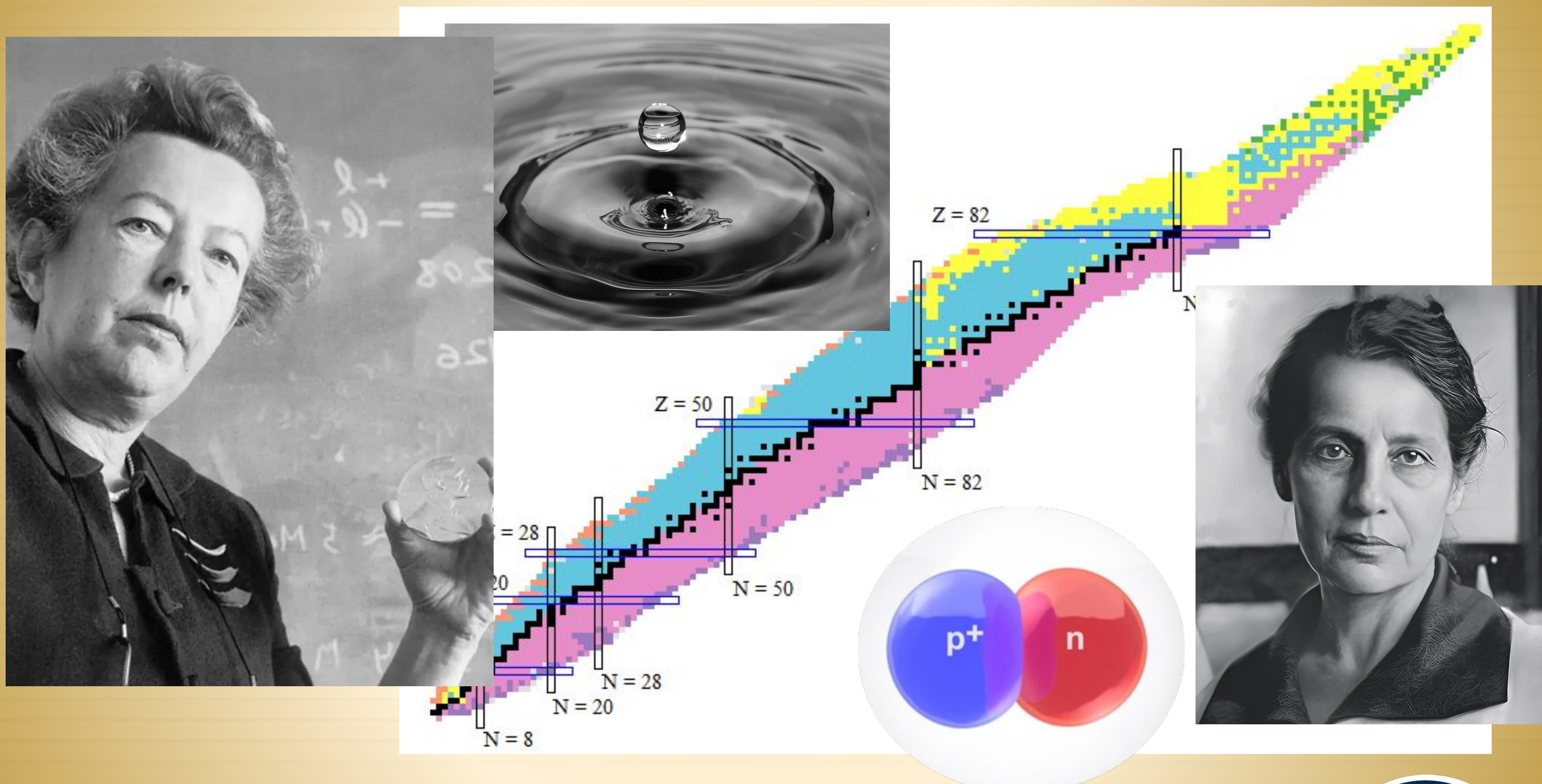
Heroines to the core

The history of the atomic nucleus

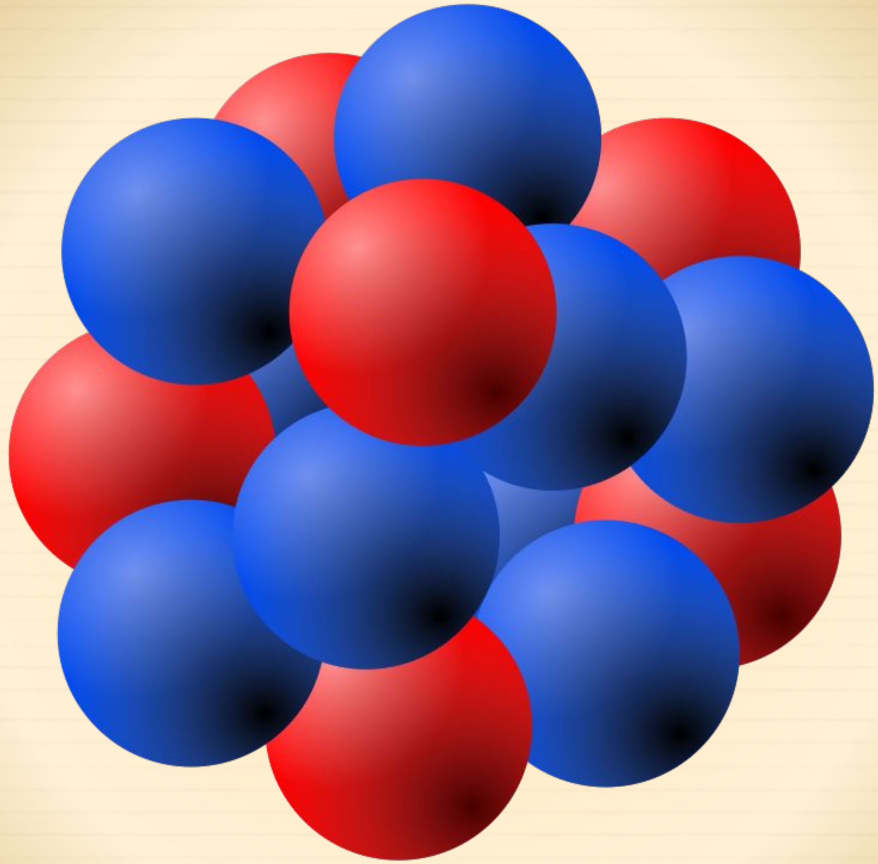


IFIC INSTITUT DE FÍSICA CORPUSCULAR

EXCELENCIA SEVERO OCHOA

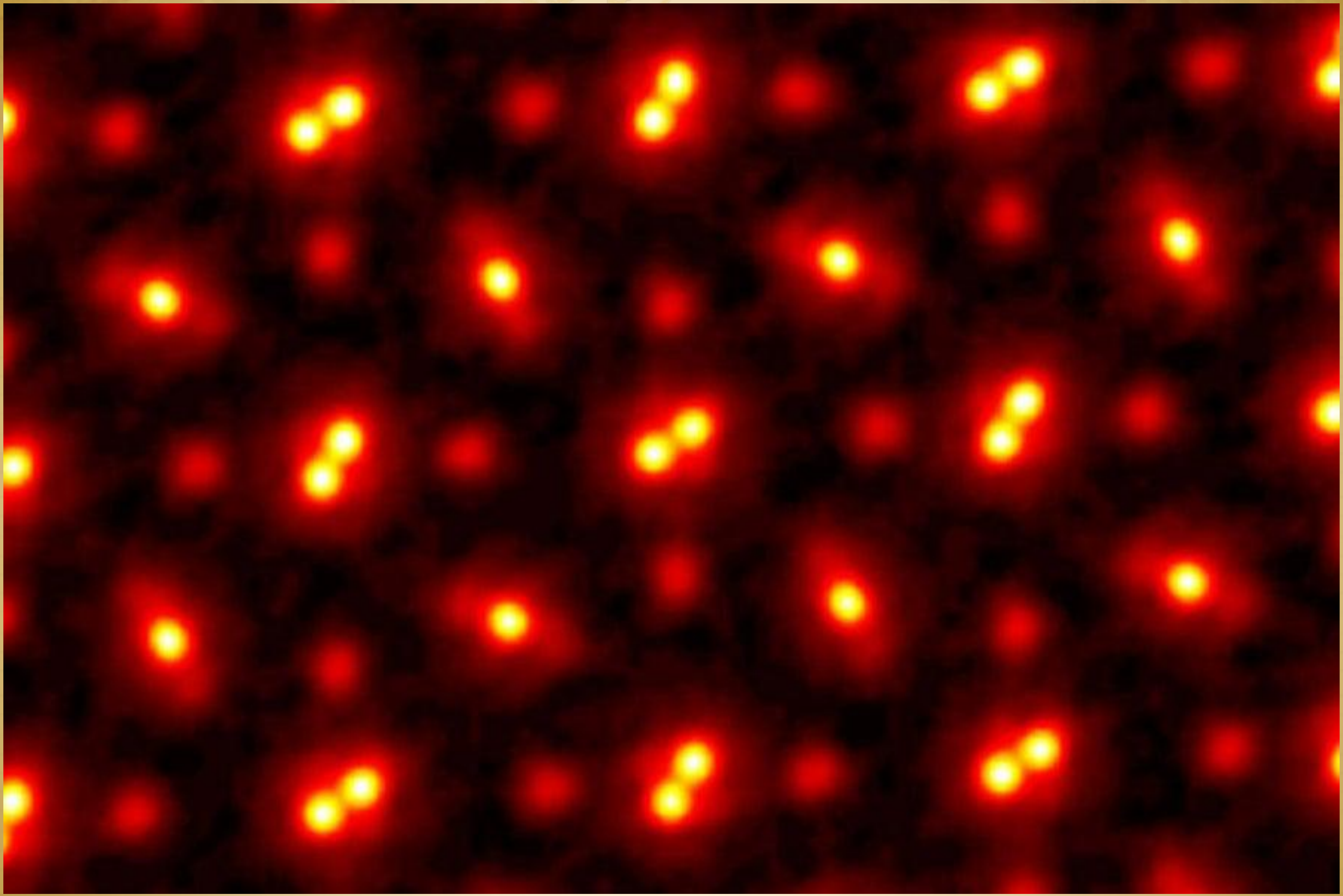
Alberto Aparici

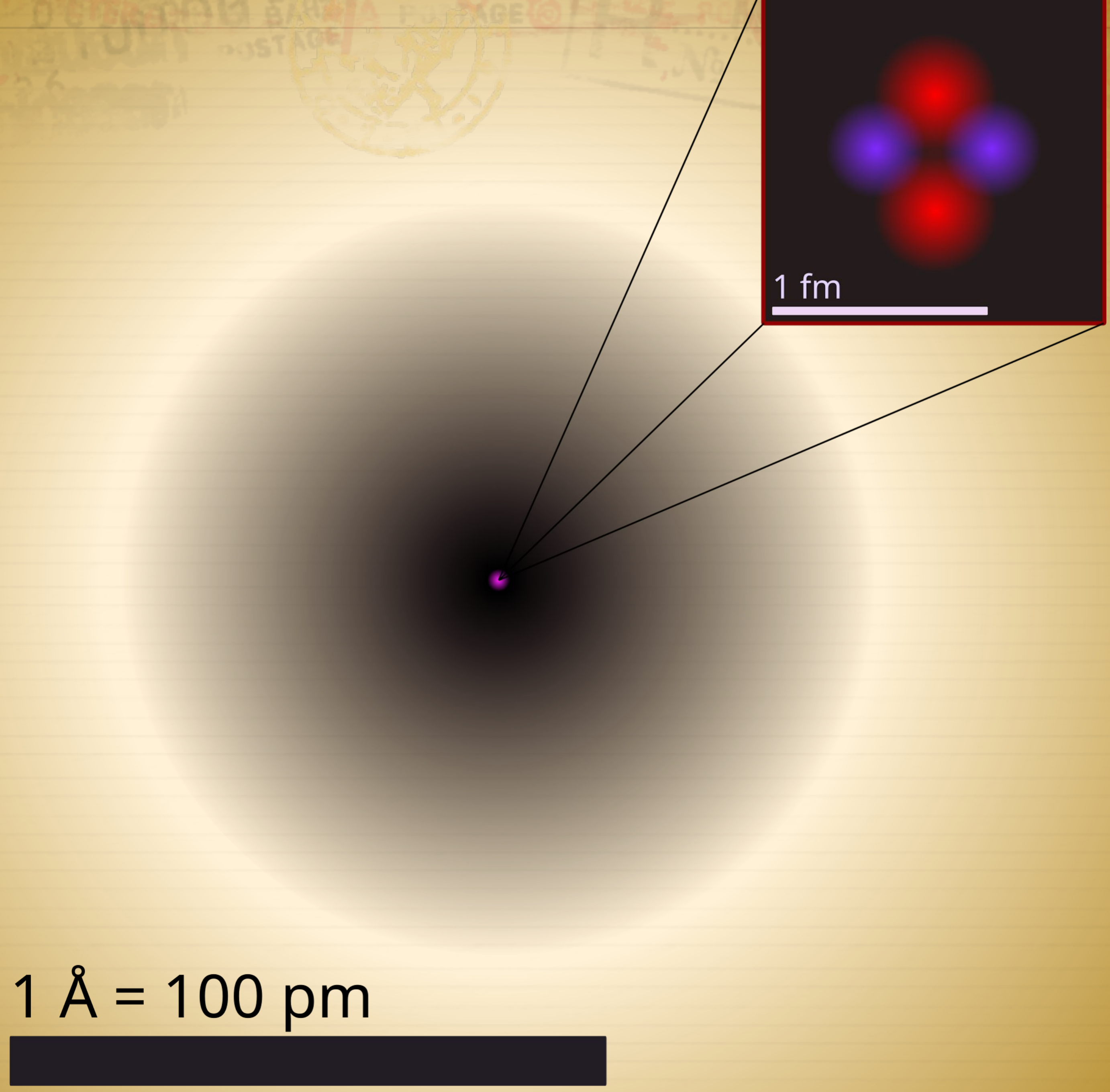
E³f

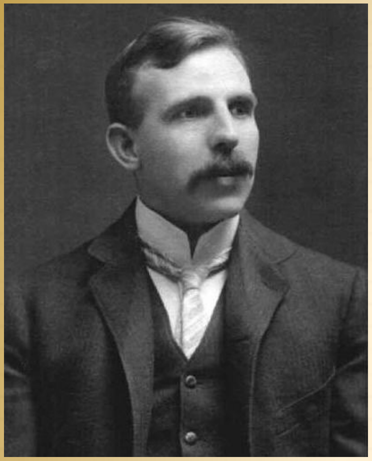


Part 1:

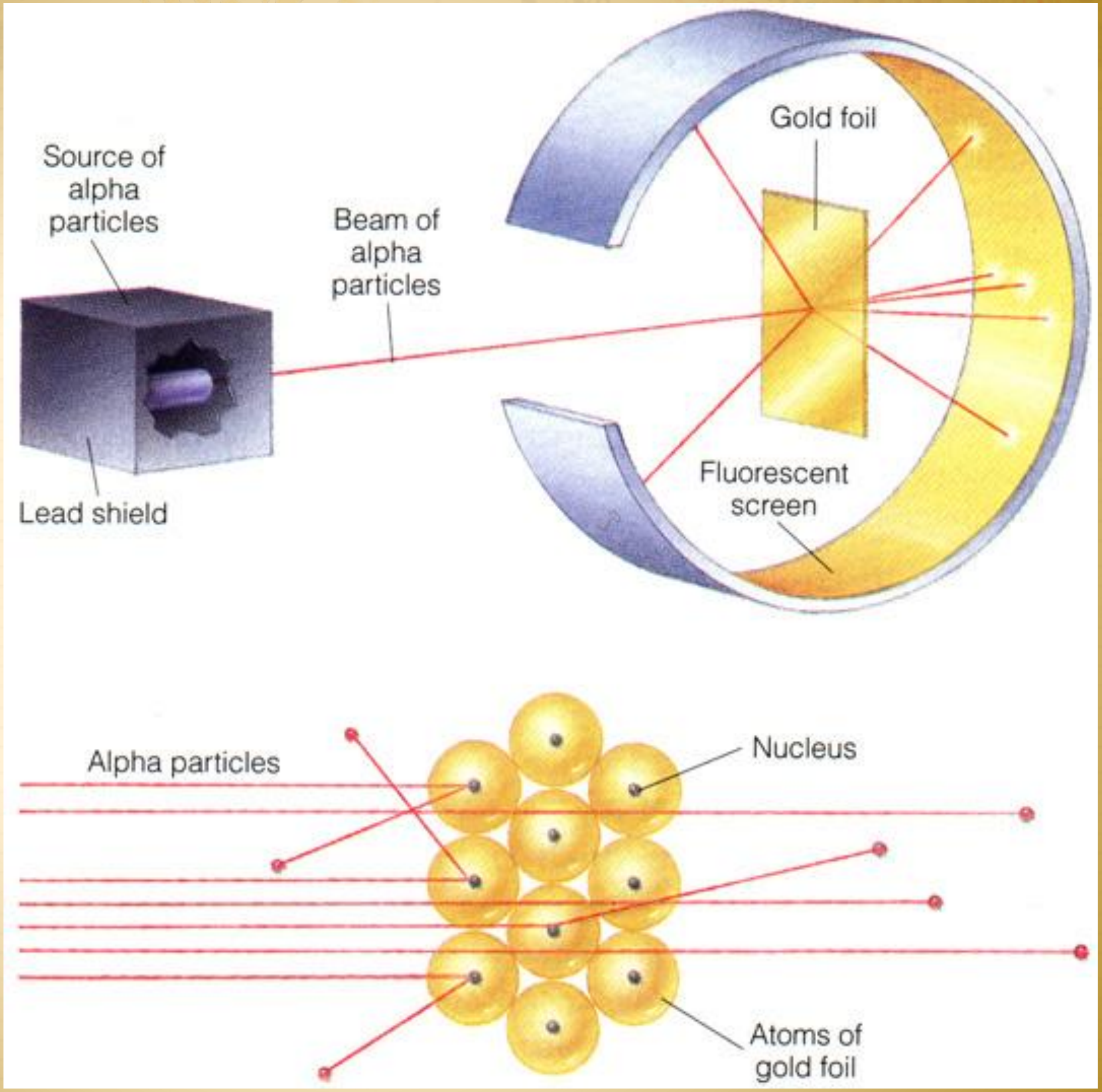
Deep digging

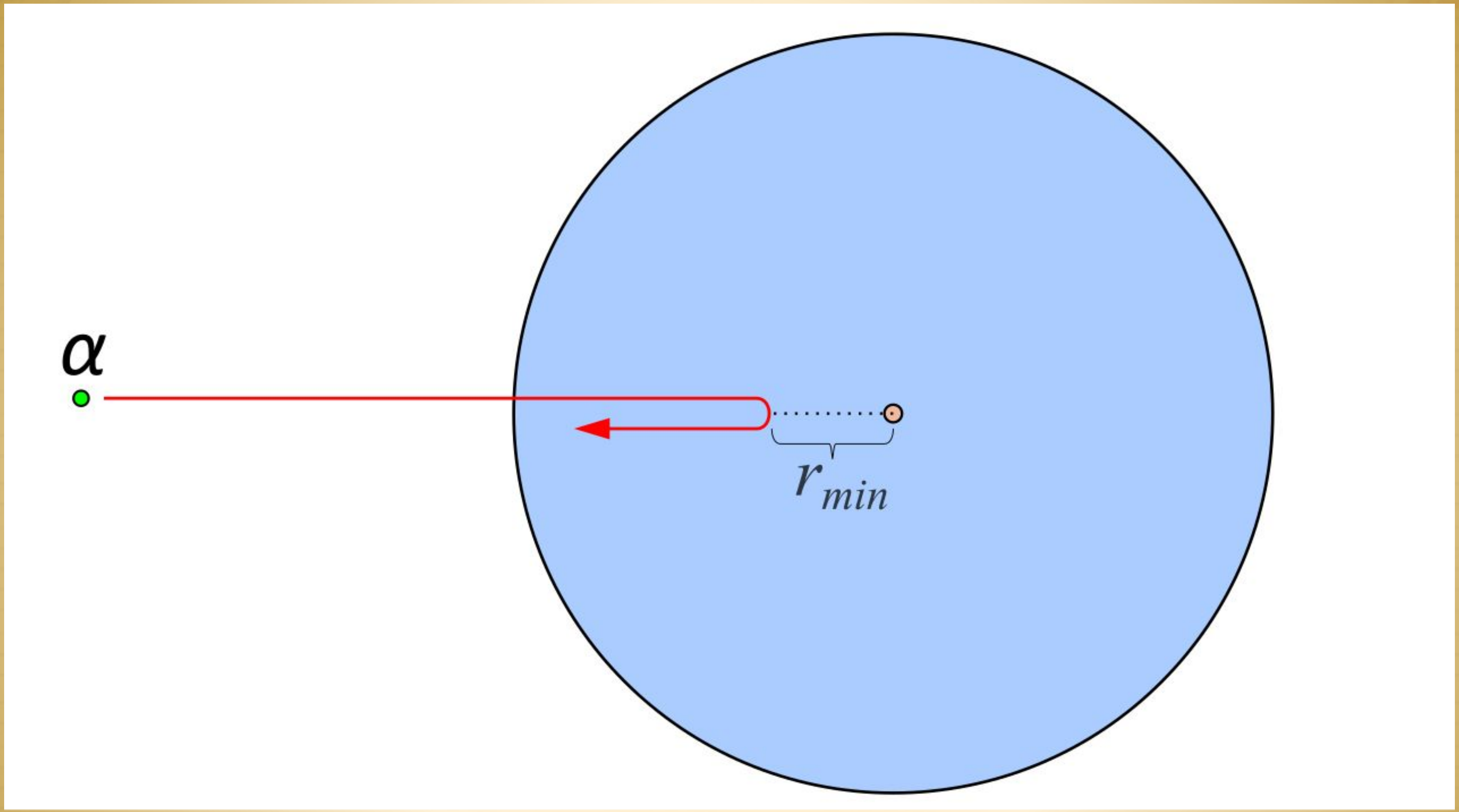



1 fm
1 Å = 100 pm



Rutherford
1906 - 1913

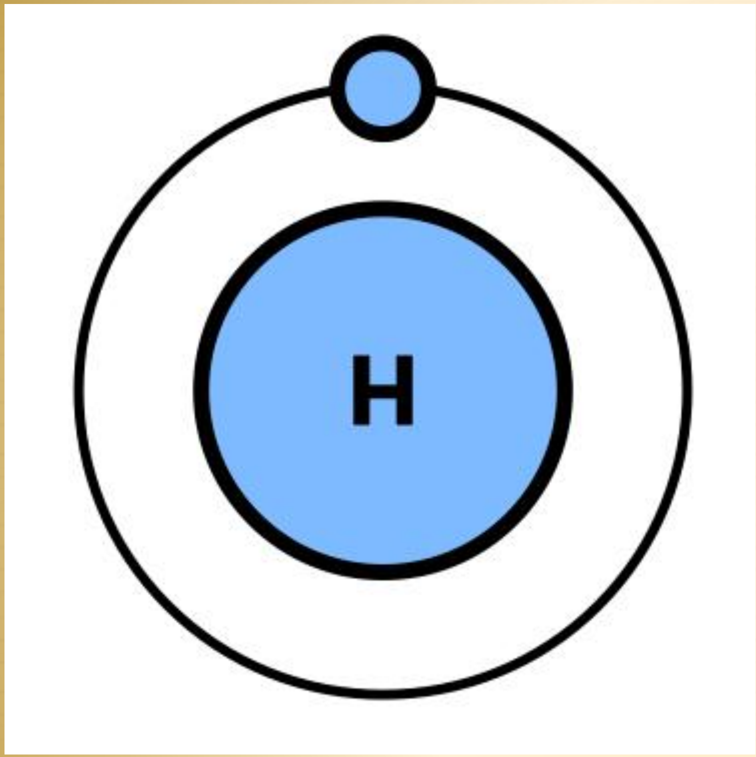


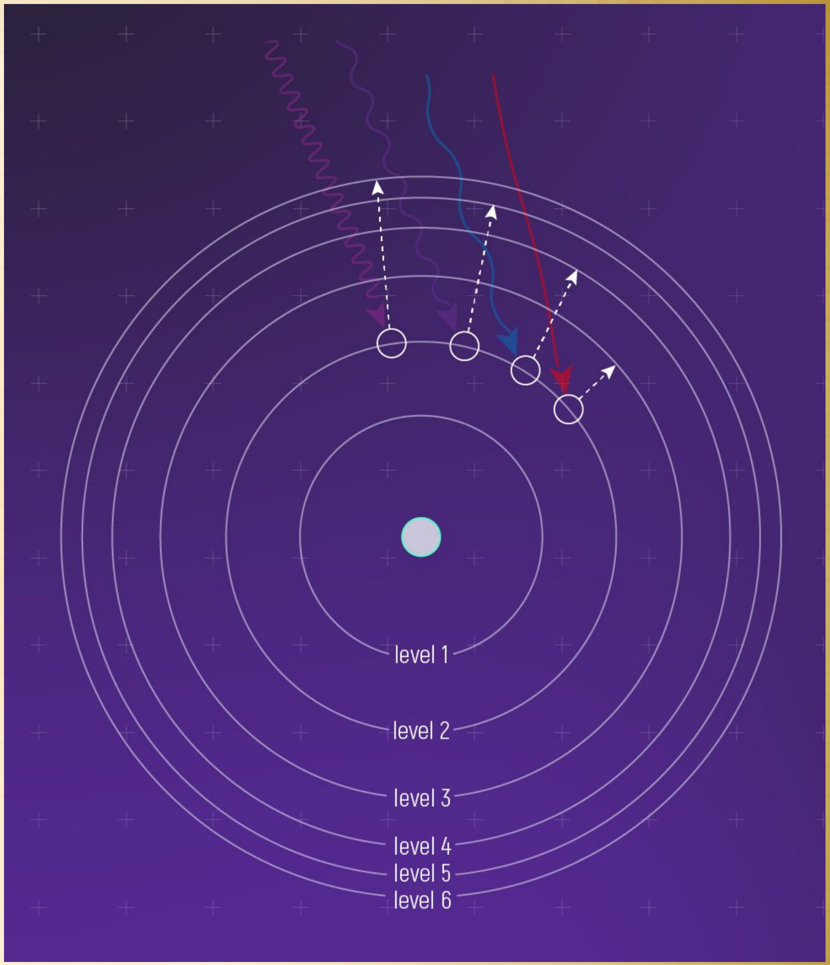


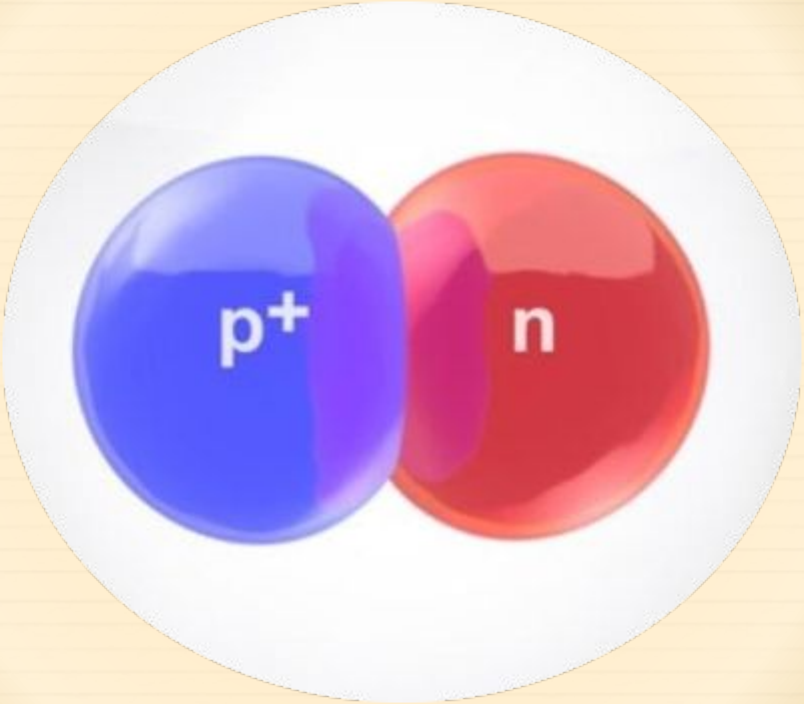
α
r_{min}

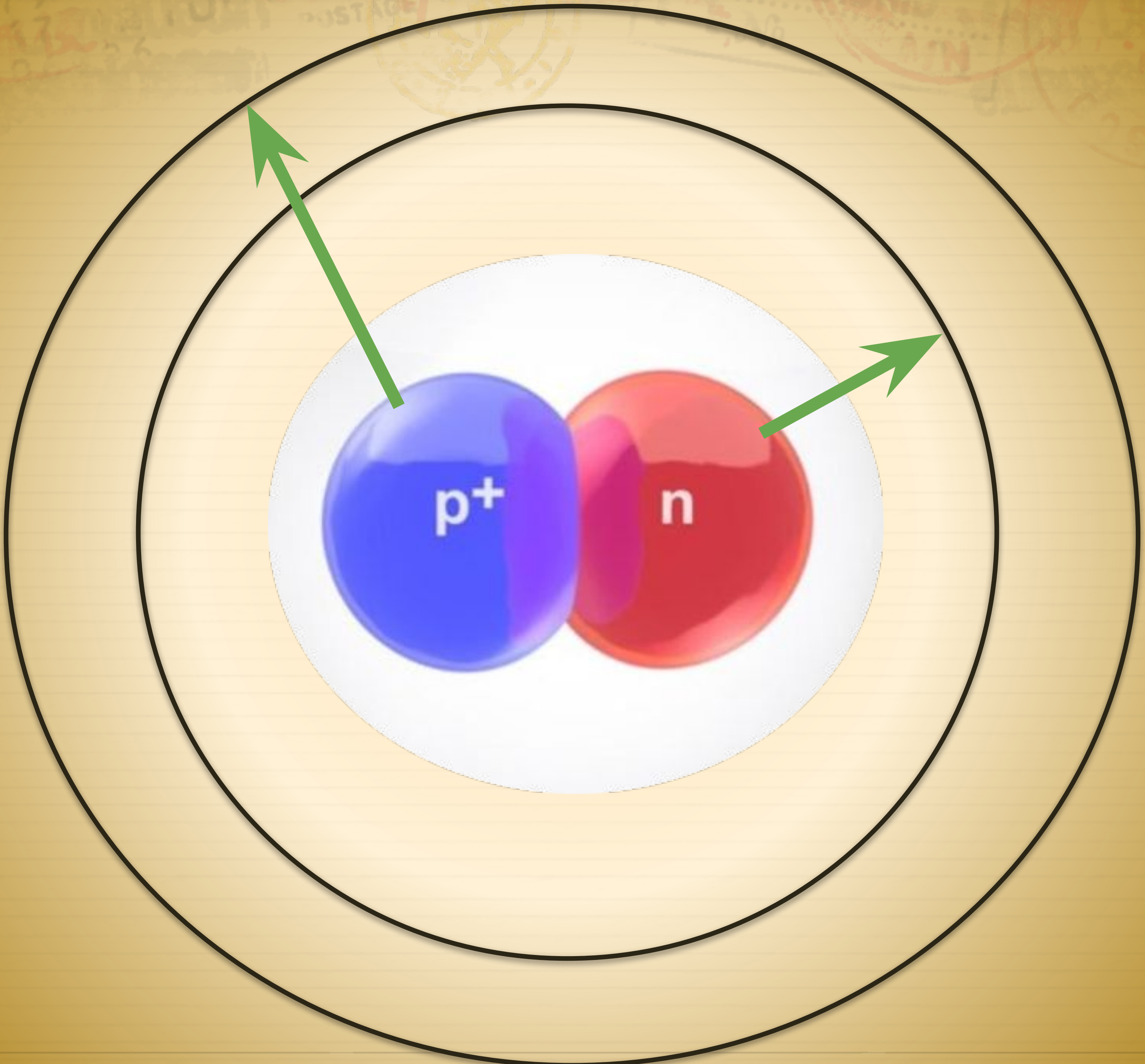
Interlude:

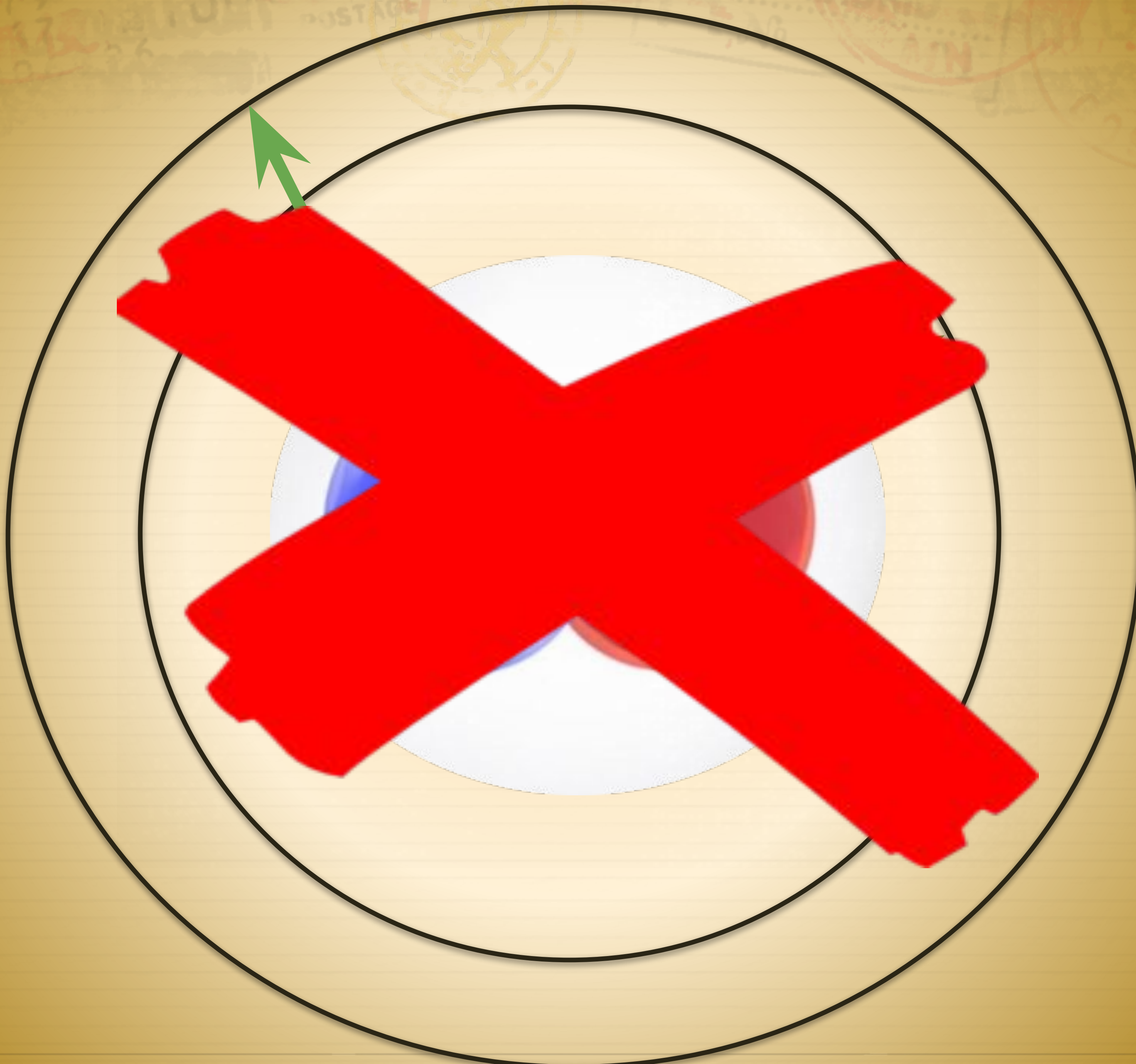
A toy to play with

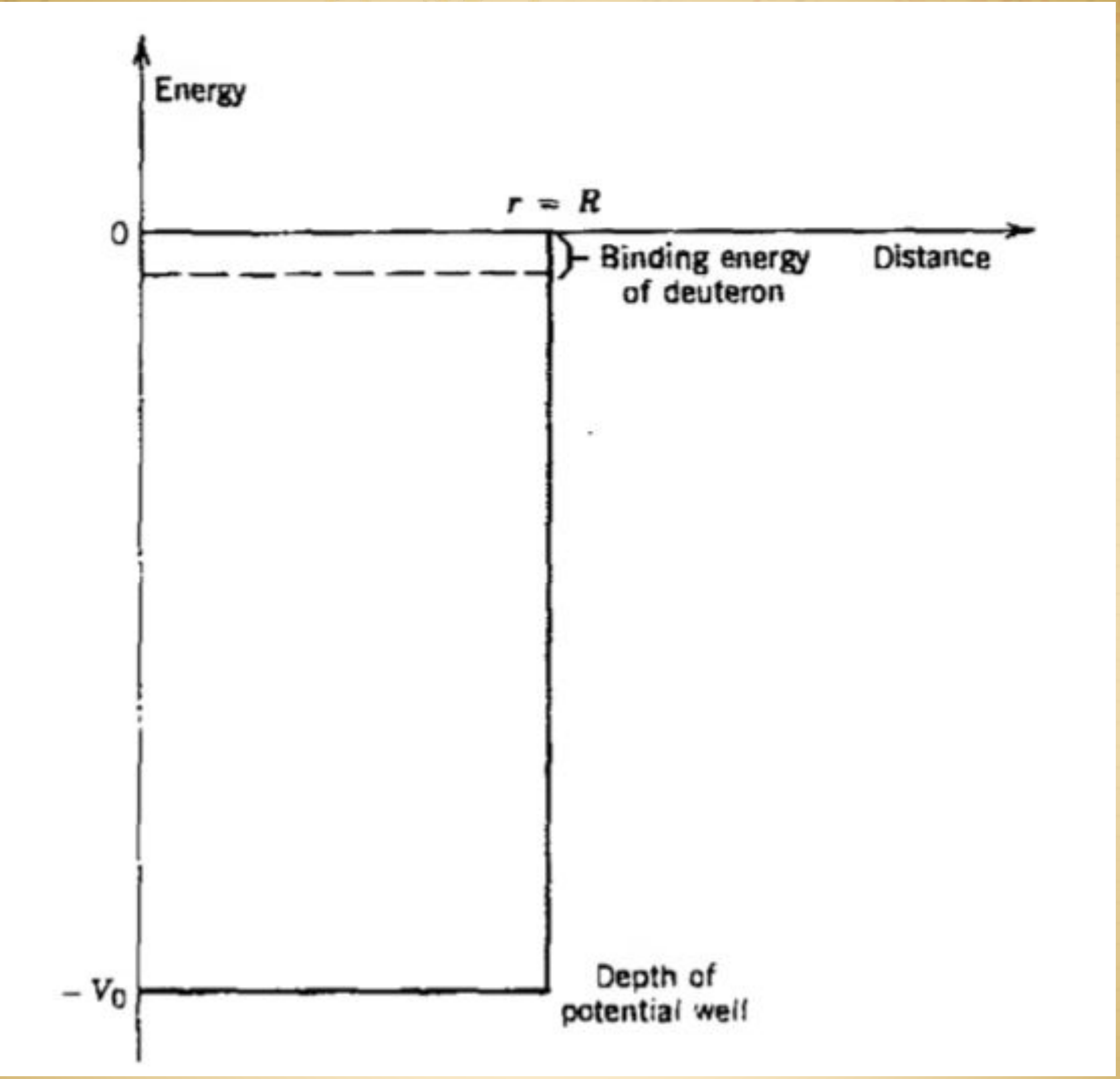

H

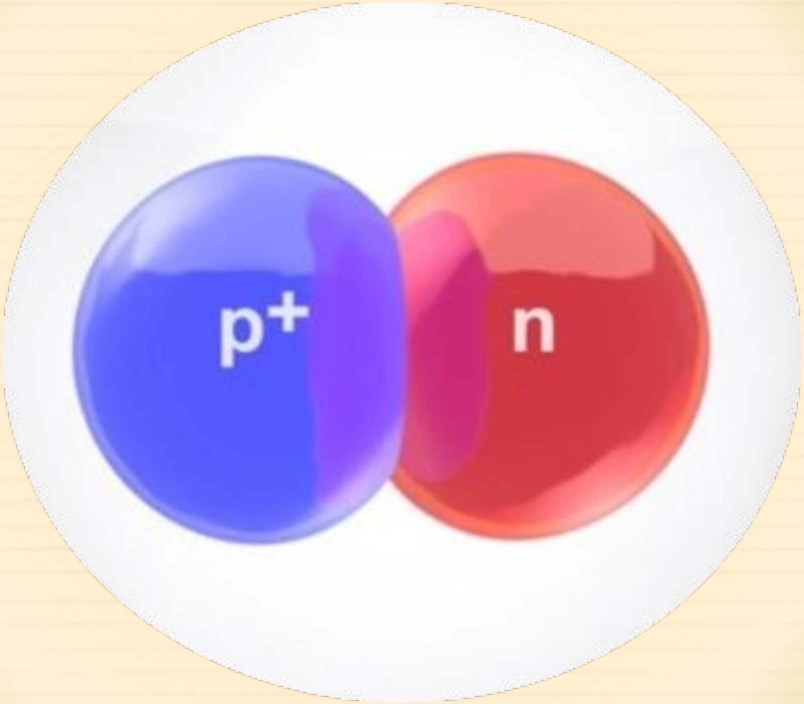

level 1
level 2
level 3
level 4
level 5
level 6


p+
n


p+
n

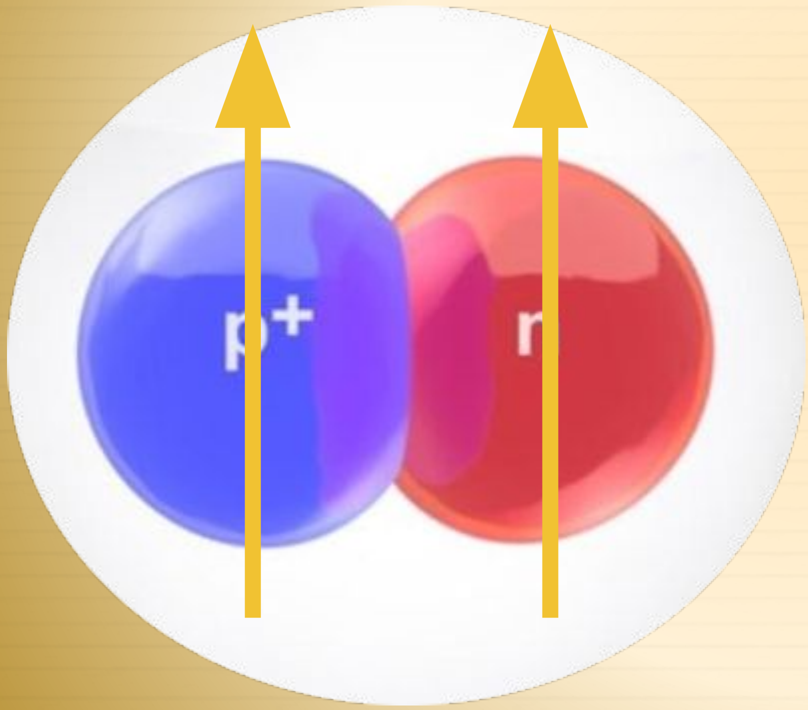


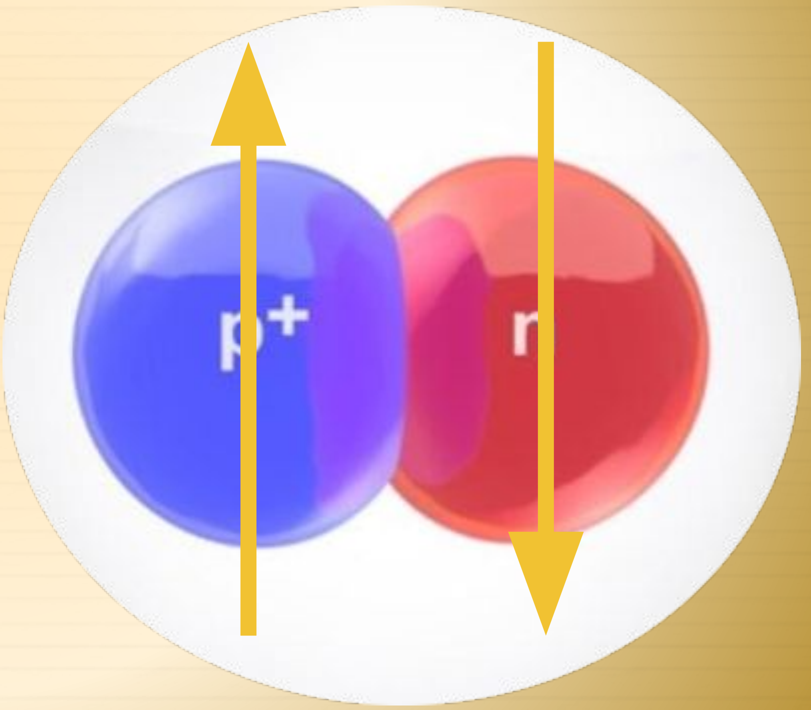

Energy
r = R
0
Binding energy of deuteron
Distance
− V0
Depth of potential well


p+
n

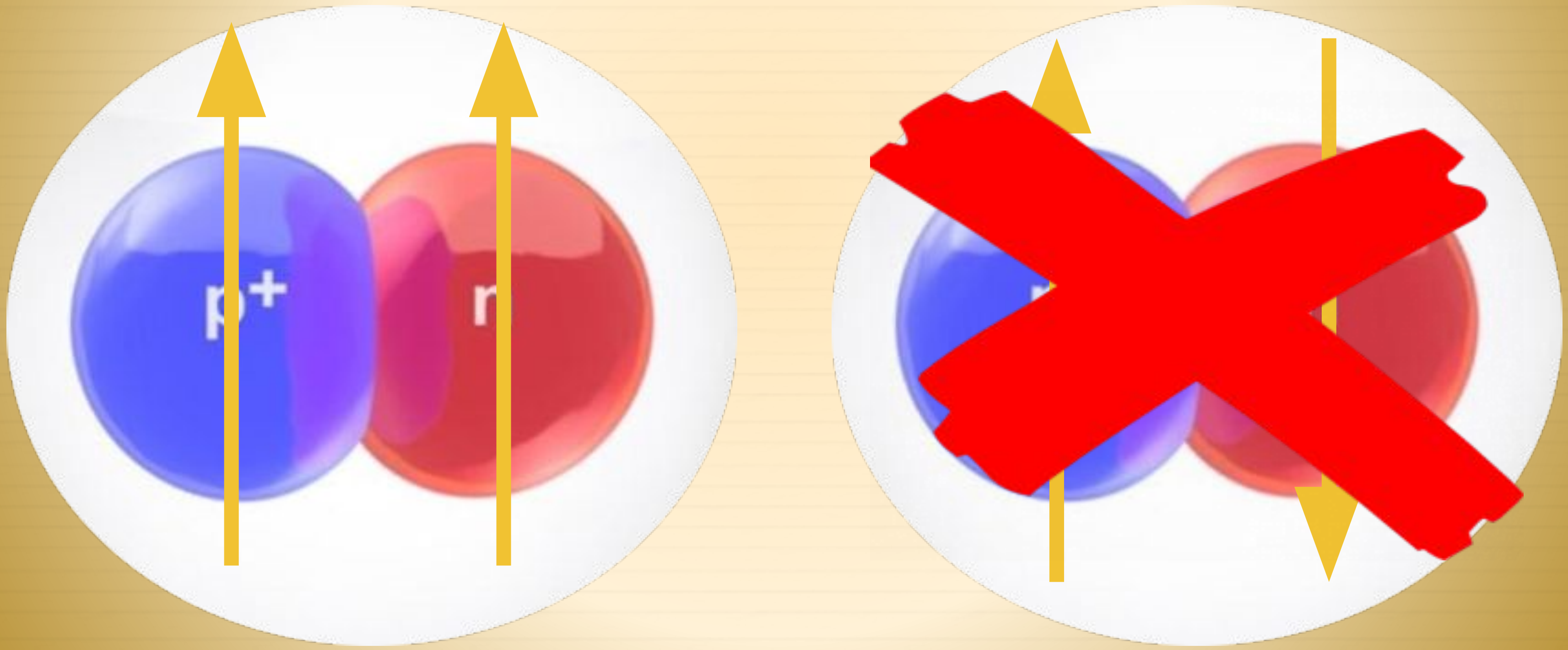
Spin: +1

Spin: +1



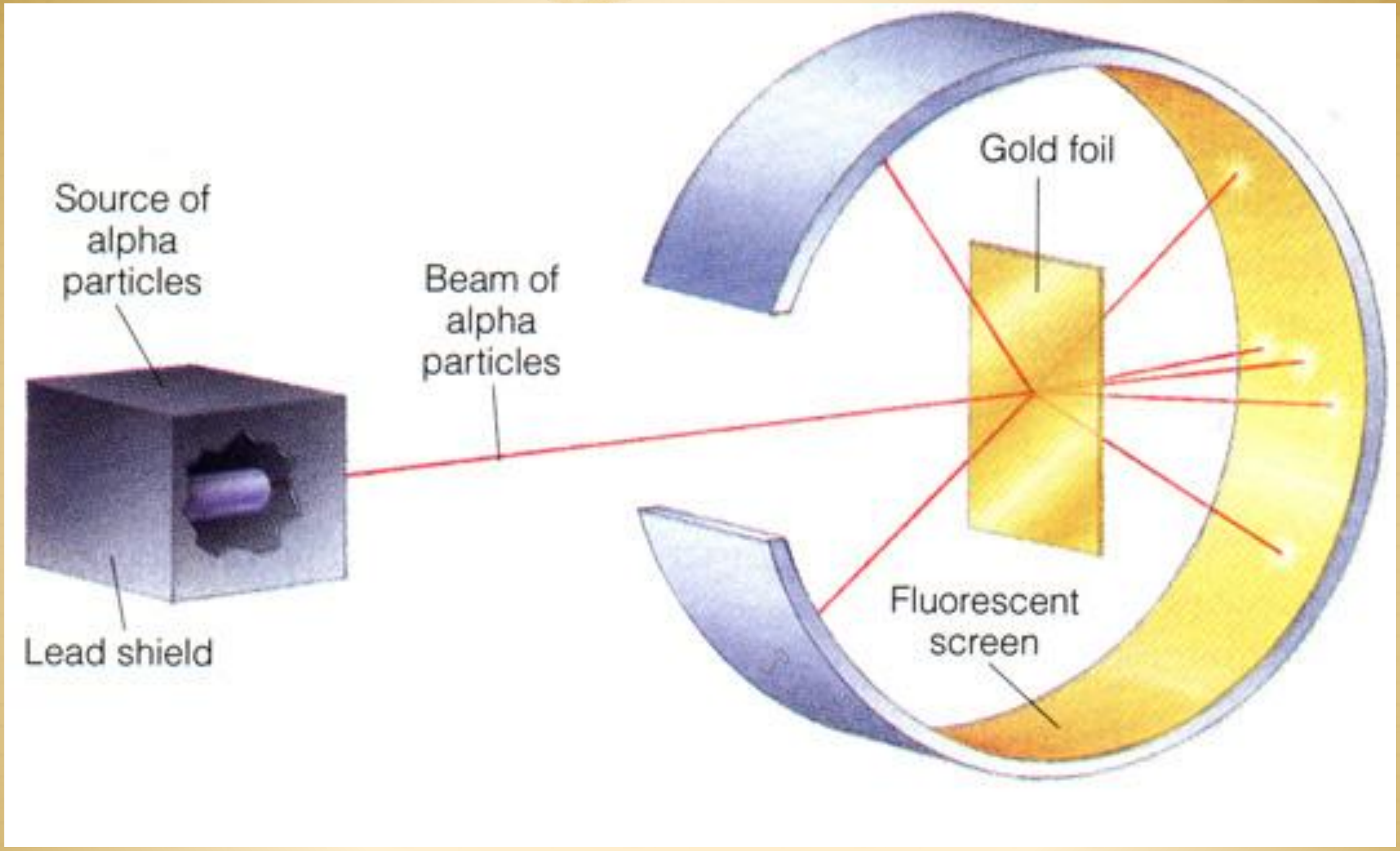


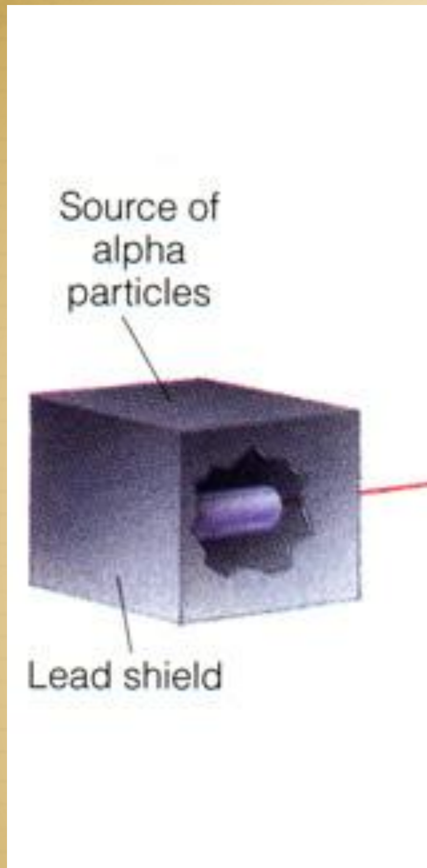
Spin: +1



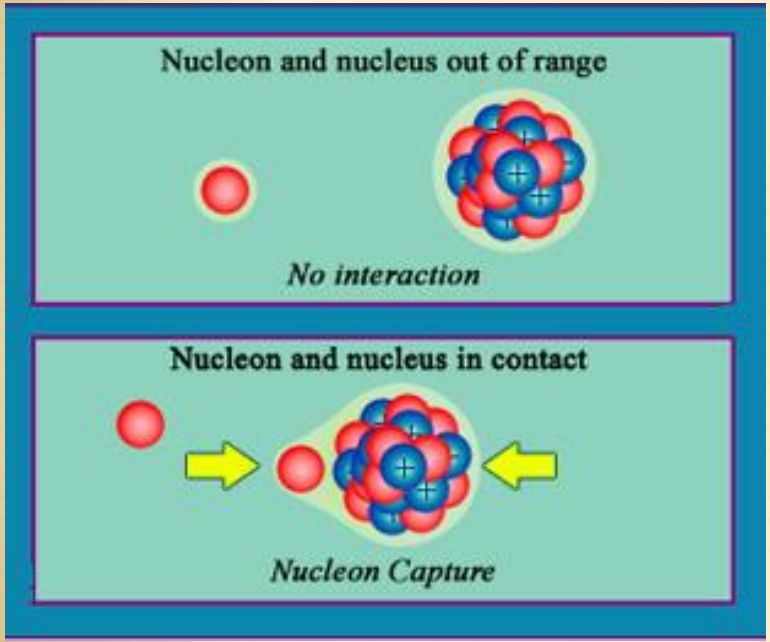
Part 2:

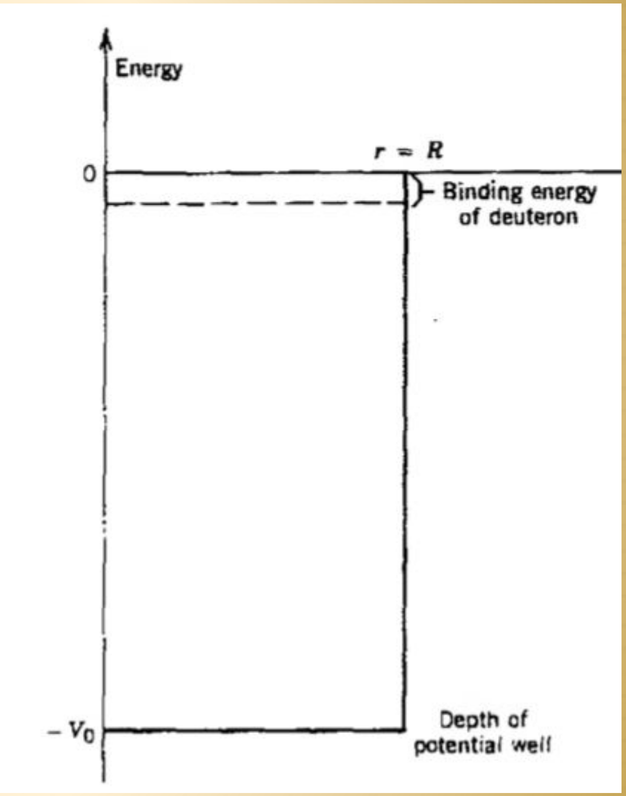
Hard hitting


Source of
alpha
particles
Beam of
alpha
particles
Gold foil
Lead shield
Fluorescent
screen

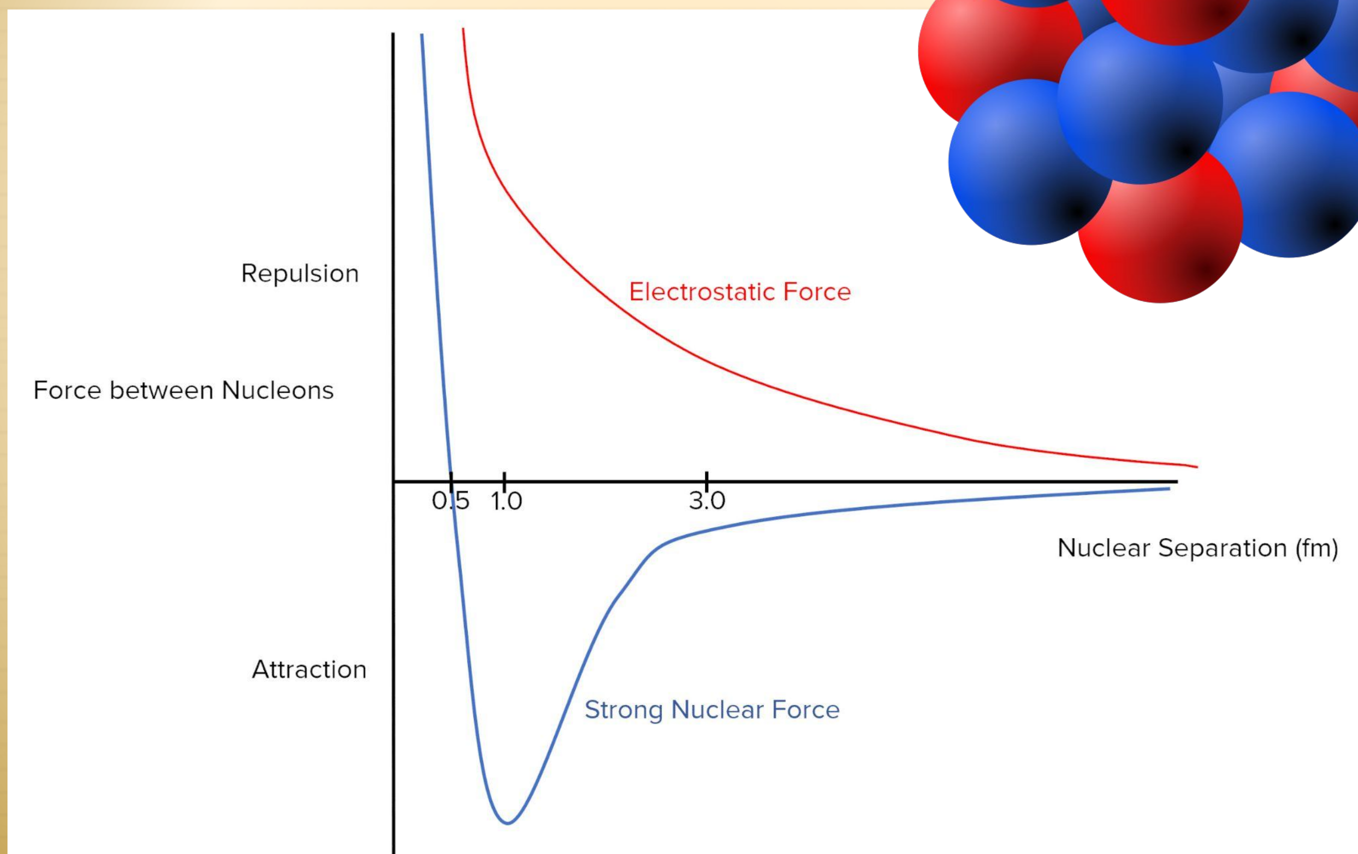

Source of alpha particles
Lead shield

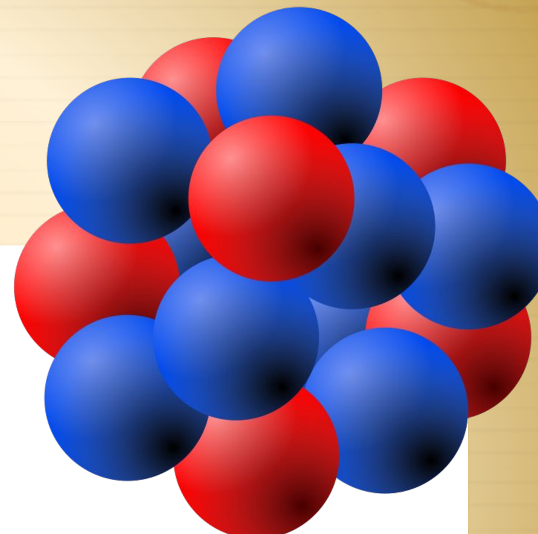
1. Short range



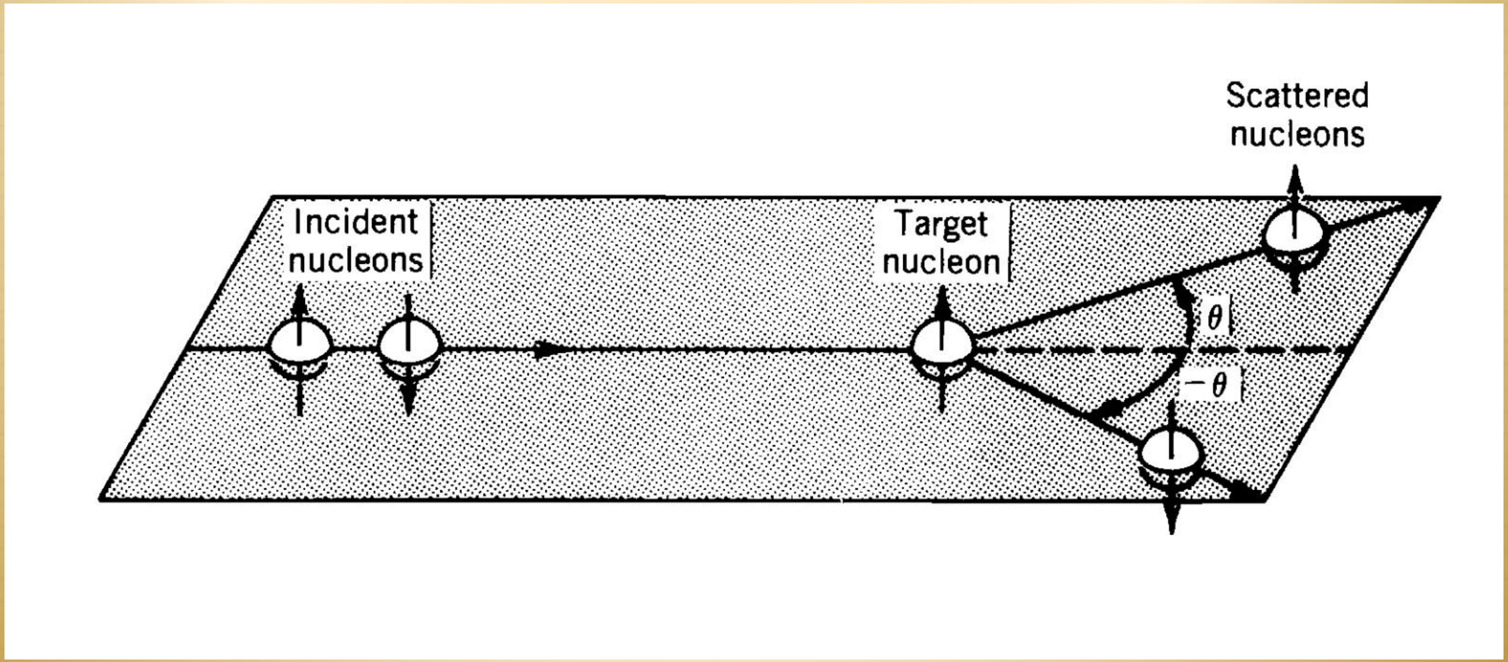


1. ***Short range***
2. ***Crowded core***





1. **Short range**
2. **Crowded core**
3. **Spin dependence**



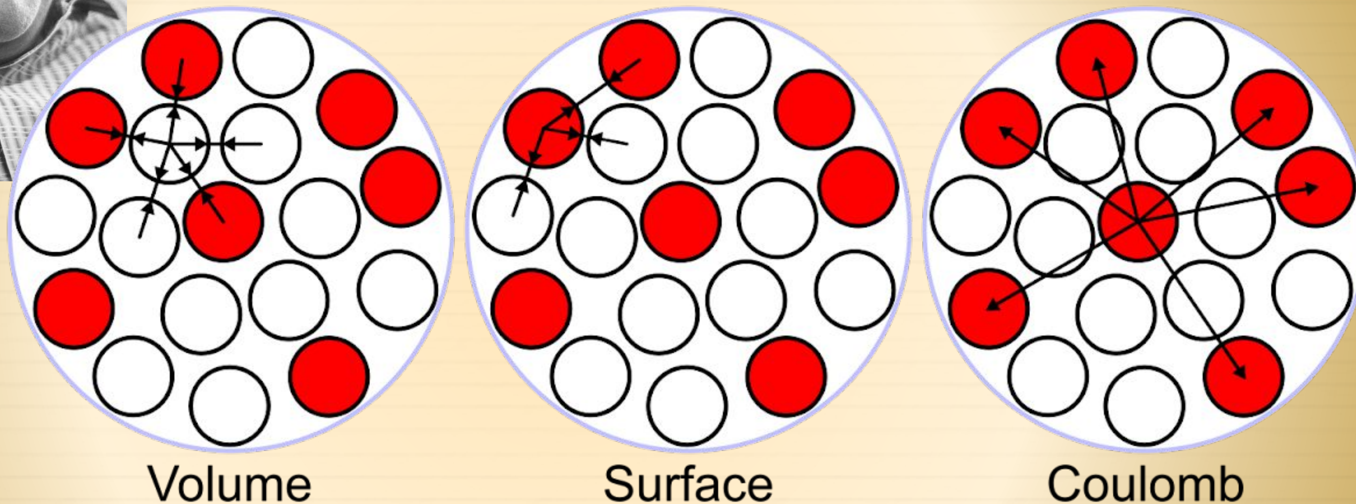
Part 3:

Answers in a drop of water

Incompressible* = *Crowded core

Surface tension* = *Short range

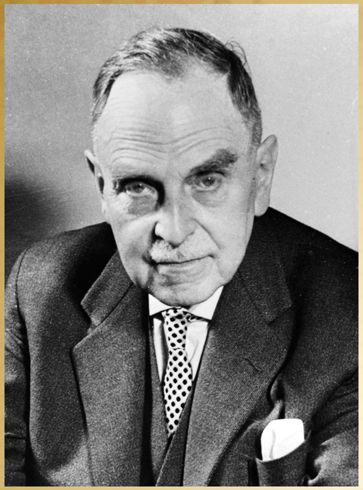
Gamow, 1930

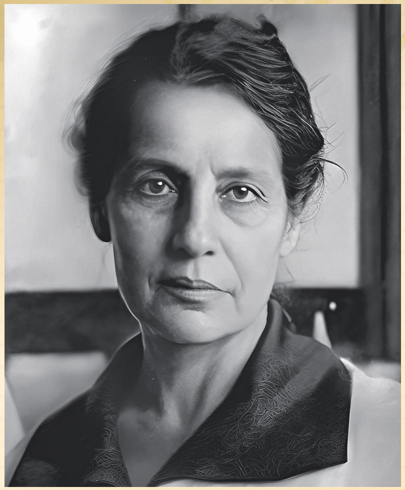


$$E_{\mathrm{B}} = a_{\mathrm{V}} A - a_{\mathrm{S}} A^{2/3} - a_{\mathrm{C}} \frac{Z(Z-1)}{A^{1/3}} - a_{\mathrm{A}} \frac{(N-Z)^2}{A} \pm \delta(N,Z).$$

Interlude:

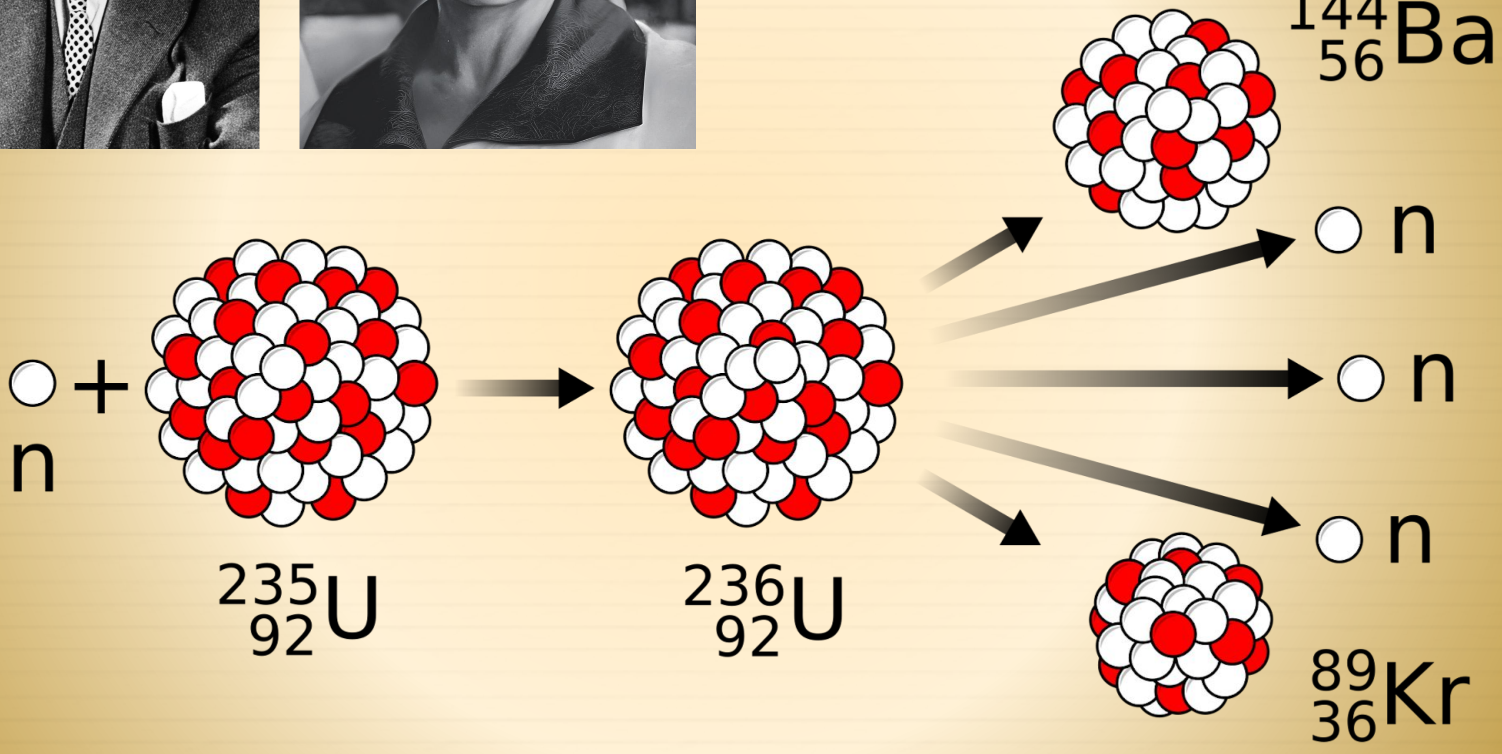
Exploding balloons

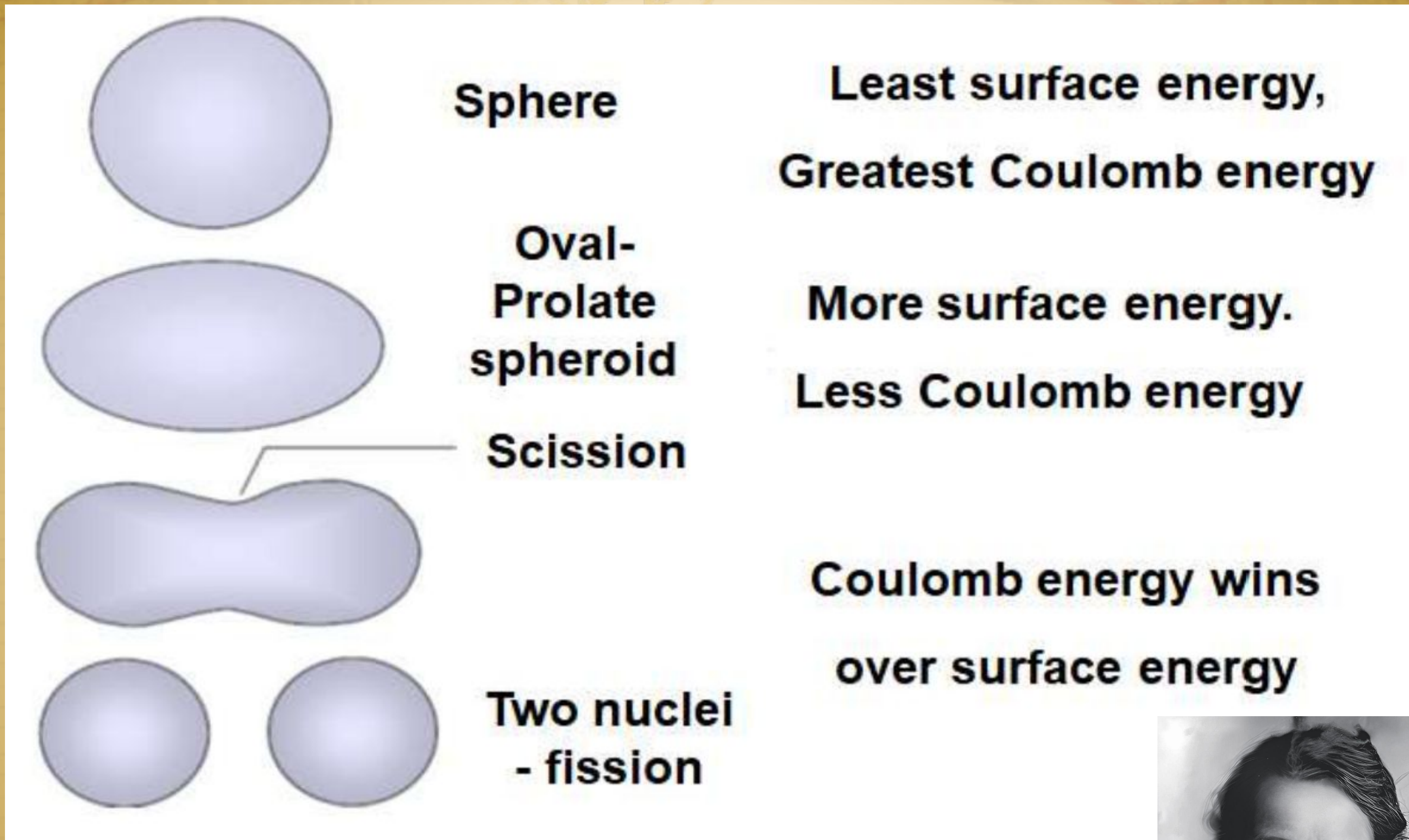


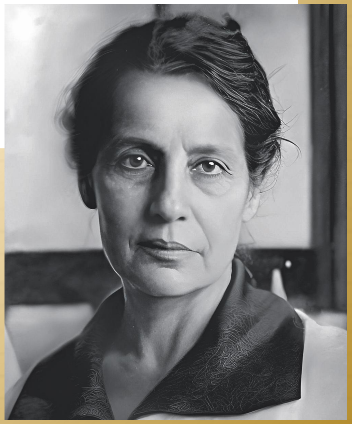


Hahn, Meitner

1934 - 1938

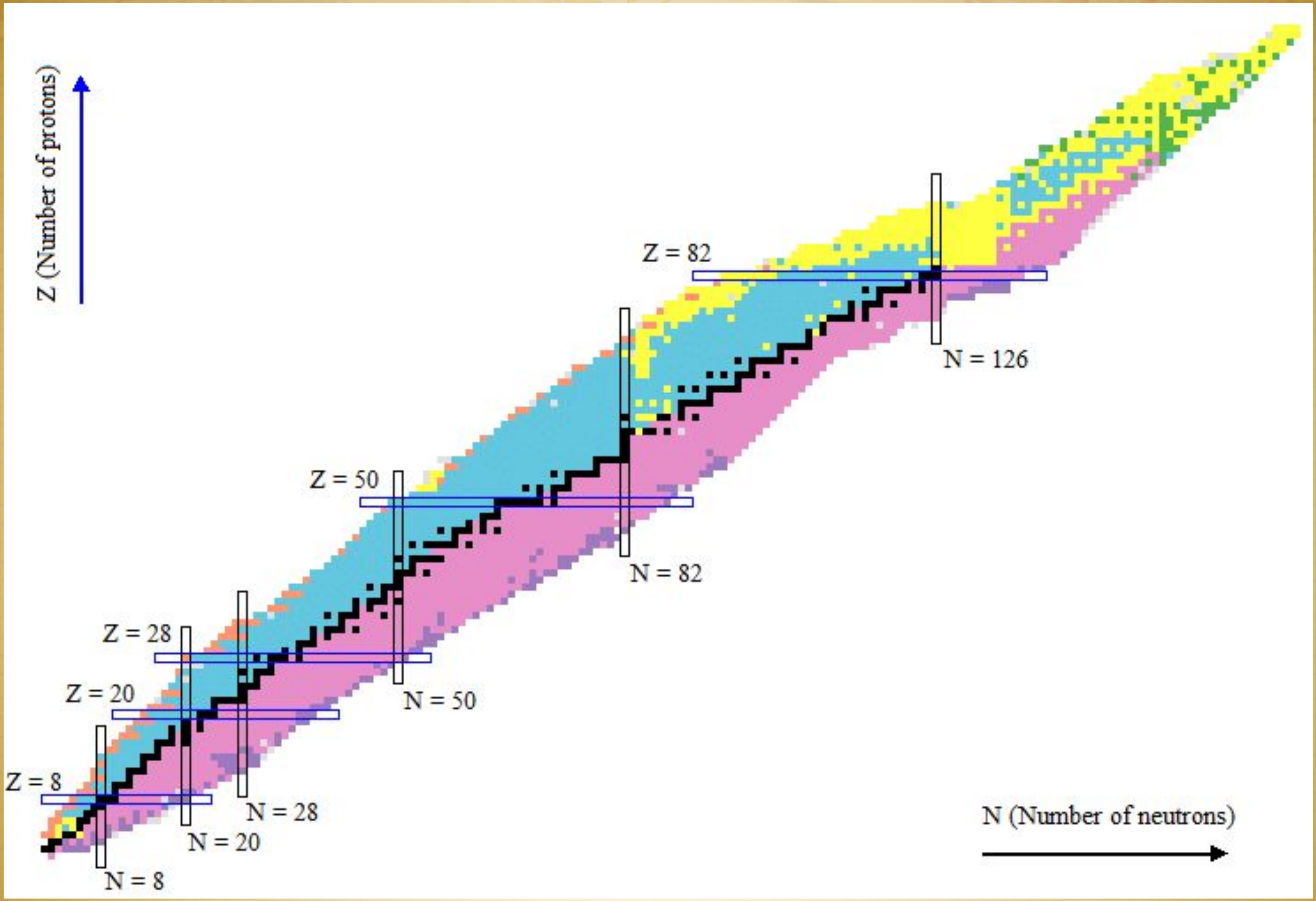


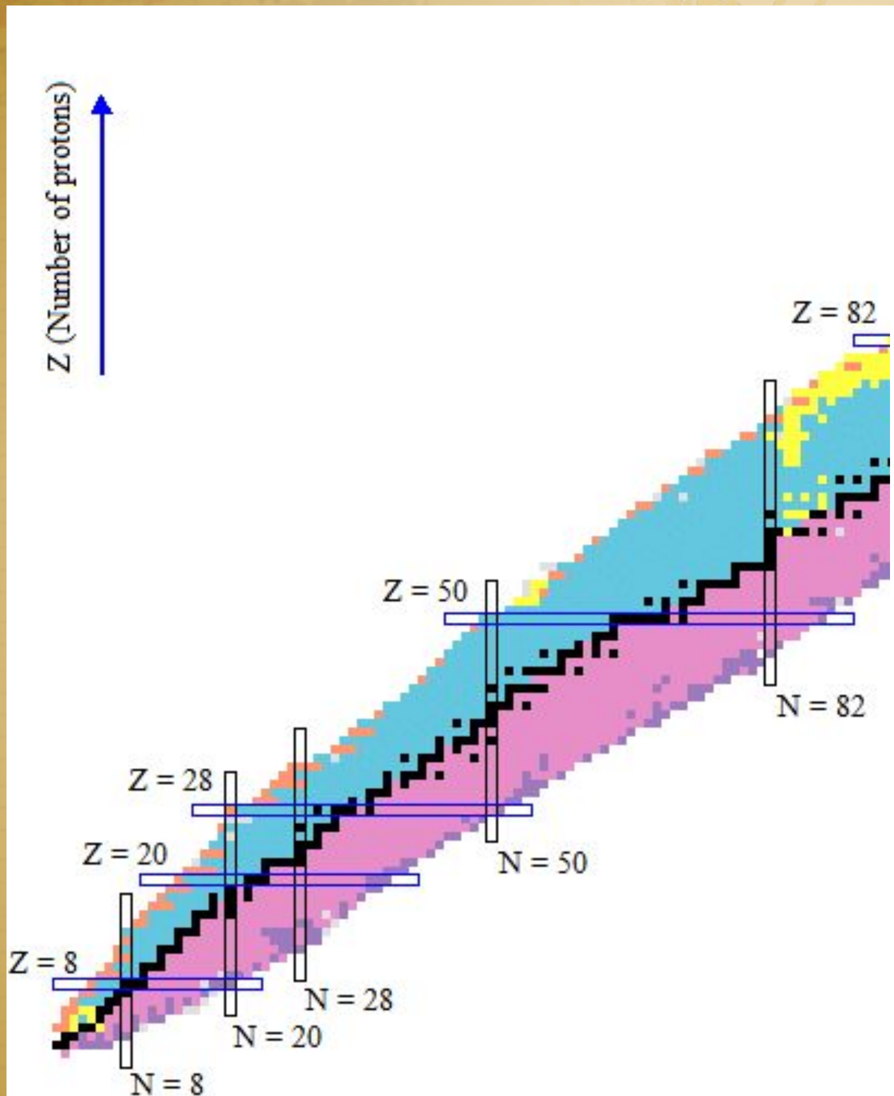

Sphere
Least surface energy,
Greatest Coulomb energy
Oval-
Prolate
spheroid
More surface energy.
Less Coulomb energy
Scission
Coulomb energy wins
over surface energy
Two nuclei
- fission

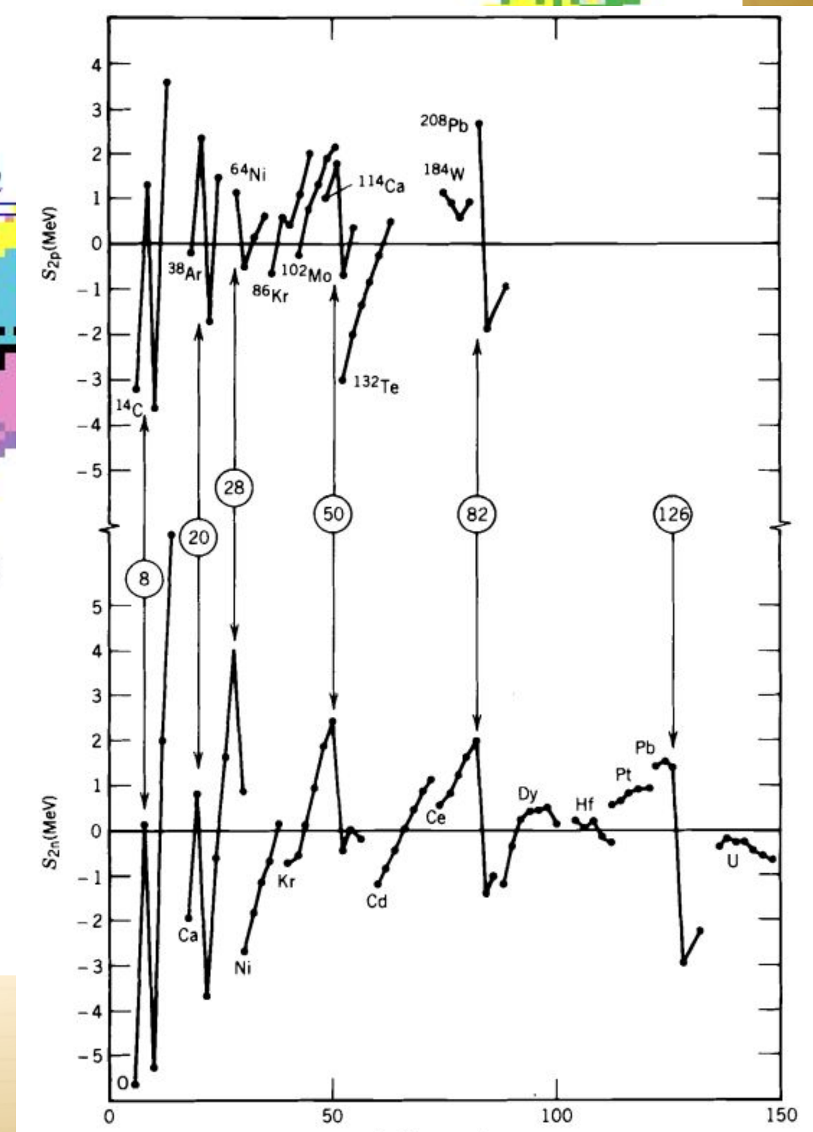


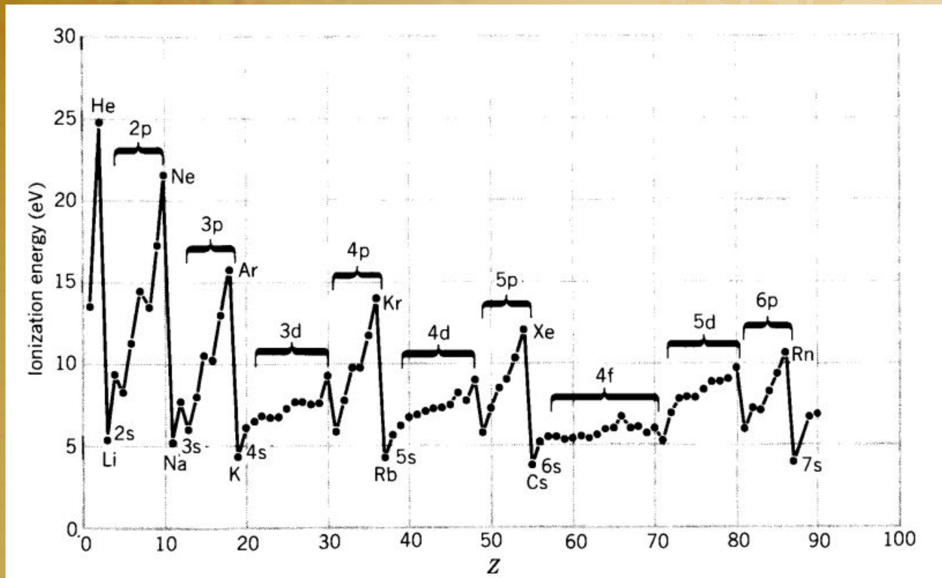
Part 4:

Finding the layers

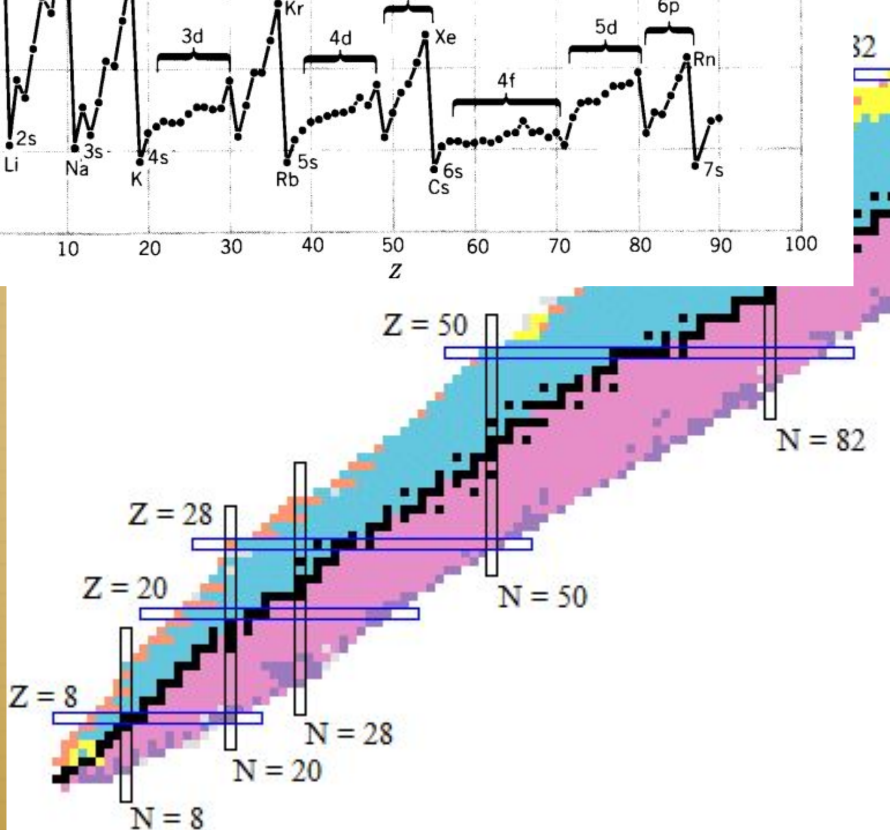

Z (Number of protons)
Z = 82
N = 126
Z = 50
N = 82
Z = 28
Z = 20
N = 50
Z = 8
N = 28
N = 20
N = 8
N (Number of neutrons)


Z (Number of protons)
Z = 82
Z = 50
Z = 28
Z = 20
Z = 8
N = 8
N = 20
N = 28
N = 50
N = 82

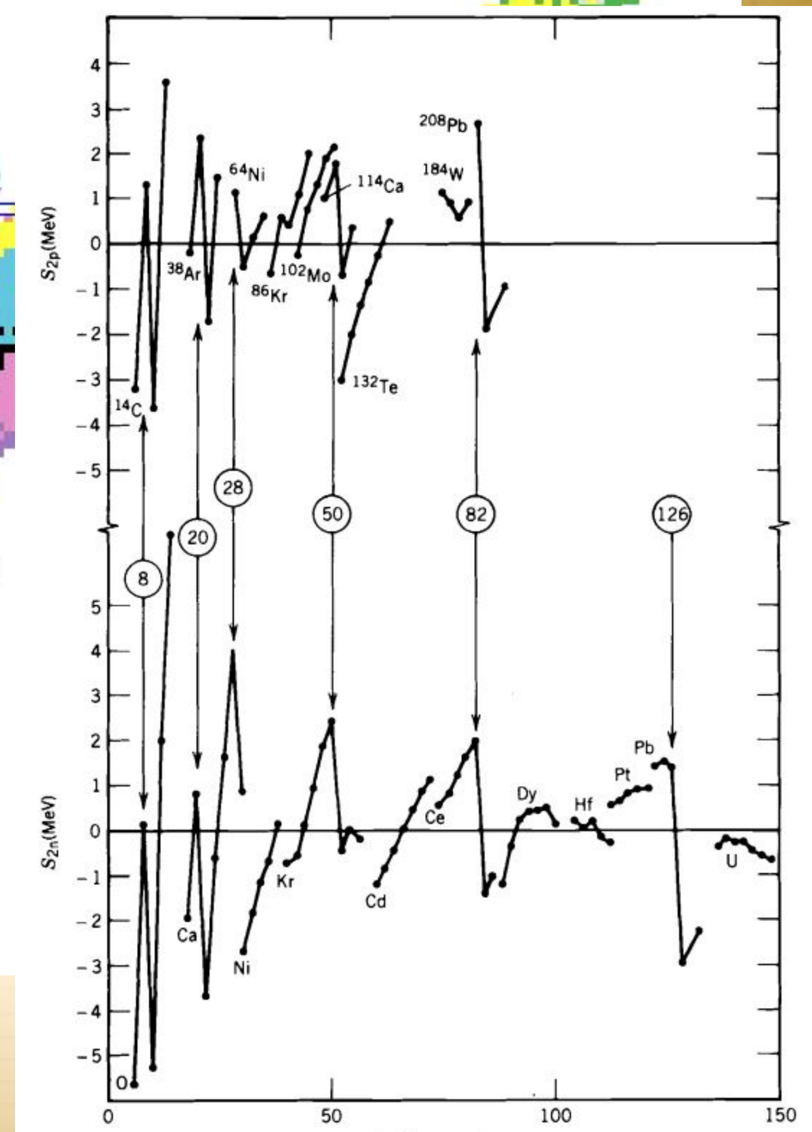

S_{2p}(MeV)
S_{2n}(MeV)
^{208}Pb
^{184}W
^{64}Ni
^{114}Ca
^{38}Ar
^{86}Kr
^{102}Mo
^{132}Te
^{14}C
8
20
28
50
82
126
O
Ca
Ni
Kr
Cd
Ce
Dy
Hf
Pt
Pb
U
0
50
100
150
Nucleon number



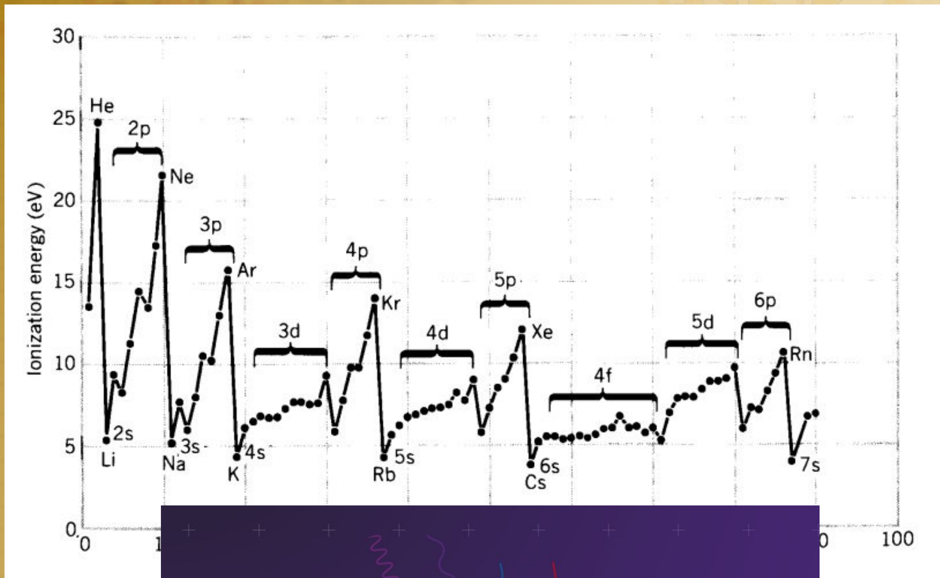
Ionization energy (eV)
Z
He
Ne
Ar
Kr
Xe
Rn
Li
Na
K
Rb
Cs
2s
3s
4s
5s
6s
7s
2p
3p
4p
5p
6p
3d
4d
5d
4f



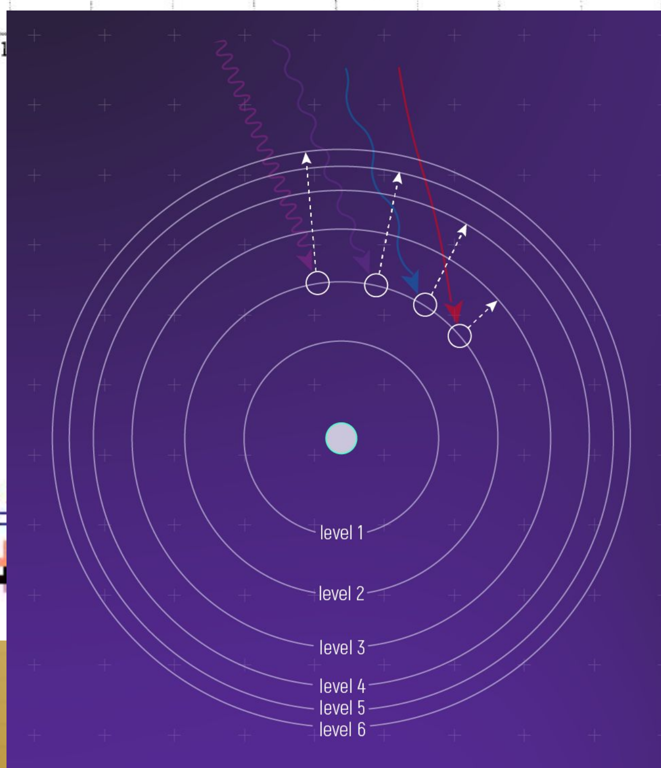
Z = 8
Z = 20
Z = 28
Z = 50
N = 8
N = 20
N = 28
N = 50
N = 82
82



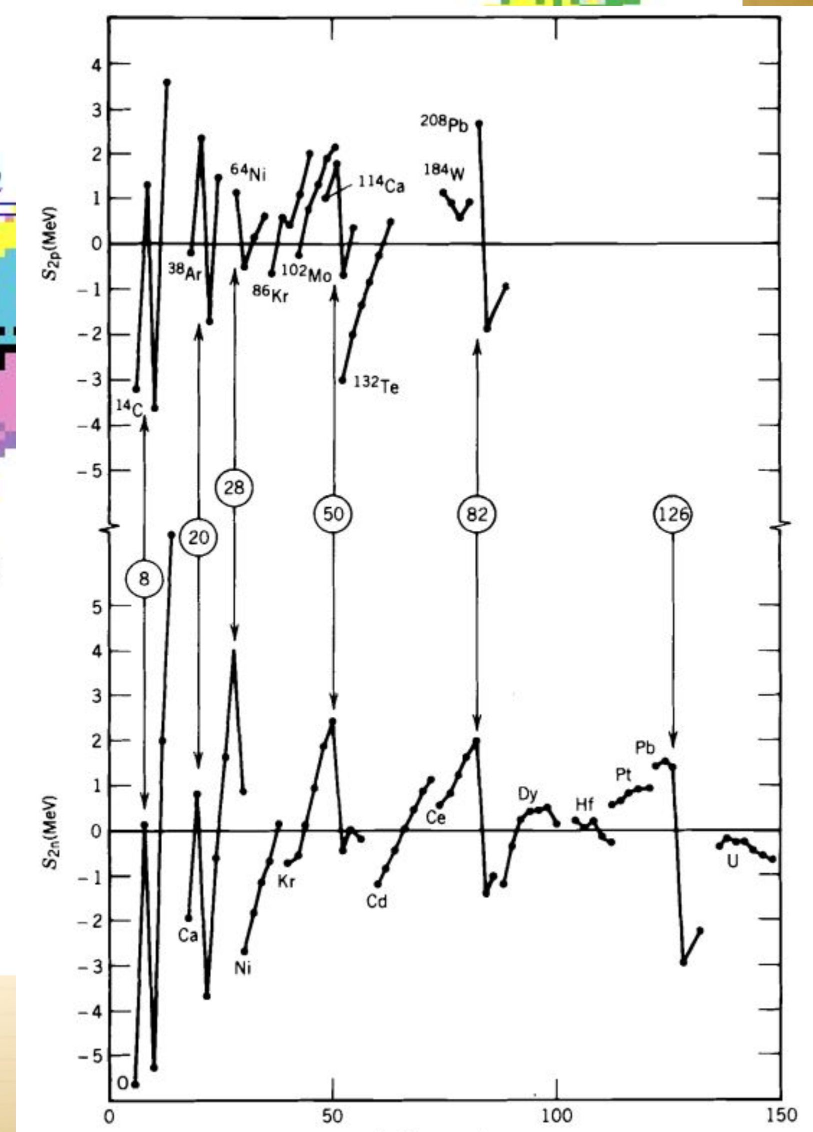
S_{2p}(MeV)
S_{2n}(MeV)
Nucleon number
^{14}C
^{38}Ar
^{64}Ni
^{86}Kr
^{102}Mo
^{114}Ca
^{132}Te
^{184}W
^{208}Pb
8
20
28
50
82
126
O
Ca
Ni
Kr
Cd
Ce
Dy
Hf
Pt
Pb
U



Ionization energy (eV)
He
Ne
Ar
Kr
Xe
Rn
Li
Na
K
Rb
Cs
2s
3s
4s
5s
6s
7s
2p
3p
4p
5p
6p
3d
4d
5d
4f



level 1
level 2
level 3
level 4
level 5
level 6



S_{2p}(MeV)
S_{2n}(MeV)
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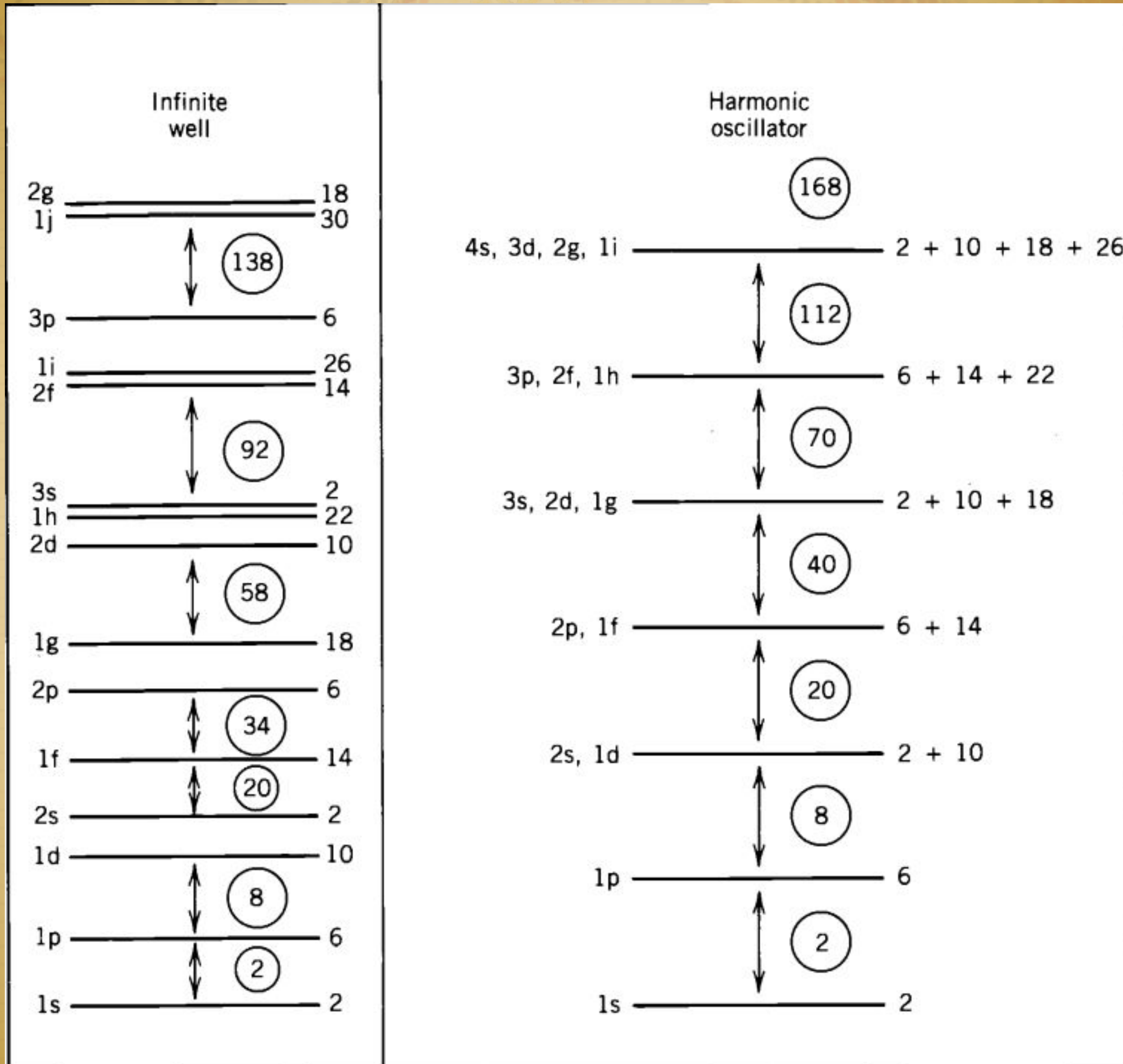
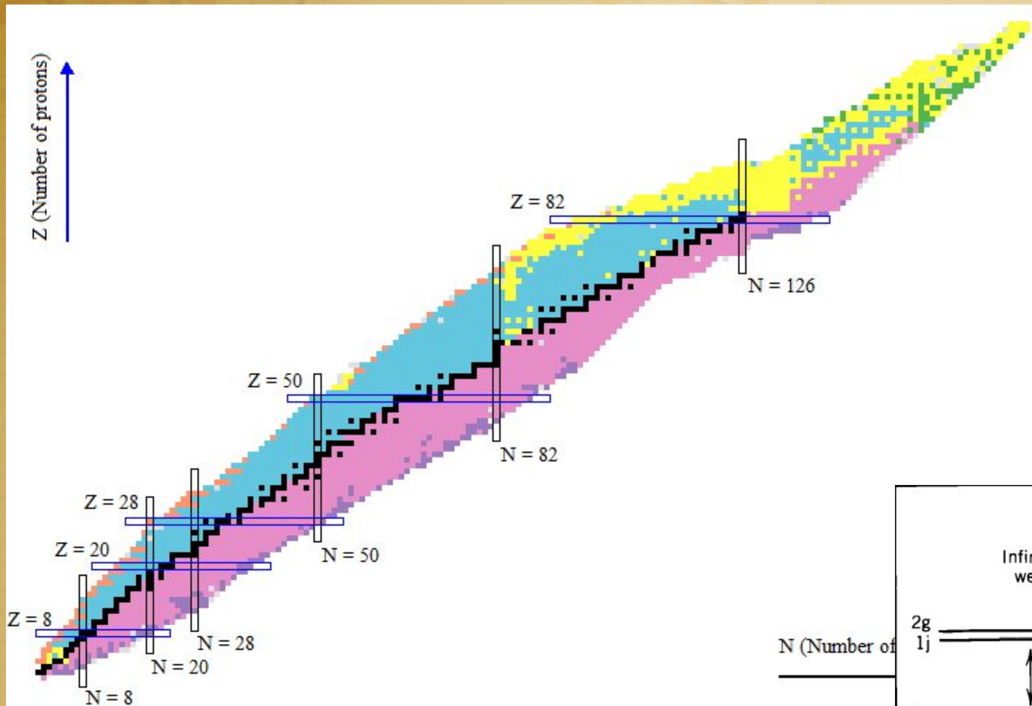
20
28
50
82
126
O
Ca
Ni
Kr
Cd
Ce
Dy
Hf
Pt
Pb
U
Nucleon number


Infinite well
2g 18
1j 30
138
3p 6
1i 26
2f 14
92
3s 2
1h 22
2d 10
58
1g 18
2p 6
34
1f 14
20
2s 2
1d 10
8
1p 6
2
1s 2
Harmonic oscillator
168
4s, 3d, 2g, 1i 2 + 10 + 18 + 26
112
3p, 2f, 1h 6 + 14 + 22
70
3s, 2d, 1g 2 + 10 + 18
40
2p, 1f 6 + 14
20
2s, 1d 2 + 10
8
1p 6
2
1s 2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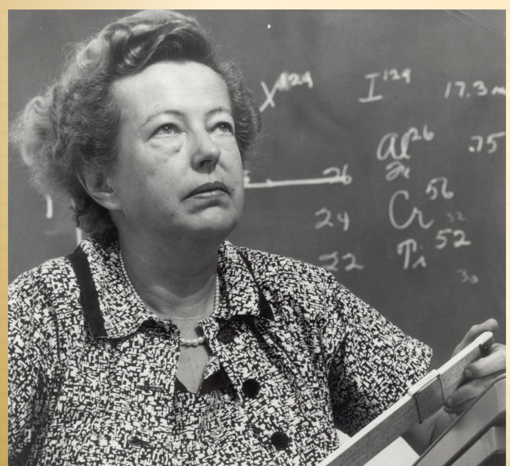
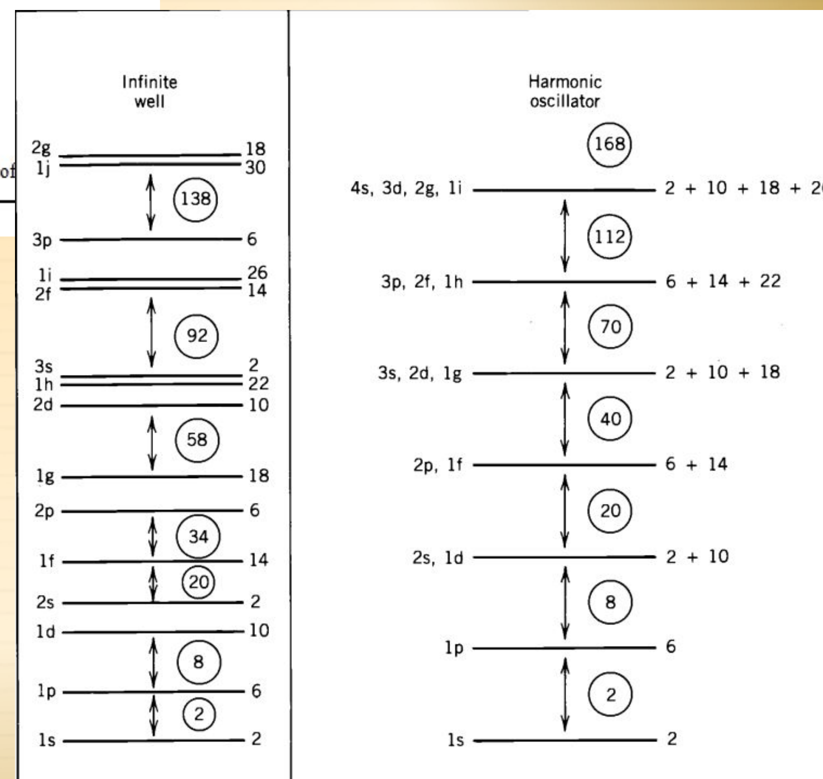
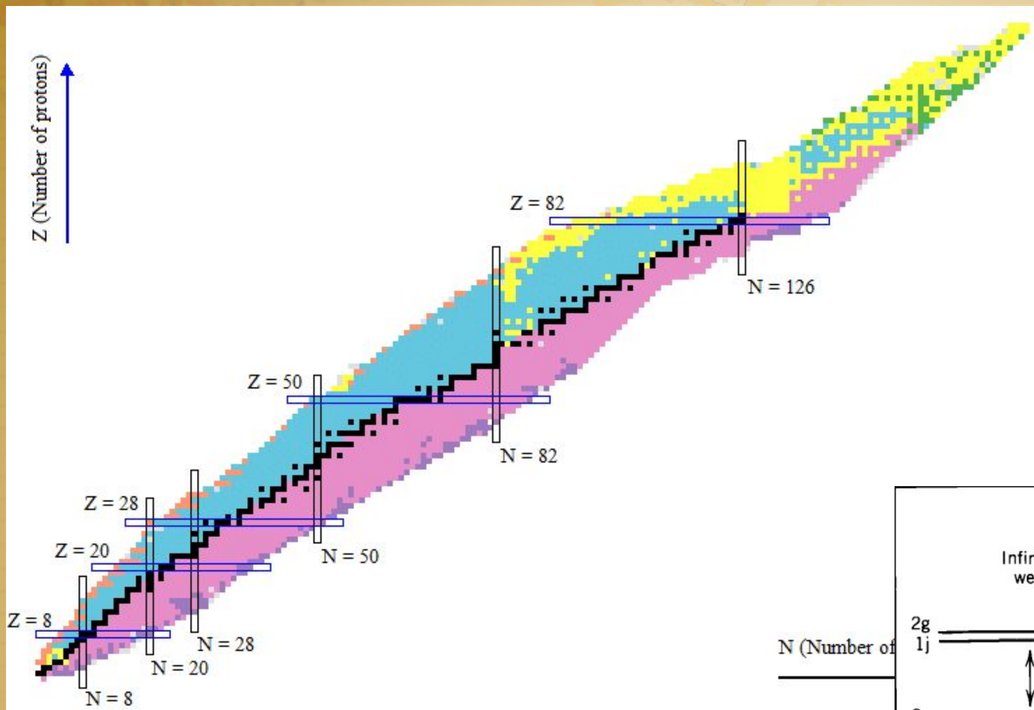
Z = 20
N = 50
Z = 8
N = 28
N = 20
N = 8
N (Number of




Infinite well
2g 18
1j 30
138
3p 6
1i 26
2f 14
92
3s 2
1h 22
2d 10
58
1g 18
2p 6
34
1f 14
20
2s 2
1d 10
8
1p 6
2
1s 2
Harmonic oscillator
168
4s, 3d, 2g, 1i 2 + 10 + 18 + 26
112
3p, 2f, 1h 6 + 14 + 22
70
3s, 2d, 1g 2 + 10 + 18
40
2p, 1f 6 + 14
20
2s, 1d 2 + 10
8
1p 6
2
1s 2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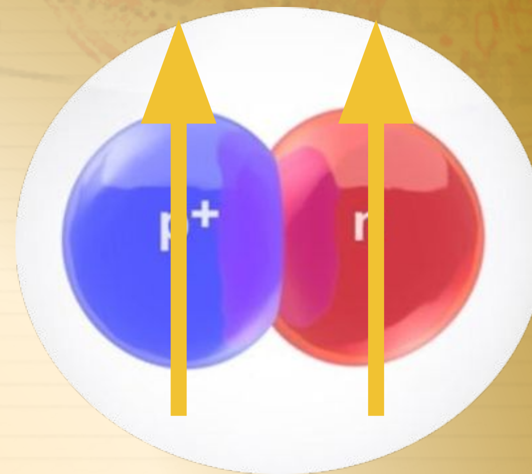
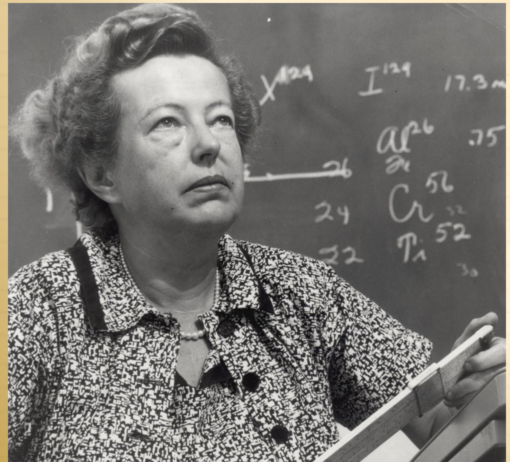
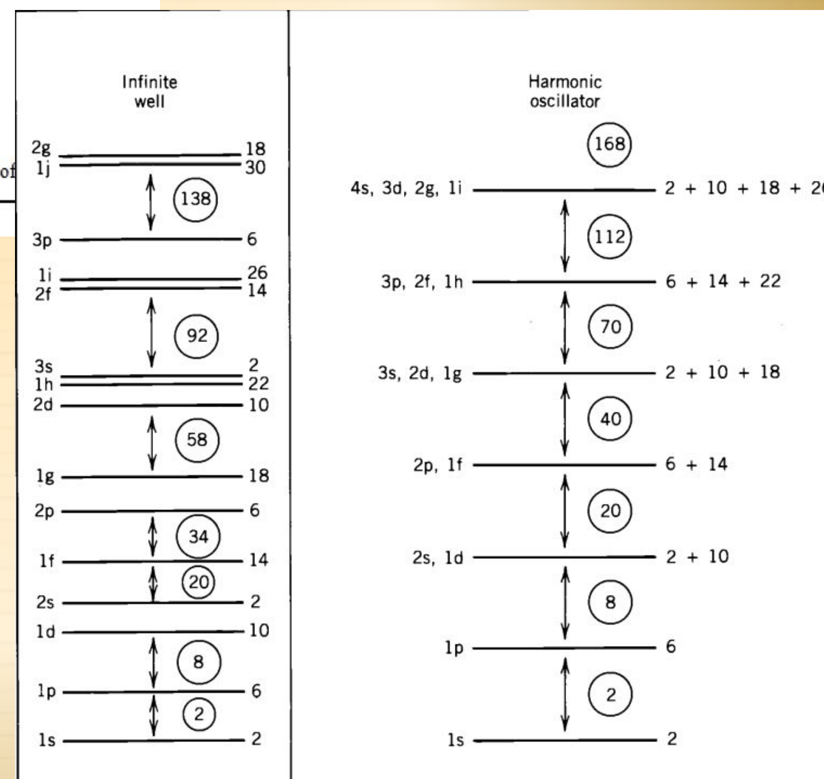
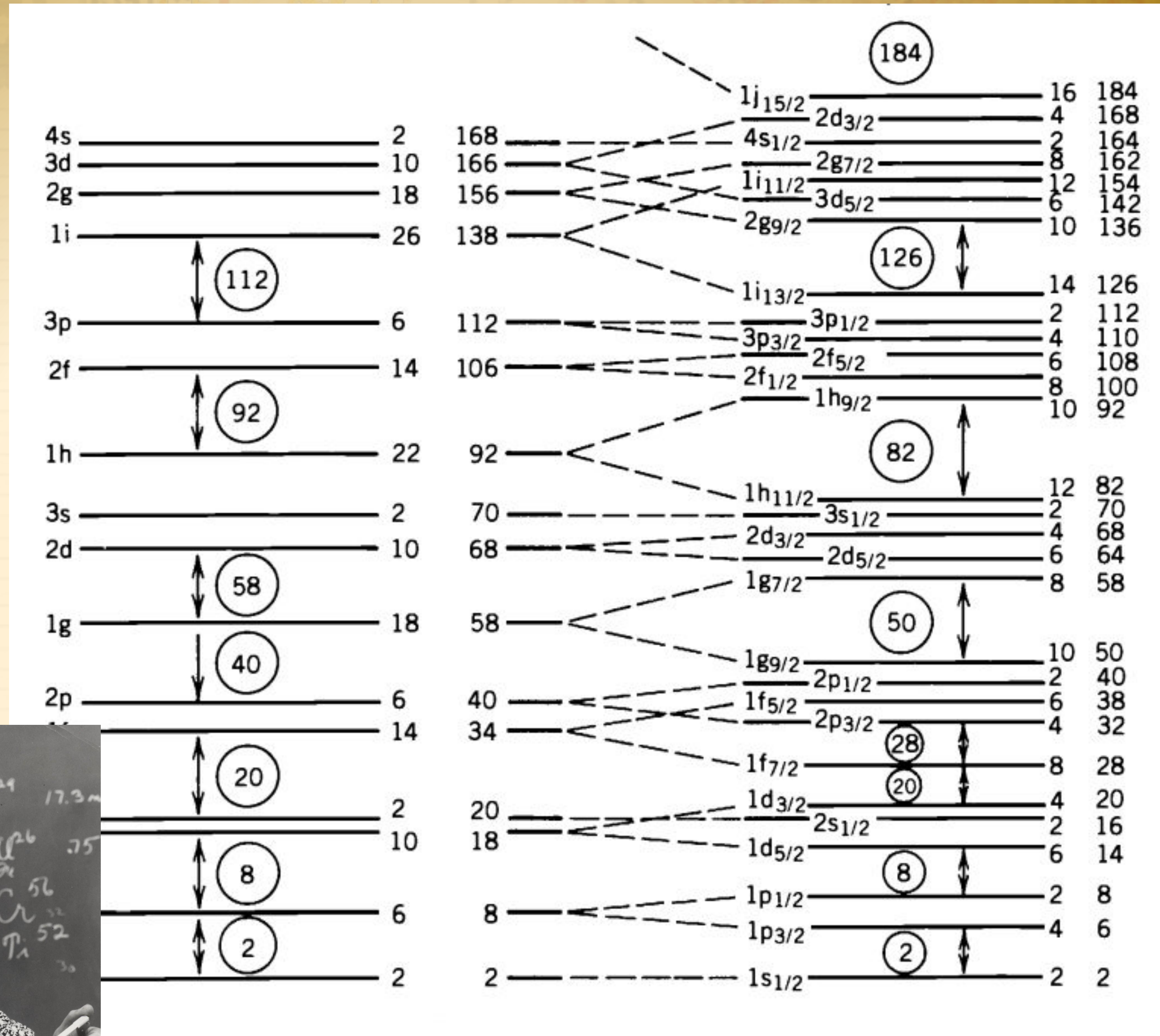
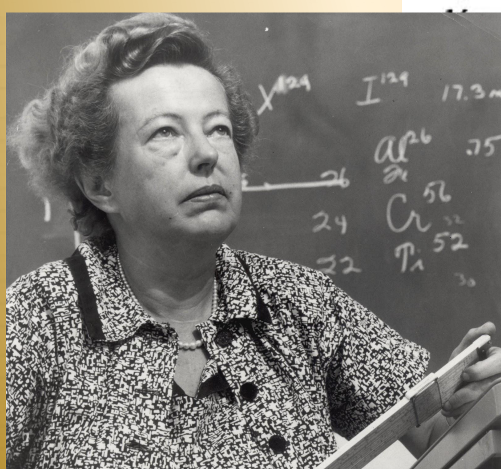
N = 126
Z = 50
N = 82
Z = 28
Z = 20
N = 50
Z = 8
N = 28
N = 20
N = 8
N (Number of


p+
n

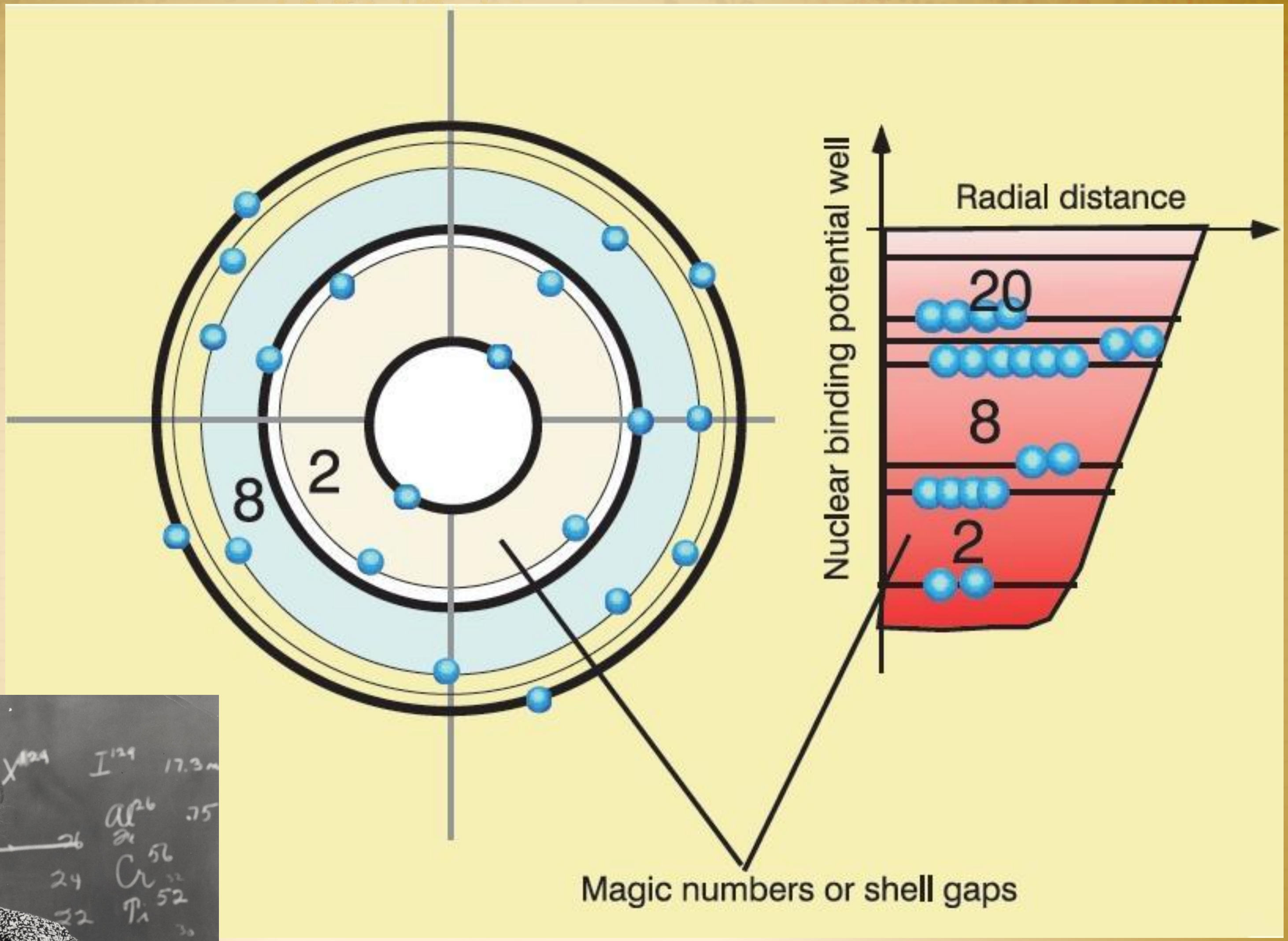


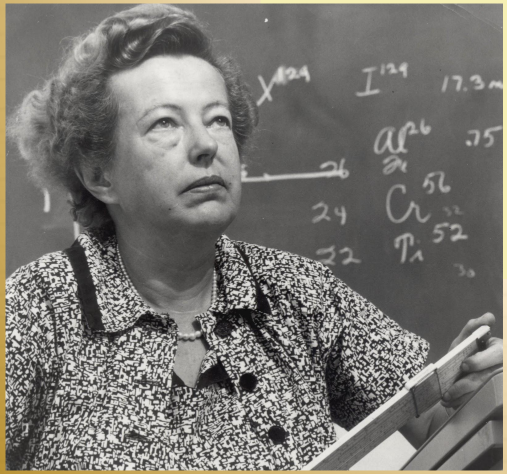

Infinite well
2g 18
1j 30
138
3p 6
1i 26
2f 14
92
3s 2
1h 22
2d 10
58
1g 18
2p 6
34
1f 14
20
2s 2
1d 10
8
1p 6
2
1s 2
Harmonic oscillator
168
4s, 3d, 2g, 1i 2 + 10 + 18 + 26
112
3p, 2f, 1h 6 + 14 + 22
70
3s, 2d, 1g 2 + 10 + 18
40
2p, 1f 6 + 14
20
2s, 1d 2 + 10
8
1p 6
2
1s 2





Goeppert-Mayer, 1949





Goeppert-Mayer, 1949

The end:

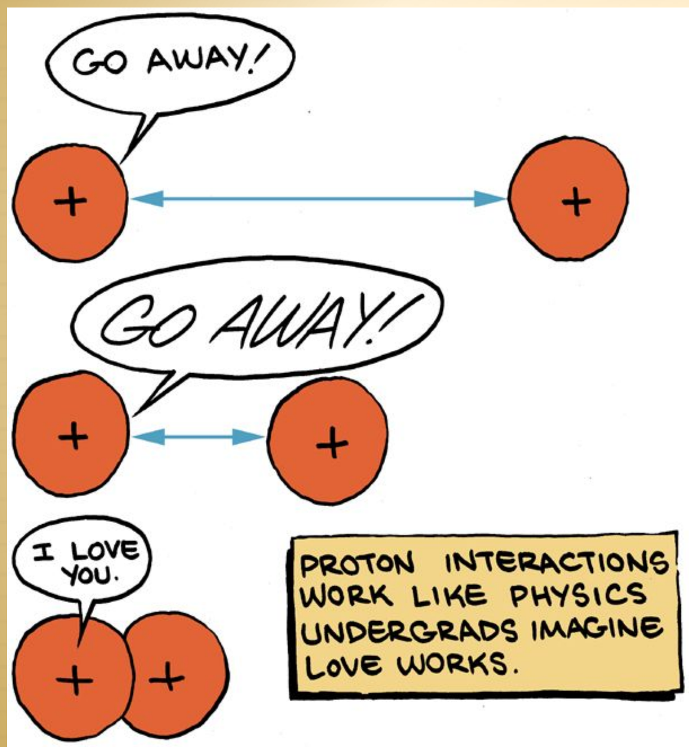
Conclusions

- *We know many things about the nuclear force, but still cannot* ***deduce it*** *from first principles*

- *A first approach to the nucleus is that of a* ***"liquid of nucleons"****, sustained by short-range forces*

- *A more accurate picture emerges if we realise that the liquid must be organised in* ***layers****, just like the electrons*

Thank you very much!



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Aparici en Órbita