Radiation and Nuclear Chemistry

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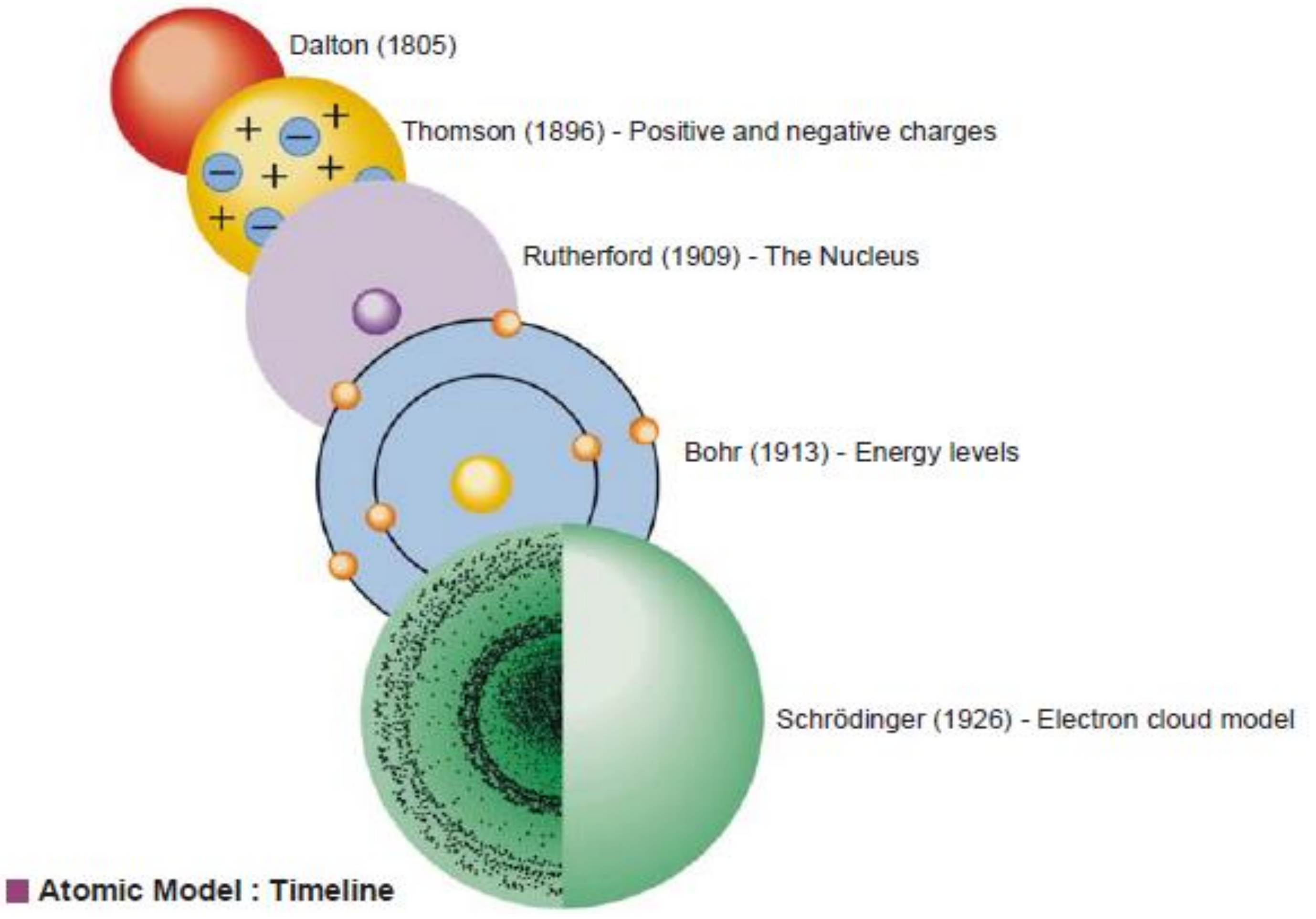
John Dalton (1805) considered that all matter was composed of small particles called atoms.

He visualized the atom as
a hard solid individual particle incapable of subdivision.



CATHODE RAYS – THE DISCOVERY OF ELECTRON

The knowledge about the electron was derived as a result of the study of the electric discharge in the discharge tube (J.J. Thomson, 1896). The discharge tube consists of a glass tube with metal electrodes fused in the walls (Fig. 1.1). Through a glass side-arm air can be drawn with a pump. The electrodes are connected to a source of high voltage (10,000 Volts) and the air partially evacuated.
The electric discharge passes between the electrodes and the residual gas in the tube begins to glow.
If virtually all the gas is evacuated from within the tube, the glow is replaced by faintly luminous 'rays' which produce fluorescence on the glass at the end far from the cathode. The rays which proceed from the cathode and move away from it at right angles in straight lines are called Cathode Rays.

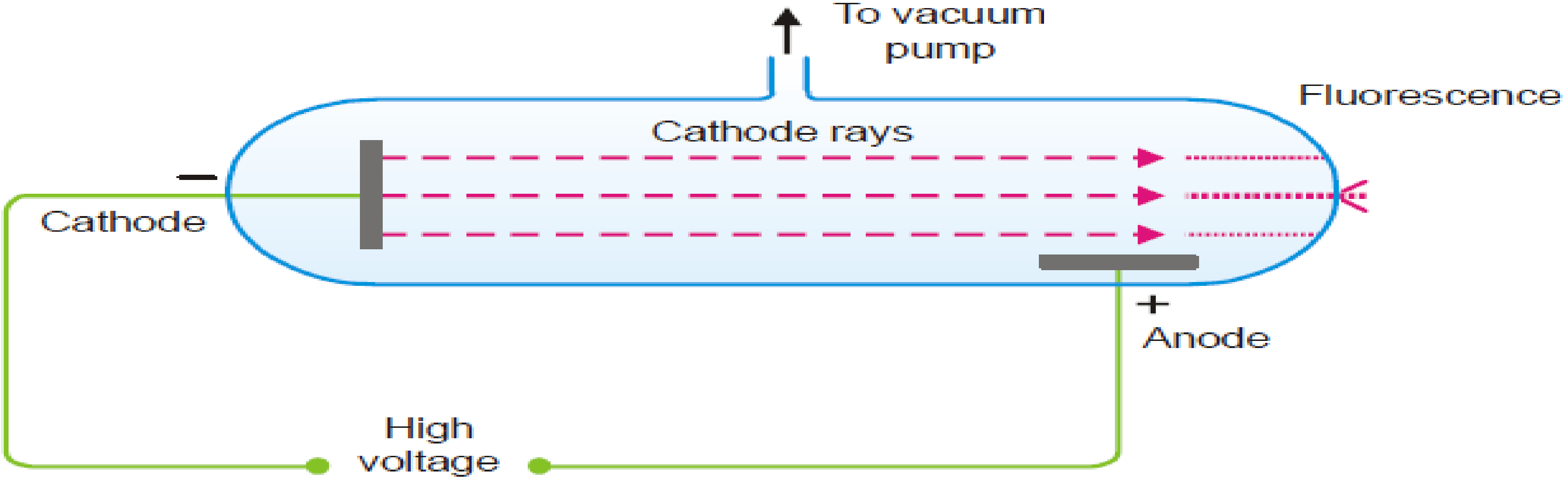


Figure 1.1
Production of cathode rays.

PROPERTIES OF CATHODE RAYS

1. They travel in straight lines away from the cathode and cast shadows of metallic objects placed in their path.
2. Cathode rays cause mechanical motion of a small pin-wheel placed in their path. Thus they possess kinetic energy and must be material particles.
3. They produce fluorescence (a glow) when they strike the glass wall of the discharge tube.
4. They heat up a metal foil to incandescence which they impinge upon.
5. Cathode rays produce X-rays when they strike a metallic target.
6. Cathode rays are deflected by the electric as well as the magnetic field in a way indicating that they are streams of minute particles carrying negative charge.

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DEFINITION OF AN ELECTRON

Having known the charge and mass of an electron, it can be defined as :

An electron is a subatomic particle which bears charge – 1.60×10^{-19} coulomb and has mass 9.1×10^{-28} g.

Alternatively, an electron may be defined as :

A particle which bears one unit negative charge and mass (1/1835)th of a hydrogen atom.

Since an electron has the smallest charge known, it was designated as unit charge by Thomson.

POSITIVE RAYS

In 1886 Eugen Goldstein used a discharge tube with a hole in the cathode (Fig. 1.2). He observed that while cathode rays were streaming away from the cathode, there were coloured rays produced simultaneously which passed through the perforated cathode and caused a glow on the wall opposite to the anode. Thomson studied these rays and showed that they consisted of particles carrying a positive charge. He called them Positive rays.

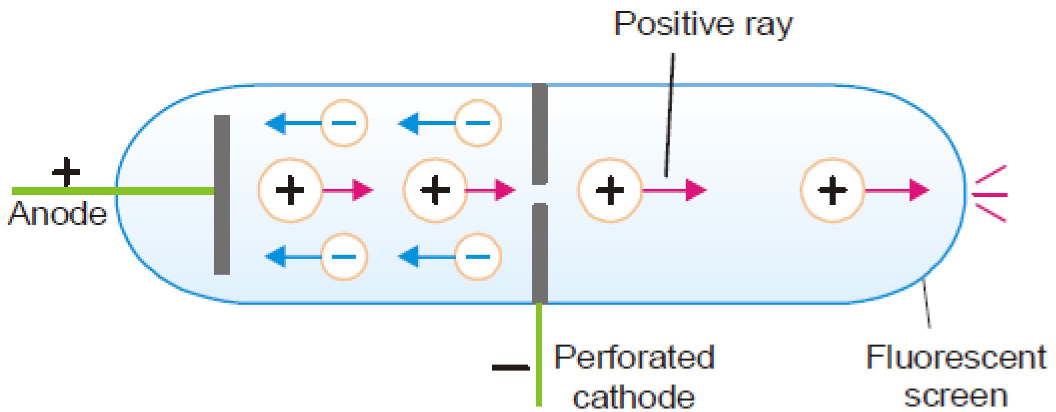

Figure 1.2
Production of Positive rays.

PROPERTIES OF POSITIVE RAYS

(1) They travel in a straight line in a direction opposite to the cathode.
(2) They are deflected by electric as well as magnetic field in a way indicating that they are positively charged.
(3) The charge-to-mass ratio (e/m) of positive particles varies with the nature of the gas placed in the discharge tube.
(4) They possess mass many times the mass of an electron.
(5) They cause fluorescence in zinc sulphide.

PROTONS

E. Goldstein (1886) discovered protons in the discharge tube containing hydrogen.

$$H \rightarrow H^{+} + e^{-}$$

proton

It was J.J. Thomson who studied their nature. He showed that :

(1) The actual mass of proton is 1.672×10^{-24} gram. On the relative scale, proton has mass 1 atomic mass unit (amu).

(2) The electrical charge of proton is equal in magnitude but opposite to that of the electron.

Thus proton carries a charge $+1.60 \times 10^{-19}$ coulombs or +1 elementary charge unit.

Since proton was the lightest positive particle found in atomic beams in the discharge tube, it
was thought to be a unit present in all other atoms. Protons were also obtained in a variety of nuclear
reactions indicating further that all atoms contain protons.

Thus a proton is defined as a subatomic particle which has a mass of 1 amu and charge + 1 elementary charge unit.

A proton is a subatomic particle which has one unit mass and one unit positive charge.

Canal rays

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NEUTRONS

In 1932 Sir James Chadwick discovered the third subatomic particle. He directed a stream of alpha particles ${}^{4}_{2}He$ at a beryllium target. He found that a new particle was ejected. It has almost the same mass (1.674×10^{-24} g) as that of a proton and has no charge.

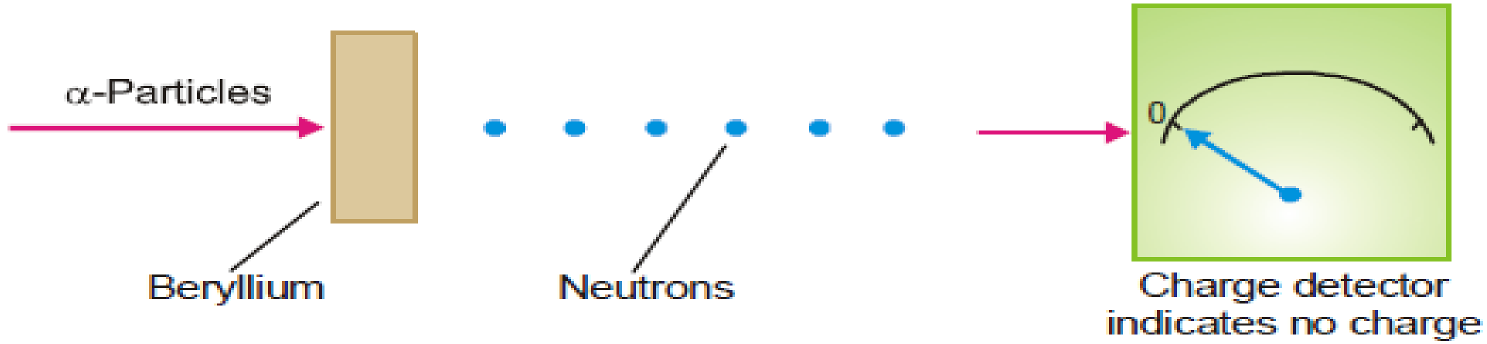


Figure 1.5
α-Particles directed at beryllium sheet eject neutrons whereby the electric charge detector remains unaffected.

He named it neutron. The assigned relative mass of a neutron is approximately one atomic mass unit (amu). Thus :

A neutron is a subatomic particle which has a mass almost equal to that of a proton and has no charge.

The reaction which occurred in Chadwick's experiment is an example of artificial transmutation
where an atom of beryllium is converted to a carbon atom through the nuclear reaction.

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

TABLE 1.1. CHARGE AND MASS OF ELECTRON, PROTON AND NEUTRON

Particle	Symbol	Mass		Charge	
		amu	grams	Units	Coloumbs
Electron	e^-	$\frac{1}{1835}$	9.1×10^{-28}	-1	-1.60×10^{-19}
Proton	p^+	1	1.672×10^{-24}	$+1$	$+1.60 \times 10^{-19}$
Neutron	n or n^0	1	1.674×10^{-24}	0	0

ALPHA PARTICLES

Alpha particles are shot out from radioactive elements with very high speed. For example, they come from radium atoms at a speed of 1.5×10^7 m/sec. Rutherford identified them to be di-positive helium ions, He^{2+} or ${}^4_2He$. Thus an alpha particle has 2+ charge and 4 amu mass.

α-Particles are also formed in the discharge tube that contains helium,

$$He \rightarrow He^{2+} + 2e^-$$

It has twice the charge of a proton and about 4 times its mass.

Conclusion

Though α-particle is not a fundamental particle of the atom (or subatomic particle) but because of its high energy $\frac{1}{2}mv^2$, Rutherford thought of firing them like bullets at atoms and thus obtain information about the structure of the atom.

(1) He bombarded nitrogen and other light elements by α-particles when H^+ ions or protons were produced. This showed the presence of protons in atoms other than hydrogen atom.

(2) He got a clue to the presence of a positive nucleus in the atom as a result of the bombardment of thin foils of metals.

RUTHERFORD’S ATOMIC MODEL – THE NUCLEAR ATOM

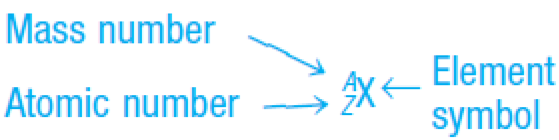
In 1909 Rutherford and Marsden performed their historic Alpha Particle-Scattering Experiment, They directed a stream of very highly energetic α-particles from a radioactive source against a thin gold foil provided with a circular fluorescent zinc sulphide screen around it.

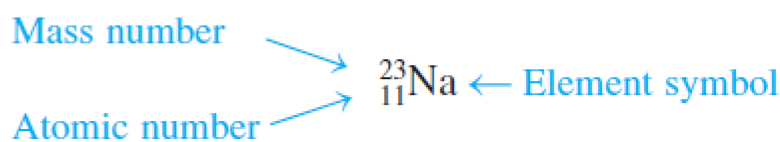
Whenever an α-particle struck the screen, a tiny flash of light was produced at that point.

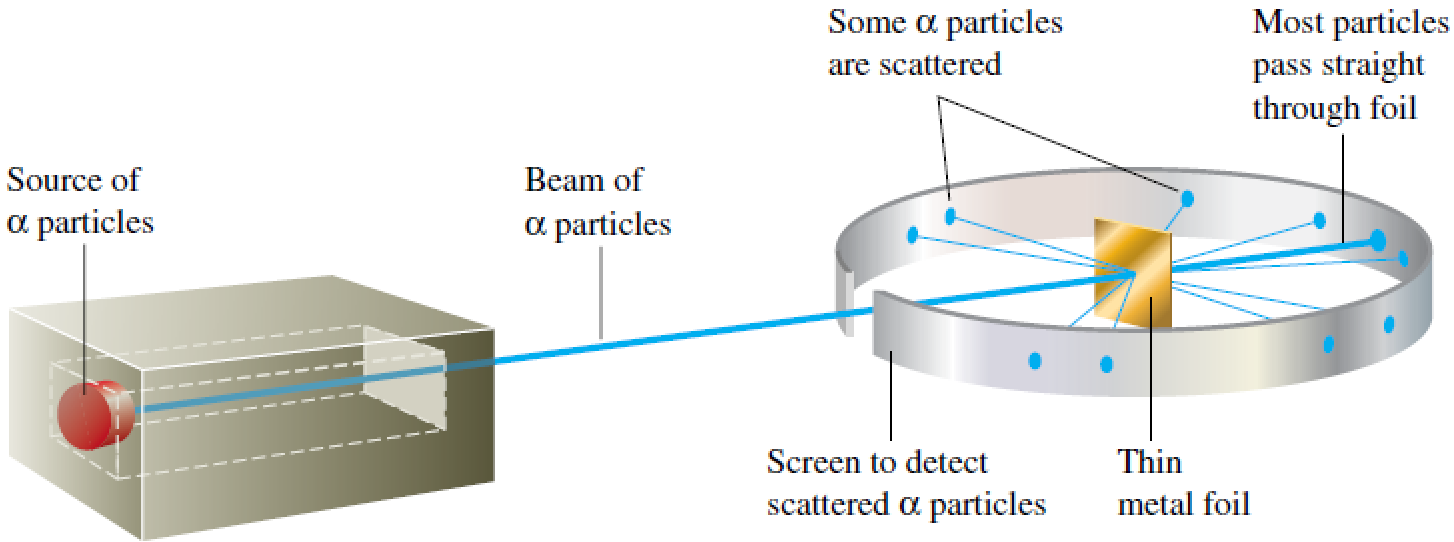
Rutherford and Marsden noticed that most of the α-particles passed straight through the gold foil and thus produced a flash on the screen behind it. This indicated that gold atoms had a structure with plenty of empty space. To their great astonishment, tiny flashes were also seen on other portions of the screen, some time in front of the gold foil. This showed that gold atoms deflected or ‘scattered’ α-particles through large angles so much so that some of these bounced back to the source. Based on

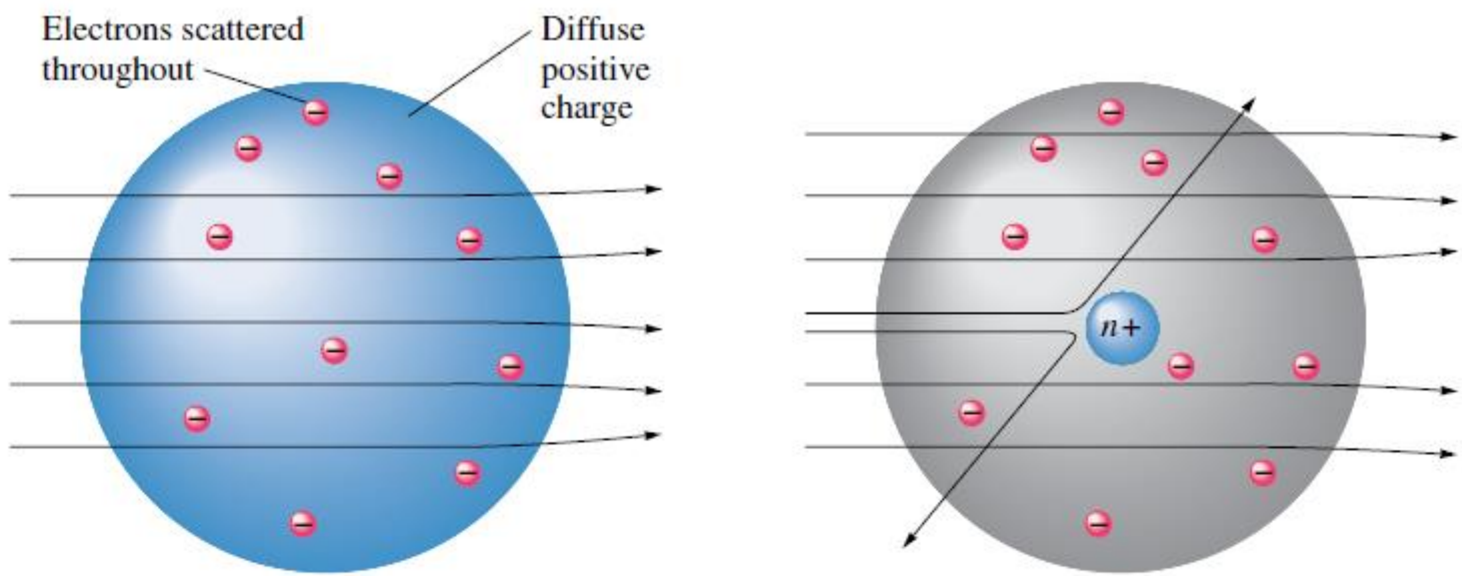
these observations, Rutherford proposed a model of the atom which is named after him. This is also called the Nuclear Atom. According to it :

Atom has a tiny dense central core or the nucleus which contains practically the
entire mass of the atom, leaving the rest of the atom almost empty.
The entire positive charge of the atom is located on the nucleus, while electrons
were distributed in vacant space around it.
The electrons were moving in orbits or closed circular paths around the nucleus
like planets around the sun.









(a) (b)

(a) The expected results of the metal foil experiment if Thomson's model were correct. (b) Actual results.

COMPOSITION OF THE NUCLEUS

Atomic Number, Z = Number of protons

Mass Number, A = Number of protons + Number of neutrons

∴ The number of neutrons is given by the expression :

$$N = A - Z$$

SOLVED PROBLEM. Uranium has atomic number 92 and atomic weight 238.029. Give the number of electrons, protons and neutrons in its atom.

SOLUTION

Atomic Number of uranium = 92

∴ Number of electrons = 92

and Number of protons = 92

Number of neutrons (N) is given by the expression

$$N = A - Z$$

Mass Number (A) is obtained by rounding off the atomic weight

= 238.029 = 238

$$\therefore N = 238 - 92 = 146$$

Thus uranium atom has 92 electrons, 92 protons and 146 neutrons

TABLE 1.2. COMPOSITION OF THE NUCLEUS OF SOME ATOMS

Atom	Mass Number (A)	Atomic Number (Z)	COMPOSITION	
			Protons = Z	Neutrons = A – Z
Be	9	4	4	5
F	19	9	9	10
Na	23	11	11	12
Al	27	13	13	14
P	31	15	15	16
Sc	45	21	21	24
Au	197	79	79	118

Rutherford Experiment:
Nuclear Atom