Spectroscopy of Alpha Particles

Serdar Ali Andırınlıoğlu

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1 Introduction

In this experiment energy spectrum of α particles emitted from ^{226}Ra will be investigated. Also an unknown α source will be identified together with its activity.

2 Theory

The forces that holds nucleus together is much more stronger then the repulsive force between protons in the nucleus, however the strong nuclear force is also very short-range and beyond 1 femtometer drops down very quickly. In a nucleus with more than 210 or more nucleon, strong nuclear forces nearly balances the counter electromagnetic forces. In such systems, in order for an atom to reduce the size of the nucleus and become more stable, the alpha decay can be observed. It must be pointed out that this process is spontaneous, meaning it does not require any force outside.

Alpha particle is essentially the helium nuclei consisting of two protons and two neutrons. Classically, in order to bring the alpha particle near the nucleus to a point at "infinity" would require 25MeV. However decay alpha particles have energies around 6MeV. So this system can be considered as a finite potential well problem with particle energy lower then the potential barrier. Classically such particle is not allowed to leave the nucleus, however quantum mechanically the wave function ψ that represents the particle is non-zero in an interval on the half line (in 1-d problem) in which the measure of the interval is non-zero. Thus, the probabilistic interpretation gives us a non-zero probability of finding the particle outside of the interval, or the nucleus.

That brings up the concept of radioactivity. It is when a nucleus emits an α or β particle. It obeys the exponential law

$$N = N_0 e^{\lambda t} \tag{1}$$

Where $N$is the number of atoms present at the system at time t, N_0 is the initial number of atoms present and λ is the decay (disintegration) constant.

From these radioactivity R can be defined as following

$$R = -\frac{dN}{dt} = N\lambda \tag{2}$$

The unit of R is becquerel (Bq) and 1bq = 1 event/s

From these another important quantity can be defined, namely the half life $t_{1/2}$. It is defined as the time required so that the radioactivity of a sample of atoms decreases by half. Since the radioactivity is proportional to the number of atoms present a specific time, substituting $N = N_0/2$ and $t = t_{1/2}$ to the equation (2) yields the following

$$t_{1/2} = \frac{ln2}{\lambda} = \frac{0.693}{\lambda} \tag{3}$$

The disintegration process of α-decay can be given schematically as follows

$$ {}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X} \rightarrow {}^{\mathrm{A-4}}_{\mathrm{Z-2}}\mathrm{Y} + {}^{4}_{2}\mathrm{He} \tag{4} $$

Where X, Y and He represents the mother nucleus, daughter nucleus and the α particles respectively. It can be seen that the daughter nucleus has a smaller radius, mass number. Thus daughter nucleus is more stable than the mother nucleus. From energy conservation principle the following equality can be easily derived

$$ K_\alpha = \frac{A-4}{A} Q \tag{5} $$

Where K_α is the kinetic energy of the alpha particle and Q is the disintegration energy. It can be concluded that the most of the disintegration energy is taken by the α particle.

In contrast to the β-decay, α particles have definite, discreet energies. Inspecting an alpha particles energies, would yield a few distinct energy lines. That means every alpha source has its own characteristic alpha spectrum thus an unknown source may be identified.

Since the alpha particles are positively charged, when an alpha particle interacts with an object it has a high probability to ionize them by taking electrons. And because of their high mass, it has the least penetration power when compared with β or γ-decays.

3 Experiment Setup

As mentioned above, since alpha particles can not penetrate when interacting with objects. To measure the energies of the alpha particles such interactions must be prevented. That is why alpha source is placed in a vacuum tube. A digital measurement device is connected to the tube. Between those a pre-amplifier placed to enhance the signal. Energies of α particles assigned channels in a linear fashion.

The digital measurement device is a silicone radiation detector and its working principle can be explained as follows: cell of a silicone detector consist of mainly three parts. N-doped p-doped silicone and pn junction side. P side has an excess of positive charges and N side consist of negatively charged atoms. When alpha particles strikes on the junction region, it causes diffusion of electrons in the p-type region and holes in n-type region since the alpha particles are highly ionizing. The potential drop across the junction region causes a drift current opposite to the diffusion current. The equilibrium will be reached when the potential drop prevents further junction[2]. This built in potential is called reverse-bias voltage. Junction formation can be seen below.

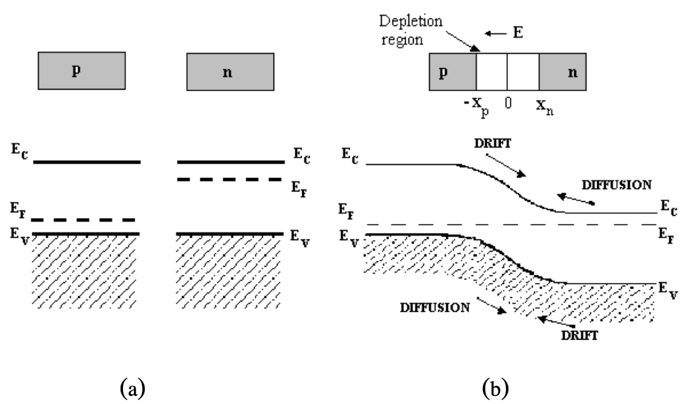


Figure 1: Bond diagram (a) uniformly doped p-type and n-type silicone (b) after the junction formation.

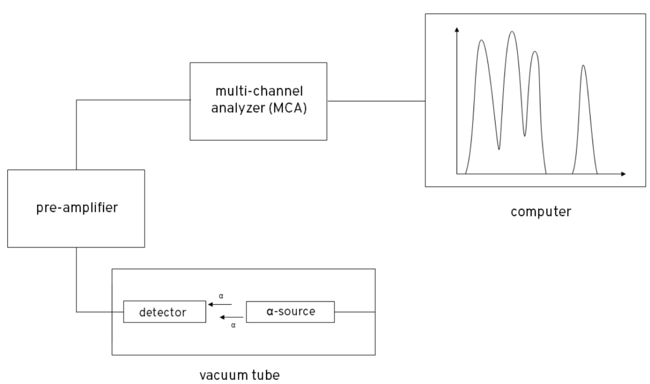


Figure 2: Schematic diagram of the experiment setup

4 Data & Measurements

Peak (channel no.)	Source of α particles	Energy (keV)
851	^{226}Ra	4780
1072	^{222}Rn	5385
1297	^{218}Po	6001
1910	^{214}Po	7680

Table 1: Resolved peaks in the spectrum of ^{226}Ra in vacuum.

Since energies assigned in a linear fashion, a general line formula can be found to determine the peaks as following

$$slope = \frac{y_2 - y_1}{x_2 - x_1} = \frac{E_{lastrow} - E_{firstrow}}{Ch\#_{lastrow} - Ch\#_{firstrow}} = \frac{7680 - 4780}{1910 - 851} = 2.74 \tag{6}$$

So general line equation is

$$y = 2.74x + 2450 \tag{7}$$

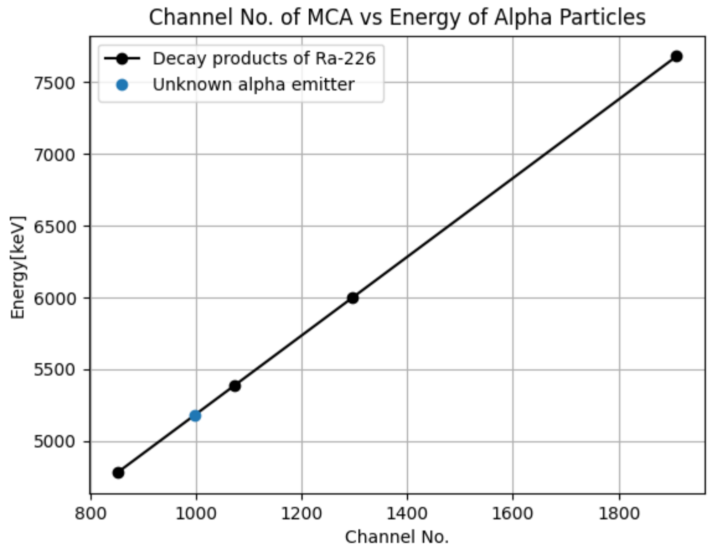
For the unknown alpha emitter with the equation (7) above, the measurement yields

Peak channel no.	Energy (keV)	Source of alpha particle
997	5180	^{241}Am

Table 2: Data for unknown alpha source in the vacuum.

The Source of alpha particle is found from the table below.

Energy	Intensity	Parent
5173	0.227 *7*	^{228}Th(1.9131 y)
~5173		^{242}Am(141 y)
5173.7		^{242}Am(141 y)
5175 *4*	0.21 *6*	^{210}At(8.1 h)
5179 *3*	2.6×10^{-3} *2*	^{211}Rn(14.6 h)
5179.34 *13*	0.0003	^{241}Am(432.2 y)
5180.6 *40*	0.00120 *24*	^{227}Th(18.72 d)
5181 *5*	0.084 *15*	^{190}Pb(1.2 m)
5181 *2*	0.0011	^{218}Po(3.10 m)
5181 *1*	1.1	^{243}Am(7370 y)
5181.64 *13*	0.0009	^{241}Am(432.2 y)
5183 *3*	0.5 *2*	^{230}Pa(17.4 d)
5184	0.61 *6*	^{214}Bi(19.9 m)
5188 *3*	5.2×10^{-5} *15*	^{242}Cm(162.8 d)



5 Discussion

The unknown α source is guessed with the following things in mind. Firstly since this α source held by naked hand, the activity of the sample can not be to high. This suggest that the half life of the sample can not be too low. Secondly since this experiment conducted in a modest laboratory the resolution of the silicone detector is not exceptionally high and noises can not be cancelled. This situation suggest that the α emitter's half life can not be too low. Among the suspected atoms, the ^{241}Am isotope suits best to the expectations.

Given the fact that the particle that is being used is also ^{241}Am but with a different energy of alpha particles. The percentage error is as following

$$\left| \frac{E_{experimental} - E_{excepted}}{E_{excepted}} \right| \times 100 = \left| \frac{5486 - 5018}{5486} \right| \times 100 = 5.57\% \tag{8}$$

The error in this experiment can be reduced using a better vacuum tube. Since the presence of molecules in air decreases the possibility of α particles to reach the detector thus reduces the resolution. Also using a better quality (i.e high density pn junction cells) silicone detector might be used to decrease the error. To overcome the random error, the measuring time might also be increased. It must be pointed out that the peak points is selected with naked eye, a simple maximum point calculator would have fixed the issue. Since the error percentage is very low, it can be said the main problem is selecting the peak points with naked eye.

Lastly a possible use of Americanium-241 can be shown as the smoke detection. In such smoke detectors, ^{241}Am ionizes the air molecule inside of the smoke detector and creates a current flow between the anode and cathode in the detector[3]. When however the smoke fills in between the anode and the cathode plates, it intercepts the current flow and such interception triggers the alarm.

6 References

1-https://en.wikipedia.org/wiki/Alpha-decay
2-https://hep.ph.liv.ac.uk/gcasse/THESIS/chap2.pdf
3-https://www.epa.gov/radtown/americium-ionization-smoke-detectors