**FYS 3500 - Midterm Exam Spring 2018 (home exam)**

Deadline to hand it in is 23 of March 2018

The delivery will be in Devilry - we are promised that this will be set up by Tuesday, March 20.

**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 width (...)
  http://pdg.lbl.gov

Please cite external references where used.

## 1. Some shorter questions (20p)

Answer the following questions (you're welcome to be brief where possible).

a) How big is the atomic nucleus? How big is an atom?

b) What is the density (Mass/Volume) of the nucleus?

c) Does the nuclear density depend on the mass number A?

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

e) Is it harder to steal a neutron from $^{208}$Pb or $^{11}$Li or $^{4}$He?

g) What is the ground-state spin and parity of even-even nuclei?

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

i) What is the J/ψ meson? How can we detect it?

## 2. Nuclear binding energy (20p)

a) Use the semi empirical mass formula to determine the mass of $^{163}$Er . How well does it agree with the measured value(s)?
b) Estimate the energy needed to remove one neutron from $^{40}$Ca nucleus (which has N=Z=20).
c) The masses of the mirror nuclei $^{27}$Al and $^{27}$Si are 26.9981539 u and 26.986704 u, respectively. Use this to determine an approximate value of the Coulomb's coefficient in the semi-empirical mass formula.
d) For A=133 find the most stable nucleus using the semi empirical mass formula. Sketch the mass as a function of Z for the A=133 isobars ("mass parabola") and explain how the beta decay flows between nuclei with A=133. Make also a sketch for a case where A is an even number, for example A=126, explain the difference from the odd A case.

## 3. Nuclear forces (5p)

a) The nuclear force is often described as "charged independent". Does it mean that a system of two protons is the same as a system of one proton and one neutron? Why don't we observe a bounded system of two protons or two neutrons in nature?

b) What is the range of the nuclear force? Why is it so short? What is its microscopic origin?

## 4. It's hard to choose... (25p)

a) Find and explain ground state spin and parity of 41Sc
b) What are plausible configurations that may explain the (spin and parity of the) energy levels of 41Sc below 2.7 MeV.
c) Draw all possible $\gamma$ transitions and indicate their most possible multipole assignment(s). Which of the transitions would you expect to be have the smallest chance to happen?
d) Consider $^{40}$Ca (N=20, Z=20). If we now take one neutron from the level $1d_{3/2}$ and promote it to the level $1f_{7/2}$, we would have an excited state. What are the possible values for the spin and parity of this excited configuration?

## 5. Dreaming about radioactive decay (10p)

a) Assuming you share a double bed with your partner, what is the dose you receive during the night? You may safely assume that the main contribution is from K-40, of which an average person has 2.5*10^20 nuclei in the body.

Specify assumptions that you make, e.g. the geometry of the problem. (Rough estimates are fine – eg. like all radiation impinging on your body will be absorbed. as your body a "thick target".)

b) Compare this to the dose you receive from eating a banana. What is more dangerous from a radiation safely point of view?

## 6. Particle annihilation - (10p)

a) What is the cross-section for the e- e+ annihilation process creating a single photon in free space?
b) Calculate the energy of a positron beam colliding with electrons at rest, at which it is most probable to produce the J/ $\psi$ meson. How precisely do we need to hit this energy?

## 7. Neutrino oscillations - (4p)

What is and how can we know about neutrino mixing?

## 8. Allowed, suppressed and forbidden processes (30p)

Which of the following processes are allowed and which are forbidden?

a) If allowed, draw the (dominant) Feynman diagram(s) and state which interaction(s) is(are) at work.
b) For allowed decays check that the interaction type and lifetime are compatible.
c) If suppressed or forbidden, give a reason. You may consider new physics scenarios if and when appropriate.

1) $e^+e^- \to \nu_e\bar{\nu}_e$ 2) $e^+e^- \to \gamma\gamma$ 3) $\phi \to \pi^0\pi^0$

4) $e^+e^- \to q\bar{q}\gamma\gamma$ 5) $\Lambda^0 \to \bar{p}\pi^+$ 6) $\Sigma^+ \to \pi^0 p$

7) ${}^{82}_{34}\text{Se} \to {}^{82}_{36}\text{Kr} + 2\text{e}^- + 2\bar{\nu}_e$ 8) ${}^{76}_{32}\text{Ge} \to {}^{76}_{34}\text{Se} + 2\text{e}^-$

Note: Isotopes in 7 and 8 have been updated (typo in first version)

d) Assuming process 4 is allowed, which property or behavior of the underlying theory can be obtained?
e) Assuming processes 7 and 8 are allowed, how would you separate them experimentally? What would be the consequences of such an observation?

Good Luck!