PHYS20161 final project: ^{79}Rb decay

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^{79}Rb is an artificial radioactive isotope that is part of both the ^{79}Zr and ^{81}Nb decay chains. It is produced in the β^+ decay of ^{79}Sr and then decays to ^{79}Kr, also via β^+ emission accompanied by a γ ray.

A sample of 10^{-6} moles of ^{79}Sr was collected and subsequently decayed. However the detectors used could only detect the γ from $^{79}\text{Rb}\rightarrow{}^{79}\text{Kr}+\beta^+ + \nu_e + \gamma$. Your task is to determine the half-lives and decay constants of both ^{79}Sr and ^{79}Rb from this data and, if possible, obtain the uncertainty on these values. Your work should produce some graphics to support your analysis.

1 Theory

The sample of ^{79}Sr decays through the standard formula for nuclear decay,

$$N_{^{79}\text{Sr}}(t) = N_{^{79}\text{Sr}}(0)\exp(-\lambda_{^{79}\text{Sr}}t), \tag{1}$$

where $N_{^{79}\text{Sr}}(t)$ is the number of nuclei at a given time, t, and $\lambda_{^{79}\text{Sr}}$ is the decay constant. For ^{79}Rb, the rate of decay must be adjusted to take into account the production of ^{79}Rb from the decay of ^{79}Sr:

$$\frac{dN_{^{79}\text{Rb}}(t)}{dt} = -\lambda_{^{79}\text{Rb}}N_{^{79}\text{Rb}} + \lambda_{^{79}\text{Sr}}N_{^{79}\text{Sr}}. \tag{2}$$

This can be solved to give

$$N_{^{79}\text{Rb}}(t) = N_{^{79}\text{Sr}}(0)\frac{\lambda_{^{79}\text{Sr}}}{\lambda_{^{79}\text{Rb}} - \lambda_{^{79}\text{Sr}}}\left[\exp(-\lambda_{^{79}\text{Sr}}t) - \exp(-\lambda_{^{79}\text{Rb}}t)\right]. \tag{3}$$

The experiment measured the activity of ^{79}Rb which is related to $N_{^{79}\text{Rb}}(t)$ by

$$A_{^{79}\text{Rb}}(t) = \lambda_{^{79}\text{Rb}}N_{^{79}\text{Rb}}(t). \tag{4}$$

The half-life is defined as the time taken for the number of atoms to halve from an initial value,

$$N(t_{1/2}) = \frac{N(0)}{2} = N(0)e^{-\lambda t_{1/2}}. \tag{5}$$

This can be solved and related to the decay constant;

$$t_{1/2} = \frac{\ln(2)}{\lambda}. \tag{6}$$

2 Project description

In the experiment two detectors were used in alternating intervals of 10 minutes, you can find the data they produced in the files `Nuclear_data_1.csv` and `Nuclear_data_2.csv`. There are some faulty measurements which you will also have to filter. Note that the time measurements are recorded in hours and the activity in TBq (10^{12} decays per second). Previous studies suggest that $\lambda_{^{79}\mathrm{Rb}}$ & $\lambda_{^{79}\mathrm{Sr}}$ are 0.0005 and 0.005 s^{-1} respectively.

To find both the decay constants you must write a program that performs a minimised χ^2 fit on equation 4 against the data. This is non-linear and dependent on two parameters, $\lambda_{^{79}\mathrm{Rb}}$ & $\lambda_{^{79}\mathrm{Sr}}$.

Do not attempt to turn the fit into a linear problem and do not try and fit the parameters separately.

Your program should:

- Read in, validate, and combine both data files. Ideally[1] using inbuilt functions.
- Perform a minimised χ^2 fit by varying $\lambda_{^{79}\mathrm{Rb}}$ & $\lambda_{^{79}\mathrm{Sr}}$. Ideally using inbuilt functions.
- Calculate both $\lambda_{^{79}\mathrm{Rb}}$ & $\lambda_{^{79}\mathrm{Sr}}$ to 3 significant figures in s^{-1}.
- Calculate both $t_{1/2,^{79}\mathrm{Rb}}$ & $t_{1/2,^{79}\mathrm{Sr}}$ to 3 significant figures in minutes.
- Calculate $\chi^2_{\mathrm{red.}}$ to 2 decimal places.
- Produce a useful plot of your result.
- Ideally you should also find the uncertainty on the decay constants and half-lives.

With regards to style, in addition to the previous two assignments, we expect your code:

- To make plots by attaching axes attributes to a figure object.
- Save any plots as a `.png` file.

Additional marks are available for extra features. You do not need to include them all to get full marks for this aspect. Can you display extra information in these plots? Can you format these plots nicely? Could it be applied to different data files with *different validation issues*? Can you make the initial guess on the decay constants general?

[1] All cases marked *ideally* mean there will be a small deduction if this is not done.