A simple college experiment to measure half-life of ^{40}K using GM counter.

Abstract. This is a simple college experiment to measure the half-life of ^{40}K which is about 1.248 ± 0.003 billion years as given in literature. This experiment can be carried out without any standard radioactive sources, thereby, allowing the educational institutions to avoid the purchase of radioactive sources involving a lot of procedural steps. This experiment can be performed with standard KI salt available in the market.

Introduction: At college level it is very essential to conduct simple experiments which support theoretical topics being covered in the syllabus. Measuring life times of nuclei, which are in the range of billion years, can be a very attractive topic for college students.

In this experiment, KI salt available without requiring any permissions, from the market can be used to measure the half-life of ^{40}K.

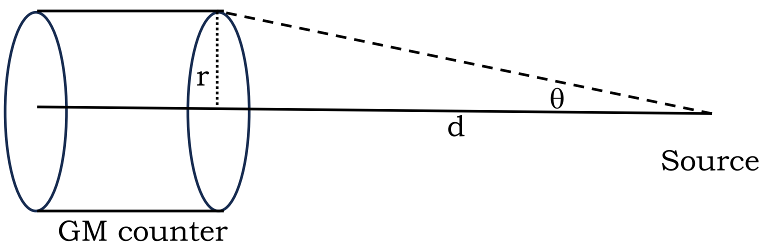
$\frac{dN}{dt} = -\lambda N$ is the standard equation where λ is the decay constant, N is the number of radioactive nuclei, which have not yet decayed and dN/dt is the rate at which nuclei are decaying.

dN/dt is the quantity which can be determined from the counts in a GM counter.

Experiment. In order to detect and count the beta particles, Geiger Muller Counter, of Nucleonix corporation, was used. The GM probe, of 2 cm radius and 8 cm length was used, operated at recommended 505 volts.

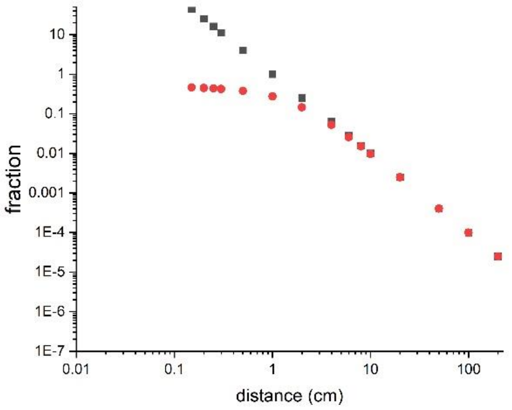
A small sample of KI was measured to have mass of 0.53 ± 0.01 g. Molecular mass of KI being 166.025g, implies $1.92 \pm 0.04 \times 10^{21}$ atoms of K. From literature, it is known that 0.0117% atoms belong to ^{40}K. Thus, N is determined to be $2.25 \pm 0.04 \times 10^{17}$ atoms of ^{40}K.

Once we determine the background counts, the sample is placed in such a way that it encompasses smallest area possible and at the same time has smallest thickness to avoid attenuation of β particles in the sample itself. Having counted for a certain period of time (around 9000 seconds) the background is subtracted; two factors are required to obtain the value of dN/dt.



First is the solid angle

If one assumes a point source at a distance d from the front face of the detector having radius r= 2 cm then the standard method is that the solid angle factor f is given by $f = \frac{\pi r^2}{4\pi d^2}$ However, this equation is not valid for small d values. For small values of d the solid angle factor f is given by a modified equation, $f_s = \frac{2\pi}{4}\left(1 - \frac{d}{\sqrt{d^2+r^2}}\right)$.



These functions plotted against distance d is shown in figure – 1.

Figure. 1 Plot of two factors as a function of d. The y axis is a ratio of the solid angle subtended divided by 4π, (the total solid angle). The x-axis is the distance between the source and the detector, in cm. The red curve shows f_s the modified version of equation for f.

Here it can be seen that for large values of d, the source can be treated as point source and the two equations match.

But for small values of d, the factor approaches the value of 0.5 which is half of the full solid angle of 4π.

It can be seen that for the distance beyond d= 2r (the diameter of the GM tube) the two equations are nearly in agreement. Thus, for distances less than the diameter of the tube, the standard equation is not valid anymore and the modified version applies.

Second factor is the combination of efficiency of the detector and the amount of β particles that will reach the detector.

In literature the efficiency of β particle detection is listed as 0.97 whereas the same for γ is 0.03 [1].

When ^{40}K decays it decays 89% of the time to ^{40}Ca with 1.3 MeV beta and 11% of the time to ^{40}Ar, with around 0.45 MeV of beta followed by 1.46 MeV of gamma. Thus, the total detector efficiency is 0.89*0.97 + 0.11*0.97 + 0.11*0.03 = 0.9733 which we assume to be 1.0 for the purposes of the current study.

Experimental Data.

For different distances counts of KI decay were collected. The data is given in table 1. For this data collection the plastic cap in front of the GM probe was removed to reduce the attenuation by the plastic cap.

Background counts, 1582, were collected for 3009 seconds. Thus, background was 0.526 ± .013 counts/s. In table 2, the values in last two rows are after background subtraction.

Table 1. Data collected for various distances of KI source.

Sr No	1	2	3	4
Distance of source from front of the probe	4.1 cm	4.6 cm	5.5 cm	6.1 cm
Time (sec)	7719	49026	4700	4250
Counts	5537	34405	3091	2606
Cts/sec	.192	.176	.131	.087
Error	.016	.013	.018	.018

Note, the data for distance 4.6, was collected for more than 13 hours to indicate that there is not much change in the data collection, except for some reduction in the error.

Using these values of dN/dt, N and the half life were calculated using the expression, $t_{\frac{1}{2}} = \frac{0.693N}{\frac{dN}{dt}}$

The values of $t_{1/2}$ calculated are given in table 3.

Table 2. Values of $t_{1/2}$ as a function of distance d.

Sr. No	Distance d (cm)	$t_{1/2}$ (10^9 years)
1	4.1	1.31 ± .11
2	4.6	1.16 ± .10
3	5.5	1.13 ± .15
4	6.1	1.38 ± .29

It is very clear that for smaller distances the geometry is not that of a point source as 0.5 g of KI source has to be given because the source is spread in the shape of a thin disk. This is to avoid self-attenuation of β over the thickness of the sample.

It is clear from figure 1 that the source should be kept at a d greater diameter of the GM tube, so that it can be treated as a point source.

It is clear from Table 1, at a distance of 6.1 cm the counts are 0.087 counts/sec, above the background of 0.5 counts per second. For distances greater than 6.1 cm the counts merge with background.

The weighted average of the half life values measured for distances between 4 and 6.1 cm is 1.21 ± .06 x 10^9 years.

Conclusion.

In this work we have demonstrated that a nuclear physics experiment to measure half life, is possible using commonly available radioactive isotope of ^{40}K. The salt used is KI, which is not considered hazardous.

The source is to be kept between a distance of 1 to 1.5 times the diameter of the GM tube for effective counting.

Reference.

1 . Ref :
https://www.vernier.com/files/innovate/determining_the_efficiency_of_a_geiger-mueller_tube.pdf