IN THE SEARCH OF SUPERHEAVY ELEMENTS

BY RUKIYA ALIYI

SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE

AT

ADDIS ABABA UNIVERSITY

ADDIS ABABA (ETHIOPIA)

JUNE 2011

ADDIS ABABA UNIVERSITY EPARTMENT OF

PHYSICS

APPROVED BY THE EXAMINATION

COMMITTEE

A.K.CHAUBEY (PROFESSOR) **Signature**

Advisor **———————**

Dr.TILAHUN TESFAYE

Examiner **———————**

Contents

Lists of tables:

Acknowledgment

I would like to pass my heart felt gratitude and appreciation of my advisor professor A.K Chaubey at Addis Ababa University for his critical educative advise and painstaking and time consuming reading of the draft of this project. I want to thanks my Allah.

And then I would to express my sympathetic appreciation to my family, mywevr and all of my friend's.

Abstract

The radioactive decay is discussed here. The main points on which this project work gives focuses are on the discovery of trans-uranium elements, synthesis of trans-uranium elements, properties of them and their applications. The concept of Island stability also discussed under this project and some details of SHE (Super Heavy Elements) are discussed.

CHAPTER ONE

INTRODUCTION

1.1 RADIOACTIVITY

Radioactive decay is the process by which an atomic nucleus of an unstable atom loses energy by emitting ionizing particles. The emission is spontaneous, in that the atom decays without any interaction with another particle from outside the atom (without a nuclear reaction). The decay, or loss of energy, results when the parent radionuclide transforms to an atom with a nucleus in a different state (the daughter nuclide). Often the parent and daughter are different chemical elements, and in such cases the decay process results in nuclear transmutation.

The rate at which a radioactive element decays is expressed in terms of its half-life; i.e. the time required for one-half of any given quantity of the isotope to decay. The product of a radioactive decay process called the daughter of the parent isotope may itself be unstable, in which case it, will decay. The process continues until a stable nuclide has been formed.

The emissions of the most common forms of spontaneous radioactive decay are the alpha (α) particle, the beta (β) particle, the gamma (γ) ray, and the neutrino. The alpha particle is actually the nucleus of a helium-4 atom, with two positive charges $^{4}_{2}He$. Such charged atoms are called ions. The neutral helium atom has two electrons outside its nucleus balancing these two charges. Beta particles may be negatively charged (e^{-}) or positively charged (e^{+}). The beta minus (β^{-}) particle is actually an electron created in the nucleus during beta decay without any relationship to the orbital electron cloud of the atom. The

beta plus particle, also called the positron, is the antiparticle of the electron; when brought together, two such particles will mutually annihilate each other. Gamma rays are electromagnetic radiations such as radio waves, light, and X-rays. Beta radioactivity also produces the neutrino and antineutrino, particles that have no charge and very little mass, symbolized by ν and $\tilde{\nu}$ respectively.

Neutrons and protons are, of course, the basic building blocks of complex nuclei, having approximately unit mass on the atomic scale and having zero charge or unit positive charge, respectively. The neutron cannot long exist in the free state. It is rapidly captured by nuclei in matter; otherwise, in free space it will undergo beta-minus decay to a proton, an electron, and an antineutrino with a half-life of 12.8 minutes. The proton is the nucleus of ordinary hydrogen and is stable.

1.2. Occurrence of radioactivity

Radioactive decay is a property of several naturally occurring elements as well as of artificially produced isotopes of the elements. Some species of radioactivity occur naturally on Earth. A few species have half-lives comparable to the age of the elements (about 6×10^9 years), so that they have not decayed away after their formation in stars. Notable among these are uranium-238, uranium-235, and thorium-232. Also, there is potassium-40, the chief source of irradiation of the body through its presence in potassium of tissue. A number of naturally occurring radio-nuclides are short-lived radiogenic nuclides that are the daughters of radioactive primordial nuclides (types of radioactive atoms that have been present since the beginning of the Earth and solar system). A radionuclide is an atom with an unstable nucleus, which is a nucleus characterized by excess energy available to be imparted either to a newly created

radiation particle within the nucleus or to an atomic electron. The radionuclide, in this process, undergoes radioactive decay, and emits gamma rays or subatomic particles. These particles constitute ionizing radiation. Radionuclides occur naturally, and can also be artificially produced.

Naturally occurring radionuclides fall into three categories: primordial radionuclides, secondary radionuclides and cosmogenic radionuclides. Primordial radionuclides originate mainly from the interiors of stars and, like uranium and thorium, are still present because their half-lives are so long that they have not yet completely decayed. Secondary radionuclides are radiogenic isotopes derived from the decay of primordial radionuclides. They have shorter half-lives than primordial radionuclides. Cosmogenic isotopes, such as carbon-14, are present because they are continually being formed in the atmosphere due to cosmic rays.

Another category of natural radioactivity includes species produced in the upper atmosphere by cosmic ray bombardment. Notable are 5,720-year carbon-14 and 12.3-year tritium (hydrogen-3), 53-day beryllium-7, and 2,700,000-year beryllium-10. Meteorites are found to contain additional small amounts of radioactivity, the result of cosmic ray bombardments during their history outside the Earth's atmospheric shield. Activities as short-lived as 35-day argon-37 have been measured in fresh falls of meteorites. Nuclear explosions since 1945 have injected additional radioactivity into the environment, consisting of both nuclear fission products and secondary products formed by the action of neutrons from nuclear weapons on surrounding matter.

The fission products encompass most of the known beta emitters in the mass region 75–160. They are formed in varying yields, rising to maxima of about 7 percent per fission in

the mass region 92–102 (light peak of the fission yield versus atomic mass curve) and 134–144 (heavy peak). Two kinds of delayed hazards caused by radioactivity are recognized. First, the general radiation level is raised by fallout settling to Earth. Protection can be provided by concrete or earth shielding until the activity has decayed to a sufficiently low level. Second, ingestion or inhalation of even low levels of certain radioactive species can pose a special hazard, depending on the half-life, nature of radiations, and chemical behavior within the body.

Nuclear reactors also produce fission products but under conditions in which the activities may be contained. Containment and waste-disposal practices should keep the activities confined and eliminate the possibility of leaching into groundwater’s for times that are long compared to the half-lives. A great advantage of thermonuclear fusion power over fission power, if it can be practically realized, is not only that its fuel reserves, heavy hydrogen and lithium, are vastly greater than uranium, but also that the generation of radioactive fission product wastes can be largely avoided.

In this connection, it may be noted that a major source of heat in the interior of both the Earth and the Moon is provided by radioactive decay. Theories about the formation and evolution of the Earth, Moon, and other planets must take into account these large heat production sources. Desired radioactivity other than natural activities and fission products may be produced either by irradiation of certain selected target materials by reactor neutrons or by charged particle beams or gamma ray beams of accelerators.

1.3. Types of radioactivity

1.3.1. Alpha decay

The alpha particle is a nucleus of the element helium; it composed of two protons and two neutrons and is the nucleus of highest stability. Because of its very large mass and its charge, it has a very short range. It is not suitable for radiation therapy since its range is less than a tenth of a millimeter inside the body. Its main radiation hazard comes when it is ingested into the body; it has great destructive power within its short range.

In contact with fast-growing membranes and living cells, it is positioned for maximum damage. A nucleus can decay to an alpha particle plus a daughter product if the mass of the nucleus is greater than the sum of the mass of the daughter product and the mass of the alpha particle or if some mass is lost during the transformation. The amount of matter defined by the difference between reacting mass and product mass is transformed into energy and is released mainly with the alpha particle.

It can be shown that, because of the inequality between the mass of a nucleus and the masses of the products, most nuclei beyond about the middle of the periodic table are likely to be unstable because of the emission of alpha particles. In practice, however, because of the reaction rate, decay by ejection of an alpha particle is important only with the heavier elements. Indeed, beyond bismuth (element 83) the predominant mode of decay is by alpha-particle emission, and all the trans-uranium elements are alpha-unstable. Alpha particle emission is modeled as a barrier penetration process.

In alpha decay, an energetic helium ion (alpha particle) is ejected, leaving a daughter nucleus of atomic number two less than the parent and of atomic mass number four less than the parent. An example is the decay of the abundant isotope of uranium, ^{238}U, to a thorium daughter plus an alpha particle:

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He \qquad Q_\alpha = 4.268 \text{ MeV}, \quad t_{1/2} = 4.51 \times 10^9 \text{ years}$$

General reaction: ${}^{A}_{Z}X \rightarrow {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$ or $M \rightarrow m_\alpha + M_1$, If $M > m_\alpha + M_1$ α-decay is possible. $Q=C^2[M-(m_\alpha + M_1)]$ or $Q=E_\alpha(A/A-4)$

Given for this and subsequent reactions are the energy released (Q) in millions of electron volts (MeV) and the half-life ($t_{1/2}$).

1.3.2. Beta decay

In elements lighter than lead, beta-particle decay in which a neutron is transformed into a proton or vice versa by emission of either an electron or a positron or by electron capture is the main type of decay observed. Beta-particle decay also occurs in the trans-uranium elements, but only by emission of electrons or by capture of orbital electrons; positron emission has not been observed in trans-uranium elements. When the beta-particle decay processes are absent in trans-uranium isotopes, the isotopes are said to be stable to beta decay. This Beta decay has two types (see below):

Beta-plus decay

During the 1930s new types of radioactivity were found among the artificial products of nuclear reactions: beta-plus decay, or positron emission, and electron capture. In beta-plus decay an energetic positron is created and emitted, along with a neutrino, and the nucleus transforms to a daughter, lower by one in atomic number and the same in mass number. When beta-plus is emitted a proton in the nucleus is converted to a neutron with simultaneous emission of neutrino. So the proton number is decreased by one. For

instance, carbon-11 (Z = 6) decays to boron-11 (Z = 5), plus one positron and one neutrino:

$$^{11}_{6}\mathrm{C} \longrightarrow {}^{11}_{5}\mathrm{B} + e^{+} + \nu \qquad Q_{\beta^+} = 0.97\ \mathrm{MeV}, \quad t_{1/2} = 20.4\ \mathrm{min}$$

Beta-minus decay

In beta-minus decay, an energetic negative electron is emitted, producing a daughter nucleus of one higher atomic number and the same mass number. When beta-minus is emitted a neutron in the atomic nucleus is converted to proton with the simultaneous emission of an antineutrino. An example is the decay of the uranium daughter product thorium-234 into protactinium-234:

$$^{234}_{90}\mathrm{Th} \longrightarrow {}^{234}_{91}\mathrm{Pa} + e^{-} + \bar{\nu} \qquad Q_{\beta^+} = .263\ \mathrm{MeV}, \quad t_{1/2} = 24.1\ \mathrm{days}$$

General reaction: ${}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + -e^{0} + Q_{в-}$ $\quad Q_{в-} = [{}^{A}_{Z}M_n - (M_n + m_0)]\ C^2$, For B^- -decay $Q_{в-}$ must be positive. In the above reaction for beta decay, $\tilde{\nu}$ represents the antineutrino. Here, the number of protons is increased by one in the reaction, but the total charge remains the same.

1.3.3. Gamma decay

Gamma rays are photons and photons are without rest mass or charge. Alpha or beta decay may simply proceed directly to the ground state of the daughter nucleus without gamma emission, but the decay may also precede wholly or partly to higher energy states of the daughter. In the latter case, gamma emission may occur as the excited states transform to lower energy states of the same nucleus.

Alternatively to gamma emission, an excited nucleus may transform to a lower energy state by ejecting an electron from the cloud surrounding the nucleus. This orbital electron ejection is known as internal conversion and gives rise to an energetic electron and often an X-ray as the atomic cloud fills in the empty orbital of the ejected electron.

1.3.4. Electron capture

Electron capture (EC) is a process in which decay follows the capture by the nucleus of an orbital electron. It is similar to positron decay in that the nucleus transforms to a daughter of one lower atomic number. It differs in that an orbital electron from the cloud is captured by the nucleus with subsequent emission of an atomic X-ray as the orbital vacancy is filled by an electron from the cloud about the nucleus. An example is the nucleus of beryllium-7 capturing one of its inner electrons to give lithium-7:

$$^{7}_{4}\mathrm{Be} + e^{-} \longrightarrow {}^{7}_{3}\mathrm{Li} + \nu \qquad Q_{EC} = 0.8616\ \mathrm{MeV} \qquad t_{1/2} = 53\ \mathrm{days}$$

The Q_{EC} is necessarily a calculated value because there is no general practical means of measuring the neutrino energies accompanying EC decay. With a few electron-capturing nuclides, it has been possible to measure directly the decay energy by measurement of a

rare process called inner bremsstrahlung (braking radiation). In this process the energy release is shared between the neutrino and a gamma ray. The measured distribution of gamma-ray energies indicates the total energy release. Usually there is so much ordinary gamma radiation with radioactive decay that the inner bremsstrahlung (braking radiation) is unobservable.

1.3.5. Decay by spontaneous fission

In this process the nucleus splits into two fragment nuclei of roughly half the mass of the parent. This process is only barely detectable in competition with the more prevalent alpha decay for uranium, but for some of the heaviest artificial nuclei, such as fermium-256, spontaneous fission becomes the predominant mode of radioactive decay. Kinetic-energy releases from 150 to 200 MeV may occur as the fragments are accelerated apart by the large electrical repulsion between their nuclear charges. The reaction is as follows:

$$^{256}_{100}\mathrm{Fm} \longrightarrow {}^{140}_{54}\mathrm{Xe} + {}^{112}_{46}\mathrm{Pd} + 4n \qquad Q = 150\text{–}200\ \mathrm{MeV}$$

$$+\ \text{other fission products} \qquad t_{1/2} = 2.7\ \text{hours}$$

Only one of several product sets is shown. A few neutrons are always emitted in fission of this isotope, a feature essential to chain reactions. Spontaneous fission is not to be confused with induced fission, the process involved in nuclear reactors. Induced fission is a property of uranium-235, plutonium-239, and other isotopes to undergo fission after absorption of a slow neutron. Other than the requirement of a neutron capture to initiate it, induced fission is quite similar to spontaneous fission regarding total energy release, numbers of secondary neutrons, and so on. The lighter actinides such as uranium rarely decay by spontaneous fission, but at californium (element 98) spontaneous fission becomes more common (as a result of changes in energy balances) and begins to compete favorably with alpha-particle emission as a mode of decay [1, 4, 6, 7, 8].

Application of radioactive isotopes

1) In medicine

Radiation and radioactive substances are used for diagnosis, treatment and research. X-rays for examples, pass through the muscles and other soft tissue but are stopped by denser materials. This property of X-rays enables doctors to find the broken bones and to locate cancers that might be growing in the body. Doctors also find certain diseases by injecting a radioactive substances and monitoring the radiation give off as the substance moves through the body.

2) In communication

All modern communication systems use form of electromagnetic radiation. Variations in the intensity of the radiations represent changes in the sound, picture and other information being transmitted. Example, a human voice can be sent as a radio wave or microwave by making the wave vary to correspond variation in the voice.

3) In science

Researchers use the radioactive atoms to determine the age of materials that were once apart of a living organism. The age of such materials can be estimated by measuring the amount of radioactive carbon they contain in a process called radioactive dating. Environmental scientists use radioactive atoms known as tracer atoms to identify the path ways taken by pollutants through the environment. Radiation is used to determine the composition of materials in the process called neutron activation analysis. In this process, the scientists bombard a sample of a substance with particle called neutrons. Some of the atoms in the sample absorb neutrons and become radioactive. The scientist can identify the elements in the sample by studying the radiation given off.

Trans-uranium element is any of the chemical elements that lie beyond uranium in the periodic table i.e., those with atomic numbers greater than 92. More than 20 of these

elements have been discovered and named or are awaiting confirmation of their discovery. Eleven of them, from neptunium through lawrencium, belong to the actinide series. The others, which have atomic numbers higher than 103, are referred to as the trans-actinides. All the trans-uranium elements are unstable, decaying radioactively, with half-lives that range from tens of millions of years to mere fractions of a second.

The super-heavy elements (SHE) are considered to be those that lie above element 103 (Lawrencium, Lr), the last of the actinides. Starting with Rutherfordium (Rf), element 104, these elements are sometimes referred to as the super-transactinides. Collectively, they represent the very top end of the Periodic Table of Elements and a study of their properties is intrinsically linked to an understanding of the physics and chemistry at the limit of stability in mass and charge. Super-heavy atoms have all been created during the latter half of the 20^{th} century and are continually being created during the 21^{st} century as technology advances. They are created through the bombardment of elements in a particle accelerator [2, 5].

CHAPTER TWO

TRANSURANIUM ELEMENTS

Any of the chemical elements after uranium in periodic table. All are radioactive and produced in the laboratory. Only, two, neptunium (93) and plutonium (94), occurs in nature, and only as traces in uranium ores as a result of neutron irradiation. Each appears to resemble the elements above it in periodic table. In particular, the actinides thorium (90) through lawrencium (103), are similar to the lanthanides, cerium (58) through lutetium (71).

In chemistry, trans-actinide elements (or super heavy elements) are the chemical elements with atomic numbers greater than those of the actinides, the heaviest of which is lawrencium (103).Trans-actinide elements are also trans-uranic elements that are, have an atomic number greater than that of Uranium (92), an actinide. They are radioactive and have only been obtained synthetically in laboratories.

The further distinction of having an atomic number greater than the actinides is significant in several ways:

-The trans-actinide elements all have electrons in the 6d sub-shell in their ground state (and thus are placed in the d-block).

-Except for Dubnium, even longest-lasting isotopes of transactide elements have extremely short, half-lives, measured in seconds, or smaller units.

-The element naming controversy involved 1st five or six trans-actinide elements. These elements thus used three letter systematic names for many years after their discovery had

been confirmed. (Usually the three letter names relatively shortly after a discovery has been confirmed).

Due to the rapid increase of the repulsive Coulomb forces between the protons, the number of chemical element is limited by fission. This macroscopic behavior is governed by shell effects, without which the nuclear chart may end near Element 106 (Seaborgium, Sg). There is evidence to suggest that nuclei can survive beyond the macroscopic limit, far into the trans-uranium region, where the necessary balance between the nuclear force and the Coulomb force is achieved only through shell stabilizations.

All of the elements with higher atomic numbers have been discovered in the laboratory, other than neptunium and plutonium. They are all radioactive, with a half-life much shorter than the age of the Earth, so any atoms of these elements, if they ever were present at the Earth's formation, have long since decayed. Trace amounts of neptunium and plutonium form in some uranium-rich rock, and small amounts are produced during atmospheric tests of atomic weapons. The Np and Pu are generated from neutron capture in uranium ore with two subsequent beta decays

$$^{238}\mathrm{U} \rightarrow {}^{239}\mathrm{U} \rightarrow {}^{239}\mathrm{Np} \rightarrow {}^{239}\mathrm{Pu}$$

Those that can be found on Earth now are artificially generated synthetic elements, via nuclear reactors or particle accelerators. The half lives of these elements show a general trend of decreasing with atomic number. There are exceptions, however, including dubnium and several isotopes of curium.

2.1. Discovery and naming of trans-uranium elements

The first attempt to prepare a trans-uranium element was made in 1934 in Rome, where a team of Italian physicists headed by Enrico Fermi and Emilio Segrè bombarded uranium nuclei with free neutrons. Although trans-uranium species may have been produced, the experiment resulted in the discovery of nuclear fission rather than new elements. The German scientists Otto Hahn, Fritz Strassman, and Lise Meitner showed that the products Fermi found were lighter, known elements formed by the splitting, or fission, of uranium. Not until 1940 was a transuranium element first positively produced and identified, when two American physicists, Edwin Mattison McMillan and Philip Hauge Abelson's, working at the University of California at Berkeley, exposed uranium oxide to neutrons from a cyclotron target. One of the resulting products was an element found to have an atomic number of 93. It was named neptunium.

Transformations in atomic nuclei are represented by equations that balance all the particles of matter and the energy involved before and after the reaction. The above transformation of uranium into neptunium may be written as follows:

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} + \gamma$$

$$^{239}_{92}\mathrm{U} \xrightarrow{\beta^-} {}^{239}_{93}\mathrm{Np}\,.$$

The uranium-238 isotope reacts with a neutron (n) to produce uranium-239 ($^{239}_{92}$U) and the quantum of energy called a gamma ray (γ). In the next equation the arrow represents a spontaneous loss of a negative beta particle (β^-), an electron with very high velocity, from the nucleus of uranium-239. What has happened is that a neutron within the nucleus has been transformed into a proton, with the emission of a beta particle that carries off a single negative charge; the resulting nucleus now has one more positive charge than it had before the event and thus has an atomic number of 93.

Because the beta particle has negligible mass, the mass number of the nucleus has not changed, however, and is still 239. The nucleus resulting from these events is an isotope of the element neptunium, atomic number 93 and mass number 239. The above process is called negative beta-particle decay. A nucleus may also emit a positron, or positive electron, thus changing a proton into a neutron and reducing the positive charge by one (but without changing the mass number); this process is called positive beta-particle decay.

The discovery of the next element after neptunium followed rapidly. In 1941 three American chemists, Glenn T. Seaborg, Joseph W. Kennedy, and Arthur C. Wahl, produced and chemically identified element 94, named plutonium (Pu). In 1944, after further discoveries, Seaborg hypothesized that a new series of elements called the actinide series, akin to the lanthanide series (elements 58–71), was being produced, and that this new series began with thorium (Th), atomic number 90. Thereafter, discoveries were sought, and made, in accordance with this hypothesis.

The naming of transuranium elements has been fraught with controversy regarding which laboratory, first made the discovery and should proposed the name and whether elements should be named for living persons. They are named after nuclear physicist, chemists, astronomer, planet or important locations involved in the synthesis of the elements. Chemistry Novelists GlennT.seaborg who 1st proposed the actinide concept which led to the acceptance of the actinide series also proposed the existence of a transactinide series ranging from element 104 to 121 and a super actinide series approximately spanning elements 122 to 153.The transactinide Seaborgium is named in his honor.

The majority of the transuranium elements were produced by three groups:

- A group at the University of California, Berkeley, under three different leaders:
  - Edwin Mattison McMillan, first to produce a transuranium element:
    - 93. Neptunium, Np, named after the planet Neptune, as it follows uranium and Neptune follows Uranus in the planetary sequence (1940).
  - Glenn T. Seaborg, next in order, who produced:
    - 94. Plutonium, Pu, named after the dwarf planet Pluto, following the same naming rule as it follows neptunium and Pluto follows Neptune in the pre-2006 planetary sequence (1940).
    - 95. Americium, Am, named because it is an analog to europium, and so was named after the continent where it was first produced (1944).
    - 96. Curium, Cm, named after Pierre and Marie Curie, famous scientists who separated out the first radioactive elements (1944).
    - 97. Berkelium, Bk, named after the city of Berkeley, where the University of California, Berkeley is located (1949).
    - 98. Californium, Cf, named after the state of California, where the university is located (1950).
  - Albert Ghiorso, who had been on Seaborg's team when they produced curium, berkelium, and californium, took over as director to produce:
    - 99. Einsteinium, Es, named after the theoretical physicist Albert Einstein (1952).
    - 100. Fermium, Fm, named after Enrico Fermi, the physicist who produced the first controlled chain reaction (1952).
    - 101. Mendelevium, Md, named after the Russian chemist Dmitri Mendeleev, credited for being the primary creator of the periodic table of the chemical elements (1955).

- 102. Nobelium, No, named after Alfred Nobel (1956).
- 103. lawrencium, Lr, named after Ernest O. Lawrence, a physicist best known for development of the cyclotron, and the person for whom the Lawrence Livermore National Laboratory and the Lawrence Berkeley National Laboratory (which hosted the creation of these transuranium elements) are named (1961).

❖ A group at the Joint Institute for Nuclear Research in Dubna, Russia (then the Soviet Union) who produced:

- 104. Rutherfordium, Rf, named after Ernest Rutherford, who was responsible for the concept of the atomic nucleus (1966).
- 105. Dubnium, Db, an element that is named after the city of Dubna, where the JINR is located. Also known in Western circles as "Hassium" in honor of Otto Hahn (1968).
- 106. Seaborgium, Sg, named after Glenn T. Seaborg. This name caused controversy because Seaborg was still alive, but eventually became accepted by international chemists (1974).
- 107. Bohrium, Bh, named after the Danish physicist Niels Bohr, important in the elucidation of the structure of the atom (1981).

❖ A group at the Gesellschaft für Schwerionenforschung (Society for Heavy Ion Research) in Darmstadt, Hessen, Germany, under Peter Armbruster, who produced:

- 108. Hassium, Hs, named after the Latin form of the name of Hessen, the German Bundesland where this work was performed (1984).
- 109. Meitnerium, Mt, named after Lise Meitner, an Austrian physicist who was one of the earliest scientists to become involved in the study of nuclear fission (1982).

- 110. Darmstadtium, Ds, named after Darmstadt, Germany, the city in which this work was performed (1994).
- 111. Roentgenium, Rg, named after Wilhelm Conrad Röntgen, discoverer of X-rays (1994).
- 112. Copernicium, Cn, named after astronomer Nicolas Copernicus (1996).

Table 2:1 List of the trans-uranium elements

Actinides	Trans-actinide elements	Period 8 elements**
93 Neptunium Np	104 Rutherfordium Rf	119 Ununennium Uue
94 Plutonium Pu	105 Dubnium Db	120 Unbinilium Ubn
95 Americium Am	106 Seaborgium Sg	121 Unbiunium Ubu
96 Curium Cm	107 Bohrium Bh	122 Unbibium Ubb
97 Berkelium Bk	108 Hassium Hs	123 Unbitrium Ubt
98 Californium Cf	109 Meitnerium Mt	124 Unbiquadium Ubq
99 Einsteinium Es	110 Darmstadtium Ds	125 Unbipentium Ubp
100 Fermium Fm	111 Roentgenium Rg	126 Unbihexium Ubh
101Mendelevium Md	112 Copernicium Cn	
102 Nobelium No	113 Ununtrium Uut*	
103 Lawrencium Lr	114 Ununquadium Uuq*	
	115 Ununpentium Uup*	
	116 Ununhexium Uuh*	
	117 Ununseptium Uus*	
	118 Ununoctium Uuo*	

*The existence of these elements has been confirmed; however the names and symbols given are provisional as no names for the elements have been agreed on. **The existence of these elements has not been confirmed. Element 126 is hypothesized to lie on the peak of the island of stability [5, 9].

2.2. Synthesis of trans-uranium elements

It is well known that the man-made elements heavier than uranium are synthesized in reactions of successive neutron captures during long term exposures at high flux nuclear reactors. Heaviest stable natural element: Uranium (Z = 92). The next elements up to fermium (Z = 100) can be created by neutron capture process with subsequent beta decay.

$$^{238}U+n\rightarrow{}^{239}U\rightarrow{}^{239}Np\rightarrow{}^{239}Pu$$

For elements with Z > 100 this process ends because of short life times due to fission and emission. They are created in nuclear fusion reaction and can be obtained by fusion of heavy-ion Projectiles and heavy element targets. For the synthesis of elements 101 or greater, so-called heavy ions (with atomic number greater than 2 and mass number greater than 5) have been used for the projectile nuclei.

General reaction: $a + A\rightarrow C^{*}\rightarrow B + b$

Depending on the beam-target combination employed, two broadly defined categories of reaction mechanisms are in use.

They are 1.Cold-fusion

2. Hot-fusion

1) Cold fusion reactions were first recognized as a method for the synthesis of heavy elements by Yuri Oganessian of the Joint Institute for Nuclear Research at Dubna, Advance to the domain of elements heavier than 106 became possible after the discovery in 1974 of the so-called cold-fusion reactions. In these reactions, magic nuclei of the stable isotopes 208Pb (Z = 82, N = 126) or 209Bi (Z = 83, N = 126) are used as target material, and are bombarded by ions heavier than argon.

In the process of fusion, the high binding energy of nucleons in the magic target nucleus leads to absorption of energy in rearrangement of the two interacting nuclei into a heavy nucleus of the summed mass. This difference in the packing energy of nucleons in the

interacting nuclei and the resulting nucleus compensate considerably the energy necessary to overcome the high Coulomb barrier of the reaction. As a result, the compound nucleus has excitation energy of only 10–20 MeV.

Therefore, in the synthesis of heavy elements in cold-fusion reactions, the heavy nucleus needs to emit only one or two neutrons to reach the ground state. Cold-fusion reactions with massive nuclei are successfully applied for synthesizing six new elements with Z = 107–112 at Gesellschaf für schwerionenforschung (Society for Heavy Ion Research) in Darmstadt. Beginning with element 106, the elements have been synthesized and identified (i.e., discovered) by the use of cold, or soft, fusion reactions. In this type of reaction, medium-weight projectiles are fused to target nuclei with protons numbering close to 82 and neutrons numbering about 126 i.e., near the doubly magic lead-208 resulting in a relatively cold compound system.

Because the newly formed compound nuclei have lower excitation energies than those produced in the hot fusion of heavy actinide targets and relatively light projectiles, they may emit only 1 or 2 neutrons and thus have a much higher probability of remaining intact instead of undergoing the competing prompt fission reaction. However, with increasing the atomic charge of the projectiles, the probability of their fusion with the 208Pb or 209Bi target nuclei significantly drops because of the increase of the Coulomb repulsion forces that are proportional to the nuclear charges.

From element 104, this can be produced in the reaction 208Pb + 50Ti (Z1.Z2 = 1804) to element 112 in the reaction 208Pb + 70Zn (Z1.Z2 = 2460), the fusion probability decreases by a factor of more than 104. There exists yet another limitation. Compound nuclei produced in cold-fusion reactions have a relatively low number of neutrons. In the

above case of the formation of element 112, the resulting nucleus with Z = 112 has only 165 neutrons, while an increase of stability is expected for neutron number N > 170.

Cold fusion reactions, following the emission of one or two neutrons from a cold system, use Lead or bismuth targets with appropriate projectiles. The reaction products are typically created via successive alpha-decays ending by spontaneous fission (SF) in the region of the known elements. Their identification is facilitated through alpha-alpha, or parent-daughter correlations. Cold fusion reactions have been used at GSI to produce Elements 107 to 112. A reasonable estimate of the limit of cold fusion experiments comes from the measurement of a single isotope of Element 113 which was synthesized at RIKEN, Japan with the extremely small production cross-section on the order of Femto-barns.

2) Hot fusion, following the evaporation of 3 to 5 neutrons, has been used successfully to produce the more neutron rich species ranging from Rutherfordium to Element 118. Unlike cold fusion, these decay chains end in unknown regions presenting additional challenges to the conclusive identification of the nuclides especially in the absence of elemental or isotopic signatures. The Elements 113 to 118 have been produced with hot fusion at Flerov Laboratory of Nuclear Research (FLNR) using actinide targets from uranium to californium with beams of the extremely rare isotope - ^{48}Ca. To connect the emerging Dubna Island to the known region remains a challenging task for the future.

The limit of hot fusion may be reached short of arriving at the proposed magic region around N=184. Extremely neutron rich rare ion beams at very high intensities may be required to reach the heaviest species. Hot fusion experiments have demonstrated that there is an increase in stability with increasing neutron number. Next generation

accelerators could greatly assist in uncovering the mysteries of new and more neutron rich regions of stability.

All of the heaviest elements beyond plutonium are artificially produced in heavy–ion reactions, mostly by complete fusion involving the amalgamation of two heavy species. The resulting neutron deficient isotopes are created through neutron evaporation followed by successive alpha decays from the compound system, until the chains end with a fashioning nucleus. For each step in neutron evaporation, there is a strong fission competition which increases greatly for the heaviest systems making them highly fissile. The survival probability of the compound nucleus (CN) is on the order of 10^{-2} to 10^{-3} per evaporation step. The hindrance to fusion progressively limits the cross section and quasi-fission (QF) becomes very important. It has been suggested that QF could account for over 90% of the hindrance to fusion.

Assuming the CN is formed, daughter products are identified by genetic correlations and simultaneous lifetime measurements. With decreasing alpha decay half-lives of less than a second and down to microseconds and steeply diminishing cross sections for every additional proton, heavy and superheavy element research represents physics with single atoms, a fact that imposes exacting constraints on the experimental method.

The heaviest elements are synthesized in accelerator based experiments with extremely high in-flight separation efficiencies ensuring that a single event of interest is separated from ~10^{10}-10^{11} in-beam products. With the heavy–ion accelerators available at present, beam intensities of around $5x10^{12}$ ions/s can be delivered on a target of about $10^{18}/cm^{2}$. Under these conditions typical production rates are about one atom per week and a single experimental run could take months to complete.

The use of doubly magic projectiles such as Lead and ^{48}Ca in the complete fusion of heavy ions deserves special mention. Theoretical investigations have shown that doubly magic nuclei keep their spherical shape until rather late into the process of amalgamation between projectile and compound nucleus. As a consequence, there is no dynamic heating and the cold formation of the mononuclear system is facilitated.

The ^{48}Ca projectile is uniquely suited. Apart from being a doubly magic nucleus with the associated advantages, it provides one of the most n-rich beams available. Among other remarkable features, the ^{48}Ca data show higher production cross sections than expected and follow a completely different systematic which is not completely understood. Surprisingly large cross-sections (~ 0.5 to 5 Pb) for the synthesis of spherical SHE around Z=114 have been observed. Recently, the Lawrence Berkeley National Laboratory (LBNL), USA, has undertaken a comprehensive and systematic study of fusion evaporation reactions in an attempt to understand the mechanisms at play.

Apart from the many formidable challenges present in the artificial synthesis of the heaviest elements, once created, their chemistry and subsequent placement in the Periodic table cannot be taken for granted. With an increasing number of nucleons, relativistic effects may influence the ordering of atomic orbital and may play a progressively important role in defining the chemical properties of a given element. Verifying through independent chemical studies if Element 112 belongs in Group 12 remains a hot topic.

However, in order to submit themselves to chemical studies, the nuclides must have half-lives of at least a few seconds. All the observed isotopes of elements between Meitnerium (Mt, Z=109) and Röentgenium (Rg, Z=111) are too short lived. Chemical studies have been carried out for some Dubnium (Db, Z=105), Sg and Hassium (Hs, Z=108) isotopes and for the longer lived ^{283}112.

The most abundant isotope of neptunium is neptunium-237. Neptunium-237 has a half-life of approximately 2×10^6 years and decays by the emission of alpha particles. Neptunium-237 is formed in kilogram quantities as a by-product of the large-scale production of plutonium in nuclear reactors. This isotope is synthesized from the reactor fuel uranium-235 by the reaction

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{236}_{92}\mathrm{U} + \gamma$$

$$^{236}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{237}_{92}\mathrm{U} + \gamma$$

$$^{237}_{92}\mathrm{U} \xrightarrow{\beta^-} {}^{237}_{93}\mathrm{Np}$$

and from uranium-238 by

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{237}_{92}\mathrm{U} + 2\,{}^{1}_{0}\mathrm{n}$$

$$^{237}_{92}\mathrm{U} \xrightarrow{\beta^-} {}^{237}_{93}\mathrm{Np}\,.$$

Plutonium, as the isotope plutonium-239, is produced in ton quantities in nuclear reactors by the sequence

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} + \gamma$$

$$^{239}_{92}\mathrm{U} \xrightarrow{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow{\beta^-} {}^{239}_{94}\mathrm{Pu}\,.$$

Because of its ability to undergo fission with neutrons of all energies, plutonium-239 has considerable practical applications as an energy source in nuclear weapons and as fuel in nuclear power reactors.

Heavy isotopes of some trans-uranium elements are also produced in nuclear explosions. Typically, in such events, a uranium target is bombarded by a high number of fast (high-energy) neutrons for a small fraction of a second, a process known as rapid-neutron

capture, or the r-process. Underground detonations of nuclear explosive devices during the late 1960s resulted in the production of significant quantities of einsteinium and fermium isotopes, which were separated from rock debris by mining techniques and chemical processing. Again, the heaviest isotope found was that of fermium-257.

An important method of synthesizing transuranium isotopes is by bombarding heavy element targets not with neutrons but with light charged particles (such as the helium nuclei) from accelerators. Targets and projectiles relatively rich in neutrons are required so that the resulting nuclei will have sufficiently high neutron numbers; too low a neutron number renders the nucleus extremely unstable and unobservable because of its resultantly short half-life [2, 5, 9].

2.3. Nuclear properties

Isotopes of the trans-uranium elements are radioactive in the usual ways: they decay by emitting alpha particles, beta particles, and gamma rays; and they also fission spontaneously. The predominant modes of decay of transuranium elements are alpha-decayed because of the binding energy of the nucleons. Due to the binding energy of the nucleon emission in natural radioactivity is not observed (proton and neutron emission is not found in nature).

The Table lists significant nuclear properties of certain isotopes that are useful for chemical studies. Only the principal mode of decay is given, though in many cases other modes of decay also are exhibited by the isotope. In particular, with the isotope californium-252, alpha-particle decay is important because it determines the half-life, but the expected applications of the isotope exploit its spontaneous fission decay that produces an enormous neutron output. Other isotopes, such as plutonium-238, are useful because of their relatively large thermal power output during decay (given in the Table in watts per gram).

Table 2:2 nuclear properties of selected transuranium element isotopes see below:

Names and mass	Principal decay mode	Half-life	Specific disintegration per min per microgram	Watts per gram*
Neptunium-237	alpha	2.14×10^{6} years	1565	2.07×10^{-5}
Plutonium-238-	alpha	87.74 years	3.8×10^{7}	0.570
Plutonium-239	alpha	2.411×10^{4} years	1.38×10^{5}	1.91×10^{3} **
Americium-241	alpha	432.2 years	7.4×10^{6}	0.114
Americium-243	alpha	7.37×10^{3} years	4.4×10^{5}	6.45×10^{3}
Curium-242	alpha	162.8 days	7.4×10^{9}	122
Curium-244	alpha	18.1 years	1.80×10^{8}	2.83
Berkelium-249	Beta minus	320 days	3.6×10^{9}	0.358
Californium249	alpha	351 years	9.1×10^{6}	0.152
Mendelevium-256	Electron capture	78.1 minute	….	….

Research on the chemical and solid-state properties of these elements and their compounds obviously requires that isotopes with long half-lives be used. Isotopes of plutonium and curium, for example, are particularly desirable from this point of view. In the Table the specific activities (a measure of the intensity of a radioactive source) are given for those elements that can be produced in nuclear reactors. Beyond element 100 the isotopes must be produced by charged-particle reactions using particle accelerators, with the result that only relatively few atoms can be made at any one time.

2.4. Nuclear structure and stability

Although the decay properties of the transuranium elements are important with regard to the potential application of the elements, these elements have been studied largely to develop a fundamental understanding of nuclear reactions and nuclear and atomic structure. Study of the known transuranium elements also helps in predicting the properties of yet-undiscovered isotopes and elements as a guide to the researcher who can then design experiments to prepare and identify them. The relative stabilities of the isotopes are indicated by their relative heights. In this metaphoric representation, the known isotopes resemble a peninsula rising above a sea of instability. The most stable isotopes, appearing as mountaintops, occur at specific values called magic numbers.

The magic numbers derive from calculations of the energy distribution based on the theoretical structure of the nucleus. According to theory, neutrons and protons (collectively, nucleons) are arranged within the nucleus in shells that are able to accommodate only fixed maximum numbers of them; when the shells are closed (i.e., unable to accept any more nucleons), the nucleus is much more stable than when the shells are only partially filled. The number of neutrons or protons in the closed shells yields the magic numbers. These are 2, 8, 20, 28, 50, 82, and 126. Doubly magic nuclei,

such as helium-4, oxygen-16, calcium-40, calcium-48, and lead-208, which have both full proton shells and full neutron shells, are especially stable. As the proton and neutron numbers depart further and further from the magic numbers, the nuclei are relatively less stable.

As the highest atomic numbers are reached, decay by alpha-particle emission and spontaneous fission sets in. At some point the peninsula of relatively stable isotopes (i.e., with an overall half-life of at least one second) is terminated. There has been, however, considerable speculation, based on a number of theoretical calculations, that an island of stability might exist in the neighborhood of Z = 114 and N = 184, both of which are thought to be magic numbers. Isotopes in this region, which theoretically should have significantly longer half-lives than the neighboring known heavy isotopes, are sometimes termed super-heavy elements (SHE). There is also evidence for subshells (regions of somewhat increased stability) at Z = 108 and N = 162.

2.5. Characterization and identification

Two important factors provided the key to the discovery and identification of many of the earliest-known trans-uranium elements. One was the actinide concept, which stated that the trans-uranium elements were part of a series of elements that paralleled the earlier lanthanide series. It was demonstrated that this actinide series started at thorium and that its chemistry would be similar to that of the lanthanides.

The second factor was the technique of separating elements with similar properties from a mixture by using the principle of ion exchange. Ion-exchange reactions depend on the fact that some complex molecules have a charge that will attract ions of the opposite charge, hold them, and then exchange them for other ions of the same charge when brought in

contact with them. Although other separation methods are possible, many of the trans-uranium elements have been separated and identified and their chemistries studied by the use of ion-exchange reactions that are highly specific.

For example, the tripositive ions of the lanthanides and the actinides have been separated using a cation- (positive-ion-) exchange process. The striking similarity between the patterns of behavior exhibited by the two groups in this process constitutes strong support for the actinide concept. Nobelium, for example, exists in aqueous solution in the dipositive oxidation state, which might be expected for the next-to-last member of the actinide series because of the stability of the filled 5f electron shell ($5f^{14}$). The tripositive state of lawrencium has also been confirmed by a very rapid solvent-exchange experiment in which the lawrencium displayed the behavior of the tripositive actinides and not that of the dipositive nobelium or radium, again in accord with the predictions of the actinide concept.

When the yields of a new element are small and its half-life is short, chemical identification and characterization are frequently not possible. In such cases the atomic number is deduced from the method of production, from the parent-daughter relationship of the new element to known elements of lower atomic number resulting from its nuclear decay, and from its nuclear-decay systematic that cannot be attributed to any known nuclides. Additionally, the variation in the yield of the new element is noted when the bombarding energy is changed or when the target or projectile or both are changed.

Separation of the product nuclide from the target has been accomplished in the discoveries of elements 101 and heavier by a recoil collection method. When the target nucleus is struck by a heavy-ion projectile, the product nucleus recoils out of the very thin target and is either attracted to a substrate by an electrostatic potential or is swept onto a

substrate by a jet of helium gas. The new element is then in a position to be observed and characterized by suitable detection techniques, essentially free of the parent isotope.

It is desirable, though not essential, that the mass number of the new element be established by evidence related to its mode of production or to its parent-daughter relationship through radioactive decay to a radioactive isotope of known mass number. When weighable quantities of an element are available, more extensive characterization experiments can be performed. The most important of these is the preparation of the metal, frequently done by high-temperature reduction of the fluoride of the trans-uranium element with an alkali or alkaline-earth metal.

Another method used for preparation of larger quantities of high purity is electrolytic reduction of the chloride of the trans-uranium element. Physical characterization of these metal samples includes determination of the density, melting point, vapor pressure, boiling point, hardness, and other properties. X-ray diffraction measurements permit the determination of the crystal structure and calculation of the metallic radius and metallic valence. Chemical characterization includes a determination of the reactivity of the metal with other substances and the chemical stability of the compounds formed. Also of importance are the oxidation states and chemical bonding properties of the element in its compounds.

2.6. Practical applications of trans-uranium isotopes

The practical significance of the actinides arises from the fissionability, or potential for splitting, of certain of their isotopes. When an atomic nucleus breaks apart, or undergoes fission, a far more disruptive process than ordinary radioactive decay, enormous amounts of energy are liberated. This energy can be allowed to generate an atomic explosion, or it can be controlled and used as a fuel to generate heat for the production of electrical power.

More plutonium-239 has been produced than any other trans-uranium isotope. Like uranium-235, it is primarily used as a fuel to generate nuclear power and in nuclear weapons. Three other trans-uranium isotopes plutonium-238, americium-241, and californium 252 have demonstrated substantial practical applications. One gram of plutonium-238 produces approximately 0.57 watt of thermal power, primarily from alpha-particle decay, and this property has been used in space exploration to provide energy for small thermoelectric-power units.

Americium-241 has predominant gamma-ray energy (60 keV) and a long half-life (432 years) for decay by the emission of alpha particles. It is particularly useful for measuring and controlling the thickness of a wide range of industrial materials, for the diagnosis of thyroid disorders, and for smoke detectors. When mixed with beryllium, it generates neutrons at the rate of 1.0×10^7 neutrons per second per gram of americium-241. The mixture is designated ^{241}Am-Be, and many such sources are used worldwide in oil-well operations to monitor how much oil a well produces in a given time span, such as a day.

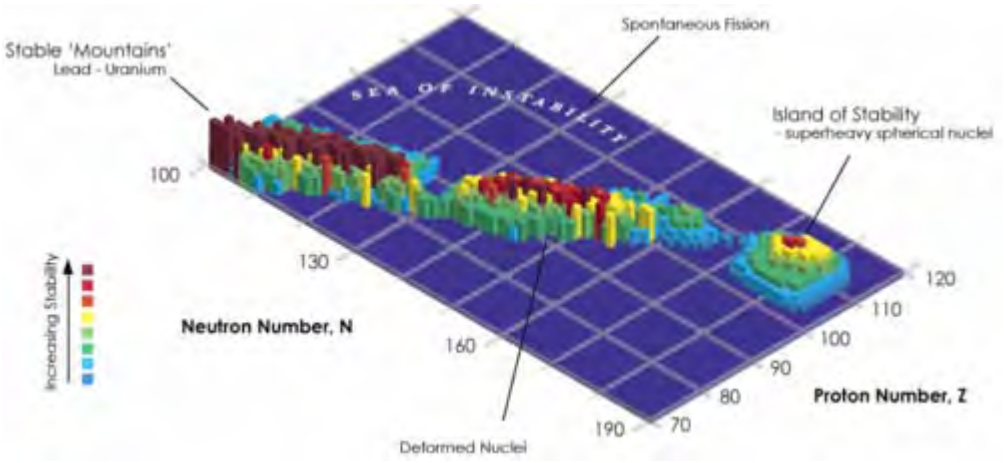
Californium-252 is an intense neutron source: one gram emits 2.3×10^{12} neutrons per second. It has been used to provide neutrons for numerous applications of neutron-activation analysis, including mineral prospecting and the monitoring of oil wells. It is

also used in neutron radiography, in airport neutron-activation detectors for nitrogenous materials (explosives), and for the irradiation of tumors for which gamma-ray treatment is relatively ineffective. Its most important industrial application, however, is as a start-up source (used to calibrate instrumentation) for nuclear reactors [5, 9].

CHAPTER THREE

ISLAND OF STABILITY

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. Existing on this island would allow the isotopes of some transuranium elements to be far more stable than others; that is, to decay much more slowly with half-lives of at least minutes or days as compared to seconds. Some theorists have suggested the possibility that the half-lives of these isotopes could be on the order of millions of years.



3-dimensional rendering of the theoretical Island of Stability.

The postulated nuclear island of stability is important to chemistry. The periodic table of the elements classifies a wealth of physical and chemical properties, and study of the chemical properties of the heavy elements would show how far the classification scheme of the table could be extended on the basis of the nuclear island of stability. Such study would shed new light on the underlying properties of electrons orbiting the nucleus because it is these properties that produce the periodic system.

The positions of heavy elements in the periodic table ultimately would be determined by the characteristic energies of the electrons of their atoms, especially the valence electrons. Complex calculations have predicted meaningful distribution of electrons in orbital for a number of heavy elements. Results for elements 104–118 are given in the Table, the configurations being those that the atoms have when they are at their lowest energy level, called the ground state

It must be stated that these calculations are oversimplified; the actual electronic configurations are determined by complicated relativistic effects, and hence the consequent predicted chemical properties will need eventually to be modified based on additional chemical experiments on the transactinide elements. However, the simplified predictions are accurate to a good first approximation.

Table 3.1 Electron configuration of super-heavy elements

Atomic number	Electronic structure of two outer most shells
104	$6d^2 7s^2$ or $6d^1 7s^2 7p^1$ or $7s^2 7p^2$
105	$6d^3 7s^2$
106	$6d^4 7s^2$
107	$6d^5 7s^2$
108	$6d^6 7s^2$
109	$6d^7 7s^2$
110	$6d^8 7s^2$
111	$6d^9 7s^2$
112	$6d^{10} 7s^2$
113	$7s^2 7p^1$
114	$7s^2 7p^2$
115	$7s^2 7p^3$
116	$7s^2 7p^4$
117	$7s^2 7p^5$
118	$7s^2 7p^6$

From 104-112 added to the structure of radon element 86, plus orbital $5f^{14}$ and from 113-118 added to the structure of radon element 86, plus $5f^{14}\,6d^{10}$

3.1. Theory and origin

The possibility of an island of stability was first proposed by Glenn T. Seaborg. 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 maximum and thus that particular configuration will have a longer lifetime than nearby isotopes that do not have filled shells.

A filled shell would have magic numbers of neutrons and protons. One possible magic number of neutrons for spherical nuclei is 184, and some possible matching proton numbers are 114, 120 and 126 which would mean that the most stable spherical isotopes would be ununquadium-298, unbinilium-304 and unbihexium-310. Of particular note is Ubh-310, which would be doubly magic (both its proton number of 126 and neutron number of 184 are thought to be magic) and thus the most likely to have a very long half-life. The next lighter doubly-magic spherical nucleus is lead-208, the heaviest stable nucleus and most stable heavy metal.

Recent research indicates that large nuclei are deformed, causing magic numbers to shift. Hassium-270 is now believed to be a doubly-magic deformed nucleus, with deformed magic numbers 108 and 162. However, it has a half-life of only 3.6 seconds. Isotopes have been produced with enough protons to plant them upon an island of stability but with too few neutrons to even place them upon the island's outer shores. It is possible that these elements have unusual chemical properties and, if they have isotopes long-lived

enough, various practical applications (such as targets in nuclear physics and neutron sources).

3.2. Half-lives of large isotopes

The interval of time required for one-half of the atomic nuclei of a radioactive sample to decay (change spontaneously into other nuclear species by emitting particles and energy), or, equivalently, the time interval required for the number of disintegrations per second of a radioactive material to decrease by one-half. The half-life, or the precise time required for one half of any amount of a particular isotopes to disappear due to radioactive decay is a measure of the stability of that isotopes. The naturally occurring isotopes in the actinide series have long half-life of the order of billions of years.

Half-lives are characteristic properties of the various unstable atomic nuclei and the particular way in which they decay. Alpha and beta decay are generally slower processes than gamma decay. Half-lives for beta decay range upward from one-hundredth of a second and, for alpha decay, upward from about one one-millionth of a second. Half-lives for gamma decay may be too short to measure (around 10^{-14} second).

Fermium is the heaviest element that can be produced in a nuclear reactor. The stability (half-life of the longest-lived isotope) of elements generally decreases from element 101 to element 109 and then approaches an island of stability with longer-lived isotopes in the range of elements 111 and 114.

Table 3:2 The longest-lived observed isotopes.

Number	Name	Longest-lived measured isotope	Half-life	Article
100	Fermium	^{257}Fm	101 days	Isotopes of fermium
101	Mendelevium	^{258}Md	52 days	Isotopes of Mendelevium
102	Nobelium	^{259}No	58 minutes	Isotopes of Nobelium
103	Lawrencium	^{262}Lr	3.6 hours	Isotopes of Lawrencium
104	Rutherfordium	^{267}Rf	1.3 hours	Isotopes of Rutherfordium
105	Dubnium	^{268}Db	29 hours	Isotopes of Dubnium
106	Seaborgium	^{271}Sg	1.9 minutes	Isotopes of Seaborgium
107	Bohrium	^{270}Bh	61 seconds	Isotopes of Bohrium
108	Hassium	^{277}Hs	16.5 minutes	Isotopes of Hassium
109	Meitnerium	^{278}Mt	~8 seconds	Isotopes of Meitnerium
110	Darmstadtium	^{281}Ds	11 seconds	Isotopes of Darmstadtium
111	Roentgenium	^{281}Rg	22.8 seconds	Isotopes of Roentgenium
112	Copernicium	^{285}Cn	29 seconds	Isotopes of Copernicium
113	Ununtrium	^{286}Uut	19.6 seconds	Isotopes of Ununtrium
114	Ununquadium	^{289}Uuq	2.6 seconds	Isotopes of Ununquadium
115	Ununpentium	^{289}Uup	220 ms	Isotopes of Ununpentium
116	Ununhexium	^{293}Uuh	61 ms	Isotopes of Ununhexium
117	Ununseptium	^{294}Uus	78 ms	Isotopes of Ununseptium
118	Ununoctium	^{294}Uuo	0.89 ms	Isotopes of Ununoctium

Note that for elements 109-118 the longest-lived known isotope is always the heaviest one discovered, making it likely that there are still longer-lived isotopes among the undiscovered heavier ones.

The half-lives of nuclei in the island of stability itself are unknown since none of the isotopes that would be on the island have been observed. Many physicists think they are relatively short, on the order of minutes or days. However, some theoretical calculations indicate that their half-lives may be long, on the order of 10^9 years. The alpha-decay half-lives of 1700 nuclei with $100 \leq Z \leq 130$ have been calculated in a quantum tunneling model with both experimental and theoretical alpha-decay Q-values. The theoretical calculations are in good agreement with the available experimental data.

3.3. Island of relative stability

Thorium (^{232}Th), ^{235}U and ^{238}U (uranium) are the only naturally occurring isotopes beyond bismuth that are relatively stable over the current lifespan of the universe. Bismuth was found to be unstable, with an α-emission half-life of 1.9×10^{19} years for ^{209}Bi. All other isotopes beyond bismuth are relatively or very unstable. So the main periodic table ends at bismuth, with an island at thorium and uranium. Between bismuth and thorium there is a sea of instability, which renders such elements as astatine, radon, and francium extremely short-lived relative to all but the heaviest elements found so far. Current theoretical investigation indicates that in the region Z=106−108 and N≈160−164, a small island might be stable with respect to fission and beta decay, such superheavy nuclei undergoing only alpha decay.

Also, ^{298}Uuq is not the center of the magic island as predicted earlier. On the contrary, the nucleus with Z=110, N=183 appears to be near the center of a possible magic island (Z=104−116, N≈176−186). In the N≈162 region the beta-stable,

fission survived ^{268}Sg is predicted to have alpha-decay half-life ~3.2 hours that is greater than that (~28 s) of the deformed doubly-magic ^{270}Hs. The superheavy nucleus ^{268}Sg has not been produced in the laboratory as yet (2009). For superheavy nuclei with Z>116 and N≈184 the alpha-decay half-lives are predicted to be less than one second. The nuclei with Z=120, 124, 126 and N=184 are predicted to form spherical doubly-magic nuclei and be stable with respect to fission. Calculations in a quantum tunneling model show that such superheavy nuclei would undergo alpha decay within microseconds or less.

3.4. Synthesis problems

The manufacturing of nuclei in the island of stability proves to be very difficult, because the nuclei available as starting materials do not deliver the necessary sum of neutrons. For the synthesis of isotope 298 of element 114 one could use an isotope of plutonium and one of calcium, that together have a sum of at least 298 nucleons, for example calcium-50 and plutonium-248. However these and the heavier isotopes are not available in weighable quantities, making production in this way virtually impossible with current methods. The same problem exists for the other possible combinations of isotopes needed to generate elements on the island using target-projectile methods. It may be possible to generate the isotope 298 of element 114, if the multi-nucleon transfer reactions would work in low-energy collisions of actinide nuclei. One of these reactions may be:

$$^{248}\mathrm{Cm} + {}^{238}\mathrm{U} \rightarrow {}^{298}\mathrm{Uuq} + {}^{186}\mathrm{W} + 2\,{}^{1}\mathrm{n} \quad [3]$$

Summary

The first 92 elements from the lightest hydrogen to the heaviest uranium on periodic table exist naturally. The trans-uranium element that exists after uranium extends to element 118 was created by scientists in atomic nuclei collision with aid of particle accelerator except neptunium and plutonium. The predominant modes of decay of trans-uranium elements are alpha-decayed because of the binding energy of the nucleons. The positions of heavy elements in the periodic table ultimately would be determined by the characteristic energies of the electrons of their atoms, especially the valence electrons.

The practical significance of the actinides arises from the fissionability, or potential for splitting, of certain of their isotopes. When an atomic nucleus breaks apart, or undergoes fission, a far more disruptive process than ordinary radioactive decay, enormous amounts of energy are liberated. This energy can be allowed to generate an atomic explosion, or it can be controlled and used as a fuel to generate heat for the production of electrical power.

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. The possibility of an island of stability was first proposed by Glenn T. Seaborg. The hypothesis is that the atomic nucleus is built up in shells in a manner similar to the electron shells in atoms. The stability (half-life of the longest-lived isotope) of elements generally decreases from element 101 to element 109 and then approaches an island of stability with longer-lived isotopes in the range of elements 111 and 114.

Conclusion

The studies of super heavy elements are difficult because of their short half-lives cause them to decay after a few minutes. The half-lives of these elements show a general trend of decreasing with atomic number. Trans-uranium elements are difficult and expensive to produce, and their prices go up rapidly with atomic number.

Recommendation

1) In order to study the physical and chemical properties of the current and yet to be discovered super-heavy elements, we will need to produce many more nuclides than they have been able to do so far.

2) We have to use neutron rich target and projectiles to get the nuclei that have sufficiently high neutron numbers; too low a neutron number renders the nucleus extremely unstable and unobservable because of its resultantly short half-life.

3) We have to prepare high energetic particle accelerator for the production of undiscovered heavy elements and their uses.

Bibliography

[1] B.R Martin, (2006), Nuclear and particle physics, Johan Wiley & sons, Ltd

[2] Gupta, M. (2010, April 13).The super heavy elements

[3] http://en.wikipedia.org/wiki/_of_Island stability

[4] http://en.wikipedia.org/wiki/Radioactive

[5] http://en.wikipedia.org/wiki/Transuranium_elements.

[6] Johan Lilley, (2001), Nuclear physics, Johan Wiley & sons,

[7] K.Heyde, (1999) (2^{nd}ed), Basic ideas and concepts in nuclear Physics, pub Institute of physics publishing.

[8] N.Bohr and J.A.Wheeller.phys.Rev.56, 426(1939).

[9] Transuranium element. (2010). Encyclopedia Britannica. Encyclopaedia Britannica Ultimate Reference