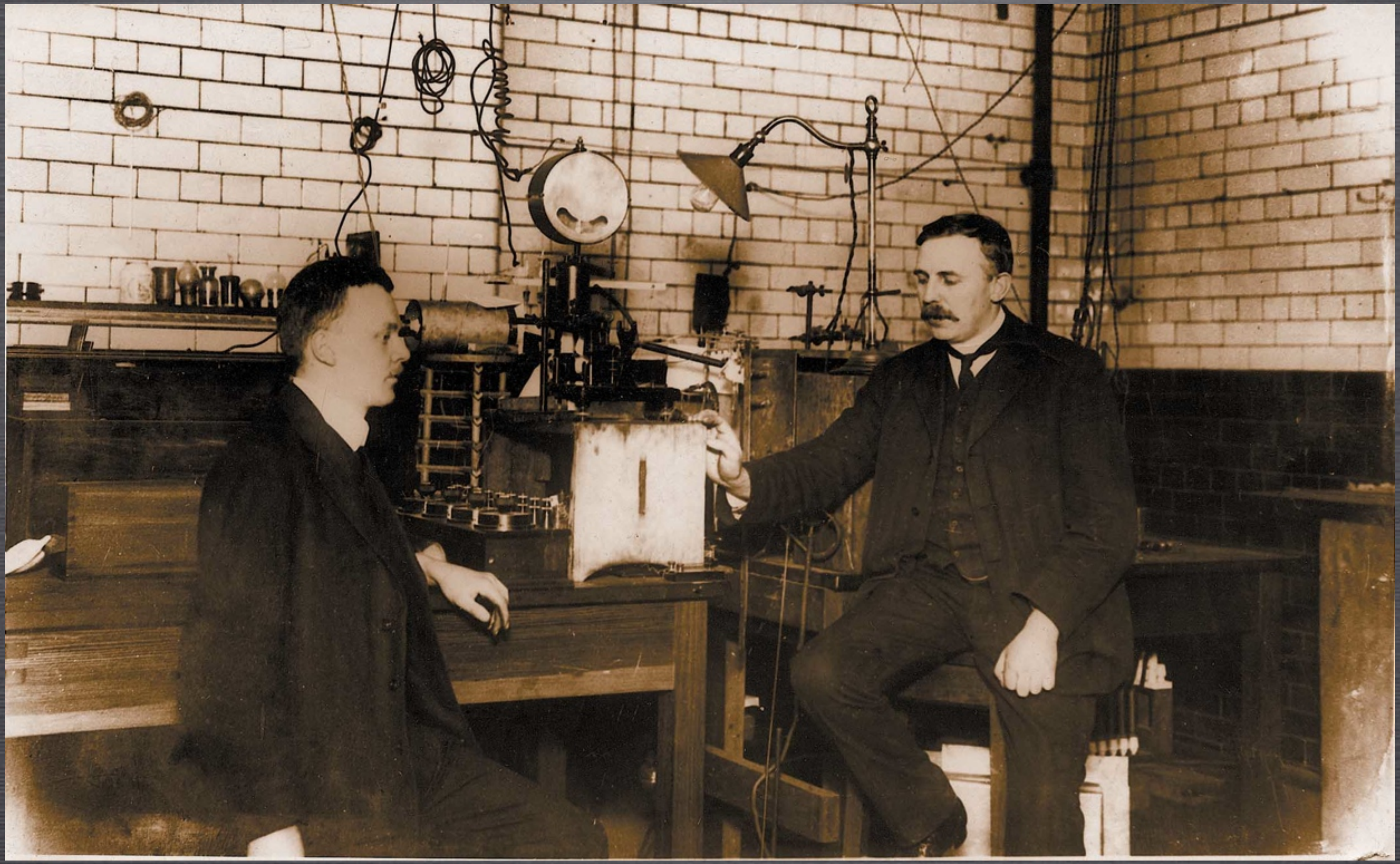
Photograph: The University of Manchester

Rutherford's legacy in nuclear physics

Sean J Freeman
University of manchester

Questions in rutherford's day



Rutherford and Geiger in the Manchester Physical Laboratories circa 1910
(Photograph: The University of Manchester)

- 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 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

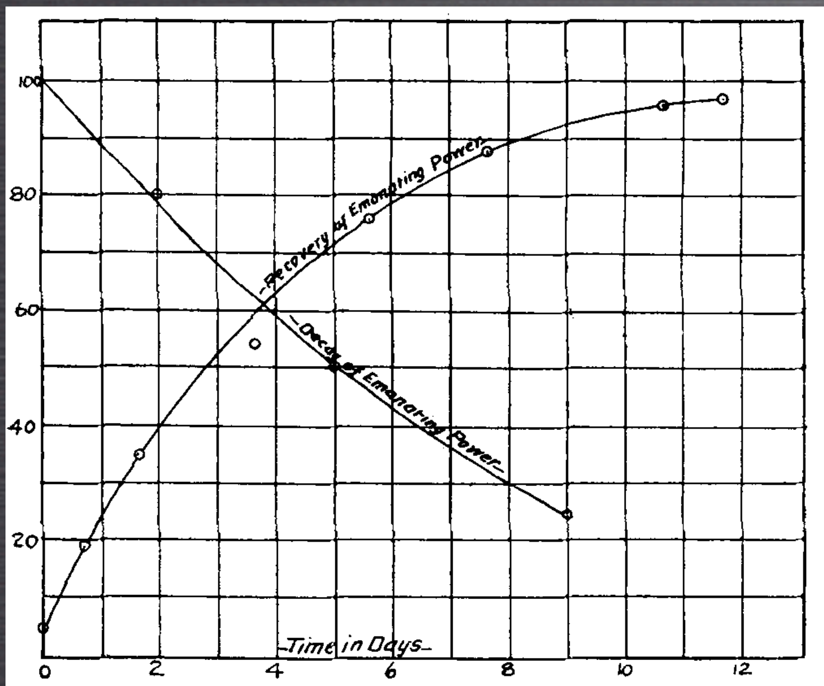
Manchester Physical Laboratories 1913

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

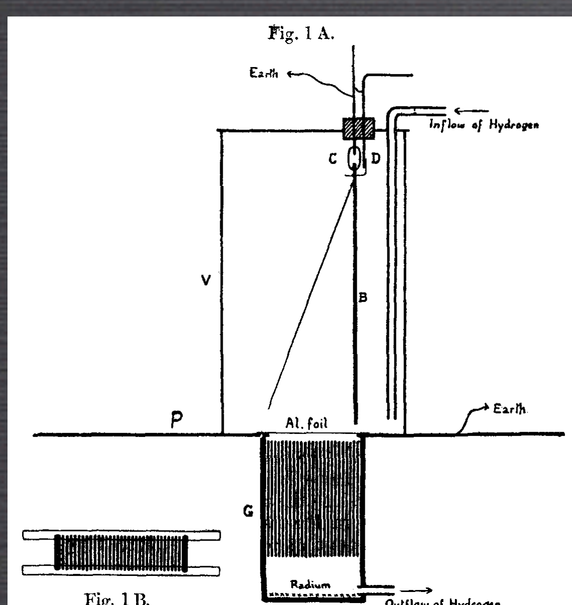
II. The discovery of the nucleus and its components.

III. The artificial initiation of nuclear reactions.

I: Radioactivity

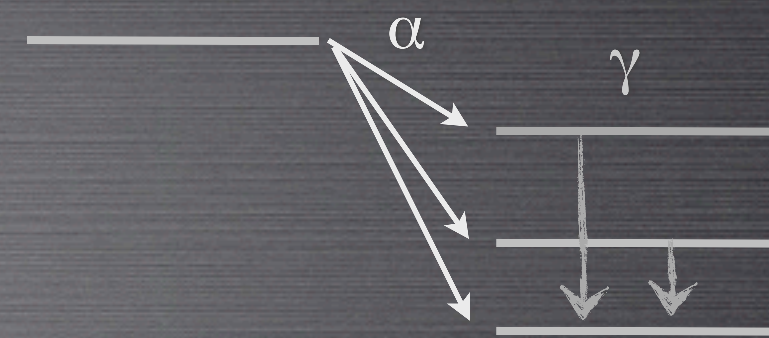


E. Rutherford and F. Soddy
The Cause and Nature of Radioactivity Part II Phil Mag VI 4 (1902) 569

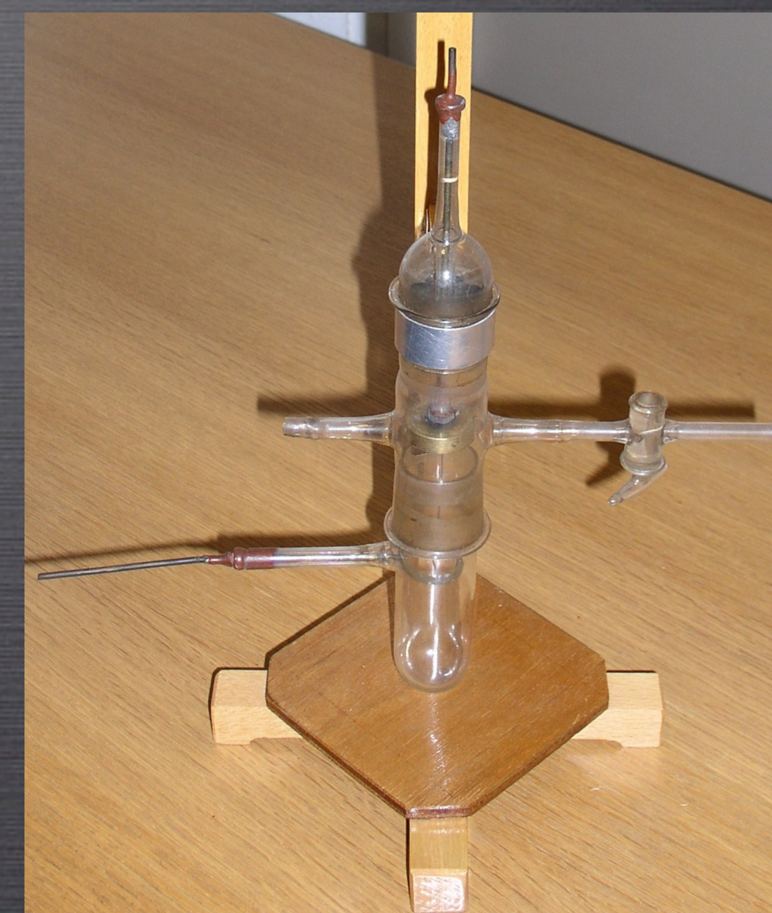


E. Rutherford
The Magnetic and Electric Deviation of Easily Absorbed Rays from Radium
Phil Mag VI 5 (1903) 177

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

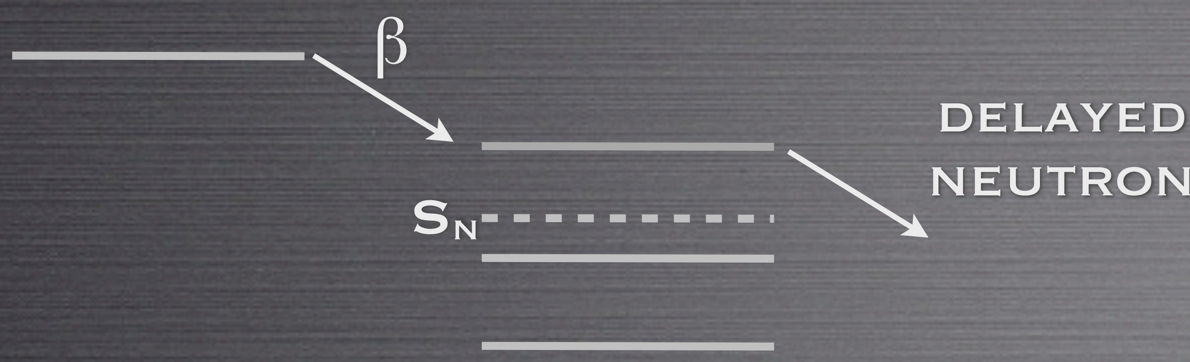


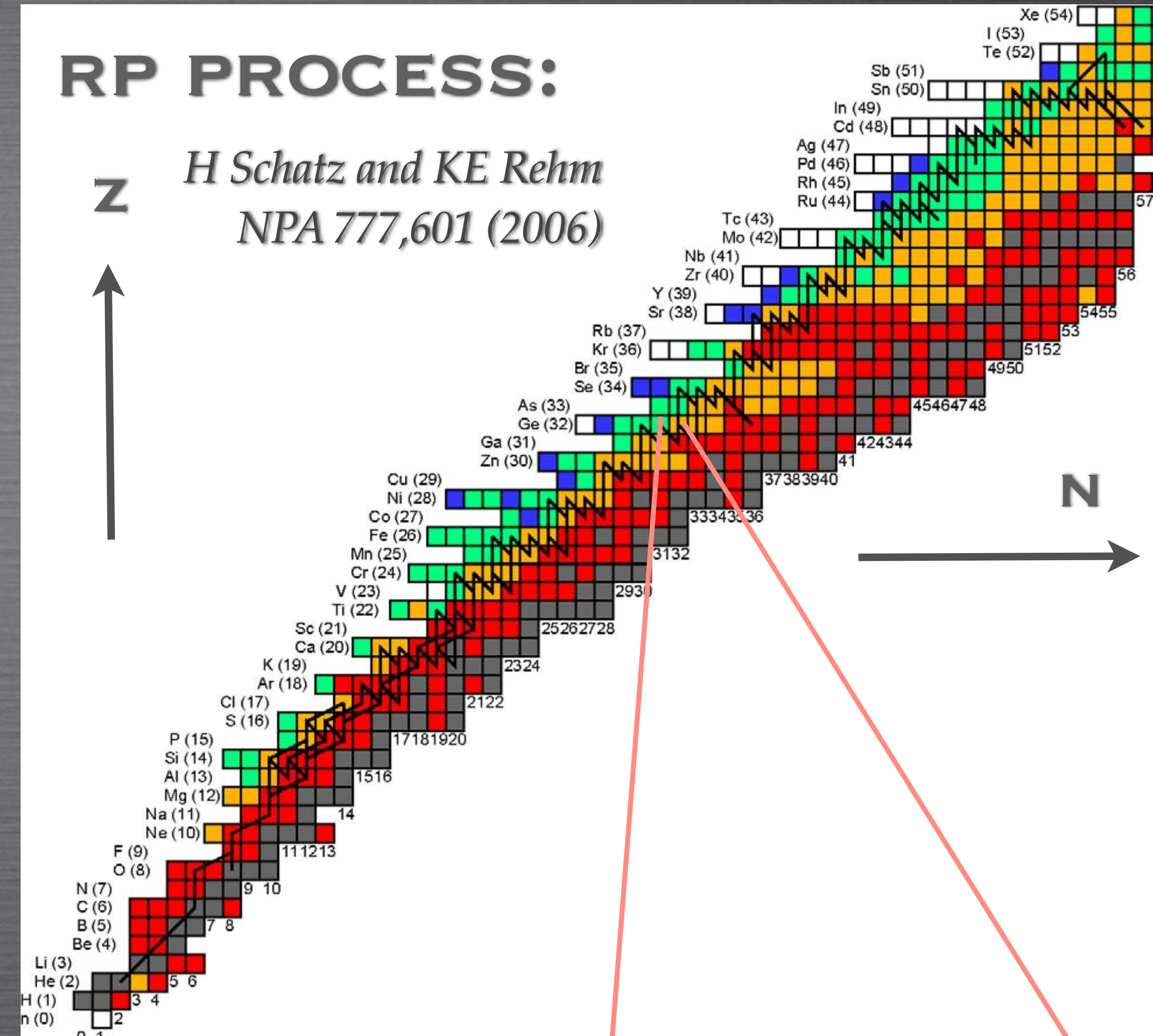
E. Rutherford, F. Ward and W. Lewis
Analysis of Long-Range α Particles from Radium C
Proc Roy Soc A131 (1931) 684



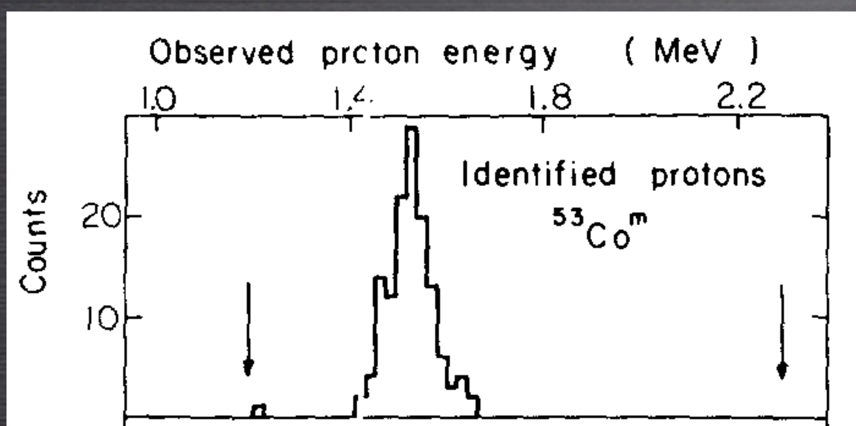
E. Rutherford and H. Geiger
The Charge and Nature of the Alpha Particle
Proc Roy Soc A 81 (1908) 162

I: Radioactivity

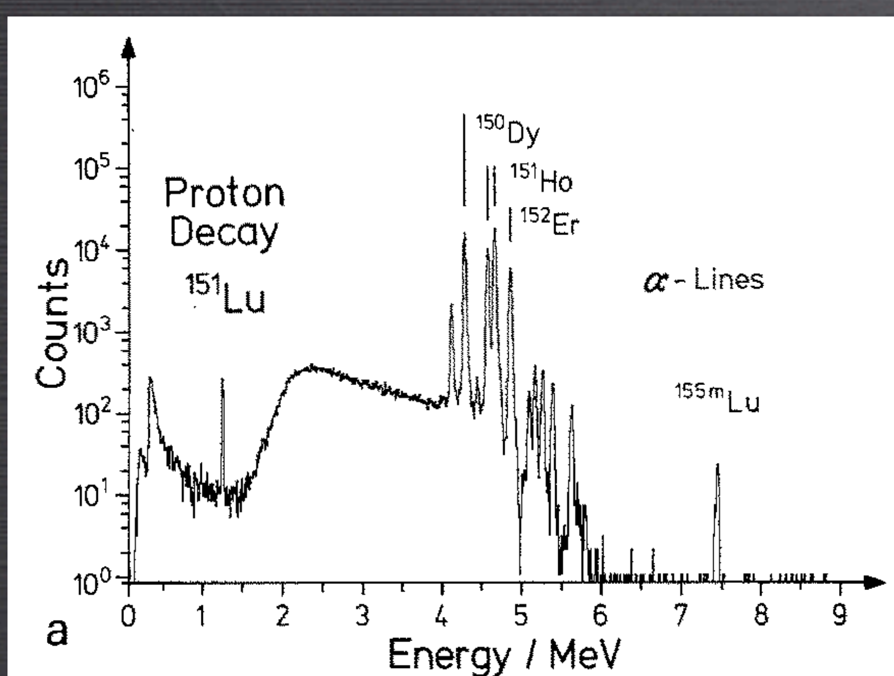




Proton Decay:

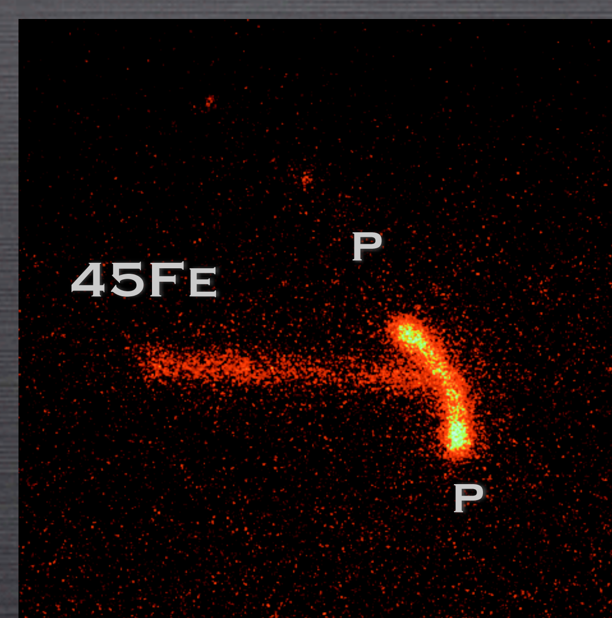


Cerny et al., PLB 33, 284 (1970)

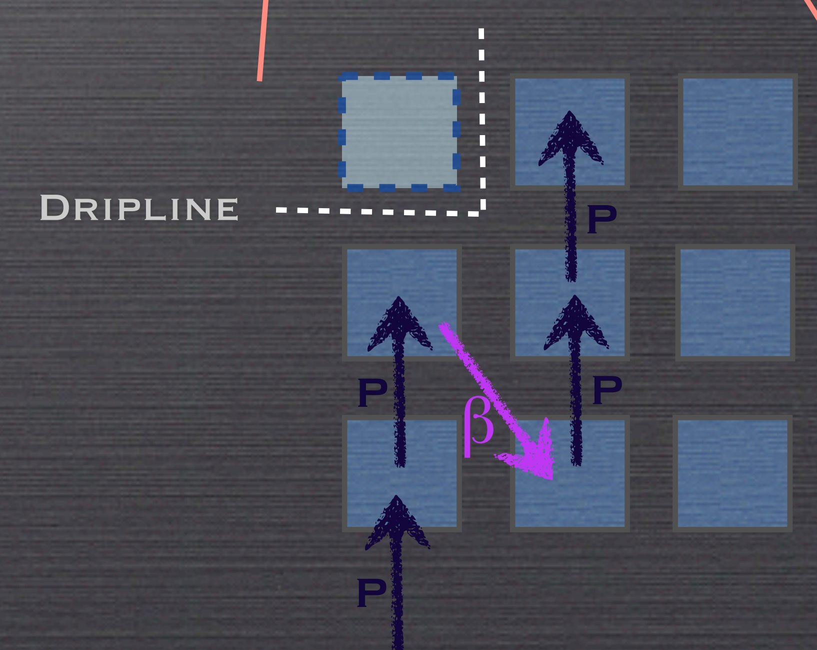


Hofmann et al., Z Phy A 305, 111 (1981)

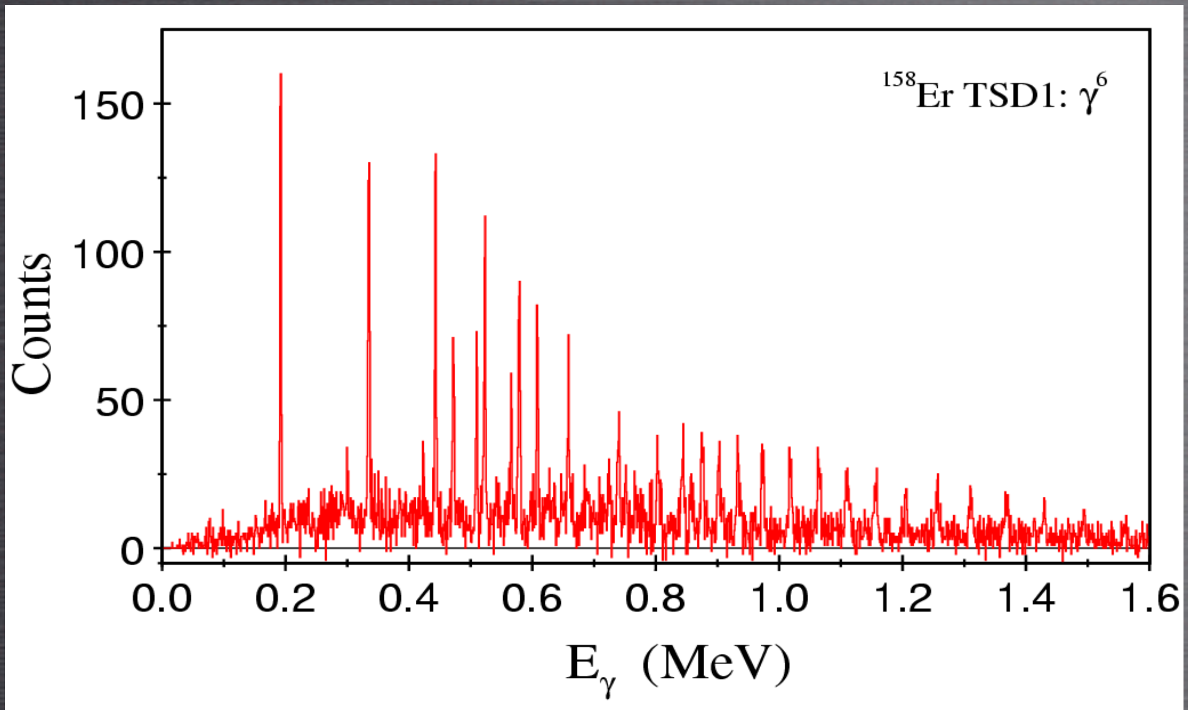
Two Proton Decay:



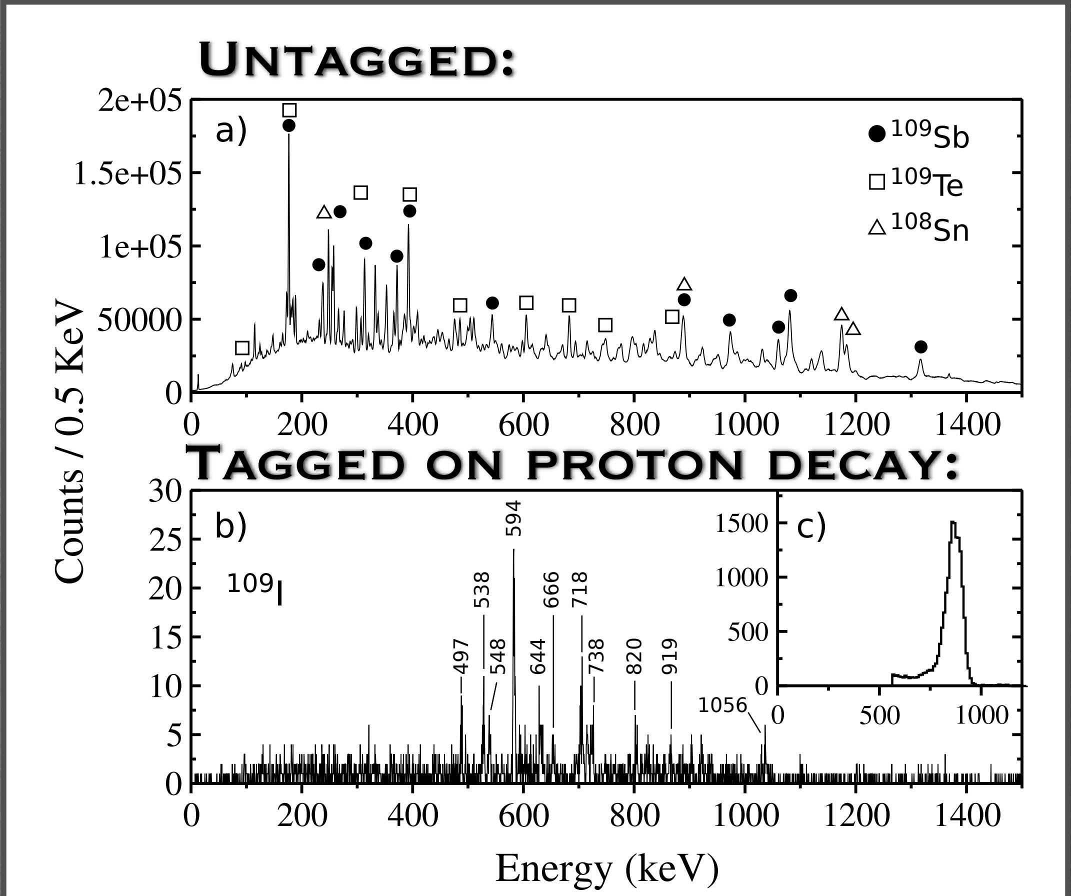
Miernik et al., PRL 99, 192501 (2007)



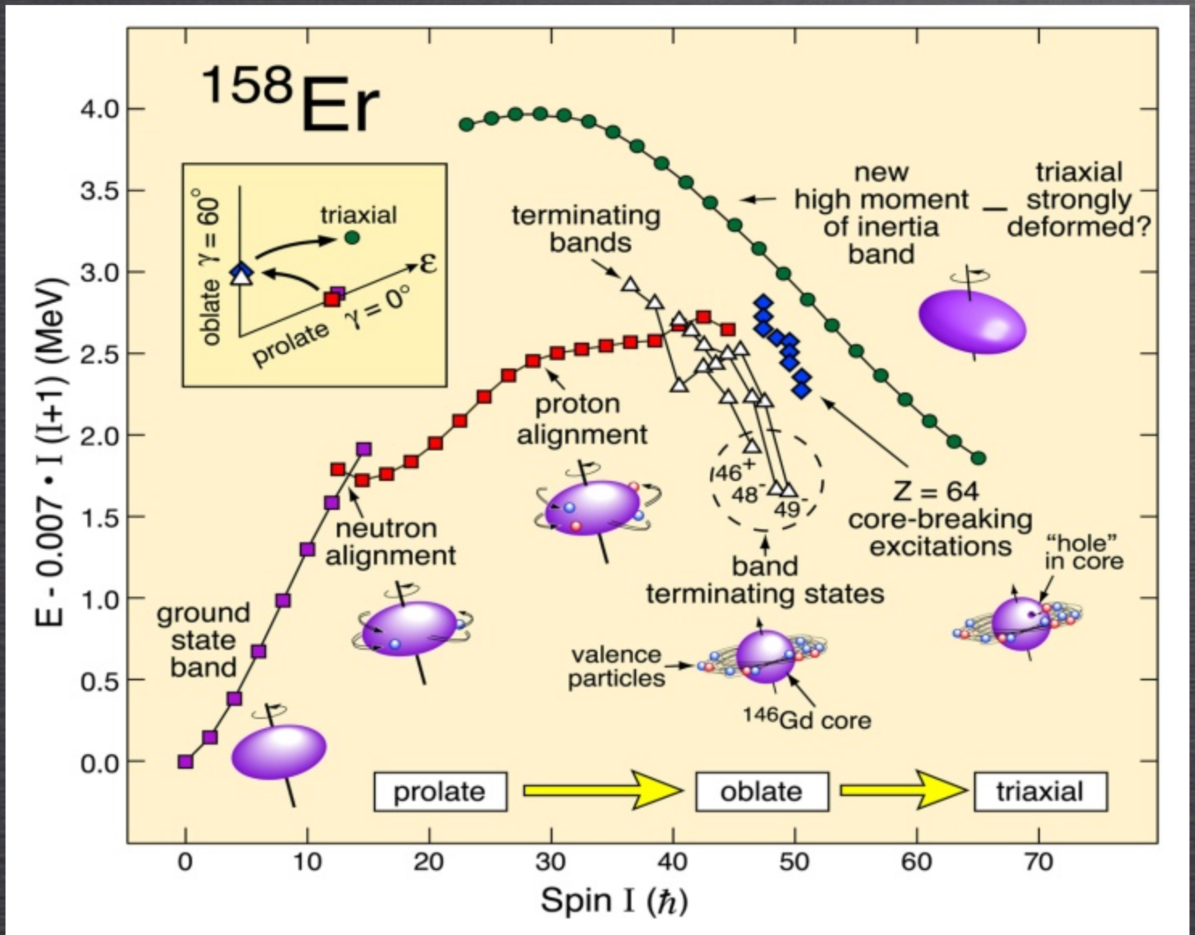
I: Radioactivity

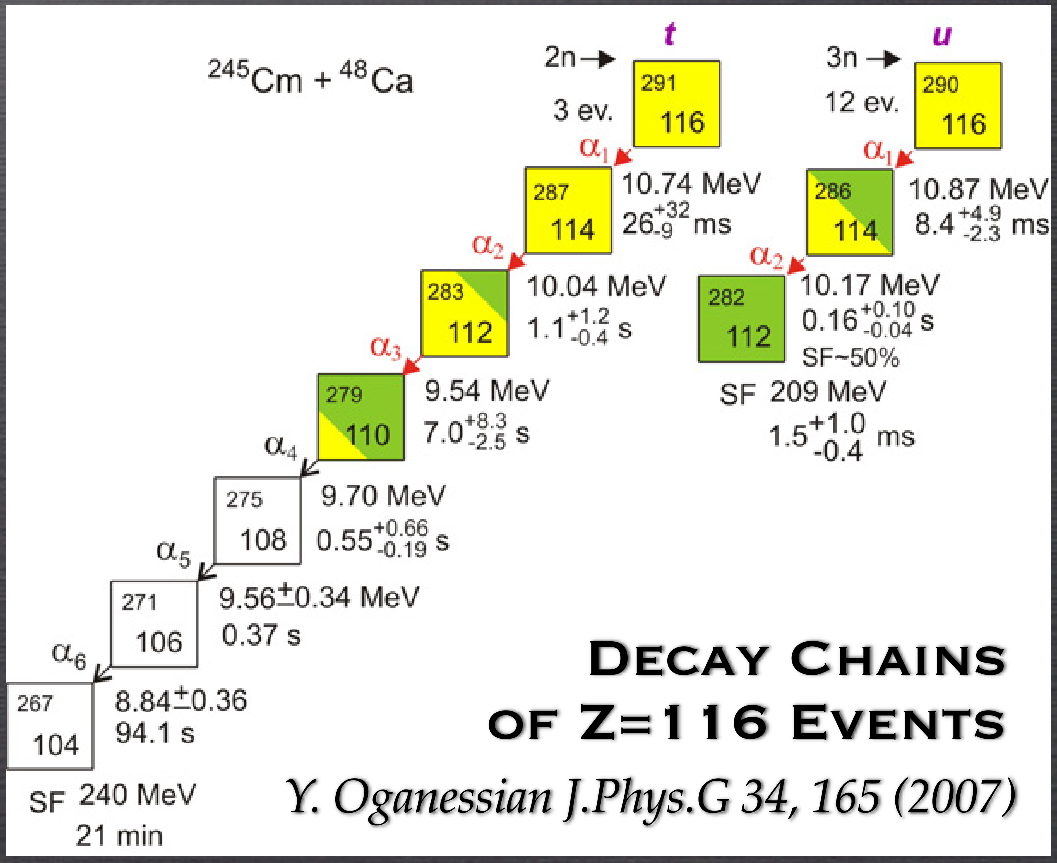


Figures Courtesy of J Simpson and M Riley



M Procter et al,. PLB 704, 118 (2011)





Decay Chains of Z=116 Events

Y. Oganessian J.Phys.G 34, 165 (2007)

I: Radioactivity

^{10}Be:

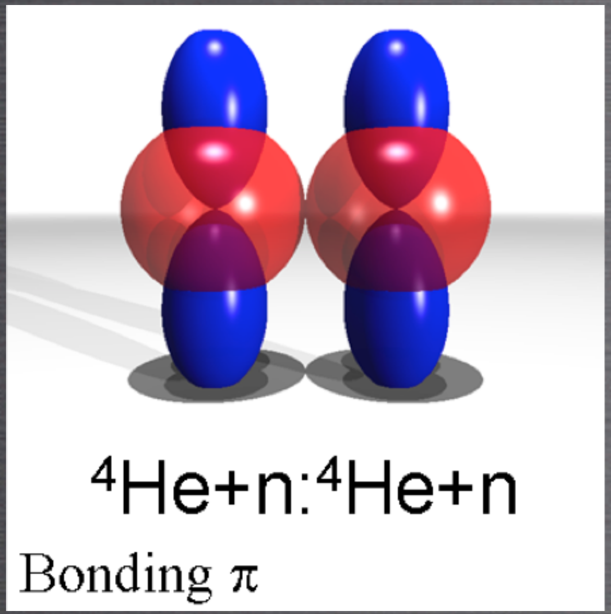
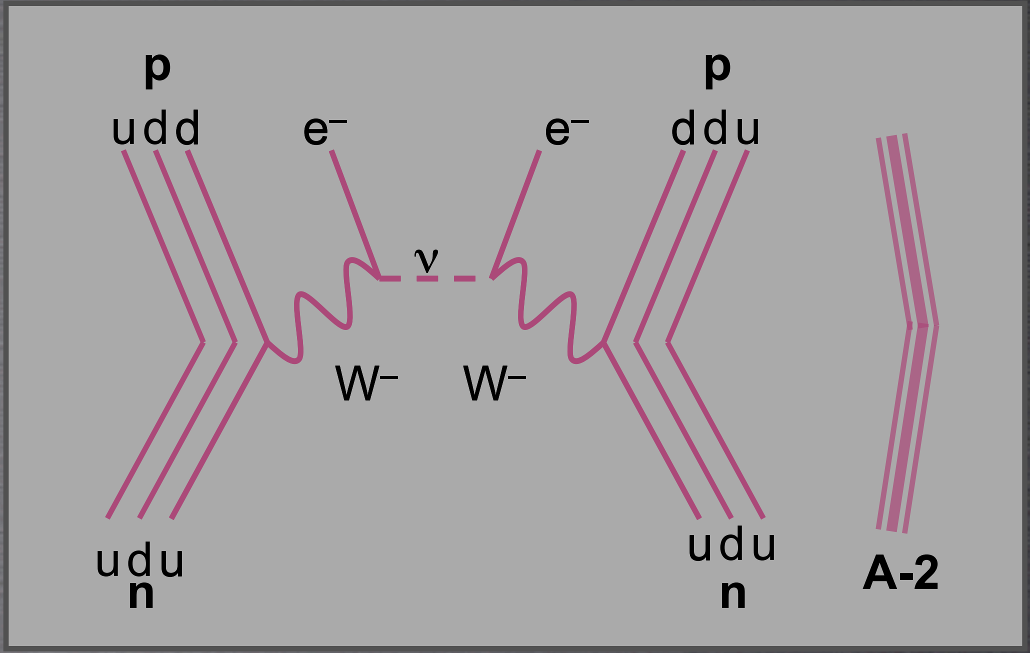


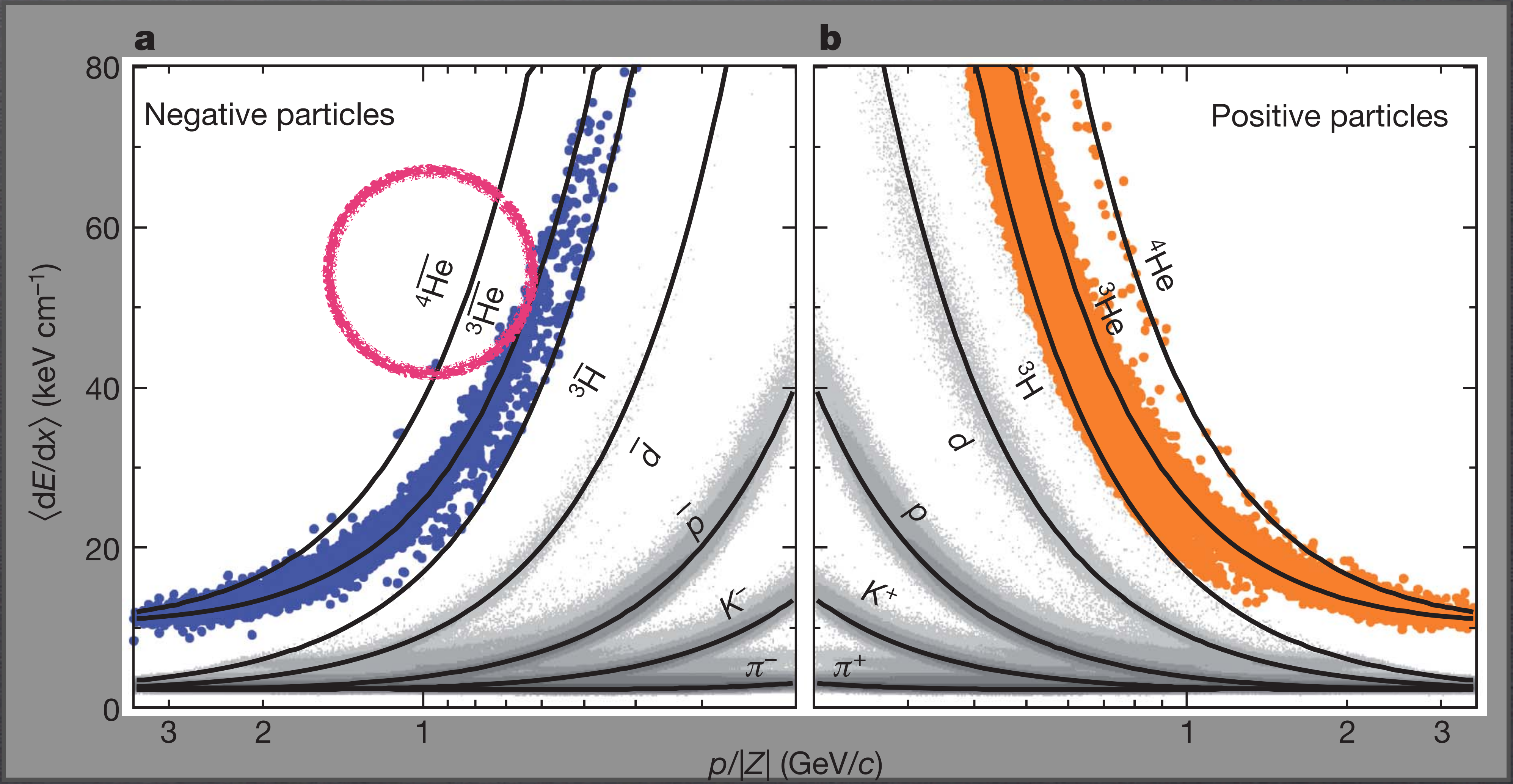
Figure Courtesy of M Freer

0ν2β Decay:



$$\text{Rate} = G^{0\nu}\,|M^{0\nu}_{\rm GT} - \left(\frac{g_V}{g_A}\right)^2 M^{0\nu}_{\rm F}|^2\,\langle m_\nu\rangle^2$$

Particle ID Spectra:



The Star Collaboration
Nature 473 (2011) 353

II: The Nucleus and Scattering

[669]

LXXIX. *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 6×10^{-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 10^9 ABSOLUTE UNITS WOULD BE REQUIRED.

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

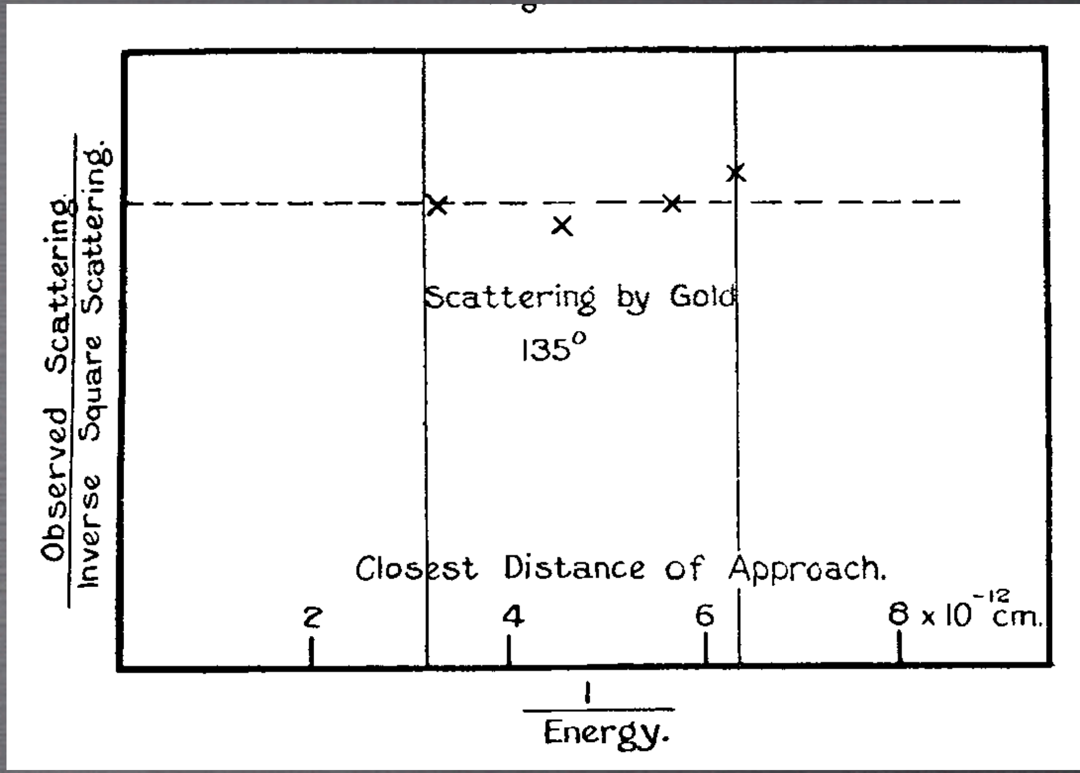
$$\frac{d\sigma}{d\Omega} = \left[\frac{zZe^2}{4\pi\epsilon_0}\right]^2 \frac{1}{16E^2}\frac{1}{\sin^4\theta/2}$$

E. Rutherford
The Scattering of α and β Particles by Matter and the Structure of the Atom
Phil Mag VI 21 (1911) 669

II: The Nucleus and Scattering

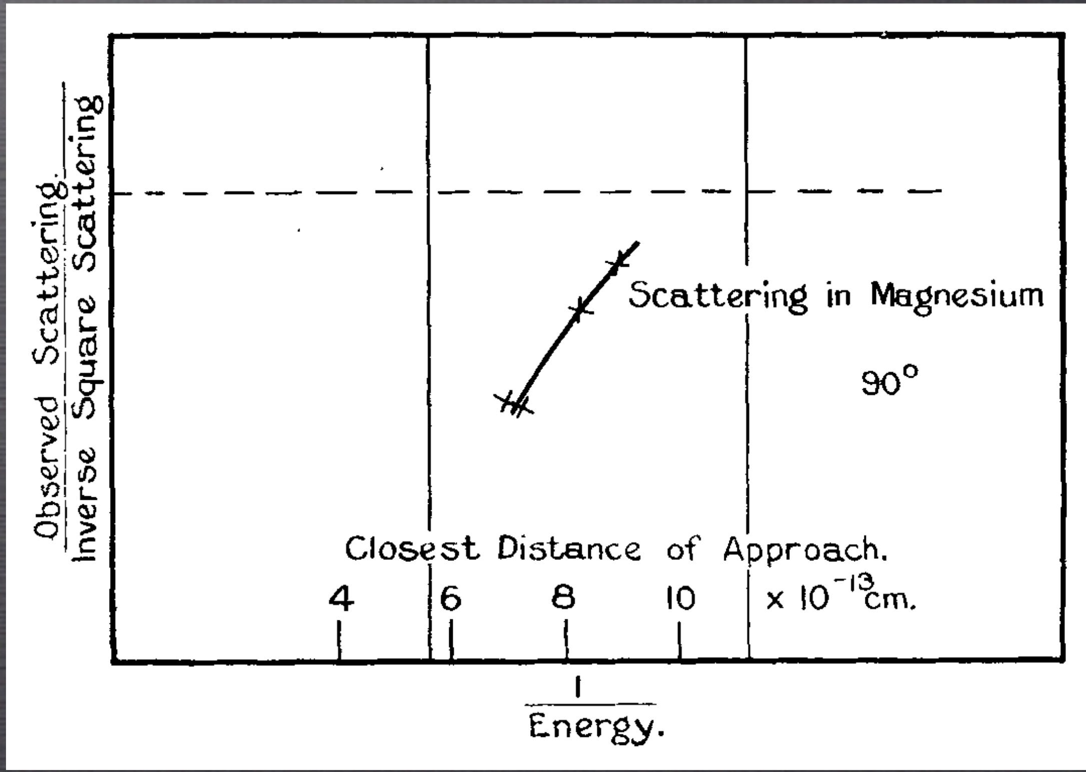
"IN SUCH CLOSE COLLISIONS...THE NUMBER AND DISTRIBUTION OF H ATOMS ARE ENTIRELY DIFFERENT FROM THOSE CALCULATED ON THE ASSUMPTION THAT NUCLEI ARE REGARDED AS POINT CHARGES REPELLING EACH OTHER ACCORDING TO THE LAW OF INVERSE SQUARES."

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



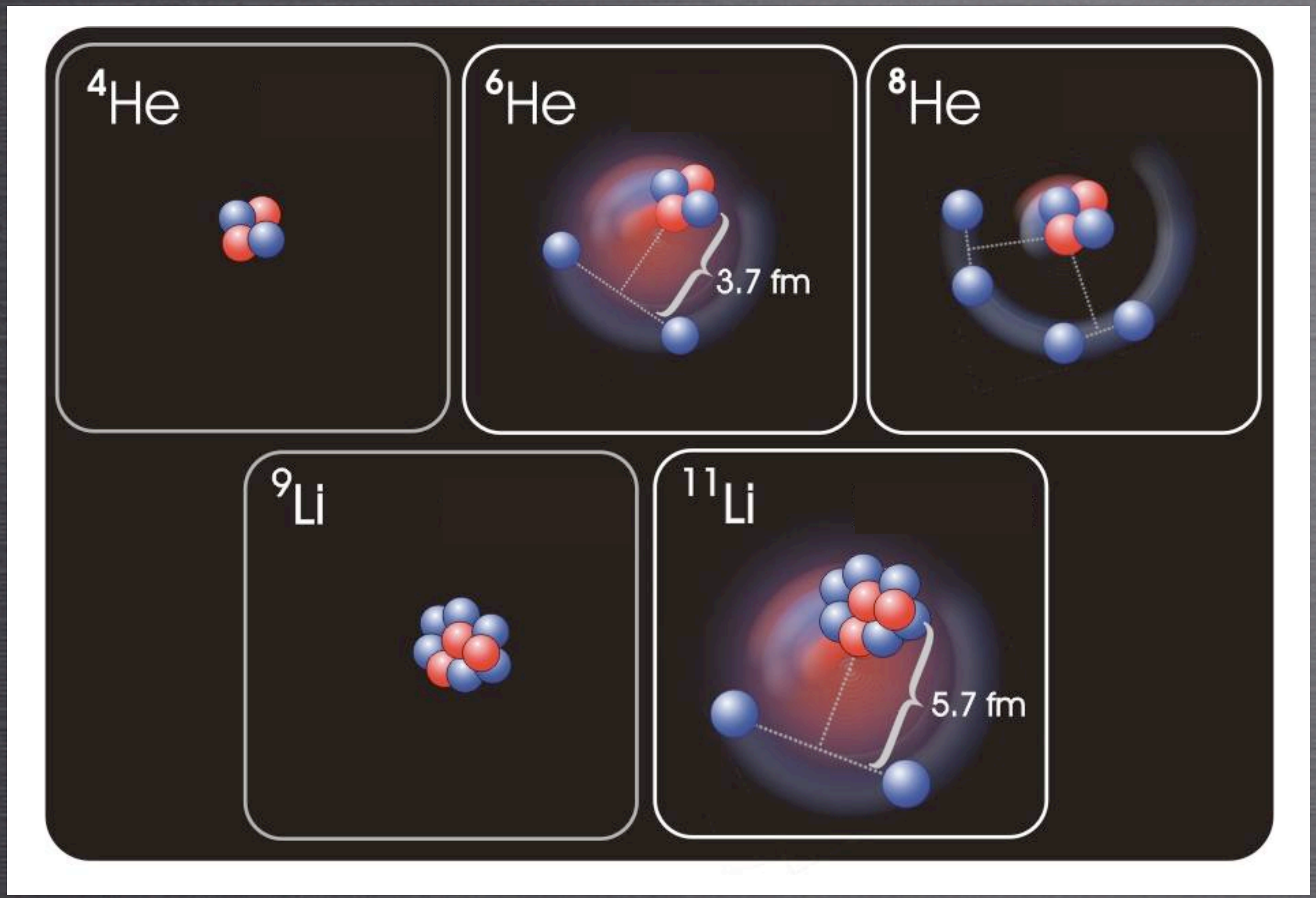
"...NOT INCONSISTENT WITH THE VIEW THAT THE FORCES BETWEEN COLLIDING ATOMS AUGMENT RAPIDLY FOR VALUES OF D<3×10^{-13}CM"

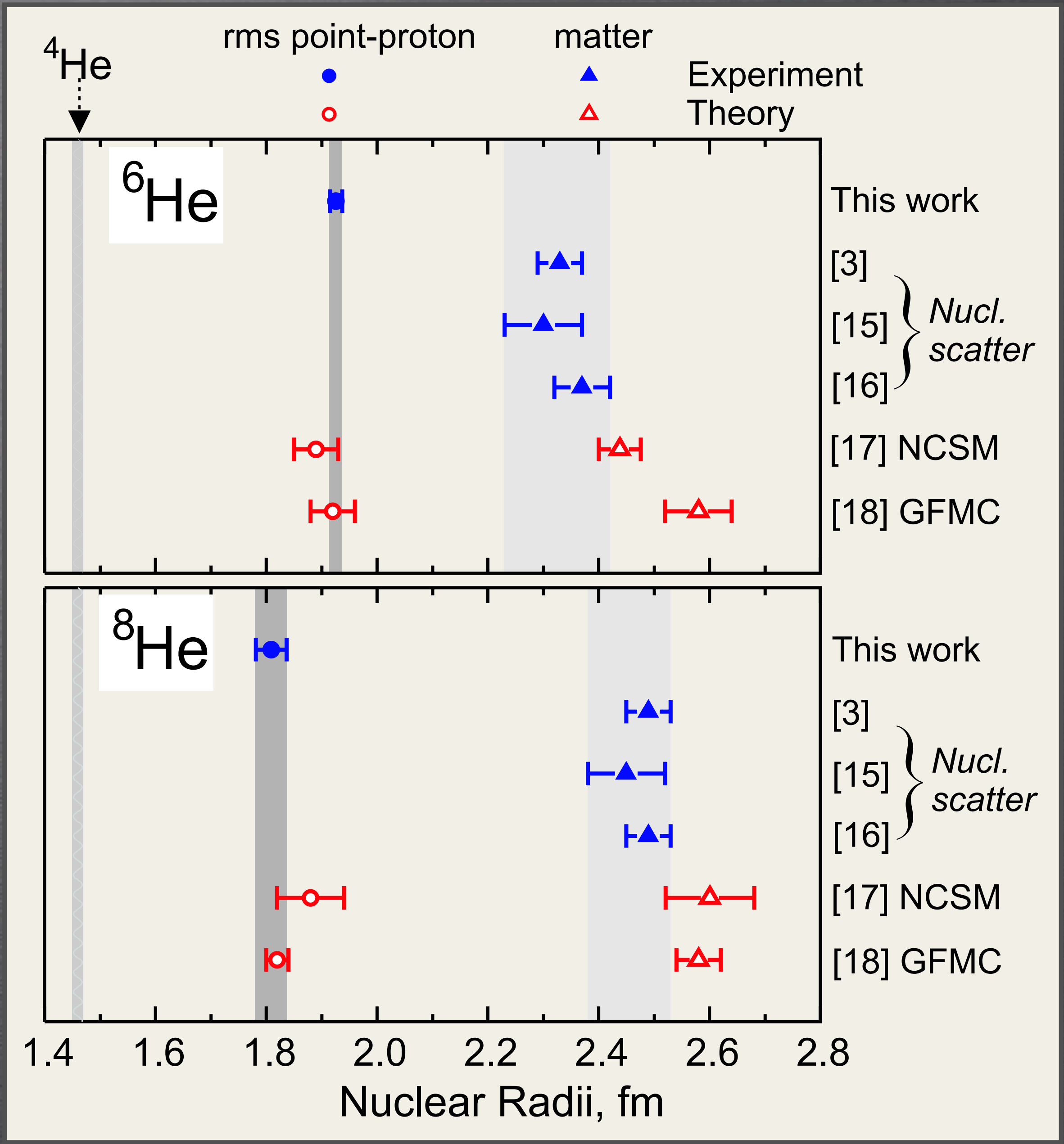
E. Rutherford
Collision of α Particles with Light Atoms I: Hydrogen
Phil Mag VI 37 (1919) 537



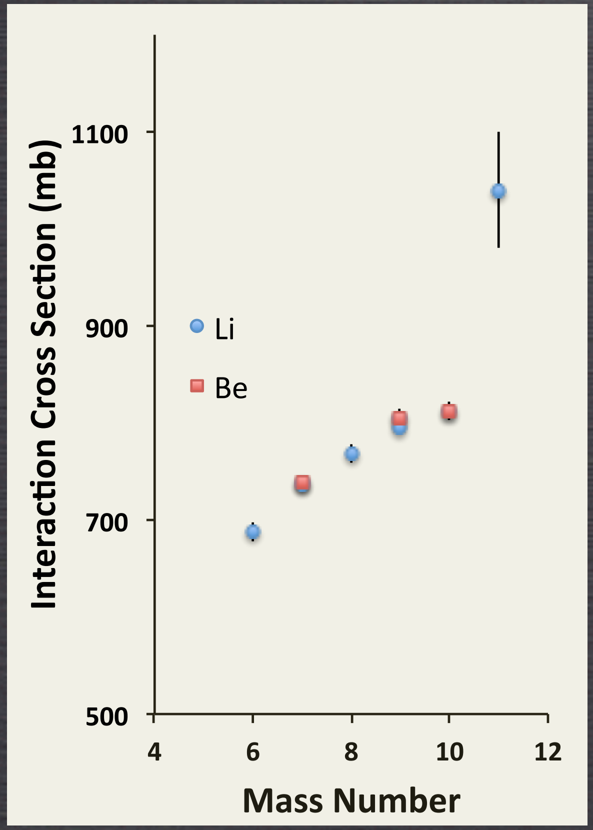
E. Rutherford and J. Chadwick
Scattering of α Particles by Atomic Nuclei and the Law of Force
Phil Mag VI 50 (1925) 889

II: The Nucleus and Scattering





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



Tanihata et al.,
PRL 55, 2676 (1985)

III: Nuclear Reactions

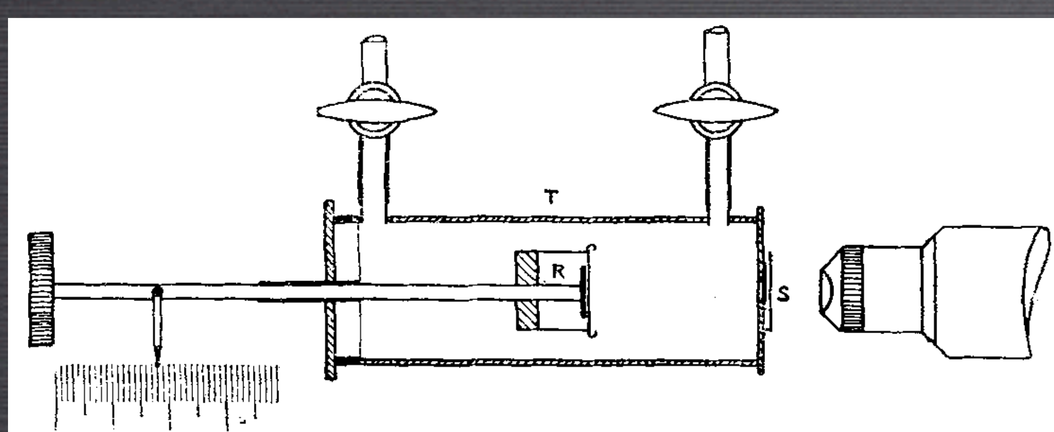
$$^{14}\mathrm{N}+\alpha \Longrightarrow {}^{17}\mathrm{O}+\mathrm{p}$$

"...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 α Particles with Light Atoms IV: An Anomalous Effect in Nitrogen

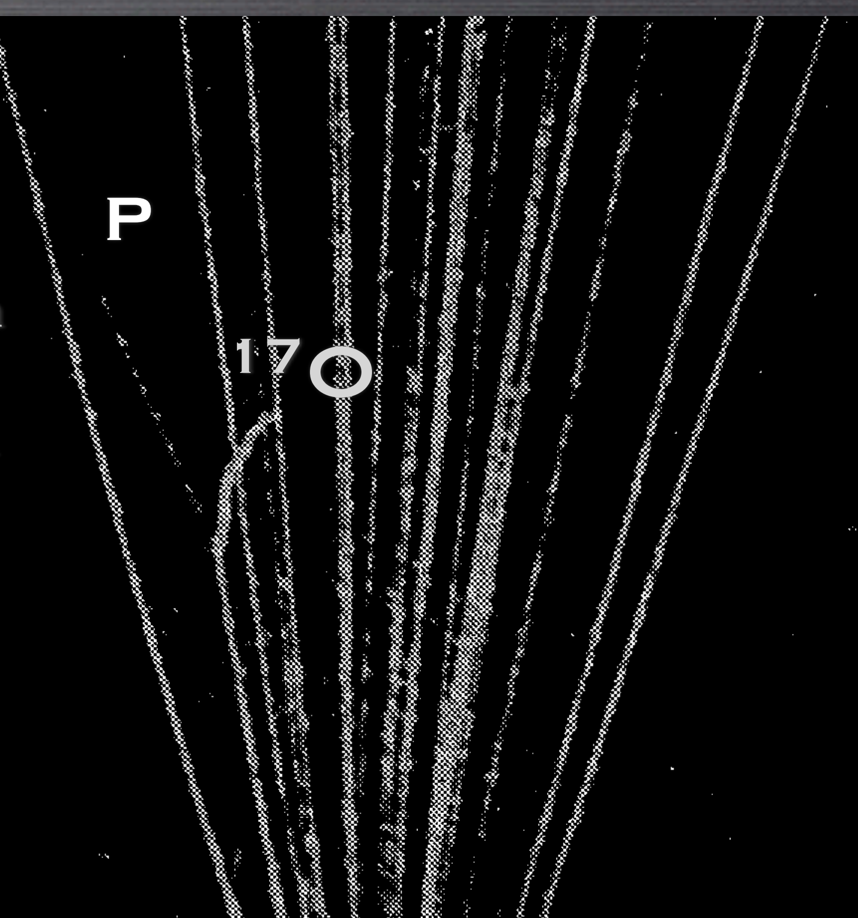
Phil Mag VI 37 (1919) 581



E. Rutherford and J. Chadwick

The Artificial Disintegration of Light Elements

Phil Mag VI 42 (1921) 809

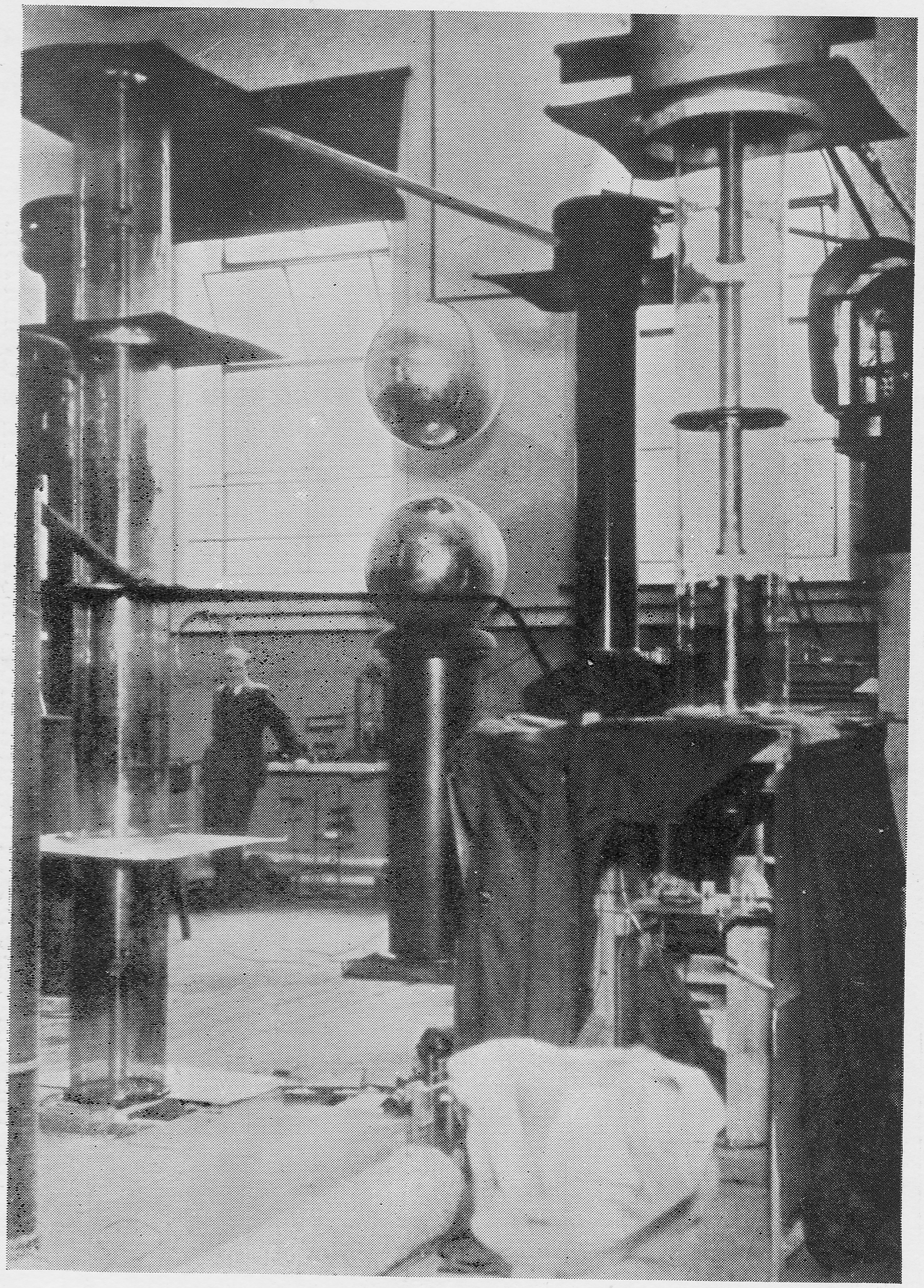


P.M.S. Blackett

The Ejection of Protons from Nitrogen Nuclei Photographed by the Wilson Method

Phil Mag VI 42 (1921) 809

III: Nuclear Reactions



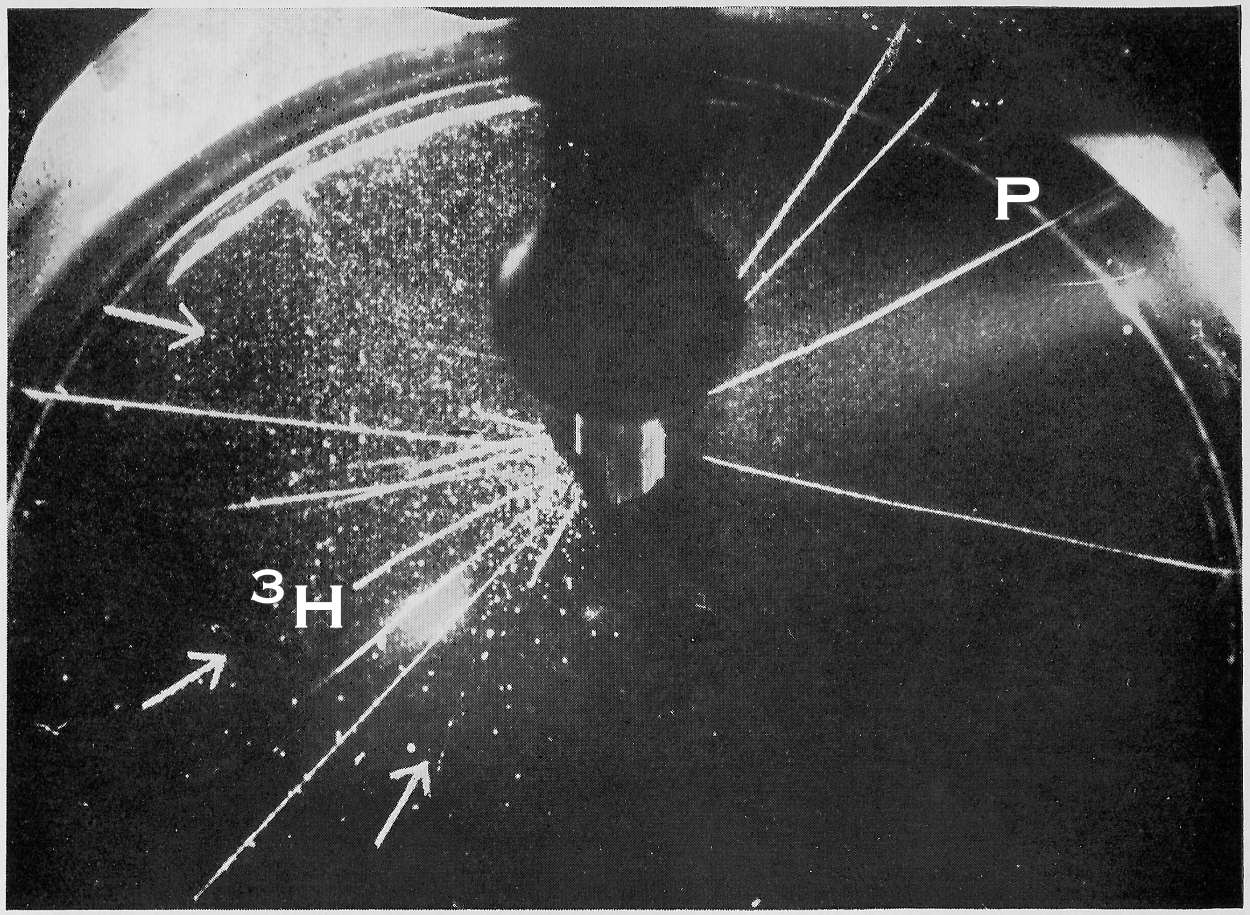
High voltage installation used at Cambridge by Cockcroft and Walton in their pioneer experiments upon artificial transmutation.

"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

$$d + d \Longrightarrow p + {}^3H$$
$$\Longrightarrow {}^3He + n$$

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



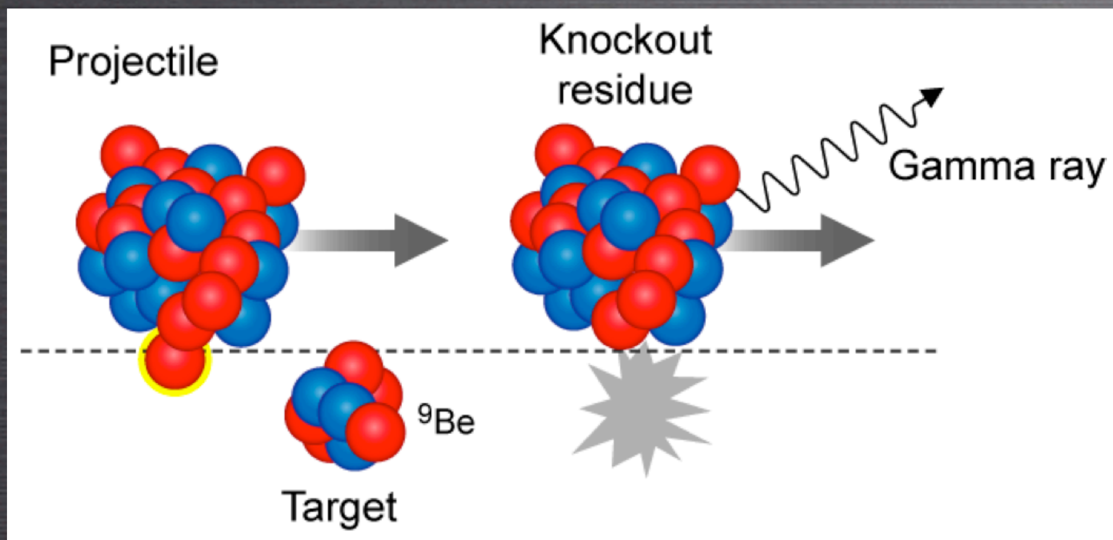
(*Photographed by* P. I. DEE.)

Photographs from *E. Rutherford*
The Newer Alchemy Cambridge (1937)

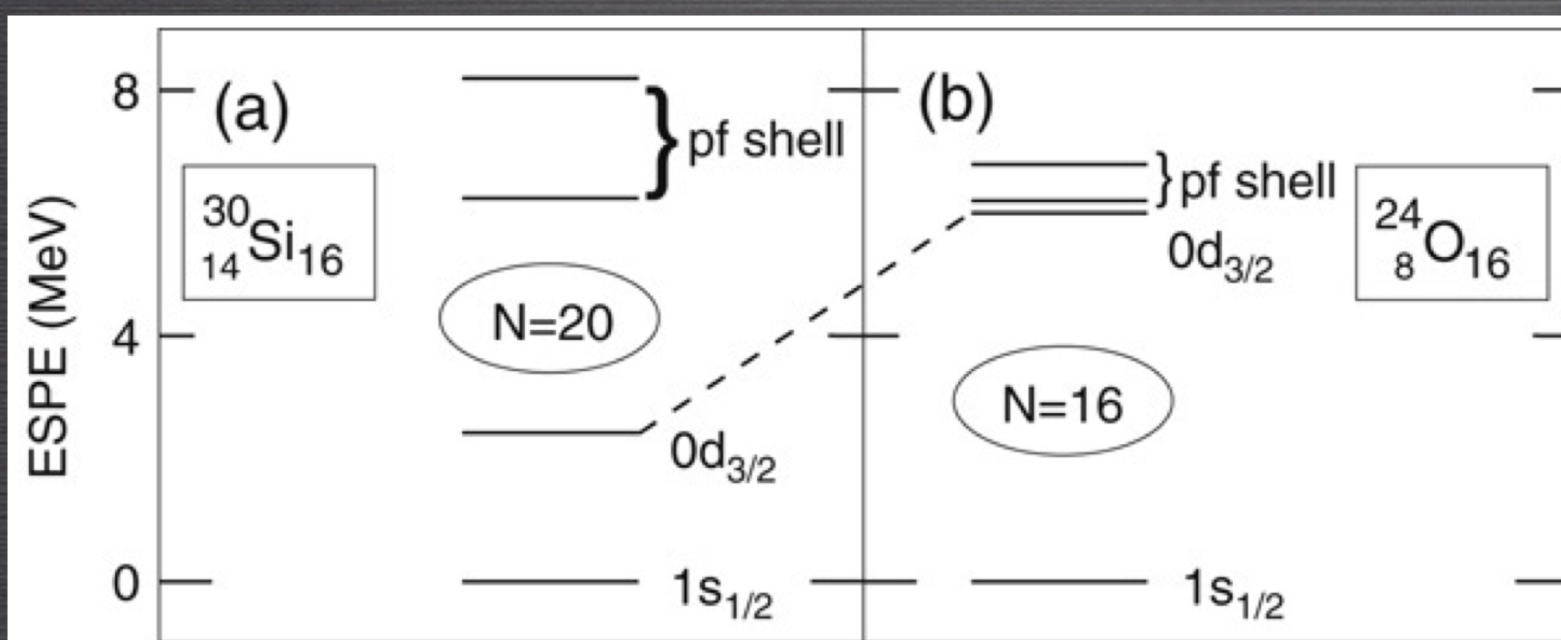
III: Nuclear Reactions

Third-Year Undergraduate Nuclear Physics:

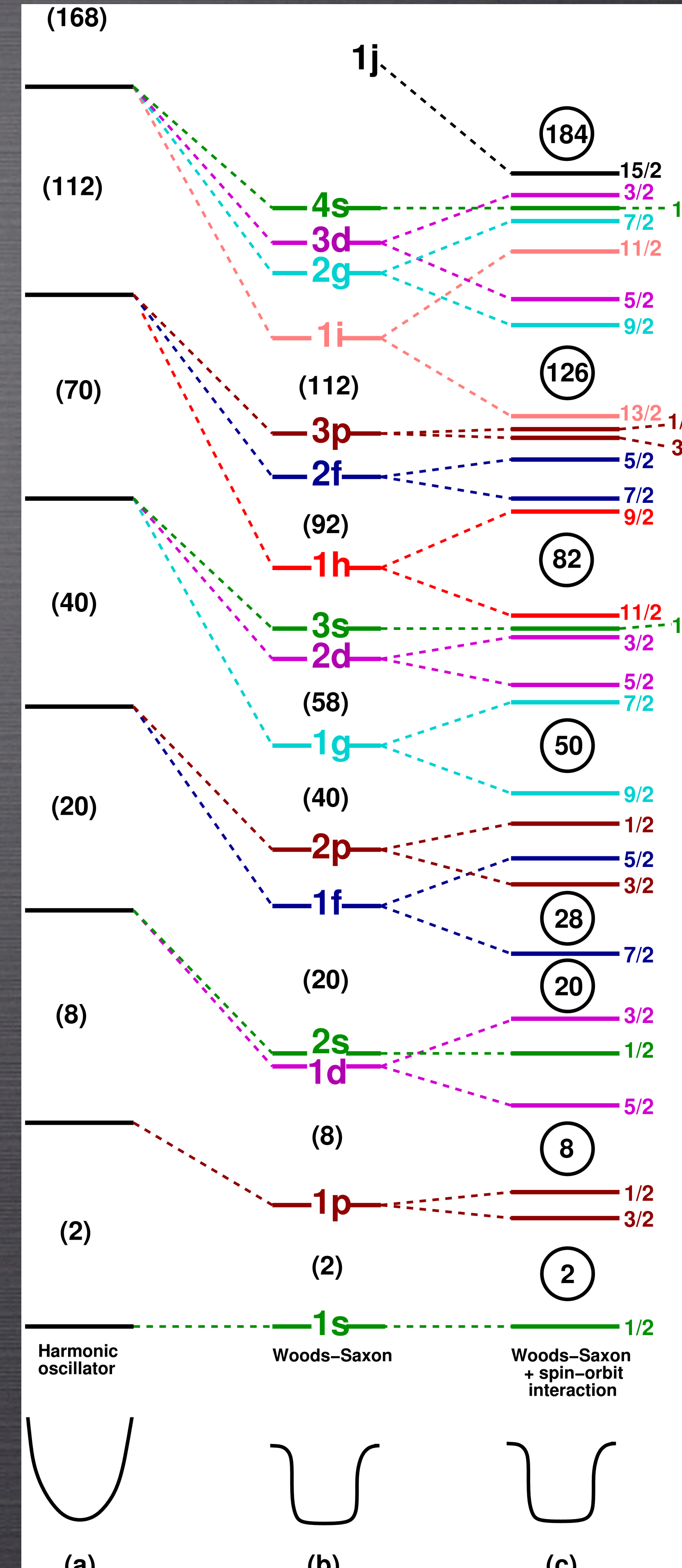
Single-step "knockout":



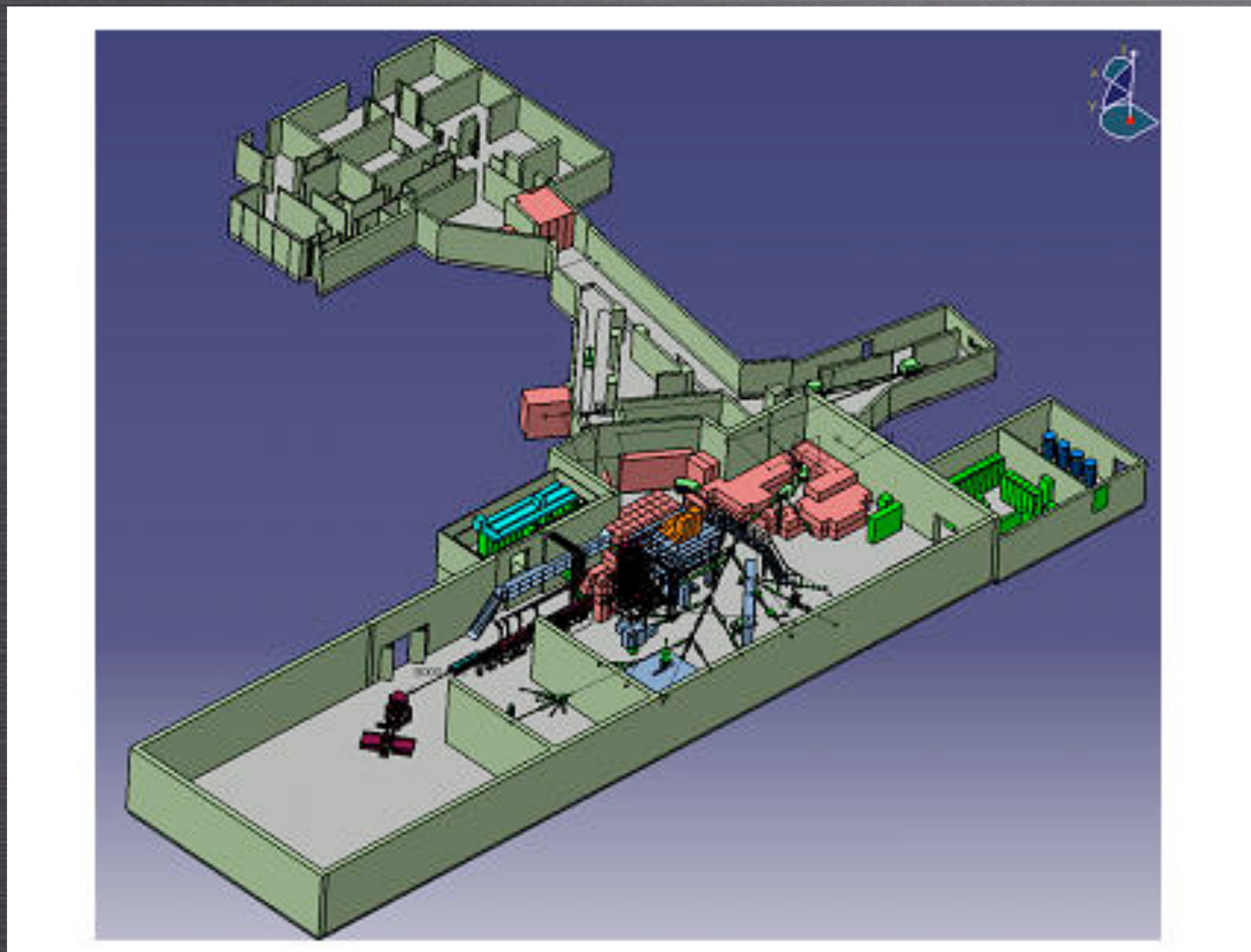
Changing Magic Numbers in SD Shell:

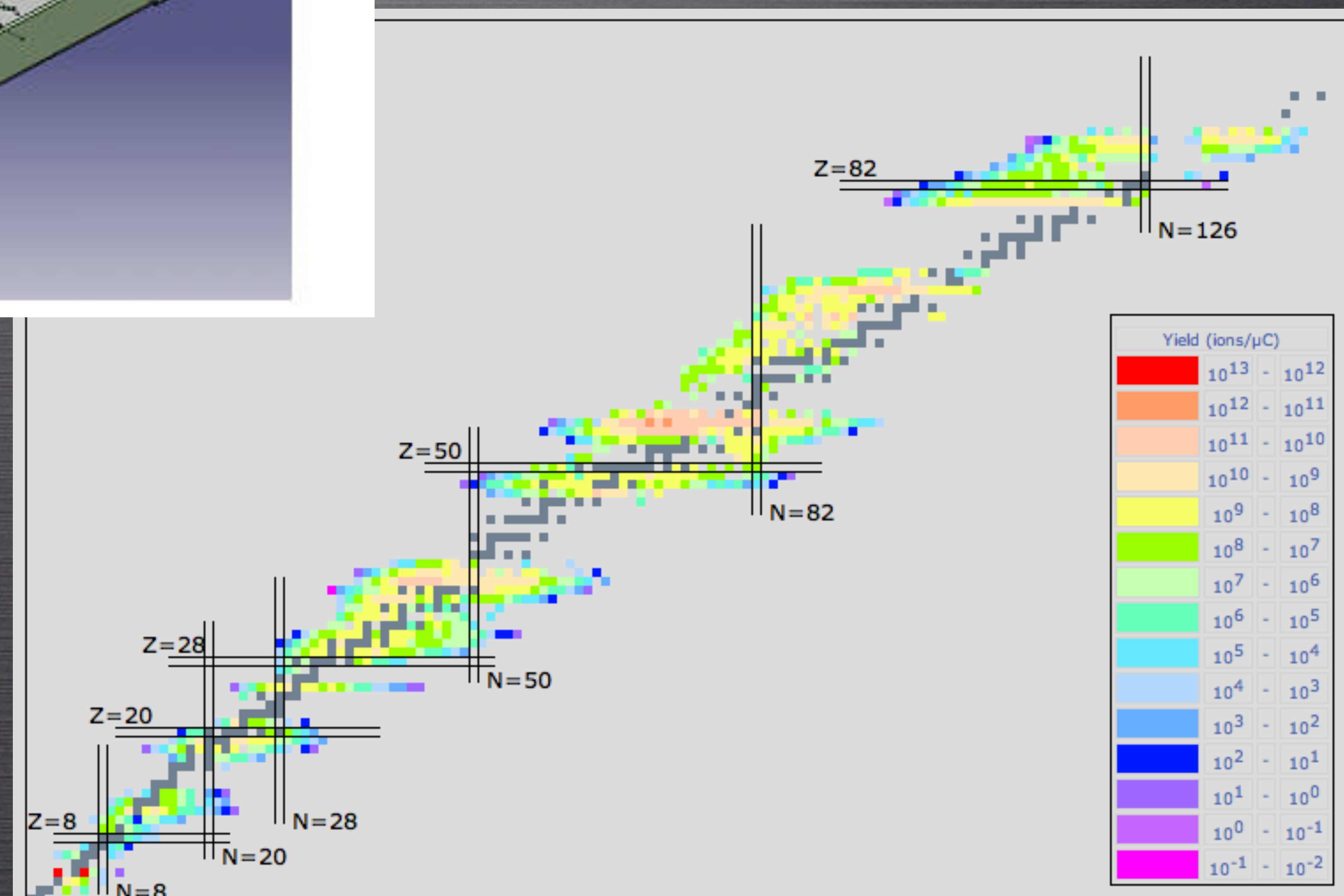


T Otsuka et al.,
PRL 87, 082502 (2001)

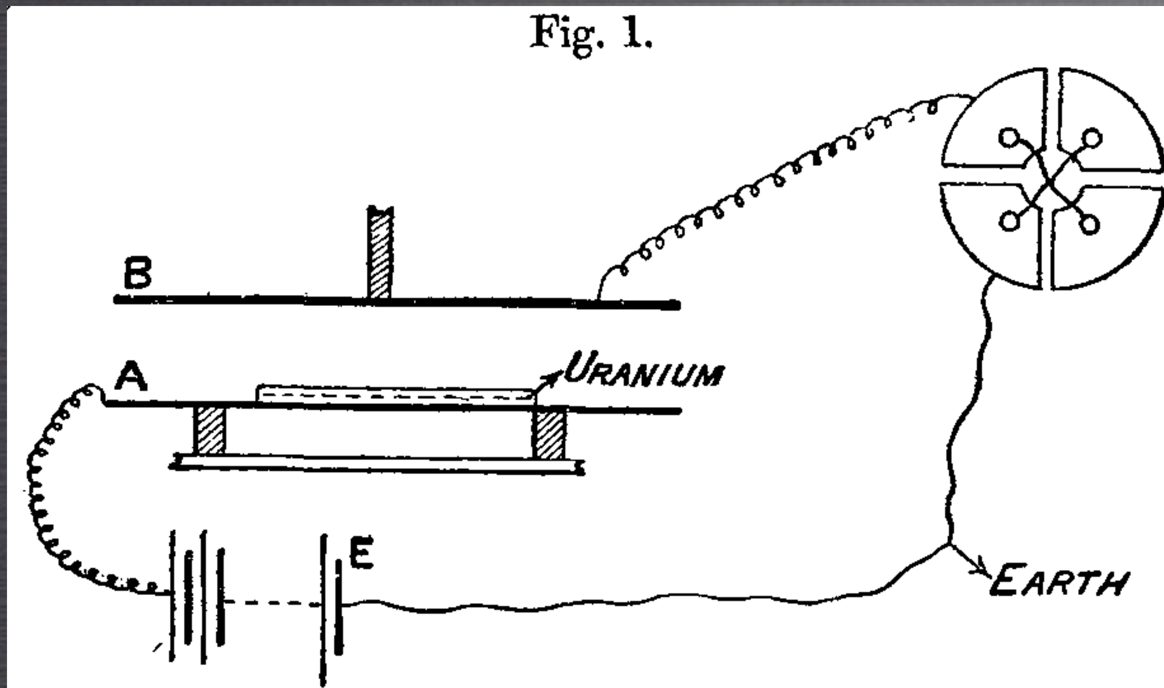


III: Nuclear Reactions

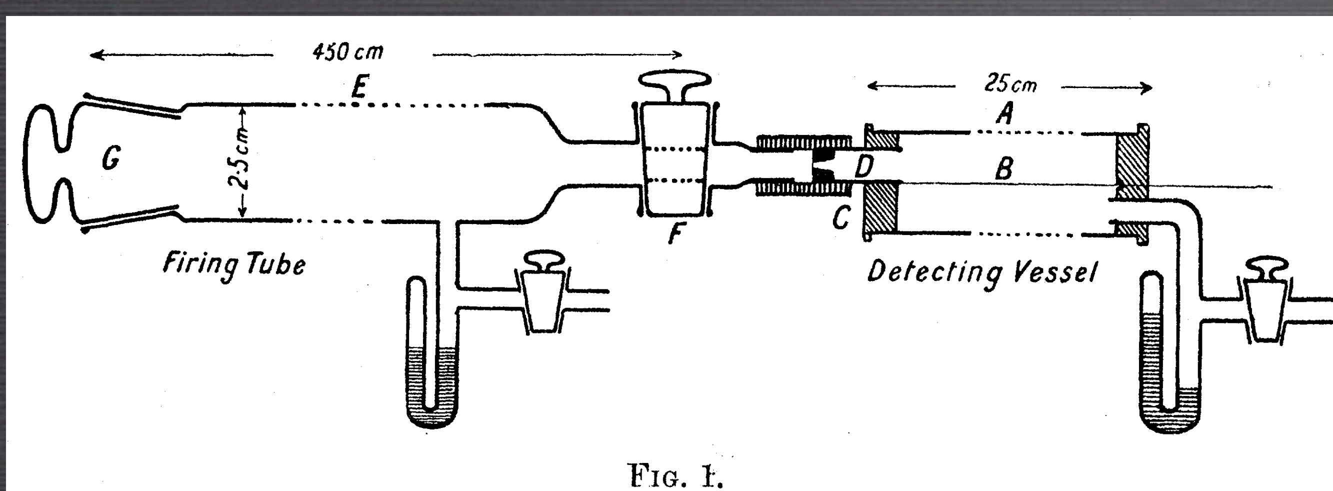




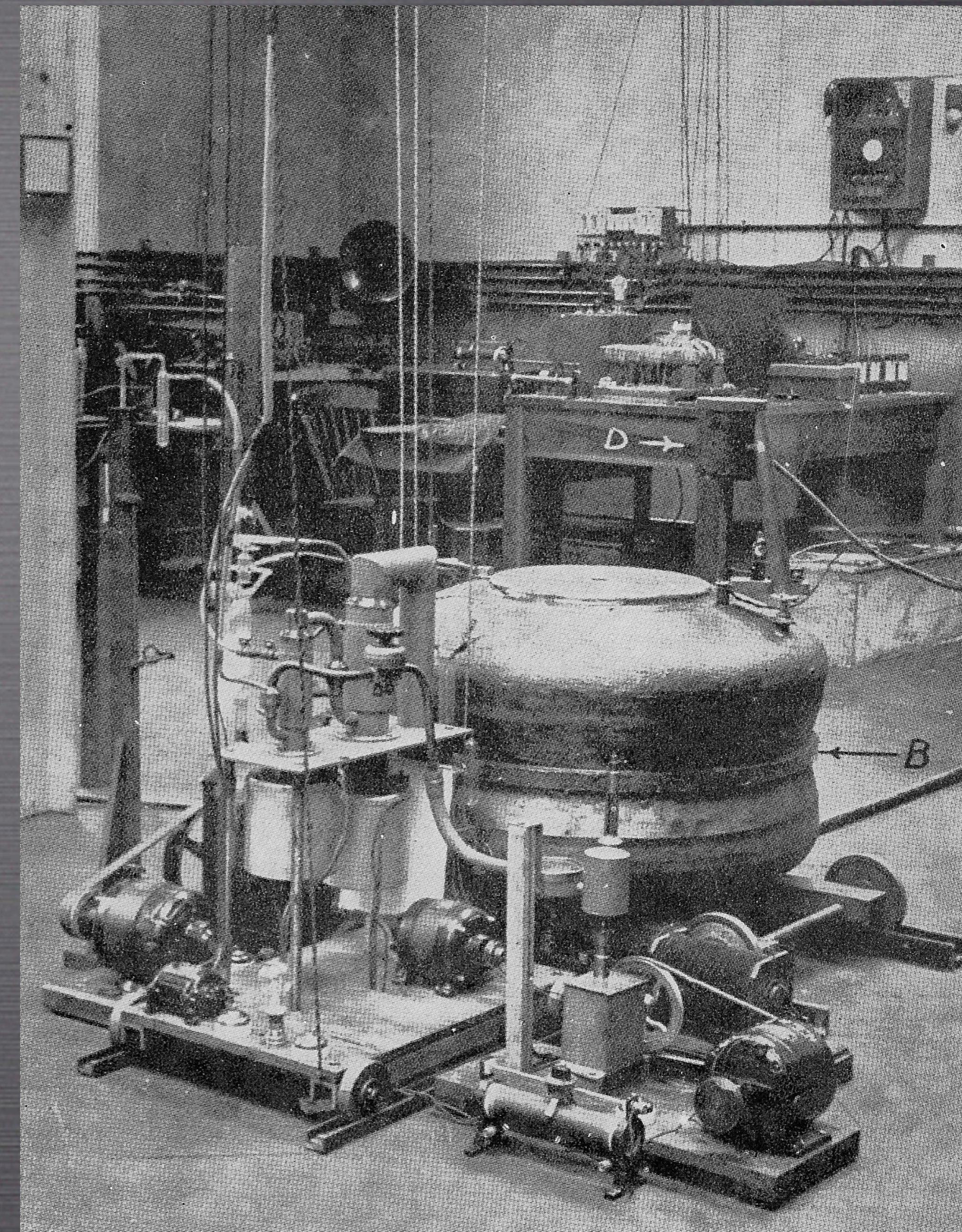
IV: Nuclear Technology



E. Rutherford
Uranium Radiation and the Electrical Conduction Produced by It
Phil Mag V 47 (1899) 109



E. Rutherford and H. Geiger
An Electrical Method of Counting the Number of α-Particles from Radio-active Substances
Phil Mag V 47 (1899) 109



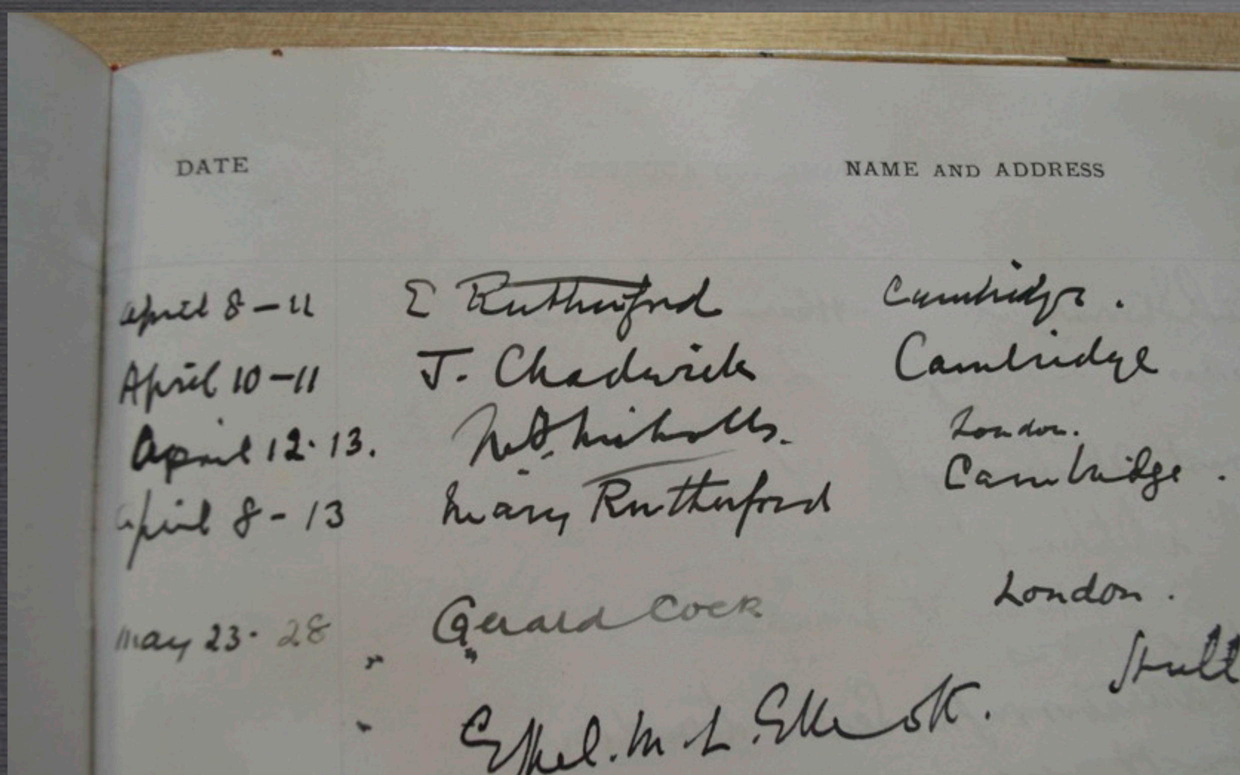
E. Rutherford C.E. Wynn-Williams, W.B. Lewis and B.V. Bowden
Analysis of α-Rays by an Annular Magnetic Field
Proc Roy Soc A 139 (1933) 617

V: Leadership

1930s Management Training Manual?

"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



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

- (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) Insensitivity to Standing.
- (vii) Instilled a Desire to Please.
- (viii) Generous in Assigning Credit.
- (ix) Gathered Consensus Opinion.
- (x) Allowed Space for Projects to Develop.

E. Rutherford's leadership characteristics culled from several colleagues reminiscences.

The End

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.

T.S.TAYLOR A.S.RUSSELL
H.RICHARDSON J.M.NUTTALL B.WILLIAMS W.KAY
A.B.WOOD E.GREEN R.H.WILSON S.OBA E.MARSDEN H.GERRARD J.CHADWICK F.W.WHALEY H.G.J.MOSELEY
H.ROBINSON D.C.H.FLORANCE Miss M.WHITE J.N.PRING Prof. E.RUTHERFORD W.MAKOWER E.J.EVANS C.G.DARWIN

JUNE 1913