Rutherford’s legacy in nuclear physics

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Photograph: The University of Manchester
Questions in Rutherford’s day

- What is the nature of radioactivity?
- What is the structure of atoms?
- What are the components of the nucleus?
Questions in modern nuclear physics

+ How are hadrons and nuclei understood in terms of the underlying fundamental interactions?

+ What is the equation of state of nuclear matter?

+ What symmetries give rise to the simple patterns found in complex nuclei?

+ How do the properties of exotic short-lived nuclei influence the formation of the elements?

Bronze Bust in the Rutherford Lecture Theatre
Schuster Laboratory, The University of Manchester
RUTHERFORD’S LEGACY

I. The understanding of the basis of radioactivity and radioactive change.

II. The discovery of the nucleus and its components.

III. The artificial initiation of nuclear reactions.
I: Radioactivity

E. Rutherford, F. Ward and W. Lewis
Analysis of Long-Range $\alpha$ Particles from Radium C
Proc Roy Soc A 131 (1931) 684

E. Rutherford and F. Soddy
The Cause and Nature of Radioactivity
Part II Phil Mag VI 4 (1902) 569

E. Rutherford
The Magnetic and Electric Deviation of Easily Absorbed Rays from Radium
Phil Mag VI 5 (1903) 177

E. Rutherford and T. Royds
The Nature of the $\alpha$ Particle from Radioactive Substances
Phil Mag VI 16 (1908) 313

E. Rutherford and H. Geiger
The Charge and Nature of the Alpha Particle
Proc Roy Soc A 81 (1908) 162
**Radioactivity**

Proton Decay:

Cerny et al., PLB 33, 284 (1970)

Hofmann et al., Z Phy A 305, 111 (1981)

Miernik et al., PRL 99, 192501 (2007)
I: Radioactivity

Figures Courtesy of J Simpson and M Riley
Particle ID

Spectra:

The Star Collaboration
Nature 473 (2011) 353
II: The Nucleus and Scattering

I. XXIX. The Scattering of α and β Particles by Matter and the Structure of the Atom. By Professor E. Rutherford, F.R.S., University of Manchester*.

§ 1. It is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been

...It seems surprising that some of the alpha particles, ...can be turned within a layer of 6x10⁻⁵ cm of au through an angle of 90 degrees, and even more. To produce a similar effect by magnetic field, the enormous field of 10⁹ absolute units would be required.

H. Geiger and E. Marsden
On the Diffuse Reflection of Alpha Particles
Proc Roy Soc A 82 (1909) 495

\[ \frac{d\sigma}{d\Omega} = \left[ \frac{zZe^2}{4\pi\epsilon_0} \right]^2 \frac{1}{16E^2} \frac{1}{\sin^4 \theta/2} \]

E. Rutherford
The Scattering of α and β Particles by Matter and the Structure of the Atom
Phil Mag VI 21 (1911) 669
"In such close collisions...the number and distribution of H atoms are entirely different from those calculated on the assumption that nuclei are regarded as point charges repelling each other according to the law of inverse squares."

E. Rutherford
Collision of $\alpha$ Particles with Light Atoms I: Hydrogen
Phil Mag VI 37 (1919) 537

"...not inconsistent with the view that the forces between colliding atoms augment rapidly for values of $D<3\times10^{-13}\text{cm}$"

E. Rutherford
Collision of $\alpha$ Particles with Light Atoms I: Hydrogen
Phil Mag VI 37 (1919) 537

E. Rutherford and J. Chadwick
Scattering of $\alpha$ Particles by Atomic Nuclei and the Law of Force
Phil Mag VI 50 (1925) 889
II: The Nucleus and Scattering

P Mueller et al.,
PRL 99, 252501(2007)

Tanihata et al.,
PRL 55, 2676 (1985)
III: Nuclear Reactions

\[ ^{14}\text{N} + \alpha \rightarrow ^{17}\text{O} + p \]

"...we must conclude that the nitrogen atom is disintegrated...and that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus"

E. Rutherford

Collision of \( \alpha \) Particles with Light Atoms IV: An Anomalous Effect in Nitrogen
Phil Mag VI 37 (1919) 581

E. Rutherford and J. Chadwick
The Artificial Disintegration of Light Elements
Phil Mag VI 42 (1921) 809

P.M.S. Blackett
The Ejection of Protons from Nitrogen Nuclei Photographed by the Wilson Method
Phil Mag VI 42 (1921) 809
“IF ALPHA PARTICLES —OR SIMILAR PARTICLES— OF STILL GREATER ENERGY WERE AVAILABLE FOR EXPERIMENT, WE MIGHT EXPECT TO BREAK DOWN THE NUCLEAR STRUCTURE OF THE LIGHTER ELEMENTS”

E. Rutherford

Collision of α Particles with Light Atoms IV: An Anomalous Effect in Nitrogen
Phil Mag VI 37 (1919) 581

\[
d + d \Rightarrow p + ^3H \\
\Rightarrow ^3He + n
\]

M. Oliphant, P. Harteck and E. Rutherford
Transmutation Effects Observed in Heavy Hydrogen
Proc Roy Soc A 144 (1934) 692

High voltage installation used at Cambridge by Cockcroft and Walton in their pioneer experiments upon artificial transmutation.

Photographs from E. Rutherford
The Newer Alchemy Cambridge (1937)
III: Nuclear Reactions

Single-step “knockout”:

Changing Magic Numbers in SD Shell:

T Otsuka et al.,
PRL 87, 082502 (2001)
III: Nuclear Reactions
Prof. E. Rutherford on Uranium Radiation and others have observed that the x-rays are in general of a complex nature, including rays of wide differences in their power of penetrating solid bodies. The penetrating power is also dependent to a large extent on the stage of exhaustion of the Crookes tube.

In order to test the complexity of the radiation, an electrical method was employed. The general arrangement is shown in fig. 1.

The metallic uraniun or compound of uranium to be employed was powdered and spread uniformly over the centre of a horizontal zinc plate $A$, 20 em. square. A zinc plate $B$, 20 em. square, was fixed parallel to $A$ and 4 em. from it. Both plates were insulated. $A$ was connected to one pole of a battery of 50 volts, the other pole of which was to earth; $B$ was connected to one pair of quadrants of an electrometer, the other pair of which was connected to earth.

Under the influence of the uranium radiation there was a rate of leak between the two plates $A$ and $B$. The rate of movement of the electrometer-needle, when the motion was steady, was taken as a measure of the current through the gas. Successive layers of thin metal foil were then placed over the uranium compound and the rate of leak determined for each additional sheet.

The table (p. 115) shows the results obtained for thin Dutch metal. In the third column the ratio of the rates of leak for each additional thickness of metal leaf is given. Where two thicknesses were added at once, the square root of the observed ratio is taken, for three thicknesses the cube root. The table shows that for the first ten thicknesses of metal the rate of leak diminished approximately in a geometrical progression as the thickness of the metal increased in an arithmetical progression.
V: Leadership

“IT SOUNDS RATHER COMIC TO MYSELF, TO HAVE TO SUPERVISE THE RESEARCH OF OTHER MEN, BUT I HOPE I GET ALONG ALRIGHT”

E. Rutherford
Letter to Mary Newton August 1898

1930s Management Training Manual?

(i) Personal Enthusiasm, Interest and Delight.
(ii) Personally Driven.
(iii) Young Staff Given Productive Projects.
(iv) Frequent Formal and Informal Contact.
(v) Social Interaction.
(vi) Insensitvity to Standing.
(vii) Instilled a Desire to Please.
(viii) Generous in Assigning Credit.
(ix) Gathered Consensus Opinion.
(x) Allowed Space for Projects to Develop.

from Arthur Schuster’s Visitors’ Book
The University of Manchester

E. Rutherford’s leadership characteristics culled from several colleagues reminiscences.
Photograph taken in Westminster Abbey by unknown staff member from the Victoria University of Manchester circa 1961.
To Vivian Bowden
to remind him of the happy
days in The Cavendish.

James Chadwick.