Új Nemzeti Kiválóság Program

Nuclear Physics Lecture

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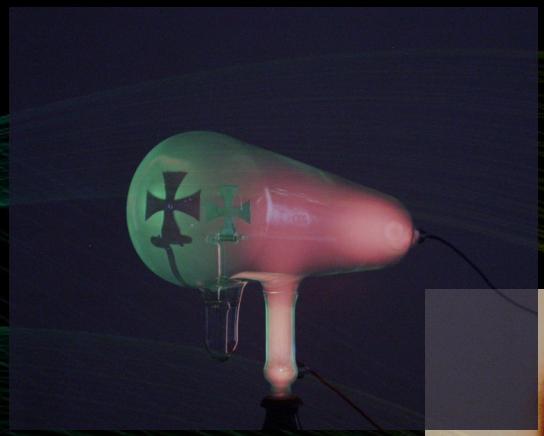
I. Historical overview

Discovery of nucleus I.

- **W. Roentgen**: X-ray (1895)
- **H. Becquerel**: uranium „radiation”
  - Continuous radation without external power
- **M. Curie**: thorium „*radioactivity*”, polonium, radium → born of radiotherapy
- **J.J Thompson**: cathode-ray tube (CRT)
  - X-rays ionize air!
  - Electric charge in „packets”→ discovery of electrons… (Nobel prize)
- **E. Rutherford**: transmutation (With F. Soddy)
  - From X-rays to radioactivity: he founded two types (alpha, beta) of radioactivity!
  - Exponential decay law: half life of the radioactive material (independent of quantity) → **Quantummechanics**
  - Identification of alpha and beta radiation



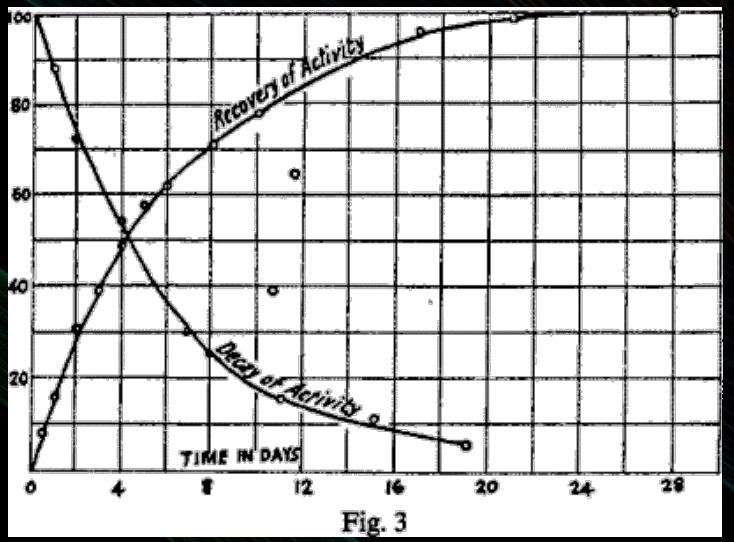
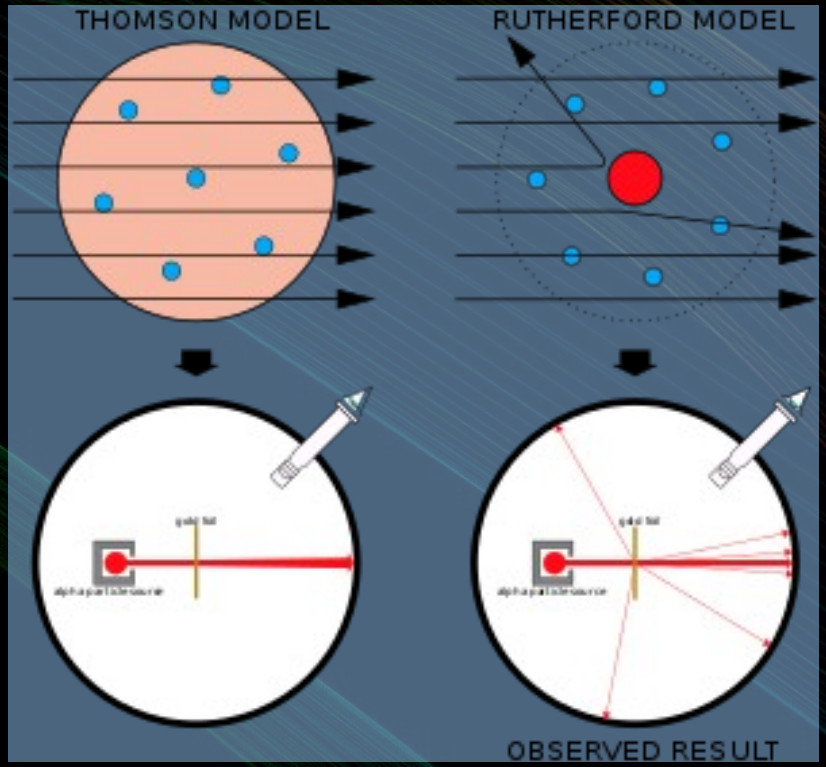


Fig. 3

Discovery of nucleus II. – The Rutherford experiment

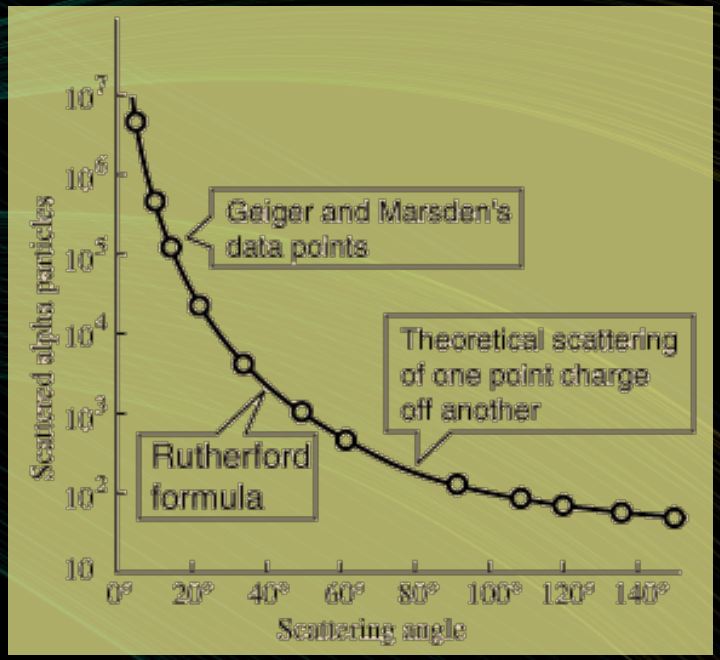
- J.J Thompson: electrons (m_e = 0.001 m_A) are in atoms with negative charge
  - „Plum-pudding" model: a positively charged sphere, small negative spots everyweher
- Rutherford (1909-11):
  - Geiger and Marsden
  - Scattering of ^{4}He on thin Au foil
    - (100 years later we still use scattering as a techique to study nuclear structure)
  - They found large very angles!

„It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." - E. Rutherford



The Rutherford experiment II.

- *"One day, obviously in the best spirits, he came into my room and told me that he now knew what the atom looked like and how the large deflections were to be understood. On the very same day I began an experiment to test the relation expected between the number of particles and the angle of scattering."* - Geiger to Chadwick



$$\sigma(\theta) = \left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{Z^2 e^4}{M^2 v^4} \times \frac{1}{\sin^4(\theta/2)}$$

Ze = the positive charge of the target atom,

M = the mass of the α particle,

v = incident speed of the α particle,

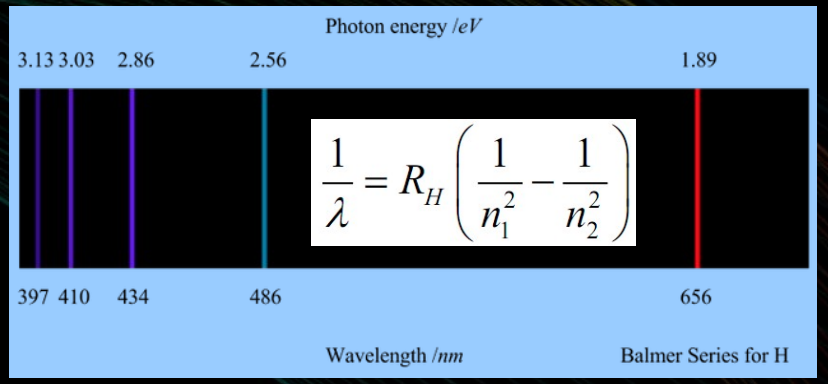
θ = scattering angle,

- Rutherford model:
  - +Ze point-like charge → **Nucleus**
  - Z x electron (-e)
  - Coulomb force

The structure of the atom

- Problem with Rutherford model: why atoms are stable? Electrons are accelerating → radiation → loss of energy → falling into the nucleus...
- N. Bohr (1913):
  - visible spectral lines of atoms (H – Balmer series with Rydberg constant)
  - reason: electrons are moving in orbits in such a way that angular momentum can only be

    $mvr = n\hbar$, where $n=1,2,3, \ldots$ ($\hbar$ is Planck constant)



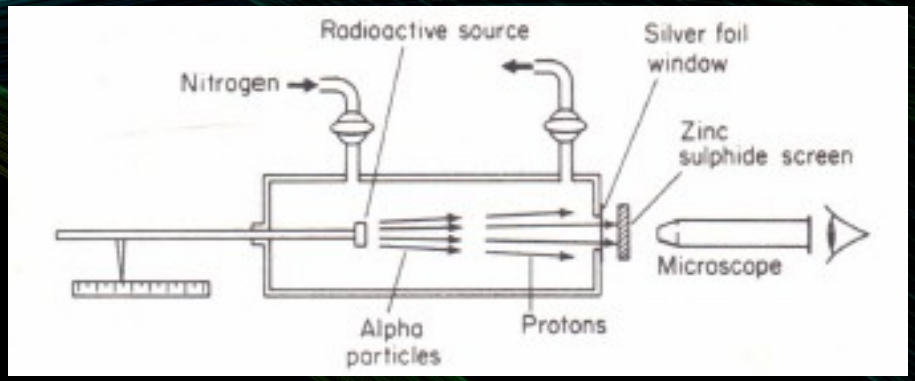
$$E = -\frac{Z^2 me^4}{8n^2h^2\varepsilon_0^2} = \frac{-13.6Z^2}{n^2}eV \qquad r = \frac{n^2h^2\varepsilon_0}{Z\pi me^2} = \frac{n^2a_0}{Z}$$

$$a_0 = 0.0529nm = Bohr\ radius$$

The structure of the nucleus

- Aston (1919): $M=AxM_H$ somehow Hydrogen is important!
- Rutherford – Blackett: the first nuclear reaction

$$^{14}N + {}^{4}He \rightarrow {}^{17}O + {}^{1}H$$



- Further studies: 1e+ particle, named *proton* → nucleus of ^{1}H
- Problem! For heavier nucleus: A≈2-2.5xZ Why?

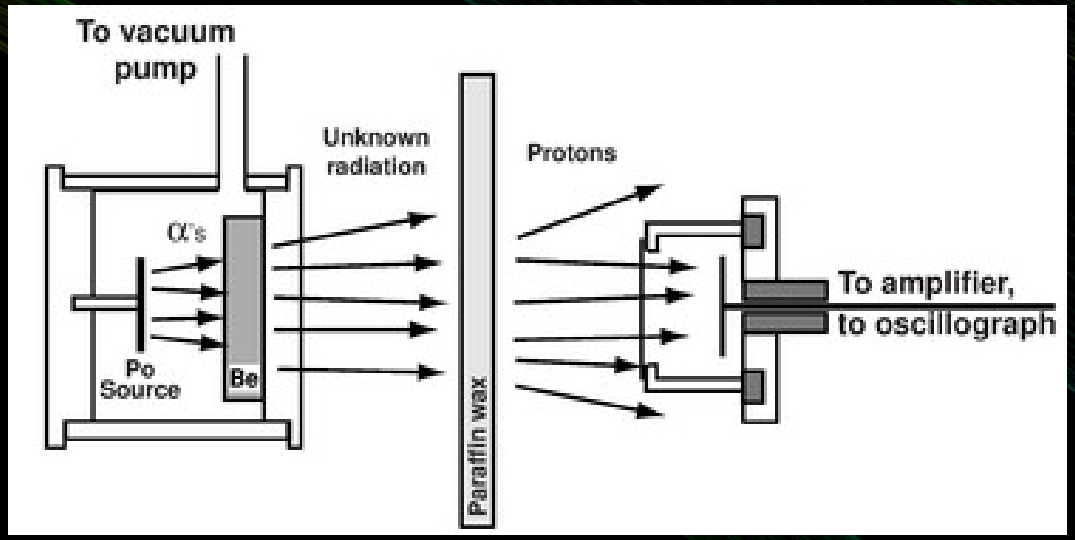
"Under some conditions, however, it may be possible for an electron to combine much more closely with the H nucleus forming a kind of neutral doublet. ... The existence of such atoms seems almost necessary to explain the building of the nuclei of heavy elements; …"
- E. Rutherford

The structure of nucleus II.

- Bothe and Becker (1930): a very penetrating, neutral (no effect of magnetic and electric fields) radiation first believed to be γ radiation

$$^{4}He + {}^{9}Be \rightarrow {}^{12}C + \gamma??$$

- Chadwick (1932): a neutral particle with the mass of proton → neutron



- Heisenberg: A mass, Z proton, N=A-Z neutron (proton, neutron → nucleon)
- What hold the Z protons together? Not the gravity → unknown strong force!

The Rutherford formula

- Derivation of the formula based on classic kimenatics and conservation laws
- Cross-section is then derived by geometrical considerations