DETERMINATION OF ENERGY LOSS CHARACTERISTIC IN DIFFERENT DENSITY MATERIALS BY ALPHA SPECTROSCOPIC SYSTEM

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Abstract

Nowadays, alpha Spectroscopy system is very popular and widely used radionuclide assay method in human resources and various research topics. The alpha particles are emitted from the well of the nucleus. Alpha spectroscopy is important role in the identification of radioisotope, radiation protection and radiation therapy in which alpha particle have the ability to deliver their energies to the target. In this research work, characteristics of α-radiation in different density materials were investigated by using silicon semiconductor detector and α-radiation sources: ^{241} Am and ^{226}Ra. In the present study, the measurement of alpha spectroscopy was performed for the determination of α-radiation characteristic such as energy loss, range, stopping power and effective path length not only in air medium but also in aluminum (Al) and gold (Au) foils samples of 8μm and 2μm respectively. Radionuclide Identification (RID) program is created in this research work. The measured spectra were analyzed by using this program based on the CASSY Lab and MATLAB software packages. Moreover, the experimental results data were compared with the theoretical calculated values by using Geiger Law, Bragg's Law and Bethe-Bloch formula. The results data from the measurement were found in good agreement with the theoretical values less than 10%.

Keywords- α-spectroscopy, Bethe-Bloch, Bragg Curve, CASSY Lab, Energy loss, Geiger Law, MATLAB, Range, Silicon Semiconductor, Stopping Power.

Introduction

Alpha particles were first described in the investigations of radioactivity by Ernest Rutherford in 1899, and by 1907 the identified as He^{2+} ions. By 1928, George Gamow had solved the theory of alpha decay via tunneling. The alpha particles trapped in a potential well by the nucleus. In the classical sense, escaping is not allowed. However, based on the recently uncovered principles of quantum mechanics, there exists a minuscule chance of "tunning" through the barrier and emerging on the opposite side to exit the nucleus.[6]

Gamow tacked a theoretical potential model for nucleus. He deduced a connection between the half-life and the emission of energy from fundamental principles. This relation was observed empirically before and was called the Geiger-Nuttal Law. Americium -241, an alpha-emitting substance finds use in smoke detectors. These alpha particles cause air to become ionized within an open chamber, leading to a slight flow of current through the ionized air. Alpha decay offers a secure energy supply for radioscope thermoelectric generators applied in space missions and was also utilized in artificial heart pacemakers. Alpha decay is more effectively blocked compared to other types of radioactive decay. In the case of static eliminators, they commonly employ polonium-210, an alpha emitting material, to ionize the air [4].

AIM

The aim of this research work is to investigate energies loss of alpha particles in gold and aluminum foils by using alpha spectroscopic method.

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Background Theory

Heavy charged particles, such as alpha particle, interact with matter primarily through coulomb forces between their positive charges of the orbital electrons within the absorber atoms. Although interactions of particle with nuclei (Rutherford scattering or alpha particle-induced reactions) are also possible, such encounters occur only rarely and they are not normally significant in the response of radiation detectors. Instead, charged particle detectors must rely on the results of interactions with electrons for their response.

The linear stopping power *S* for charged particles in a given absorber is simply defined as the differential energy loss for that particle within the material divided by the corresponding differential path length:

$$\mathrm{S} = -\frac{dE}{dx} \tag{1}$$

The value of *-dE/dx* along a particle track is also called its *specific energy loss* or, more casually, its "rate" of energy loss. Particles with a given charge state energy loss increases as the particle velocity is decreased. The classical expression that describes the specific energy loss is known as the Bethe formula and is written

$$-\frac{\mathrm{dE}}{\mathrm{dx}} = \frac{4\pi \mathrm{e}^4 \mathrm{z}^2}{\mathrm{m}_0 \mathrm{v}^2}\mathrm{NB} \tag{2}$$

where, $B = z\left[ln\frac{2m_0v^2}{I} - ln\left(1-\frac{v^2}{c^2}\right) - \frac{v^2}{c^2}\right]$

$$\frac{\mathrm{dE}}{\mathrm{dx}} = 4\pi \mathrm{r}_0^2 z^2\frac{\mathrm{mc}^2}{\beta^2}\mathrm{NZ}\left[\ln\left(\frac{2\mathrm{mc}^2}{I}\beta^2\gamma^2\right) - \beta^2\right] \tag{3}$$

In these expressions, *v* and *ze* are the velocity and charge of the primary particle, N and *Z* are the number density and atomic number of the absorber atoms, m_o is the electron rest mass, and *e* is the electronic charge. The parameter I represents the average excitation and ionization potential of the absorber and is normally treated as an experimentally determined parameter for each element.[8].

Energy Loss in Thin Absorbers

For thin absorbers (or detectors) that are penetrated by a given charged particle, the energy deposited within the absorber can be calculated from

$$\Delta E = -\left(\frac{dE}{dx}\right)_{avg} t \tag{4}$$

where, t is the absorber thickness and *(-d~/dx), ΔE* is the linear stopping power averaged over the particle-energy while in the absorber. The energy of α- particle is consumed after it has passed the path length:

$$R = \int_{E_0}^{0}\frac{dx}{dE}.dE \tag{5}$$

This range is a measure for the initial energy E_0 of α- particle. Empirically, the relation between E_0 and R is given by the *Geiger* law:

$$R \infty E_0^{\frac{3}{2}} \tag{6}$$

For air,

$$R_{air}[cm] = 0.46E_0^{\frac{3}{2}}\,(MeV) \tag{7}$$

Material And Method

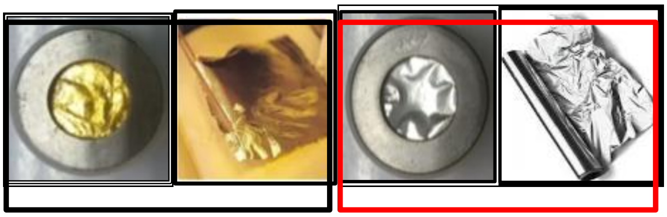
The experimental research was under alpha spectroscopy system, which installed at Nuclear Physics laboratory of the Department of Nuclear Physics in Défense Services Academy. In this alpha particle spectroscopy system, absorbers (gold and aluminium) and standard radioactive sources (^{241}Am and ^{226}Ra) were used. In this present research work, the alpha radiation sources of ^{241}Am and ^{226}Ra were used at Nuclear Physics Laboratory. The isotope Am-241 decays into Np-237 by emitting α-particle.

Table 1. Technical Data of Sources use in Experiment

Radioisotope	Decay mode	Decay energy [MeV]	Half-life [Years]
Americium-241	Alpha Gamma	5.468 0.059	432.2
Radium-226	Alpha Gamma	4.871 0.186	1600

(a) (b)

Figure.1 Standard Radioisotopes (a) ^{241}Am and (b) ^{226}Ra Source Preparation



(a) (b)

Figure2. Thin Absorbers (a) Gold Foil and (b) Aluminium Foil

Table 2. Technical Data of Aluminium and Gold Foils Used in Experiment

Properties	**Absorber Element Properties**	
Element	Al	Au
Atomic Number (Z)	13	79
Mass Number (A)	26	197
Density	2.7 g/cm^3	19.32 g/cm^3
Mean Ionization Potentials(I)	160 eV	771 eV
Thickness	8 µm	2 µm

For analysis of energy loss in different density materials by alpha spectroscopic method, the energy loss of the α radiation from the ^{241}Am and ^{226}Ra source are measured in the spectroscopy chamber in dependence on the air. Alpha spectrometer system also consists of vacuum chamber, vacuum pump, silicon-semiconductor detector, discriminator preamplifier, sensor CASSY with multichannel analyzer (MCA) and computer installed CASSY Lab spectrum analysis software or implemented RID program. Schematic diagram of alpha spectrometer shown in figure3.

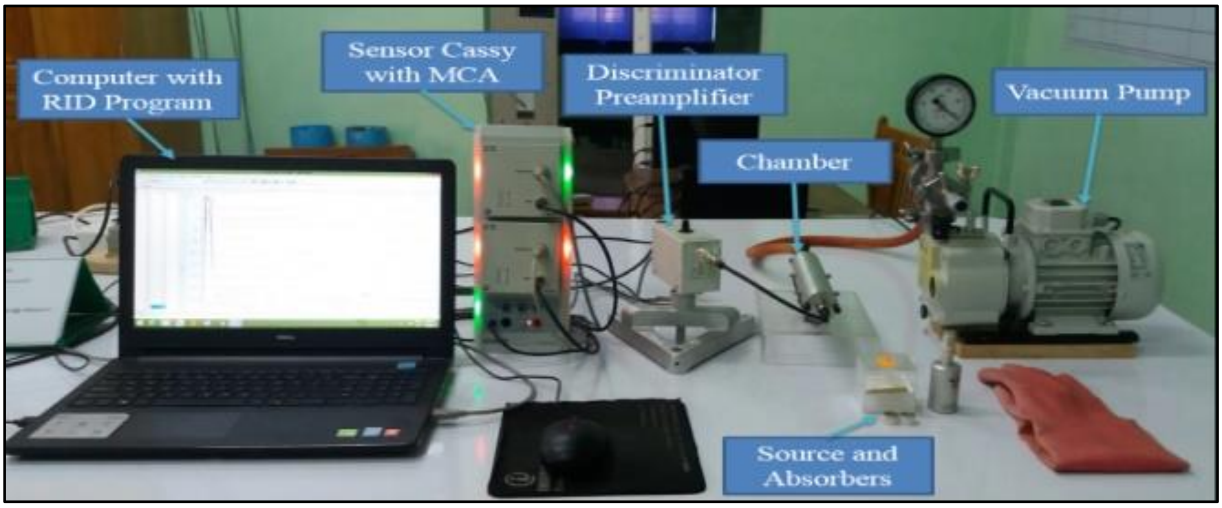


Figure3. Experimental Setup of Alpha Spectroscopic Measurement

Applied Programs of Radionuclide Identification (RID) for Analysis of Energy Loss of Alpha Particles

Experimental design of radionuclide identification system is constructed in Nuclear Physics Laboratory, Department of Nuclear Physics at Defence Services Academy. This system is the identification and concentration analysis system, which is based on the gamma and alpha spectroscopy measurement systems. In this present research work, the measurement and analysis programs were created for alpha spectroscopic measurements of standard sample, mineral ore sample and other research samples by using with the MATLAB software and CASSY modules.

(a) Measurement program for gamma radiation measurement based on NaI detector and detection assembly.

(b) Measurement program for alpha radiation measurement based on silicon semiconductor detector and detection assembly.

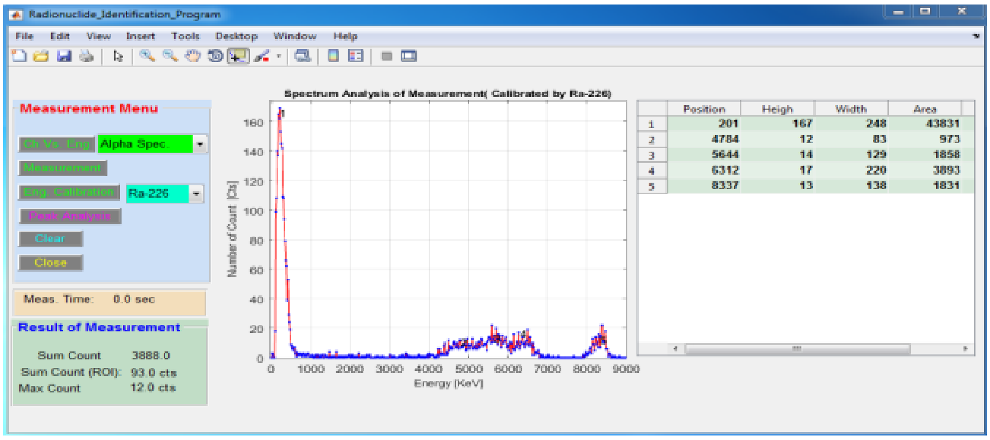


Figure 4. The Result Interface of in Peak Analysis Radionuclide Identification Program

Results And Discussion

In this experimental result of energy loss characteristics of Au and Al different densities materials by using with alpha spectroscopic system and created program based on CASSY Lab and MATLAB software packages are represented.

Energy loss of alpha particles for americium-241 source in air medium, in gold foil with mass thickness of 2 μm and 8 μm are determined in different air pressures. The gold foil and aluminum foil are suitable absorbers for determination of energy loss per unit distance, dE/dx measurements. The resolution of alpha particles energy in gold foil become poor and spectra are broadened than in the air medium due to the density and thickness of absorbing medium. The loss energy of alpha particle in gold foil for the entire energy range are measured and calculated.

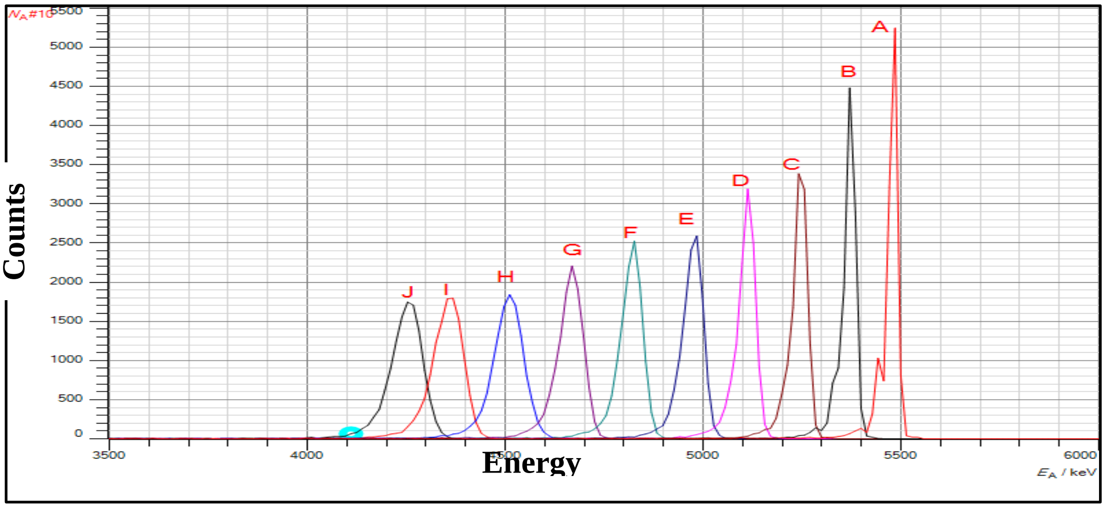


Figure 5. Measured Loss Energy of Alpha Particles in Air Medium (Without Absorber) Using Am-241 Source

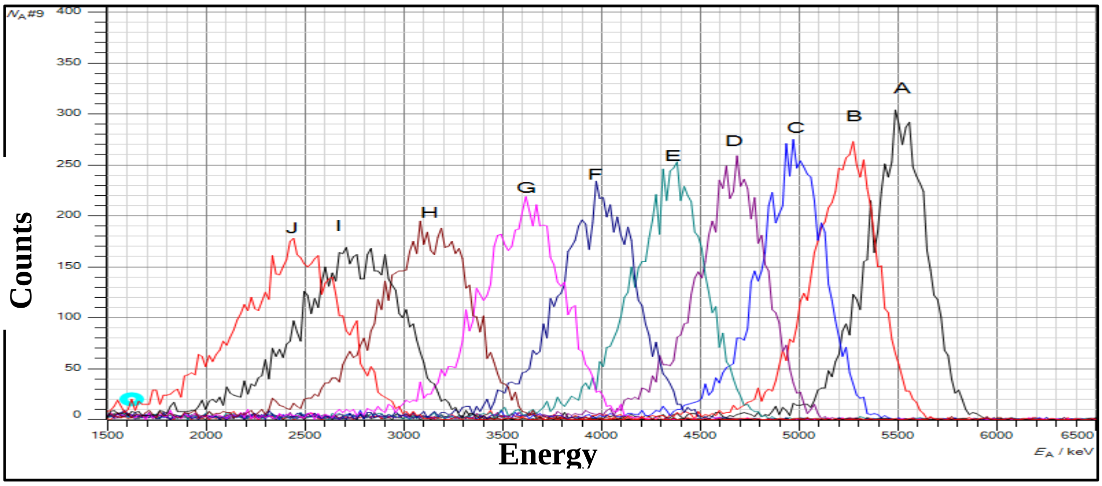


Figure 6. Measured Loss Energy of Alpha Particles in Gold Absorber Using Am-241 Source

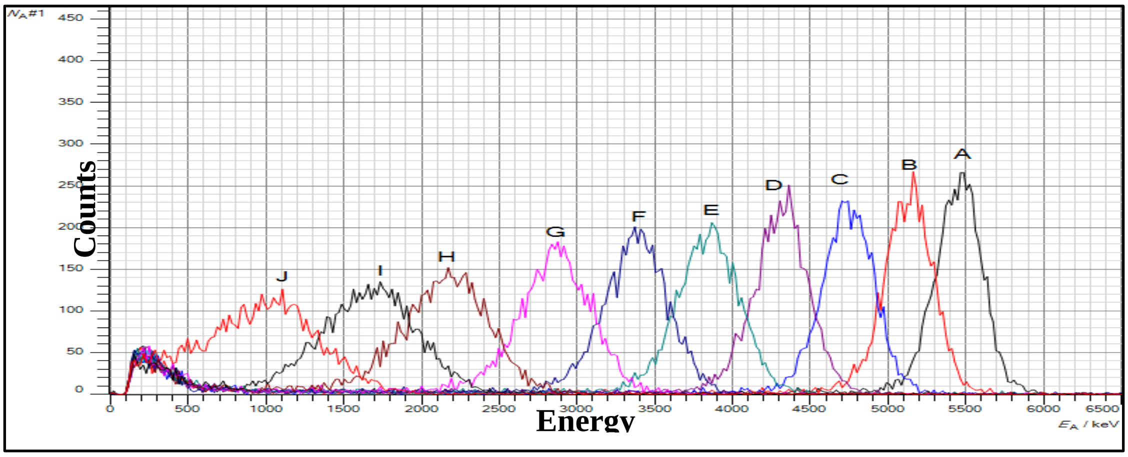


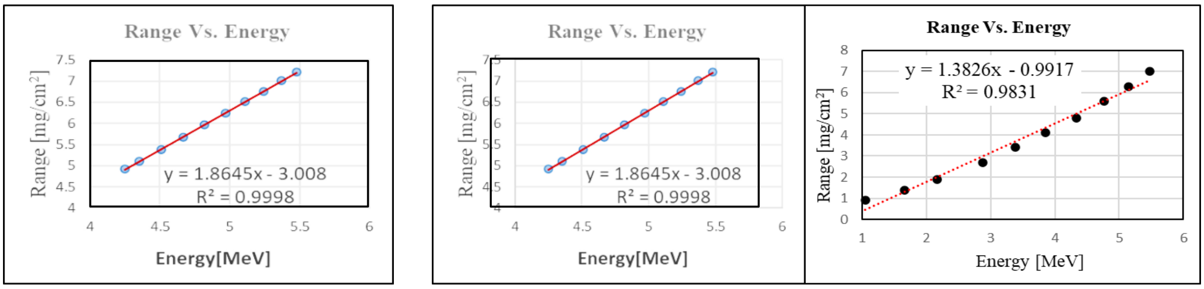
Figure 7. Measured Energy Loss of Alpha Particles in Aluminium Absorber Using Am-241 Source

Table 3. **Results Data of Range and Energy Relation of Alpha Particle in Gold Foil using Am-241 Source**

Pressure [mbar]	Energy [MeV]	Stopping Power [MeV/mg/cm^2]	Range [mg/cm^2]
100	5.4729	0.228	18.9
200	5.219	0.231	17.5
300	4.946	0.234	16.1
400	4.653	0.236	14.6
500	4.332	0.239	13
600	3.995	0.240	11.7
700	3.597	0.241	10
800	3.121	0.244	8
900	2.738	0.245	6.7
1000	2.428	0.255	5.7

Table 4. The Result Data of Range and Energy Relation of Alpha Particle in Aluminum Foil Using Am-241 Source

Pressure [mbar]	Energy [MeV]	Stopping Power [MeV/mg/cm^2]	Range [mg/cm^2]
100	5.4702	0.615	7
200	5.109	0.640	6.3
300	4.763	0.673	5.6
400	4.613	0.715	4.8
500	3.863	0.769	4.1
600	3.396	0.831	3.4
700	2.886	0.912	2.7
800	2.172	1.061	1.9
900	1.682	1.200	1.4
1000	1.074	1.398	0.9



(a) (b) (c)

Figure 8. Range and Energy Relation of Alpha Particle (a) in Air Medium (b) in Gold and (c) in Aluminium using Am-241 Source

Table 5. The results data of theoretical and experimental energy loss of alpha particle in gold and aluminium foils using Am-241 source

Curves	Pressure [mbar]	Foil Thickness of Al [mg/cm^2]	Foil Thickness of Au [mg/cm^2]	ΔE[MeV] in Al			ΔE[MeV] in Au		
				Meas. Energy Loss	Theory Energy Loss	Error %	Meas. Energ y Loss	Theory Energy Loss	Error %
A	100	2.16	3.86	0.0058	0.006	3	0.0031	0.003	3
B	200	2.16	3.86	0.216	0.232	6	0.151	0.153	1
C	300	2.16	3.86	0.478	0.454	5	0.295	0.303	2
D	400	2.16	3.86	0.499	0.545	8	0.459	0.454	1

Curves	**Pressure [mbar]**	**Foil Thickness of Al [mg/cm²]**	**Foil Thickness of Au [mg/cm²]**	**ΔE[MeV] in Al**			**ΔE[MeV] in Au**		
				Meas. Energy Loss	**Theory Energy Loss**	**Error %**	**Meas. Energ y Loss**	**Theory Energy Loss**	**Error %**
E	500	2.16	3.86	1.120	1.161	3	0.651	0.663	1
F	600	2.16	3.86	1.430	1.794	2	0.841	0.868	3
G	700	2.16	3.86	1.782	1.970	9	1.071	1.027	4
H	800	2.16	3.86	2.339	2.293	2	1.390	1.405	1.0
I	900	2.16	3.86	2.686	2.592	3	1.630	1.661	1.8
J	1000	2.16	3.86	3.193	3.019	5	1.839	1.793	2.5

Range of alpha particles for Ra-226 source in air medium, gold foil with mass thickness of 2µm and aluminum foil with thickness of 8µm are determined in different air pressures. The gold foil is suitable absorbers for determination of range R measurements. The resolution of alpha particles energy in gold foil become lower. The range of alpha particles in without absorbers in air pressures and the range of alpha particle in gold foil for the entire energy range are measured and calculated.

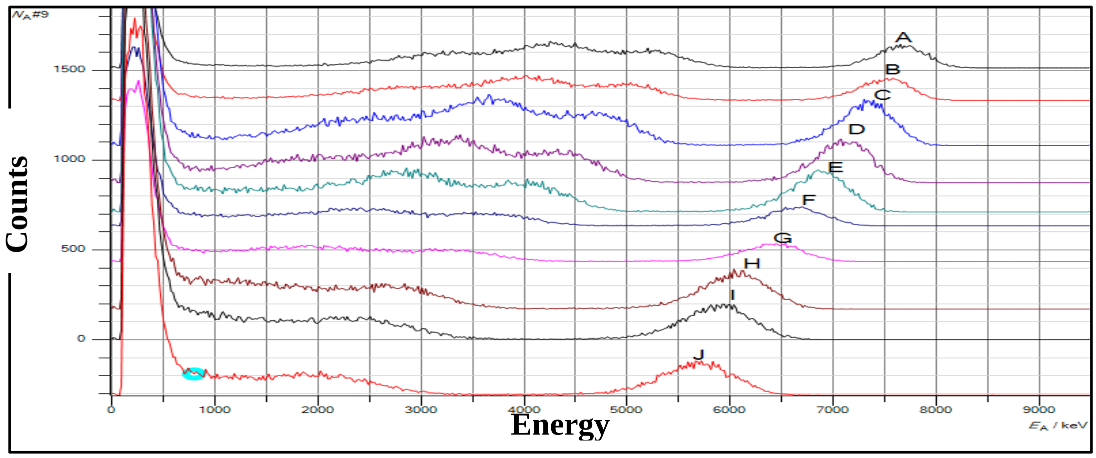


Figure 9. Energy loss of Alpha Particles in Gold Absorber Using Ra-226 Source

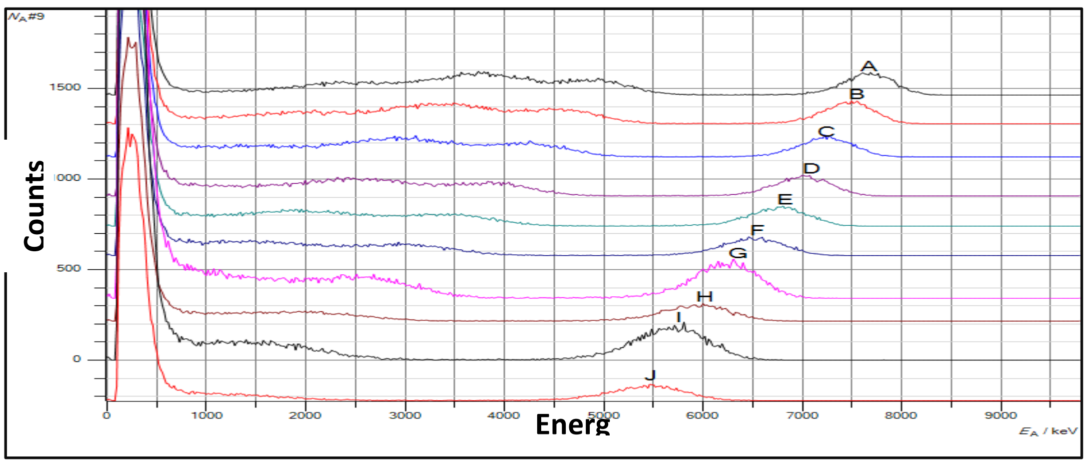


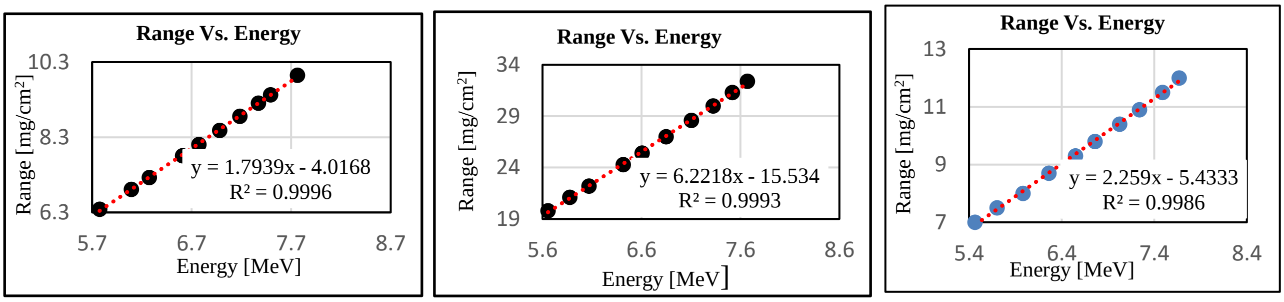
Figure 10. Energy loss of Alpha Particles in Aluminium Absorber Using Ra-226 Source

Table 6. Range and Energy Relation of Alpha Particles in Gold Foil at Different Pressure Using Ra-226 Source

Pressure [mbar]	Energy [MeV]	Range [mg/cm^2]
100	7.7601	32.4
200	7.381	31.3
300	7.262	30
400	7.074	28.6
500	6.861	27
600	6.646	25.4
700	6.480	24.3
800	6.149	22.2
900	5.975	21.1
1000	5.655	19.8

Table 7. Range and Energy Relation Graph of Alpha Particles in Aluminium Foil at Different Pressures Using Ra-226 Source

Pressure [mbar]	Energy [MeV]	Range [mg/cm^2]
100	7.7562	12
200	7.344	11.5
300	7.224	10.9
400	7.027	10.4
500	6.831	9.8
600	6.628	9.3
700	6.464	8.7
800	6.123	8
900	5.937	7.5
1000	5.615	7



(b) (c)

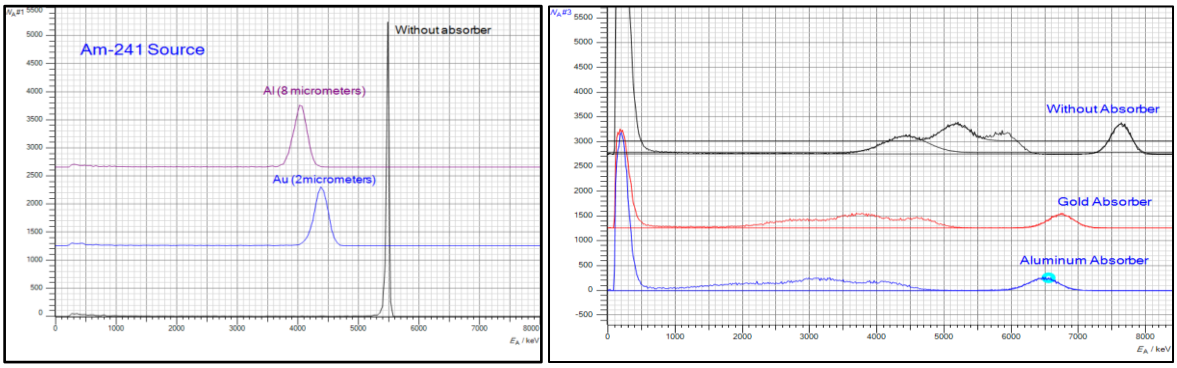
Figure 11. Range and Energy Relation of Alpha Particle (a) in Air Medium (b) in Gold and (c) in Aluminium using Ra-226 Source

Table 8. The Results Data of Theoretical and Experimental Energy Loss of Alpha Particle in Au and Al Foils using Ra-226 Source

Curves	Pressure [mbar]	Foil Thickness of Al [mg/cm^2]	Foil Thickness of Au [mg/cm^2]	ΔE[MeV] in Al			ΔE[MeV] in Au		
				Meas. Energy Loss	Theory Energy Loss	Error %	Meas. Energy Loss	Theory Energy Loss	Error %
A	100	2.16	3.86	0.0078	0.008	2.5	0.0039	0.004	2.5
B	200	2.16	3.86	0.148	0.150	1.3	0.111	0.115	3.4
C	300	2.16	3.86	0.148	0.154	3.8	0.110	0.116	5.1
D	400	2.16	3.86	0.159	0.157	1.2	0.112	0.117	4.2
E	500	2.16	3.86	0.151	0.161	6.2	0.121	0.119	1.6
F	600	2.16	3.86	0.145	0.165	12	0.127	0.121	4.9
G	700	2.16	3.86	0.144	0.170	15	0.128	0.122	4.9
H	800	2.16	3.86	0.152	0.175	13	0.126	0.124	1.6
I	900	2.16	3.86	0.157	0.181	13	0.119	0.125	4.8
J	1000	2.16	3.86	0.160	0.186	13.9	0.120	0.127	5.5

Comparison Results of Energy Loss of Alpha Particle in Gold and Aluminium Foils for Americium and Radium Sources at 100mbar

Energy loss of alpha particles in different absorbing media of gold and aluminium are compared for americium source. Measured energy loss spectra for the americium and radium sources in aluminium and gold are shown in Figures 12 (a) and (b). According to the results alpha particle energy loss is greater in aluminium foil than in gold foil due to greater absorber thickness. The calculated results for energy loss in gold and aluminium foils are shown in table 9. The relation between initial and final energy of alpha particles in gold and aluminium measured at 100mbar is shown in Figure 13. Stopping power of alpha particles in gold and aluminium is shown in Table 9. According to the results stopping power of alpha particles in gold is greater than in aluminium due to high atomic number of golds have greater chance to Coulomb interaction between the atoms.



(a) (b)

Figure 12. Energy Loss Spectra of Alpha Particles at 100 mbar using (a) Am-241 and (b) Ra-226 Source

Table 9. **Initial and Final Energy Relation of Alpha Particles and Energy Loss**

Elements	Without Absorber Energy [MeV]	After Passing Au Foil Energy [MeV]	After Passing Al Foil Energy [MeV]	Energy Loss in Au [MeV]	Energy Loss in Al [MeV]
Ra-226	4.777	3.154	2.450	1.623	2.327
Rn-222	5.249	4.288	3.380	0.961	1.869
Am-241	5.476	5.473	5.470	0.003	0.014
Po-218	5.980	5.327	4.992	0.653	0.988
Po-214	7.684	7.671	7.670	0.013	0.013

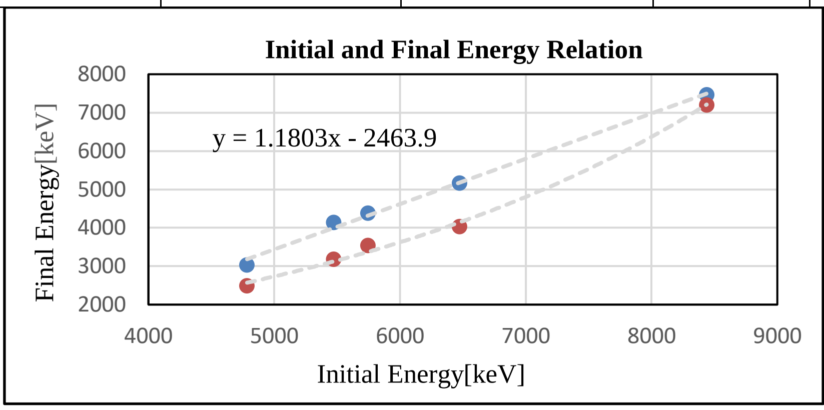


Figure 13. Initial and Final Energy Relationship of Alpha Particles at 100 mbar using Two Sources

Conclusion

In this research work, the alpha spectroscopic method was studied and determined the characteristics of alpha particles in the air and different absorbing medium of gold and aluminium foils using both two sources. Measurements were carried out using silicon semiconductor detector and the measured spectra are also analysed by RID program. In the present research work, the quantitative analysis of characteristics of alpha particles energy loss, range, stopping power and effective path length in air and in different density materials of Al and Au. The measured energy loss of alpha particles increases with an increase in the pressure inside the vacuum chamber. It was due to the reduction of air molecules in the vacuum chamber or in traversing path of the ions in the medium at higher pressures. This was resulted in a higher energy loss at high pressures or standard temperature and pressure. Further, the transmitted energy of alpha particles decreases exponentially as pressure decreases and that was resulted in the lower projected range of alpha particles. Measured energy loss and calculated energy loss, range and stopping power are also studied. In the case of transmitted energy of alpha particles increases the stopping power decreases exponentially. The measured energy loss characteristics are consistent with theoretical values. Experimental data of current experimental setup using with applied program are good in agreement with theoretical data. The current experimental research work could be used in determination of alpha energy and characteristics of energy loss in materials and also applied to radiation monitoring, safety, protection health physics and many other cases.

Finally, we conclude that the current experimental research work could be used in determination of alpha energy and characteristics of energy loss in materials and also applied to radiation safety and protection health physics.

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