ISSN No:-2456-2165

The Szilard-Chalmers Reaction

Anas Shehu
Sokoto State University

Abstract:- The aim of this experiment is to study the annealing processes associated to the Szilard-Chalmers reaction that gives the proper way of taking out radioactive isotopes from the solution due to the differences in their chemistry, permanganate solution was expose to neutron by placing the solution near the AmBe source in a water tank, which gives an account that when the solution of potassium permanganate exposed to neutrons from the moderate neutron irradiator, most of the radioactive could be separated and leave with some percentage in the form of permanganate. For the first filtration, the percentage retention for the filtered solution is 32.8±0.6 % and the precipitate is 67.2% while for the second percentage retention for the filtered solution is 17±0.4 % and the precipitate is 83%. The 3.05 hours was determined using the table figured (4.2) as half-life of the isotope ^{56}Mn.

I. INTRODUCTION

The Szilard-Chalmers process is often applied for the purpose of obtaining very high specific activities of a radio-nuclide. In order to obtain the highest specific activities one would like to carry out the reaction in the highest neutron fluxes available. This is, unfortunately, impossible in most cases since the radiation damage inflicted on the target-compound increases sharply with the dose, bringing about a sharp decrease in the enrichment factors. The process is therefore capable of reaching a certain specific activity and any further irradiation or increase in neutron flux may at times even lower the specific activity.(Schwartz, et. 1969).

In 1934, it was discovered that the bond breaking could occur for atoms following the nuclear reaction or radioactive decay even though the recoil energy in the initial process is not sufficient to overcome the bonding energy. In the case of thermal neutron capture, the processes involved in the emission of the gamma-ray, which removes the nuclear excitation energy, impart recoil energy to the atom to break most chemical bonds. The product atoms exist in a chemical state different and separable from that of the target atoms, the former may be isolated from the large mass of inactive target. This provides a means of obtaining high specific activities in reactions where target and product are isotopic. This is called Szilard-Chalmers reaction and was discovered following the irradiation of ethyl iodide with thermal neutrons, it was found that radioactive iodide could be extracted from the ethyl iodide with water (Gregory, et, 2013). The main purpose of Szilard-Chalmers separation is to produce radioactivity preparation of the activity.

II. THEORY

Potassium permanganate (VII) is an inorganic chemical compound with the following properties; chemical formula of $KMnO_4$, density of 2.70 g/cm^3, molar mass 158.034 g/mol and melting point of 464°F (240°C). Soluble and salt consisting of K^+ and MnO^-_4 ions. Formerly known as permanganate of potash or Condy's crystals, it is a strong oxidizing agent. Potassium permanganate has the following structure:

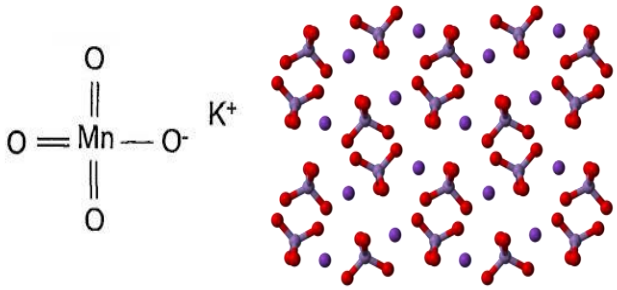

Fig 1:- $KMnO_4$

In the above figure (2.1) usually, manganese exist in the ^{55}Mn isotopes whenever the solution is exposed to neutron element and very few of them may changes to ^{56}Mn isotopes which is totally unstable. Chemically, there is no any distinct between isotopes of the same elements. The negatively ion (per manganese) is unstable with ^{55}Mn isotopes but whenever the center of manganese changes to ^{56}Mn the negatively ion become less stable.

In this very experiment, the element ^{56}Mn was initially generated through the irradiation of the element ^{55}Mn in a neutron beam. The element ^{56}Mn was exposed to AmBe neutron source. There is an emission of gamma rays with energy:

$$^{55}\text{Mn} + \text{n} \rightarrow {}^{56}\text{Mn} + \text{E} \qquad \text{(i)}$$

Gamma rays are emitted of neutron when a nuclear undergoes some certain reaction. The energy of gamma rays will then be equal to binding energy within the nucleus of an atom. Therefore from Plank hypothesis, E = hv.
Where h is the Plank's constant = 6.63x10^{34}JS and v is the frequency with unit Hz.

Also from the momentum (p) = MV. Where M is stands for mass in kg and V is stands for velocity in m/s.
Since electro-magnetic wave travels at the speed of light, c, in a vacuum. They must have zero mass in that case, the linear momentum of such particle is related to its energy, by E = PC, where P is the momentum of the particle.

ISSN No:-2456-2165

$$P = \frac{E}{C} \quad \text{(ii)}$$

Therefore momentum of the particle is the product of mass of the particle and its velocity (N s).

$$P = MV = \frac{E}{C} = \frac{h\nu}{C} \quad \text{(iii)}$$

The chemical method of separation radioactive atom from the radioactive compounds in its new chemical way must be reliable so that the radioactive atoms in the process of forming must be loose from their molecules.

In this experiment, the manganese ^{56}Mn isotopes was prepared by irradiation of an aqueous solution of potassium permanganate in a conical flask and the activity presence in the potassium permanganate was removed using filter paper. The activity remained in a thin deposited of manganese dioxide the filtration paper so that no any thermal interchange that will occur between the $^{55}MnO_2$ and $^{56}MnO_4$ under any ordinary condition of the system.

The experiment is considering the filtering of the generated radioactive solution of the system and also measuring the retained percentage in the precipitate and filtered as well as measuring the half-life of ^{56}Mn is 2.58 hours.

III. EXPERIMENTAL METHOD:

The protective hand gloves, lab coat, overshoes and thermo luminescent dosimeter (TLD) badge was wore and the following sources ^{137}Cs and ^{60}Co were taken into a Petri dish using tweezers and placed in the center detector annular. The multichannel analyzer (MCA) was calibrated using the following peaks for ^{137}Cs 662KeV and ^{60}Co with two different energy 1173KeV and 1333KeV also the time was set to read for 300 seconds for each collection. The sources were removed for the background spectrum to be taken at 60 seconds. The ^{54}Mn source was placed on the Petri dish and located its back and then placed on the counter detector, the spectrum was also taken and region of interest was set around the ^{54}Mn with the energy peak at 834.81KeV.

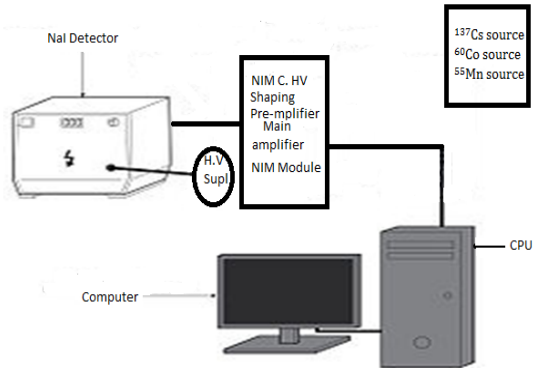

Fig 2:- Experimental set-up for Szilard-Chalmers Reaction and Sources

Then 1 liter solution of 35g/l KMnO4 was studied carefully and the solution have been irradiated purposely for using moderated AmBe neutron source. A 5ml sample of the potassium per manganese solution was taken and also counted; the remaining solution was filtered using filter paper for easy removal of precipitate. The precipitated filter paper was then taken in to the counter using tweezers to find out whether the precipitate activity present on the filter paper has increase or not.

The conical flask containing 1 litter solution of 35g/l KMnO4 was removed from the neutron irradiator and then taken into the Fume cupboard gently. The conical flask of the solution held correctly and mixed gently in other to make the solid material presence in the solution to disperse equally in the solution. 5 ml of the same solution was put in a vial by the used of pipette and placed into the well counter beside by the right in the Fume cupboard and the time was known.

The filter paper was placed in the Buchner funnel and slightly wetted with distilled water for proper setting and the remaining irradiated KMnO4 solution was swirled properly to avoid the residue from staining at the bottom of the conical flask. The solution was poured for filtered and waited for 35to 40 seconds for the solution to drain through the filter and wash with distilled water till it left with brown; the pair of plastic forceps was used to fold the paper and placed the filter paper into 5 ml a vial. Using pipette, 5 ml was taken out of the filtered solution and also taken in to the counter to determine the activity present in the filter paper.

The Multichannel Analyzer was calibrated by the used of ^{137}Cs and ^{60}Co source for half-life of ^{56}Mn. The region of interest was set over the full energy range by the used of ^{54}Mn source and a liter of conical flask of $KMnO_4$ source was removed from the AmBe neutron irradiator so that to place it in the fume cupboard and the time was monitored. The solution was filtered, paper was washed and folded and put in to the 5 ml plastic vial. The vial was placed in to the well counter and net counts ware set after every 5 minutes. Graph was plotted to determine the half-life of the ^{56}Mn.

IV. DISCUSSION OF RESULT

The experiment carried out with different sources shows clearly that the best result results were obtained. The multichannel analyzer (MCA) was first calibrated by finding the peaks of both Cesium and Cobalt (^{137}Cs and ^{60}Co) at 662 for ^{137}Cs and the two main peaks for ^{60}Co were noticed each with different energy of 1173.2KeV and 1332.5KeV that gives the sum energy of 2505.7KeV which made us to expand the wideness of the peak energy. Proper calibration can only be achieved by enlarging the peak energy.

The first precipitate was found to contain more than 90% of the extracted activity from the solutions and the second filtered paper was found to have $^{56}MnO_4$. The potassium permanganate was shook properly and filtered with filter

paper severally to reduce the presence of radioactivity in the solution.

S/N	Time (s)/pm	Samples	ROI in 300sec.
1	03:47	Not irradiated solution	305±143
2	03:53	Irradiated solution	14 ± 362
3	03:59	Filter paper once	2168±477
4	04:05	Filtered solution 1	460±241
5	04:12	Filter paper twice	1346±154
6	04:22	Filtered solution 2	238±162

Table 4.1. Calibrated Table

The percentage of the retention solution 1

Filtered solution 1 = (460±241)/(14 ± 362) x 100
= 32.8± 0.6 %.

The percentage of the retention solution 2

Filtered solution 2 = (238±162)/(14 ± 362) x 100
= 17±0.4 %.

These shows for the first and second percentages precipitate are 67.2% and 83% respectively.

For the half-life of ^{56}Mn to be obtain, the below table is used:

S/N	Total Time (s)	Change in Time (ΔT)	Gross Counts (N)	Change in Counts (ΔN)	ΔN / ΔT	ln(ΔN/ΔT)
1	119.8	119.8	8414	8414	70.23372	4.25
2	239.7	119.9	16541	8127	67.78148	4.22
3	529.9	290.2	36143	19602	67.54652	4.21
4	649.8	119.9	44178	8035	67.01418	4.20
5	769.6	119.8	51995	7817	65.25042	4.18
6	889.6	120	59832	7837	65.30833	4.18
7	1009.6	120	67592	7760	64.66667	4.17
8	1129.6	120	75329	7737	64.475	4.17
9	1249.4	119.8	82831	7502	62.62104	4.14
10	1369.3	119.9	90497	7666	63.93661	4.16
11	1489.4	120.1	98067	7570	63.03081	4.14
12	1609.4	120	105427	7360	61.33333	4.12
13	1729.4	120	112900	7473	62.275	4.13
14	1849.1	119.7	120244	7344	61.35338	4.12
15	1969.2	120.1	127659	7415	61.74022	4.12
16	2089.2	120	134887	7228	60.23333	4.10
17	2209.2	120	142128	7241	60.34167	4.10
18	2329	119.8	149328	7200	60.10017	4.10
19	2449	120	156533	7205	60.04167	4.10
20	2569	120	163624	7091	59.09167	4.08
21	2689	120	170682	7058	58.81667	4.07
22	2808.8	119.8	177553	6871	57.35392	4.05
23	2928.8	120	184455	6902	57.51667	4.05
24	3048.8	120	191209	6754	56.28333	4.03
25	3168.8	120	198076	6867	57.225	4.05
26	3288.6	119.8	204770	6694	55.87646	4.02
27	3408.7	120.1	211526	6756	56.25312	4.03
28	3528.7	120	218156	6630	55.25	4.01
29	3600	71.3	222132	3976	55.76438	4.02

Table 4.2. Table for the Szilard-Chalmers Reaction

The half-life for ^{56}Mn was calculated and removing the high percentage of the activity by filtering the potassium permanganate solution through filter paper which was found by irradiated solution.

The measured value was compared with the expected value and the differences was found due to the fact that the errors in measuring time through the experimental procedure.

ISSN No:-2456-2165

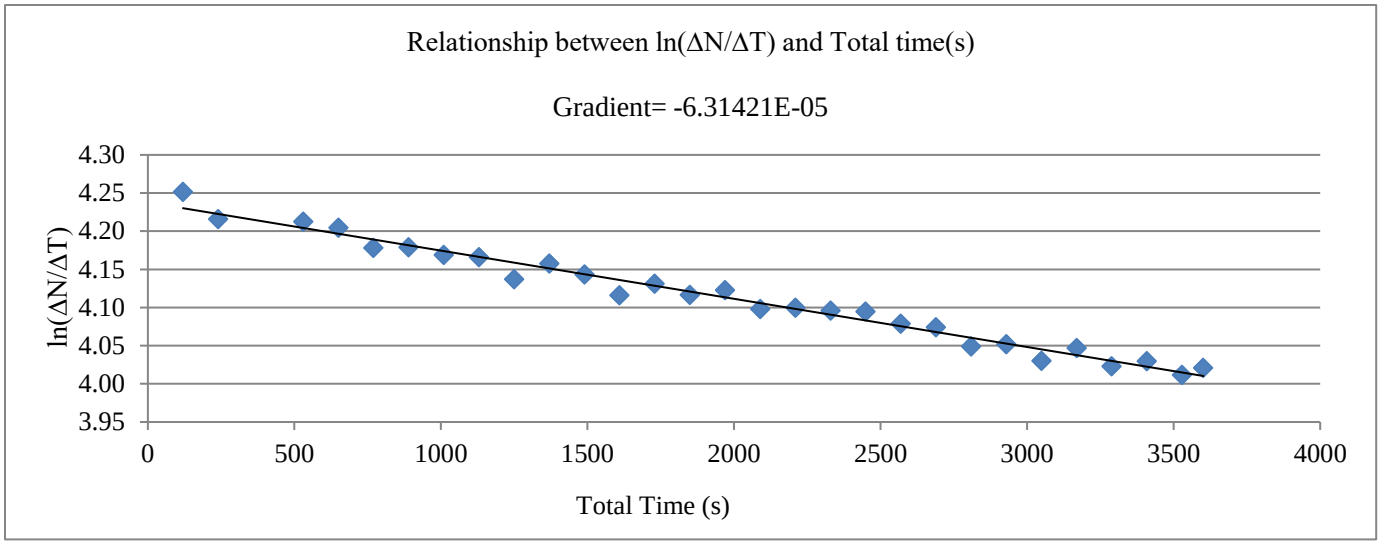

Fig 3:- Relationship between ln(ΔN/ΔT) and Time (s)

To find the half-life of ^{56}Mn,

$$t_{1/2} = \frac{-ln2}{\lambda}$$

And λ = gradient = $-$ 6.31421x10^{-5}

Therefore

$$t_{1/2} = \frac{-ln2}{-6.3x10^{-5}}$$

$$t_{1/2} = \frac{0.693}{6.3x10^{-5}}$$

$t_{1/2}$ = 11000 Sec.

By converting it to hour, we have:

$t_{1/2}$ = 3$\pm$0.5hours.

The given short half-life of ^{54}Mn is 2.58 hours which is equal to 9288 Seconds and the determined ^{54}Mn half-life is 3.05 hours, which is also equal to 11000 Seconds. With these I can say that the

V. CONCLUSION

To summarize this experiment, the ^{173}Cs and ^{60}Co sources were taken to the window of the detector; Cobolts-60 gives the output sum of the two different peaks accumulatively as 2505.5KeV while Cesium-137 gives 662KeV. This gives the courage to enlarge the range of the energy peak so that to have suitable calibration for ^{60}Co.

Therefore the irradiation of the ^{55}Mn leads to ^{56}Mn half-life together with the emission of gamma- rays which can or will easily leads in the recoil of ^{56}Mn nucleus and also the efficiency of precipitate of the potassium permanganate ($KMnO_4$) solution from irradiated solution was observed to be reducing with the decreases with time.

The precipitation and concentration of ^{56}Mn half-life in the filtered paper was found to be 3$\pm$0.5Hours which was compared with the expected half-life of 2.58Hours and found some errors which were encountered while taken the experiment which was due to the fact that, the time set for the detector to takes the readings of each was 300 seconds and also the time taken before placing the filtered paper precipitate in to the veil and detector. This experiment acquired me with broad knowledge of how to make use of unsealed radioactive sources and radioactive solutions also gains how to use fume cupboard.

VI. ACKNOWLEDGEMENT

I would like to express my gratitude to my lecturers and laboratory supervisor for their useful guides throughout the experiment and learning process. I would also like to thank my lab partner in person of Mr. Andrew for his immense support while studying the experiment. Furthermore I would like to thank all the staff and PhD students that help me while taking this experiment.

REFERENCE

[1]. A. Wahl, & N. Bonner, (1951). Radioactivity Applied to Chemistry.
[2]. C. Gregory, L. Jan-Olov, R. Jan, & E. Christian, (2013). Radiochemistry and Nuclear Chemistry. (Fourth Edition).
[3]. RAD 4 – University of Surrey, Department of Physics, Szilard-Chalmers Reaction lab. Script, (2015).
[4]. Some useful equations for half-lives (2015) Available at: http://www.nuffieldfoundation.org/practical-physics/some-useful-equations-half-lives (Accessed: 28 December 2015).
[5]. Schwartz, R. Rafaeloff & E. Yellin Soreq. (1969). Nuclear Research Centre, Yavne, Israel