FYS 3500 - Midterm Exam Spring 2019 (home exam)

Deadline to hand it in is 29 of March 2019

The (anonymous) delivery will be in Devilry - it should be available well before the deadline.

Useful resources:

- Books presented in the lecture/problem sessions
- Chart of nuclides on http://www.nndc.bnl.gov/
  Eg masses, lifetimes, energy levels, decay schemes, …
- Also: Livechart – Table of Nuclides:

  https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

- Particle physics: Lifetimes, decay widths (...)
  http://pdg.lbl.gov

Please cite external references where used.

1. **Some shorter questions (14p)**
   Answer the following questions (you're welcome to be brief where possible).

   a) What is the ground-state spin and parity of even-even nuclei? Why? (2)

   b) What are antiparticles? What is their origin in theory? (How) can we measure them? (2)

   c) Sketch the density of the nucleus. Indicate reasonable dimensions on the axes. How does it depend on the mass number A? (4)

   d) The neutron has no charge, but still it has a magnetic moment, why? (2)

   e) Is it harder to steal a neutron from ^{11}Li, ^{12}C, ^{240}Pu? (2)

   f) What is the Υ (upsilon) meson? How can we detect it? (2)

2. **Nuclear binding energy (15p)**

   a) Use the semi empirical mass formula to determine the mass of ^{56}Fe . How well does it agree with measured value(s)?

   b) Estimate the energy needed to remove one neutron from ^{42}Ca nucleus.

   c) For A=136 find the most stable nucleus using the semi empirical mass formula. Sketch the mass as a function of Z for the A=136 isobars ("mass parabola") and explain how the beta decay flows between nuclei with A=136. Make also a sketch for a case where A is an odd number, for example A=135, explain the difference from the even A case.

3. Creating a level scheme following beta-decay (15p)

Assume that you have measured three electron spectra from a β^- decay with the end-point energies E_{max} of (1) 672 keV, (2) 536 keV and (3) 256 keV. You have also measured the γ-rays that are in coincidence with each of the electrons:

- In coincidence with (1) you have measured γ's of energy 468 keV and 316 keV. Both γ-rays are also in coincidence with each other.
- In coincidence with (2) are γ's of 604, 308, 136, 468, 612, 296 and 316 keV. You were not able to determine the coincidences between the γ's [there could be any number of γ's coincident, or not].
- In coincidence with (3) are all previously named γ's. In addition There are γ's of 884, 416, 280 and 588 keV.

a) Create the decay scheme which shows the energy levels of the daughter nucleus and γ-ray transitions.

b) How big is the mass difference (Q-value) between the ground-states of the daughter and parent nucleus? How can you read this from the decay scheme?

c) You should find that there is an excited level at 784 keV, from which you have not measured any transition to the ground-state. Briefly explain two possible reasons.

Some explanation: We call γ-rays coincident if they are measured within a specified short time window. In Figure 1, we see have an example on the decay scheme of ^{60}Co into the daughter nucleus ^{60}Ni with subsequent γ-decay. The 1.17 MeV γ-rays from the decay of the 4^+ to the first excited level and the 1.33 MeV γs from the first excited to the ground state are in coincidence (unless the first excited state has for some reason an exceptionally long lifetime.) In contrast, the 0.34 MeV γ-ray from the decay 4^+ to the second excited level would not be measured in coincidence with 1.17 MeV γ-ray – however depending on the further decay path to the ground state, it may also be in coincidence with the 1.33 MeV γ.

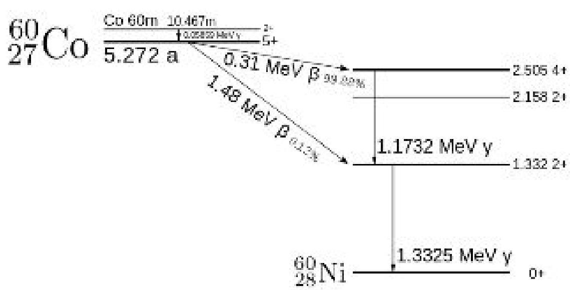

Figure 1: β-decay of ^{60}Co.

4. Lifetime, decay rate, branching ratios (10p)

Given the lifetime $\tau = 10^{-6}$ s of a nuclear state (or an unstable particle) and three possible decay channels with branching ratios B_1=50%, B_2= 35%, and B_3=15%, what is the decay rate for channel 2 in natural and physical units?

5. Proton-antiproton annihilation - (6p)

Find the momenta of the pions in the process $p\bar{p} \rightarrow \pi^+\pi^-$ with the proton-antiproton annihilation occurring approximately at rest (formula result - don't replace numerical constants).

6. Neutrino physics - (10p)

Make a rough estimate of the branching ratio for the lepton-number violating decay $\mu^+ \rightarrow e^+\gamma$.

7. Higgs boson decay width - (10p)

The 4'th edition of Martin and Shaw's "Particle Physics" claims that the lifetime τ of the Higgs boson is about $\tau = 1.6 \cdot 10^{-22}$ s and its decay width (or total decay rate) Γ is about 4.1 GeV.

a) Show that these two statements can not both be correct.

b) Suppose that Γ turned out to be 4.1 GeV instead of the much smaller value we expect in the Standard Model. Suggest and explain briefly one way we could reconcile this with all the *other* results from the LHC that indicate so far that this Higgs boson has all the properties (e.g. production rates and relative decay rates) we expect in the Standard Model.

8. Quantum numbers - (10p)

a) Describe the parity (P) and charge conjugation (C) quantum numbers.

b) What values do we expect for the lightest spin-zero mesons in the simple quark model of hadrons?

c) Find and explain spin and parity of ^{15}N for the ground state and 1st excited state.

d) What are the possible gamma transitions between the two levels? Indicate the transitions with the shortest half-life.

9. Allowed, suppressed and forbidden processes (20p)

$$1)\ \nu_e e^- \rightarrow \nu_\mu \mu^- \quad 2)\ \gamma\gamma \rightarrow b\bar{b} \quad 3)\ \phi \rightarrow K^+K^-$$
$$4)\ e^+e^- \rightarrow q\bar{q}\gamma \quad 5)\ \Lambda p \rightarrow K^-pp \quad 6)\ D^- \rightarrow K^-\pi 0$$
$$7)\ \mu^+\mu^- \rightarrow \gamma \quad 8)\ {}^{82}_{34}\mathrm{Se} \rightarrow {}^{82}_{36}\mathrm{Kr} + 2e^- + 2\bar{\nu}_e \quad 9)\ {}^{76}_{32}\mathrm{Ge} \rightarrow {}^{76}_{34}\mathrm{Se} + 2e^-$$

a) Which of the above processes are allowed and which are forbidden?
b) If allowed, draw the (dominant) Feynman diagram(s) and state which interaction(s) is(are) at work.
c) For allowed *decays* check that the interaction type and lifetime are compatible.
d) If suppressed or forbidden, give a reason. You may consider new physics scenarios if and when appropriate.
e) Can we use any of these processes to test the hypothetical values of the electric charges of quarks? Discuss briefly how this could be done.
f) Assuming processes 7 and 8 are allowed, how would you separate them experimentally? What would be the consequences of such an observation?

Good Luck!