

Introdução geral à Física Nuclear – Wong (1998)

O que é o núcleo e de que é constituído:

- Núcleons (p, n, ...)

Constituintes dos núcleons: Quarks (u, d, ..)

A força nuclear: uma das 4 (3) Forças da Natureza
(parcialmente conhecida)

Conceitos básicos de estrutura e reações nucleares

Física Nuclear I - 2019

Interesses atuais:

Simetrias fundamentais (ou não...)

Física além do MP

Feixes radioativos

Astrofísica – origem dos núcleos

Neutrinos

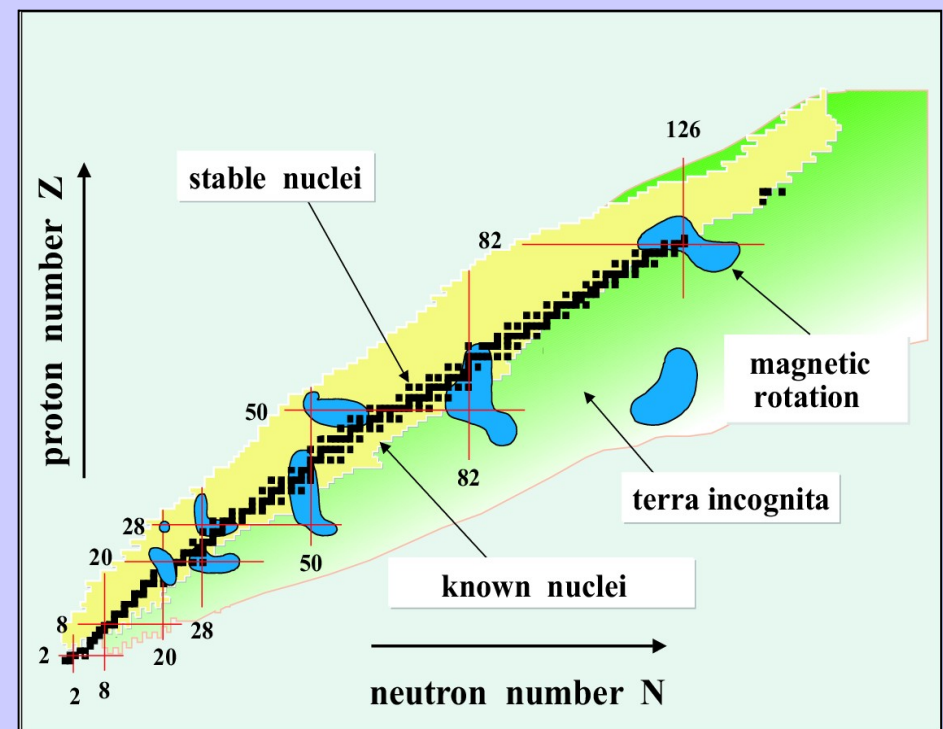
Condições extremas:

(I, A, Tz, E*, caos, S)

QGP

Aplicações

Tabela de nuclídeos



Física Nuclear I

Atividades e pesos na nota (sugeridos)

Leituras prévias (antes de cada aula) – questões para discussão (moodle, 10%)

Participação em classe? (30%)

Listas (20%)

Tarefas individualizadas – seminários (20%)

Provas +revisão oral de erros $\times \frac{1}{2}$ (20%)

Outras

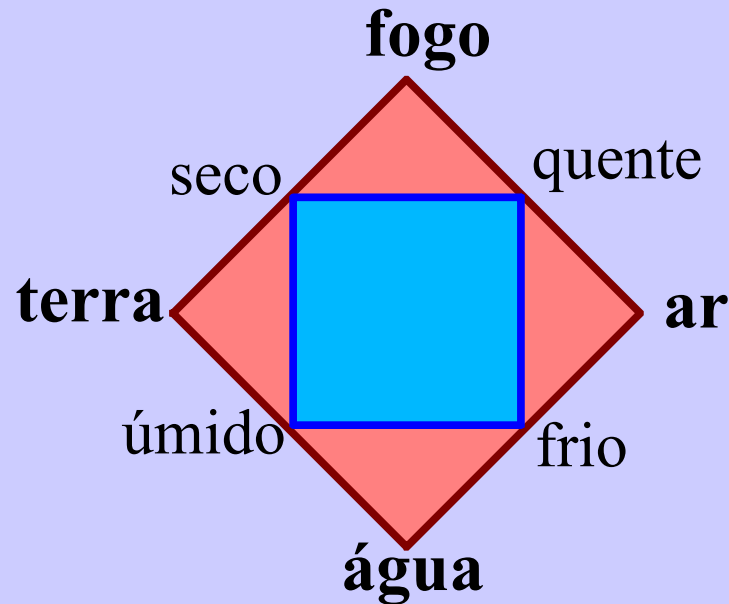
Conceito: A(8.1-10), B(6.5-8.0), C(5.0-6.4), R, T

Introdução:

Tentativas de sistematização dos componentes básicos da natureza

“Tudo é água” - Tales de Mileto ~600 AC

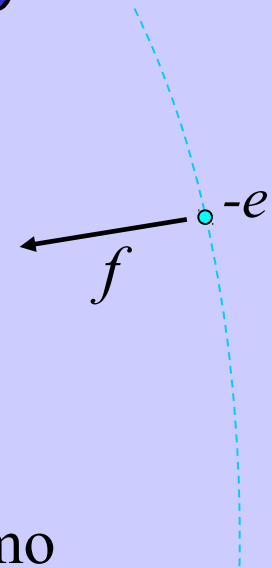
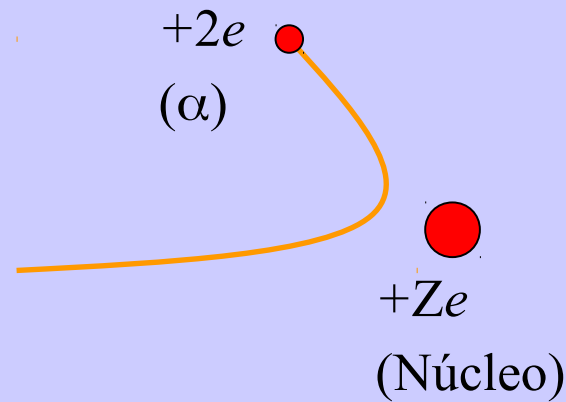
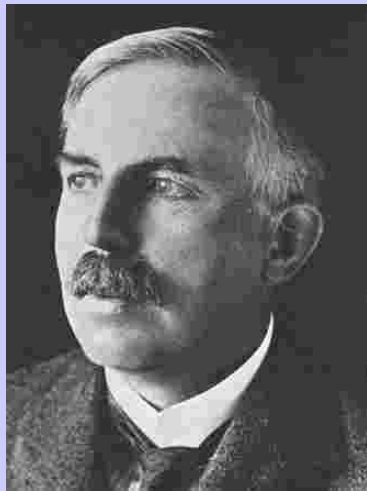
Empédocles,
450 AC ...
4 elementos



5º: éter – Aristóteles ~350AC

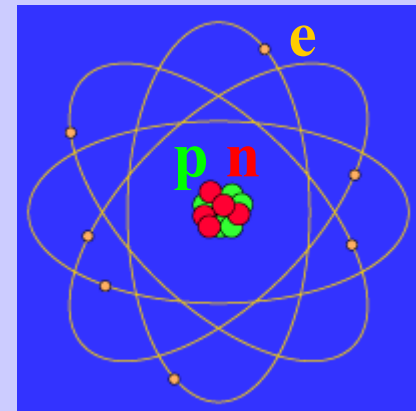
Rutherford 1911 - Carga positiva ($=+Ze$) concentrada no centro do átomo, $R < 10^{-14} \text{m}$. (Seção de choque σ_R ok.)

Espalhamento alfa



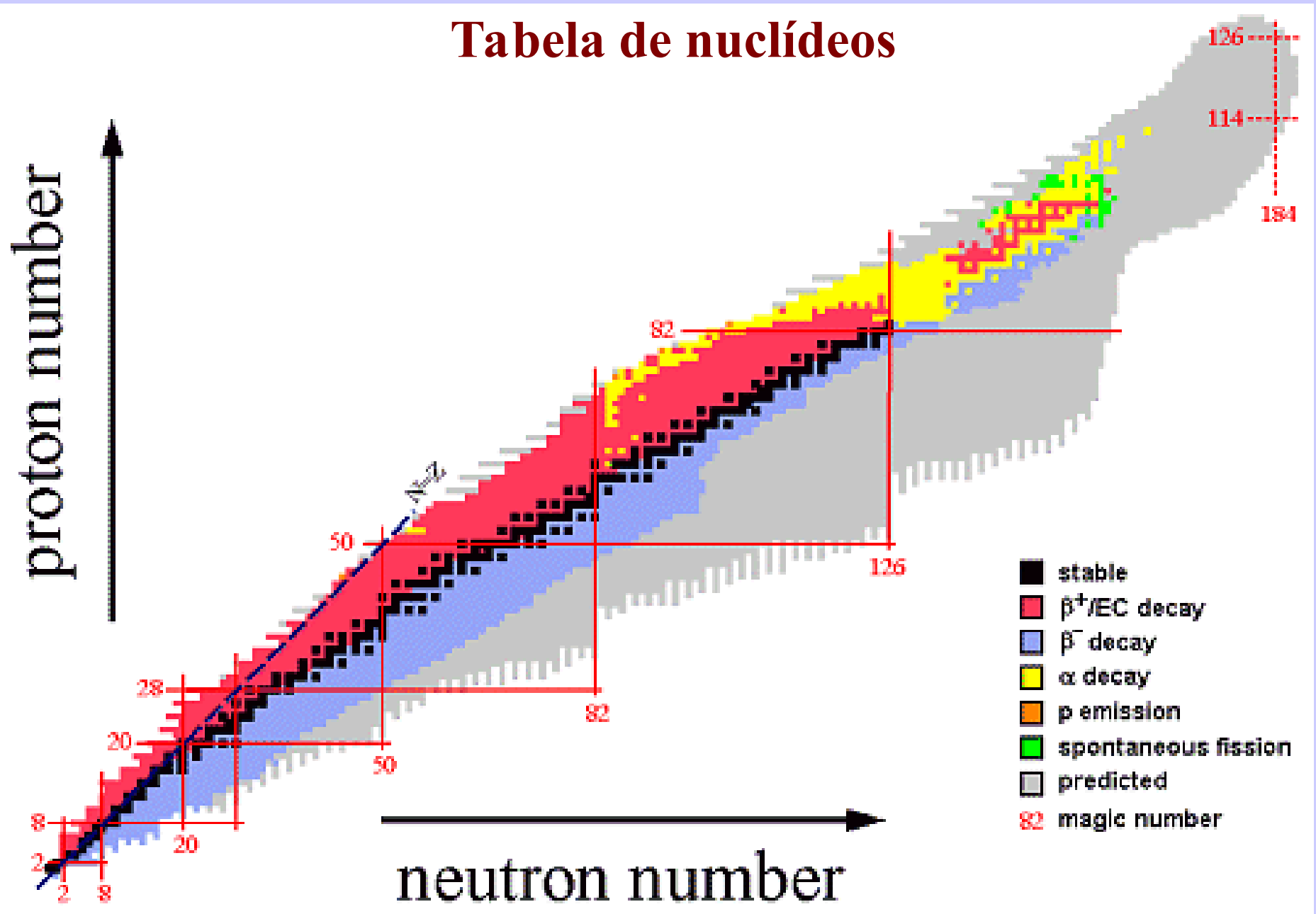
Átomo
($\sim 10^{-10} \text{m}$)

1920... A-Z?
Chadwick - 1932, n

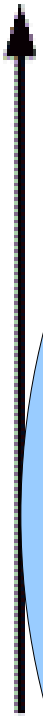


Núcleo
($\sim 10^{-15} \text{m}$)

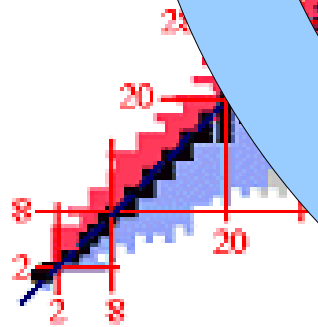
Tabela de núclídeos



proton number



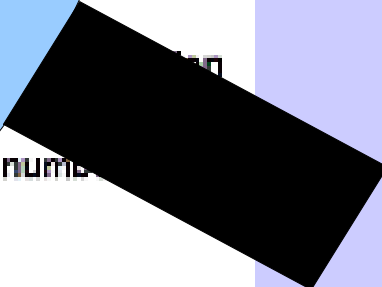
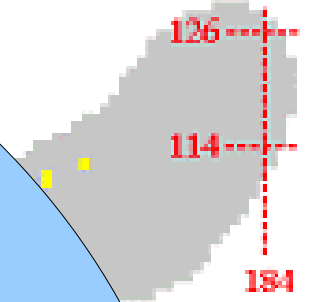
28	Ni 1455 2913 58.6934 0.000161%	Ni51	Ni52 0+	Ni53 45 ms (7/2-) ECp	Ni54 0+	Ni55 212.1 ms 7/2- EC	Ni56 5.9 d 0+ EC	Ni57 35.60 h 3/2- EC					
27	Co 1495 2927 58.93320 0.0000073%	Co50	Co51	Co52 18 ms EC	Co53 240 ms (7/2-) EC	Co54 193.23 ms 0+ EC	Co55 17.53 h 7/2- EC	Co56 77.27 d 4+ EC	Co57 271.79 d 7/2- EC				
26	Fe 1538 2861 55.847 0.00294%	Fe48	Fe49 75 ms (7/2-) ECp	Fe50 0+	Fe51 305 ms (5/2-) EC	Fe52 8.275 h 0+ EC	Fe53 8.51 m 7/2- EC	Fe54 0+ 5.8 EC	Fe55 2.73 y 3/2- EC	Fe56 0+ 91.72			
25	Mn 1246 2617 54.93805 0.000031%	Mn46	Mn48 158.1 ms 4+ ECp, ECα, ...	Mn49 384 ms 5/2- EC	Mn50 283.0 ms 0+ EC	Mn51 46.2 m 5/2- EC	Mn52 5.591 d 6+ EC	Mn53 3.74E+6 y 7/2- EC	Mn54 312.3 d 3+ EC, β-	Mn55 5/2- 100			
24	Cr 1907 2671 51.9961 0.000044%	Cr45 50 ms (7/2-) ECp	Cr46 0+ EC	Cr47 508 ms 3/2- EC	Cr48 21.56 h 0+ EC	Cr49 42.3 m 5/2- EC	Cr50 1.8E+17 y 0+ ECEC 4.345	Cr51 27.702 d 7/2- EC	Cr52 0+ 83.789 EC	Cr53 3/2- 9.501 EC	Cr54 0+ 2.365		
23	V 1910 2407 50.9415 9.6E-7%	V44 90 ms ECα	V45 547 ms 7/2- EC	V46 422.37 ms 0+ EC	V47 32.6 m 3/2- EC	V48 15.9735 d 4+ EC	V49 330 d 7/2- EC	V50 1.4E+17 y 6+ EC, β- 0.250	V51 330 d 7/2- EC	V52 3.75 m 3+ β-	V53 1.61 m 7/2- β-		
		Ti41 80 ms 3/2+ ECp	Ti42 199 ms 0+ EC	Ti43 509 ms 7/2- EC	Ti44 0+ EC	Ti45 184.8 m 7/2- EC	Ti46 0+ 8.0 EC	Ti47 5/2- 7.3 EC	Ti48 0+ 73.8 EC	Ti49 7/2- 5.5 EC	Ti50 0+ 5.4 EC	Ti51 5.76 m 3/2- β-	Ti52 1.7 m 0+ β-
		Sc40 182.3 ms 4- ECp, ECα, ...	Sc41 596.3 ms 7/2- EC	Sc42 681.3 ms 0+ EC	Sc43 3.891 h 7/2- EC	Sc44 3.927 h 2+ EC	Sc45 7/2- 100 EC	Sc46 83.79 d 4+ β-	Sc47 3.345 d 7/2- β-	Sc48 43.67 h 6+ β-	Sc49 57.2 m 7/2- β-	Sc50 102.5 s 5+ β-	Sc51 12.4 s (7/2-) β-
		Ca39 859.6 ms 3/2+ EC	Ca40 0+ EC	Ca41 1.03E+5 y 7/2- EC	Ca42 0+ 0.647 EC	Ca43 7/2- 0.135 EC	Ca44 0+ 2.086 EC	Ca45 163.8 d 7/2- β-	Ca46 0+ 0.004 EC	Ca47 4.536 d 7/2- β-	Ca48 6E+18 y 0+ β-, β- E167	Ca49 8.715 m 3/2- β-	Ca50 13.9 s 0+ β-
		K38 636 m 3/2+ EC	K39 3/2+ 93.2581 EC, β-	K40 1.277E+9 y 4- EC, β- 0.0117	K41 3/2+ 6.7302 EC	K42 12.360 h 2- β-	K43 22.3 h 3/2+ β-	K44 22.13 m 2- β-	K45 17.3 m 3/2+ β-	K46 105 s (2-) β-	K47 17.5 s 1/2+ β-	K48 6.8 s (2-) β _n	K49 1.26 s (1/2+, 3/2+) β _n



neutron number

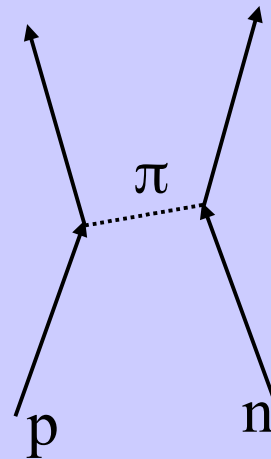


stable
β⁺/EC
β⁻ dec
α dec
p e
f



O que mantém o núcleo unido?

- Troca de mésons (Yukawa 1935).



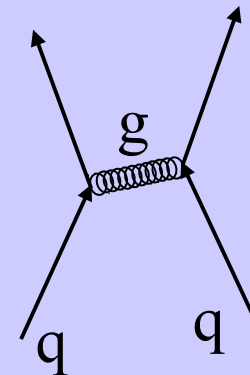
$$\Delta t \Delta E \approx \hbar$$

$$c \Delta t mc^2 \approx \hbar c$$

$$\Delta R \approx c \Delta t \approx \frac{\hbar c}{mc^2} = \frac{\hbar}{mc}$$

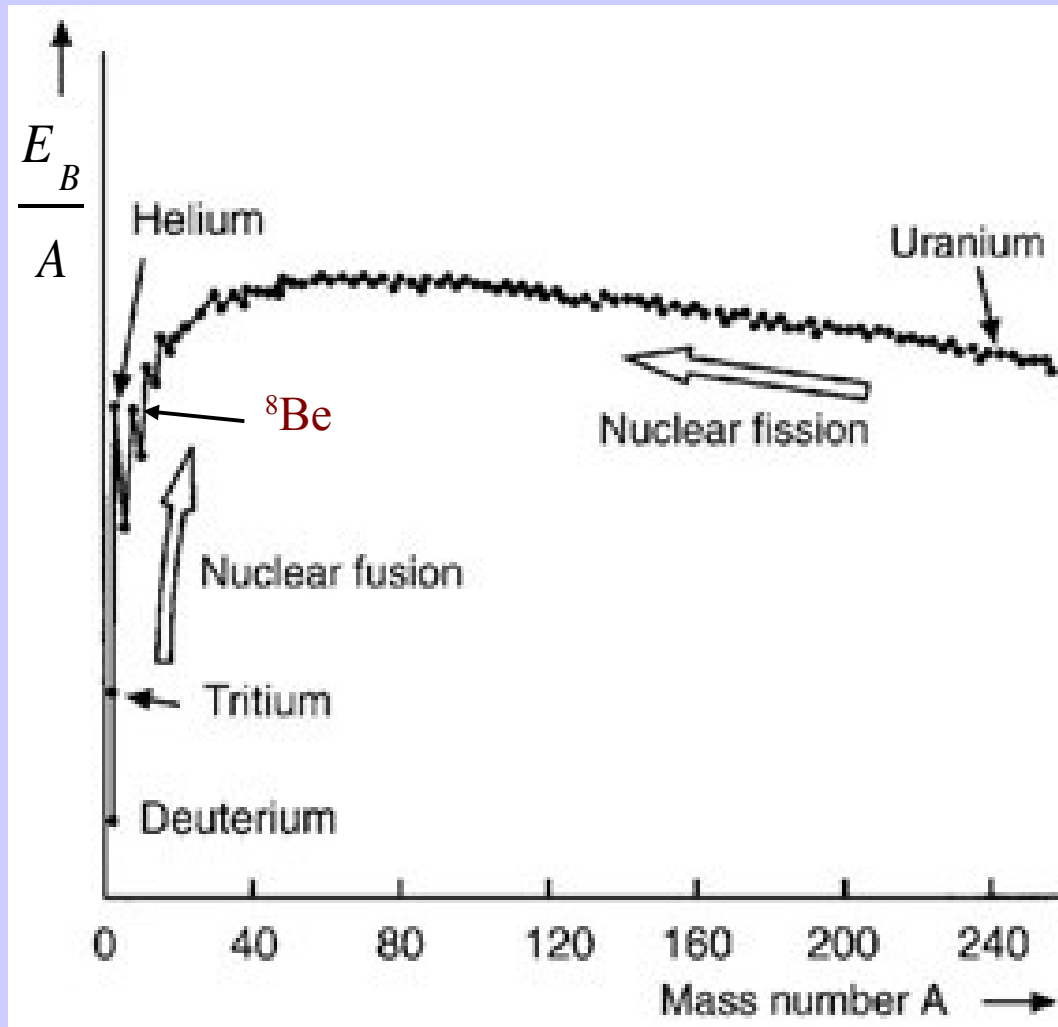
$$\hbar c \approx 200 \text{ MeV}\cdot\text{fm}$$

- QCD, Gluons, Quarks
(Gell-Mann, Nishijima 1961...)



Saturação da força nuclear :

Energia de ligação: $E_B(N, Z) = (ZM_H + NM_N - M(Z, N))c^2$



Raio Nuclear:

$$R_A = 1.2A^{1/3} \text{ fm}$$

Ex: Pb (208), $R=7.1$ fm

Descoberta do Píon (Lattes 1949), +partículas...

Mesons									
Particle	Symbol	Anti-particle	Makeup	Rest mass MeV/c ²	S	C	B	Lifetime	Decay Modes
Pion	π^+	π^-	$u\bar{d}$	139.6	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
Pion	π^0	Self	$u\bar{u}, d\bar{d}$	135.0	0	0	0	0.83×10^{-16}	2γ
Kaon	K^+	K^-	$u\bar{s}$	493.7	+1	0	0	1.24×10^{-8}	$\mu^+\nu_\mu, \pi^+\pi^0$
Kaon	K^0_s	K^0_s	1^*	497.7	+1	0	0	0.89×10^{-10}	$\pi^+\pi^-, 2\pi^0$
Kaon	K^0_L	K^0_L	1^*	497.7	+1	0	0	5.2×10^{-8}	$\pi^+e^-\nu_e$
Eta	η^0	Self	2^*	548.8	0	0	0	$<10^{-18}$	$2\gamma, 3\mu$
Eta prime	$\eta^{0'}$	Self	2^*	958	0	0	0	...	$\pi^+\pi^-\eta$
Rho	ρ^+	ρ^-	$u\bar{d}$	770	0	0	0	0.4×10^{-23}	$\pi^+\pi^0$
Rho	ρ^0	Self	$u\bar{u}, d\bar{d}$	770	0	0	0	0.4×10^{-23}	$\pi^+\pi^-$
Omega	ω^0	Self	$u\bar{u}, d\bar{d}$	782	0	0	0	0.8×10^{-22}	$\pi^+\pi^-\pi^0$
Phi	φ	Self	$s\bar{s}$	1020	0	0	0	20×10^{-23}	$K^+K^-, K^0\bar{K}^0$
D	D^+	D^-	$c\bar{d}$	1869.4	0	+1	0	10.6×10^{-13}	$K^+ _ , e^+ _$
D	D^0	\bar{D}^0	$c\bar{u}$	1864.6	0	+1	0	4.2×10^{-13}	$[K, \mu, e]^+ _$
D	D^+_s	D^-_s	$c\bar{s}$	1969	+1	+1	0	4.7×10^{-13}	$K^+ _$
J/Psi	J/ψ	Self	$c\bar{c}$	3096.9	0	0	0	0.8×10^{-20}	$e^+e^-, \mu^+\mu^- \dots$
B	B^-	B^+	$b\bar{u}$	5279	0	0	-1	1.5×10^{-12}	$D^0 _$
B	B^0	\bar{B}^0	$d\bar{b}$	5279	0	0	-1	1.5×10^{-12}	$D^0 _$
B_s	B^0_s	\bar{B}^0_s	$s\bar{b}$	5370	0	0	-1	...	$B^-_s _$
Upsilon	Υ	Self	$b\bar{b}$	9460.4	0	0	0	1.3×10^{-20}	$e^+e^-, \mu^+\mu^- \dots$

+partículas...

Baryons								
Particle	Symbol	Makeup	Rest mass MeV/c ²	Spin	B	S	Lifetime (seconds>	Decay Modes
Proton	p	uud	938.3	1/2	+1	0	Stable	...
Neutron	n	ddu	939.6	1/2	+1	0	920	p e ⁻ ν _e
Lambda	Λ ⁰	uds	1115.6	1/2	+1	-1	2.6x10 ⁻¹⁰	pπ ⁻ , nπ ⁰
Sigma	Σ ⁺	uus	1189.4	1/2	+1	-1	0.8x10 ⁻¹⁰	pπ ⁰ , nπ ⁺
Sigma	Σ ⁰	uds	1192.5	1/2	+1	-1	6x10 ⁻²⁰	Λ ⁰ γ
Sigma	Σ ⁻	dds	1197.3	1/2	+1	-1	1.5x10 ⁻¹⁰	nπ ⁻
Delta	Δ ⁺⁺	uuu	1232	3/2	+1	0	0.6x10 ⁻²³	pπ ⁺
Delta	Δ ⁺	uud	1232	3/2	+1	0	0.6x10 ⁻²³	pπ ⁰
Delta	Δ ⁰	udd	1232	3/2	+1	0	0.6x10 ⁻²³	nπ ⁰
Delta	Δ ⁻	ddd	1232	3/2	+1	0	0.6x10 ⁻²³	nπ ⁻
Xi Cascade	Ξ ⁰	uss	1315	1/2	+1	-2	2.9x10 ⁻¹⁰	Λ ⁰ π ⁰
Xi Cascade	Ξ ⁻	dss	1321	1/2	+1	-2	1.64x10 ⁻¹⁰	Λ ⁰ π ⁻
Omega	Ω ⁻	sss	1672	3/2	+1	-3	0.82x10 ⁻¹⁰	Ξ ⁰ π ⁻ , Λ ⁰ K ⁻
Lambda	Λ ⁺ _c	udc	2281	1/2	+1	0	2x10 ⁻¹³	...

Modelo Padrão

