Sensorveiledning Fys 3500 eksamen
Vår 2019 kjernefysikk delen

Oppgave 2 multiple choice (3p)

1. b (1p) $t_{1/2}$ decreases with increasing Q value
2. a (1p) $t_{1/2}$ decreases with increasing deformation
3. b (1p) Shorter $t_{1/2}$ → larger width

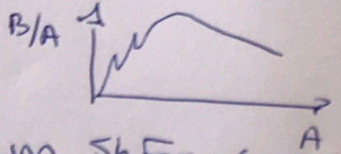
Oppgave 3 Nuclear Force (4p)

a) The nuclear force is spin dependent For the deutron only the triplet state (s=1) is bound. Due to the Pauli principle 2 protons or 2 neutrons must be in a singlet (s=0) state.
(1p) For mentioning spin dependence
(1p) for Pauli prinsiple.

b) The range of the nuclear force is ~ 1fm (or size of nucleon) (1p) And the range is short due to that the mediating particle has mass (1p)

Oppgave 4 Nuclear Binding Energy (16p)

a) Sketch



(1p) $-\frac{1}{2}$p for missing shell effect peaks

(2p)

maximum ^{56}Fe (1p)

b) $$B = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_{sym}\frac{(A-2Z)^2}{A} - \delta$$

(5p)

$$\delta = \begin{cases} +a_p A^{-3/4} & \text{For even } Z \text{ and even } N \\ 0 & \text{For odd } A \\ -a_p A^{-3/4} & \text{For odd } Z \text{ and odd } N \end{cases}$$

- Correct formula (2p)
- Almost correct (1p)
- Surface term: reduction in binding energy due to nucleons having fewer neighbours (1p)
- Symmetry term: seperate filling of single particle levels for neutrons and protons ⇒ N=Z more bound (1p)
- Pairing (δ-term): even-even nuclei more bound due to paring and odd-odd least bound. (1p)

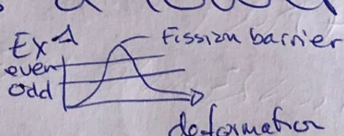
c) Volume term (1p)

(2p) Explanaition that binding energy follows A and not A^2 which we expect if the force had a longer range (1p)

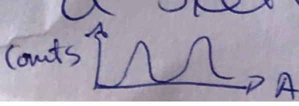
continued 4, Nuclear binding energy

d) For heavier nuclei deviation
(3p) towards more neutron rich (1p)
Due to coulomb force (1p)
explained that coulomb force
longer range, goes as Z^2
compared to binding energy
which only increases ~ A (1p).

due to δ-term → e) neutron seperation energy for
even-even nuclei higher than for
(2p) nuclei with odd neutron number.
So, neutron capture on odd
nuclei leads to a compound
nucleus with higher Excitation (E_x)
energy. (1p) with higher E_x the
nucleus sees a lower fission
barrier (1p)



f) Due to shell-effects it is energetically
favorable (maximizing binding energy)
(2p) to form fission fragments
with neutron and proton numbers
close to "magic numbers" (2p)
a sketch with 2 peaks (1p)



or any mention of shell-effects (1p)

5. Shell model (6p)

a) ^{43}Sc ground state $7/2^-$

(2p) right spin (1p) right parity (1p)

b) spin of exited state is a sum of the spins of unpaired nucleons (1p)

(4p) Promoting a neutron from $1f_{7/2}$ to $2p_{3/2}$ leaves an unpaired neutron in both these levels.

- $I_{max} = 7/2 + 3/2 = 5$ $\quad I = 2, 3, 4, 5$ (2p)
  $I_{min} = 7/2 - 3/2 = 2$
- Parity : $\pi_1 \cdot \pi_2 = (-1)(-1) = +$ (1p)

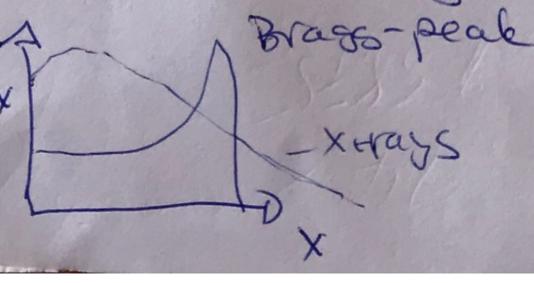
if only I_{max} and or I_{min} (1p)

8. Medical applications (4p)

a) Proton therapy gives less dose to

(2p) healthy tissue compared to x-rays before the tumor (1p) And no dose after the Bragg-peak (1p) Can adjust Bragg-peak to tumor site (1p) Can treat tumors close to vital organs (1p)

b)



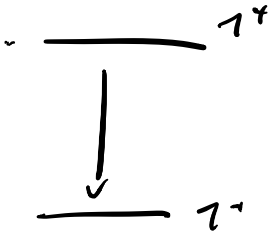
Bragg-peak shape (1p)

(2p) axis text (1p)

Ex6 |

a)

4p



($\underline{\text{M1}}$, E2)

possible decays :

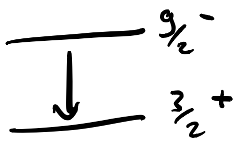
$$|J_f - J_i| \leq L \leq |J_f + J_i|$$

& correct parity

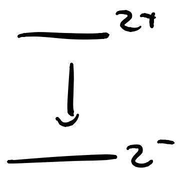
	ΔΠ=y	no	
ΔL=0	—	—	no γ
1	E1	M2	
2	M2	E2	
3	E3	M3	

⋮

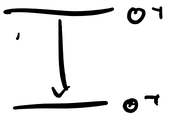
underligned most probable



$\underline{\text{E3}}$, M4, E5, M6



$\underline{\text{E1}}$, M2, E3, M4



no γs !

- 1p per subtask,
  - 0.5 XLs
  - 0.5 most prob.

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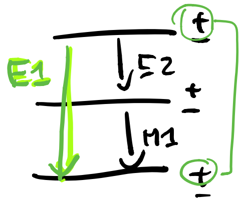
b)

4p

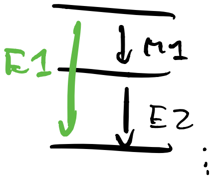
- 3 γ rays with 100 keV : E2
200 keV : M1
300 keV : E1,

$\underline{\text{not possible}}$ due to parity

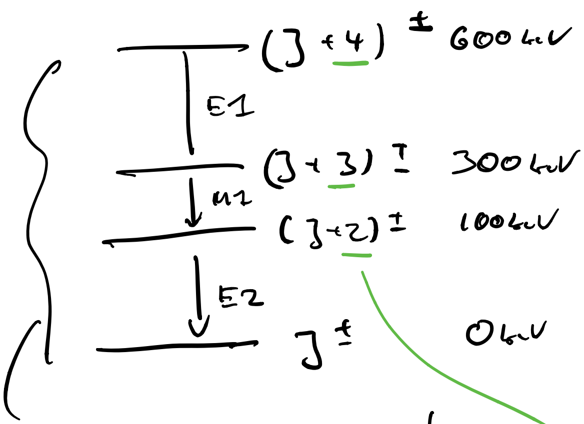
⊛



or the other way around!



therefor it
needs to be something like



→ direct decay from higher levels could be surpressed due to spins → high L necessary → low probability

or any reordering! could also be

not strictly necessary with max spin difference, but no more difference then this!

- sensible levelscene: 2p (one per level sceme)
- correct deduced spins 2p
  - −1p if not allowed by parity

⊛ wrong scheme but deduced that it does not work: 2p

c) Possible solutions:

- observe α or β decay into this nucleus and combine allowed/forbidden transition

or
- deduce branching ratio with internal conversion by e^- measurements

or
- combine with Mass/charge measurement & shell modell calculations → deduce agreement with theory

Fully correct : 2p

$1/2$ ways : 1p

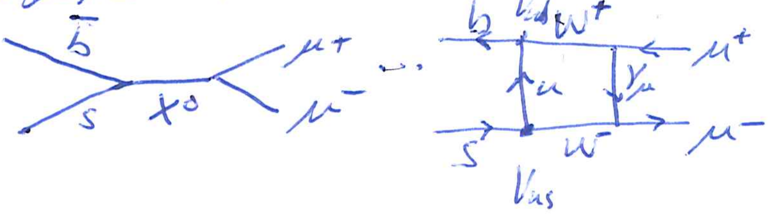
improbabe : 0.5p

non-sense 0p

①

1) CONCEPTS IN PARTICLE PHYSICS (1 POINT EACH)

a) FCNC → (6) $B_s^0 \to \mu^+\mu^-$ BOTH $\tilde{B}$ AND S CHANGE AND INITIAL AND FINAL STATES ARE NEUTRAL.



b) ISOSPIN SYMMETRY → (1) 3 BARYONS WITH NEARLY EQUAL MASS, DIFFERING ONLY IN NUMBERS OF u, d QUARKS. THEY ARE AN ISOSPIN TRIPLET $I_3 = (1, 0, -1)$, $I = 1$

c) PARITY VIOLATION → (4) THE DECAY RATE FOR $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ IS NOT THE SAME FOR θ AND π−θ, WHICH ARE CONNECTED BY A PARITY-TRANSFORMATION $\vec{r} \to -\vec{r}$

d) COLOR CONFINEMENT → (7) THE NET COLOR ISOSPIN (3rd COMPONENT) AND COLOR HYPERCHARGE OF A ~~PHYSICAL~~ PHYSICAL STATE MUST BE ZERO.

e) ELECTROWEAK UNIFICATION → (3) THERE IS AN INTIMATE CONNECTION BETWEEN ELECTRIC CHARGE AND THE CHARGED AND NEUTRAL WEAK COUPLING CONSTANTS $\frac{e}{2\sqrt{2\varepsilon_0}} = g_W \sin\theta_W = g_Z \cos\theta_W$

f) LEPTON-UNIVERSALITY → (2) THE DECAY RATES OF THE W BOSON TO ELECTRONS OR τ (OR μ FOR THAT MATTER) ARE THE SAME, INCLUDING THE SMALL EFFECT OF THE NON-ZERO LEPTON MASS.

9) LEPTON–QUARK SYMMETRY → (5)

THE DECAY RATE OF W TO A QUARK PAIR (THE WEAK EIGENSTATE) IS THE SAME AS TO A LEPTON PAIR UP TO THE FACTOR OF 3 DUE TO 3-COLOR STATES POSSIBLE FOR THE QUARK PAIR.

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9) QUARK – GLUON PLASMA (4 POINTS)

2 POINTS

$c\bar{c}$ AND $b\bar{b}$ BOUND STATES WILL BE "MELTED" BY THE HOT Q-G PLASMA, WHICH WOULD INSERT QUARKS OF THE OTHER [illegible] IN THE WAY OF THE E.G. $c\bar{c}$. THUS ONE

2 POINTS

WOULD EXPECT MESONS AND BARYONS (AND ANTIBARYONS) TO BE PRODUCED ~~WITH~~ CONTAINING A SINGLE c OR b (OR ANTIS) QUARK.

Or mention QCD analog of Debye screening

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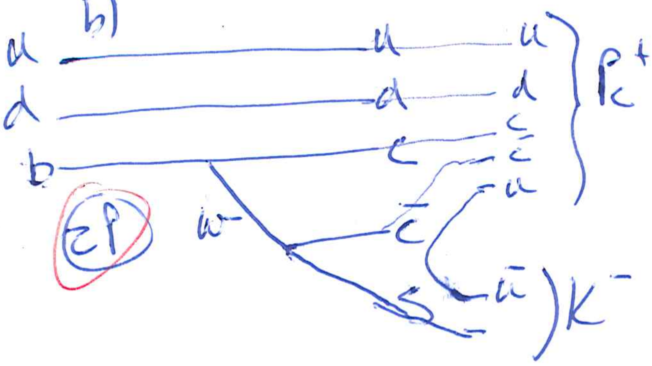
10) $\Lambda_b^0 \to K^- P_c^+$, $P_c^+ \to p\,J/\psi$, $P_c^+ = uudc\bar{c}$

2P

a) A b-QUARK IS DECAYING, SO THERE MUST BE A WEAK INTERACTION IN THE FIRST DECAY. ~~SINCE~~ THERE IS A $c\bar{c}$ THIS COULD BE A STRONG (MOST LIKELY) OR EM INTERACTION.

b)

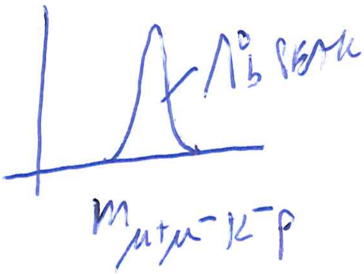


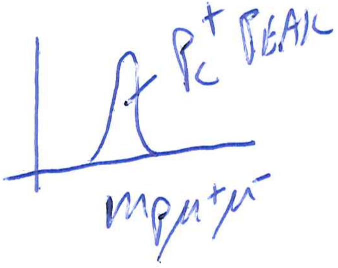
THE SECOND DECAY IS MOST LIKELY STRONG

c) TO ESTABLISH THE P_c^+ IN Λ_b^0-DECAYS ONE WOULD FIRST DETERMINE THE MASS OF $K^- p \mu^+\mu^-$ GIVING A J/ψ-PEAK THE THE $\mu^+\mu^-$-SPECTRUM AND A Λ_b^0-PEAK IN THE $K^- p\, J/\psi$ SPECTRUM. IF THE P_c^+ IS A BOUND STATE ONE SHOULD ALSO SEE A PEAK IN THE $p\, J/\psi$ SPECTRUM.

2P

VERY ROUGHLY:





[GRAPHS NOT NECESSARY FOR FULL CREDIT]

11) $\Gamma(H\to f\bar{f}) = N_c\, \alpha_w \,(m_f^2/m_W^2)\, m_H$

a) FACTOR N_c IS NUMBER OF COLORS, WHICH IS 3 FOR QUARKS AND 1 FOR CHARGED LEPTONS.

2P

b) $B_x = \frac{\Gamma_x}{\Gamma_{TOT}}$, ONLY DIFFERENCE FOR DIFFERENT FERMIONS IS m_f^2, $B(H\to f\bar{f}) \propto m_f^2 \cdot N_c$

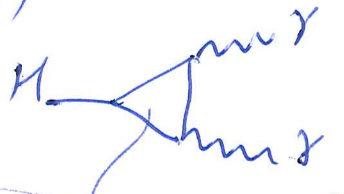
3P

$B(H\to b\bar{b}) : B(H\to c\bar{c}) : B(H\to \tau^+\tau^-) = 3m_b^2 : 3m_c^2 : m_\tau^2$

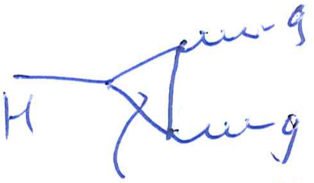
[BONUS: SEE WHY $B(H\to b\bar{b})$ DOMINATES]

c) HAVE TO FIND SOME LOOP-DIAGRAMS

~~2P~~ 3 p



CAN HAVE e.g. $W^\pm, t, b, \tau^\pm$ DOMINATE



ONLY QUARKS, e.g. t, b DOMINATES

AS LONG AS AT LEAST 2 CORRECT DIAGRAMS FOR γγ, gg EACH THEN 2P TOTAL.

12) STANDARD MODEL PARAMETERS

a) [6 QUARK MASSES, 3 ANGLES AND A PHASE IN CKM-MATRIX

3P [6 LEPTON MASSES, 3 ANGLES + PHASE IN NEUTRINO-MIXING-MATRIX (IN ANALOGY W/ CKM MATRIX FOR QUARKS).

RELATED BY

3 COUPLING CONSTANTS (ELECTRIC CHARGE, WEAK ISOSPIN, WEAK HYPERCHARGE)

MIXING ANGLE (UNIFICATION CONDITION) e.g. $\sin^2\theta_W$

3P 2 HIGGS PARAMETERS (MASS AND λ)

— OR —

$\alpha_s, e, G_F, m_H, \sin^2\theta_W,$

Gf or mW or Mz

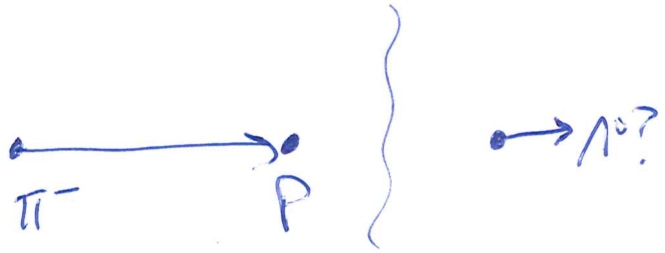
26 if we include the strong-CP parameter, which is 0 for all we know (full credit for 25)

∴ 25 PARAMETERS

b) ALL MUST BE DETERMINED EXPERIMENTALLY!! 2P

⑤

13)



THE Λ° IS uds SO THIS CAN'T BE DONE BY A STRONG INTERACTION. SIMPLEST WAY IS TO PAIR-PRODUCE $s\bar{s}$ AND ASSOCIATE THE Λ° TO ($\bar{s}$ CONTENT - POSSIBLE $\bar{s}$-PARTICLE (SO A MESON, TO CONSERVE B AS WELL).

(2p) SOMETHING IN ADDITION TO Λ°

$\pi^- p \to \Lambda^0(uds)\, K^0(\bar{s}d)$ WORKS. (2p) "SOMETHING" IS K°

(1p) THE THRESHOLD IN THE CENTER OF MASS WILL GIVE BOTH K° AND Λ° AT REST.

(1p) USE CONS. OF ENERGY AND MOMENTUM IN LAB FRAME, OR, MORE SIMPLY, THE INVARIANT MASS

4 p ~~6p~~

$$W^2(\pi^- p) = \left(\Sigma E\right)^2 - \left(\Sigma \vec{p}\right)^2 = \left(m_p + E_\pi\right)^2 - p_\pi^2$$

$$= W^2(\Lambda^0 K^0) = \left(m_{K^0} + m_{\Lambda^0}\right)^2$$

$$m_p^2 + E_\pi^2 + 2m_p E_\pi - p_\pi^2 = m_p^2 + m_\pi^2 + 2m_p E_\pi$$

$$= \left(m_{K^0} + m_{\Lambda^0}\right)^2$$

$$\Rightarrow E_\pi = \frac{1}{2m_p}\left[\left(m_{K^0} + m_{\Lambda^0}\right)^2 - m_p^2 - m_\pi^2\right]$$ ← FULL CREDIT

ALSO 4p IF ABOVE THEY DECIDE ON $\pi^- p \to \Lambda^0$ AND ARRIVE TO RESULT W/ $m_{K^0} = 0$

INSERTING VALUES FROM TABLE

$E_\pi = 909$ MeV

$p_\pi = \sqrt{E_\pi^2 - m_\pi^2} = 898$ MeV

1 POINT FOR DOING THE CHECK EVEN IF IT TURNS OUT BADLY.

⑥

7) RADIOACTIVE DECAY (3 POINTS EACH PART)

$A \to B \to C$ WITH λ_A FOR $A \to B$ AND λ_B FOR $B \to C$

a) DECAY LAW: AT ANY GIVEN TIME THE DECAY RATE PER NUCLEUS (ANY UNSTABLE PARTICLE!) IS DEFINED AS $\frac{1}{N}\frac{dN}{dt} = -\lambda$

$$\int \frac{dN}{N} = \int -\lambda dt, \quad \ln N = a - \lambda t$$

SAY THERE ARE N_0 NUCLEI @ $t=0$

$$\Rightarrow \ln N_0 = a$$

CAN BE REWRITTEN $N = e^{\ln N} = N_0 e^{-\lambda t}$

$$\boxed{N(t) = N_0 e^{-\lambda t}}$$

b) FIND $N_B(t)$

INITIAL CONDITIONS ARE $N_A(t=0) = N_{A,0}$, $N_B = 0$

THE RATE OF CHANGE IN THE NUMBER OF B'S IS GIVEN BY THE INCREASE DUE TO DECAYS OF A AND THE DECREASE CAUSED BY THE DECAYS OF B, i.e.

$$\frac{dN_B}{dt} = -N_B(t)\lambda_B + N_A(t)\cdot\lambda_A$$

TRY A SOLUTION $N_B(t) = \alpha e^{-\lambda_A \cdot t} + \beta e^{-\lambda_B \cdot t}$

FROM ~~$N_B(t)$~~ $N_B(t) = 0 = \alpha + \beta \Rightarrow \alpha = -\beta$

SINCE THERE ARE NO B'S @ $t=0$

$$\frac{dN_B(t=0)}{dt} = N_A(t=0)\,\lambda_A = -\lambda_A\alpha - \lambda_B\beta$$

$$= N_{A,0}\,\lambda_A = \beta\left(\lambda_A - \lambda_B\right)$$

$$\Rightarrow \beta = \frac{N_{A,0}\,\lambda_A}{\lambda_A - \lambda_B}$$

$$\Rightarrow N_B(t) = \frac{N_{A,0}\,\lambda_A}{\lambda_A - \lambda_B}\left(-e^{-\lambda_A \cdot t} + e^{-\lambda_B \cdot t}\right)$$

$$\Rightarrow N_B(t) = \frac{N_{A,0}\,\lambda_A}{\lambda_B - \lambda_A}\left(e^{-\lambda_A \cdot t} - e^{-\lambda_B \cdot t}\right)$$

c) $6\cdot 10^{23}$ ${}^{76}_{32}Ge$ ATOMS @ $t=0$, $t_{1/2} = 1.78\cdot 10^{21}\,y$

$N = N_0 e^{-\lambda t}$, $\frac{N}{N_0} = \frac{1}{2} = e^{-\lambda t_{1/2}} \Rightarrow \lambda = \frac{\ln 2}{t_{1/2}}$ (1P)

$\frac{dN}{dt} = -\lambda N_0 e^{-\lambda t}$, USE $t = t_{UNIV.} = 13.8\cdot 10^{9}$ YEARS

SINCE $t_{UNIV}/t_{1/2} \ll 1$ $e^{-\lambda t_z} \underset{(1P)}{\cong} 1.0$ (decay rate very constant since $t=0$ until today!)

NUMBER OF DECAYS/WEEK $= N_0 \cdot \lambda \cdot \frac{1\,y}{52\,w}$ (1P)

$$= \frac{6\cdot 10^{23}\cdot \ln 2}{1.78\cdot 10^{21}\,y}\cdot\frac{1\,y}{52\,w} = 4.5\ \frac{\text{decays}}{\text{week}}$$

⑧

d) THE NUCLEUS HAS CHARGE +
POSITRONS (β^+) WILL BE REPELLED/ACCELERATED
WHILE ELECTRONS (β^-) WILL BE ATTRACTED/DECCELERATED
THUS THE POSITRON SPECTRUM WILL TEND
TO BE HARDER THAN THE ELECTRON SPECTRUM.