Measuring the half life of ^{238m}Pa
KJM 5900 Laboratory Exercise C

Written by JPO, last updated by JPO 21. August 2004

Learning goals

- Understand mother-daughter relations and radioactive equilibrium.
- Understand how a radio-nuclide generator works and how it is used.
- Understand how radioactivity is "growing in".
- Be able to analyse a decay curve and determine the half life.
- More training in contamination control.

Theory

This exercise highlights the following concepts from the curriculum: Radioactive decay, half life, radioactive equilibrium, mother-daughter relations, radio-nuclide generators, measurement of β-activity, counting uncertainty.

The theory behind these concepts can be found in

- The text book: Sections 4.1 - 4.5 explains about radioactive decay, equilibrium, etc.; Sections 7.1 - 7.3, and 7.11 explains about measurement of radioactivity.
- The compendium: Sections 1.1 - 1.5 explains about radioactivity and decay (in Norwegian!).

In particular, you should notice that in this exercise we take advantage of the mother-daughter relationship in the ^{238}U series:

$$^{238}U \xrightarrow{4.5\cdot 10^{9}\,y} {}^{234}Th \xrightarrow{24\,d} {}^{234m}Pa \xrightarrow{1.18\,m} {}^{234}U \xrightarrow{2.5\cdot 10^{5}\,y}$$

Your task is to measure and verify the half life of ^{234m}Pa. Remember that in laboratory exercise A you explained why the disintegration rate for ^{234m}Pa was equal to that of ^{238}U in a uranium sample which was more than one year old.

Today we shall first separate the protactinium from uranium, otherwise we can not measure its half life as it constantly is produced in the disintegration of ^{238}U. We do this by using an ionexchange column.

Under the chemical conditions we apply, uranium will not stick to the column but go straight through. Thorium on the other hand, will attach itself to the column. The thorium will constantly produce ^{234m}Pa and after about 12 minutes saturation will be reached (i.e. ^{234m}Pa is in radioactive equilibrium with its mother ^{234}Th).

Thus, we can flush out the protactinium from the column by using a suitable complexing agent, which bonds to the protactinium but not to thorium. In this way we have produced an ^{234m}Pa radio-nuclide generator.

You use samples of ^{234m}Pa from the generator to measure a decay curve of ^{234m}Pa. By keeping track of the time and counting at suitable intervals you will get counts rates $R(t_i)$ along the decay curve. Since

$$R(t_i) = R_0 e^{-\lambda t_i} \Leftrightarrow \log R(t_i) = \log R_0 - \lambda t_i \cdot \log e$$

we can find the half life by plotting $R(t_i)$ vs. t_i on semi-logarithmic plotting paper and measure the slope, which is equal to $\lambda \cdot \log e$.

A quicker method of finding the half life from the semi-logarithmic plot is to see how long, Δt it takes for the activity to be reduced by a factor of $\left(\frac{1}{2}\right)^n$, the half life would then simply be $\Delta t/n$. E.g. after five half-lives the activity would be reduced to 1/32 of its original activity. If it takes 50 seconds for this to happen, the half life would be 5 seconds.

Procedure

1. Start a background measurement with the sample beaker which will be used to receive the ^{234m}Pa inserted.
2. Prepare a Dowex 50-4 ionexchange column:
   a. Mix 4-5 g Dowex and about 20 mL 2 M HCl in a beaker, stir to prevent the Dowex to lie on the bottom. Pour this into your column and top up with HCl solution to prevent the column to run dry.
   b. Dissolve about 2 g of uranium in 10 mL 2 M HCl og pour it into the column. Add 2 M HCl as needed to prevent the column to run dry. *The HCl solution exiting the column will contain uranium an must be treated as radioactive waste.*
   c. Flush the column with 2 M HCl until there are no more uranium exiting the column (add HCl solution 5-6 times, letting the reservoir above the column nearly empty each time). You can also check if the the solution exiting the column contains uranium with a specially prepared solution of $K_4(Fe(CN)_6)$.
   d. Flush the column with 5% citric acid solution until there is no more HCl present (you can check with a $AgNO_3$ solution).
   e. When finished, cap the column and check that it stops dripping.
   f. You can elute ^{234m}Pa after 12 minutes. The elution can be speeded up by carefully applying pressure to the column.
3. Counting procedure:
   a. You shall measure the decay curve twice.
   b. To measure a decay curve, insert a freshly eluted sample of ^{234m}Pa and perform a series of 60 seconds count (with e.g. 30 seconds pause in between). Continue counting until the count rate becomes constant.
4. Analyse the measured decay curves!

Suggested time schedule

10:00 Read through the exercise and relevant parts of the course book.
10:30 Perform exercise 2.1.
12:00 Lunch.
12:30 Perform exercise 2.2. Clean and tidy up the lab when you are done!
13:30 Answer and perform the calculations in exercise 2.3
14:30 Summary and review of the exercise (everybody together).

When are through at the laboratory remember to remove your lab coat, wash your hands and perform a contamination check of your hands and feet on the monitor outside VU55!