Ernest Rutherford and the Discovery of the Atomic Nucleus

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This is a talk about history of nuclear physics on the occasion of the centenary of the discovery of the atomic nucleus. It is on the life and discoveries of great physicist and chemist Ernest Rutherford, in particular on his discovery of the atomic nucleus.

On 7 March 1911 Ernest Rutherford spoke at the Manchester Literary and Philosophical Society about his research and view of the atom structure. This talk was published in the *Proceedings of the Manchester Literary and Philosophical Society* in April and more fully paper was published in the *Philosophical Magazine* in May 1911. These events declared one of the greatest discoveries in Physics – the discovery of the atomic nucleus. By this and other discoveries E. Rutherford became known as the father of nuclear physics.

It is worth mentioning knowledge on the atom at some time before the discovery. During 19th century it was established a concept of the atom as an elementary unit of the chemical element. In 1897 J.J. Thompson discovered the electron and in 1904 he proposed the plum pudding model of the atom. According to this model, the atom was composed of electrons surrounded by positively charged cloud like pudding.

E. Rutherford (1871 - 1937) was born in New Zealand. With respect to the place of stay, his life can be divided into the following periods.

- *1871-1895: New Zealand.* School and faculty studies finished excellently, and got a scholarship for further studies in Cambridge.

- *1895-1898: Cavendish Laboratory, University of Cambridge, England.* He worked in group of J.J. Thompson. He started to investigate radioactivity and determined two types of rays, which he named "alpha" and "beta" rays.

- *1898-19007: McGill University, Montreal, Canada.* Here he showed that radioactivity was the spontaneous transmutation of certain atoms (for this he received the 1908 Nobel Prize in Chemistry). He demonstrated that alpha rays were helium atoms without two electrons, and deflected them in magnetic and electric fields for the first time.

- *1907-1919: University of Manchester, England.* He continued to work with alpha particles. With his assistant Hans Geiger he developed scintillation screens and the Rutherford-Geiger tube to count alphas scattered on metal folios. Rutherford observed already before Manchester that narrow beam of alphas became fuzzy when it was passed through metals or gases. Rutherford started to investigate this phenomenon with Geiger systematically. He asked Geiger and student Ernest Marsden to look for alpha particles with very high deflection angles. Then Marsden observed alpha particles scattered at large angles. Subsequently Rutherford made a model to interpret experimental results. The model was tested and confirmed that the alpha scattering through large angles varied as $1/sin^4(\theta/2)$, i.e. it is in agreement with the nonrelativistic form of differential cross section (see, e.g., [1] for quantum field theory derivation of Coulomb scattering)

$$d\sigma\theta = \left(\frac{Ze^2}{8\pi\varepsilon_0 mv^2 \sin^2 \frac{\theta}{2}} \right)^2 d\Omega.$$

  Equating kinetic energy (E) of an alpha particle and its maximum potential energy before reflection of an atom Rutherford could estimate radius of the atomic nucleus according to formula (see Rutherford's original paper [2])

$$E = \frac{2e \cdot Ze}{4\pi\varepsilon_0 R}.$$

  If $E \sim 5\,MeV$ for the gold atom one obtains radius of the nucleus $R \sim 10^{-14}\,m$, i.e. the radius of the nucleus is about 10^4 times smaller than the radius of the atom. All these consistent interpretations led Rutherford to formulate the Rutherford planetary model of the atom in 1911, i.e. a very small positively charged nucleus was orbited by electrons, what is unlike the Thompson pudding model. In 1917 Rutherford performed the first transmutation of elements in the nuclear reaction

$$\alpha + {}^{14}N \rightarrow {}^{17}O + p,$$

  where p was a constituent of the nucleus named "proton" by him.

- *1919-1937: Director of the Cavendish Laboratory, University of Cambridge, England.* In 1921 Rutherford conjectured existence of the neutron in the nucleus which was discovered by J. Chadwick in 1932. He continued to work and made further significant contributions to nuclear physics. He died in 1937.

Rutherford discoveries have been appreciated by many ways. For example, his ashes were interred in London's Westminster Abbey near Sir Isaac Newton's tomb and some other great British scientists.

References

[1] F. Mandl, *Introduction to Quantum Field Theory*, Interscience Publishers Inc., New York, 1959

[2] E. Rutherford, "The Scattering of α and β Particles and the Structure of the Atom", *Philosophical Magazine* **21** (6) (1911) pp. 669–688.