
Michael

Nuclear Properties and Processes

- Discoveries, Theories and Inventions
  - Discoveries:
    - X-rays (Rontgen)
    - Radioactivity (Becquerel; M. and P. Curie)
    - Cathode rays - electrons (Crooks; J.J. Thomson)
    - Special relativity (Poincare; Einstein)
    - Periodic law (Rutherford, Moseley)

Nuclear Properties and Processes

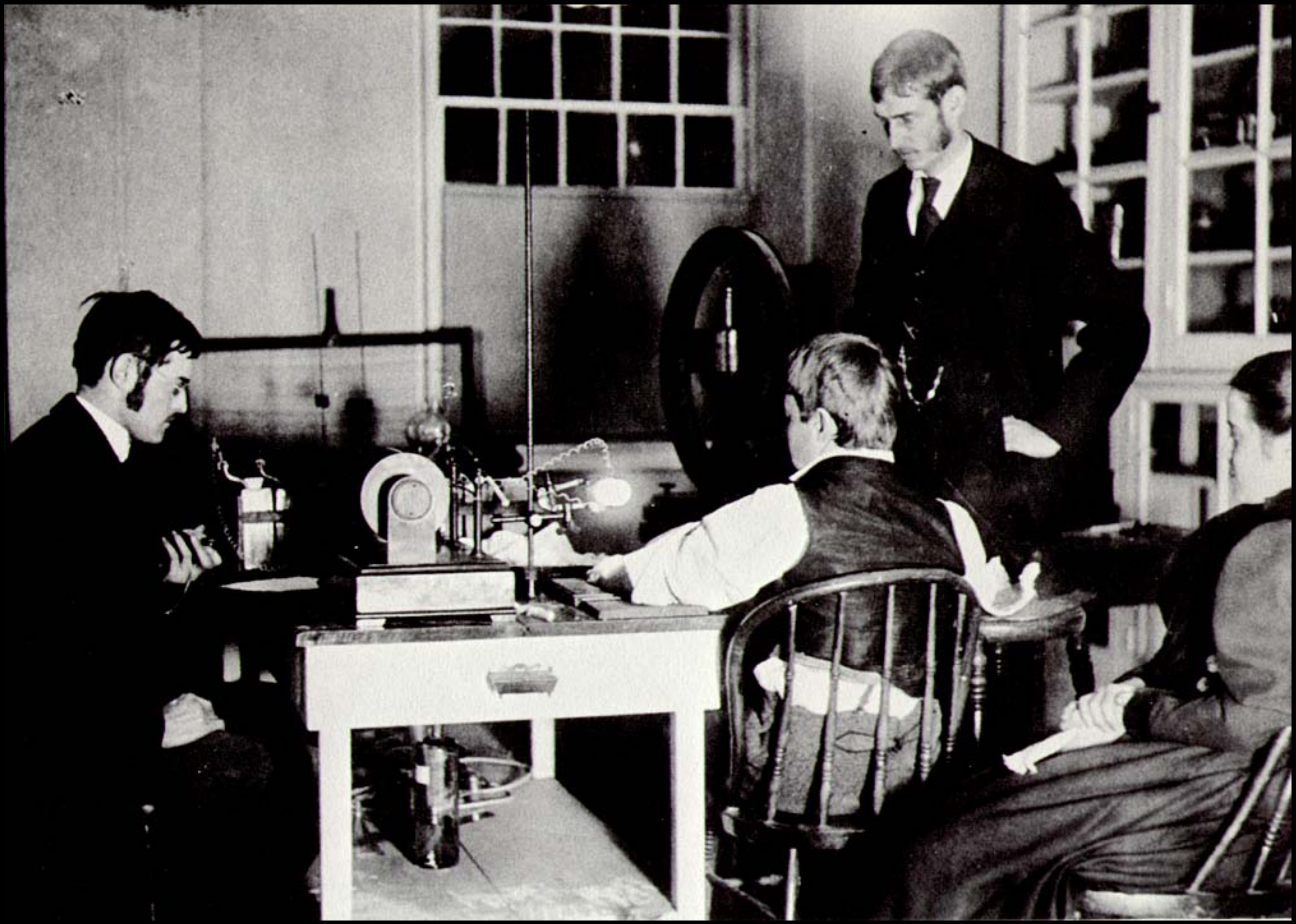
- Discoveries, Theories, and Inventions
  - Theories:
    - Nuclear atom (Rutherford; Bohr)
    - Quantum mechanical atom (Heisenberg, Schrodinger, Born, and many others)
    - Fisson and nucleosynthesis (Fermi; Hahn, Strassmann and Meitner; Bohr and Wheeler; Landau)
    - Fusion and nucleogenesis (Tamm, Sakharov, Artsimovich, Teller, Bethe)

Nuclear Properties and Processes

- Discoveries, Theories, and Inventions
  - Inventions:
    - Vacuum pump; Hittorf tube
    - Cyclotrons and accelerators
    - Geiger counters and cloud chambers
    - Power plants and Weapons
    - Mass spectrometer; Isotopes; new (heavy) elements
    - Radiocarbon dating; dating methods
    - Medicines and drugs

Nuclear properties and processes

- X-rays discovered by Rontgen (Wurzburg) in December, 1895).
- Highly penetrating, high energy radiation of short wavelength, on the order of 10^{-8} m.
- Certain fluorescent salts stimulated to emit light by cathode rays.

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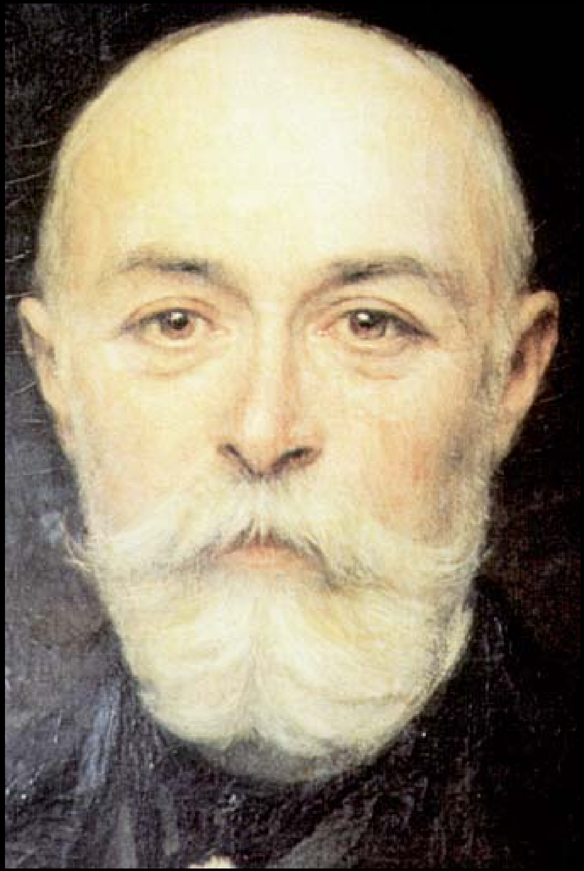
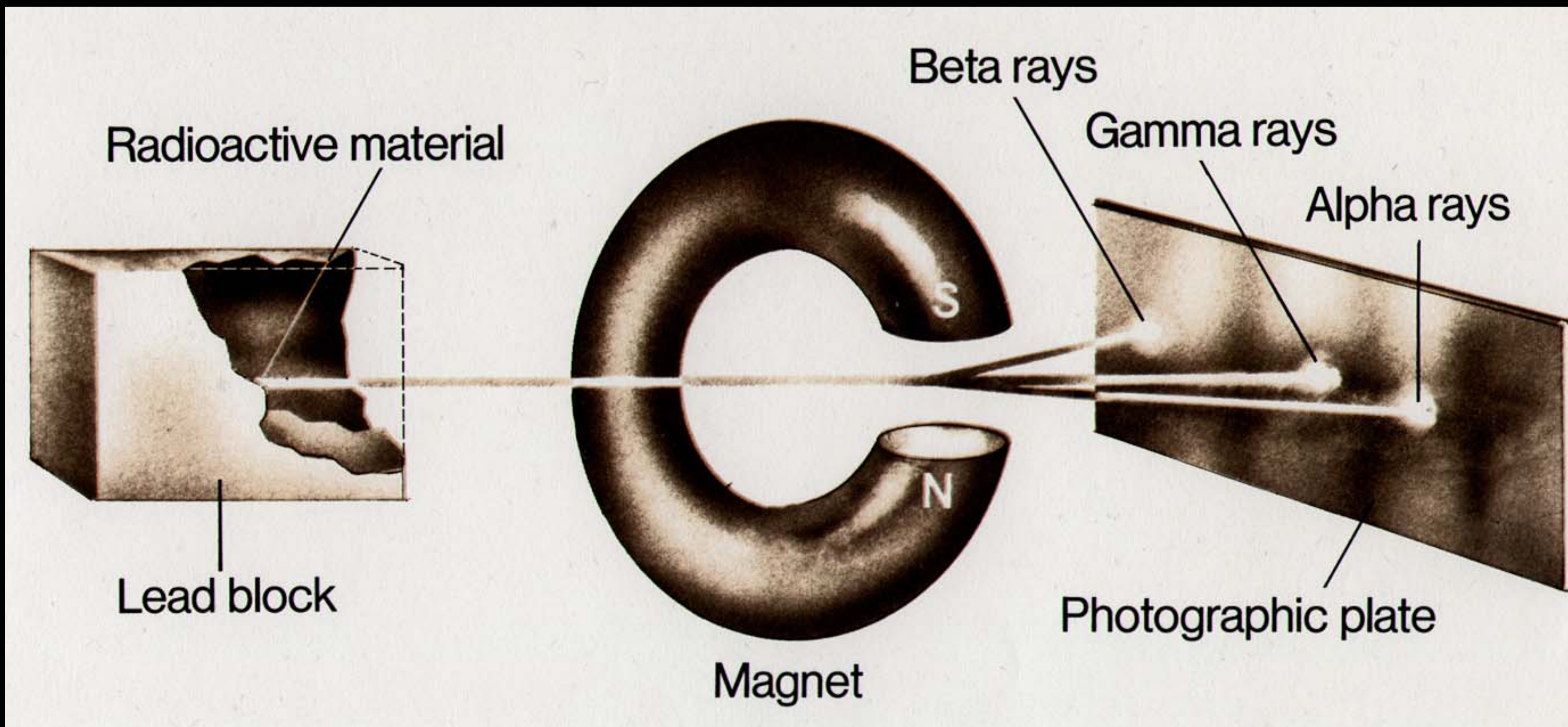
Nuclear properties and processes



- Henri Becquerel discovers radioactivity in double salt of uranium.
- Three kinds of radioactive decay products identified.
- Alpha and beta particles; gamma rays.

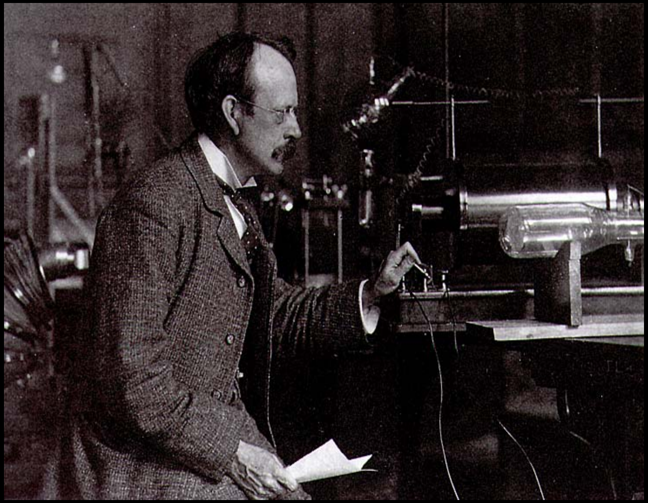


Radioactive material
Lead block
S
N
Magnet
Beta rays
Gamma rays
Alpha rays
Photographic plate

Relative Penetrating Power, Charge, and Mass Data for Radium Radiation

Type	Foil Thickness	Relative Penetrating Power	Charge	Rest Mass
α	0.005 mm	1	2+	4 amu
β	0.50 mm	100	1−	1/1837 amu
γ	5.0 mm	1000	0	0

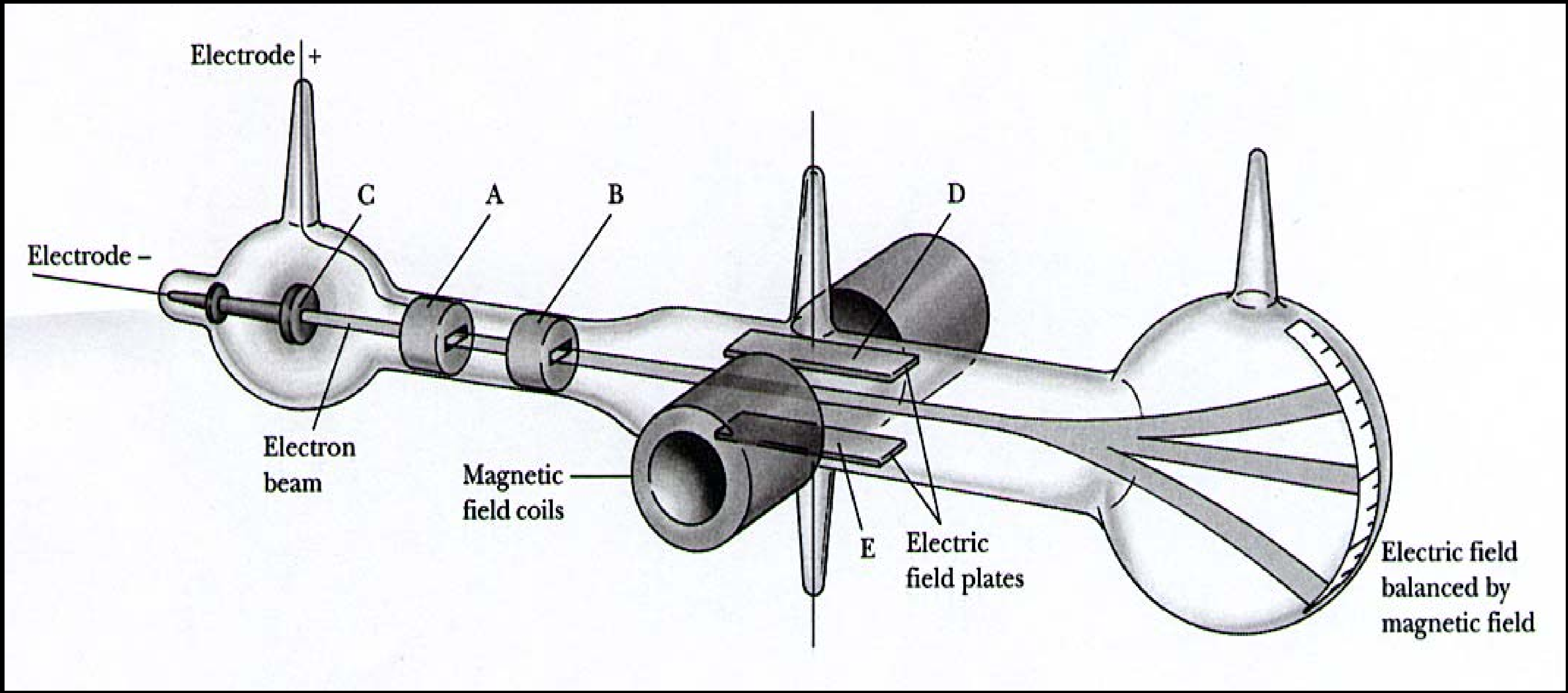
Electrons in atoms



- The strange radiation emanating from the cathode in highly evacuated discharge tubes include charged particles called electrons.
- Thomson could only measure e/m ratio.

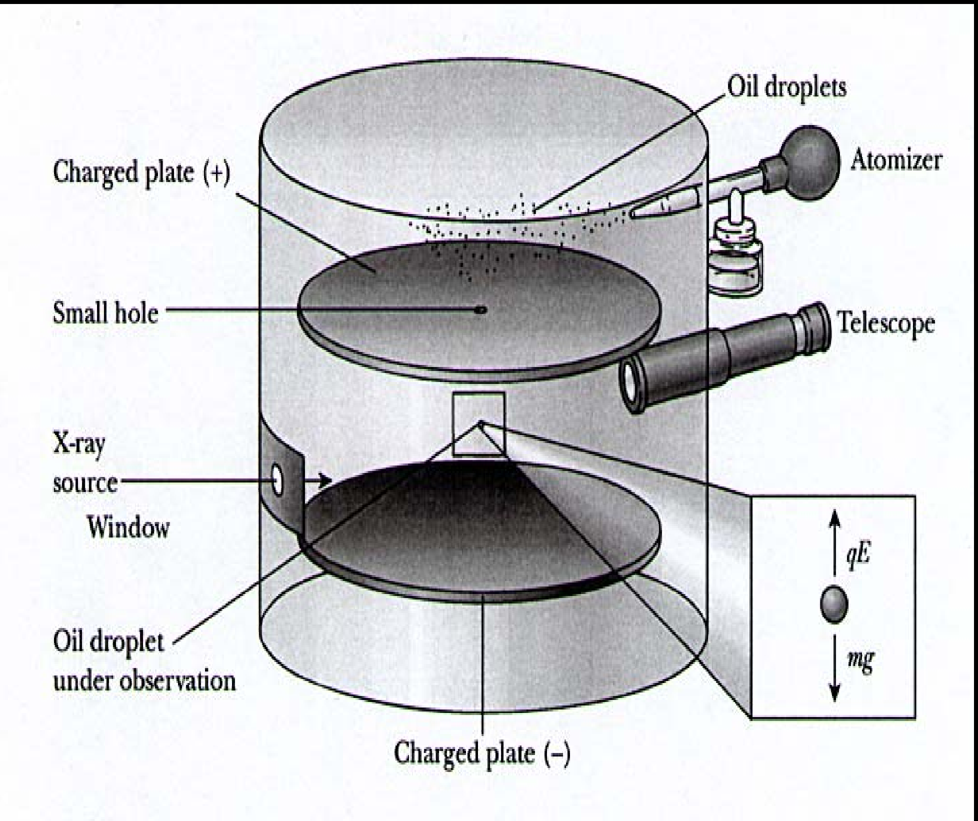
Electrons in atoms

- In J.J. Thomson's experiment, cathode rays (electrons) were directed across a region in space between two charged plates where there was also a magnetic field acting perpendicular to an electric field.
  - Where one field cancels the other, the velocity of the particles can be found: $v = 3 \times 10^9$ cm/s
  - $e/m = 1.76 \times 10^8$ C/g $= 5.27 \times 10^{17}$ esu/g

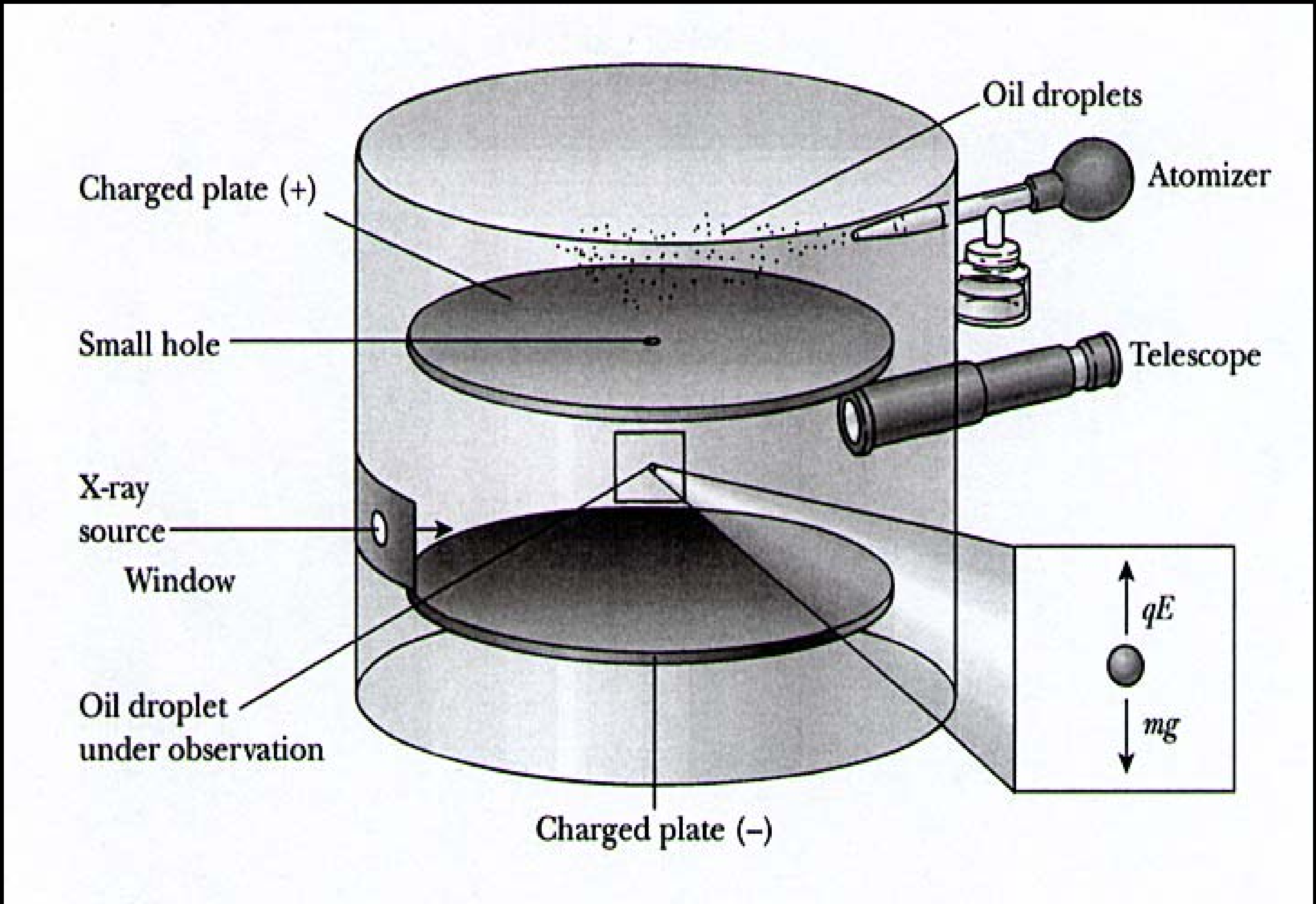


Electrode +
C
A
B
D
Electrode –
Electron beam
Magnetic field coils
E
Electric field plates
Electric field balanced by magnetic field

Nuclear properties and processes

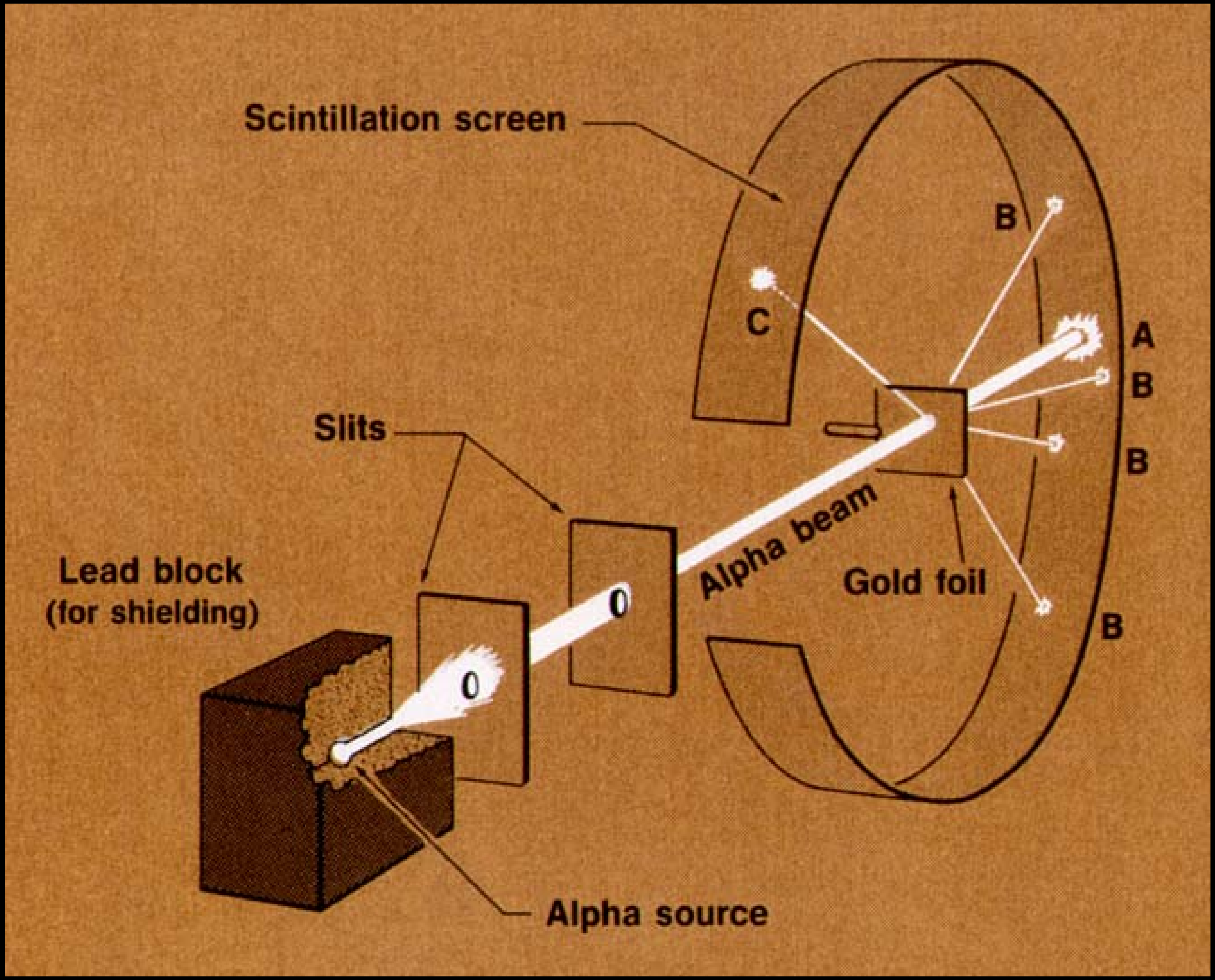


- Millikan oil drop experiment.
- All electric charges are multiples of one elementary unit:
  $e = 1.6 \times 10^{-19}$C
  $e = 4.8 \times 10^{-10}$ esu.
- On that basis:
  $m = 9.1 \times 10^{-28}$ g

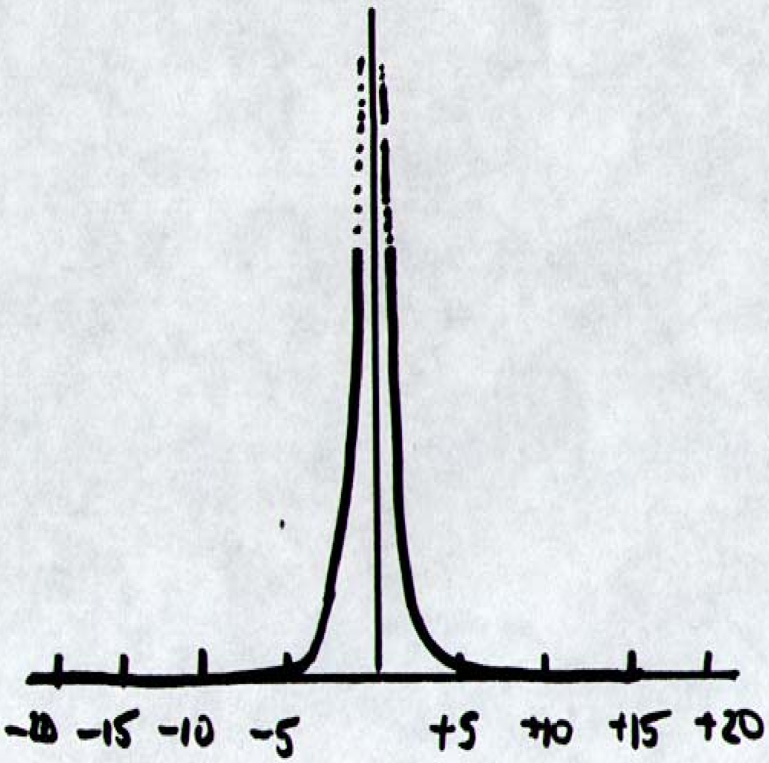

Oil droplets
Atomizer
Charged plate (+)
Small hole
Telescope
X-ray
source
Window
qE
mg
Oil droplet
under observation
Charged plate (–)

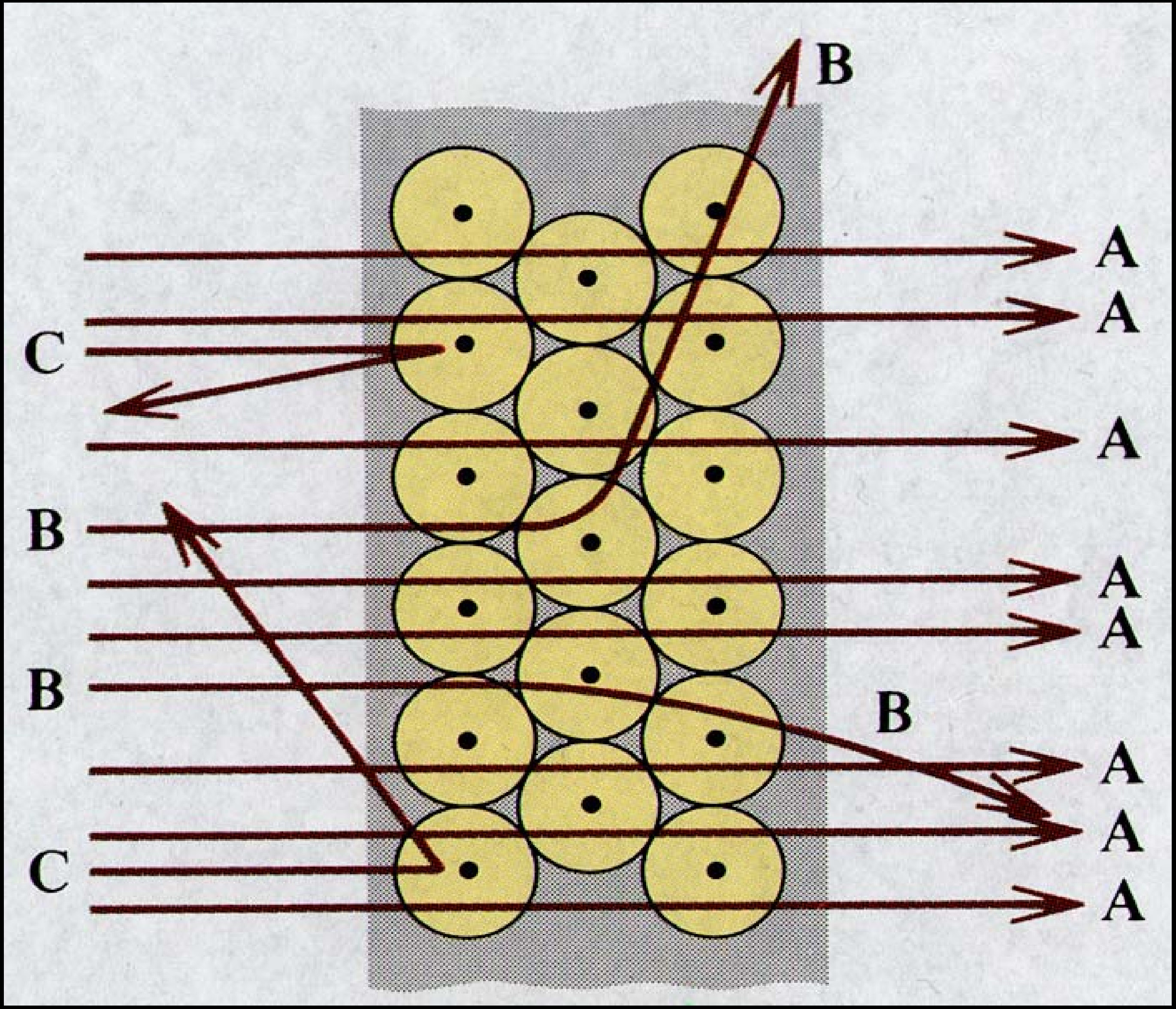
Nuclear properties and processes

- Ernest Rutherford
- Nuclear (planetary) atom model based on results of “scattering” experiments.
- Qualitatively describes the atomic nucleus.


Scintillation screen
B
C
A
B
Slits
B
Alpha beam
Gold foil
Lead block
(for shielding)
B
Alpha source

Deflection	# of hits
5°	8,289,000
10°	502,570
15°	120,570
30°	7,800
45°	1,435
60°	477
75°	211
105°	70
120°	52
135°	43
150°	33





B
A
A
C
A
B
A
A
B
B
A
A
C
A

Nuclear Notation

- Nuclei consist of protons (p) and neutrons (n) and carry a positive charge which is balanced by the net charge of the extranuclear (e) electrons.
- Z = Proton number
- N = Neutron number
- A = Mass number = Z + N

Nuclear size and shape

- Conclusion drawn from Rutherford's "scattering" experiments:
  - Alpha (α) particle probing an atom approaches to within 10^{-14} m of center and is scattered away by forces calculated from Coulomb's law.
  - Energy barrier (well).
  - Accelerated alpha-particles can penetrate energy barrier.

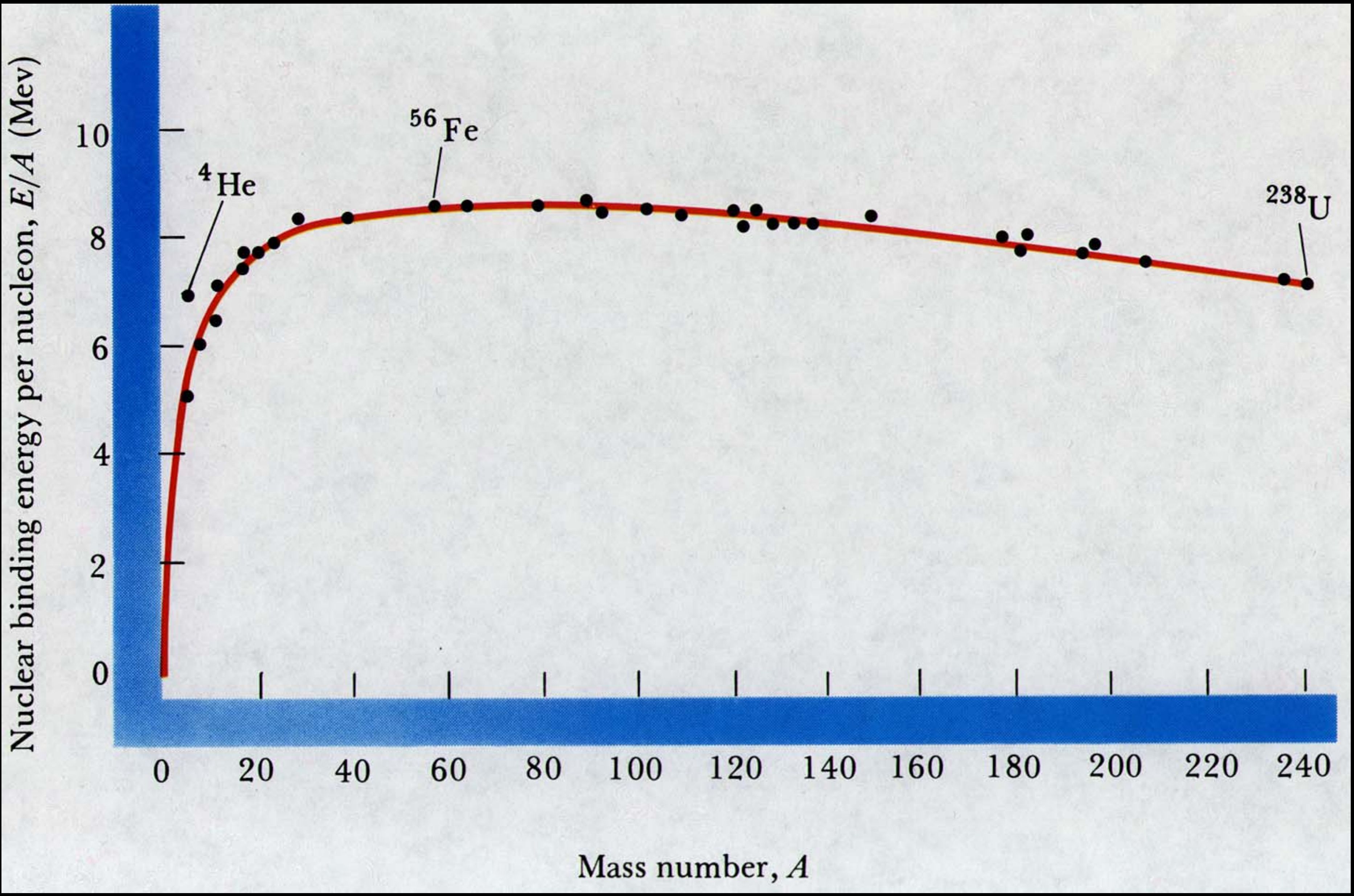
Nuclear size and shape

- Isotopes distinguished by differences in N.
- Hydrogen (1.008)
  - ^{1}H ^{2}H ^{3}H
- Oxygen (16.00)
  - ^{16}O ^{17}O ^{18}O
- Chlorine (35.453)
  - ^{35}Cl ^{37}Cl
- Coulomb barrier
- Nuclear radius

  $$R = R_0 A^{1/3}$$
- Density is on the order of 10^{-14}g/cm^3
- Shapes are spheres or spheroids (footballs).

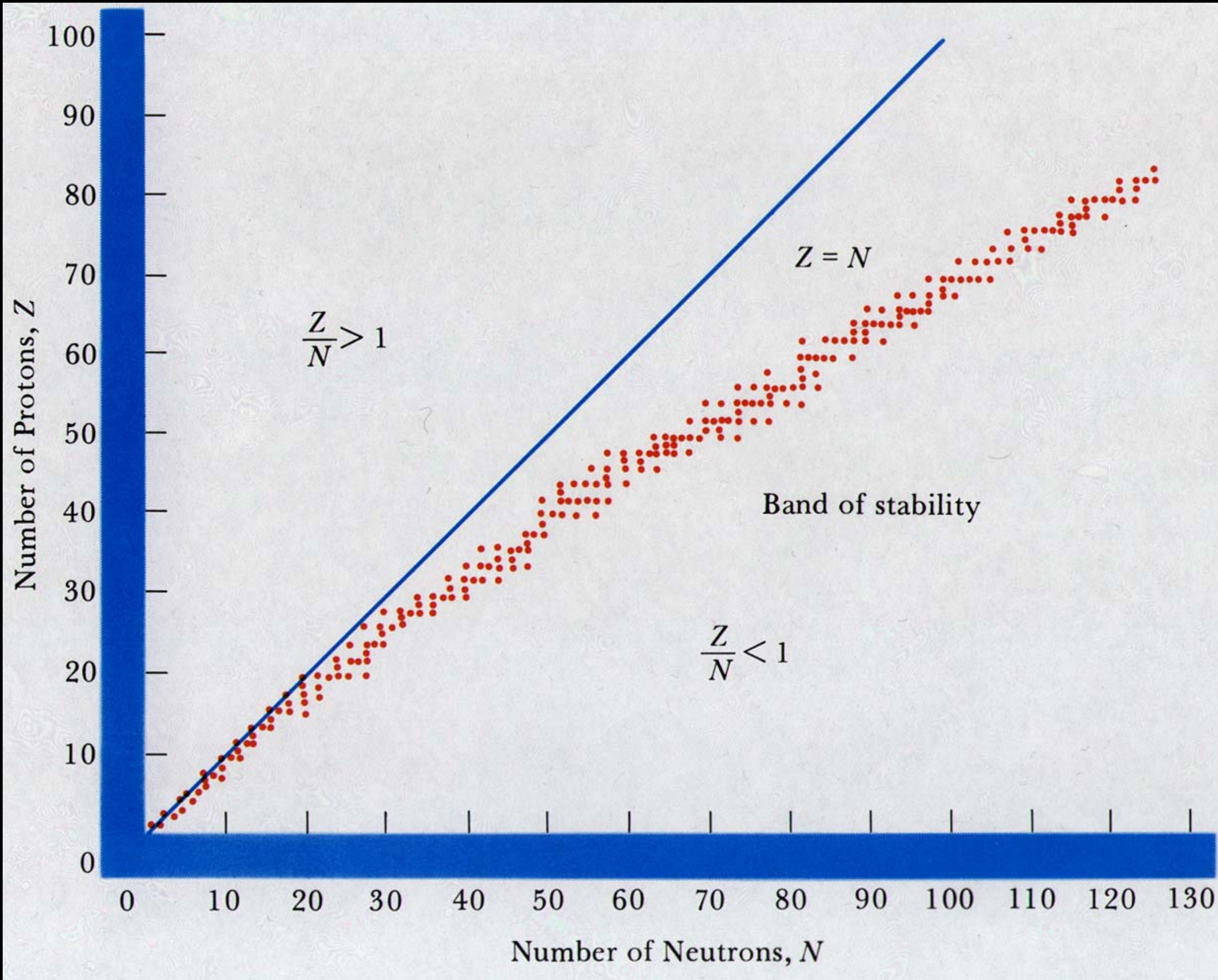
Mass defect

- Einstein relationship: $E = mc^2$
- The oxygen atom
  - eight electrons and eight protons as 8 H atoms
  - eight neutrons.
- Total *combined* mass is 15.994 915 amu
- Total *separated* mass is 16.131 925 amu
- Curve of binding energy

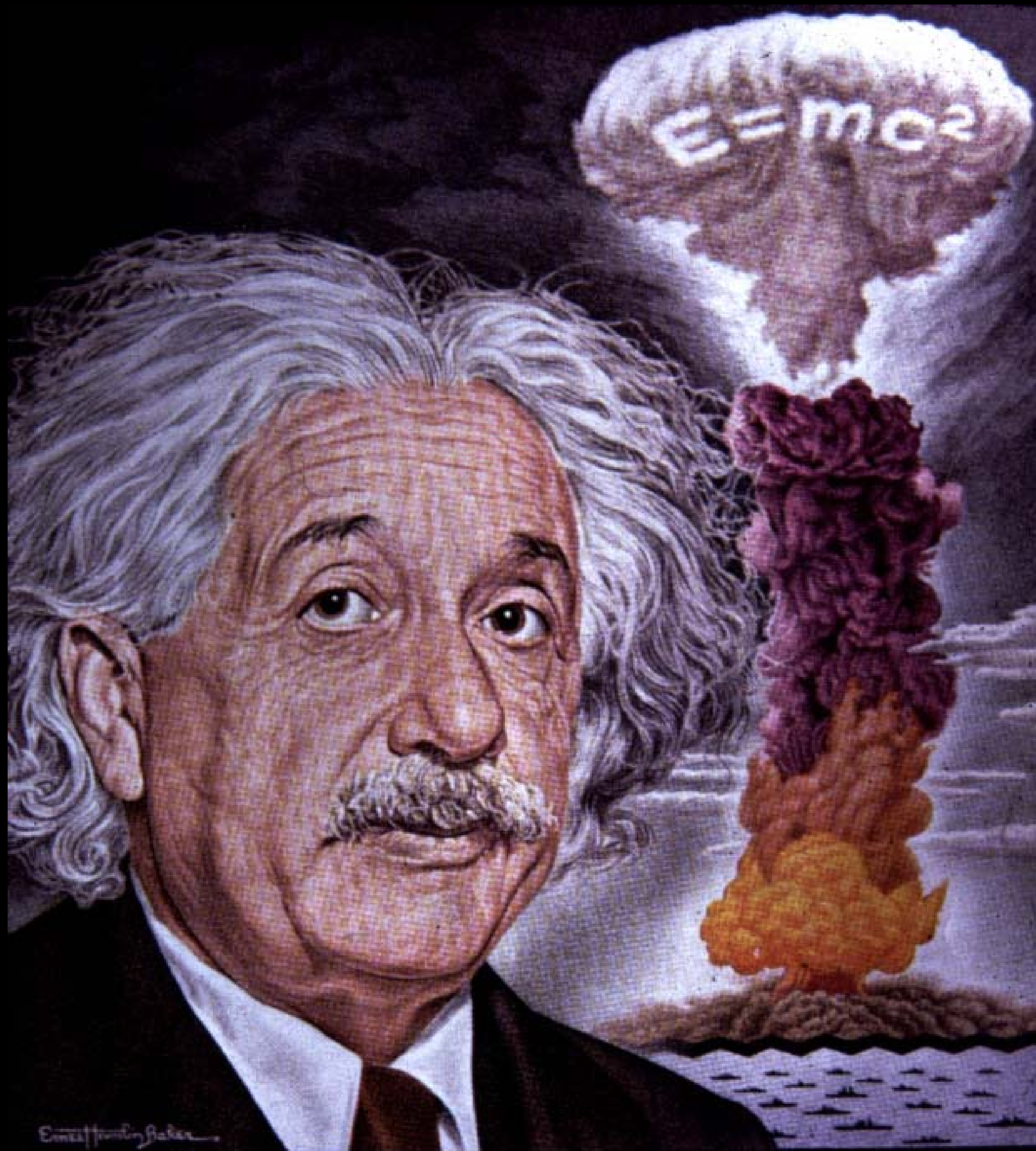

Nuclear binding energy per nucleon, E/A (Mev)
10
8
6
4
2
0
^{4}He
^{56}Fe
^{238}U
0
20
40
60
80
100
120
140
160
180
200
220
240
Mass number, A

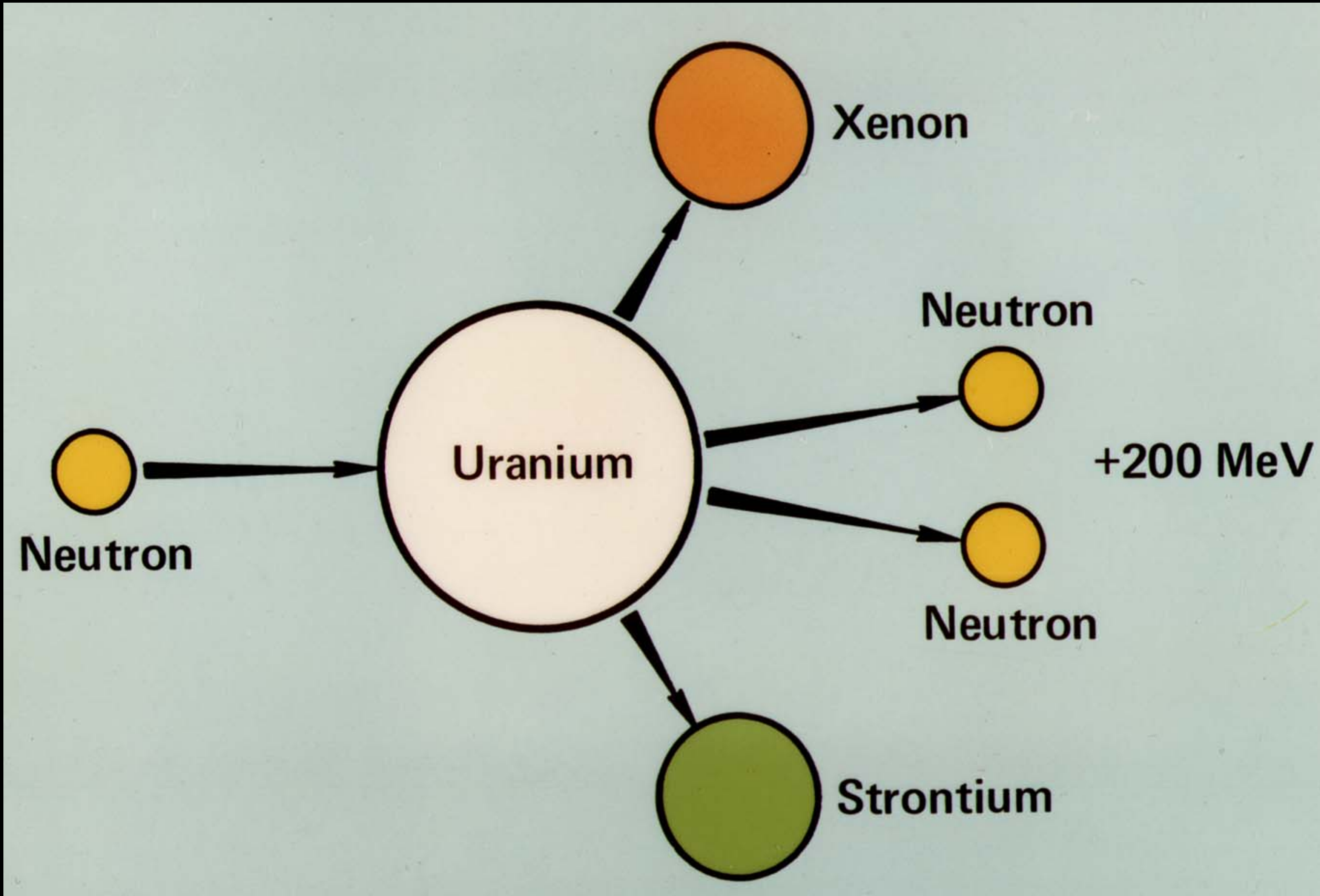
Nuclear stability

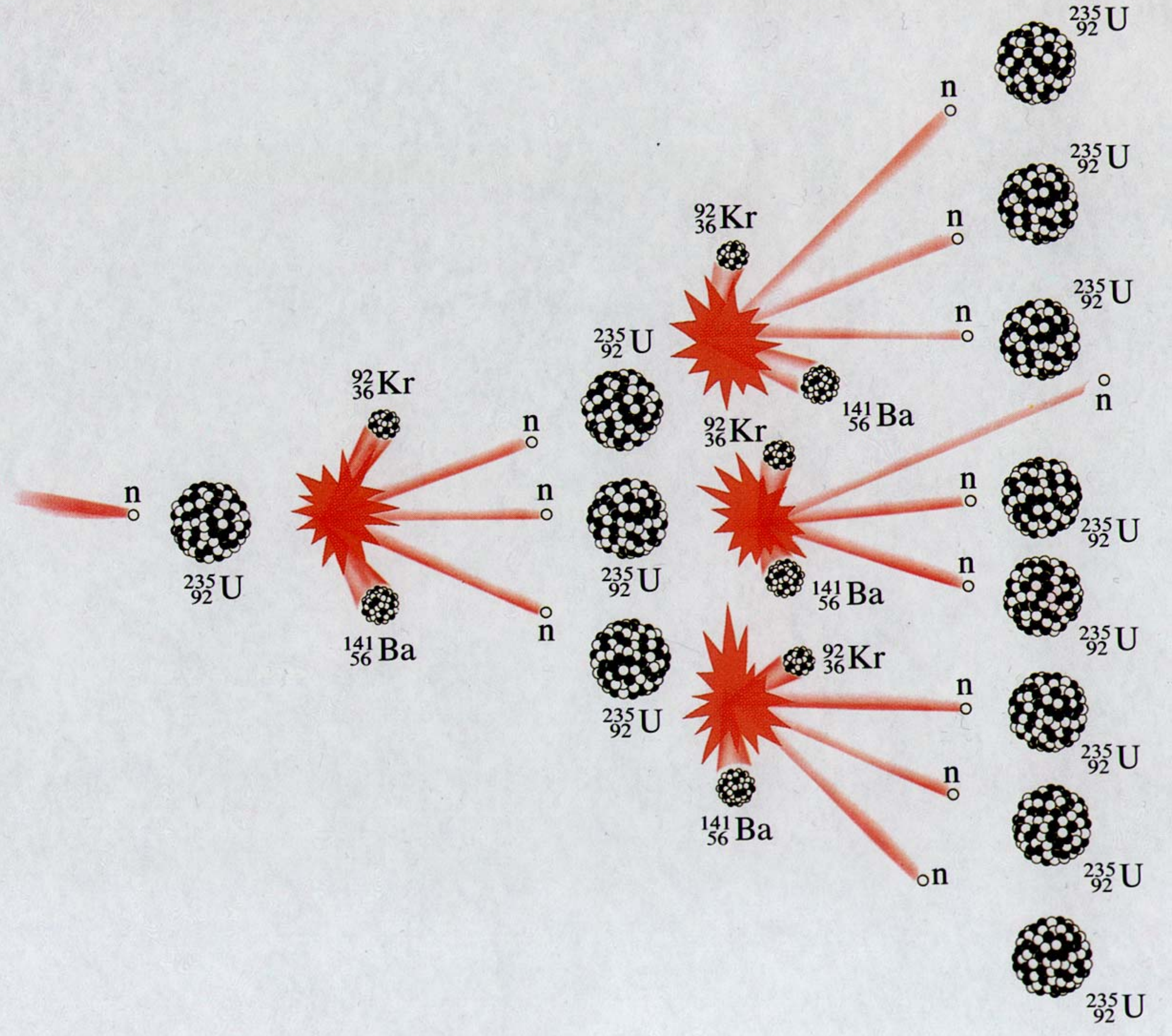
- Heaviest elements undergo alpha and/or beta decay as they move to greater stability.
  - Alpha decay produces isotopes of elements earlier in the periodic table, twice-removed, and less massive by four units of mass.
  - Beta decay produces isotopes of elements later in the periodic table, once-removed and with mass unchanged.



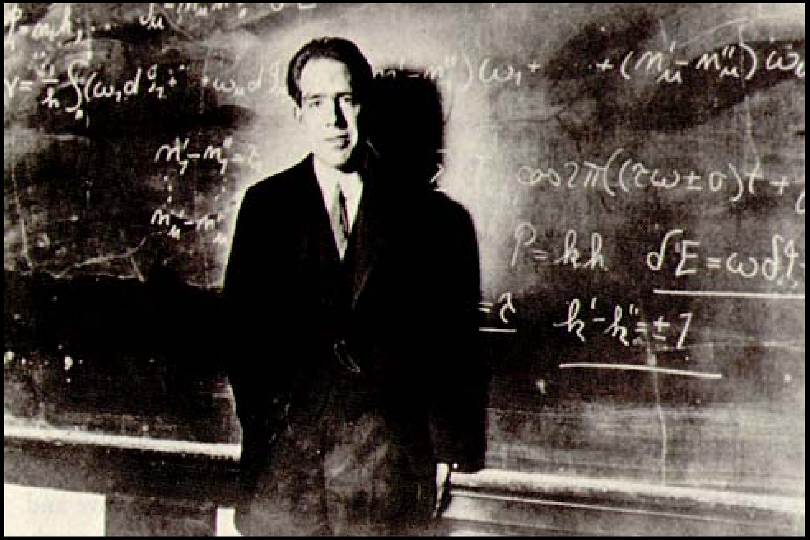
Number of Protons, Z
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Number of Neutrons, N
Z = N
Z/N > 1
Z/N < 1
Band of stability


E=mc2

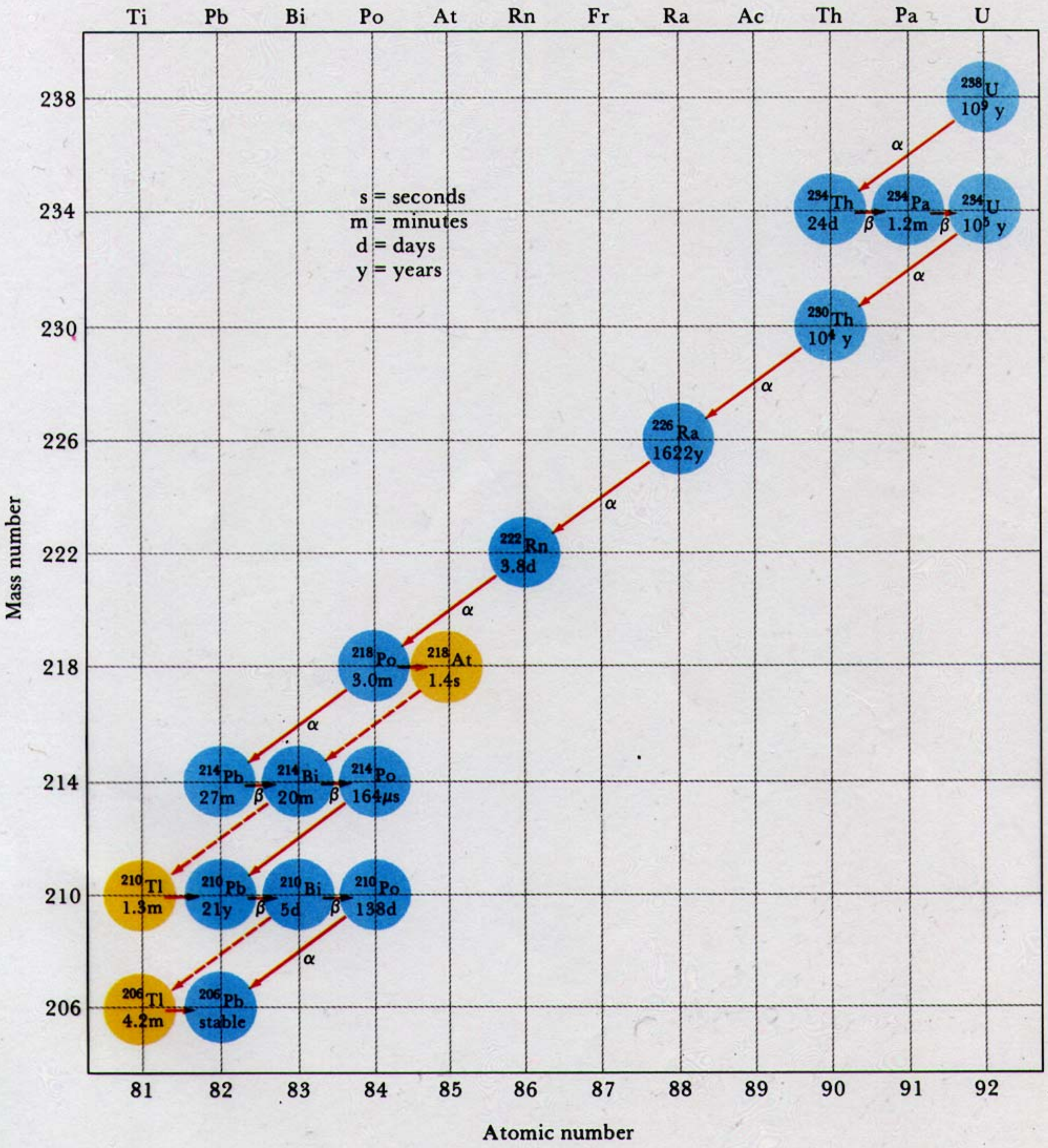

Xenon
Neutron
Uranium
+200 MeV
Neutron
Neutron
Strontium


n
$^{235}_{92}U$
$^{92}_{36}Kr$
$^{141}_{56}Ba$
n
n
n
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{92}_{36}Kr$
$^{141}_{56}Ba$
$^{92}_{36}Kr$
$^{141}_{56}Ba$
$^{92}_{36}Kr$
$^{141}_{56}Ba$
n
n
n
n
n
n
n
n
n
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$
$^{235}_{92}U$

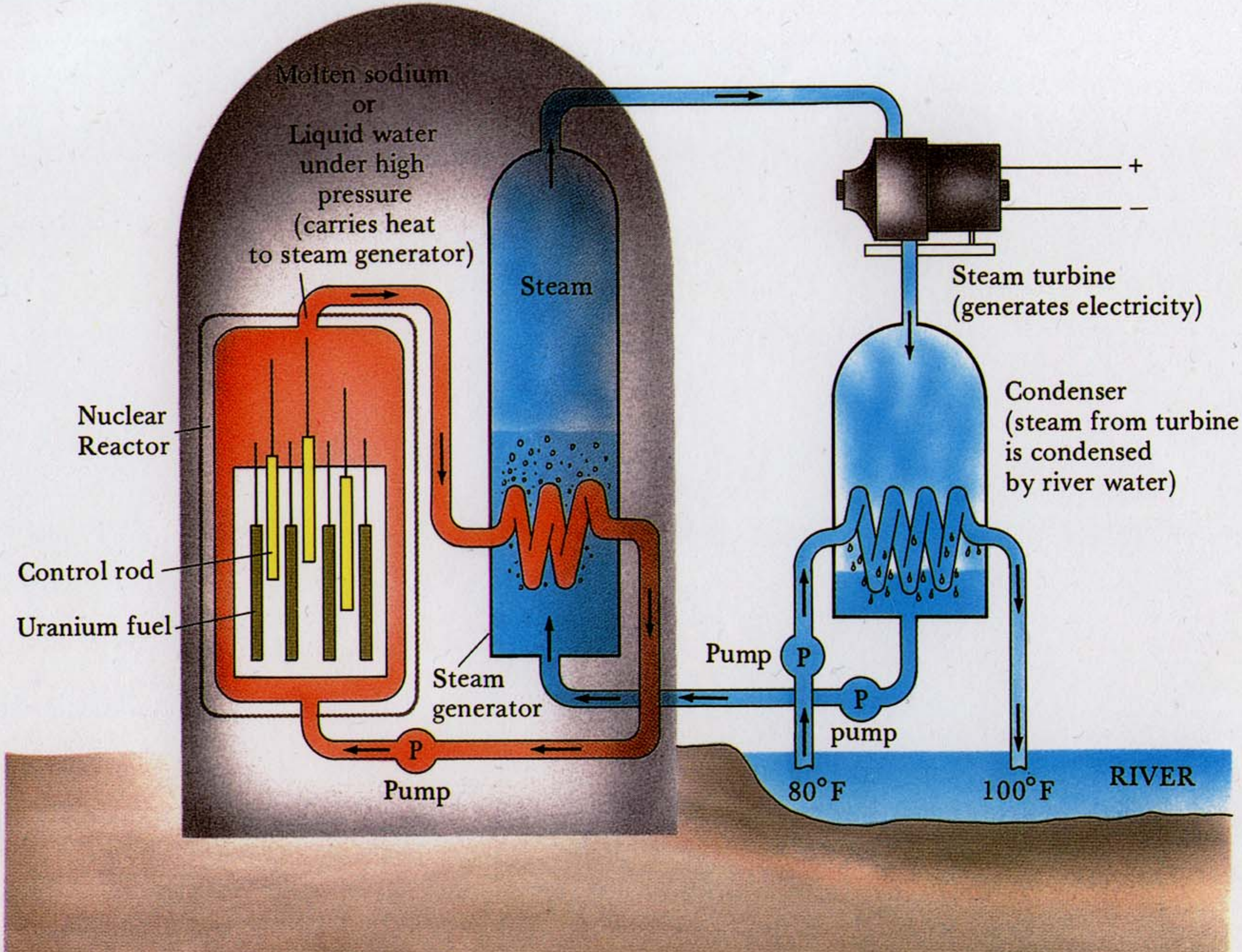
Liquid drop model

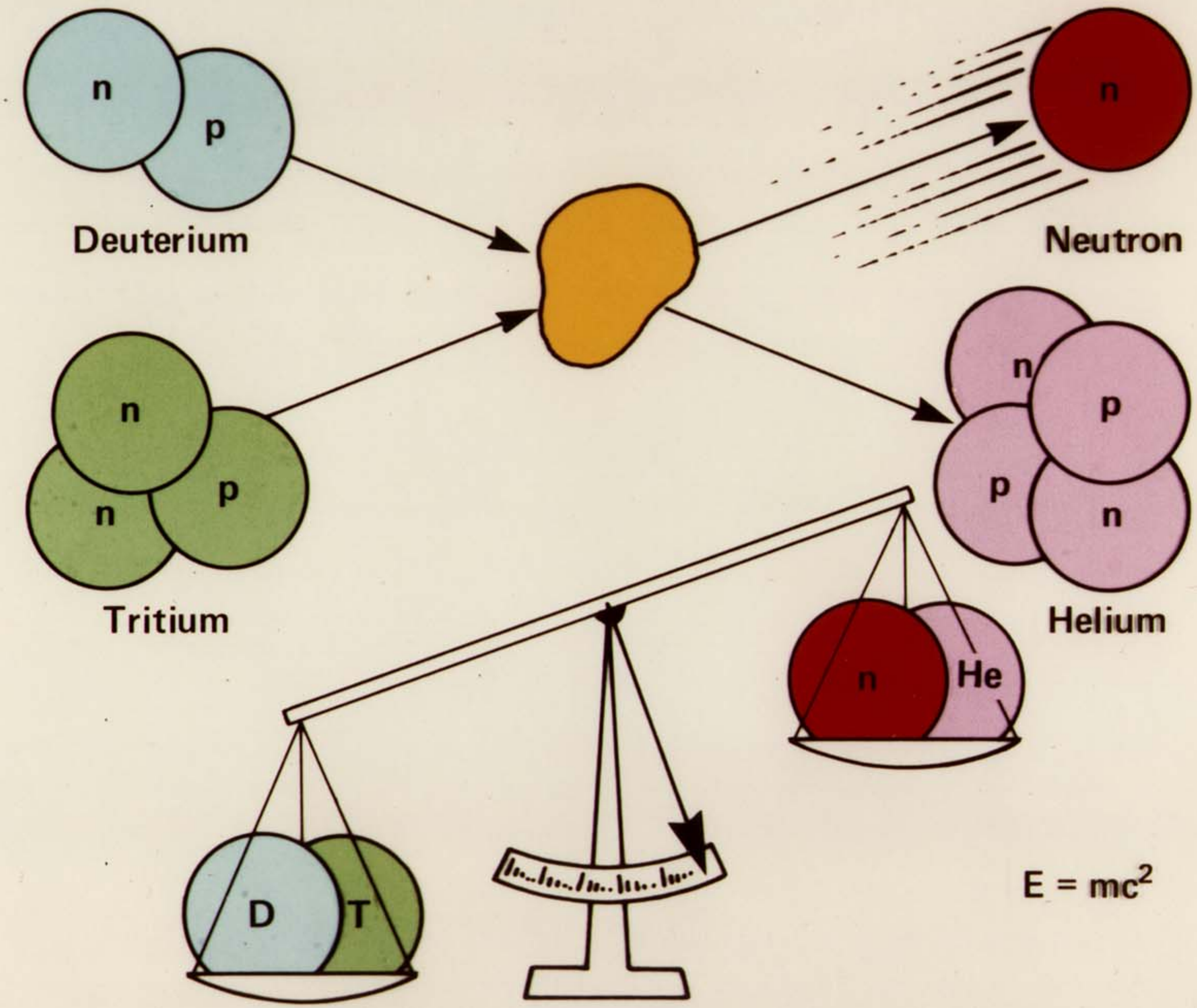


- Nucleus comes apart as a liquid drop in free fall
- Deforms and splits into simpler, more stable elements



Ti
Pb
Bi
Po
At
Rn
Fr
Ra
Ac
Th
Pa
U
Mass number
238
234
230
226
222
218
214
210
206
Atomic number
81
82
83
84
85
86
87
88
89
90
91
92
s = seconds
m = minutes
d = days
y = years
238U 10⁹ y
234Th 24d
234Pa 1.2m
234U 10⁵ y
230Th 10⁴ y
226Ra 1622y
222Rn 3.8d
218Po 3.0m
218At 1.4s
214Pb 27m
214Bi 20m
214Po 164μs
210Tl 1.3m
210Pb 21y
210Bi 5d
210Po 138d
206Tl 4.2m
206Pb stable
α
β


Molten sodium
or
Liquid water
under high
pressure
(carries heat
to steam generator)
Steam
+
–
Steam turbine
(generates electricity)
Nuclear
Reactor
Condenser
(steam from turbine
is condensed
by river water)
Control rod
Uranium fuel
Steam
generator
Pump
P
P
pump
P
Pump
80°F
100°F
RIVER


n
p
Deuterium
n
Neutron
n
n
p
Tritium
n
p
p
n
Helium
n
He
D
T
E = mc²