Electron scattering experiments: Electron beam is directed at target containing nuclei. Electrons interact with the nuclei and their trajectory is changed

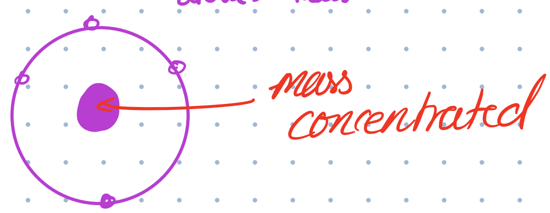
Radius of atom: e^- - beam at nucleus and outgoing e^- - angles are measured, those are used to calculate radius of nucleus $\sin\theta = \frac{1{,}22\lambda}{d}$

Hadron scattering experiment: Hadrons: mesons + baryons, alpha-particles: interact with protons and neutrons of the target nucleus

→ alpha-beam at nucleus and outgoing alphas measured

→ Rutherford's gold foil experiment:

- most α travel through it → atom is mostly empty space
- some are deflected by small angles → nucleus has positive charges that deflect α (which is also positive)
- occasionally an α travels back → nucleus carries most of atom's mass



At low energies: α interact w/ nucleus only via Coulomb int.

At high energies: Coulomb force is overcome α-particles absorbed and we get diffraction pattern again

Conclusion: there exists a nucleus that holds most of the atom's mass

Nuclear charge distribution:

- $\acute{e}$-scattering experiments probed charge distribution
- charge of nucleus given by protons
- From experiments:
  - radius increases with A
  - charge density is nearly same for all nuclei
  - constant distribution of nucleons out to the surface of nucleus

- number of nucleons per unit volume is roughly constant

↳ we can calculate radius from it:

$$R = R_0 A^{1/3}$$

Nuclear matter distribution:

- probed by Hadron scattering
- Radius calculated from diffraction pattern and scattering angles is characteristic of the nuclear force, not Coulomb force. Radius then reflects distribution of nucleons in the nucleus

Conclusion charge + matter distribution:

→ they are nearly equal

→ $A^{1/3}$ dependence

Heavy nuclei: more neutrons than protons, so expect larger neutron radius (= larger matter radius)

→ proton repulsion pushes protons outward and n-p-force pulls neutrons in so radii are equal

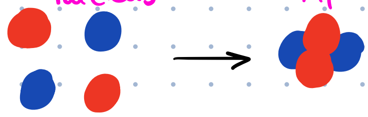
Nuclear radius:

- average radius calculated by $R = R_0 A^{1/3}$
- Radius increases with mass number A
- Nucleus doesn't have sharp boundary (defined radius)

Binding energy

energy required to keep protons + neutrons together inside the nucleus

$M_{nucleus}$ $\quad\quad$ $Zm_p + Nm_n$ $\quad\quad$ Δm



+ mass excess

mass of nucleus is not equal to sum of the mass of its nucleons

Mass excess: $\Delta m = Zm_p + Nm_n - M_{nucleus}$

Einstein: transform mass excess to binding energy

$\hookrightarrow \Delta m \rightarrow \Delta m c^2$ (MeV)

$\Rightarrow$ measure of how tightly nucleons are bonded to each other

Large B.E. $\rightarrow$ lot of energy required to seperate the nucleons

mass of atom: $M_{atom} = M_{nucleus} + Zm_e \underbrace{- \sum_{i=1}^{Z} B_i / c^2}_{=0}$

$$M({}^A_Z X_N) = M_{nucleus}({}^A_Z X_N) + Zm_e$$

$$M_{nucleus}({}^A_Z X_N) = M({}^A_Z X_N) - Zm_e \quad | \cdot c^2$$

$$M_{nucleus} \cdot c^2 = (M({}^A_Z X_N) - Zm_e) \cdot c^2$$

Deriving B.E. $\quad B.E. = (Zm_p + Nm_n - M_N({}^A_Z X_N)) \cdot c^2$

$$= (Z\underbrace{(m_p + m_e)}_{= m({}^1H)} + Nm_n - M({}^A_Z X_N))\, c^2$$

$c^2 = 931{,}5$ MeV/u

Binding energy is very small compared to rest mass energy of the nucleus $\frac{B.E.}{M(^4He)c^2} = 0{,}75\%$

Average binding energy: B/A, increases linearly with A

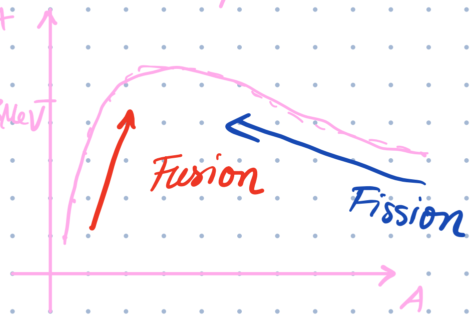
↳ B.E. per nucleon

Energy released, because higher B/A means less weight (tighter bound)

$Q = (M_i - M_f)c^2$

$Q > 0$ if $M_i > M_f$

↳ exotherm



Nucleon separation energy

S_n & S_p

one separation energy (S_n) is energy needed to remove a neutron from a nucleus $^A_Z X_N$

$$^A_Z X_N \rightarrow {}^{A-1}_{Z} X_{N-1} + n$$

$$S_n = \left(M({}^{A-1}_{Z}X_{N-1}) - M({}^A_Z X_N) + m_n\right)c^2$$
$$= B({}^A_Z X_N) - B({}^{A-1}_{Z} X_{N-1})$$

- it is easier to remove a neutron from nucleus with odd number of neutrons
  ↳ last unpaired neutron easy to remove
- Pairing → more stable nucleus

S_p: —— " —— to remove a proton from nucleus

$$^A_Z X_N \rightarrow {}^{A-1}_{Z-1} X_N + p$$

– S_n and S_p show evidence of shell structure in nuclei

Liquid drop model

a model that describes the nucleus of an atom as a liquid, held together by the nuclear force
- high, constant density
- classical physics

SEMF

consists of 5 terms, based on liquid drop model
based on both theory and experimental data

Liquid drop model | shell-model

$$B.E. = \boxed{\underbrace{a_V A}_{\text{volume}} \underbrace{- a_S A^{2/3}}_{\text{surface}} \underbrace{- a_C Z(Z-1) A^{-1/3}}_{\text{Coulomb}} - a_{sym} \frac{(A-2Z)^2}{A} + \delta}$$

Volume:
- dominates B.E.
- linear
- $a_V = 16$ MeV
- energy ~ volume: nucleons packed together into smallest volume in contact w/ each other

Surface:
- at the surface nucleons are surrounded by fewer nucleons = less attraction/ tightly bound
- subtract from volume term
- $a_S = 16{,}8$ MeV

Coulomb:
Coulomb repulsion of protons, makes nucleus less tightly bound
⇒ long range, proportional to Z^2
$a_C = 0{,}72$ MeV

Symmetry:
light nuclei have equal no. of protons + neutrons, deviation from this makes nucleus less bound
- Pauli principle: ???
- $a_{sym} = 23$ MeV
- small for heavy nuclei

- linearity of B and A:

if long range nuclear force: $B \sim A^2$ every nucleon would attract the others
since $B \sim A$: means each nucleon attracts only its closest neighbors

Pairing:
like nucleons couple pairwise to give spin zero
- closer together than when coupled differently ⇒ tighter bound

$a_p = 34$ MeV

even-even: more bound $\delta = +a_p A^{-3/4}$

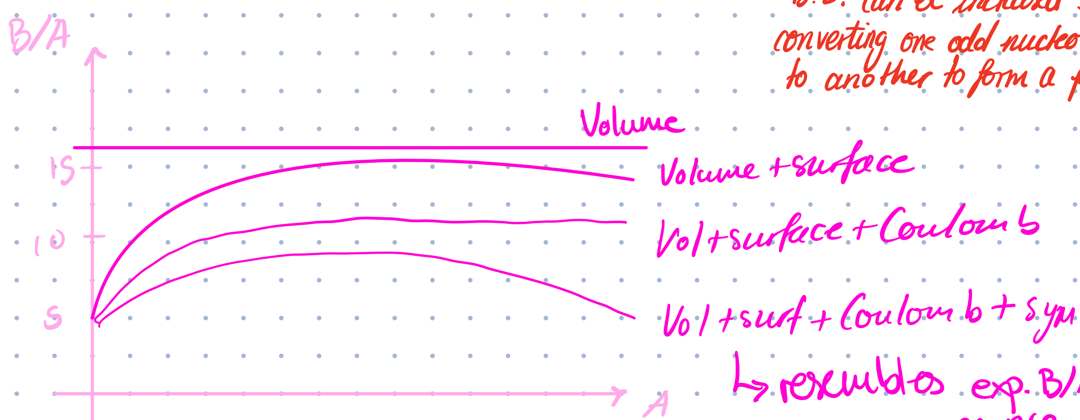
odd A: $\delta = 0$

odd-odd: $\delta = -a_p A^{-3/4}$

B.E. can be increased by converting one odd nucleon to another to form a pair

$$a_V A - a_S A^{2/3} - a_C Z(Z-1) A^{-1/3}$$

$$- a_{sym} \frac{(A-2Z)^2}{A}$$



↳ resembles exp. B/A curve

SEMF FOR MASSES: 1. B.E. of nucleus:

$$B.E. = \left[Zm(H) + Nm_n - M({}^A_Z X_N)\right]c^2$$

2. SEMF included:

$$M({}^A_Z X_N) = Zm(H) + Nm_n - B.E(SEMF)/c^2$$

Chart of nuclides

stability line: stable nuclei that follows the $N=Z$ line until higher N, where it curves down

nuclear drip line: boundary at which adding a new proton or neutron to a nucleus will lead to it being unbound or just forming a new nucleus

Mass parabolas

also called "Beta Valley"

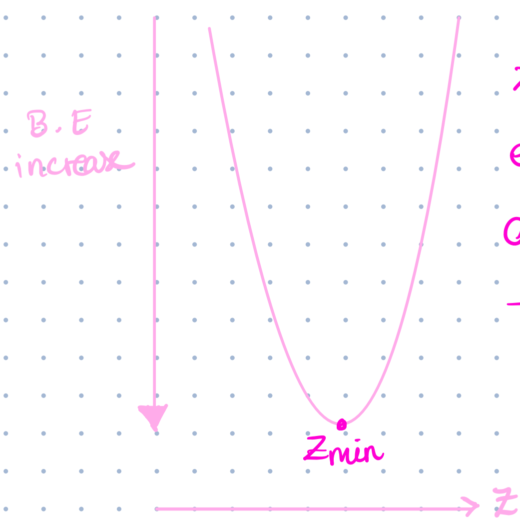
The mass eq.: $M(A,Z) = Zm(H) + (A-Z)m_n - \frac{B(A,Z)}{c^2}$

↳ has the form of a parabola of M vs. Z

Minimum at $\frac{\partial M}{\partial Z} = 0$, obtain Z_{min}

For light nuclei: $\frac{Z_{min}}{A} = 1/2 \Rightarrow$ so $N=Z$

for heavy nuclei: $\frac{Z_{min}}{A} = 0{,}4 \rightarrow$ neutron excess

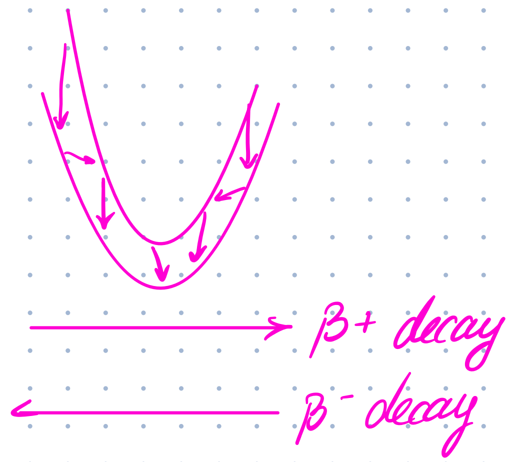


Z_{min} = most tightly bound nucleus

everything else is unstable and decays towards Z_{min}

→ beta decay

For odd-odd and even-even, we get double parabola
↳ PAIRING TERM δ ⇒ double beta decay



Nuclear force the force acting between the protons and neutrons in the atom, binds them together

Properties: 1. strongly attractive at short range
→ stronger than Coulomb at short range
Evidence: α - scattering

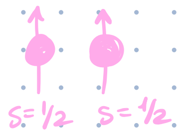
2. negligible at long distances
→ nuclei in molecules don't interact by nuc. force
Evidence: linear dependence of B on A
long range would mean $B \sim A^2$

3. electrons don't feel it
Evidence: e^- further away from nucleus than range of force

4. Charge independent
→ nearly independent whether its protons or neutrons
→ pp, nn, pn interactions are equal
Evidence: mirror nuclei have same excited states
ex. ${}^{11}_{5}B_6$ & ${}^{11}_{6}C_5$

OBS: still have different B.E.

5. dependence on parallel and antiparallel spin
→ stronger for aligned pairs



6. includes a repulsive term, that keeps nucleons at certain distance

7. has a noncentral/tensor component that doesn't conserve orbital ang. momentum → spin-dependent
non-spherical shape

Deuteron

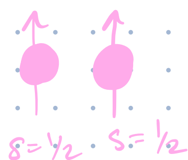
- bound state of 1 N and 1 Z
- no excited states
- low B.E., weakly bound

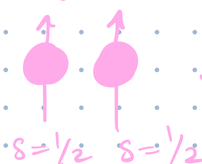
Spin & Parity

$I = s_n + s_p + l = \underline{1}$ and Parity $= \underline{+1}$

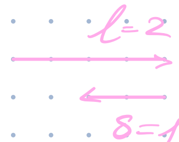
two allowed spin alignments that give $I = 1$:

$l = 0$
$S = 1$





$l = 2$
$S = 1$



$$\pi = (-1)^l = (-1)^0 = (-1)^2 = \underline{\underline{+1}}$$

Magnetic moment

$\mu = \mu_n + \mu_p$

for $l=0$, $\mu_l = 0$
$\mu_s \neq 0$
$\mu_s = g_s \mu_N \cdot s$

calculated μ_N deviates from experimental value, assume that there is a mixture of $l=2$ state in the deuteron wavefunction

$$\psi = a_s \psi(l=0) + a_d \psi(l=2)$$

$a_S^2 = 0{,}96 \qquad a_d^2 = 0{,}04$

The deuteron is 96% $\ell=0$ and 4% $\ell=2$

Electric quadrupole moment

reflects shape of charge distribution
- deviates from sphere
- $\ell=2$ introduc non-spherical shape

Conclusions

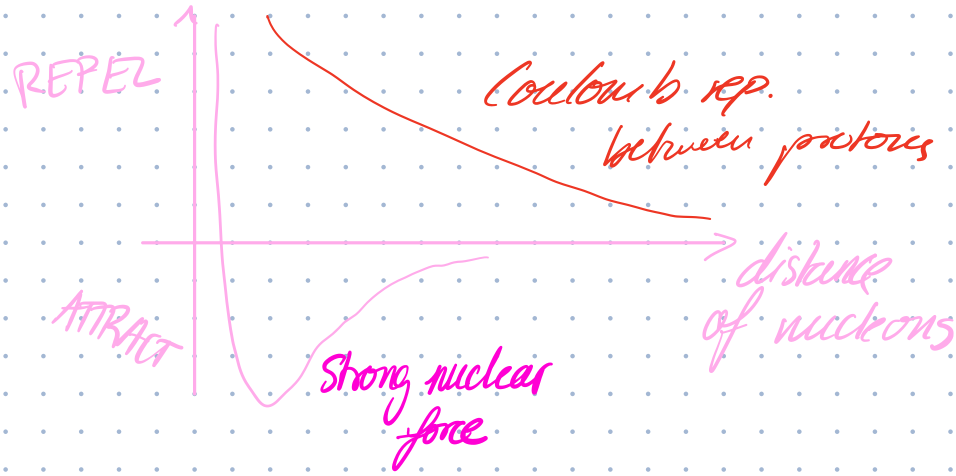
- the mixture of $\ell=0$ and $\ell=2$ gives the 1^+ ground state (Spin $I=1$ and Parity $=+1$)
- the mix indicates that there is another non-central component causing the mixing of two states
  ↳ Tensor interaction
- $S=1$ triplet state increases the binding, $S=0$ singlet state decreases binding

- $S=0$ only allowed for pp or nn interactions (antiparallel due to Pauli)

Range of the nuclear force

Range (1-2) fm

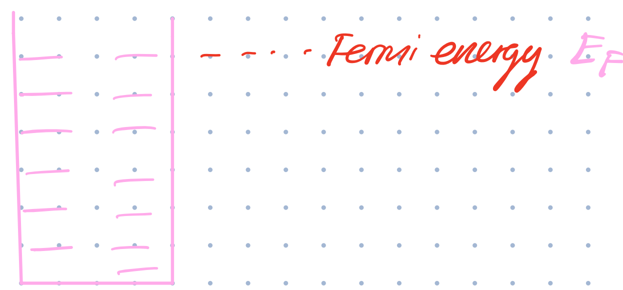
exchange particle: Pions?



Fermi gas model

model of an ensemble of many non-interacting fermions that obey Fermi-Dirac statistics → identical fermions can't merge (no overlap)

→ Potential well of p + n, obey Pauli



Shell model

– inspo: shell structure of atom
nuclei with magic numbers have greater stability

evidence: 1. S_p and S_n separation energies experience sudden drop after p/n number passes magic number by one n/p ???

2. higher B.E. for magic nuclei

3. first excited state lies higher (MeV) in nuclei with magic numbers
$\Rightarrow$ more E required to excite them

4. smaller electric quadrupole moments
↳ less spherical = tighter bound

- non-int particles in spherically symmetric potential $U(r)$

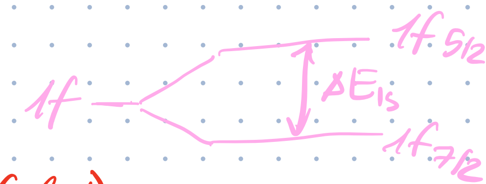
- want shell model to predict magic numbers

- spin-orbit removes degeneracy and obtains the correct magic numbers ???

↳ coupling of $l + s$: $\quad j = l + s$

$$\begin{cases} l + \frac{1}{2} \text{ and} \\ l - \frac{1}{2} \end{cases}$$

splitting between them: $\Delta E_{ls} = \frac{2l+1}{2} \hbar^2 \langle V_{ls} \rangle$



$N = 2(2l+1)$
$= 14$

$N = 2j + 1 = 2(l \pm \frac{1}{2}) + 1$
$= 8$ and 6

How to use: 1. fill n and p's into the shell orbits
2. Check level of last unpaired nucleon

$n l_j$

ex. $1d_{5/2}$ $\Rightarrow$ I^{π}

n l j

parity π

spin I

ex! $^{15}_{8}O_7$: last unpaired neutron N is in $1p_{1/2}$ $\rightarrow n=1$, $l=p$, $j=1/2$
$l=1$

$^{17}_{8}O_9$ → last n in $1d_{5/2}$

$n=1$, $l=d=2$, $j=5/2$

$J=L+S \Rightarrow S=J-L=5/2-2=\underline{\underline{1/2}}$

$\pi=(-1)^L=(-1)^2=\underline{+1}$

$\pi^L_{gs}=\underline{\underline{1/2^+}}$

$J=L+S$

$S=J-L$

$=1/2-1=\ominus 1/2$???

$\pi=(-1)^L=(-1)^1=\underline{\underline{-1}}$

$\underset{\text{ground state}}{I^{\pi}}=1/2^-$

Degeneracy of each level: $2j+1$

odd-A: I = half-int. ex. $1/2$ ...

odd-odd: one unpaired n and one unpaired p → couple up

$|j_p-j_n|\leq I\leq|j_p+j_n|$, Parity $=(-1)^{l_p}(-1)^{l_n}$

even-A: I = integral, Parity = always positive

even-even: $I=\underline{\underline{0}}$ Ground state: 0^+

<u>Magnetic moment</u> → all nucleon pairs result in zero magnetic moment

→ magnetic moment value comes from unpaired nucleon

<u>Electric moment</u> → paired nucleons ⇒ zero Quadrupole mom.

→ neutrons ⇒ 0 quad. mom.

→ valence neutron orbiting around core will cause deformation (core polarisation)
→ SM does not consider this

Radioactive decay

process where unstable nucleus loses energy by radiation

main decays: α, β, γ, e^--capture

↳ spontaneous: $Q = (M_i - M_f)c^2 > 0$

energy released in decay

Decay: statistical, we can't know when, only how probable

- in time period t: $\frac{dN}{dt} = -\lambda N$

decay constant

no. of present nuclei

- remaining unstable nuclei at time t: $N(t) = N_0 e^{-\lambda t}$
- time at which intensity of radiation is half of original value:

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

- avg. time a nucleus is likely to survive before decay:

$$\tau = \frac{1}{\lambda}$$

- number of decays per unit time = activity

$$A = \frac{dN(t)}{dt} = \underbrace{-\lambda N_0}_{A_0} e^{-\lambda t}$$

unit: 1 Bq

Alpha decay

occurs in the heaviest nuclei

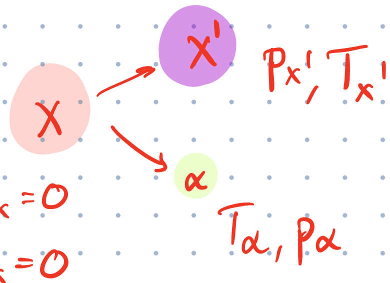
→ Coulomb force $\sim Z^2$, so for big Z the nucleus decays to get rid of their Z

→ α-particle is favorable

↳ ^4He tightly bound $\quad ^4He \rightarrow (Z=2, N=2)$

$$ {}^{A}_{Z}X_{N} \longrightarrow {}^{A-4}_{Z-2}X'_{N-2} + \alpha $$

Energy conservation:

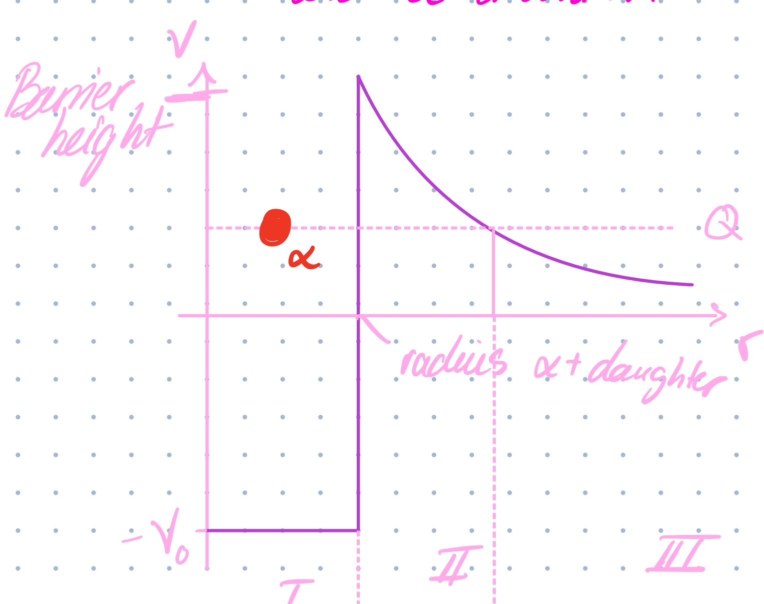


at rest $\begin{cases} P_x = 0 \\ T_x = 0 \end{cases}$

$$ m_x c^2 = m_{x'} c^2 + T_{x'} + m_\alpha c^2 + T_\alpha $$

$$ Q = T_{x'} + T_\alpha \qquad \boxed{P_\alpha = P_{x'}} $$

- most of Q decay energy goes to α-particle: $Q \approx T_\alpha$
- higher Q → smaller $t_{1/2}$ of α
- $t_{1/2}$ shorter for even-even than other combos
- for more stable nuclei → reduced Q-energy and therefore larger $t_{1/2}$
- near magic numbers: large shell gaps, less α emission

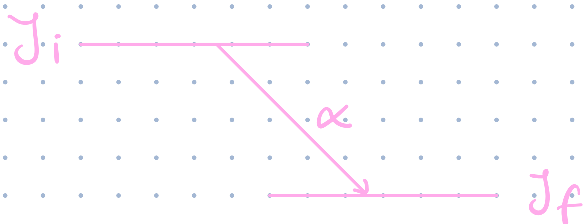


classical mech. $\begin{cases} \text{I.} & \alpha \text{ inside well with } T_\alpha = Q + V_0 \text{, cannot escape} \\ \text{II.} & \alpha \text{ cannot enter here since } V(r) > Q \\ \text{III.} & \alpha \text{ can exist here since } Q > V(r) \end{cases}$

Quantum mech: α tries to penetrate barrier, eventually escapes
barrier delays the α's emission $\rightarrow$ long $t_{1/2}$

Spin & parity selection rules

total ang. momentum is purely orbital in α decay
$\underbrace{\text{orbital}}_{l_\alpha}$



$|J_i - J_f| \leq L \leq J_i + J_f$

Parity: $\pi = (-1)^{l_\alpha}$

Parity sel. rule: $\pi = (-1)^{l_\alpha}$ must be conserved

even $l_\alpha \rightarrow (+)$ parity

odd $l_\alpha \rightarrow (-)$ parity

Decay probability of α decay dependent on:

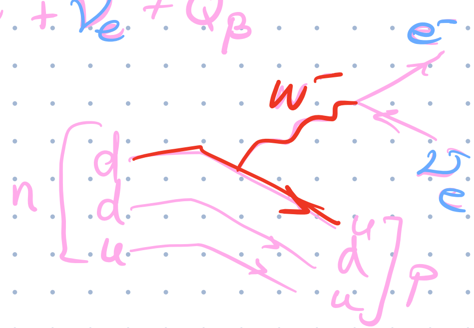
1. high Q_{ex}
2. low J total spin

so low l_α, high Q_{ex} is more probable

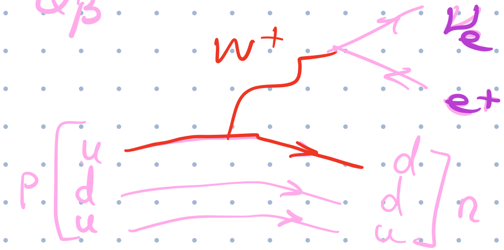
Beta decay

atomic nucleus emits beta particle, — β^+ or β^-
conversion of protons and neutrons

β^--decay: $\quad n \to p + e^- + \bar{\nu}_e + Q_\beta$



β^+-decay: $\quad p \to n + e^+ + \nu_e + Q_\beta$



$\Longrightarrow$ in β-decay the e^-/e^+ and $\bar{\nu}_e/\nu_e$ do not initially exist, they are created from decay energy Q_β

$\Longrightarrow$ A remains unchanged

$n \xrightarrow{\beta^-} p$: $\quad {}^{A}_{Z}X_N \longrightarrow {}^{A}_{Z+1}X'_{N-1} + e^- + \bar{\nu}$

$\Longrightarrow$ A is constant

$p \xrightarrow{\beta^+} n$: $\quad {}^{A}_{Z}X_N \longrightarrow {}^{A}_{Z-1}X'_{N+1} + e^+ + \nu$

electron capture ε: $\quad p + e^- \to n + \nu_e + Q_\varepsilon$

proton captures an orbital e^- and turns into a neutron

$$Q_\varepsilon \approx T_\nu$$

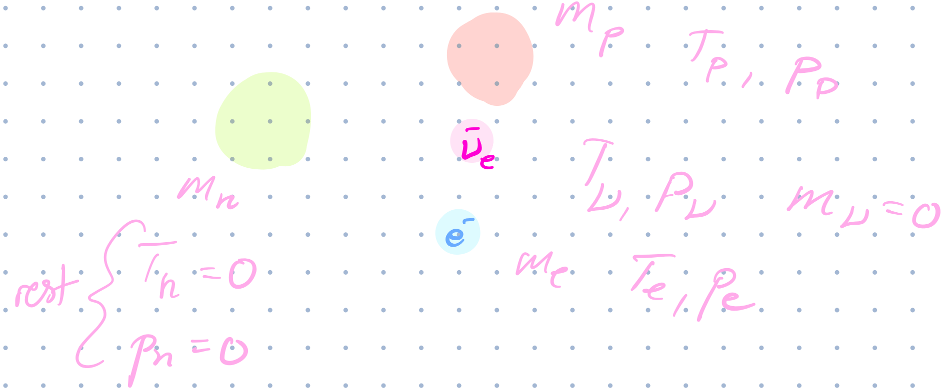
why doesn't a free proton decay?

↳ is the lightest baryon (least energetic)

→ is stable

Energetics: Q is shared between e^- and $\bar{\nu}_e$

$$Q = T_e + T_\nu + T_p \approx T_e + T_\nu$$



$$M_{atom} c^2 = M_{nucleus} c^2 + Z \cdot m_e c^2 - \sum_{i=1}^{Z} B_i$$

$$Q_{\beta^-} = \left[m_{Nuc}(X) - m_{Nuc}(X') - m_e \right] c^2$$

$$Q_{\beta^-} = \left[m(X) - m(X') \right] c^2$$

$$= T_e + E_{\bar{\nu}}$$

$e^- + \nu_e$ require relativistic kinematics!

$$m_\nu = 0 \, , \; E_\nu = T_\nu$$

$$E_e = T_e + m_e c^2$$

???

3-body: continuous energy spectrum of e^+ and ν_e

2-body: monoenergetic spectrum of ν

nucleus can undergo both β^+ and e^--capture if β^+-decay is energetically possible

for β^+ to spontaneously happen:

$$Q_{\beta^+} \geq 2 m_e c^2$$

large Q → short $t_{1/2}$ → greater prob.

Theory: Fermi's Golden rule:

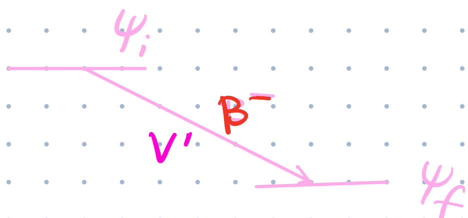
decay prob. dependent on: - matrix element (strength of int)
- density of final states
- overlap of initial + final state wavefunctions

Matrix element

$$\lambda = \frac{2\pi}{\hbar} |V_{fi}|^2 \rho(E_f)$$

density of final states

→ Beta decay caused by weak int.



V' is like a weak perturbation that causes the transition between states

Fermi-Kurie plot? ???

$$\lambda = f = \frac{\ln 2}{t_{1/2}}$$

comparable half-life $\quad ft_{1/2} = \ln 2 \, \frac{2\pi^3 \hbar^7}{g^2 m_e^5 c^4 |M_{fi}|^2}$

log ft ???

most allowed decay: $0^+ \to 0^+$ decay

↳ has smallest log ft value

shorter $t_{1/2} \Rightarrow$ more allowed

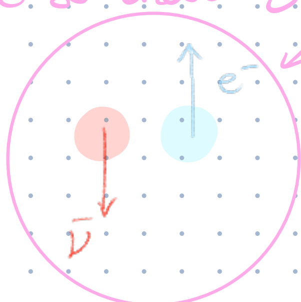
Spin + parity selection rules β-decay

$l=0$ for e^- and ν_e, only change in ang. mom. is by spin

$s=1/2$, singlet state so that $S=0$

Fermi decay (Superallowed decay)

$0^+ \to 0^+$



anti-parallel

must be 0 since $L=0$ and no change in S

$\Delta I = |I_i - I_f| = 0$

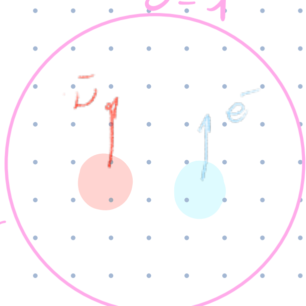
$\Delta J = |J_i - J_f| = 0$

$\pi_i \cdot \pi_f = +1$

$\Delta \pi = 0$

$S=1$

triplet state ???



Gamow-Teller decay

$0^+ \to 1^+$

$I_i = I_f + 1$ (total change of 1 in the ang. mom)

$\Delta I = 0, \pm 1 \qquad I=0 \not\to I=0$

$\pi_i \cdot \pi_f = +1 \quad (\Delta\pi = 0)$

$\Delta J = 0$ or 1 → $|J=1 - J=1|$, $|J=1 - J=0|$

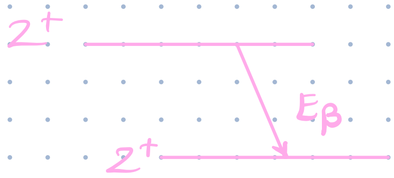
$J = L+S \qquad J = L+1 = 1$
$\qquad\qquad\qquad\quad = L+0 = 0$

selection rules:

$\Delta I = 0, 1 \qquad \Delta\pi = no$

???

what about $2^+ \rightarrow 2^+$?



$\Delta l = 0$

$J = L + S$
$J = S$

Forbidden decays = (less probable)

↳ when parity $\Delta\pi \neq 0$ (parity changes)

$\pi = (-1)^L$

→ e^- and $\bar{\nu}_e$ must be emitted with odd l-value

$L = 1, 3, 5 \ldots$
↳ first-forbidden

for $L = 1$ we have both F and GT decay:

F: $S = 0$

$J = L + S$
$= 1 + 0 = 1$

$\Delta I = 0$ or 1

GT: $S = 1$

$J = L + S = 1 + 1 = 2$

$\Delta I = 0, 1$ or 2

selection rules forbidden decays:

$\Delta I = 0, 1, 2 \qquad \Delta\pi = yes$

for $\Delta I \geq 2$ and $\Delta\pi = no$: second-forbidden for $\ell = 2$ we have $\Delta I = \underbrace{0, 1}_{\text{allowed}}, \underbrace{2, 3}_{\text{2nd forbidden}}$

selection rules second-forbidden decays:

$\Delta I = 2, 3 \qquad \Delta\pi = \text{no}$

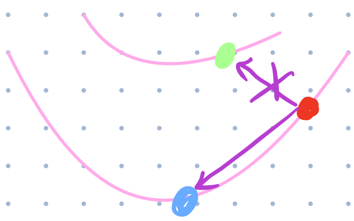
selection rules third-forbidden decays:

$\Delta I = 3, 4 \qquad \Delta\pi = \text{yes}$

$\ell = 3 \quad J = 3 + 0 \text{ or } 1$

$= \underbrace{0, 1, 2}_{\text{first-forbidden}}, \underbrace{3, 4}_{\text{3rd forbidden}}$

Double β-decay



red nucleus wants to decay to blue, but single β-decay (green) energetically forbidden

$$^{A}_{Z}X_{N} \rightarrow \,^{A}_{Z+2}X''_{N-2} + 2e^{-} + 2\bar{\nu}_e$$

Neutrino-less β-decay

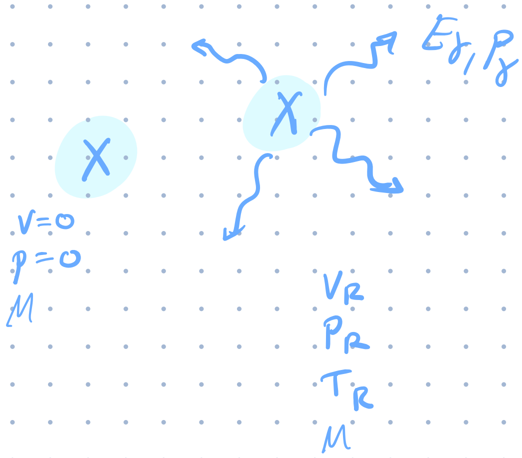
$$^{A}_{Z}X_{N} \rightarrow \,^{A}_{Z+2}X''_{N-2} + 2e^{-}$$

Gamma decay

– unstable atomic nuclei radiates e.m. energy (ex. photon) and nuclei remains unchanged
- emitted particle has no charge
- massless → do not carry away mass
- nucleus gets rid of its excitation energy

Energetics

$$E_i = E_f + E_\gamma + T_R$$



$$P_{for} = P_{after}$$

$$0 = P_R + P_\gamma$$

$$E_i - E_f = \Delta E = E_\gamma + T_R \approx E_\gamma$$

low energy γ-rays: $T_R \approx 0$

high energy γ-rays: bigger T_R, radiation damage in lattice

Cause of γ-rays

nucleus is distribution of oscillating charges

- create a radiation field → el. dipole field
  → magnetic dipole field

Dipole radiations:

- identical ang. distr. (E+M), $\sin^2\theta$ dependency
- E and M have opposite parity

E: $\pi = (-)$

M: $\pi = (+)$

- P = power (energy per time) radiated for el. + magn. multipole

- $\lambda = \frac{P}{\hbar\omega} \sim |m_{fi}|^2$

energy of photon

multipole op. responsible for changing nuc. state from ψ_i to ψ_f + creating photon

Electric transitions

Weisskopf estimate → e.m. transition is due to a single proton

- lower multipolarity dominate

Magnetic transitions

- lower multipolarity dominate

Compared

- medium heavy nucleus ($A=100$)
  ↳ el. multipoles more probable

Experimental data

- measured λ much smaller than Weisskopf estimate
  ↳ poor overlap of init. and final wavefunctions
    ↳ slows decay
- measured $\lambda \gg$ Weisskopf: more than one single nucleon responsible for the transition ⇒ collective excitations
- measured $\lambda \approx$ Weisskopf: transition caused by single nucleon excitation

Selection rules

→ γ-ray carries away π and L + energy E_γ

→ e.m. process: π and L conserved

$\Delta\pi = (-1)^3 (-1)^2 =$

$\Delta\pi = (-1)^{1+1} (-1)^1 = (-)$

yes

π: $\pi(ML) = (-1)^{L+1}$

$\pi(EL) = (-1)^L$

$\Delta\pi = \pi_i \cdot \pi_f$

$J_{init} = L + J_{final} \longrightarrow |J_i - J_f| \leq L \leq J_i + J_f \quad (L \neq 0)$

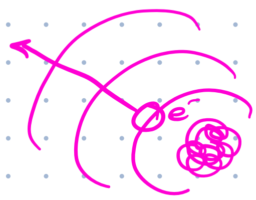
- lowest M and E (M1, E1) are dominant

- photons have non-zero l, so $L \neq 0$.

what carries π and L then? $(0^+ \to 0^+)$

↳ orbiting nearby e^-, nucleus gives energy to this e^-

⇒ Internal conversion



excitation energy transferred to e^- in nearby shell

- competes with γ-ray
- e^- already exists, not created like photon

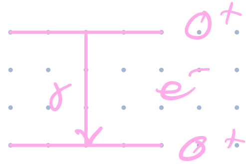
α int. conversion coefficient

↳ ratio between gamma ray transition prob. and conversion electron prob.

$$\alpha = \frac{\lambda_c}{\lambda_\gamma} \qquad \lambda_{tot} = \lambda_\gamma (1 + \alpha)$$

$0^+ \longrightarrow 0^+$ transition

internal conversion is only mode for this transition



high λ_c : medium-to-heavy nuclei, high L and low $E_{transition}$

Angular distributions

$\longrightarrow$ governed by Legendre polynomial