Half life of Protaktinium

Data acquisition (TI83/TI84)

Before setting up the experiment make sure that you have the program DATARAD in your TI-83 calculator. If not download DATARAD.
Remark: If you are using the old CBL you must use the program RADIATIN instead.

Connect the Radiation Monitor to the calculator. Be sure that you use the Dig/Sonic input.

Arrange your experimental setup so that the window of the GM-tube points towards the upper layer of the Protactinium generator.

Start the program DATARAD. After the start screen you arrive at the menu screen where your choices are:
1 SETUP, 2: START, 3: GRAPH and 4: QUIT. Press 1 for SETUP.

In the SETUP MENU press 3 for TIME GRAPH.
In the TIME GRAPH SETTINGS MENU you have just two alternatives 1: OK and 2: CHANGE TIME SETTINGS.

When you run the experiment for the first time you have to choose alternative 2. Do so! We suggest the following settings: INTERVAL IN SECONDS: Enter 15 and NUMBER OF INTERVALS: Enter 20.
You are now back in the TIME GRAPH SETTINGS MENU. Press 1 for OK.

This brings you back to the menu screen where your choices are:
1 SETUP, 2: START, 3: GRAPH and 4: QUIT. Once more press 1 for SETUP.

In the SETUP MENU press 2 for BACKGROUND CORRECTION.
In the BACKGROUND CORRECTION SCREEN choose 1: PERFORM NOW.
Enter number of intervals: 20.
Follow the instructions given at the calculator screen. Be sure that the Radiation Monitor is ON and in position x1. Press ENTER to collect information about the background radiation. You will have to wait for 300 s (with these entries) while this is performed. When finished the number of counts per minute is presented. This background will be deducted automatically from the data in the main experiment.

Back in the SETUP MENU once more you choose 3: TIME GRAPH. In the TIME GRAPH SETTINGS MENU choose 1: OK

You are back in the MAIN MENU. You are almost ready to run the actual experiment.

Shake the Protactinium Generator strongly for about 10 seconds and put it in place in front of the Radiation Monitor as is described by the photo and text above. Wait for 100 seconds for the generator to form a layer of Protactinium at the top of the generator.
And now, finally, press 2: START.

When the experiment is finished the calculator screen will show a graph. The y-axis is the the number of counts per minute in each of the time intervals corrected for background radiation. The x-axis is the time in seconds.
Press ENTER on the calculator to return to the main screen. There, press 5: QUIT to leave the DATARAD program. Counts are stored in list L_2 and time data in list L_1.

If you are unable to perform the experiment there are files set up so that you can study the experiment and analyse previously collected data.

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Data sample -TI 83/TI84

L1.8xl L2.8xl

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Analysis using TI83/TI84

If you have any problems handling the graphing calculator help is available using the links that are underlined and highlighted in blue.

Time data (unit s) is in list L1 and number of counts per minute with background deducted in list L2.

Graph the number of counts per minute versus time in a Scatter plot.

Study the graph. Is it in agreement with your assumptions?

Looking at the data plot try to find out how long it will take until the number of counts per minute is half of the start value.

Is it possible to find a smooth function to fit the data? Try to figure out what kind of mathematical model it can be. Try to make an appropriate curve fit to decay data. Which regression equation do you find?

From the regression equation solve for the half life of this protactinium isotope. Is your value in accordance with the table value? If not try to figure out why.

The protactinium nucleus is beta active decaying with a negative beta particle. Write down the appropriate formula for the decay!

According to the theoretical model the decay rate is proportional to the number of nuclei that can decay. If you are able to do this, write down the appropriate differential equation that fits this statement and solve the differential equation. Is the solution in agreement with your experimental result?

When you have finished your work, but not before, you can compare your conclusions with the completed analysis.

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Completed analysis using TI83/TI84

The plot of the data set in file RAD is shown below. It is evident that the decay rate must decrease since the number of active nuclei will be less. After a while, that for many nuclei is a very long time, the decay rate will approach zero.
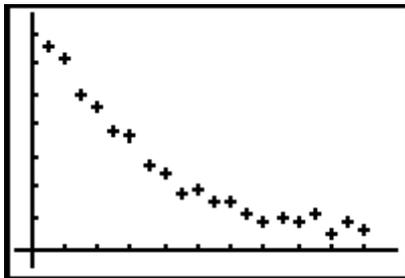

The tic marks on the y-axis is every 100 counts per minute and at the x-axis each 30 s.

By eye we try to fit a smooth curve to the data points. Such a smooth graph starts at time zero around 750 counts per minute. Half of this is 375. The smooth graph intersects an horizontal line at 375 counts per minute at approximately 70-80 seconds. The by eye inspection thus gives us a half life that is 70-80 seconds.

To fit a regression curve click STAT, CALC and choose exponential. Paste the regression equation into the Y= editor by adding Y1 as the last parameter.

The screen shot above gives the regression equation. The data points together with the regression curve appears below:
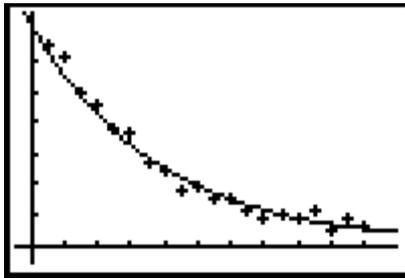
The half life can be found in a simple way by drawing another curve, namely a horizontal line at a level of half the start value i.e. 722/2. Then the intersection between the two functions can be found using the calculator. See the following screen shots:
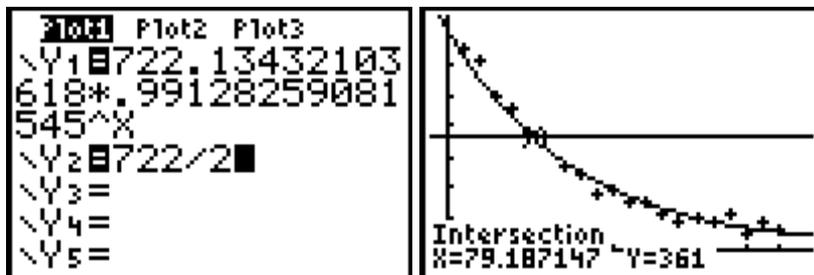
As can be seen in the right picture the half life is 79 s.

This value is in good agreement with the table value of 70 s. If you are using your own data and you find a less "accurate" value this is nothing to feel ashamed of. Since the decay is of statistical nature it is a minor coincidence that one single measurement gives as an accurate number.

The decay formula is as follows: $^{m\,234}_{91}Pa \rightarrow\ ^{234}_{92}U + \beta^- + \bar{\upsilon}$

Theoretical model:

If the number of active nuclei at a certain moment is N then the decay rate at that moment is $-\dfrac{dN}{dt}$. If you are annoyed by the negative sign make the following reflection. Since the function is decreasing the derivative is negative.

The decay rate is proportional to the number of active nuclei so $-\dfrac{dN}{dt} = \lambda \cdot N$, where λ is a positive constant. This differential equation has the solution $N = N_0 \cdot e^{-\lambda t}$, where N_0 is the number of nuclei at time zero. This is in agreement with our experimental result.

If T is the half life that is the time when the number of nuclei is half of the start value we get:

$$\frac{N_0}{2} = N_0 \cdot e^{-\lambda T}$$

Solving for T gives: $\frac{1}{2} = e^{-\lambda T} \Leftrightarrow \ln \frac{1}{2} = -\lambda \cdot T \Leftrightarrow -\ln 2 = -\lambda \cdot T \Leftrightarrow T = \frac{\ln 2}{\lambda}$.

Compare this to the numerical calculation above.

Comments:

The m in $^{m\,234}_{91}Pa$ means metastable. This isotope has a half life of 1.17 minutes.

This is an isomer of the $^{234}_{91}Pa$ isotope that has a half life of 6.70 h

You can find a nuclear chart with more information at the website:
http://nucleardata.nuclear.lu.se/nucleardata/charts.asp