PHY492: Nuclear & Particle Physics

Lecture 11

Exam 1

Elementary Particle Physics

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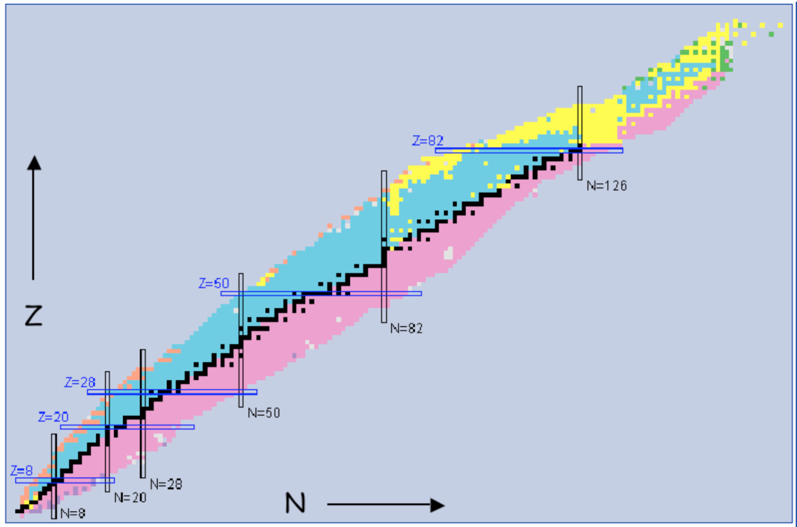


4) The numbers are the Magic #'s of the Shell model

a) Shell Model with a <u>L•S</u> term in the potential correctly predicts the magic #'s

b) Nuclei in black are the <u>stable nuclei</u>

c) Curvature downward indicates <u>large A nuclei have larger N than Z</u>

d) The SEMF predicts N>Z at large A, because <u>protons are on average further apart</u> leading to a <u>weaker Coulomb repulsion</u>, <u>stronger binding</u>, and <u>lower mass</u>.

5) Decay reactions of the blue, pink and yellow colors

blue: +β decay

$$ {}^{A}X^{Z} \rightarrow {}^{A}Y^{Z-1} + e^{+} + \nu_{e} $$

pink: −β decay

$$ {}^{A}X^{Z} \rightarrow {}^{A}Y^{Z+1} + e^{-} + \bar{\nu}_{e} $$

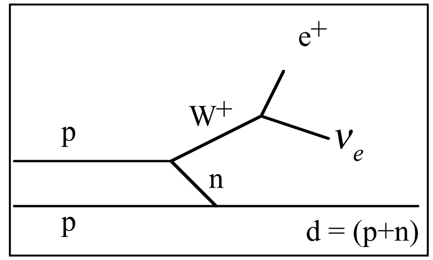
yellow: α decay

$$ {}^{A}X^{Z} \rightarrow {}^{A-4}Y^{Z-2} + {}^{4}\mathrm{He}^{2} $$

Exam 1

6) Weak reaction in the sun before hydrogen fusion can proceed

$$pp \rightarrow np + e^{+} + \upsilon_e$$



8) SEMF: $Mc^2 = a_0 - a_1 A + a_2 A^{\frac{2}{3}} + a_3 Z^2 A^{-\frac{1}{3}} + a_4 \left(N - Z\right)^2 A^{-1} \pm a_5 A^{-\frac{3}{4}}$

a) + sign for odd N, odd Z, (2 unpaired nucleons lead to weakest binding)

b) - sign for even N, even Z, (pairing leads to strongest binding)

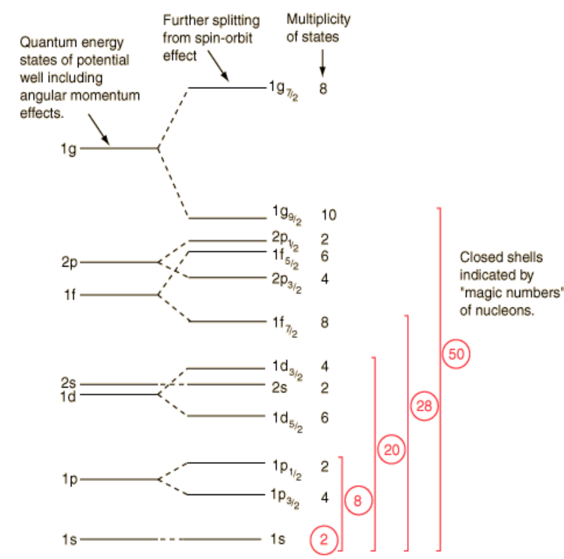
c) 0 for even N, odd Z or odd N, even Z (partial pairing average binding)

9) ^{14}O, ^{16}O, ^{18}O, (all even-even nuclei are $J^p = 0^+$)

^{15}O, $1p_1, J^P = \frac{1}{2}^-$ (p-states have ℓ=1, and P = –)

^{17}O, $1d_{5/2}, J^P = \frac{5}{2}^+$ (d-states have ℓ=2, and P = +)

^{19}O, $1d_{5/2}, J^P = \frac{5}{2}^+$ (d-states have ℓ=2, and P = +)



Leptonic (point-like) particles of the Standard Model

- Lepton "flavors" ($s = 1/2$)
  - Electric $Q = -e$
    - Flavor states
      - e^-, electron, mass = 0.511 MeV/c^2
      - μ^-, muon, mass = 105 MeV/c^2
      - τ^-, tau, mass = 1.77 GeV/c^2
  - Electric $Q = 0$ ($s = 1/2$, left-handed)
    - Flavor states
      - ν_e, electron neutrino
      - ν_μ, muon neutrino
      - ν_τ, tau neutrino
    - Mass states
      - ν_1, ν_2, ν_3

      ($m < 0.2$ eV/c^2)
- Anti-Lepton "flavors" ($s = 1/2$)
  - Electric $Q = +e$
    - Flavor states
      - e^+, positron (e-plus)
      - μ^+, mu-plus
      - τ^+, tau-plus
  - Electric $Q = 0$ (right-handed)
    - Flavor states
      - anti-ν_e, anti-electron neutrino
      - anti-ν_μ, anti-muon neutrino
      - anti-ν_τ, tau neutrino
    - Mass states
      - anti-ν_1, anti-ν_2, anti-ν_3
- Also written as

$$e^+,\ \mu^+,\ \tau^+$$

$$\bar{\nu}_e,\ \bar{\nu}_\mu,\ \bar{\nu}_\tau$$

Quarks (point-like), hadronic particles of the Standard Model

- Quark "flavors" (spin = 1/2)
  - Electric charge Q = +2/3e
    - *u*, up, mass ~ 3 MeV/c^2
    - *c*, charm, mass ~ 1.2 GeV /c^2
    - *t*, top, mass ~ 175 GeV /c^2
  - Electric charge Q = –1/3e
    - *d*, down, mass ~ 7 MeV/c^2
    - *s*, strange, mass ~ 120 MeV/c^2
    - *b*, bottom, mass ~ 4.2 GeV/c^2

- Anti-Quark "flavors" (spin = 1/2)
  - Electric charge Q = –2/3e
    - *u-bar*, anti-up
    - *c-bar*, anti-charm
    - *t-bar*, anti-top
  - Electric charge Q = +1/3e
    - *d-bar*, anti-down
    - *s-bar*, anti-strange
    - *b-bar*, anti-top
- Also written as

$$\bar{u},\ \bar{c},\ \bar{t}$$

$$\bar{d}\ ,\ \bar{s},\ \bar{b}$$

Long-lived hadronic composites: Baryons

	Quark flavors					Anti-Quark flavors	
$Q=+2/3$	u	c	t	$Q=-2/3$	$\bar{u}$	$\bar{c}$	$\bar{t}$
$Q=-1/3$	d	s	b	$Q=+1/3$	$\bar{d}$	$\bar{s}$	$\bar{b}$

- Hadrons (colorless quark combinations)
  - Baryons: three quarks, each with a QCD color (Q = –1 to +2e, spin = 1/2, 3/2)

light quarks u,d: $\text{p}\,(uud)$ $\text{n}\,(udd)$ s = 1/2

: $\Delta^{++}(uuu)$ $\Delta^{+}(uud)$ $\Delta^{0}(udd)$ $\Delta^{-}(ddd)$ s = 3/2

s: $\Omega^{-}(sss)$ s = 3/2

$\Xi^{0}(uss)$ $\Xi^{-}(dss)$

$\Sigma^{+}(uus)$ $\Sigma^{0},\Lambda^{0}(uds)$ $\Sigma^{-}(dds)$

heavy quarks c,b: $\Omega_c^{0}(ssc)$ no u,d

$\Xi_c^{+}(usc)$ $\Xi_c^{0}(dsc)$ 1 u,d

$\Sigma_c^{++}(uuc)$ $\Sigma_c^{+},\Lambda_c^{+}(udc)$ $\Sigma_c^{0}(ddc)$ 2 u,d

similarly with b quark

NO top baryons
Top quark is too short lived

Long-lived hadronic composites: Mesons

	Quark flavors		
$Q = +2/3$	u	c	t
$Q = -1/3$	d	s	b

	Anti-Quark flavors		
$Q = -2/3$	$\bar{u}$	$\bar{c}$	$\bar{t}$
$Q = +1/3$	$\bar{d}$	$\bar{s}$	$\bar{b}$

- Mesons: one quark, one anti-quark, color/anti-color (Q = –1 to +1e, integer spin)

light quarks u,d,s: $K^+(u\bar{s})$ $K^0\ (d\bar{s})$

s = 0 $\pi^+(u\bar{d})$ $\pi^0(\frac{u\bar{u}-d\bar{d}}{\sqrt{2}})$ $\pi^-(d\bar{u})$ $\eta^0,\omega^0,\phi^0 \ldots c_1\left(\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}\right)+c_2(s\bar{s})$

$\bar{K}^0(s\bar{d})$ $K^-\ (s\bar{u})$ short hand for $\frac{1}{\sqrt{2}}(|u\bar{u}\rangle + |d\bar{d}\rangle)$

s = 1 $\rho^+\rho^0\rho^-,\ K^{*+},K^{*0},\bar{K}^{*0},K^{*-}$

heavy quarks c,b: $D^+(\bar{d}c)$ $D^0\ (\bar{u}c)$ $D_S^+(c\bar{s})$ $D_S^-\ (\bar{c}s)$

$\bar{D}^0(u\bar{c})$ $D^-\ (d\bar{c})$

$B^+(u\bar{b})$ $B^0(d\bar{b})$ $\bar{B}_S^0(b\bar{s})$ $B_S^0\ (\bar{b}s)$

$B^-(\bar{u}b)$ $\bar{B}^0(\bar{d}b)$

NO top mesons
Top quark is too short lived

"Stability" in elementary particle physics

- Hadronic particle lifetimes
  - Weak decay ~10^{-10} s

e.g. $\Lambda^0 \to p + \pi^-$ $\quad \pi^+ \to \mu^+ + \nu_\mu$

  - Electromagnetic decay ~10^{-16} s

e.g. $\pi^0 \to \gamma + \gamma$ $\quad \Sigma^0 \to \Lambda^0 + \gamma$

  - Strong decay ~10^{-23} s

e.g. $\Delta^{++} \to p + \pi^+$ $\quad K^{*+} \to K^+ + \pi^0$