further, it therefore does not take into account the existence of sub-atomic particles like electrons, protons & neutrons.

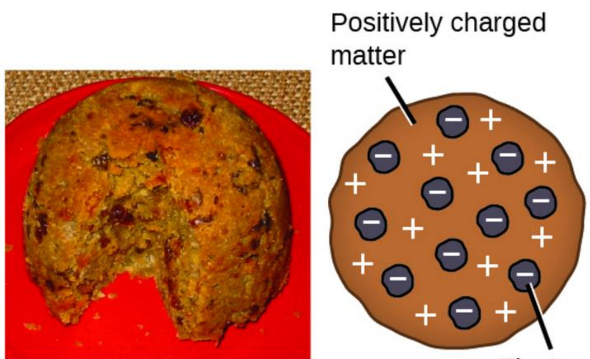
Inasmuch as Dalton's model was not entirely an accurate description of the atom, it laid foundation for the concept of atomic theory and the idea that matter is composed of discrete, indivisible particles called atoms.

### Thomson's Model (1897)

After several experiments with cathode ray tubes, J.J Thomson discovered that when certain metals were heated, they emitted special particles. Using charged plates to deflect (repel) the particles, Thomson was able to establish that these particles were negatively charged; consequently, he was able to measure the mass of these particles and found that they were much lighter than the atom itself.

Thomson concluded that these negatively charged particles must be subatomic and therefore the atom wasn't the smallest indivisible unit of matter as earlier proposed by Dalton. But he also knew that the atom is electrically neutral, therefore if an atom contained negative charge, it must contain an equal amount of positive charge to neutralize it.

To reconcile his discoveries, Thomson proposed a new model of the atomic structure in which an atom is made up of a positively charged sphere with negative charged embedded in it. This was named the *plum pudding model* because of its similarity with a popular English dessert – the plum pudding.



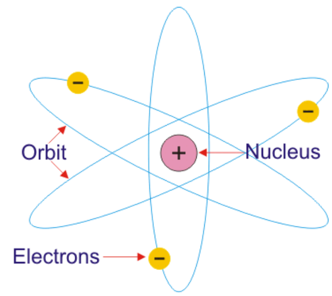
(a)

**Rutherford's Model (1911)**

In 1911, Ernest Rutherford performed the *gold foil experiment* in which he fired a narrow beam of alpha particles (positively charged) towards a thin foil of gold. Basing on Thomson's model, he expected the alpha particles to evenly penetrate through the gold foil but to his surprise, a few of them were deflected through more than $90^0$. The result of this experiment suggested that the positive charges (protons) are not evenly spread within the atom but rather concentrated at the center.

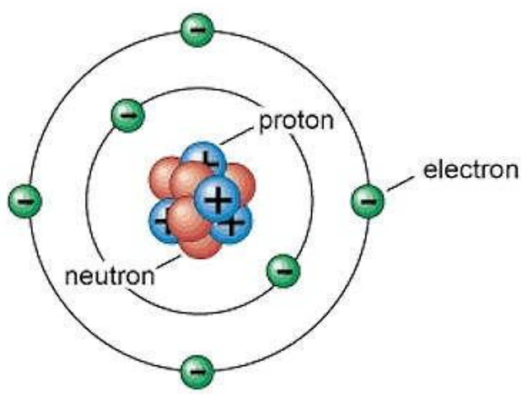
Rutherford had not only discovered the ***nucleus*** but also a new structure of an atom, this is now referred to as the nuclear model.

The nuclear model consists of a nucleus at the center of an atom containing protons with electrons orbiting around the nucleus, Rutherford also predicted the existence of neutrons (particles with mass but no charge) in the nucleus but he wasn't able to detect them in any of his experiments, the neutron was later discovered by his student, James Chadwick in 1932.




## Modern Structure of an Atom (Bohr's Model)

Physicist Neils Bohr refined Rutherford's model by proposing that electrons are not simply scattered around the nucleus but rather occupy specific orbits or energy levels or shells around the nucleus, furthermore, each shell can accommodate a specific number of electrons and the position of the shell from the nucleus determines the energy of the electrons therein. Bohr's model is based on the quantum theory and it is our best known atomic model today.




## Atomic Number, Mass Number and Isotopes

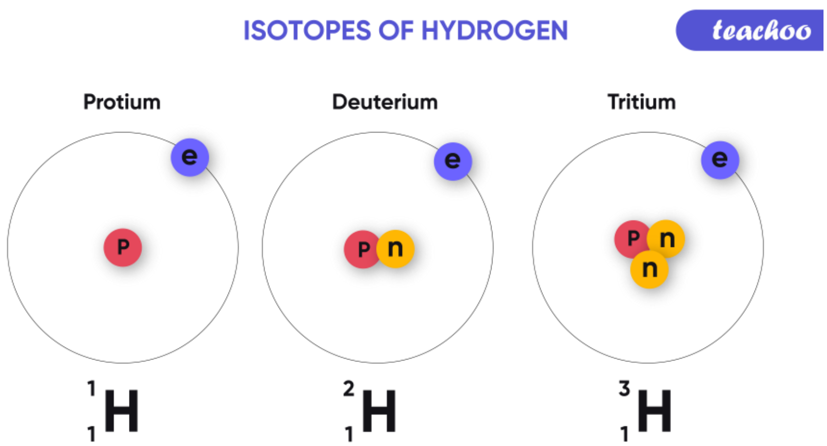
**Atomic Number (Z):** Represents the number of protons in an atom's nucleus. It determines the element's identity on the periodic table.

**Mass Number (A):** Represents the total number of protons and neutrons in an atom's nucleus. It helps determine the atom's mass.

As a standard, an atom of an element is written as $^{A}_{Z}X$

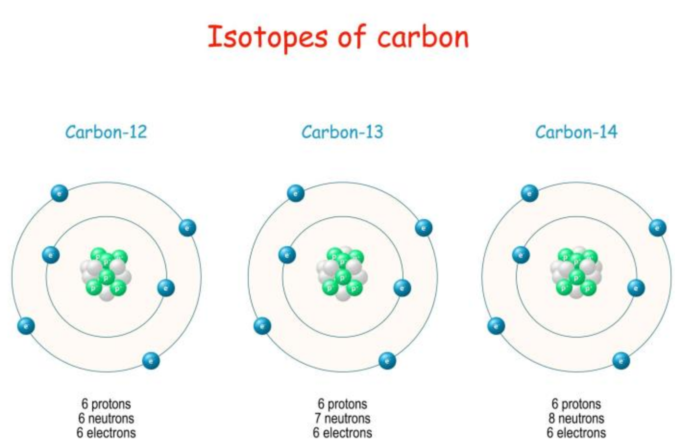
The nature and properties of an element are determined by its atomic number. There are some atoms that have the same atomic number but different mass numbers. These are known as **isotopes**.

Hydrogen for example has 3 isotopes;




Much as the contents of the nucleus are different as seen in the pictures above, the number of protons (atomic number) is the same for all and since atomic number is the biggest determinant of an element's properties, they are all still called 'hydrogen' but of different varieties.

Carbon also has three isotopes,




## ELECTRON EMISSION FROM ATOMS

Since electrons have a very small mass, they can easily be accelerated to high speeds under appropriate conditions; these fast moving electrons are responsible for a number of applications in modern technology including x-ray machines.

But before electrons are accelerated, they have to be ejected from atoms; this can be done in a number of ways, we shall explore two of them here;

## Thermionic emission

Thermionic emission is the release of electrons from a material when it is heated and the electrons gain sufficient energy to loosen and escape from the material.

This process is very useful in old television vacuum tubes, Cathode Ray Tubes, X-ray tubes and Electron Microscopes.

## Photoelectric emission

Photo electric emission is very similar to Thermionic emission, except that instead of using heat energy, it makes use of light energy.

Photoelectric emission occurs when light particles (photons) strike a material and give energy to electrons, causing them to be emitted.

This process is very useful to the operation of solar panels and photo electric sensors.

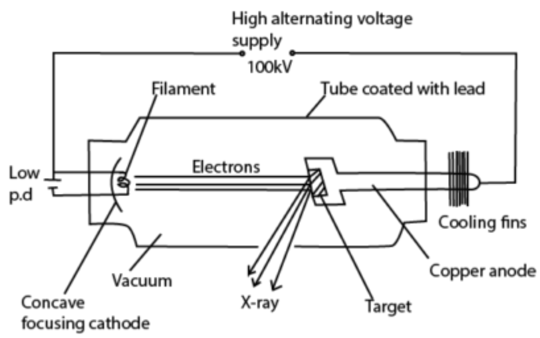
## Applications of thermionic emission

We now look at some devices whose operation largely depends on thermionic emission; we shall focus on the cathode ray tube & the x-ray tube

- **The X-ray tube**

An X-ray tube is a device used to generate X-rays, which are a form of high-energy electromagnetic radiation. The tube consists of a cathode and an anode enclosed in a vacuum-sealed glass or metal envelope. The cathode is heated to emit electrons through thermionic emission. These electrons are then accelerated towards the anode by a high voltage applied across the tube. When the high-speed electrons collide with the anode, typically made of tungsten, they decelerate rapidly, producing

X-rays through a process called bremsstrahlung (braking radiation). Some of the electrons also dislodge inner-shell electrons in the tungsten atoms, causing the emission of characteristic X-rays specific to tungsten.

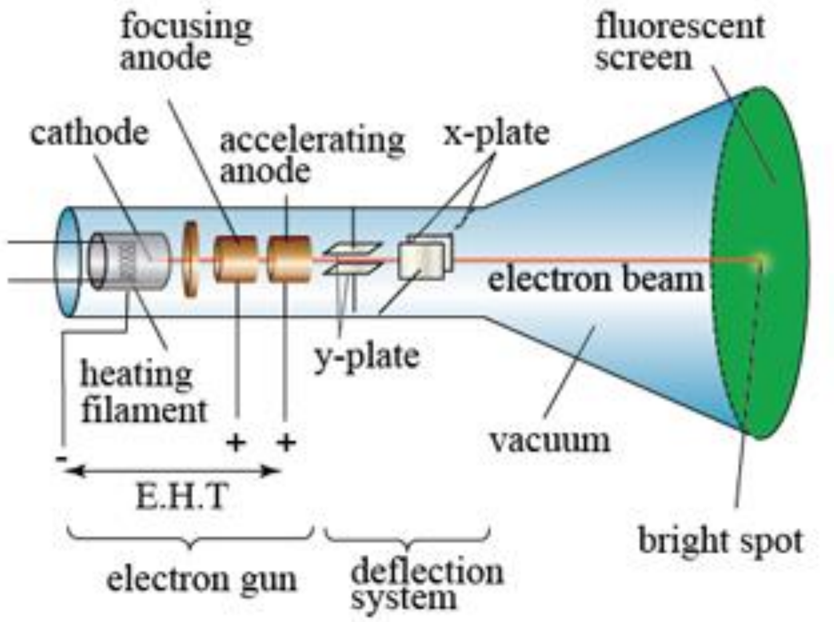



(**Left**: Schematic Diagram of an X-ray; **Right**: An X-ray tube)

The X-rays produced in the tube are directed through a window and used for various applications, most notably in medical imaging to view the inside of the body, such as in X-ray radiography and computed tomography (CT) scans. X-ray tubes are also used in industrial settings for non-destructive testing and material analysis, as well as in scientific research. The efficiency and quality of the X-rays generated depend on factors like the voltage applied, the current through the tube, and the materials used for the cathode and anode. Proper shielding and cooling mechanisms are essential to manage the high-energy radiation and heat produced during operation.

- **The Cathode Ray Tube**

A Cathode Ray Tube (CRT) is a device that was widely used in older television sets, computer monitors, and oscilloscopes to display images. The CRT operates by emitting a stream of electrons from an electron gun, which consists of a heated cathode and control grids. When the cathode is heated, it emits electrons through thermionic emission. These electrons are then accelerated and focused into a narrow beam by the control grids and anode. The beam travels through the vacuum inside the tube and strikes a phosphorescent screen at the opposite end.




The inside surface of the screen is coated with phosphor materials that emit light when struck by the electron beam, creating visible images. By varying the intensity and position of the electron beam using deflection coils or plates, which generate magnetic or electric fields, the CRT can scan the screen in a raster pattern to produce images. Color CRTs use three electron guns and corresponding phosphor dots in red, green, and blue, which combine to create a full spectrum of colors. Although largely replaced by modern flat-panel displays, CRTs were instrumental in the development of television and computer display technology.

**Control Grid**

The control grid is a crucial component in a Cathode Ray Tube (CRT) that regulates the flow of electrons from the cathode to the anode. Positioned between the cathode and the anode, the control grid functions by applying a negative voltage relative to the cathode. This voltage modulates the intensity of the electron beam by controlling the number of electrons that can pass through to the anode. By adjusting the voltage on the control grid, the brightness of the spot on the screen can be varied, allowing the CRT to create images with varying intensity levels. This modulation is essential for displaying different shades of brightness and achieving detailed, high-quality images.

**X and Y Plates**

The X and Y plates, also known as deflection plates, are responsible for directing the electron beam to specific positions on the phosphorescent screen. These plates are usually arranged in pairs: one pair for horizontal (X-axis) deflection and another pair for vertical (Y-axis) deflection. By applying varying voltages to these plates, an electric field is created that deflects the electron beam in the desired direction. The X plates control the horizontal movement of the beam, while the Y plates control the vertical movement. This deflection mechanism allows the electron beam to scan across the entire screen in a systematic manner, forming images by lighting up specific phosphor-coated spots on the screen. In older CRT displays and oscilloscopes, the precise control of the X and Y plates is crucial for accurately rendering graphical information and waveforms.

## Next Topics:

## Modern Physics, Part II: Nuclear Processes

## Modern Physics, Part III: Digital Electronics