CHAPTER II

A review on heavy and super heavy elements

The “island of stability” is a term from nuclear physics that describes the possibility of elements with particularly stable “magic numbers” of protons and neutrons. This would allow certain isotopes of some transuranic elements to be far more stable than others; i.e., they decay much more slowly. The idea of the island of stability was first proposed by Seaborg [44]. The hypothesis is that the atomic nucleus is built up in “shells” in a manner similar to the electron shells in atoms. In both cases shells are just groups of quantum energy levels that are relatively close to each other. Energy levels from quantum states in two different shells will be separated by a relatively large energy gap. So when the number of neutrons and protons completely fill the energy levels of a given shell in the nucleus, the binding energy per nucleon will reach a local minimum and thus that particular configuration will have a longer life time than the nearby isotopes that do not have filled shells.

The present chapter is a review on heavy and super heavy elements which includes the production, life time and all other decay properties of all the experimentally observed isotopes in this region. This study treats the heavy elements as belonging to the region with atomic number greater than 92 ($92 > Z \leq 104$) and super heavy elements with atomic number greater than 104.

2.1 Heavy elements

In 1939 Bohr and Wheeler [45] studied mechanism of nuclear fission on the basis of the liquid drop model which treats the nucleus as a drop of charged liquid without any structure. As long as the surface tension in the drop is larger than the repulsive Coulomb

force due to the protons, a potential barrier prevents it from splitting. The liquid drop model suggests that the potential barrier approaches zero when the atomic number Z >100 [46, 47], this puts an upper limit to the stability of nuclei. In the mid sixties the importance of nuclear shell effects in stabilising heavy nuclei was realized.

The chemical elements heavier than iron can not be produced by fusion reactions, since the binding energy per nucleon is decreasing past the iron group nuclei and because of the increasing Coulomb barriers, the nuclei heavier than iron are essentially synthesised by neutron capture reactions. Three different processes can be identified in this mass region, the slow (s) neutron capture process during stellar helium burning, the rapid (r) neutron capture process, and the photo-dissociation (p) process, the latter two being presumably related to supernova explosions. Whether a fourth process, the rapid proton (rp) capture process, contributes also to the production of the heavy elements or whether further additional processes are needed to explain their abundances is still under discussion. All heavy elements are produced artificially using accelerator machine in lab.

2.1.1 Production and decay properties of heavy elements

2.1.1.1 Neptunium (Z=93)

The first heavy element is neptunium (Np), which has an atomic number of 93. Neptunium was first discovered by McMillan et al [48] in 1940 at Berkeley, California. Berkeley Radiation Laboratory of the University of California, produced the neptunium isotope ^{239}Np (2.4 day half-life) by bombarding uranium with slow moving neutrons. It was the first transuranium element produced synthetically and the first actinide series transuranium element discovered.

Tables 2.1-2.5 show the measured half life time, decay energy and all other decay properties of the heavy elements with the atomic number ranging from 93-101. Nineteen radioisotopes of neptunium have been characterised, with the most stable being ^{237}Np with a

half-life of 2.14 million years, ^{236}Np with a half-life of 154,000 years and ^{235}Np with a half-life of 396.1 days. All of the remaining radioactive isotopes have half-lives that are less than 4.5 days and the majority of these have half-lives that are less than 50 minutes. The ^{236}Np element has 4meta states, with the most stable being ^{236m}Np ($T_{1/2} = 22.5$ hours). The isotopes of neptunium range in atomic weight from 225.0339 u (^{225}Np) to 244.068 u (^{244}Np). The primary decay mode of the isotopes before the most stable isotope, ^{237}Np, is electron capture (with a good deal of alpha emission), and the primary decay mode of the isotopes after this is beta emission. The primary decay products before ^{237}Np are elements of uranium isotopes (alpha emission produces element protactinium) and the primary products after are elements of plutonium isotopes. The isotopes with ^{230,232,234}Np (β^+) and the isotopes $^{238\text{-}244}$Np (β^-) have beta emission as the dominant decay mode.

2.1.1.2 Plutonium (Z = 94)

Twenty radioactive isotopes of Plutonium have been characterised. The isotopes of plutonium range in mass number from 228 to 247. The longest-lived are ^{244}Pu, with a half-life of 80.8 million years, ^{242}Pu with a half-life of 373,300 years and ^{239}Pu, with a half-life of 24,110 years. All of the remaining radioactive isotopes have half-lives that are less than 7,000 years. This element also has eight meta stable states, though none are stable and all have half-lives less than one second. The primary decay modes of isotopes with mass numbers lower than the most stable isotope, ^{244}Pu decays by spontaneous fission and α emission, forming uranium and neptunium isotopes as decay products. The primary decay mode for isotopes with mass numbers higher than ^{244}Pu is β emission, mostly forming americium isotopes as decay products. ^{241}Pu is the parent isotope of the neptunium decay series, decaying to ^{241}Am via β or electron emission. Also the isotopes with $^{228,\ 230,\ 231}$Pu (β^+) and the isotopes $^{243,\ 245\text{-}247}$Pu (β^-) have beta decay as the dominant decay emission.

Plutonium (specifically ^{238}Pu) was first produced and isolated in 1940, and chemically identified by Seaborg et al [49] by deuteron bombardment of uranium in the 60-inch cyclotron at the University of California, Berkeley. ^{239}Pu is synthesized through the reaction of uranium U and neutrons via beta decay (β^-) with neptunium Np as an intermediate [50].

2.1.1.3 Americium (Z = 95)

A radioactive metallic element, americium was first isolated by Kennedy et al [51] in 1944 at the wartime Metallurgical Laboratory at the University of Chicago. Seaborg et al [51] created the isotope ^{241}Am by subjecting ^{239}Pu to successive neutron capture reactions in a nuclear reactor, this created ^{240}Pu and then ^{241}Pu which in turn decayed into ^{241}Am via beta decay. Eighteen radioisotopes of americium have been characterised. The isotopes of americium range in atomic weight from 231.046u (^{231}Am) to 249.078u (^{249}Am). The most stable being ^{243}Am with a half-life of 7370 years and ^{241}Am with a half-life of 432.2 years. All of the remaining radioactive isotopes have half-lives that are less than 51 hours, and the majority of these have half-lives that are less than 100 minutes. This element also has eight meta states, with the most stable being ^{242m}Am ($T_{1/2} \approx 141$ years). The isotopes with ^{231,232,234,235,236}Am (β^+) and the isotopes $^{244\text{-}249}$Am (β^-) have beta decay as the dominant decay emission.

2.1.1.4 Curium (Z = 96)

Curium was first synthesized at the University of California, Berkeley by Seaborg et al [52] in 1944. ^{242}Cm (half-life 163 days) and one free neutron were made by bombarding alpha particles onto a ^{239}Pu target in the 60-inch cyclotron at Berkeley. Nineteen radioisotopes of curium have been characterized, The isotopes of curium range in atomic weight from 233.051 u (^{233}Cm) to 252.085 u (^{252}Cm) with the most stable being ^{247}Cm with a half-life of 1.56×10^7 years, ^{248}Cm with a half-life of 3.40×10^5 years, ^{250}Cm with a half-life of

9000 years, and ^{245}Cm with a half-life of 8500 years. All of the remaining radioactive isotopes have half-lives that are less than 30 years and the majority of these have half-lives that are less than 33 days. This element also has 4 meta states with the most stable being ^{244m}Cm ($T_{1/2} = 34ms$). The isotopes $^{235\text{-}237}$Cm (β^+) and the isotopes $^{249,\ 251,252}$Cm (β^-) have beta decay as the dominant decay emission.

2.1.1.5 Berkelium (Z = 97)

In 1949, Thompson et al [53-55] first discovered the ^{247}Bk (247.070299u) isotope. At present nineteen radioisotopes of berkelium have been characterised with masses ranging from 235.057u (^{235}Bk) to 254.091u (^{254}Bk). The most stable isotope is ^{247}Bk with a half-life of 1380 years, ^{248}Bk with a half-life >9 years and ^{249}Bk with a half-life of 330days. All of the remaining radioactive isotopes have half-lives that are less than 5 days and the majority of these have half-lives that are less than 5 hours. This element also has 2 meta states with the most stable being ^{248m}Bk ($T_{1/2} = 23.7$ hours). Again the isotopes $^{235\text{-}240,242\text{-}244}$Bk ($\beta^+$) and $^{252\text{-}254}$Bk (β^-) have beta emission as dominant mode of decay.

Thompson et al [53, 54] at the University of California, Berkeley synthesized the isotope by used a cyclotron to bombard a milligram-sized target of ^{241}Am with alpha particles to produce ^{243}Bk (half-life 4.5 hours) and two free neutrons. Production of ^{249}Bk requires 11 successive neutron captures on ^{238}U without nuclear fission or alpha decay, so it is only produced in small amounts. ^{249}Bk has a moderately large neutron capture cross section of 710 barns for thermal neutrons, 1200 barns resonance integral, but very low fission cross section for thermal neutrons. If still in a thermal reactor, much of it will therefore be converted to ^{250}Bk which quickly decays to ^{250}Cf, but some of them alpha decays to ^{245}Cm.

2.1.1.6 Californium (Z = 98)

Californium was first synthesized [56-58] in 1950 by bombarding microgram quantities of ^{242}Cm with 35MeV helium ions in the Berkeley 60-inch cyclotron. Twenty radioisotopes of californium have been characterised with masses ranging from 237.062u (^{237}Cf) to 256.093u (^{256}Cf). The most stable isotope is ^{251}Cf with a half-life of 898 years, ^{249}Cf with a half-life of 351 years, and ^{250}Cf with a half-life of 13 years. All of the remaining radioactive isotopes have half-lives that are less than 2.7 years and the majority of these have half-lives shorter than 20 minutes. ^{252}Cf has a half life of 2.645 years. ^{252}Cf undergoes α-decay with 96.9% and with 3.1% spontaneous fission and emits an average of 3.77 neutrons per fission. ^{254}Cf decays quantitatively with the spontaneous fission with a half-life of nearly 60.5 days. Both materials can be used as a neutron source. Also the isotopes ^{255}Cf has beta decay as the dominant mode and in the case of ^{238,256}Cf have spontaneous fission as their dominant mode of decay.

2.1.1.7 Einsteinium (Z = 99)

Einsteinium does not occur naturally in any measurable quantities. The modern process of creating the element starts with the irradiation of ^{239}Pu in a nuclear reactor for several years. The resulting ^{242}Pu isotope (in the form of the compound plutonium (IV) oxide) is mixed with aluminum and formed into pellets. The pellets are then further irradiated for approximately one year in a nuclear reactor. Another four months of irradiation is required in a different reactor. The result is a mixture of californium and einsteinium, which can then be separated. Ghiorso and coworkers [59, 60] produced the isotope ^{253}Es isotope (half-life 20.5 days) that was made by the neutron capture of 15 neutrons with ^{238}U by the process of seven beta emissions.

Nineteen radioisotopes of einsteinium have been characterized with masses ranging from 240.069u (^{240}Es) to 258.100u (^{258}Es)., The most stable being ^{252}Es with a half-life of

471.7 days, ^{254}Es with a half-life of 275.7 days, ^{255}Es with a half-life of 39.8 days and ^{253}Es with a half-life of 20.47 days. All of the remaining radioactive isotopes have half-lives that are less than 40 hours and the majority of these have half-lives that are less than 30 minutes. This element also has 3meta states with the most stable being ^{254m}Es ($T_{1/2}$ = 39.3 hours).

2.1.1.8 Fermium (Z = 100)

A highly radioactive metallic transuranic element of the actinide series, fermium is made by bombarding plutonium with neutrons and is named after nuclear physicist Enrico Fermi. The isotopes of Fermium is prepared [61, 62] by neutron irradiation of Pu, a sequence of neutron capture reactions and beta decay process occurs leading from Pu through Am, Cm, Bk, Cf and Es to Fm. Seventeen radioisotopes of fermium have been characterised with masses ranging from 242.073 u (^{242}Fm) to 259.101 u (^{259}Fm). The most stable isotope is ^{257}Fm, with a half life time of about 100.5 days and it was produced in prolonged bombardment of Cm with neutron in a reactor [63]. The isotope ^{250}Fm, with a half life time of 30 minutes, has been shown to be a decay product of element ^{254}102. The isotope ^{255}Fm was produced at ORNL in Oak Ridge, USA. The cross section of fermium isotopes shows an interesting pattern, i.e. the values for isotopes of mass 255 and lighter are at least one order of magnitude higher than that of ^{256}Fm and ^{257}Fm [64]. Remaining $^{242\text{-}244,258,259}$Fm isotopes have spontaneous fission as the dominant decay mode of reaction.

2.1.1.9 Mendelevium (Z = 101)

A metallic radioactive transuranic element of the actinides, mendelevium is synthesised by Ghiorso et al [65] in early 1955 at the University of California, Berkeley. The team produced ^{256}Md ($T_{1/2}$ = 76 minutes) by bombarding ^{253}Es target with alpha particles in the Berkeley Radiation Laboratory's 60-inch cyclotron. ^{256}Md was the first element to be synthesized one-atom-at-a-time.

Fifteen radioisotopes of mendelevium have been characterized with masses ranging from 245.091 u (^{245}Md) to 260.104 u (^{260}Md). The most stable isotope is ^{258}Md with a half-life of 51.5days, ^{260}Md with a half-life of 31.8 days and ^{257}Md with a half-life of 5.52 hours. All of the remaining radioactive isotopes have half-lives that are less than 97 minutes and the majority of these have half-lives that are less than 5 minutes. This element also has 1 meta state, ^{258m}Md ($T_{1/2} = 57\,\text{min}$). The isotopes ^{245,247,259}Md have spontaneous fission as dominant mode of decay and for $^{248,250\text{-}256}$Md beta decay is the dominant mode.

2.1.1.10 Nobelium (Z = 102)

Seventeen radioisotopes of nobelium have been characterized with the most stable being ^{259}No with a half-life of 58 minutes. Table 2.6 shows the half life time, decay energy, reaction leading to compound nuclei and all other decay modes for elements with atomic number ranging from 102-104. From the table we see that the isotopes $^{251\text{-}253,255\text{-}259}$No are probable for alpha decay, the isotopes $^{250,\ 258,\ 260,262}$No are decayed by spontaneous fission and the ^{254}No decayed through gamma emission. The discovery [66] of element Z= 102 was first announced by physicists at the Nobel Institute in Sweden in 1957. The team reported that they created an isotope with a half-life of 10 minutes, decaying by emission of an 8.5MeV alpha particle, after bombarding ^{244}Cm with ^{13}C nuclei. The synthesis of the same element was then claimed in April 1958 at the University of California, Berkeley by Ghiorso et al [67]. The team used the new heavy-ion linear accelerator (HILAC) to bombard a curium target (95% ^{244}Cm and 5% ^{246}Cm) with ^{13}C and ^{12}C ions. The authors were unable to confirm the 8.5MeV activity claimed by the Swedes [66] but were instead able to detect decays from ^{250}Fm, supposedly the daughter of ^{254}102, which had an apparent half-life of ~3 s. In 1959 the team continued their studies [24] and claimed that they were able to produce an isotope that decayed predominantly by emission of an 8.3MeV alpha particle with a half-life of 3s with an associated 30% spontaneous fission branch.

2.1.1.11 Lawrencium (Z = 103)

The most stable known isotope is ^{262}Lr, with a half-life of approximately 3.6 hours. Lawrencium was made in 1961 [68] at the Lawrence Berkeley National Laboratory on the University of California, Berkeley campus. It was produced by bombarding a three milligram target composed of three isotopes of californium with ^{10}B and ^{11}B ions in the Heavy Ion Linear Accelerator (HILAC). The Berkeley team reported that the isotope ^{257}103 was detected in this manner and decayed by emitting an 8.6MeV alpha particle with a half life of ~8 seconds. The assignment was later corrected to ^{258}Lr. Isotopes of lawrencium have also been identified in the decay of heavier elements. It is also synthesised by cold fusion method. Twelve isotopes of lawrencium have been synthesized with ^{262}Lr being the longest-lived and heaviest, with a half-life of 216 minutes. ^{252}Lr is the lightest isotope known to date. The decay properties and discovery reaction of all the experimentally observed Lawrencium isotopes is shown in Table 2.6.

2.1.1.12 Rutherfordium (Z = 104)

This is a radioactive synthetic element whose most stable known isotope is ^{267}Rf with a half-life of approximately 1.3hrs. The Table 2.6 shows all the experimentally observed rutherfordium isotopes with its discovery reactions and their decay properties. Element 104 was reportedly first detected [69] in 1966 at the Joint Institute of Nuclear Research (JINR) at Dubna. Researchers there bombarded ^{242}Pu with accelerated ^{22}Ne ions and separated the reaction products by gradient thermo chromatography after conversion to chlorides by interaction with $ZrCl_4$. The team identified a spontaneous fission activity contained within a volatile chloride portraying eka-hafnium properties. Although a half-life was not accurately determined, later calculations indicated that the product was most likely ^{259}Rf. In 1969, Ghiorso et al [70] at the University of California, Berkeley conclusively synthesized the

element by bombarding a ^{249}Cf target with ^{12}C ions and measured the alpha decay of ^{257}104, correlated with the daughter decay of ^{253}102.

Table 2.1 The experimentally observed half life times and other decay properties of different Np and Pu isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode and intensities (%)	Decay Energy (MeV)	Decay Product
93	^{229}Np	4.0mts	>50% α	7.01	^{225}Pa
			< 50 % β^+		^{229}U
	^{231}Np	48.8mts	2% α	6.37	^{227}Pa
			98.1% β^+		^{231}U
	^{233}Np	36.2mts	$\leq$ 0.001% α	5.83	^{229}Pa
			~ 100% β^+		^{233}U
	^{234}Np	4.4 d	100% β^+		^{234}U
	^{235}Np	361.1 d	0.0260% α	5.192	^{231}Pa
			~ 100 % ε	0.124	^{235}U
	^{236}Np	1.54x10^{-5} y	87.3% ε	0.94	^{236}U
			12.5% β^-	0.94	^{236}Pu
			0.164% α	5.02	^{232}Pa
	^{237}Np	2.144x10^{6}y	$\leq$ 2x10^{-10}% SF		
			100% α	4.959	^{233}Pa
	^{238}Np	2.117 d	100% β^-		^{238}Pu
	^{239}Np	2.356 d	100% β^-		^{239}Pu
			5x10^{-10}% α		^{235}Pa
94	^{232}Pu	33.7mts	~ 11% α	6.72	^{228}U
			ε		^{232}Np
	^{233}Pu	20.9mts	0.12% α	6.42	^{229}U
			~ 100% β^+		^{233}Np
	^{234}Pu	8.8 h	6% α	6.31	^{230}U
			~ 94% ε		^{234}Np
	^{235}Pu	25.3mts	0.0028% α	6.00	^{231}U
			~ 100% β^+		^{235}Np
	^{236}Pu	2.858 y	100% α	5.87	^{232}U
			1.36x10^{-7}% SF		
	^{237}Pu	45.2 d	0.0042% α	5.45	^{233}U
			~ 100% ε		^{237}Np
	^{238}Pu	88.0 y	1.9x10^{-7}% SF		
			100% α	5.59	^{234}U
	^{239}Pu	2.41x10^{4}y	3.1x10^{-10}% SF		
			100% α	5.245	^{235}U
	^{240}Pu	6.5x10^{3}y	5.7x10^{-6}% SF		
			100% α	5.256	^{236}U
	^{241}Pu	14.35y	~ 100% β^-	0.02078	^{241}Am
			0.00245% α	4.98	^{237}U
			SF		
	^{242}Pu	3.73x10^{5}y	5.5x10^{-4}% SF		
			100% α	4.984	^{238}U
	^{244}Pu	8.08x10^{7}y	~ 100% α	4.666	^{240}U
			0.121% SF		

Table 2.2 The experimentally observed half life times and other decay properties of different Am and Cm isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode and intensities (%)	Decay Energy (MeV)	Decay Product
95	^{237}Am	73.0mts	~ 100% β^+		^{237}Pu
			0.025% α	6.25	^{233}Np
	^{238}Am	98.0mts	~ 100% β^+		^{237}Pu
			1.0×10^{-4}% α	6.04	^{234}Np
	^{239}Am	11.9h	0.01% α	5.87	^{235}Np
			~ 100% ε		^{237}Pu
	^{240}Am	50.8h	~ 100% β^+		^{237}Pu
			1.9×10^{-4}% α	5.59	^{236}Np
	^{241}Am	432.2 y	4.3×10^{-10}% SF		
			100% α	5.638	^{237}Np
	^{242}Am	16.02 h	82.7% β^-		^{242}Cm
			17.3% ε		^{242}Pu
	^{243}Am	7370 y	3.7×10^{-9}% SF		
			100% α	5.438	^{239}Np
96	^{239}Cm	2.9 h	~ 100% β^+	6.50	^{239}Am
			< 0.1% α		^{235}Pu
	^{240}Cm	27 d	~ 100% α	6.40	^{236}Pu
			< 0.5% ε		^{240}Am
			3.9×10^{-6}% SF		
	^{241}Cm	32.8 d	1.0% α	6.04	^{237}Pu
			99% ε		^{241}Am
	^{242}Cm	162.8 d	6.2×10^{-6}% SF		
			100% α	6.10	^{238}Pu
	^{243}Cm	29.1 y	100% α	6.169	^{239}Pu
			0.29% ε	0.009	^{243}Am
			5.3×10^{-9}% SF		
	^{244}Cm	18.01 y	1.37×10^{-4}% SF		
			100% α	5.902	^{240}Pu
	^{245}Cm	8500y	6.1×10^{-7}% SF		
			100% α	5.623	^{241}Pu
	^{246}Cm	4730 y	~ 100% α	5.473	^{242}Pu
			0.02615% SF		
	^{247}Cm	1.56×10^{7} y	100% α	5.353	^{243}Pu
	^{248}Cm	3.40×10^{5}y	91.61% α	5.162	^{244}Pu
			8.39% SF		
	^{250}Cm	9000 y	74% SF		
			18% α	5.169	^{246}Pu
			8% β^-	0.037	^{250}Bk

Table 2.3 The experimentally observed half life times and other properties of different Bk and Cf isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode and intensities (%)	Decay Energy (MeV)	Decay Product
97	^{245}Bk	4.94 d	~ 100% ε	1.81	^{245}Cm
			0.12% α	6.455	^{241}Am
	^{246}Bk	1.8 d	0.1 % α	6.07	^{242}Am
			~ 100% β^+		^{246}Cm
	^{247}Bk	1380 y	100% α	5.889	^{243}Am
			SF		
	^{248}Bk	> 9 y	α	5.803	^{244}Am
	^{249}Bk	330 d	0.00145% α	5.526	^{245}Am
			~ 100% β^-	0.125	^{249}Cf
98	^{240}Cf	1.06mts	~ 98% α	7.72	^{236}Cm
			~ 2% SF		
	^{241}Cf	3.8mts	~ 75% β^+		^{241}Bk
			~ 25% α	7.66	^{237}Cm
	^{242}Cf	3.49mts	80% α	7.52	^{238}Cm
			< 0.014% SF		
	^{243}Cf	10.7mts	~ 14% α	7.28	^{239}Cm
			~ 86% β^+		^{243}Bk
	^{244}Cf	19.4mts	100% α	7.33	^{240}Cm
	^{245}Cf	45mts	36% α	7.26	^{241}Cm
			64% β^+		^{245}Bk
	^{246}Cf	35.7 h	~ 100% α	6.86	^{242}Cm
			2.5×10^{-4}% SF		
			$< 4\times10^{-3}$% ε		^{246}Bk
	^{248}Cf	333.5 d	0.0029% SF		
			~ 100% α	6.361	^{244}Cm
	^{249}Cf	351 y	5.0×10^{-7}% SF		
			100% α	6.295	^{245}Cm
	^{250}Cf	13.08y	~ 100% α	6.128	^{246}Cm
			0.077% SF		
	^{251}Cf	898 y	~ 100% α	6.176	^{247}Cm
	^{252}Cf	2.645 y	96.908% α	6.217	^{248}Cm
			3.092% SF		
	^{253}Cf	17.81 y	~ 100% β^-	0.285	^{253}Es
			0.31% α	6.124	^{249}Cm
	^{254}Cf	60.5 d	~ 100% SF		
			0.31% α	5.926	^{250}Cm

Table 2.4 The experimentally observed half life times and the decay properties of different Es and Fm isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode and intensities (%)	Decay Energy (MeV)	Decay Product
99	^{243}Es	21s	$\geq$ 30% α	8.07	^{239}Bk
			$\leq$ 90% β^+		^{243}Cf
	^{245}Es	1.1mts	10% α	7.91	^{241}Bk
			60% β^+		^{245}Cf
	^{246}Es	7.7mts	9.9% α	7.70	^{242}Bk
			90.1% β^+		^{246}Cf
	^{247}Es	4.6mts	~ 7% α	7.49	^{243}Bk
			~ 93% β^+		^{247}Cf
			~ 9x10^{-5}% SF		
	^{248}Es	27mts	0.25% α	7.15	^{244}Bk
			~ 100% β^+		^{248}Cf
			0.1% SF		
	^{249}Es	102.2mts	0.57% α	6.94	^{245}Bk
			~ 100% β^+		^{249}Cf
	^{251}Es	33 h	0.5% α	6.60	^{247}Bk
			ε		^{251}Cf
	^{252}Es	471.7 d	78% α	6.76	^{248}Bk
			22% ε	1.26	^{252}Cf
			β^-	0.48	^{252}Fm
	^{253}Es	20.47 d	8.7x10^{-6}% SF		
			100% α	6.739	^{249}Bk
	^{254}Es	275.7 d	0.03% ε	0.654	^{254}Cf
			β^-	1.09	^{254}Fm
			~ 100% α	6.628	^{250}Bk
	^{255}Es	39.8 d	92% β^-	0.288	^{255}Fm
			8% α	6.436	^{251}Bk
			0.0041% SF		
100	^{245}Fm	4.2 s	α	8.44	^{241}Cf
			4.2% β^+		^{245}Es
			0.13% SF		
	^{246}Fm	1.1 s	α	8.37	^{242}Cf
			> 10% β^+		^{246}Es
			4.5% SF		
	^{247}Fm	35 s	~ 7% α	8.19	^{243}Cf
			~ 93% β^+		^{247}Es
			9x10^{-5}% SF		
	^{248}Fm	36 s	7% α	8.00	^{244}Cf
			93% β^+		^{248}Es
			0.10% SF		

Table 2.5 The experimentally observed half life times and the decay properties of different Fm and Md isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode and intensities	Decay Energy (MeV)	Decay Product
100	^{249}Fm	2.6mts	33% α	7.81	^{245}Cf
			β^+		^{249}Es
	^{250}Fm	30mts	> 90% α	7.56	^{246}Cf
			< 10% ε		^{250}Es
			0.0069% SF		
	^{251}Fm	5.3h	98.2% β^+	6.94	^{251}Es
			1.8% α		^{247}Cf
	^{252}Fm	25.39 h	2.3×10^{-3}% SF		
			100% α	7.153	^{248}Cf
	^{253}Fm	3 d	88% ε	0.333	^{253}Es
			12% α	7.197	^{249}Cf
	^{254}Fm	3.24 h	~ 100% α	7.31	^{250}Cf
			0.0592% SF		
	^{255}Fm	20.07 h	2.4×10^{-5}% SF		
			100% α	7.241	^{251}Cf
	^{256}Fm	157.6mts	8.1% α	7.03	^{252}Cf
			91.9% SF		
	^{257}Fm	100.5 d	~ 100% α	6.864	^{253}Cf
			0.210% SF		
101	^{248}Md	7.0s	80% α	8.56	^{244}Es
			20% β^+		^{248}Fm
	^{257}Md	5.52 h	85% ε	0.406	^{257}Fm
			5% α	7.558	^{253}Es
			< 4% SF		
	^{258}Md	51.5 d	ε	1.23	^{258}Fm
	^{260}Md	31.8 d	SF		
			< 5% α	7.00	^{256}Es
			< 5% ε		^{260}Fm
			< 3.5% β^-	1.00	^{260}No

Table 2.6 The experimentally observed half life times, reaction leading to compound nuclei and other decay properties of different No, Lr and Rf isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode	Decay Energy (MeV)	Decay Product	Discovery Reaction
102	^{250}No	3.7 μs	SF			^{204}Pb (^{48}Ca, 2n)
	^{251}No	0.76s	α	8.62; 8.58	^{247}Fm	^{244}Cm (^{12}C, 5n)
	^{252}No	2.44s	75% α 25%SF	8.42; 8.37	^{248}Fm	^{244}Cm (^{12}C, 4n) ^{206}Pb (^{48}Ca, 2n)
	^{253}No	1.62mts	α γ	8.14; 8.06; 8.04	^{249}Fm	^{242}Pu (^{16}O, 5n) ^{239}Pu (^{18}O, 4n)
	^{254}No	275ms	Γ			^{208}Pb (^{48}Ca, 2n)
	^{255}No	31mts	61%α 39% ε	8.12; 8.08; 7.93 2.012	^{251}Fm ^{255}Md	^{246}Cm (^{13}C, 4n) ^{248}Cm (^{12}C, 5n)
	^{256}No	2.91s	99.5%α 0.5%SF	8.45; 8.40	^{252}Fm	^{248}Cm (^{132}C, 4n) ^{248}Cm (^{13}C, 5n)
	^{257}No	25s	α	8.32; 8.22	^{253}Fm	^{248}Cm (^{13}C, 4n)
	^{258}No	1.2ms	SF			^{248}Cm (^{18}O, α3n)
	^{259}No	58mts	75% α 25% ε	7.69; 7.61; 7.53	^{255}Fm ^{259}Md	^{248}Cm (^{13}C, 4n)
	^{260}No	106ms	SF			^{254}Es+^{22}Ne, ^{18}O, ^{13}C, transfer
	^{262}No	5ms	SF			^{254}Es+^{22}Ne,transfer (EC of ^{262}Lr)
103	^{252}Lr	0.36s	α	9.02; 8.97	^{248}Md	^{209}Bi (^{50}Ti, 3n)
	^{253}Lr	1.49s	92% α 8% SF	8.72	^{249}Md	^{209}Bi (^{50}Ti, 2n)
	^{254}Lr	13s	78% α 22% EC	8.46; 8.41	^{250}Md ^{254}No	^{209}Bi (^{50}Ti, n)
	^{255}Lr	21.5	α	8.43; 8.37	^{251}Md	^{243}Am (^{16}O, 4n)
	^{256}Lr	27s	α	8.62; 8.52; 8.32	^{252}Md	^{252}Cf (^{10}B, 6n)
	^{257}Lr	0.65s	α	8.86; 8.80	^{253}Md	^{249}Cf (^{15}N, α3n)
	^{258}Lr	4.1s	α	8.68; 8.65; 8.62	^{254}Md	^{249}Cf (^{15}N, α2n)
	^{259}Lr	6.2s	78% α 22% SF	8.44	^{255}Md	^{248}Cm (^{15}N, 4n)
	^{260}Lr	2.7mts	α	8.04	^{256}Md	^{248}Cm (^{15}N, 3n)
	^{261}Lr	44mts	SF			^{254}Es+^{22}Ne
	^{262}Lr	3.6h	EC		^{262}No	^{254}Es+^{22}Ne
104	^{253}Rf	0.048ms	SF			^{204}Pb (^{50}Ti, n)
	^{254}Rf	0.022ms	SF			^{206}Pb (^{50}Ti, 2n)
	^{255}Rf	1.8s	50% α 50% SF	8.81; 8.77; 8.74	^{251}No	^{207}Pb (^{50}Ti, 2n)
	^{256}Rf	6.2ms	99.7%SF 0.3% α	 8.79	 ^{252}No	^{208}Pb (^{50}Ti, 2n)
	^{257}Rf	3.5s	89% α 11% ε	8.90; 8.78; 8.52	^{253}No ^{257}Lr	^{249}Cf (^{12}C, 4n)

2.2 Super heavy elements

One of the fundamental questions in the study of super heavy elements is the prediction and/or production of the doubly magic nucleus, next to Z = 82, N = 126 (^{208}Pb). In the 1960s [71-74], a number of theoretical predictions were made that pointed towards the existence of an island of long-lived super heavy elements centered on Z = 114, N = 184. Modern microscopic nuclear theories [75, 76] suggest that the island of stability would be around Z = 120, 124 or 126 and N = 184 or N = 172. These predictions as well as earlier predictions [77-79] that some of the super heavy nuclei might have lifetimes comparable to the age of the earth (~ 4.567 x10^9years) have yielded a world-wide effort to search for super heavy neutron-rich long-lived nuclei in laboratories as well as in nature [46]. The study of super heavy elements is imperative to find out whether the predicted wide shell gap (or, shell stabilization of super and hyper heavy nuclei without magic gap) at high Z and N values would lead to high stability of the super heavy nuclei against alpha-decay.

A super heavy nucleus predominantly undergoes sequential α-decays followed by subsequent spontaneous fission. While conducting the experiments measures the decay energies and decay times, while one of the major goals of theory is to be able to predict the α-decay lifetimes of super heavy elements. Super heavy atoms have all been created during the latter half of the 20th century and are continually being created during the 21st century as technology advances.

All heavy and super heavy elements are produced artificially using accelerator machine in lab. The super heavy elements have mainly two modes of decay

(i) Spontaneous alpha decay

(ii) Spontaneous fission (SF)

Beta decay (less favored) is another decay process for super heavies lying beyond the beta-stability line. The possibility of long-lived Super Heavy Nuclei is explored mainly by considering spontaneous emission of alpha, beta particle and spontaneous fission.

The synthesis of super heavy elements have been mainly done in three different places, they are: GSI (Germany), JINR in Dubna (Russia), and RIKEN in Japan. The super heavy elements with Z = 107–112 have been successfully synthesized at GSI, Darmstadt [80-82]. Isotopes of these elements along with Z = 113 - 116 and 118 have been synthesized at JINR-FLNR, Dubna [83-86] and Z = 110 - 113 have been produced at RIKEN, Japan [87-89]

2.2.1. Synthesis and decay properties of super heavy elements

2.2.1.1 Dubnium (Z = 105)

This is a radioactive synthetic element whose most stable isotope is ^{268}Db with a half life of 28hours and the least stable is ^{259}Db of 0.5s. It is the longest lived transactinide isotope and is a reflection of the stability of the $Z = 108$ and $N = 162$ closed shells and the effect of odd particles in nuclear decay. There are eleven isotopes of Db with mass number ranging from 256-268 have been detected.

The first attempts to synthesise element 105 using cold fusion reactions were performed in 1976 [90-93] by the team at FLNR (Dubna) using the ^{209}Bi (^{50}Ti, xn) $^{259-x}$Db (x=1, 2, 3) reaction. The authors were able to detect a 5s spontaneous fission (SF) activity which they assigned to ^{257}105. This assignment was later corrected to ^{258}105.

By the method of hot fusion, there are very limited reports that this rare reaction (^{232}Th (^{31}P, xn) $^{263-x}$Db (x=5)) using a ^{31}P beam was studied in 1989 by Andreyev et al [94] at the FLNR. One source suggests that no atoms were detected whilst a better source from the Russians themselves indicates that ^{258}Db was synthesised in the 5n channel with a yield of 120pb. In 2006, [95] as part of their study of the use of uranium targets in superheavy

element synthesis, the LBNL team led by Ken Gregorich studied the excitation functions for the 4n and 5n channels in this (^{238}U(^{27}Al,xn)$^{265-x}$Db (x=4,5)) reaction.

Isotopes of dubnium have also been identified in the decay of heavier elements. For e.g. the isotopes ^{288}115 through a series of alpha decays transforms to ^{268}Db, the alpha decay chain from ^{287}115 to ^{267}Db, ^{282}113 to ^{266}Db, ^{267}Bh to ^{263}Dd, ^{278}113 to ^{262}Db, ^{266}Bh to ^{262}Db, ^{265}Bh to ^{261}Db, ^{266}Mt to ^{258}Db, ^{262}Bh to ^{258}Db etc. are the identified examples in the decay of super heavy elements.

Tables 2.7-2.9 show the decay properties and production reactions of super heavy elements Z ranging from 105-118. From the table it is clear that $^{256-262}$Db has alpha decay as the dominant decay mode, ^{263,267,268}Db have spontaneous fission as dominant mode and ^{266}Db decays by electron capture to ^{266}Rf.

2.2.1.2 Seaborgium (Z = 106)

Eleven isotopes of seaborgium (excluding meta-stable and K-spin isomers) are detected and its decay properties and discovery reactions are shown in Table 2.7. The longest-lived is ^{271}Sg which decays through alpha decay and spontaneous fission. It has a half-life of 1.9minutes. The shortest-lived isotope is ^{258}Sg which also decays through alpha decay and spontaneous fission. It has a half-life of 2.9ms.

For the synthesis of seaborgium isotopes by the cold fusion method, generally used ^{209}Bi, ^{206,207,208}Pb are used as targets and ^{51}V, ^{52,54}Cr as projectiles. The first attempt to synthesize element 106 in cold fusion reactions was performed in 1974 by Flerov et al [96] at the JINR, Dubna. By using this reaction (^{208}Pb (^{54}Cr, xn) $^{262-x}$Sg (x=1, 2, 3)) they reported producing a 0.48s spontaneous fission (SF) activity which they assigned to the isotope ^{259}Sg. In 1985, Muzenberg et al [97] at GSI studied the reaction for the production of ^{260}Sg using the method of correlation of genetic parent-daughter decays. The authors were able to positively identify ^{259}Sg as a product from the 2n neutron evaporation channel.

Similar isotopes are also produced by hot fusion reactions. The ^{238}U (^{30}Si, xn) $^{268-x}Sg$ (x=3, 4, 5, 6) reaction was first studied by Japanese scientists at the Japan Atomic Energy Research Institute (JAERI) in 1998. They detected a spontaneous fission activity which they tentatively assigned to the new isotope ^{264}Sg or ^{263}Db, formed by EC of ^{263}Sg [98]. In 2006, the teams at GSI and LBNL both studied this reaction using the method of correlation of genetic parent-daughter decays. The LBNL team measured an excitation function for the 4n, 5n and 6n channels, whilst the GSI teams were able to observe an additional 3n activity [99]. Both teams were able to identify the new isotope ^{264}Sg which decayed with a short lifetime by spontaneous fission. Similar studies are also studied by using different target projectile combinations as ^{248}Cm (^{22}Ne, xn) and ^{249}Cf (^{18}O, xn) to produce $^{263,264}Sg$ isotopes.

Isotopes of seaborgium have also been observed in the alpha decay chain of heavier elements. The decay of $^{291}116 \rightarrow {}^{287}114 \rightarrow {}^{283}112 \rightarrow {}^{271}Sg$, $^{271}Hs \rightarrow {}^{267}Sg$, $^{270}Hs \rightarrow {}^{266}Sg$, $^{277}112 \rightarrow {}^{273}Ds \rightarrow {}^{269}Hs \rightarrow {}^{265}Sg$, $^{271}Ds \rightarrow {}^{267}Ds \rightarrow {}^{263}Sg$, $^{270}Ds \rightarrow {}^{262}Sg$, $^{269}Ds \rightarrow {}^{265}Hs \rightarrow {}^{261}Sg$ and $^{264}Hs \rightarrow {}^{260}Sg$ are the examples of the alpha decay chain of the heavier elements.

2.2.1.3 Bohrium (Z = 107)

Bohrium is a synthetic element whose most stable isotope is ^{270}Bh having a half life of 61seconds. Nine isotopes of bohrium are detected and all the isotopes have alpha decay as the dominant decay reaction.

The synthesis of element 107 was first attempted in 1976 by Folden et al [100] at the JINR, Dubna using the (^{209}Bi (^{54}Cr, xn) $^{263-x}Bh$ (x=1, 2)) cold fusion reaction. There are many other cold fusion reactions (for e.g. ^{209}Bi (^{52}Cr, xn) $^{260,262}Bh$ and ^{208}Pb (^{55}Mn, 2n) ^{262}Bh) studied in many other laboratories for the detection of bohrium isotopes.

By the method of hot fusion, the team at the Institute of Modern Physics (IMP), Lanzhou, have studied the nuclear reaction between ^{243}Am and ^{26}Mg ions in order to

synthesize the new isotope ^{265}Bh [101] and gather more data on ^{266}Bh. In two series of experiments, the team has measured partial excitation functions of the 3n, 4n and 5n evaporation channels. Similar hot fusion reactions were studied for the first time in 2008 by the team at RIKEN, Japan, (^{248}Cm (^{23}Na, 5n) ^{266}Bh) to study the decay properties of ^{266}Bh.

Isotopes of bohrium have also been detected in the decay of heavier elements. Some of the examples for this decay chain are ^{288}115 decays to ^{272}Bh, ^{282}113 to ^{270}Bh, ^{278}113 to ^{266}Bh, ^{272}Rg to ^{264}Bh and ^{266}Mt to ^{262}Bh.

2.2.1.4 Hassium (Z = 108)

Hassium was first synthesized in 1984 by Münzenberg et al [102] at the Institute for Heavy Ion Research in Darmstadt, by the bombardment of lead target with ^{58}Fe nuclei to produce three atoms of ^{265}Hs.

There are different projectile target combinations observed for the synthesis of Hassium isotopes by the cold fusion reaction. ^{207}Pb (^{56}Fe, n) ^{264}Hs and ^{208}Pb (^{56}Fe, n) ^{263}Hs are some of the examples of these reactions.

The hot fusion reaction was first studied by Oganessian et al [103] by using ^{226}Ra and ^{48}Ca as projectile target combinations. The reaction was repeated at the FLNR in 2008 and preliminary results show that the isotope ^{270}Hs was detected with a yield of 9pb. In 1994, the team at Dubna led by the Lazerev [104] announced the detection of three atoms of ^{267}Hs in the ^{238}U (^{34}S, 5n) reaction.

2.2.1.5 Meitnerium (Z = 109)

Meitnerium is a synthetic element whose most stable isotope, ^{278}Mt, has a predicted half-life of half an hour. Meitnerium was first synthesized in 1982 Munzenberg et al [105] at the Institute for Heavy Ion Research in Darmstadt by the bombardment of a target of ^{209}Bi with accelerated nuclei of ^{58}Fe and detected a single atom of the isotope ^{266}Mt.

Isotopes of meitnerium have also been detected in the decay of heavier elements. Some of the examples of alpha decay chain are $^{287}115 \rightarrow {}^{275}Mt$, $^{288}115 \rightarrow {}^{276}Mt$, $^{282}113 \rightarrow {}^{274}Mt$, $^{278}113 \rightarrow {}^{274}Mt$ and $^{272}Rg \rightarrow {}^{268}Mt$. The alpha decay spectrum for ^{268}Mt appears to be complicated as observed from the results of several experiments. Alpha lines of 10.28, 10.22 and 10.10MeV have been observed. Half-lives of 42ms, 21ms and 102ms have been measured. The experimentally observed half life times, reaction leading to compound nuclei and other decay properties of all Meitnerium isotopes are shown in the Table 2.8

2.2.1.6 Darmstadtium (Z = 110)

Darmstadtium is one of the so-called super-heavy atoms, it decays quickly. Heavier isotopes of darmstadtium have half-lives of the order of ten seconds. Darmstadtium was first created in 1994 at the GSI, Germany, by Hofmann et al [106]. Four atoms of it were detected by a nuclear fusion reaction caused by bombarding a ^{208}Pb target with ^{62}Ni ion ($^{208}Pb + {}^{62}Ni \rightarrow {}^{269}Ds + 10n$). In the same series of experiments, the same team [107] also carried out the reaction using heavier ^{64}Ni ions. During two runs, 9 atoms of ^{271}Ds were convincingly detected by correlation with known daughter decay properties ($^{208}Pb + {}^{64}Ni \rightarrow {}^{271}Ds + 10n$). There are many other projectile target combinations identified for the detection of Ds isotopes and the corresponding discovery reaction is shown in the Table 2.8.

Isotopes of darmstadtium have also been detected in the decay of heavier elements. Some of the examples of alpha decay chain are $^{293}116 \rightarrow {}^{289}114 \rightarrow {}^{281}Ds$, $^{291}116 \rightarrow {}^{287}114 \rightarrow {}^{283}112 \rightarrow {}^{279}Ds$ and $^{277}112 \rightarrow {}^{273}Ds$. Decay data from the direct synthesis of ^{271}Ds clearly indicates the presence of two alpha groups. The first has alpha lines at 10.74 and 10.69MeV with a half-life of 1.63ms. The other has a single alpha line at 10.71MeV with a half-life of 69ms. The first has been assigned to the ground state and the latter to an isomeric level as shown in Table 2.8. The direct production of ^{270}Ds has clearly identified

two alpha groups belonging to two isomeric levels. The ground state to ground state decays of ^{266}Hs by emitting an 11.03MeV alpha particle with a half-life of 0.10ms. The isomeric level decays by alpha emission with alpha lines at 12.15, 11.15 and 10.95MeV with a half-life of 6ms. The 12.15MeV has been assigned as decay into the ground state of ^{266}Hs indicating that this high spin K-isomer lies at 1.12MeV above the ground state.

2.2.1.7 Roentgenium (Z = 111)

Five isotopes of roentgenium are known. The longest-lived of these is ^{280}Rg, which decays through alpha decay and has a half life of 3.6s. The shortest-lived isotope is ^{272}Rg, which decays through alpha decay and has a half life of 1.6ms.

Roentgenium was first discovered by Hoffman et al [106] at GSI, the authors successfully detected three atoms of ^{272}Rg by the cold fusion between ^{64}Ni ions and a ^{209}Bi target in a linear accelerator (^{209}Bi + ^{64}Ni → ^{272}Rg + 10n). The discovery of roentgenium was confirmed in 2003 by Mortia et al [88] at RIKEN measured the decays of 14 atoms of ^{272}Rg during the measurement of the 1n excitation function.

Isotopes of roentgenium have also been observed in the decay of heavier elements through the alpha decay chain emissions, for examples $^{288,\ 287}$115 → $^{280,\ 279}$Rg and ^{282,278}113 → ^{278,274}Rg.

2.2.1.8 Copernicium (Z = 112)

The element Z = 112 was reported in 1996 Hofmann et al [108] at GSI in Darmstadt. This element was created by firing accelerated ^{70}Zn nuclei at a target made of ^{208}Pb nuclei in a heavy ion accelerator. A single atom of Z = 112 was produced with a mass number of 277. (^{208}Pb + ^{70}Zn → ^{278}112→ ^{277}112 + 10n)

In 1998 Oganessian et al [109] synthesized the two atoms of element ^{283}112 in "warm" fusion with the irradiation of ^{238}U to ^{48}Ca nuclei. The product ^{283}112 has a half-life of 5min decaying by spontaneous fission (SF).

Element 112 has also been observed as decay products of elements 114, 116 and 118. For example the alpha decay chain is $^{293}116 \rightarrow {}^{285}112$, $^{292}116 \rightarrow {}^{284}112$, $^{291}116 \rightarrow {}^{283}112$ and $^{294}118 \rightarrow {}^{282}112$.

2.2.1.9 Ununtrium (Z = 113)

Only eight atoms of element Z =113 have been observed to date. It has been synthesized both directly in "cold" and "warm" fusion reactions. It was first observed by Oganessian et al [110] in the alpha decay of element Z =115. The first report of element Z =113 was in 2003 when it was identified as a decay product of element Z =115.

In 2004, Morita at al [87] at RIKEN detected a single atom of $^{278}113$ using the cold fusion reaction between ^{209}Bi and ^{70}Zn. In 2006 Oganessian et al [111] synthesized the $^{282}113$ element directly in the "warm" fusion reaction between ^{237}Np and ^{48}Ca nuclei.

2.2.1.10 Ununquadium (Z=114)

In 1998 Oganessian et al [112] at JINR, Dubna in Russia bombarded a ^{244}Pu target with ^{48}Ca ions, A single atom of element 114, decaying by 9.67MeV alpha-emission with a half-life of 30s, was produced and assigned to $^{289}114$. In 1999, the same team [113] replaced the ^{244}Pu target with a ^{242}Pu one in order to produce other isotopes. This time two atoms of element 114 were produced, decaying by 10.29MeV alpha emission with a half-life of 5.5s.

The isotopes with Z = 114 have also been observed in the decay of elements 116 and 118 for decay chain. The examples of alpha decay chain are $^{290\text{-}293}116 \rightarrow {}^{286\text{-}289}114$ [114] and $^{294}118 \rightarrow {}^{286}114$.

2.2.1.11 Ununpentium (Z = 115)

Two isotopes of Z = 115 are currently known, they are $^{287}115$ and $^{288}115$. The synthesis of Z = 115 was reported at the JINR in Dubna, and at the Lawrence Livermore National Laboratory [85, 110]. The team bombarded ^{243}Am with ^{48}Ca ions to produce three

atoms of $^{288}115$ and a single atoms of $^{287}115$. The authors [85] reported that these atoms decayed by emission of alpha-particles to become Z = 113 elements in approximately 100ms.

2.2.1.12 Ununhexium (Z = 116)

Four isotopes with Z = 116 are synthesized. The most stable isotope is $^{293}116$ having 61ms life time and the least stable one is $^{290}116$ having life time 7.1ms. This isotope has also been observed in the decay of Z = 118 isotope. One of the experiments done at Dubna [86] was designed to investigate the radioactive properties of the isotopes of element 116, the α-decay daughters of *Z* = 118 isotopes produced in the reaction $^{249}Cf + ^{48}Ca$.

2.2.1.13 Ununoctium (Z = 118)

Only one isotope with Z = 118 ($^{294}118$) is synthesized with the life time of 0.89ms. Element 118 and its immediate decay product, element 116, were discovered [86] at Joint Institute for Nuclear Research (JINR) Dubna, produced via collisions of ^{249}Cf atoms and ^{48}Ca ions. In this reaction two new isotopes of element 116 have been synthesized and they undergo sequential α decays terminated by spontaneous fission. Although both new elements almost instantly decay into other elements, the sequence of decay events is consistent with theories that have long predicted an "island of stability" for nuclei with approximately 114 protons and 184 neutrons.

Table 2.7 The experimentally observed half life times, reaction leading to compound nuclei and other decay properties of different Rf, Db and Sg isotopes. (ε denotes electron capture)

Atomic Number	Isotopes	Half life	Decay Mode	Decay Energy (MeV)	Decay Product	Discovery Reaction
104	^{258}Rf	13ms	SF			^{249}Cf (^{13}C, 4n)
	^{259}Rf	3.1s	93%α 7% SF	8.87; 8.77	^{255}No	^{249}Cf (^{13}C, 3n)
	^{260}Rf	20ms	SF			^{248}Cm (^{16}O, 4n)
	^{261}Rf	3.0s	91% SF 9% α	8.51	^{257}No	^{208}Pb (^{70}Zn, n)
	^{262}Rf	2.1s	SF			^{244}Pu (^{22}Ne, 4n)
	^{263}Rf	8s	SF			^{248}Cm (^{26}Mg, 3n)
	^{267}Rf	1.3h	SF			^{238}U (^{48}Ca, 3n)
105	^{256}Db	1.6s	70% α 30% ε	9.12; 9.08; 8.89	^{252}Lr ^{256}Rf	^{209}Bi (^{50}Ti, 3n)
	^{257}Db	1.50s	α	9.07; 8.97	^{253}Lr	^{209}Bi (^{50}Ti, 2n)
	^{258}Db	4.4s	67% α 33% ε	9.17; 9.08; 9.01	^{254}Lr ^{258}Rf	^{209}Bi (^{50}Ti, n)
	^{259}Db	0.5s	α	9.47	^{255}Lr	^{241}Am (^{22}Ne, 4n)
	^{260}Db	1.5s	α	9.13; 9.08; 9.05	^{256}Lr	^{249}Cf (^{15}N, 4n)
	^{261}Db	1.8s	α	8.93	^{257}Lr	^{249}Bk (^{16}O, 4n)
	^{262}Db	34s	67%α 33% SF	8.66; 8.45	^{258}Lr	^{249}Bk (^{18}O, 5n)
	^{263}Db	27s	56%SF 41% α 3% ε	8.36	^{259}Lr ^{263}Rf	^{249}Bk (^{18}O, 4n)
	^{266}Db	22mts	ε		^{266}Rf	^{237}Np (^{48}Ca, 3n)
	^{267}Db	1.2h	SF			^{243}Am (^{48}Ca, 4n)
	^{268}Db	16h	SF			^{243}Am (^{48}Ca, 3n)
106	^{258}Sg	2.9ms	SF			^{209}Bi (^{51}V, 2n)
	^{259}Sg	0.48s	α	9.62; 9.36; 9.03	^{255}Rf	^{207}Pb(^{54}Cr, 2n)
	^{260}Sg	3.6ms	26% α 74% SF	9.81; 9.77; 9.72	^{256}Rf	^{208}Pb(^{54}Cr, 2n)
	^{261}Sg	0.18s	98.1%α 1.3% ε 0.6%SF	9.62; 9.55; 9.47	^{257}Rf ^{261}Db	^{208}Pb(^{54}Cr, n)
	^{262}Sg	15ms	SF			^{207}Pb(^{64}Ni, n)
	^{263}Sg	0.9s	87%α 13% SF	9.25	^{259}Rf	^{249}Cf (^{18}O, 4n)
	^{264}Sg	68ms	SF			^{238}U (^{30}Si, 4n)
	^{265}Sg	8.9s	α	8.90; 8.84; 8.76	^{261}Rf	^{248}Cm (^{22}Ne, 5n)
	^{266}Sg	0.39s	SF			^{248}Cm (^{26}Mg, 5n)
	^{267}Sg	1.4mts	17% α 83% SF	8.20	^{263}Rf	^{248}Cm (^{26}Mg, 3n)
	^{271}Sg	1.9mts	67% α 33% SF	8.54	^{267}Rf	^{242}Pu (^{48}Ca, 3n)

Table 2.8 The experimentally observed half life times, reaction leading to compound nuclei and other decay properties of different Bh, Hs, Mt and Ds isotopes

Atomic Number	Isotopes	Half life	Decay Mode	Decay Energy (MeV)	Decay Product	Discovery Reaction
107	^{260}Bh	35ms	α	10.16	^{256}Db	^{209}Bi (^{52}Cr, n)
	^{261}Bh	11.8ms	α	10.4; 10.1;10.03	^{257}Db	^{209}Bi (^{54}Cr, 2n)
	^{262}Bh	84ms	α	10.08; 9.94; 9.82; 9.74; 9.66	^{258}Db	^{209}Bi (^{52}Cr, n)
	^{264}Bh	0.97s	α	9.62; 9.48	^{260}Db	^{209}Bi (^{64}Ni, n)
	^{265}Bh	0.9s	α	9.24	^{261}Db	^{243}Am (^{26}Mg, 4n)
	^{266}Bh	0.9s	α	9.77; 9.04	^{262}Db	^{209}Bi (^{70}Ni, n)
	^{267}Bh	17s	α	8.83	^{263}Db	^{249}Bk (^{22}Ne, 5n)
	^{270}Bh	61s	α	8.93	^{266}Db	^{237}Np (^{48}Ca, 3n)
	^{272}Bh	9.8s	α	9.02	^{268}Db	^{243}Am (^{48}Ca, 3n)
108	^{263}Hs	0.74ms	α	10.89;10.72;10.57	^{259}Sg	^{208}Pb(^{56}Fe, n)
	^{264}Hs	~0.8ms	50% α 50% SF	10.43	^{260}Sg	^{207}Pb(^{56}Fe, n)
	^{265}Hs	2ms	α		^{261}Sg	^{208}Pb(^{58}Fe, n)
	^{266}Hs	2.3ms	α	10.18	^{262}Sg	^{207}Pb(^{64}Ni, n)
	^{267}Hs	52ms	α	9.87	^{266}Sg	^{238}U (^{34}S, 5n)
	^{269}Hs	9.7s	α	9.21; 9.10; 8.97	^{265}Sg	^{208}Pb (^{70}Zn, n)
	^{270}Hs	3.6s	α	8.88	^{266}Sg	^{248}Cm (^{26}Mg, 4n)
	^{271}Hs	40s	α	9.27;9.13	^{267}Sg	^{248}Cm (^{26}Mg, 3n)
	^{275}Hs	0.15s	α	9.30	^{271}Sg	^{242}Pu (^{48}Ca, 3n)
	^{277}Hs	16.5mts	SF			^{244}Pu (^{48}Ca, 3n)
109	^{266}Mt	1.7ms	α	11.00	^{262}Bh	^{209}Bi (^{58}Fe, n)
	^{268}Mt	42ms	α	10.26; 10.10	^{264}Bh	^{209}Bi (^{64}Ni, n)
	^{270}Mt	5ms	α	10.03	^{266}Bh	^{209}Bi (^{70}Zn, n)
	^{274}Mt	0.44s	α	9.76	^{270}Bh	^{237}Np (^{48}Ca, 3n)
	^{275}Mt	9.7ms	α	10.33	^{271}Bh	^{243}Am (^{48}Ca, 4n)
	^{276}Mt	0.72s	α	9.71	^{272}Bh	^{243}Am (^{48}Ca, 3n)
110	^{267}Ds	2.8μs	α	12.28	^{261}Hs	^{209}Bi (^{59}Co, n)
	^{269}Ds	179μs >50μs	α SF	11.20	^{265}Hs	^{208}Pb (^{62}Ni, n)
	^{270}Ds	0.10ms	α	11.03	^{266}Hs	^{207}Pb (^{64}Ni, n)
	^{271}Ds	1.63ms	α	10.74, 10.69	^{267}Hs	^{208}Pb (^{64}Ni, n)
	^{273}Ds	170ms	α	11.14	^{269}Hs	^{244}Pu (^{34}S, 5n)
	^{279}Ds	0.20s	10% α 90% SF	9.70	^{275}Hs	^{244}Pu (^{48}Ca, 5n)
	^{281}Ds	11s	SF			^{244}Pu (^{48}Ca, 3n)

Table 2.9 The experimentally observed half life times, reaction leading to compound nuclei and other decay properties of different isotopes with Z ranging from 111-118

Atomic Number	Isotopes	Half life	Decay Mode	Decay Energy (MeV)	Decay Product	Discovery Reaction
111	^{272}Rg	1.6ms	α	11.02; 10.82	^{268}Mt	^{209}Bi (^{64}Ni, n)
	^{274}Rg	15ms	α	11.23	^{270}Mt	^{209}Bi (^{70}Zn, n)
	^{278}Rg	4.2ms	α	10.69	^{274}Mt	^{237}Np (^{48}Ca, 3n)
	^{279}Rg	170ms	α	10.37	^{275}Mt	^{243}Am (^{48}Ca, 4n)
	^{280}Rg	3.6s	α	9.75	^{276}Mt	^{243}Am (^{48}Ca, 3n)
112	^{277}112	0.7ms	α	11.45; 11.32	^{273}Ds	^{208}Pb (^{70}Zn, n)
	^{282}112	0.8ms	SF			^{238}Pu (^{48}Ca, 4n)
	^{283}112	4s	~80% α ~20%SF	9.53; 9.32; 8.94	^{279}Ds	^{244}Pu (^{48}Ca, 5n)
	^{284}112	97ms	SF			^{244}Pu (^{48}Ca, 4n)
	^{285}112	29s	α	9.15	^{281}Ds	^{244}Pu (^{48}Ca, 3n)
113	^{278}113	0.34ms	α	11.68	^{274}Rg	^{209}Bi (^{70}Zn, n)
	^{282}113	73ms	α	10.63	^{278}Rg	^{237}Np (^{48}Ca, n)
	^{283}113	0.10s	α	10.12	^{279}Rg	^{243}Am (^{48}Ca, 4n)
	^{284}113	0.49s	α	10.00	^{280}Rg	^{243}Am (^{48}Ca, 3n)
114	^{286}114	0.13s	40% α 60% SF	10.19	^{282}112	^{249}Cf (^{48}Ca, 3n)
	^{287}114	0.48s	α	10.02	^{283}112	^{244}Pu (^{48}Ca, 5n)
	^{288}114	0.8s	α	9.94	^{284}112	^{244}Pu (^{48}Ca, 4n)
	^{289}114	2.6s	α	9.82; 9.48	^{285}112	^{244}Pu (^{48}Ca, 3n)
115	^{287}115	32ms	α	10.59	^{283}113	^{243}Am (^{48}Ca, 4n)
	^{288}115	87.5ms	α	10.59	^{284}113	^{243}Am (^{48}Ca, 3n)
116	^{290}116	7.1ms	α	10.84	^{286}114	^{249}Cf (^{48}Ca, 3n)
	^{291}116	18ms	α	10.74	^{287}114	^{245}Cm (^{48}Ca, 2n)
	^{292}116	18ms	α	10.66	^{288}114	^{248}Cm (^{48}Ca, 4n)
	^{293}116	61ms	α	10.54	^{289}114	^{248}Cm (^{48}Ca, 3n)
118	^{294}118	~0.89ms	α	11.65 $\pm$ 0.06	^{290}116	^{249}Cf (^{48}Ca, 3n)

2.3 Conclusion

The present chapter is a review work on the synthesis and decay properties of all the experimentally observed heavy and super heavy elements. This work mainly concentrates on the methods of production, life time and all the possible decay modes of heavy and super heavy elements with Z ranging from 93-118. This study treats the heavy elements as belonging to the region with atomic number greater than 92 and super heavy elements with atomic number greater than 104.