QUANTIZATION IN RADIOACTIVE DECAY MEASUREMENTS 18/01/2015

Contents:

Tables 1a and 1b

Quantization in the radioactive decay rates of the parent radioactive nuclides found in nature.

Table A

Radioactive properties of the parent radioactive nuclides found in nature.

Table 2

Quantization in the radioactive decay rates of the members of the three naturally occurring radioactive transformation series.

Table B

Radioactive properties of the three naturally occurring radioactive transformation series.

Special introductory note:

To see how the quantization in radioactive decay measurements was first discerned, please read the paper "Systematic Fractional Relationships in Radioactive Decay Measurements".

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SYSTEMATIC FRACTIONAL RELATIONSHIPS IN RADIOACTIVE DECAY MEASUREMENTS 28/05/11

(Quantization in Radioactive Decay Measurements). Refreshed 03/12/13

TABLE 1a The 2.41 group of radioactive nuclides.
Note the decay constant of 2.41

Nuclide	Half Time	Fractional Relationship	Decay Constant
Light	86.4	2/3 x 129.6	.03 x 2.41
?	43.2	1/2 x 86.4	.06 x 2.41
?	28.8	2/3 x 43.2	.1 x 2.41
Nd 144	21.6	3/4 x 28.8	.13 x 2.41
Th 232	14.4	2/3 x 21.6	.2 x 2.41
U 235	7.2	1/2 x 14.4	.4 x 2.41
Rb 87	4.8	2/3 x 7.2	.6 x 2.41
Lu 176	3.6	3/4 x 4.8	.8 x 2.41
?	(2.4)	2/3 x 3.6	1.2 x 2.41
K 40	1.2	1/2 x 2.4	2.4 x 2.41
Sm 148	.8	2/3 x 1.2	3.6 x 2.41
Pt 190	.6	3/4 x .8	4.8 x 2.41
Re 187	.4	2/3 x .6	7.2 x 2.41
Hf174/Te130	.2	1/2 x .4	14.4 x 2.41
?	.13	2/3 x .2	21.6 x 2.41
?	.1	3/4 x .13	28.8 x 2.41

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TABLE 1b The 1.5 group of radioactive nuclides.
Note the decay constant of 1.5

Nuclide	Half Time	Fractional Half Time	Decay Constant
U 238	4.6	$\frac{10}{9} \times \frac{1}{2.41}$	1.5
In 115	5.1	$\frac{10}{9} \times \frac{10}{9} \times \frac{1}{2.41}$	$\frac{9}{10} \times 1.5$
Cd 113	9	$\frac{9}{10}$	$\frac{10}{9} \times \frac{10}{9} \times 1.5 \times \frac{1}{2.41}$
Se 82 La 138 Sm 147 Gd 152	1.11	$\frac{10}{9}$	$1.5 \times \frac{1}{2.41}$

NOTES.

1. 'Powers of ten' excluded. These may be found from the standard half life listings.
2. Decay constant = .693 / half life
   Half life = .693 / decay constant
3. K 40. Published decay constant = 5.8
   Half life = 1.2
   U 238. Published decay constant = 1.5
   Half life = 4.6
4. 2.41 approximate. Use 2.406(25)

TABLE A. Parent radioactive nuclides found in nature

Nuclide					
Atomic number, Z	Mass number, A	Percent abundance in nature	Half-period, years	Radioactive transitions observed[*]	Disintegration energy, MeV[*]
19 K	40	0.0117	1.3×10^9	β^-, β^+, EC	β^- 1.3 – EC 1.5
34 Se	82	9.19	1.1×10^{20}	$\beta^-\beta^-$	3.0
37 Rb	87	27.83	4.8×10^{10}	β^-	0.3
48 Cd	113	12.2	9×10^{15}	β^-	0.3
49 In	115	95.77	5.1×10^{14}	β^-	0.5
52 Te	130	34.49	2×10^{21}	Growth of ${}^{130}_{54}$Xe[†]	1.6
57 La	138	0.089	1.1×10^{11}	β^-, EC	β^- 1.0 – EC 1.75
60 Nd	144	23.8	2.1×10^{15}	α	1.9
62 Sm	147	15.07	1.1×10^{11}	α	2.3
62 Sm	148	11.3	8×10^{15}	α	1.99
64 Gd	152	0.20	1.1×10^{14}	α	2.2
71 Lu	176	2.6	3.6×10^{10}	β^-, γ	0.6
72 Hf	174	0.16	2×10^{15}	α	2.5
75 Re	187	62.6	4×10^{10}	β^-	0.003
78 Pt	190	0.013	6×10^{11}	α	3.24
90 Th	232	100	1.4×10^{10}	α	4.08
92 U	235	0.715	7.0×10^8	α, SF	α 4.68
92 U	238	99.28	4.5×10^9	α, SF	α 4.27

[*] EC = electron capture. The EC energy is between ground states, but, in ^{138}La decay, 1.44 MeV of the EC energy goes to a gamma ray that feeds the ground state.

[†] Indirect evidence for $\beta^-\beta^-$ decay.

Radioactivity in the Earth. A number of isotopes of elements found in the Earth are radioactive (Table 2). All known or theoretically predicted isotopes of elements above bismuth are radioactive. Because the Earth is composed of atoms which were believed to have been created more than 3×10^9 years ago, the naturally occurring parent radioactive isotopes are those which have such long half-periods that detectable residual activity is still observable today. As a general rule, one can detect the presence of a radioactive substance for about 10 half-lives. Therefore activities with $T \lesssim 0.3 \times 10^9$ years should not be found in the Earth. For example, present-day uranium is an isotopic mixture containing 99.3% ^{238}U, whose half-period is 4.5×10^9 years, and only 0.7% of the shorter-lived uranium isotope ^{235}U, whose half-period is 0.7×10^9 years, whereas these isotopes presumably were produced in roughly equal amounts in the Earth a few billion years ago. Geophysical evidence indicates that originally some ^{236}U was present also, but none is found in nature now as expected with its half-period of 0.02×10^9 years. The elements technetium ($Z = 43$) and promethium ($Z = 61$) are not found in the Earth's crust because all their isotopes are radioactive with much shorter half-periods (their longest-lived are $T = 2.6 \times 10^6$ years for ^{97}Tc and $T = 17.7$ years for ^{145}Pm).

Uranium-238 decays through a long series of 14 radioactive decay products before ending as a stable isotope of lead, ^{206}Pb. Some of these members of the ^{238}U decay chain have very short half-periods, so their existence in nature is entirely dependent on the presence of their long-lived parent, and thus is a genealogical accident. For example, radium occurs in nature only in the minerals of its parent, uranium. The decay series of ^{235}U supports 14, and the decay series of ^{232}Th supports 10, short-lived radioactive substances found in nature.

A few of the common elements contain long-lived, naturally radioactive isotopes. For example, all terrestrial potassium contains 0.012% of the radioactive isotope ^{40}K, which has a half-period of 1.3×10^9 years, and emits negatron or positron beta particles (plus decay via electron capture) and gamma rays in a dual decay to stable ^{40}Ca and ^{40}Ar. This isotope is the principal source of radioactivity in a normal human being; each human contains about 0.1 microcurie (3.7×10^3 becquerels) of the radioactive potassium isotope ^{40}K.

Geological age measurements are based on the accumulation of decay products of long-lived isotopes, especially in the cases of ^{40}K, ^{87}Rb, ^{232}Th, ^{235}U, and ^{238}U. *See* GEOCHRONOMETRY.

Laboratory-produced radioactive nuclei. With particle accelerators and nuclear reactors, the order of 2000 radioactive isotopes not found in detectable quantities in the Earth's crust have been produced in the laboratory since 1935, including those of 26 new chemical elements up to element 118 (as of 2004), with element 117 not known. Earlier titles of induced or artificial radioactivities for these isotopes are misnomers. Many of these now have been identified in meteorites and in stars, and others are produced in the atmosphere by cosmic rays. There are over 5000 isotopes theoretically predicted to exist. As one approaches the place where a proton or neutron is no longer bound in a nucleus of an element (the limits of the existence of that element), the half-periods become extremely short. *See* TRANSURANIUM ELEMENTS.

For example, carbon-14 is a negatron beta-particle emitter, with a half-period of about 5600 years, which can be produced in the laboratory as the

TABLE 2 Quantization in the radioactive decay rates of the members of the three naturally occurring radioactive transformation series.

Compiled 13/1/2015

(Compare Table 1a).

Parent Nuclide	Transformation Series Member	Quantized $\frac{1}{2}$ Time Position	Quantized Decay Rate x 2.406(25)	Half Time in Years	Fractional Relationships of New $\frac{1}{2}$ Times e.g. 57.6/86.4 = 2/3 43.2/57.6 = 3/4	Comments
		172.8				
		129.6				
Light		86.4	.033			
	Ra228	(57.6)	.05	5.8	2/3, 3/4	
	Po218	"	"	5.7x10^{-6}	" "	
	Po215	"	"	5.7x10^{-11}	" "	
		43.2	.066		Independent Science News	
		28.8	.1		for www.lollo.org.nz	
Nd144	Ac227	21.6	.133	22	c/o Univ of Auckland, N.Z.	
	Pb210	"	"	22		
	Th228	(19.2)	.15	1.9	8/9, 3/4	
Th232	Bi215	14.4	.2	1.44 x 10^{-5}		
U235		7.2	.4			
Rb87	At218	4.8	.6	4.75 x 10^{-8}		
	Po216	"	"	4.75 x 10^{-9}		
Lu176		3.6	.8			
	Pa234 m	2.4	1.2	2.28 x 10^{-6}	Or, 21.6 position ?	
	Rn220	(1.8)	1.6	1.77 x 10^{-6}	3/4, 2/3	
	Ra226	(1.6)	1.8	1600	2/3, 3/4	
	Po211	"	"	1.58 x 10^{-8}	" "	
K40	Pb212	1.2	2.4	.00121		
	Bi212	"	"	.000114		1.1 on Table 1b ?
Sm148	Th230	.8	3.6	80,000		
	Tl206	"	"	7.99 x 10^{-6}		
Pt190	Tl208	.6	4.8	5.89 x 10^{-6}		
Re187	Fr223	.4	7.2	4.18 x 10^{-5}	Or, 43.2 position ?	
	Bi211	"	"	4.18 x 10^{-6}	Or, 43.2 position ?	
	Th231	(.3)	9.6	.00297	3/4, 2/3	
	Ra223	"	"	.0301	" "	
Hf174		.2	14.4			
Te130		"	"			
	Bi210	.133	21.6	.0137		
	Ra224	.1	28.8	.0101		
	Rn222	"	"	.0104		
	Rn218	"	"	1.11 x 10^{-10}		1.1 on Table 1b ?
	Po212	"	"	9.51 x 10^{-15}		
	Tl207	"	"	9.13 x 10^{-6}		9/10 on Table 1b?
	Pa234	(.075)	38.4	.000764	3/4, 8/9	
	Th234	.066	43.2	.0657		
	Ac228	"	"	.000696		
	Pb211	"	"	6.84 x 10^{-5}		
	Th227	(.05)	57.6	.0520	3/4, 2/3: 5.1 on Table 1b?	
	Pb214	"	"	5.13 x 10^{-5}	" " " " " "	
	Po214	"	"	5.07 x 10^{-12}	" " " " " "	
	Bi214	(.0375)	78.6	3.80 x 10^{-5}	(3/4), 8/9: (.0375/.05)	
	Po210	"	"	.378	" "	
	Pa231	.033	86.4	33,000		
	U234	(.025)	115.2	250,000	3/4, 8/9	
	Tl210	"	"	2.47 x 10^{-6}	" "	
		.022	129.6			
	At219	.0166	172.8	1.71 x 10^{-6}	Or, 172.8 position?	
	Rn219	(.0125)	230.4	1.27 x 10^{-7}	:3/4, 8/9: 129.6 position?	
		.011		Connects Table 1a to Table 1b		

TABLE B., Names, symbols, and radioactive properties of members of the three naturally occurring radioactive transformation series*

Early name[†]	Early symbol[†]	Atomic number	Mass number	Isotopic symbol	Half-period	Type of decay
			Uranium ($4n + 2$) series			
Uranium I	UI	92	238	^{238}U	4.5×10^9 y	α, SF
Uranium X_1	UX_1	90	234	^{234}Th	24 d	β^-
Uranium X_2	UX_2	91	234	^{234m}Pa	1.2 m	IT, β^-
Uranium Z	UZ	91	234	^{234}Pa	6.7 h	β^-
Uranium II	UII	92	234	^{234}U	2.5×10^5 y	α
Ionium	Io	90	230	^{230}Th	8×10^4 y	α
Radium	Ra	88	226	^{226}Ra	1600 y	α
Radon	Rn	86	222	^{222}Rn	3.8 d	α
Radium A	RaA	84	218	^{218}Po	3.0 m	α, β^-
Astatine	At	85	218	^{218}At	1.5 s	β^-, α
Radon	Rn	86	218	^{218}Rn	3.5 ms	α
Radium B	RaB	82	214	^{214}Pb	27 m	β^-
Radium C	RaC	83	214	^{214}Bi	20 m	β^-, α
Radium C′	RaC′	84	214	^{214}Po	1.6×10^{-4} s	α
Radium C″	RaC″	81	210	^{210}Tl	1.3 m	β^-
Radium D	RaD	82	210	^{210}Pb	22 y	β^-
Radium E	RaE	83	210	^{210}Bi	5.0 d	β^-, α
Radium F	RaF	84	210	^{210}Po	138 d	α
Thallium	Tl	81	206	^{206}Tl	4.2 m	β^-
Radium G	RaG	82	206	^{206}Pb	Stable	Stable
			Thorium ($4n$) series			
Thorium	Th	90	232	^{232}Th	1.4×10^{10} y	α
Mesothorium$_1$	$MsTh_1$	88	228	^{228}Ra	5.8 y	β^-
Mesothorium$_2$	$MsTh_2$	89	228	^{228}Ac	6.1 h	β^-
Radiothorium	RdTh	90	228	^{228}Th	1.9 y	α
Thorium X	ThX	88	224	^{224}Ra	3.7 d	α
Thoron	Tn	86	220	^{220}Rn	56 s	α
Thorium A	ThA	84	216	^{216}Po	0.15 s	α
Thorium B	ThB	82	212	^{212}Pb	10.6 h	β^-
Thorium C	ThC	83	212	^{212}Bi	1.0 h	β^-, α
Thorium C′	ThC′	84	212	^{212}Po	3×10^{-7} s	α
Thorium C″	ThC″	81	208	^{208}Tl	3.1 m	β^-
Thorium D	ThD	82	208	^{208}Pb	Stable	Stable
			Actinium ($4n + 3$) series			
Actinouranium	AcU	92	235	^{235}U	7.0×10^8 y	α, SF
Uranium Y	UY	90	231	^{231}Th	26 h	β^-
Protactinium	Pa	91	231	^{231}Pa	3.3×10^4 y	α
Actinium	Ac	89	227	^{227}Ac	22 y	β^-, α
Radioactinium	RdAc	90	227	^{227}Th	19 d	α
Actinium K	AcK	87	223	^{223}Fr	22 m	β^-, α
Actinium X	AcX	88	223	^{223}Ra	11 d	α
Astatine	At	85	219	^{219}At	0.9 m	α, β^-
Actinon	An	86	219	^{219}Rn	4.0 s	α
Bismuth	Bi	83	215	^{215}Bi	7.6 m	β^-
Actinium A	AcA	84	215	^{215}Po	1.8×10^{-3} s	α
Actinium B	AcB	82	211	^{211}Pb	36 m	β^-
Actinium C	AcC	83	211	^{211}Bi	2.2 m	α, β^-
Actinium C′	AcC′	84	211	^{211}Po	0.5 s	α
Actinium C″	AcC″	81	207	^{207}Tl	4.8 m	β
Actinium D	AcD	82	207	^{207}Pb	Stable	Stable

Radon-223 has been shown to have a very weak radioactive ^{14}C decay branch to ^{209}Pb. Several of the isotopes in these chains, such as ^{234,235,238}U, ^{223}Ra, and others are predicted to have such very weak, heavy cluster decay branches.

These were the names and symbols used before the different isotopes of these elements were known.

Transformation series are now known for every element in the periodic table except hydrogen. Chains of neutron-rich isotopes have been produced and studied among the products of nuclear fission. Heavy-ion-induced reactions and high-flux reactors have been used to extend knowledge of the elements beyond uranium. The elements from number 93 (neptunium) to 118 (as yet unnamed except for element 117), which have so far not been found on Earth, were made in the laboratory. Both proton- and heavy-ion-induced reactions have extended knowledge of chains and neutron-deficient isotopes of the stable elements.

Alpha-Particle Decay

Alpha-particle decay is that type of radioactivity in which the parent nucleus expels an alpha particle (a helium nucleus). The alpha particle is emitted with a speed of the order of 1 to 2×10^7 m/s (10^4 mi/s), that is, about 1/20 of the velocity of light.

In the simplest case of alpha decay, every alpha particle would be emitted with exactly the same