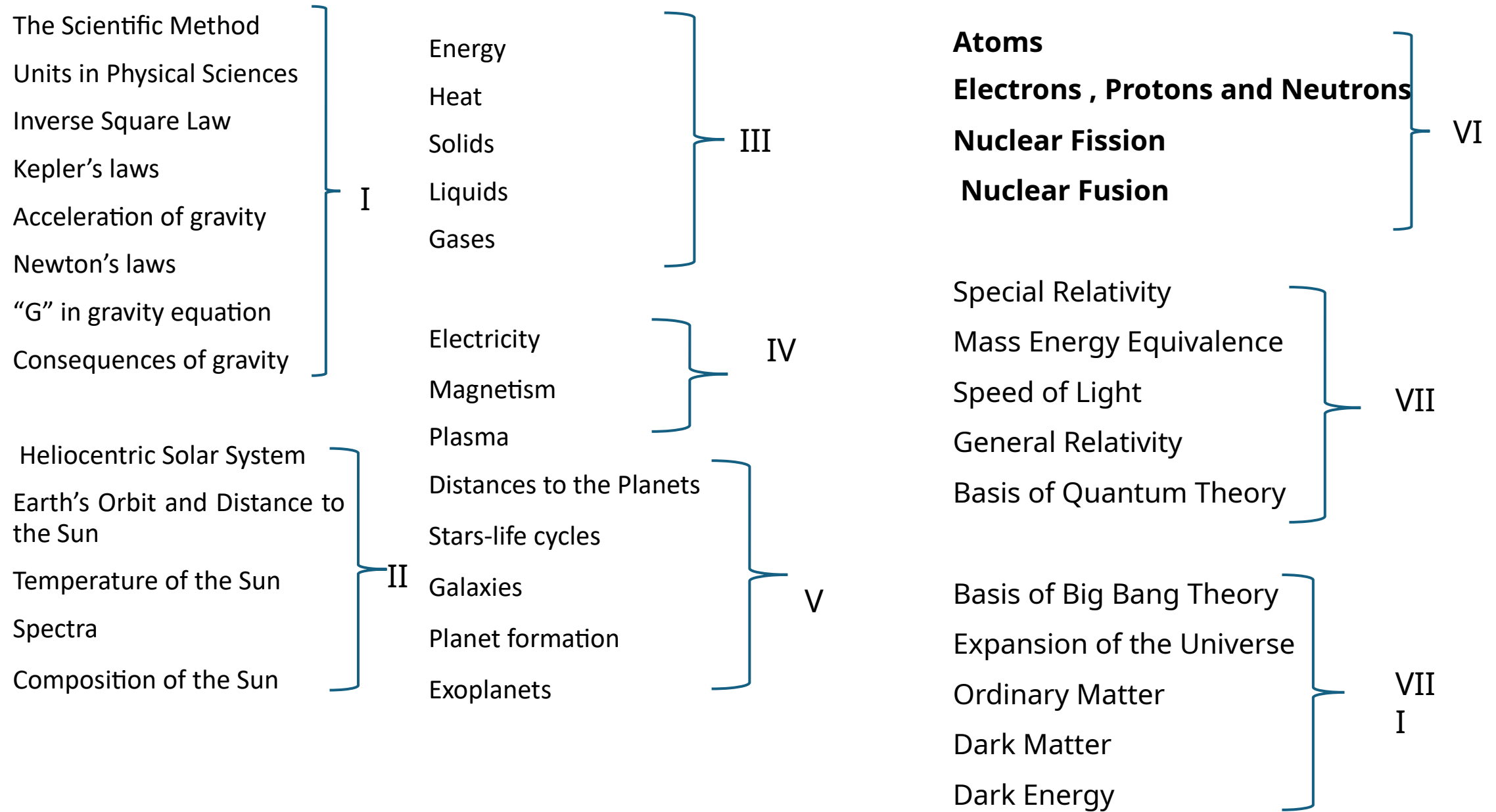


# How Do Physical Scientists Know What They Know?

## How Do We Know VI

Jim Rauf



Atoms

Electrons , Protons and Neutrons

Nuclear Fission

Nuclear Fusion

# Atoms

## Ancient Greek Philosophy (5th-4th Century BC)

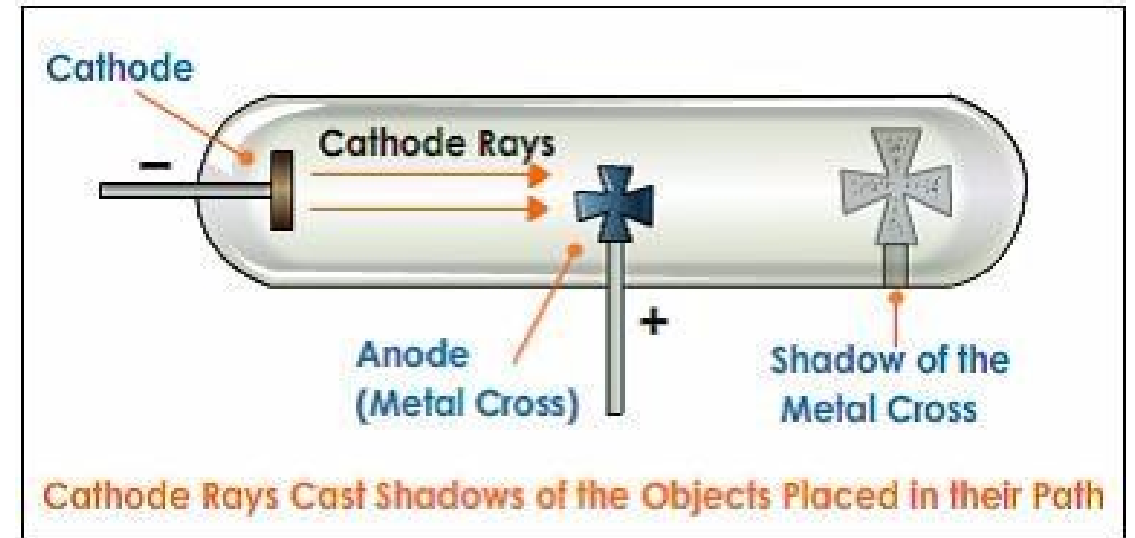
- **Democritus** (460–370 BC): Proposed that matter is composed of small, indivisible particles called "**atomos**," meaning "uncuttable"
- **Aristotle** (384–322 BC): Rejected the atomic theory, believing matter was made of four elements—earth, water, air, and fire
- His view dominated for centuries

## Revival of Atomic Theory (17th-18th Century)

- **Robert Boyle** (1661): Argued against Aristotle's four elements and defined **elements** as substances that **cannot be broken down further**
- **Antoine Lavoisier** (1789): Established the **Law of Conservation of Mass**, stating that matter cannot be created or destroyed in chemical reactions
- **John Dalton 1803** Proposed: all matter is made of atoms
  - Atoms are indivisible and indestructible
  - Atoms of the same element are identical
  - Atoms combine in simple whole-number ratios to form compounds
  - Chemical reactions involve the rearrangement of atoms

# Electrons

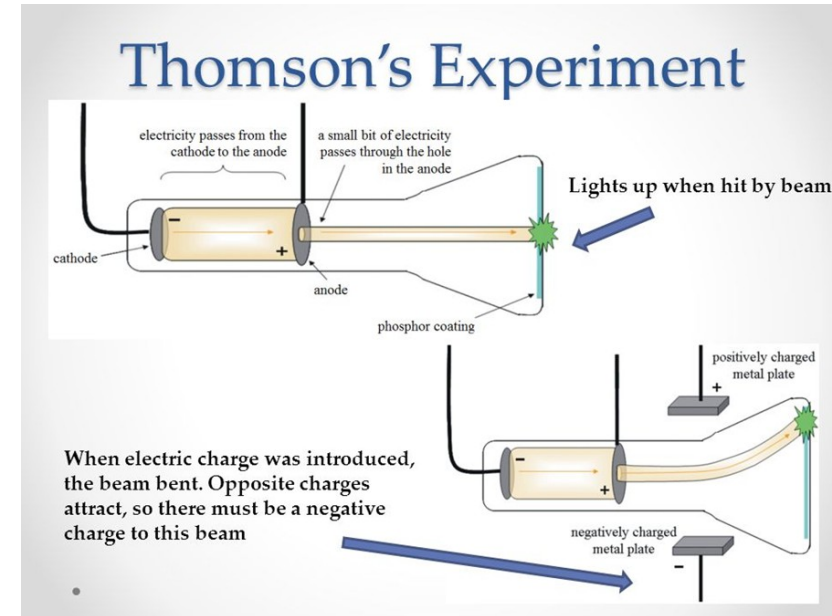
- **William Crookes** and others invented the **Crookes tube** around 1869–1875
- It is a partially evacuated glass bulb with two metal electrodes, the cathode and the anode, one at either end
- When a high voltage is applied between the electrodes, **cathode rays (electrons)** are projected in straight lines from the cathode
- It was used to study the properties of cathode rays
  - Traveled in straight lines
  - Could cast shadows
  - Were deflected by electric and magnetic fields
  - Scientists debated whether these rays were waves or particles



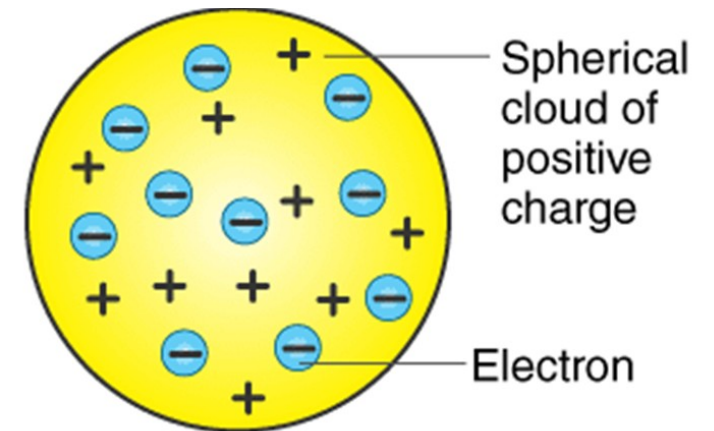
# Atoms

## Discovery of Subatomic Particles (Late 19th - Early 20th Century)

- **J.J. Thomson (1897):** Discovered the **electron** using the **cathode ray tube** experiment
- **Measured Charge-to-Mass Ratio ( $e/m$ ):** Using a specially designed cathode ray tube
- **Thomson** showed that the rays were deflected by **electric and magnetic fields**
- Indicating they were **negatively charged particles, not waves**
- By calculating the charge-to-mass ratio
$$e/m = 1.758820 \times 10^{11} \text{ C/kg}$$
He concluded that these particles were **much lighter than atoms**, identifying them as a new fundamental particle—the **electron**



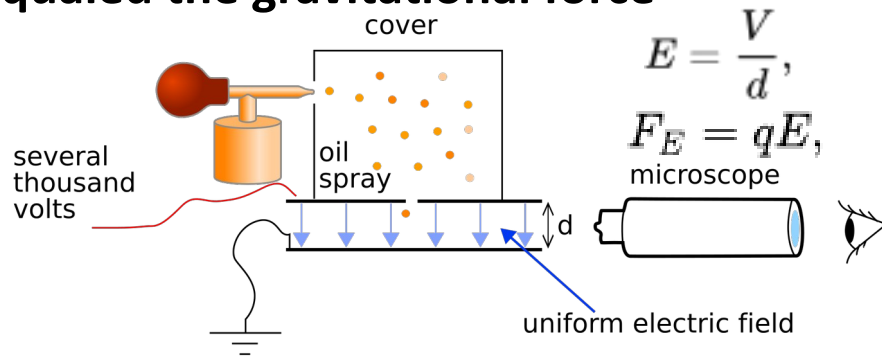
- Leading to the "**Plum Pudding Model**" (negative electrons embedded in a positive sphere).



# Mass of the Electron

## Millikan's Oil Drop Experiment (Charge of the Electron) 1909

- Millikan balanced tiny oil droplets between electrically charged plates and adjusted the field until the drops were suspended, meaning the **electric force** on the droplet **equaled the gravitational force**



- Through his experiment, Millikan calculated the charge of a single electron to be:

$$e = 1.6 \times 10^{-19} \text{ C}$$

- Once the charge  $e$  was known, the mass  $m$  could be calculated using Thomson's charge-to-mass ratio:

$$m = \frac{e}{\left(\frac{e}{m}\right)}$$

- Plugging in the values from Thomson's and Millikan's experiments:

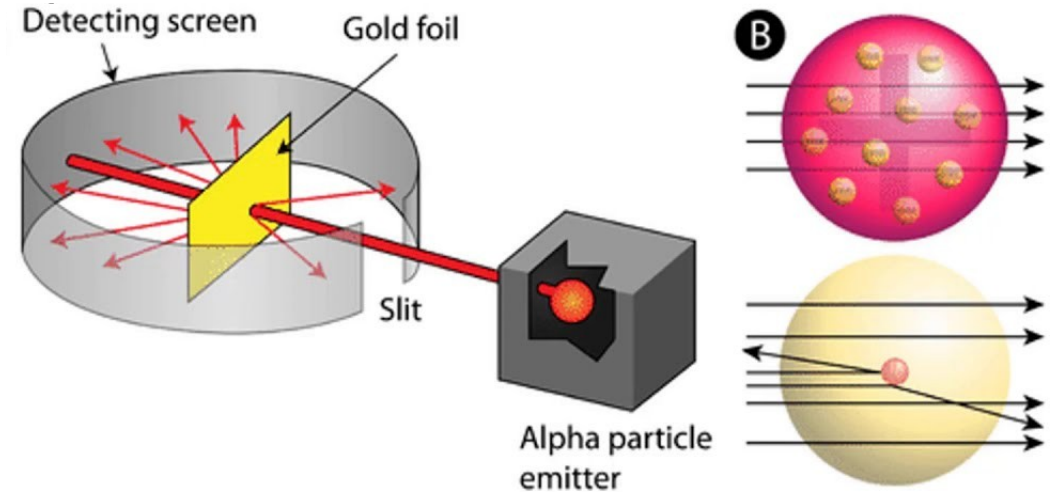
$$m = \frac{1.6 \times 10^{-19} \text{ C}}{1.76 \times 10^{11} \text{ C/kg}} \approx 9.1 \times 10^{-31} \text{ kg}$$

- Thus, the **mass of the electron** was determined to be approximately  $9.1 \times 10^{-31} \text{ kg}$

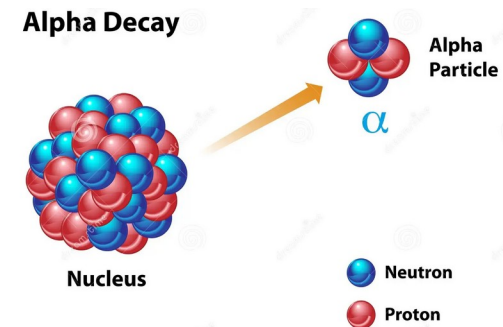
## Electrons

### Rutherford's Nuclear Model (1911)

- **Ernest Rutherford** conducted the **gold foil scattering experiments**
- **Revealing** that atoms have a small, dense, positively charged nucleus, with electrons orbiting around it
- They demonstrated that every **atom** has a **nucleus** where all of its **positive charge** and **most of its mass** is concentrated
- They deduced this after measuring how an **alpha particle** beam is scattered when it strikes a thin metal foil
- The experiments were performed between 1906 and 1913 by **Hans Geiger** and **Ernest Marsden** under the direction of **Ernest Rutherford**



- **Alpha particles** consist of two **protons** and two **neutrons** bound together into a **particle** identical to a **helium-4 nucleus**



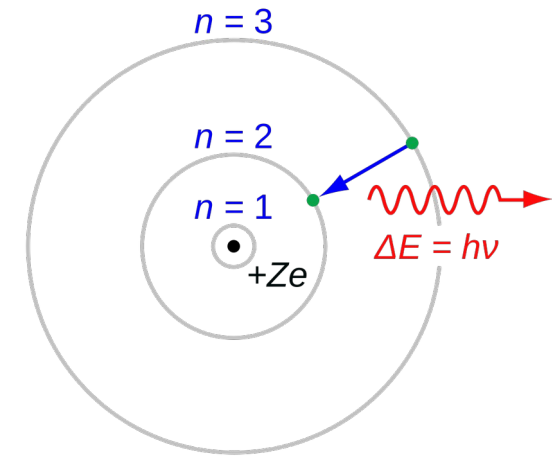
## Electrons

### Bohr's Quantum Model (1913)

- **Niels Bohr** (1913): Developed the **Bohr Model** of atoms
- He introduced the idea that electrons move in **fixed orbits (energy levels)** around the nucleus
- That electrons can move between energy levels by **absorbing** or **emitting energy**
- This explained atomic spectra but had limitations



1885-1962

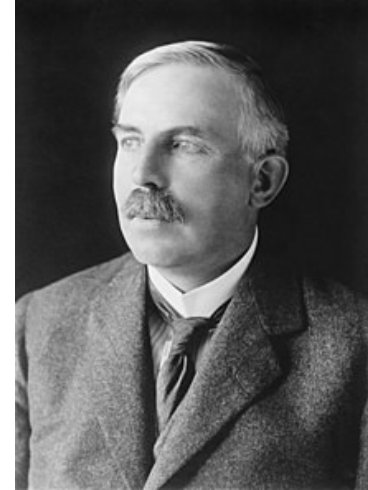


- The **Bohr model** of the **hydrogen atom**
- A **negatively charged electron**, confined to an **atomic orbital**, orbits a small, **positively charged nucleus**
- A **quantum jump** between orbits is accompanied by an **emitted** or **absorbed** amount of **electromagnetic radiation**.

# Protons

## Discovery of the Proton (1917-1919)

- **Rutherford's Alpha Particle Experiments (1917):**
  - He bombarded **nitrogen gas** with **alpha particles (helium nuclei)**.
  - This caused the emission of **hydrogen nuclei**, suggesting that hydrogen nuclei were fundamental building blocks of atoms.
- **Naming the Proton (1920):**
  - **Rutherford** concluded that the **hydrogen nucleus** was a distinct particle present in all atomic nuclei.
  - He named it the **proton**, derived from the Greek word "**prōtos**," meaning "first."



1871-  
1937

"All science is either physics or stamp collecting."

# Protons

## Confirmation and Further Developments

- By the 1920s, experiments confirmed that **protons**, along with **electrons**, determined atomic structure
- **Significance**
- The discovery of the **proton** helped establish **modern atomic theory**, paving the way for **quantum mechanics, nuclear physics**, and our **understanding of chemical elements**

## Factors that make chemistry work:

**Atomic Structure** The arrangement of electrons in energy levels (orbitals) determines how atoms interact.

**Chemical Bonds** –Sharing (covalent bonds), Transferring (ionic bonds), or Pooling (metallic bonds) electrons. These bonds hold compounds together.

**Electronegativity & Polarity** – Differences in electronegativity influence bond type and molecular properties.

**The Laws of Thermodynamics** –Reactions follow energy principles.

**Conservation of Mass & Energy** – Atoms just rearrange into new substances

# Electrons

## Louis de Broglie (1924) wave-particle duality

- The concept that **particles exhibit both matter and wave nature**
- **Louis de Broglie** proposed that **electrons** exhibit **both particle and wave properties**
- Meaning they do not travel in simple circular orbits
- **He** proposed that **particles** have **associated wavelengths**, and their behavior can be described using **wave equations**



1892-1987

- He derived the **de Broglie wavelength equation**:

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

- where:
  - $\lambda$  = wavelength of the particle
  - $h$  = Planck's constant
  - $p$  = momentum of the particle
  - $m$  = mass,
  - $v$  = velocity
- This meant **electrons and other particles could behave like waves.**

# Neutrons

## Early Clues and Predictions

- **Rutherford's Atomic Model (1911):**
  - **Ernest Rutherford** proposed that atoms have a **dense, positively charged nucleus surrounded by electrons**
  - However, the nucleus only contained **protons**, and the observed atomic masses did not match predictions.
- **Isotopes (1919 - 1920):**
  - Experiments showed that some atoms had the same number of protons but **different masses**, hinting at the presence of a **neutral particle**
  - **Rutherford** hypothesized the existence of a **neutral nuclear particle**, later called the **neutron**

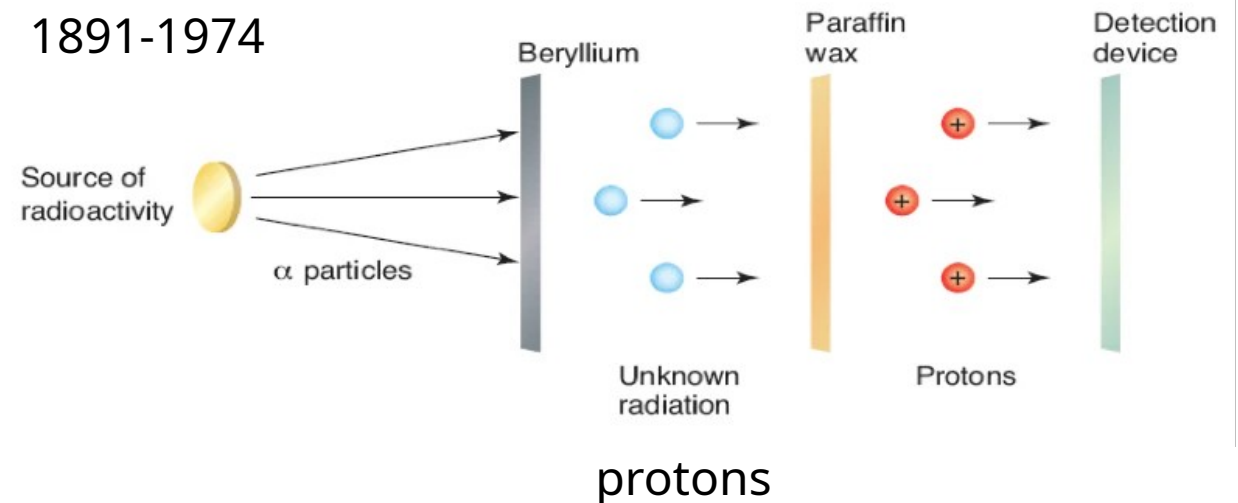
# Neutrons

## Experiments Leading to Discovery

- **James Chadwick's Experiment (1932):**
  - Chadwick bombarded **beryllium** with **alpha particles** (*helium nuclei*) and observed an unusual radiation that was **not deflected by electric or magnetic fields**
  - This indicated the presence of **uncharged particles** with nearly the same mass as protons
  - He confirmed that these particles were **neutrons**, with a mass slightly greater than a proton



1891-1974



# Neutrons

## Indirect Determination Using Mass Differences (Nuclear Masses)

- Neutrons have no electric charge, techniques used to measure the charge-to-mass ratio for electrons and protons could not be used
- Scientists used nuclear mass differences
- Using the known masses of certain isotopes scientists could compare the mass of nuclei with different numbers of neutrons
- The mass of a **hydrogen** atom (which has a single proton and no neutron) was known.
- The mass of a **deuterium** atom (which has one proton and one neutron) was known.

$$m_{\text{neutron}} \approx m_{\text{deuterium}} - m_{\text{proton}}$$

- This suggested that the **neutron's mass** was **slightly greater** than that of the **proton**

$$m_{\text{neutron}} \approx 1.008664 \text{ u or } 1.675 \times 10^{-27} \text{ kg}$$

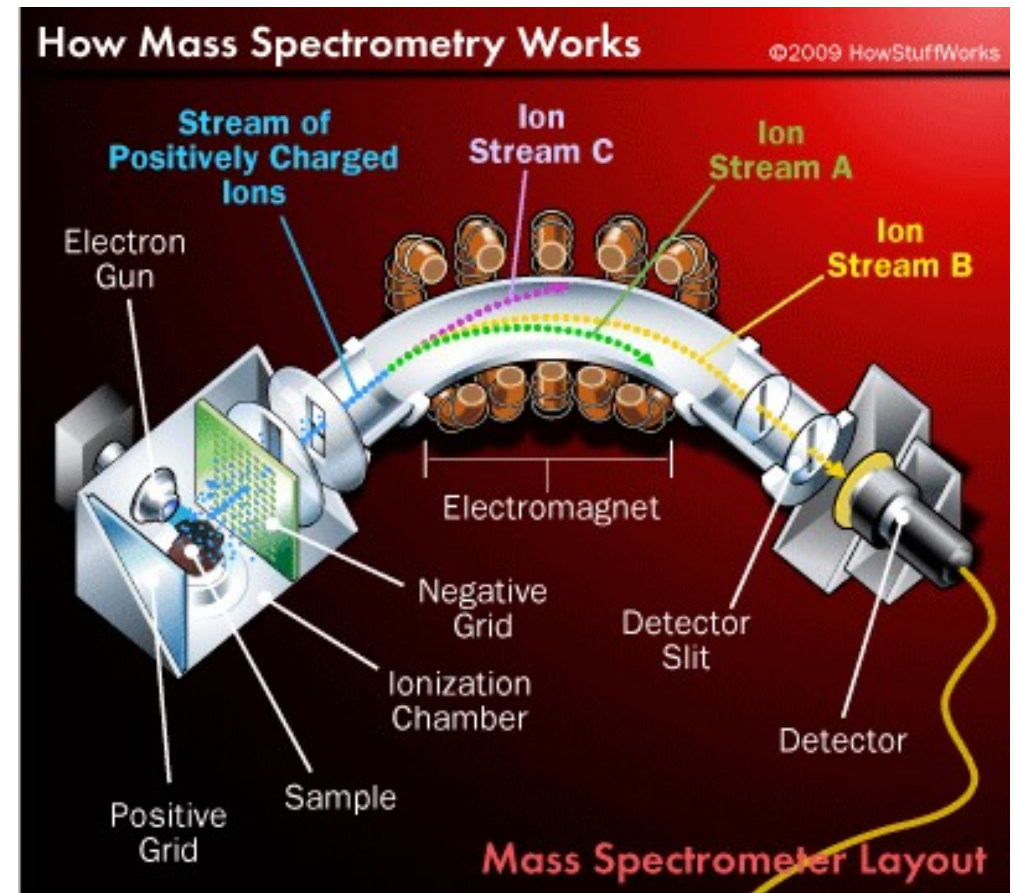
## Effect of the Discovery

- **Explained Atomic Mass Discrepancies:** The neutron helped account for the extra mass in atoms
- **Led to Nuclear Fission (1938):** Neutrons played a key role in splitting uranium atoms, leading to nuclear power and atomic bombs
- **Advancements in Particle Physics:** The discovery of neutrons contributed to the development of the **Standard Model** and **quantum mechanics**
- **Chadwick's** discovery earned him the **Nobel Prize in Physics in 1935**, cementing the neutron's role as a fundamental building block of matter

# Mass of the Proton

## Mass Spectrometry and Determination of Absolute Mass

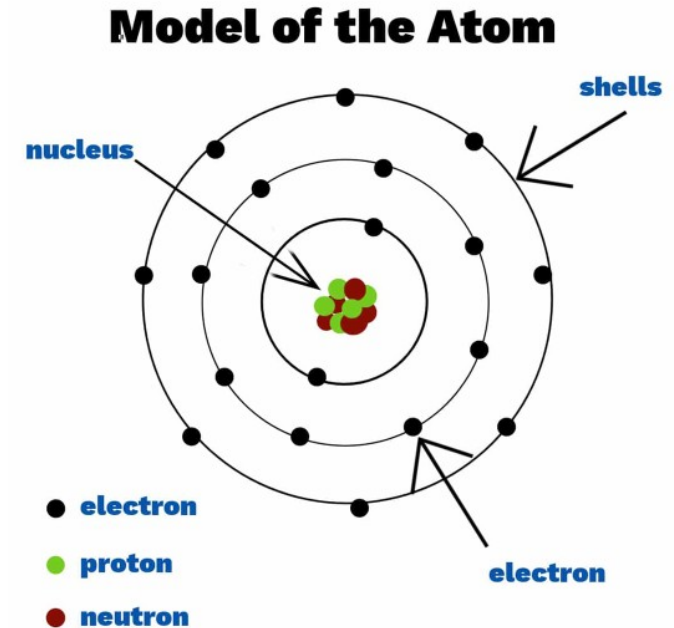
- In the 1920s and 1930s, scientists developed **mass spectrometry**, a technique that **separated particles by their mass-to-charge ratios** under electromagnetic fields
- **F. W. Aston**, was able to precisely measure the masses of various atoms and ions
- He used it to confirm that hydrogen ions (essentially **protons**) had a mass approximately 1836 times greater than that of the **electron**



# Atoms

## Atomic Components

- Protons ( +1 charge /  $1.67 \times 10^{-27}$  kg )
- Neutrons ( 0 charge /  $1.67 \times 10^{-27}$  kg )
- Electrons ( -1 charge /  $9.11 \times 10^{-31}$  kg )
- **All ( most ) elements contain all three**
- Atoms of the same element contain the same number of protons, but neutrons may vary
- Each element has a unique number of protons





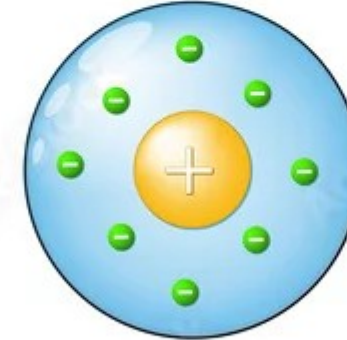
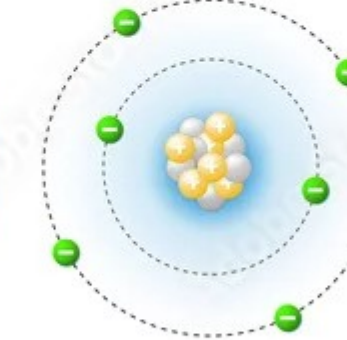
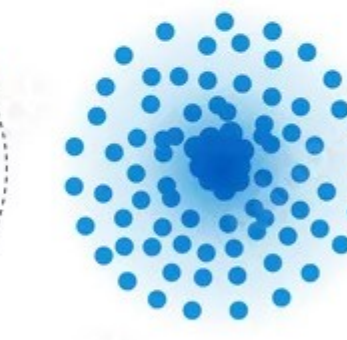





# Atoms

- **Modern Quantum Mechanics (20th Century)**
- **Erwin Schrödinger (1926)**: Introduced the **Quantum Mechanical Model**, describing electrons as probability clouds rather than fixed orbits
- **Werner Heisenberg (1927)**: Formulated the **Uncertainty Principle**, stating that the exact position and momentum of an electron cannot be simultaneously known
- **James Chadwick (1932)**: Discovered the **neutron**, explaining atomic mass and leading to a better understanding of isotopes

## Contemporary Atomic Theory

- Modern atomic theory incorporates **quantum mechanics**, recognizing that **electrons** exist in **probabilistic orbitals** rather than fixed paths
- Advances in particle physics, such as the discovery of **quarks** and the Standard Model, have further refined our understanding of atomic structure

# Atomic Models

<p>Solid sphere model</p> 	<p>Plum pudding model</p> 	<p>Planetary model</p> 	<p>Bohr model</p> 	<p>Quantum model</p> 
<p>1803</p> <p>J. Dalton</p>	<p>1897</p> <p>J. Thomson</p>	<p>1911</p> <p>E. Rutherford</p>	<p>1913</p> <p>N. Bohr</p>	<p>1926</p> <p>E. Schrödinger</p>
				

# Periodic Table of Elements

## Early Discoveries (Ancient to 18th Century)

- Alchemists and early chemists knew of some elements (gold, silver, copper, iron, etc.) but did not recognize them as part of a systematic order
- In the late 18th century, **Antoine Lavoisier** identified and classified elements into gases, metals, nonmetals, and earths

## Atomic Weights and Early Classification (19th Century)

- **John Dalton** (1803) introduced atomic theory, proposing that each element consists of unique atoms with specific weights
- **Johann Döbereiner** (1817) observed "triads" of elements (e.g., lithium, sodium, potassium) with similar properties
- **Alexandre-Émile Béguyer de Chancourtois** (1862) created the first 3D periodic system by arranging elements in a spiral based on atomic weights

# Periodic Table of Elements

## Mendeleev's Breakthrough (1869)

- **Dmitri Mendeleev** arranged elements by increasing atomic weight and grouped them by chemical properties
- He left gaps for undiscovered elements and correctly predicted properties of elements like gallium and germanium

## Refinements and Atomic Number (20th Century)

- **Henry Moseley** (1913) discovered that elements should be ordered **by atomic number (proton count)**, not atomic weight

## Modern Periodic Table

- **Glenn T. Seaborg** (1940s) restructured the table by placing the actinide and lanthanide series below the main body
- The table continues to be updated with newly synthesized elements

# The Periodic Table of the Elements

group 1 2 13 14 15 16 17 18

period 1 2 3 4 5 6 7

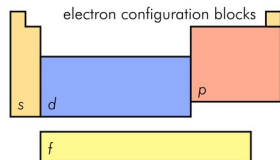
atomic mass or most stable mass number  
1st ionization energy in kJ/mol  
chemical symbol  
name  
electron configuration

atomic number  
electronegativity  
oxidation states most common are bold

alkali metals  
alkaline metals  
other metals  
transition metals  
lanthanoids  
actinoids

metalloids  
nonmetals  
halogens  
noble gases  
unknown elements  
radioactive elements have masses in parenthesis

1.00794 1312.0 2.20 H Hydrogen 1s <sup>1</sup>	6.941 520.2 0.98 Li Lithium 1s <sup>2</sup> 2s <sup>1</sup>	9.012182 899.5 1.57 Be Beryllium 1s <sup>2</sup> 2s <sup>2</sup>	22.98976 495.8 0.93 Na Sodium [Ne] 3s <sup>1</sup>	24.3050 737.7 1.31 Mg Magnesium [Ne] 3s <sup>2</sup>	44.95591 633.1 1.36 Sc Scandium [Ar] 3d <sup>1</sup> 4s <sup>2</sup>	47.867 658.8 1.54 Ti Titanium [Ar] 3d <sup>2</sup> 4s <sup>2</sup>	50.9415 650.9 1.63 V Vanadium [Ar] 3d <sup>3</sup> 4s <sup>1</sup>	51.9962 652.9 1.66 Cr Chromium [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	54.93804 717.3 1.55 Mn Manganese [Ar] 3d <sup>5</sup> 4s <sup>2</sup>	55.845 762.5 1.83 Fe Iron [Ar] 3d <sup>6</sup> 4s <sup>2</sup>	58.93319 760.4 1.91 Co Cobalt [Ar] 3d <sup>7</sup> 4s <sup>2</sup>	58.6934 737.1 1.88 Ni Nickel [Ar] 3d <sup>8</sup> 4s <sup>2</sup>	63.546 745.5 1.90 Cu Copper [Ar] 3d <sup>10</sup> 4s <sup>1</sup>	65.38 906.4 1.65 Zn Zinc [Ar] 3d <sup>10</sup> 4s <sup>2</sup>	69.723 578.8 1.81 Ga Gallium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	72.64 762.0 2.01 Ge Germanium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	74.92160 947.0 2.18 As Arsenic [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	78.96 941.0 2.55 Se Selenium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	79.904 1139.9 2.96 Br Bromine [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	83.798 1350.8 3.00 Kr Krypton [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>	8.0061 800.6 2.04 B Boron 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>1</sup>	12.0107 1086.5 2.55 C Carbon 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>2</sup>	14.0067 1402.3 3.04 N Nitrogen 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>3</sup>	15.9994 1313.9 3.44 O Oxygen 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>4</sup>	18.998403 1681.0 3.98 F Fluorine 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>5</sup>	20.1797 2080.7 Ne Neon 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup>	26.98153 577.5 1.61 Al Aluminium [Ne] 3s <sup>2</sup> 3p <sup>1</sup>	28.0855 786.5 1.90 Si Silicon [Ne] 3s <sup>2</sup> 3p <sup>2</sup>	30.97396 1011.8 2.19 P Phosphorus [Ne] 3s <sup>2</sup> 3p <sup>3</sup>	32.065 999.6 2.58 S Sulfur [Ne] 3s <sup>2</sup> 3p <sup>4</sup>	35.453 1251.2 3.16 Cl Chlorine [Ne] 3s <sup>2</sup> 3p <sup>5</sup>	39.948 1520.6 Ar Argon [Ne] 3s <sup>2</sup> 3p <sup>6</sup>	39.0983 418.8 0.82 K Potassium [Ar] 4s <sup>1</sup>	40.078 589.8 1.00 Ca Calcium [Ar] 4s <sup>2</sup>	44.95591 633.1 1.36 Sc Scandium [Ar] 3d <sup>1</sup> 4s <sup>2</sup>	47.867 658.8 1.54 Ti Titanium [Ar] 3d <sup>2</sup> 4s <sup>2</sup>	50.9415 650.9 1.63 V Vanadium [Ar] 3d <sup>3</sup> 4s <sup>1</sup>	51.9962 652.9 1.66 Cr Chromium [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	54.93804 717.3 1.55 Mn Manganese [Ar] 3d <sup>5</sup> 4s <sup>2</sup>	55.845 762.5 1.83 Fe Iron [Ar] 3d <sup>6</sup> 4s <sup>2</sup>	58.93319 760.4 1.91 Co Cobalt [Ar] 3d <sup>7</sup> 4s <sup>2</sup>	58.6934 737.1 1.88 Ni Nickel [Ar] 3d <sup>8</sup> 4s <sup>2</sup>	63.546 745.5 1.90 Cu Copper [Ar] 3d <sup>10</sup> 4s <sup>1</sup>	65.38 906.4 1.65 Zn Zinc [Ar] 3d <sup>10</sup> 4s <sup>2</sup>	69.723 578.8 1.81 Ga Gallium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	72.64 762.0 2.01 Ge Germanium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	74.92160 947.0 2.18 As Arsenic [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	78.96 941.0 2.55 Se Selenium [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	79.904 1139.9 2.96 Br Bromine [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	83.798 1350.8 3.00 Kr Krypton [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>	85.4678 403.0 0.82 Rb Rubidium [Kr] 5s <sup>1</sup>	87.62 549.5 0.95 Sr Strontium [Kr] 5s <sup>2</sup>	88.90585 600.0 1.22 Y Yttrium [Kr] 4d <sup>1</sup> 5s <sup>2</sup>	91.224 640.1 1.33 Zr Zirconium [Kr] 4d <sup>2</sup> 5s <sup>2</sup>	92.90638 640.1 1.33 Nb Niobium [Kr] 4d <sup>4</sup> 5s <sup>1</sup>	95.96 684.3 2.16 Mo Molybdenum [Kr] 4d <sup>5</sup> 5s <sup>1</sup>	(98) 702.0 1.90 Tc Technetium [Kr] 4d <sup>5</sup> 5s <sup>2</sup>	101.07 710.2 2.20 Ru Ruthenium [Kr] 4d <sup>7</sup> 5s <sup>1</sup>	102.9055 719.7 2.28 Rh Rhodium [Kr] 4d <sup>8</sup> 5s <sup>1</sup>	106.42 804.4 2.20 Pd Palladium [Kr] 4d <sup>10</sup>	107.8682 731.0 1.93 Ag Silver [Kr] 4d <sup>10</sup> 5s <sup>1</sup>	112.441 1007.1 2.00 Cd Cadmium [Kr] 4d <sup>10</sup> 5s <sup>2</sup>	114.818 558.3 1.78 In Indium [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>1</sup>	118.710 708.6 1.96 Sn Tin [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup>	121.760 834.0 2.05 Sb Antimony [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup>	127.60 1008.4 2.10 Te Tellurium [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup>	126.9044 1008.4 2.66 I Iodine [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup>	131.293 1170.4 2.60 Xe Xenon [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup>	132.9054 375.7 0.79 Cs Caesium [Xe] 6s <sup>1</sup>	137.327 502.9 0.89 Ba Barium [Xe] 6s <sup>2</sup>	174.9668 523.5 1.27 Lu Lutetium [Xe] 4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>	178.49 658.5 1.30 Hf Hafnium [Xe] 4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup>	180.9478 761.0 1.50 Ta Tantalum [Xe] 4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup>	183.84 770.0 2.36 W Tungsten [Xe] 4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup>	186.207 760.0 1.90 Re Rhenium [Xe] 4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup>	190.23 840.0 2.20 Os Osmium [Xe] 4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup>	192.22 880.0 2.20 Ir Iridium [Xe] 4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup>	195.084 870.0 2.28 Pt Platinum [Xe] 4f <sup>14</sup> 5d <sup>9</sup> 6s <sup>1</sup>	196.9665 890.1 2.54 Au Gold [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>1</sup>	200.59 1007.1 2.00 Hg Mercury [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup>	204.3833 589.4 1.62 Tl Thallium [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>1</sup>	207.2 715.6 2.33 Pb Lead [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>2</sup>	208.9804 703.0 2.02 Bi Bismuth [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>3</sup>	(210) 812.1 2.00 Po Polonium [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>4</sup>	(210) 890.0 2.20 At Astatine [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>5</sup>	(223) 380.0 0.70 Fr Francium [Rn] 7s <sup>1</sup>	(226) 509.3 0.90 Ra Radium [Rn] 7s <sup>2</sup>	(262) 470.0 Lr Lawrencium [Rn] 5f <sup>14</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(261) 580.0 Rf Rutherfordium [Rn] 5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup>	(262) 580.0 Db Dubnium [Rn] 5f <sup>14</sup> 6d <sup>3</sup> 7s <sup>2</sup>	(266) 597.6 1.38 Sg Seaborgium [Rn] 5f <sup>14</sup> 6d <sup>4</sup> 7s <sup>2</sup>	(264) 597.6 1.38 Bh Bohrium [Rn] 5f <sup>14</sup> 6d <sup>5</sup> 7s <sup>2</sup>	(277) 604.5 1.36 Hs Hassium [Rn] 5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup>	(268) 584.7 1.28 Mt Meitnerium [Rn] 5f <sup>14</sup> 6d <sup>7</sup> 7s <sup>2</sup>	(271) 578.0 1.30 Ds Darmstadtium [Rn] 5f <sup>14</sup> 6d <sup>8</sup> 7s <sup>2</sup>	(272) 581.0 1.30 Rg Roentgenium [Rn] 5f <sup>14</sup> 6d <sup>9</sup> 7s <sup>2</sup>	(285) 600.0 1.30 Cn Copernicium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup>	(284) 600.0 1.30 Uut Ununtrium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>1</sup>	(289) 601.0 1.30 Uuq Ununquadium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>2</sup>	(288) 601.0 1.30 Uup Ununpentium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>3</sup>	(292) 619.0 1.30 Uuh Ununhexium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>4</sup>	(294) 619.0 1.30 Uus Ununseptium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>5</sup>	(294) 619.0 1.30 Uuo Ununoctium [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>6</sup>
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## notes

- as of yet, elements 113-118 have no official name designated by the IUPAC.
- 1 kJ/mol ≈ 96.485 eV.
- all elements are implied to have an oxidation state of zero.

138.9054 538.1 1.10 La Lanthanum [Xe] 5d <sup>1</sup> 6s <sup>2</sup>	140.116 534.4 1.12 Ce Cerium [Xe] 4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>	140.9076 527.0 1.13 Pr Praseodymium [Xe] 4f <sup>3</sup> 6s <sup>2</sup>	144.242 533.1 1.14 Nd Neodymium [Xe] 4f <sup>4</sup> 6s <sup>2</sup>	(145) 540.0 Pm Promethium [Xe] 4f <sup>5</sup> 6s <sup>2</sup>	150.36 544.5 1.17 Sm Samarium [Xe] 4f <sup>6</sup> 6s <sup>2</sup>	151.964 547.1 Eu Europium [Xe] 4f <sup>7</sup> 6s <sup>2</sup>	157.25 593.4 1.20 Gd Gadolinium [Xe] 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	158.9253 565.8 Tb Terbium [Xe] 4f <sup>9</sup> 6s <sup>2</sup>	162.500 573.0 1.22 Dy Dysprosium [Xe] 4f <sup>10</sup> 6s <sup>2</sup>	164.9303 581.0 1.23 Ho Holmium [Xe] 4f <sup>11</sup> 6s <sup>2</sup>	167.259 589.3 1.24 Er Erbium [Xe] 4f <sup>12</sup> 6s <sup>2</sup>	168.9342 596.7 1.25 Tm Thulium [Xe] 4f <sup>13</sup> 6s <sup>2</sup>	173.054 603.4 Yb Ytterbium [Xe] 4f <sup>14</sup> 6s <sup>2</sup>	(227) 499.0 1.10 Ac Actinium [Rn] 6d <sup>1</sup> 7s <sup>2</sup>	232.0380 587.0 1.30 Th Thorium [Rn] 6d <sup>2</sup> 7s <sup>2</sup>	231.0358 568.0 1.50 Pa Protactinium [Rn] 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	238.0289 597.6 1.38 U Uranium [Rn] 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(237) 604.5 1.36 Np Neptunium [Rn] 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(244) 584.7 1.28 Pu Plutonium [Rn] 5f <sup>6</sup> 7s <sup>2</sup>	(243) 578.0 1.30 Am Americium [Rn] 5f <sup>7</sup> 7s <sup>2</sup>	(247) 581.0 1.30 Cm Curium [Rn] 5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>	(247) 601.0 1.30 Bk Berkelium [Rn] 5f <sup>9</sup> 7s <sup>2</sup>	(251) 608.0 1.30 Cf Californium [Rn] 5f <sup>10</sup> 7s <sup>2</sup>	(252) 619.0 1.30 Es Einsteinium [Rn] 5f <sup>11</sup> 6s <sup>2</sup>	(257) 627.0 1.30 Fm Fermium [Rn] 5f <sup>12</sup> 7s <sup>2</sup>	(258) 635.0 1.30 Md Mendelevium [Rn] 5f <sup>13</sup> 7s <sup>2</sup>	(259) 642.0 1.30 No Nobelium [Rn] 5f <sup>14</sup> 7s <sup>2</sup>
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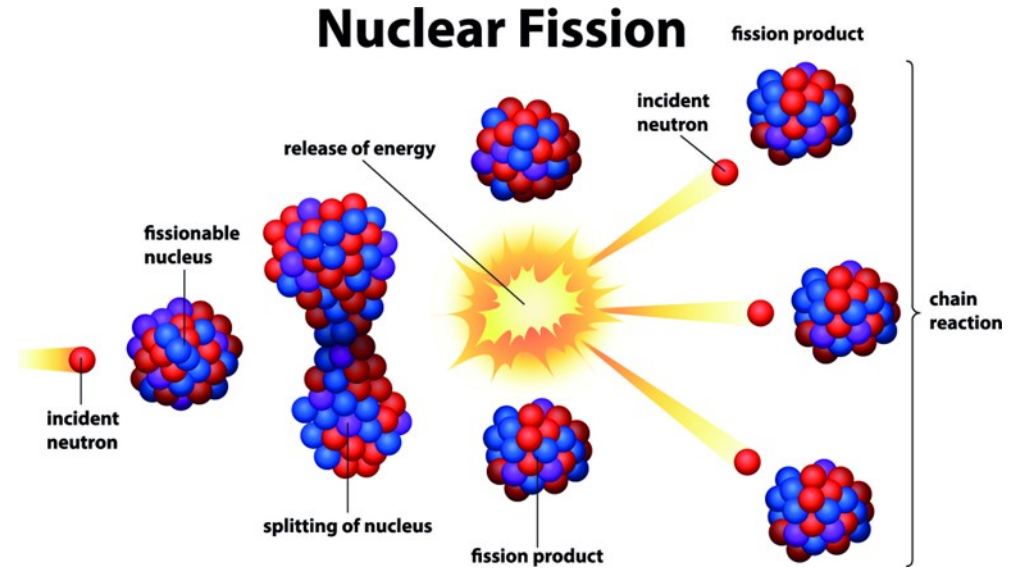
# Fission

## The Discovery of the Neutron (1932)

- **James Chadwick** discovered the **neutron**, a neutral subatomic particle, which played a crucial role in later experiments on nuclear reactions

## Enrico Fermi's Experiments (1934)

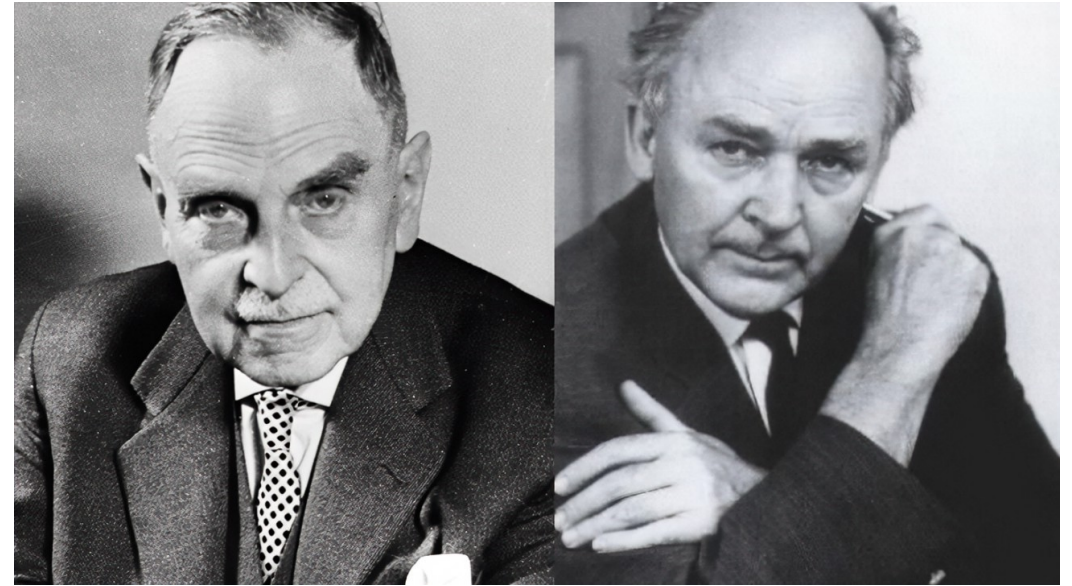
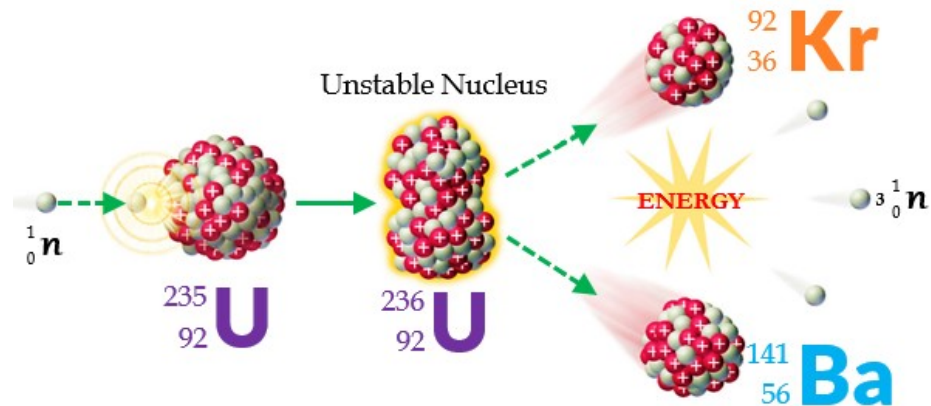
- Italian physicist **Enrico Fermi** and his team bombarded **uranium** with **neutrons**, hoping to create heavier elements
- They observed unusual radioactive decay but could not fully explain it



# Fission

## Otto Hahn and Fritz Strassmann (1938)

- German chemists **Otto Hahn and Fritz Strassmann** repeated similar experiments, **bombarding uranium with neutrons**
- Instead of heavier elements, they found **barium**, a much **lighter element**, which contradicted expectations



1879-1968

1902-1980

# Fission

## Lise Meitner and Otto Frisch (1938-1939)

- **Lise Meitner**, an Austrian physicist worked with her nephew **Otto Frisch** to interpret Hahn and Strassmann's results
- They realized that the uranium nucleus had **split into smaller fragments**, releasing an enormous amount of energy
- **Frisch** named the process "**fission**," drawing an analogy to biological cell division

## Confirmation and Further Research

- In early 1939, **Meitner** and **Frisch** published their theoretical explanation
- Shortly after, scientists like **Niels Bohr** and **John Archibald Wheeler** refined the theory of nuclear fission

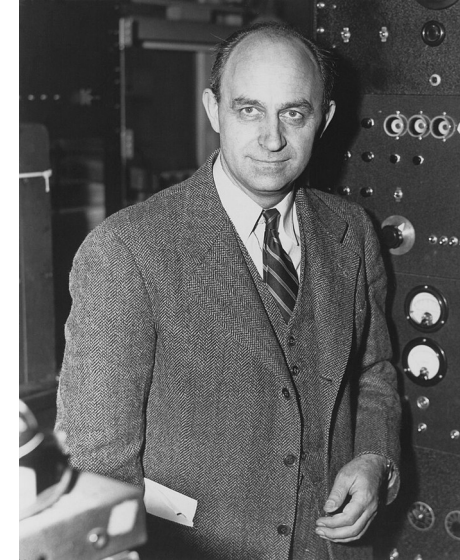
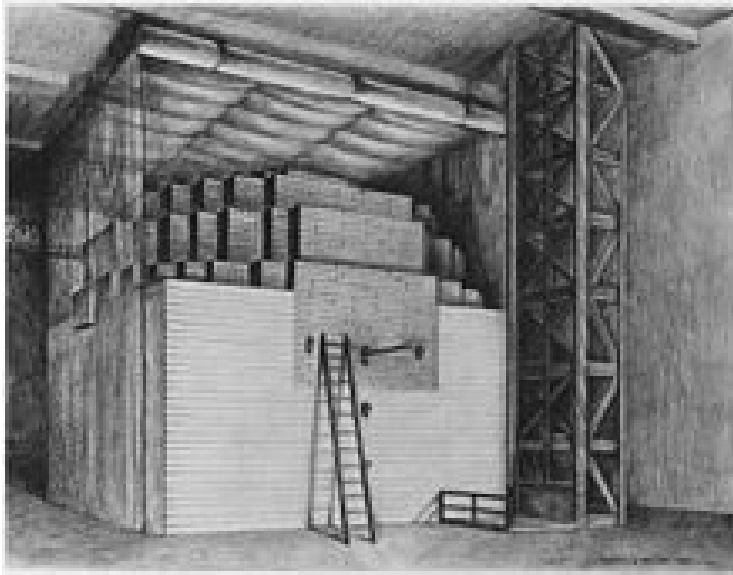


**Lise Meitner** and **Otto Hahn** in the laboratory of the Kaiser Wilhelm Society for the Advancement of Science in Berlin, 1913

- Experimental confirmation followed, showing that fission also released additional neutrons, leading to the possibility of a **chain reaction**

# Fission

- **Chicago Pile-1 (CP-1)** was the world's first artificial nuclear reactor
- On December 2, 1942, the first human-made self-sustaining **nuclear chain reaction** was initiated in **CP-1** during an experiment led by **Enrico Fermi**



1901-1954

The secret development of the reactor was the first major technical achievement for the **Manhattan Project**

# Fission

## Impact on Science and History

- This discovery led to the development of **nuclear reactors** and **atomic bombs** during World War II (**Manhattan Project**)
- It laid the foundation for nuclear energy and weapons, shaping global politics and technology
- The discovery of nuclear fission remains one of the most significant scientific breakthroughs of the 20th century, with both constructive and destructive consequences for humanity

## Fission

## Fissionable Isotopes

**Uranium-235 (U-235)** – The most commonly used fuel in nuclear reactors and weapons. It can undergo fission with both thermal (slow) and fast neutrons

**Plutonium-239 (Pu-239)** – A key material in nuclear weapons and some reactors, produced from uranium-238 in breeder reactors

**Uranium-233 (U-233)** – Produced from thorium-232 in a thorium fuel cycle, used in some experimental reactors

**Plutonium-241 (Pu-241)** – Also fissionable and contributes to energy production in mixed oxide (MOX) fuel

**Neptunium-239 (Np-239)** – A precursor to Pu-239, though not typically used directly in reactors

**Thorium-232 (Th-232)** – Not directly fissionable but can be converted into U-233 through neutron absorption and decay

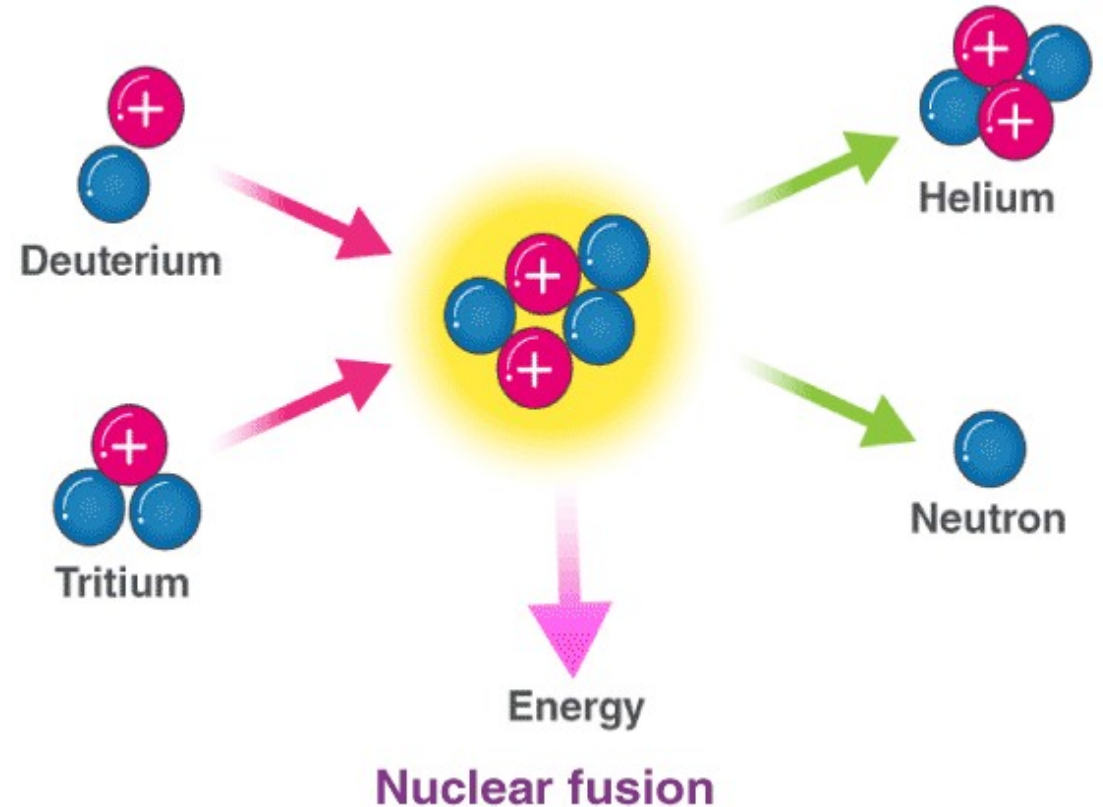
# Fusion

## Early Theoretical Foundations (1920s)

- **Francis Aston (1920):** Using a mass spectrometer, he discovered that the **mass of four hydrogen nuclei (protons) was slightly more than that of a helium nucleus**
- This suggested that **hydrogen could fuse into helium**, releasing energy

$$E = mc^2$$

- **Arthur Eddington (1920):** Proposed that **stars**, including the Sun, generate their energy by fusing **hydrogen into helium** through a yet-unknown process



# Fusion

## The Proton-Proton Chain Reaction (1930s)

- **Hans Bethe** (1938-1939): Identified two possible fusion mechanisms in stars:
- **Proton-Proton Chain** (p-p chain): Dominant in smaller stars like the Sun
- **CNO Cycle** (Carbon-Nitrogen-Oxygen Cycle): Dominant in larger stars
- Bethe's work earned him the Nobel Prize in Physics (1967)

## Early Laboratory Studies (1930s-1940s)

- Scientists experimented with **accelerating protons** to high energies to cause fusion but couldn't achieve the **extreme temperatures and pressures** required for a sustained reaction

## Thermonuclear Weapons (1950s)

- **Edward Teller** and **Stanislaw Ulam** (1951): Developed the **hydrogen bomb**, using an **atomic bomb** to create the conditions necessary for **uncontrolled nuclear fusion**
- The first successful hydrogen bomb test (Ivy Mike, 1952) proved that **fusion could release enormous energy**



1908-2003

# Fusion

## Controlled Fusion Research (1950s-Present)

- In the 1950s, Soviet scientists **Andrei Sakharov** and **Igor Tamm** proposed the tokamak design for magnetic confinement fusion
- Since then, research into fusion reactors has continued, with projects like:
  - JET (Joint European Torus)
  - ITER (International Thermonuclear Experimental Reactor)
- Recent breakthroughs (such as those in laser-induced fusion at the National Ignition Facility) bring us closer to viable fusion energy.

	ENERGY RELEASE		
	CHEMICAL	FISSION	FUSION
REACTION	$C+O = CO_2$	$N+U^{235} = Ba^{143}+Kr^{91}+2n$	$^2H + ^3H = ^4He+n$
FUEL	COAL	UO <sub>2</sub> (3% U-235 + 97% U-238)	Deuterium + Tritium
TEMPERATURE	700°K	1,000°K	100,000,000°K
ENERGY J/kg	$3.3 \times 10^7$	$2.1 \times 10^{12}$	$3.4 \times 10^{14}$

## Next Session

Special Relativity

Mass Energy Equivalence

Speed of Light

General Relativity

Basis of Quantum Theory