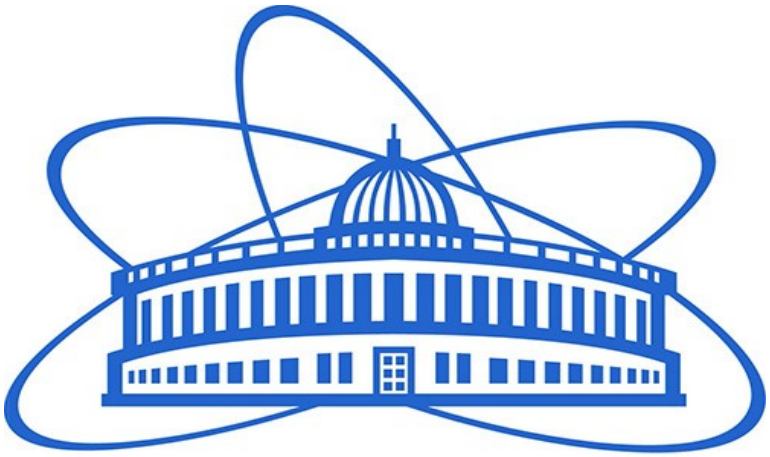
Determination of masses of the super heavy elements in the experiments on synthesis of Cn and Fl using the reactions 48Ca + 242Pu and 48Ca + 244Pu



JOINT INSTITUTE
FOR NUCLEAR RESEARCH

Name: Haitham Ashraf
Faculty of Science, Physics department, University of Science and Technology at Zewail city
Supervisor: Vyacheslav Vedeneyev
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Abstract

One of the main topics of current nuclear physics and chemistry revolves around the synthesis of superheavy elements and research of their chemical properties. For this reason, The MASHA facility was constructed at FLNR, JINR as to measure and determine the masses of superheavy elements (SHE) using classical mass spectrometry in conjunction with decay chain registration. The reactions 40Ar + 148Sm, 40Ar + 166Er, and 48Ca + 242Pu were selected for the investigation as they produce Hg and Rn, which have characteristics similar to SHE. This allows for a better understanding of the behaviour of SHE Cn, Fl, and Og atoms for future research at the facility.

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References

Introduction

The study of heavy elements revolves around examining the nuclear interaction and shell structure by which these elements exist. For this reason, many mass-spectrometric techniques and MASHA(mass analyzer of super-heavy atoms) setup were constructed and put into operation. The mass analyzer is used to estimate the mass-to-charge ratios of superheavy element isotopes to detect their α-decays energy peak and their spontaneous fission. The superheavy elements were synthesized by complete fusion reactions of accelerated 48Ca ions with targets of 238U, 242, 244 Pu,243 Am, 245,248 Cm, and 249 Cf. MASHA measures the beam energy and intensity precisely. The nuclei of superheavy elements undergo α-decays until the decay chain ends with spontaneous fission. Also, Masha is used to study the nuclei close to the N=126 neutron shell as these neutron-rich nuclei are produced in muti-nucleon transfer reactions where a target and catcher system is used.

MASHA Setup

Mass Analyzer of Super Heavy Atoms(MASHA). It was designed to perform accurate measurements of atomic masses of superheavy atoms. It's distinguished from other technologies by its ability to measure mass synthesized isotopes of heavy elements and to record their α-decays and spontaneous fission at the same time.
As seen in figure 1, The mass analyzer consists of 4 main parts: a target assembly with a hot catcher, an ion source that is based on electron cyclotron resonance, and an ion optics (D,Q,S) with the detection system.

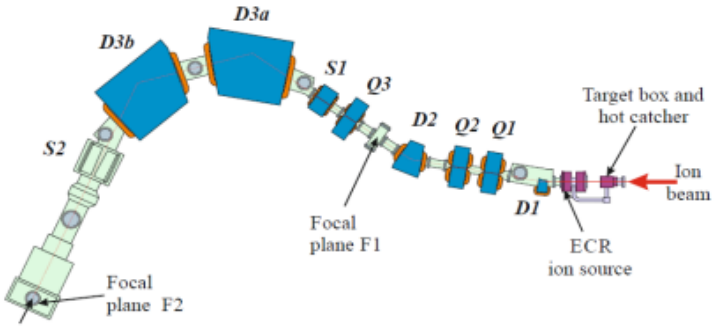


Figure 1: Mass-separator MASHA

2.1 Ion source

After nuclear fusion occurs, the resulting atoms are ionized by an ECR that contains a 2.45 GHz Microwave oscillator. Then they are accelerated up to 38 KeV by three-electrode electrostatic lenses, and then gathered into a beam. Then, the beam is separated by a magneto-optical mass-to-charge ratio analyzer. The ionization efficiency is about 90% for an

obtained noble gas. Noble gases such as Krypton and Xenon are used for optimizing ECR ion sources as their first ionization potential reaches maximum values.

2.2 Hot Catcher and Target Assembly

Hot catcher main function revolves around injecting the products of the complete fusion reaction into the ECR source. It is part of the target assembly, a full scheme of target assembly is shown in figure 2. Before the beam hits the target, it passes through a diagnostic system whose components are a split aperture, electrostatic induction sensor and a Faraday cup that are used to determine the intensity of the heavy ion primary beam. A split collimator of the four-sector split is installed in front of the pickup detector, its sectors are used to measure the portion of the beam current that does not pass through the hole of the aperture, which in turn could be used to control the beam position relative to the ion guide. The products of the fusion reaction go out of the target and pass through the separating foil, where they are later stopped in a graphite foil heated up to 1800-2000 k. Then, the products diffuse as atoms to reach the ECR source through pipeline.

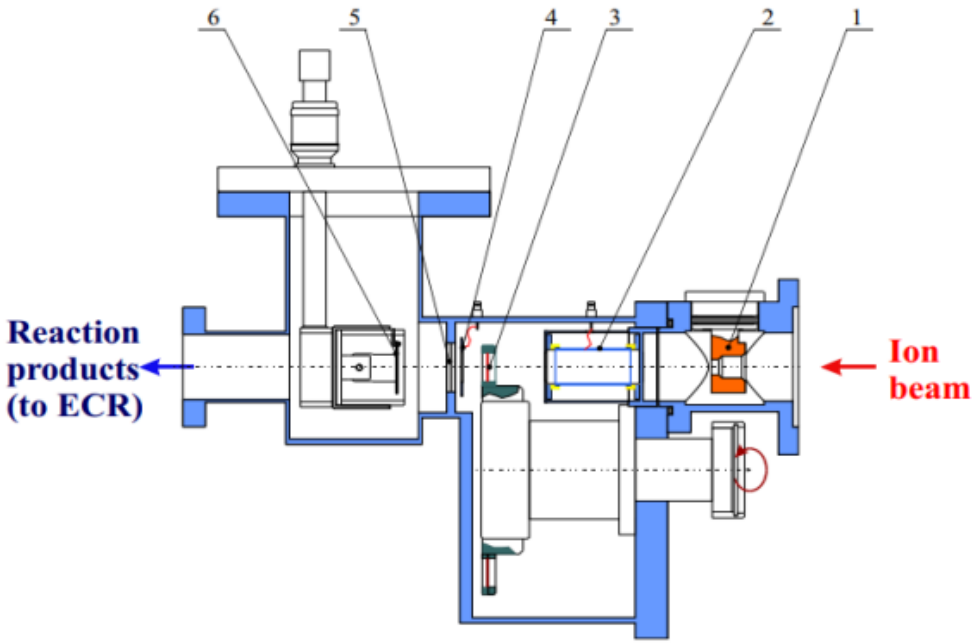


Figure 2 : Target-hot catcher system :(1) diaphragm, (2) pick-up sensor, (3) target on the wheel, (4) electron emission beam monitor, (5) separating foil, (6) hot catcher

2.3 Detection and Control System

The decaying of nuclear reaction products is detected by a silicon detector installed in the focal plane of the mass spectrometer. The frontal component of the detector consists of 192 strips that are oriented in a direction perpendicular to the beam. The side planes are divided into 64 for each side, whereas the latter planes are divided into 16 strips each. A scheme of the detector is shown in figure 3. This geometry of the detector assembly allows its detection capacity to reach 90% of particles emitted at the center of the detector in a singular nuclear decay. The program reads the signals of each strip independently, which in turn allows the

visualization of one-dimensional energy spectra from each strip, Also, it shows the dependency of the energy on the strip number per crystal.

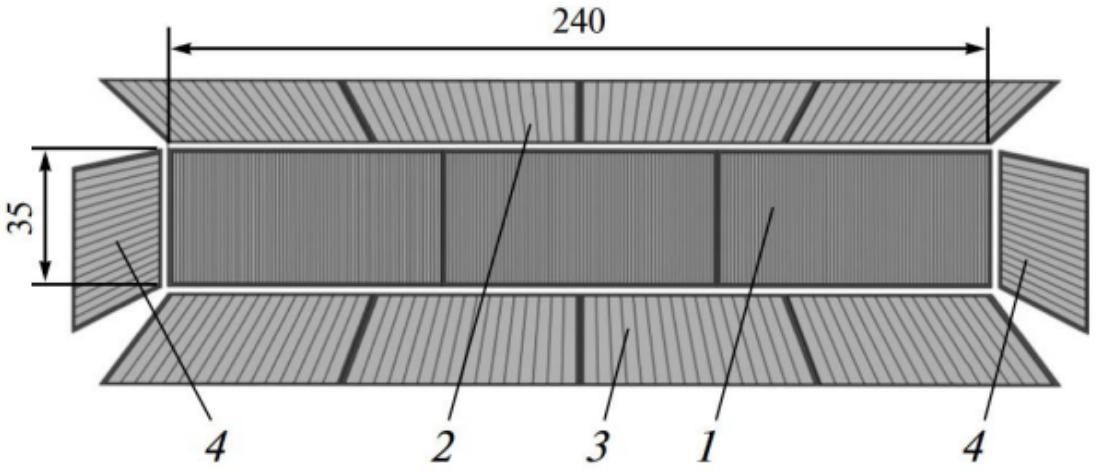


Figure 3. Frontal part (192 strips), (2) top part (64 strips), (3) bottom part (64 strips), and (4) side parts (16 strips in each).

3. Experimental Method

The U400M cyclotron accelerates a beam of 48 Ca til it hits the target with an energy of circa 7.3 MeV/n. Later, the beam is stopped by the graphite catcher at temperature 1800K as mentioned in the setup section. The beam intensity is controlled by Faraday cup. The energy of the decay reaction is measured and compared to the theoretical values. The mass of the atom is determined with a resolution of $\frac{M}{dM} = 1600$.

In the experiments, the detection would be to Hg isotopes because it is homolouge to the SHEs Cn and Fl.

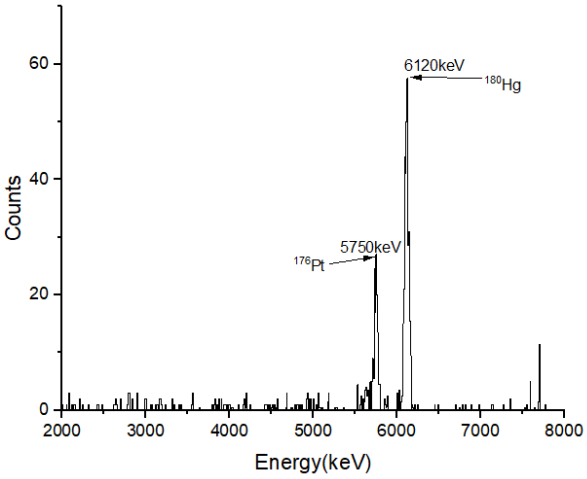
4. Results and Discussion

The synthesis of Hg and Rn will be studied by the three reactions (40 Ar+148Sm, 40Ar+166Er and 48Ca+242Pu). The spectrum from each isotope is plotted and further analysed, and a heat map for each reaction is done as to visualize the results.

4.1 $^{40}Ar + ^{144}Sm \rightarrow ^{188\text{-}xn}Hg + xn$

The reaction produces 6 different isotopes of mercury (^{180}Hg, ^{181}Hg, ^{182}Hg, ^{183}Hg, ^{184}Hg and ^{185}Hg). ‘x’ is a counter that takes values from 3 to 8, to span the different possible isotopes of Hg. This also means that the lost neutron is the product that evaporates during the reaction.

The spectrum of each isotope is detected by its release of energy. Figure 4 shows the peak energy of each spectrum for each isotope.



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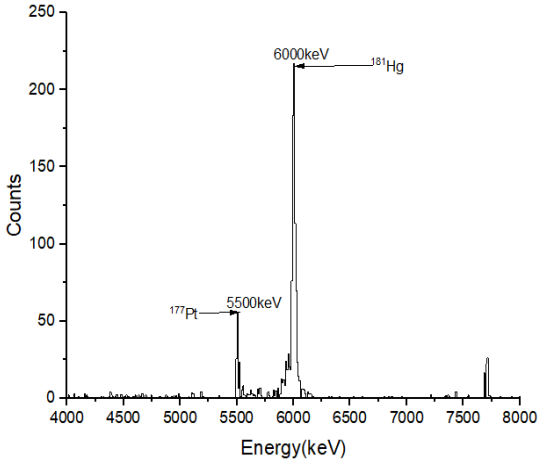

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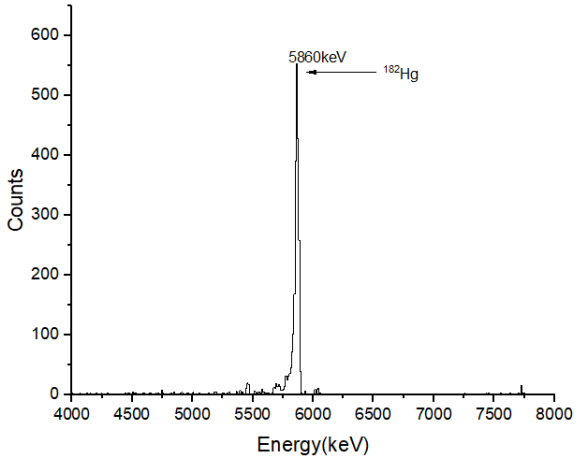

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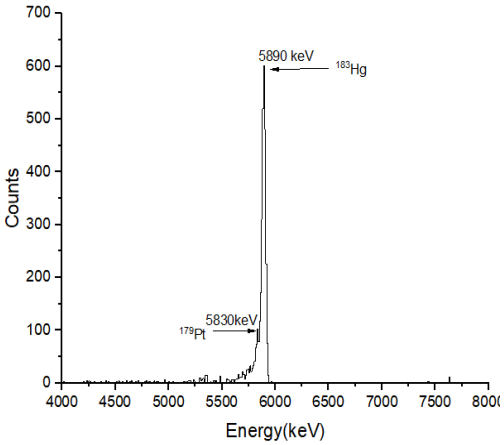

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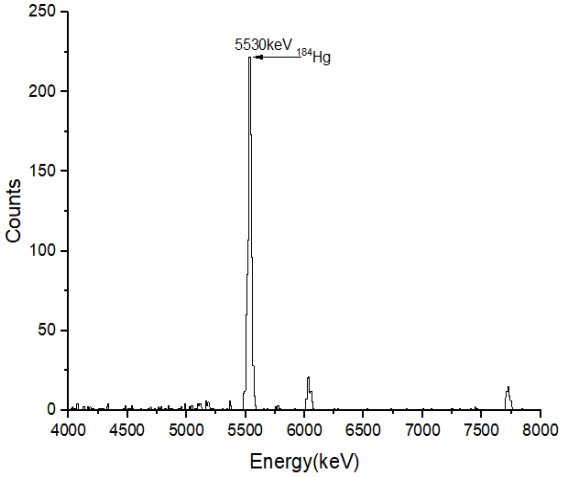

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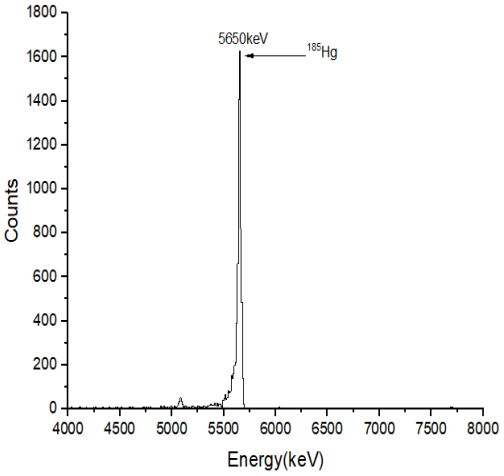

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Number	Isotope	$T_{1/2}$ (s)	E_{α} Exp(keV)	E_{α} Theo(keV)
1	^{180}Hg	2.59	6120	6258
2	^{181}Hg	3.6	6000	6284
3	^{182}Hg	10.83	5860	5996
4	^{183}Hg	9.4	5890	6039
5	^{184}Hg	30.87	5530	5660
6	^{185}Hg	49.1	5650	5773
7	^{176}Pt	6.33	5750	5884
8	^{177}Pt	10	5500	5642
9	^{179}Pt	21.2	5830	5814

Table 1: Comparison between the experimental and theoretical values of the energies between 40 Ar and 148Sm

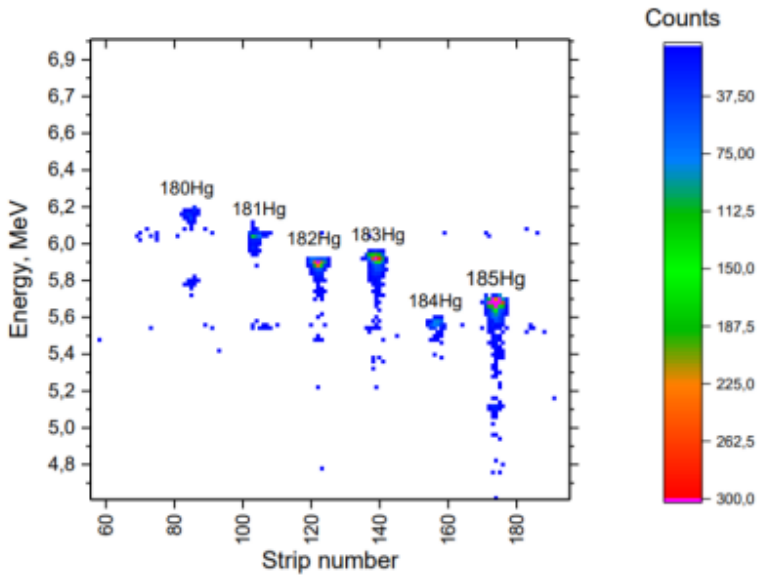
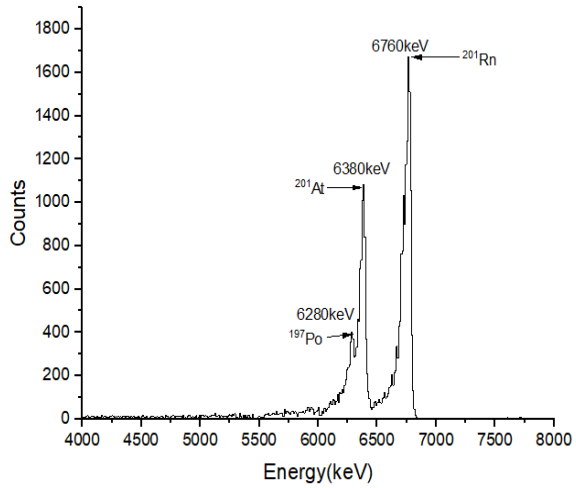


Figure 4: Energy and strip number plot of α-particles from different mercury isotopes

4.2 $^{40}Ar + {}^{166}Er \rightarrow {}^{206\text{-}xn}Rn + xn$

The reaction produces 5 different isotopes of Radon (^{201}Rn, ^{202}Rn, ^{203}Rn, ^{204}Rn and ^{205}Rn). 'x' is a counter that takes values from 1 to 5, to span the different possible isotopes of Rn.. The spectrum of each isotope is detected by its release of energy. Figure 5 shows the peak energy of each spectrum for each isotope.



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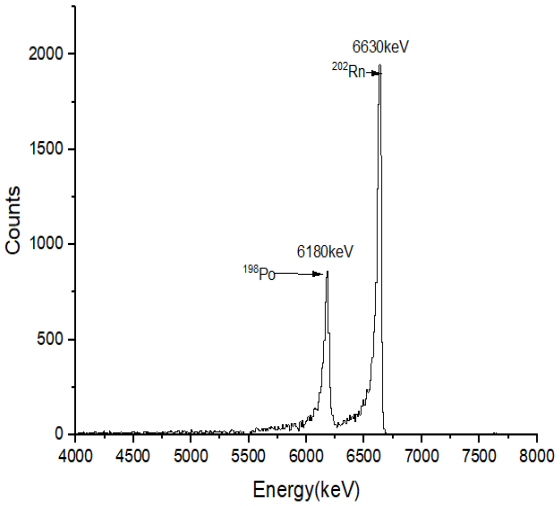

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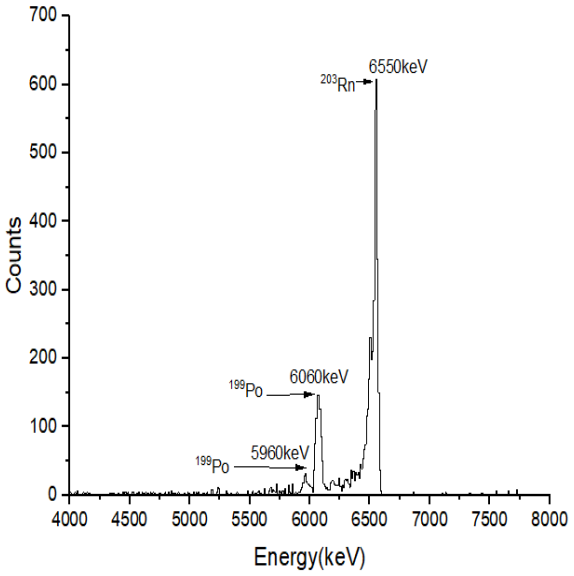

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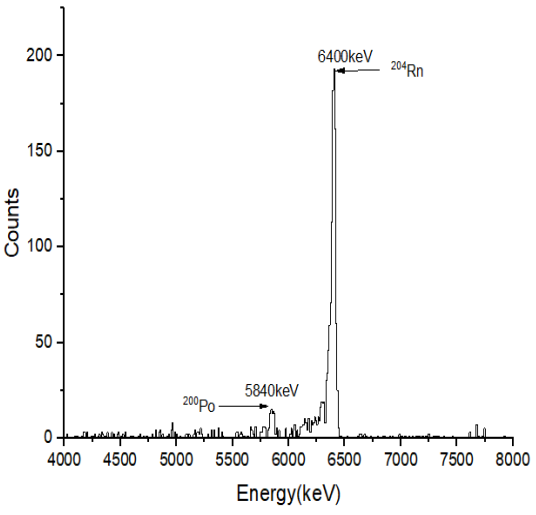

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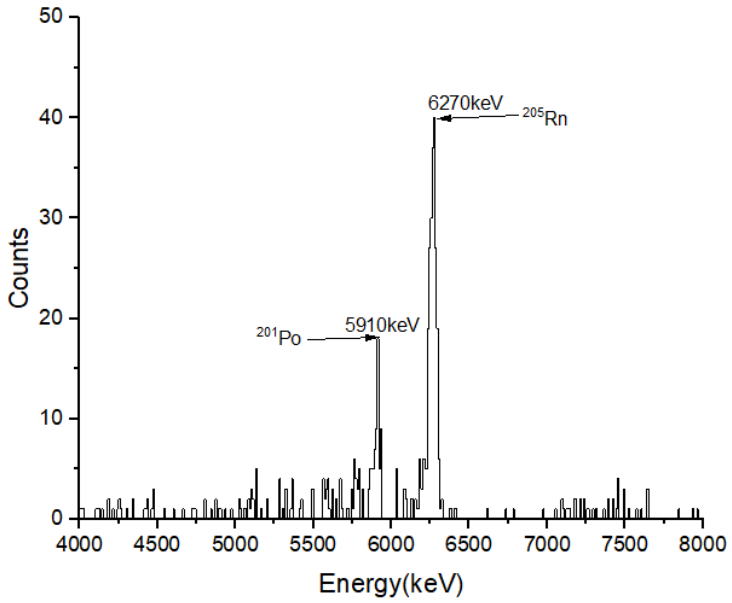


(e)

Table 2: Comparison between theoretical and experimental values of energies for 40 Ar and 166

Number	Isotope	$T_{1/2}$ (s)	E_α Exp(keV)	E_α Theo(keV)
1	^{201}Rn	7.1	6760	6860
2	^{202}Rn	10	6630	6773
3	^{203}Rn	45	6550	6630
4	^{204}Rn	75.4	6400	6546
5	^{205}Rn	170	6270	6386
6	^{197}Po	84	6280	6411

7	^{198}Po	105.6	6180	6309
8	^{199}Po	328	6060	6074
9	^{200}Po	691	5840	5981
10	^{201}Po	936	5910	5799
11	^{201}At	85.2	6380	6472

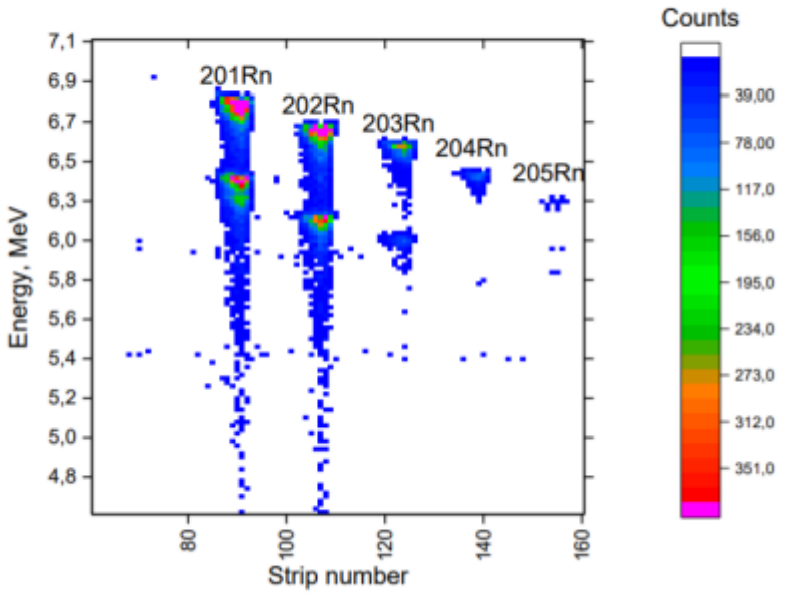
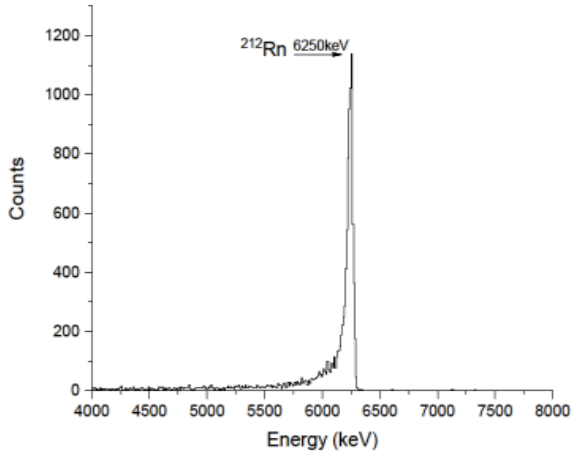


Figure 5: Energy and strip number plot of α-particles from different radon isotopes

Mutinucleaon reaction ^{48}Ca + ^{242}Pu → Rn

This process produces various isotopes of Flerovium (Z = 114), which decay to produce various Radon isotopes, which are detected. Figure 6 shows the sharpness of the peaks and the ease with which they can be identified



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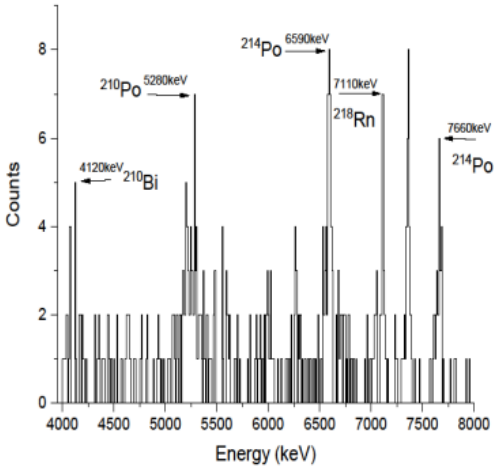

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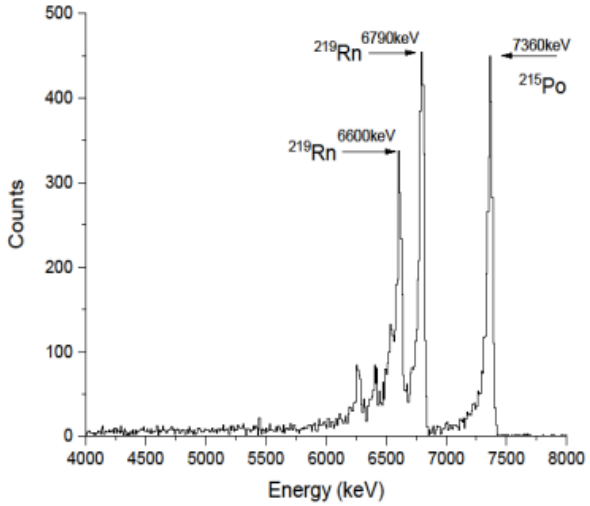

(c)

Number	Isotope	$T_{1/2}$ (s)	E_α Exp(keV)	E_α Theo(keV)
1	^{210}Bi	442368	4120	4100
2	^{210}Po	11955686	5280	5407
3	^{212}Rn	1434	6250	6385
4	^{214}Po	0.00016346	7660	7833
5	^{215}Po	0.001781	7360	7526

6	^{218}Rn	0.03375	7110	7262
7	^{219}Rn	3.96	6790	6946

Table 3:Comparison between theoretical and experimental values of energies for 48Ca and 242Pu reaction.

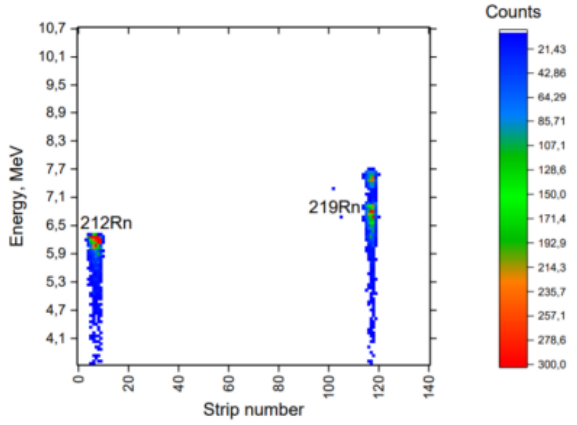

Figure 6: Energy and strip number plot of the α-particles from decays of radon isotopes

Conlusion

During the experiment, the energy spectra of the escaping α -particles were measured at the focal plane using the silicon detection system. The separation efficiency and time for mercury and radon isotopes produced by the reactions 40Ar +144 Sm, 40Ar +166 Er, and 48Ca + 242 Pu were determined. The data showed agreement within 7-9 keV between the experiment and the tabulated values, and was found to be in the 20-50 keV range.

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