PHYS 3446 – Lecture #2

Thurssday, Jan. 22 ,2015
*Dr. **Brandt***

1. Introduction
2. History of Atomic Models
3. Rutherford Scattering
4. Rutherford Scattering with Coulomb force

Why do Physics?

Exp. {
- To understand nature through experimental observations and measurements (**Research**)

Theory {
- Establish limited number of fundamental laws, usually with mathematical expressions
- Predict nature

⇒Theory and Experiment work hand-in-hand

⇒Theory works generally under restricted conditions

⇒Discrepancies between experimental measurements and theory presents opportunities to improve understanding

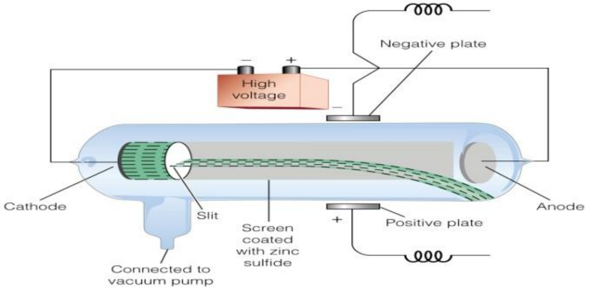
⇒Understanding leads to applications (electricity, computers, etc.)

Quantum Mechanics

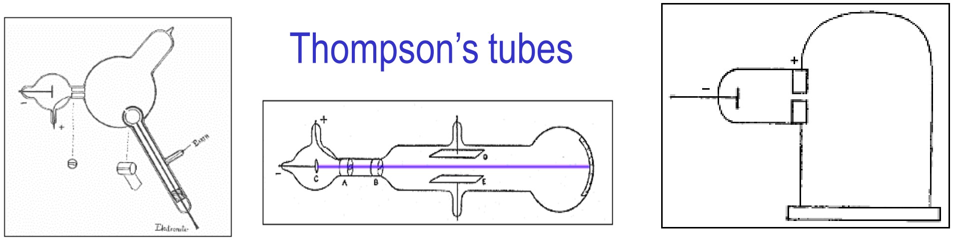
- Cannot adequately describe small scale phenomena with classical mechanics and E&M
- The study of atomic structure led to quantum mechanics (QM)
  - Long range E&M force is responsible for holding atoms together
  - Yet it is sufficiently weak that QM can be used to reliably predict properties of atoms
- The Coulomb force cannot account for the existence of nuclei:
  - The Coulomb force is attractive only for oppositely charged particles, yet a nucleus consisting totally of protons and neutrons can be stable? This implies a force that holds positively charged particles together
- The known forces in nature (not just gravity and E&M!)
  - Strong ~ 1
  - Electro-magnetic ~ 10^{-2}
  - Weak ~ 10^{-5}
  - Gravitational ~ 10^{-38}

Evolution of Atomic Models

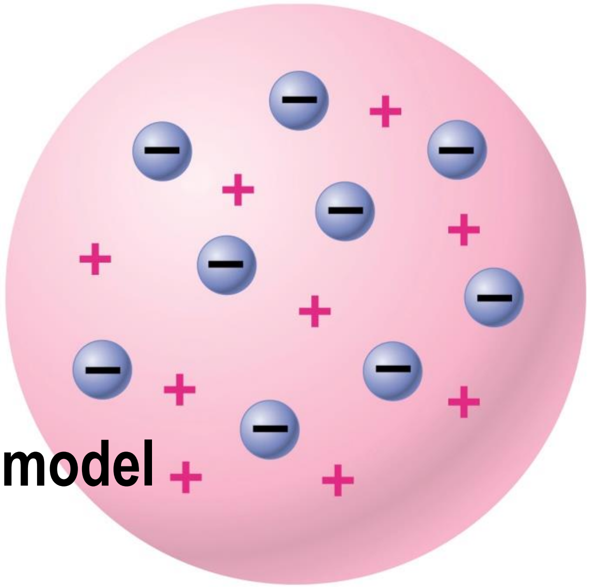
- 1803: Dalton’s billiard ball model
- 1897: J.J. Thompson Discovered electrons
  - Built on all work w/ cathode tubes
  - Called corpuscles
  - Made a bold claim that these make up atoms
  - Measured charge to mass ratio
- 1904: J.J. Thompson Proposed a “plum pudding” model of atoms
  - Negatively charged electrons embedded in a uniformly distributed positive charge



Cathode ray tube



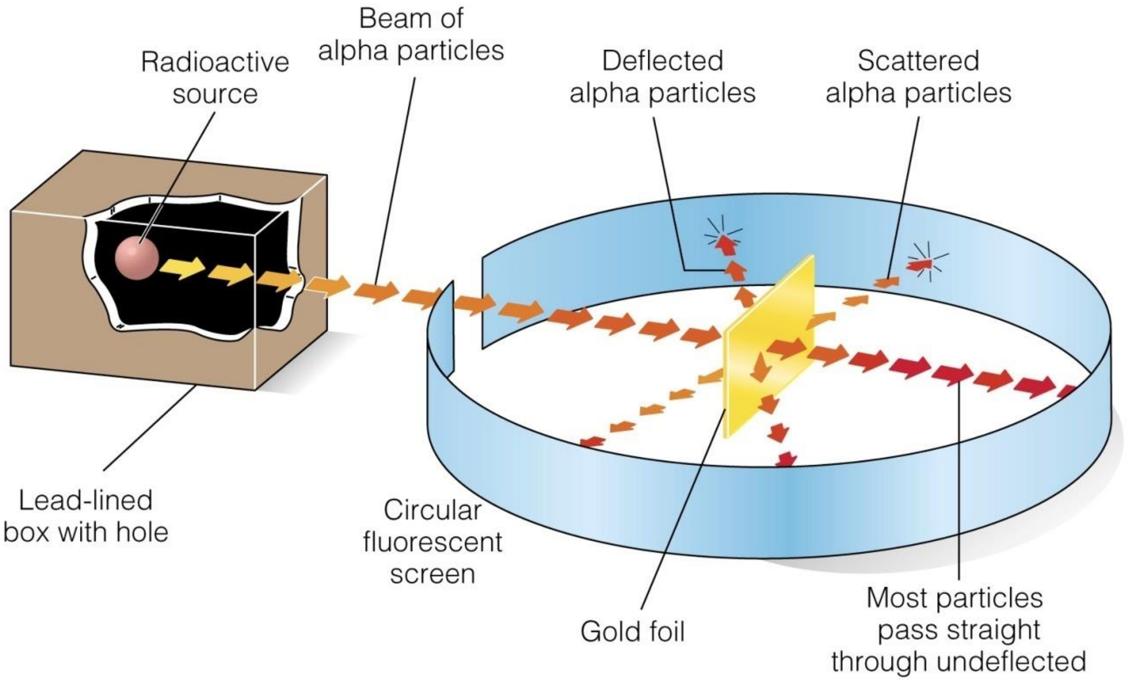
Thompson’s tubes

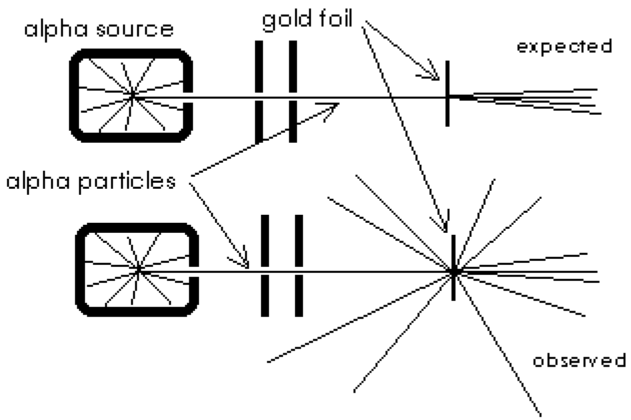


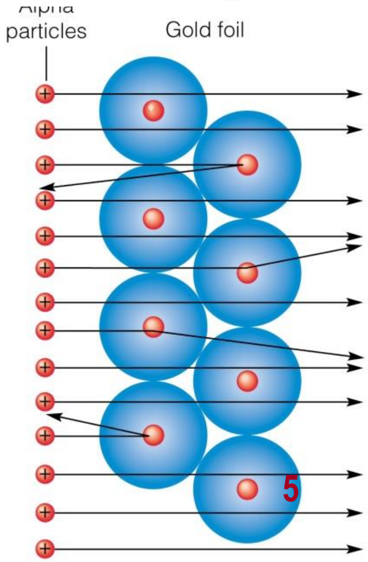
personally I prefer chocolate chip cookie model

Rutherford Scattering

- 1911: Geiger and Marsden with Rutherford performed a scattering experiment firing alpha particles at a thin gold foil

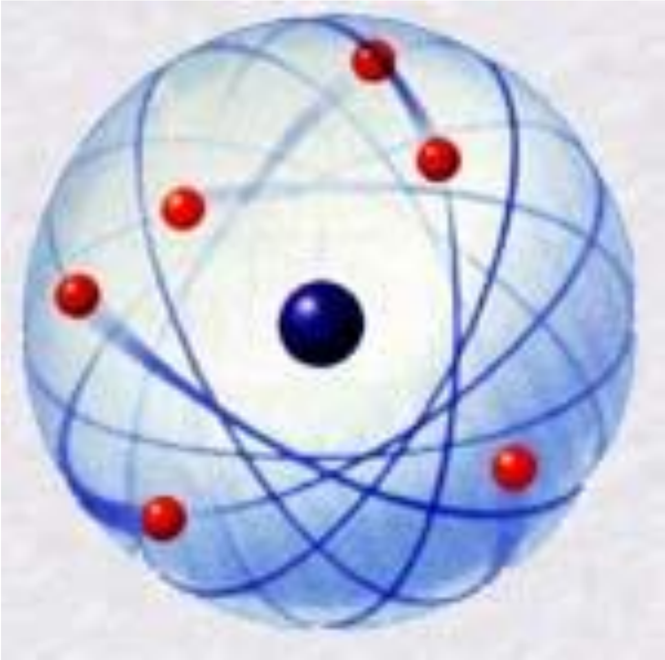


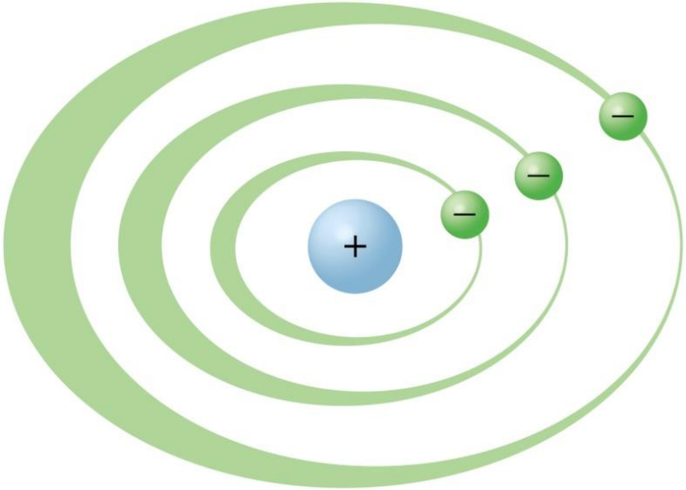




Planetary Model

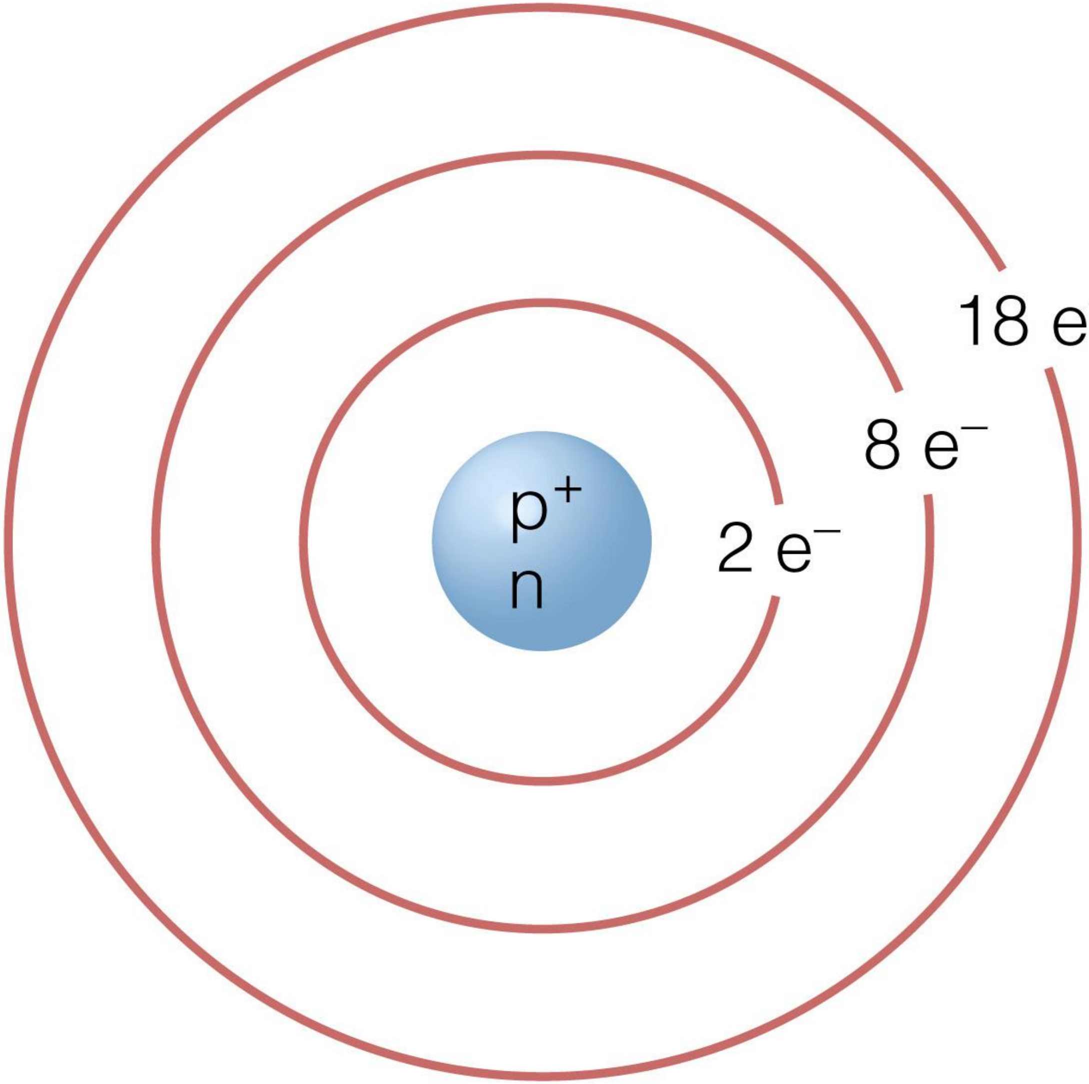
- 1912: Rutherford’s planetary model, an atomic model with a positively charged heavy core surrounded by circling electrons
  - Unstable Why?
    - The electrons will eventually get pulled in to the nucleus, destroying the atom





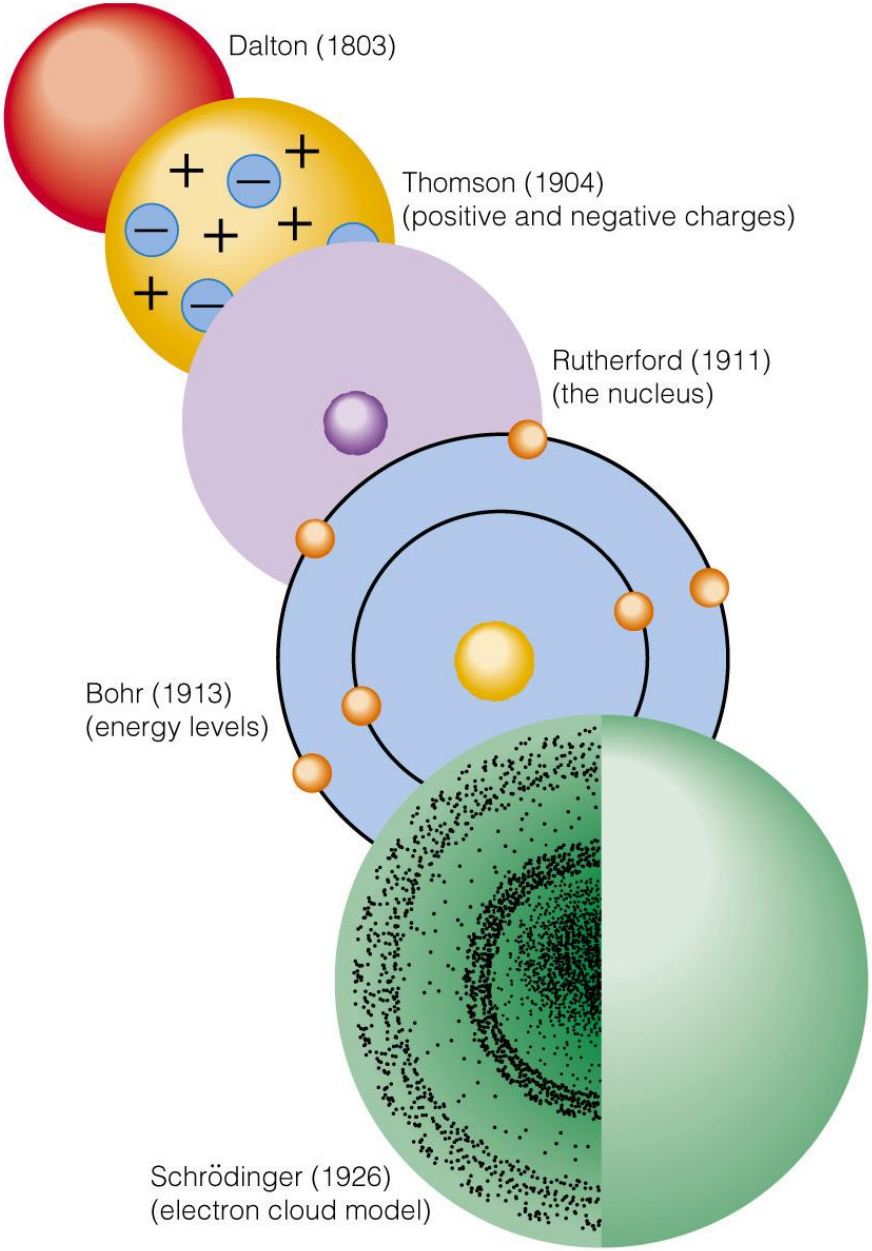
Bohr Model

- 1913: Neils Bohr proposed the Orbit Model, where electrons occupy well quantified orbits
  - Electrons can only transition to pre-defined orbits



Electron Cloud Model

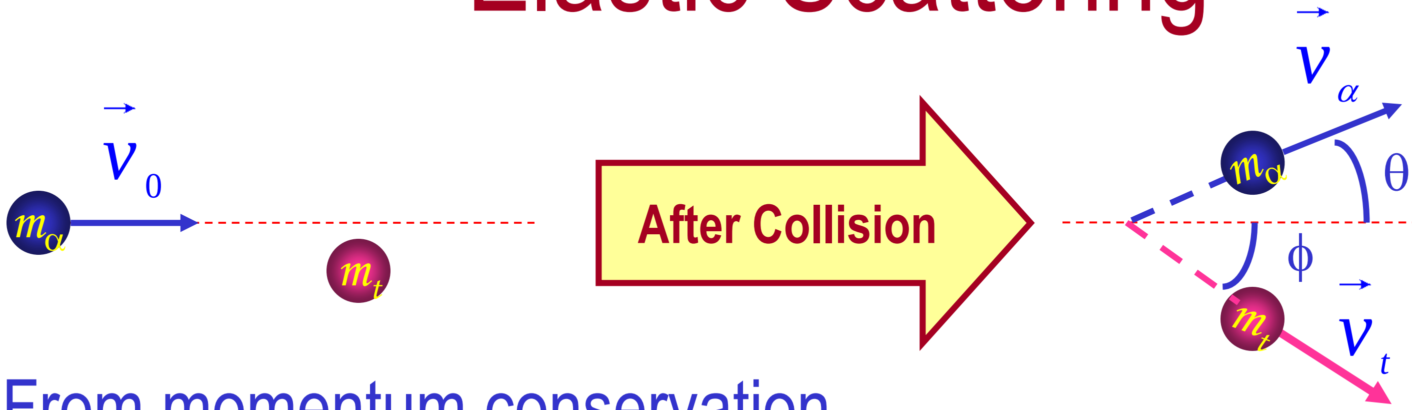
- 1926: Schrödinger and de Broglie proposed the Electron Cloud Model based on quantum mechanics



Rutherford Scattering Kinematics

- A fixed target experiment with alpha particle as a projectile fired at a thin gold foil
  - Alpha particle's energy is low ➔ Speed is well below 0.1c (non-relativistic)
- Assume an elastic scattering of the particles
- What are the conserved quantities in an elastic scattering?
  - Momentum
  - Kinetic Energy (is K.E. conserved in any type of scattering?)
- Conservation vs. Invariant

Elastic Scattering



- From momentum conservation

$$\vec{v}_0 = \frac{m_\alpha \vec{v}_\alpha + m_t \vec{v}_t}{m_\alpha} = \vec{v}_\alpha + \frac{m_t}{m_\alpha}\vec{v}_t$$

- From kinetic energy conservation

$$v_0^2 = v_\alpha^2 + \frac{m_t}{m_\alpha} v_t^2$$

*****Eq. 1.2**

- From these, we obtain

$$v_t^2\left(1-\frac{m_t}{m_\alpha}\right) = 2\vec{v}_\alpha \cdot \vec{v}_t$$

*****Eq. 1.3**

Analysis Case 1

$$v_t^2\left(1-\frac{m_t}{m_\alpha}\right)=2\vec{v}_\alpha\cdot\vec{v}_t$$

- If $m_t \ll m_\alpha$,
  - left-hand side is positive
  - v_α and v_t must be in the same direction (both positively or negatively directed)
  - Using the actual masses
  - $m_e \approx 0.5 MeV/c^2$ and $m_\alpha \approx 4\times10^3 MeV/c^2$
  - We obtain $v_e = v_t \le 2v_\alpha$
  - If $m_t=m_e$, then $m_t/m_\alpha \sim 10^{-4}$. ➔ $v_\alpha \approx v_0$ (Eq. 1.2)
  - Thus, $p_e/p_{\alpha 0} < 10^{-4}$.
  - Change of momentum of alpha particle is negligible

Analysis Case 2

$$v_t^2\left(1-\frac{m_t}{m_\alpha}\right)=2\vec{v}_\alpha\cdot\vec{v}_t$$

- If $m_t >> m_\alpha$,
  - left-hand side of the above becomes negative
  - v_α and v_t in opposite direction
  - Using the actual masses
  - $m_t \approx m_{Au} \approx 2\times10^5 MeV/c^2$ and $m_\alpha \approx 4\times10^3 MeV/c^2$
  - We obtain $v_t \le 2m_\alpha v_\alpha / m_t$
  - If $m_t=m_{Au}$, then $m_t/m_\alpha \sim 50$. ➔ $v_\alpha \approx \pm v_0$ (Eq 1.2)
  - Thus, $p_{Au}<2p_{\alpha 0}$
  - alpha particle deflected backwards

HW 1 (due 1/29

1. Compute the masses of electron, proton, neutron and alpha particles in GeV/c^2 starting from the SI mass (kg).

2. Compute the gravitational and the Coulomb force for a Hydrogen atom with the electron and proton separated by 5×10^{-11}m and calculate the ratio Fcoul/Fgrav.
3. Derive the following equations in your book:
   - Eq. # 1.3, 1.17, 1.32
   - Show detailed work and any necessary explanation
4. Is there a higher probability of an alpha particle scattering off a foil if there were no Coulomb force? What if there were no strong force?
5. Calculate the wavelength of an electron with velocity a) 1×10^6 m/sec b)1×10^8 m/sec