Master Sciences de la Matière **ENS Lyon**
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Travaux Dirigés de Physique Nucléaire

Basic Radioactivity: life times, dating, radioactive channels

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<u>Exercice 1 :</u> Medical use of radioactivity

A nurse injects ^{131}I into a patient's thyroid gland. The sample has an activity of 0.16 μCi, and iodine's period is of 8.3 days. After 24 hours she measures the residual activity by using a counter with an intrinsic efficiency of 0.1. When the counter is approached to the patient's neck, it has a 1 Sr solid angle opening. This measurement leads to a counting ratio of 1700 hits per minute.

A thyroid absorbs iodine with an efficiency of 34% if it is healthy, 16% if it is hypoactive and 65% if it is hyperactive. What is the status of that patient?

<u>Exercice 2 :</u> Muonic life span

Muons decay into electrons. A detector counts 200 hits after 2 μs and 310 hits after 6μs.

What is the average life time of the muons?

<u>Exercice 3 :</u> ^{14}C dating

We shall estimate SNEFROU's date of decease by radioactive carbon dating. (SNEFROU was an Egyptian Pharaoh)

The cosmic radiation produces, in particular, slow neutrons in the atmosphere. The latter react with nitrogen to form ^{14}C. Radioactive carbon, carried by the air, mixes with the stable isotope ^{12}C. Thus it takes part in all the biological exchange processes involved with life : eating, breathing, or photosynthesis. However, once a being dies, the exchanges with the atmosphere stop. Thence, ^{14}C isn't renewed in the body, and its concentration decreases in time with a period of $T_{^{14}C} = 5730$ years. This is the pillar of radiocarbon dating. A measure of the residual activity of a sample allows to determine the moment when the life supporting exchanges with the atmosphere have changed. We remind that, on average, one gram of today's air contained carbon has 15 ^{14}C atom decays per minute.

In the case of SNEFROU, scientific archaeologists have extracted 5 grams of carbon out of the wood contained in the Pharaoh's coffin. Then a 4π detector measured an activity of 2475 decays of ^{14}C per hour.

1 / What was the date of the Pharaoh's death?

2 / Discuss the possible sources of errors associated to this dating method.

3 / Will radiocarbon dating be as much effective in a couple of millennia?

Exercice 4 : Dose

An 80 kg worker at the Chernobyl nuclear plan eats accidentally 2 mg of pure ^{239}Pu dust. The plutonium remains 15 hours in his body. ^{239}Pu decays through α decay with a period of 24110 years. It emits α particles with an average energy of 5.2 MeV. Knowing that, at such beam densities, 95% of the α particles are stopped by the human body, compute the absorbed dose (in Grays and its equivalent biological dose in Sievert).

Will the man die or suffer from any other radioactivity-related illness?

Exercice 5 : Parallel decays

$^{212}_{83}Bi$ decays through α (36%) and β (64%) decays. What is the activity of a sample containing N_0 $^{212}_{83}Bi$ at $t = 0$? One will assume given the half periods of Bi, Tl and Po.

$$\begin{array}{lllll} ^{212}_{83}Bi & \Longrightarrow \texttt{channel}\ \alpha\ (36\%) & ^{208}_{81}Tl & \Longrightarrow \texttt{channel}\ \beta\ (100\%) & ^{208}_{82}Pb \\ & \Longrightarrow \texttt{channel}\ \beta\ (64\%) & ^{212}_{84}Po & \Longrightarrow \texttt{channel}\ \alpha\ (100\%) & ^{208}_{82}Pb \end{array}$$

Exercice 6 : Activation-Decay

One wants to study the unstable nucleus ^{198}Au. The method consists in exposing a mass of 10g of ^{197}Au to a neutron flux of $10^{14} cm^{-2}.s^{-1}$ for half an hour. The decay scheme is as follows :

$$\begin{array}{cccccc} ^{197}Au \rightarrow (n,\gamma)\ \ (\sigma_1 = 94\ b) & \Longrightarrow & ^{198}Au & \rightarrow (n,\gamma)\ \ (\sigma_2 = 35000\ b) & \Longrightarrow & ^{199}Au \\ & & \Downarrow \beta & & & \Downarrow \beta \\ & & T_1 = 2.7j & & & T_2 = 3.15j \end{array}$$

1 / Compute the activity of ^{198}Au.

2 / Repeat the steps for ^{199}Au.

Exercice 7 : ^{238}U chain

A gram of Earth's rock contains on average 3 μg of ^{238}U. The average density of such rocks is 5 g.cm^{-3}.

The ^{238}U (Z=92) isotope is the starting element of a chain of α and β decays that end up on the stable isotope of lead ^{206}Pb. All these decays are listed in the table below:

	decay	$T_{1/2}$		decay	$T_{1/2}$
1	$^{238}U \to {}^{234}Th + \alpha$	4.468 $\times 10^9$ years	8	$^{218}Po \to {}^{214}Pb + \alpha$	3.05 minutes
2	$^{234}Th \to {}^{234}Pa + \beta^-$	24.10 days	9	$^{214}Pb \to {}^{214}Bi + \beta^-$	26.8 minutes
3	$^{234}Pa \to {}^{234}U + \beta^-$	6.75 hours	10	$^{214}Bi \to {}^{214}Po + \beta^-$	19.7 minutes
4	$^{234}U \to {}^{230}Th + \alpha$	2.45 $\times 10^5$ years	11	$^{214}Po \to {}^{210}Pb + \alpha$	164 μs
5	$^{230}Th \to {}^{226}Ra + \alpha$	8.0 $\times 10^4$ years	12	$^{210}Pb \to {}^{210}Bi + \beta^-$	22.3 days
6	$^{226}Ra \to {}^{222}Rn + \alpha$	1.60 $\times 10^3$ years	13	$^{210}Bi \to {}^{210}Po + \beta^-$	5.01 days
7	$^{222}Rn \to {}^{218}Po + \alpha$	3.824 days	14	$^{210}Po \to {}^{206}Pb + \alpha$	138.4 days

1 / What is the atomic number of the descendants of ^{238}U?

2 / All the elements but radon (Rn) are solid. Thus, radon can escape from the rock and contaminate the air. Imagine a cellar having no exchanges with the exterior such that its floor if is built on the rock. The room is 2 m by 3 m and it is 2 m high. We assume that only the radon produced within 10 cm of the surface of the floor can penetrate the room. Explain this hypothesis. We also suppose that the diffusive coefficient of radon in the air is very large (with respect to what?). Determine the amount of ^{238}U contained in the 10c m layer below the cellar's floor.

3 / What will be the number of Radon atoms in the cave's air? We shall assume that the amount of time elapsed from the date of creation of the rock is far superior to the longest period of the descendants of ^{238}U. We will also assume a secular equilibrium. Discuss the two hypotheses.

4 / Do you think that radon will constitute the main contribution to the α particle present in the cellar? What will be the radon activity in Bequerels per liter? Compare it to its EU recommended value of $0.15 Bq.\ell^{-1}$. What to do in order to reduce this pollution?

5 / What is the mass of uranium necessary to produce one gram of radium (Ra)?

6 / There also exists another isotope ^{232}Th, almost just as heavy that ^{238}U. Its life time is of the same order of magnitude as well. Its period is 1.41 $\times 10^9$ years. Just as uranium it decays into lead through a series of α and β^- decays. Is thorium 232's chain able to produce ^{222}Rn?

7 / Assume that the abundances of ^{232}Th and ^{238}U where equal 10 billion years ago during the creation of Earth. What is then today's abundance of ^{232}Th in earthbound rock?