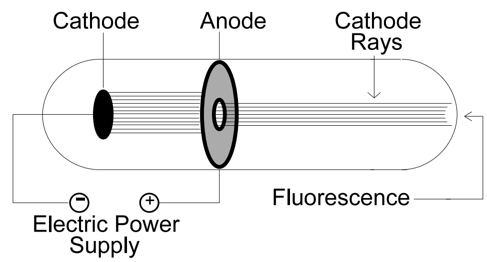
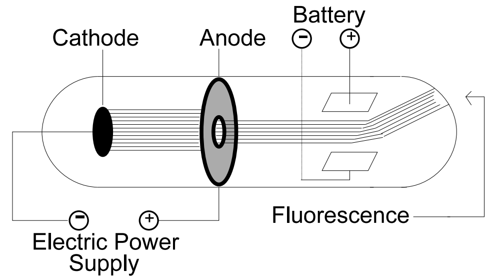
# Fundamental Subatomic Particles

**Early Cathode Ray Tube (CRT) Experiments (Cathode Rays)**

- Evacuated of gases
- Negative charge on cathode (small electrode in picture)
- Positively charged anode (big electrode) perforated to allow passage of a narrow beam of cathode rays
- Cathode ray is invisible and detected by fluorescent screen coated with ZnS

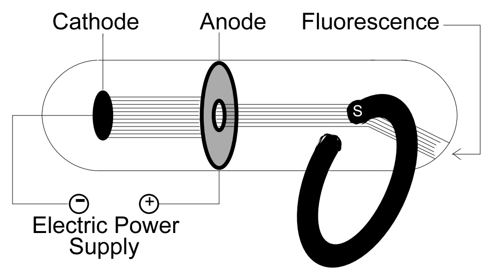



**Observations**
- Objects in beam produce shadow on screen
- Velocity of rays is less than the speed of light
- Direction of deflection of the beam in magnetic and electric fields is the same as that expected for a negative charge



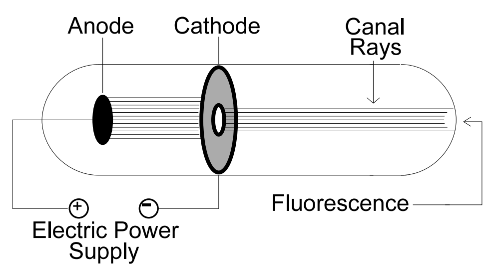

**Conclusions**
- Beam must consist of particles since it travels at a speed which is less than that of light
- Beam must carry a negative charge

- **THEREFORE**, Cathode rays are actually negatively charged particles




**Modified CRT Experiments (Canal Rays)**

- Same basic setup but charges on electrodes reversed
- Negatively charged cathode (now big electrode in picture) perforated to allow passage of a narrow beam of "canal rays"
- Positive charge on anode (small electrode)



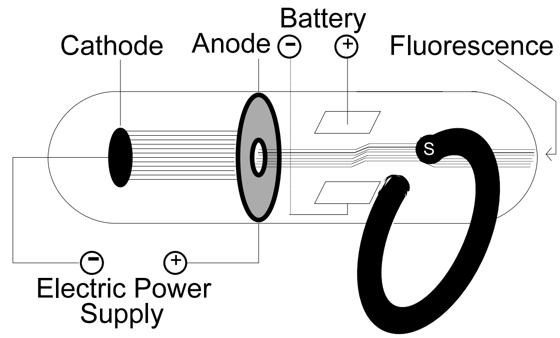

**Observations**

- Objects in beam produce shadow on screen
- Velocity of rays is less than the speed of light
- Direction of deflection of the beam in magnetic and electric field is the same as that expected for a positive charge

**Conclusions**
- Beam must consist of particles since they travel at speeds which are less than that of light
- Beam must carry a positive charge

- **THEREFORE**, Canal rays are actually positively charged particles

**Work of J.J. Thomson ~ 1897**
**A) Work on Cathode Rays**




- Used CRT in magnetic and electric fields
- Measured the degree of deflection in each field
- Determined the charge-to-mass ratio, e/m ratio, (see below) using many different metals as electrodes and using many different residual gases

Determination of e/m of Cathode Rays.

The magnetic and electric fields deflect the cathode rays in opposite directions. By varying these two opposing forces until they balance (an often-used principle in the design of experiments), Thomson was able to calculate from the field strengths, the e/m value for the cathode rays.

**Observations**

- All cathode rays produced from the different metals and using different residual gases left in tube after evacuation had the same e/m ratio. That being,

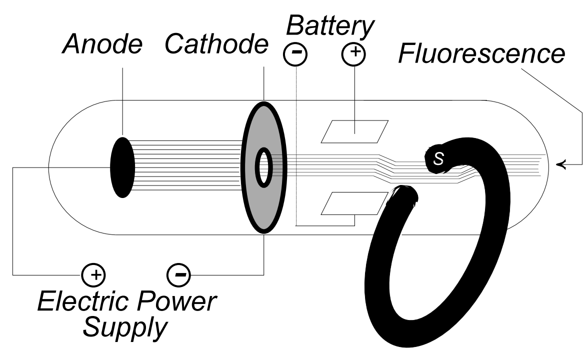
$$\boxed{\frac{e}{m_e} = -1.75882 \times 10^8 \; C/g}$$

**Conclusions**

- As only one type of cathode ray was ever produced it must be a **fundamental particle** found in all atoms (Now called the **electron**).

**B) Work on Canal Rays**

- Used modified CRT with electrode reversed
- Measured the deflection of canal rays in electric and magnetic fields
- Determined the e/m ratio for canal rays using different metals as electrodes and with differing residual gases




**Observations**

- Different e/m ratios produced when different gases were left in tube after evacuation
- Largest e/m ratio produced when hydrogen gas used as residual gas
- All other e/m ratios were integer fractions of this value (i.e. the other gases produced canal rays with masses which were integer multiples of hydrogen)

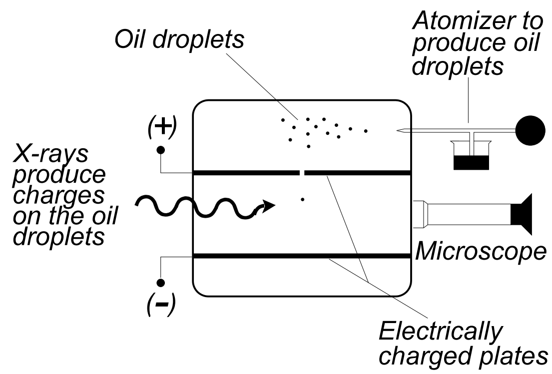
**Conclusions**

- There are many types of canal rays and thus canal rays are not fundamental particle of matter
- The smallest particle of positive charge was that produced by hydrogen gas (called the **Proton)**
- As other canal rays have masses which are multiples of hydrogen, the **Proton** is the fundament particle of positive charge
- The e/m ratio measured for the proton is,

$$\boxed{\frac{e}{m_p} = +9.57886 \times 10^4 \; C/g}$$

**The Millikan Oil Drop Experiment ~ 1909**

A spray of oil droplets is produced by the atomizer. These enter the apparatus through a tiny hole in the top electric plate. The motion of the oil droplet is observed with a telescope equipped with a micrometer eyepiece. The mass of the oil droplet is calculated by measuring the rate of descent of the droplet under the force of gravity. Ions are produced by ionizing radiation, such as x-rays, from a suitable source. Some of the oil droplets acquire an electric charge by adsorbing ions (attaching ions to their surface). For all practical purposes the adsorptions of ions does not alter the mass of the oil droplet to any measurable extent. The fall of the now-charged oil droplet is either sped up or slowed down to an extent which depends on the sign and the magnitude of the charge on the droplet. By analyzing the data from large numbers of droplets, Millikan concluded that the magnitude of the charge, q, on any droplet was always an integral multiple of the electronic charge, e.
That is, **q = n • e**, where n may be 1, 2, 3, etc.




**Observed fundamental charge:**

$$\boxed{e \;=\; \pm 1.60218 \times 10^{-19}\ C\ (coulombs)}$$

**Note:** **This quantity of charge is the fundamental unit of both positive and negative charge, and are further defined as one unit of charge, i.e., ±1.**

**Calculation of the mass of the electron:**

From Thomson's experiments:

$$\frac{e}{m_e} = -1.75882 \times 10^{8}\ C/g$$

$$m_e = \frac{e}{-1.75882 \times 10^{8}\ C/g} = \frac{-1.60218 \times 10^{-19}\ C}{-1.75882 \times 10^{8}\ C/g}$$

$$\text{or} \quad \boxed{m_e = 9.10939 \times 10^{-28}\ g}$$

**Calculation of the mass of the proton:**

From Thomson's experiments:

$$\frac{e}{m_p} = +9.57886 \times 10^{4}\ C/g$$

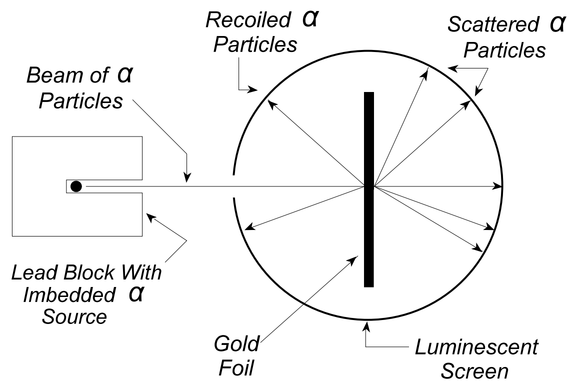
$$m_p = \frac{e}{+9.57886 \times 10^{4}\ C/g} = \frac{+1.60218 \times 10^{-19}\ C}{+9.57886 \times 10^{4}\ C/g}$$

$$\text{or} \quad \boxed{m_p = 1.67262 \times 10^{-24}\ g}$$

**The Nuclear Atom**
**The Work of Ernest Rutherford**

**Alpha (α) Particle**

- α particles are a natural form of radiation emitted at very high speeds from radioactive (unstable) elements.
- They have masses about four times that of a Hydrogen atom.
- They possess +2 charges.




**Experimental Procedure**

- A sample of radioactive material which emits α particles was imbedded in a block of lead to collimate the emitted α particles into a narrow beam.
- A beam of α particles was focused on a thin gold foil surrounded by a luminescent screen used to locate the α particles after collision with the foil.

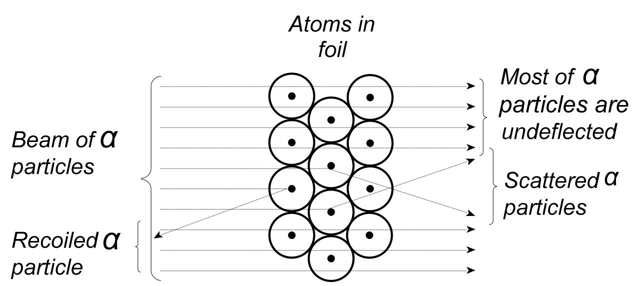
**Observations**

- The great majority of α particles passed through the foil undeflected.
- Approximately one in every 20,000 α particles suffered rather drastic deflections as they passed through the foil.
- A smaller fraction failed to pass through the foil but instead recoiled in the direction of the source.

**Rutherford's Explanation (Rutherford's Atomic Model)**

- The matter of the atom could not be evenly distributed throughout the atom as this would result in matter of insufficient density to deflect α particles. Instead he proposed that most of the mass and all of the positive charge (protons) is concentrated in a very tiny region which he called the nucleus.
- The great volume of the atom proper is occupied by the low mass electrons. Furthermore, there must be a number of electrons outside the nucleus which is equal to the charge on (or the number of protons in) the nucleus to yield an electrically neutral atom.

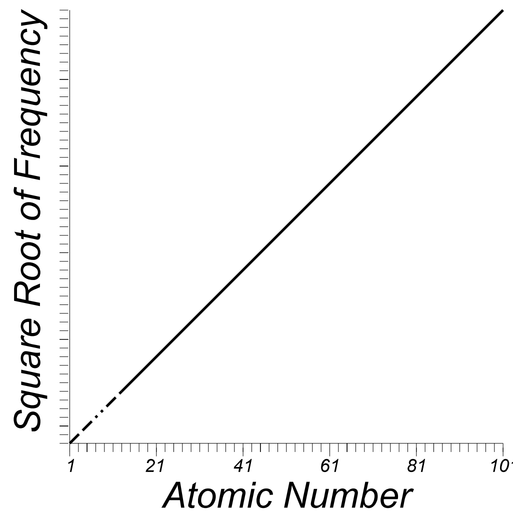
**The Rutherford Model**



**Atomic Numbers**
**The work of Henry Moseley ~ 1914**

**Experimental Setup**

- Studied X-rays produced when electrons in cathode ray tubes strike an anode made of various metals.




**Observations**

- The square root of the frequencies of the X-rays produced by the various elements correlated by assigning each element a unique integer (which he called an atomic number).
- The atomic numbers were found to be identical to the charges on the various nuclei as found by Rutherford.

**Conclusions**

- The atomic number represent the number of protons present in the nucleus of each atom.
- The periodic properties exhibited by the elements are determined by their atomic numbers and not by their atomic masses (as had been previously believed).
- There must be another (uncharged!) particle in the nucleus as the sum of the masses of the protons and electrons amounts to less than half the total mass of any given atom.

**The Neutron**
**The Work of James Chadwick ~ 1932**

Chadwick bombarded Be atoms with α particles and observed that the collisions produced a new atom (carbon) and an uncharged particle which contained no protons or electrons which was named the neutron.

$$\boxed{m_n \; = \; 1.67493 \times 10^{-24}\ g}$$

$$^{9}_{4}\text{Be} + {}^{4}_{2}\alpha \longrightarrow {}^{12}_{6}\text{C} + {}^{1}_{0}\text{n}$$

**Summary of the Properties of Subatomic Particles**

| | Electronic Charge | | Mass | |
|---|---|---|---|---|
| | **SI Units** | **Atomic Units** | **SI Units** | **Atomic Units** |
| **proton** | **$+1.60218 \times 10^{-19}$ C** | **+1** | **$1.67262 \times 10^{-24}$ g** | **1.00728 amu** |
| **neutron** | **0** | **0** | **$1.67493 \times 10^{-24}$ g** | **1.00866 amu** |
| **electron** | **$-1.60218 \times 10^{-19}$ C** | **−1** | **$9.10939 \times 10^{-28}$ g** | **0.00054858 amu** |