FYS3520 - Problem set 9

Spring term 2017

Problem 1 – in class

a) First part: Lecture on internal conversion and absorption of γ-rays

b) Discussion of γ-decay

c) In the midterm examine you should calculate the dose absorbed by sleeping in a bed besides your partner. You were given the hint that you might assume that all radiation impinging on your body will be absorbed. Is this assumption justified for a γ-ray of 100 keV (20 keV, 1 MeV)?

Problem 2 γ-decay and Weisskopf units

The reduced transition probabilities are expressed in $e^2\mathrm{fm}^{2L}$ for EL multipoles and in $\mu_\mathrm{N}^2\mathrm{fm}^{2L-12}$ for ML multipoles, see eg. Krane.

a) For the following transitions between levels, give all permitted γ-ray multipoles and indicate which multipole might be the most intense in the emitted radiation.
a) $\frac{9}{2}^- \to \frac{7}{2}^+$ b) $\frac{1}{2}^- \to \frac{7}{2}^-$ c) $1^- \to 2^+$ d) $0^+ \to 0^+$ e) $3^+ \to 3^+$ e) $4^+ \to 2^+$
f) $\frac{11}{2}^- \to \frac{3}{2}^+$

b) A nucleus has the following sequence of states beginning with the ground state: $\frac{3}{2}^-, \frac{7}{2}^-, \frac{5}{2}^+, \frac{1}{2}^-$ and $\frac{3}{2}^-$ Draw a level scheme showing the intense γ transitions likely to be emitted and indicate their multipole assignment. Which of the transitions would you expect to be have the smallest chance to happen?

c) From the vibrational model for even-even nuclei we discussed how the level scheme is created up to the $0^+, 2^+, 3^+, 4^+, 6^+$ three-phonon multiplet. The model also gives selection rules for the γ emission: the phonon number must change by exactly one unit, and only E2 transitions are permitted (why so?). Draw a vibrational level scheme showing all permitted γ transitions starting with the three-phonon multiplet.

d) For a light nucleus ($A = 10$), compute the ratio of the emission probabilities for electric quadrupole (E2) and magnetic dipole (M1) radiation according to the Weisskopf estimates. Consider all possible choices for the parities of the initial and final states.

e) Compare this to the ratio calculated for a heavy nucleus (A = 200).

Problem 3 Bonus: Parity non-conservation in weak interaction

From the β^- decay of ^{60}Co it is experimentally observed that the parity is not conserved in the weak interaction. This is a fundamental results in nuclear and particle physics. It shows that the nature on smallest scales distinguishes between image and mirror image. This exercise shall help you to understand this central result by looking at the original data.

One of the most fundamental results in nuclear physics was the non-conservation of parity in the weak interaction, which has been experimentally observed for the β^- decay of ^{60}Co.

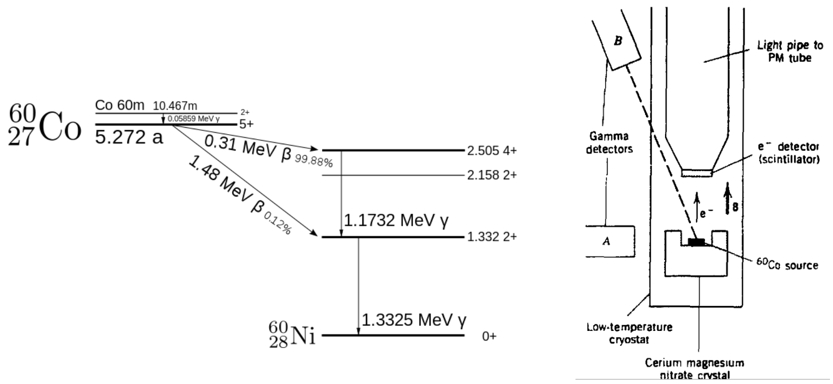
a) Calculate the Q-value for the β^--decay of ^{60}Co into the ground-state of ^{60}Ni. Why is the ground-state transition strongly suppressed? Which transitions are observed most instead? Classify these according to allowed and forbidden transitions.

b) Sketch what you would expect in case parity was conserved for the direction of the electron emission, when the to the nuclear spin $\boldsymbol{I}$ is aligned to an external field $\boldsymbol{B}$. How would it compare to the direction of the field being changed from $\boldsymbol{B}$ to $-\boldsymbol{B}$?

c) Follow the original publication of C.S. Wu *et al.* to see what happens instead. Describe the experiment where the allowed Gamow-Teller decay to the excited 4^+ state in ^{60}Ni was observed. Why did one need to cool the ^{60}Co source to 0.01 K? What can one deduce from the measured γ-anisotropy and β-anisotropy?

Original publication:
C.s. Wu.*et al.*: `https://journals.aps.org/pr/abstract/10.1103/PhysRev.105.1413`

Decay scheme and experimental setup:



(a) (b)

Figure 1: a) Decay scheme from the β-decay of ^{60}Co. The $J^{\pi} = 2^+$ isomer of ^{60}Co is also shown. (source: wikipedia). b) Experimental set-up of C.s. Wu.*et al.* for the measurement of the parity non-conservation in the β-decay. (source: Krane, Fig 9.22.)

Problem 4 Bonus: How constant is the decay constant?

In most of our work in nuclear physics, we regard the decay constant λ as a true constant for a given nuclear species. However, you have studied two processes in which the nuclear decay rate could be sensitive to the chemical state of the atom. Discuss these two processes and explain how the atomic state might influuence the nuclear decay rate.
For a discussion and some examples of cases in which this can occur, see the review by G.T. Emery, `https://doi.org/10.1146/annurev.ns.22.120172.001121`