Nuclear Binding and Half-Lives

Reported by Editor David L. Bergman

Strong electromagnetic forces inside the atom hold its nucleus together. When the forces are barely strong enough, a particle may escape the nucleus. By modeling the nucleus according to the proposals of Lucas [1, 2] and Bergman [3, 4], researchers Boudreaux[1] and Baxter[2] have explained and predicted the time required for half the nuclei in specific isotopic species to undergo radioactive decay.[5]

Nuclear Forces. Protons give the nucleus of an atom a *net positive charge*. So, why doesn't the nucleus explode? Nuclear stability is possible because the particles in the nucleus are each tiny *magnets*, and magnets can be arranged to *attract* one another. When the particles inside the nucleus have specific locations, the forces from electrical charge can be in balance with the magnetic forces from moving charge. But if the location of even one particle is sufficiently changed, the entire nucleus can become unstable.

Energy in the Nucleus. It takes work to "assemble" charged particles into a given configuration. Imagine lifting a bowling ball from the floor and placing it on the top shelf for storage. It is "work" to lift the ball, and once raised to the top shelf, the ball has additional *energy* stored in it. The bowling ball is *stable* as long as it stays on the shelf. But any small event could *trigger* a disaster if the ball rolls off the shelf and strikes your foot. You would quickly realize that some of the energy in the ball has been transferred to your smashed foot!

This report is *not* about "assembling" particles in the nucleus. Rather, it is about the conditions that dissemble the nucleus. Such an event is called *fission*. The process that causes fission is called *radioactivity*. The rate of radioactivity is quantified by an atom's *half-life*.

Nuclear Binding Energies (NBEs) are the result of interactions between protons and proton/electron pairs that produce neutrons. This report shows how theoretical calculations of NBEs have confirmed the basic nuclear structure of many elements, some with multiple configurations known as isotopes, and in at least one case, ^{40}K, a nucleus with *two* shell structures within the same isotope. In this case, the two NBEs take on separate values and predict vastly different half-lives.

Radiometric Dating of Rocks. Since geologists rely upon the rate of radioactive decay of potassium-40 (^{40}K) to date rock samples, the finding of a second half-life for ^{40}K should lead to more accurate predictions of the age of certain rocks.

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Geologist Philip Budd explains an important use made of the Radiometric Dating Method:

> Radiometric Decay Dating is used to date igneous rocks if a sufficient concentration of long half-life radioactive elements is present…. Radioactive elements have an unstable nucleus that decays to stable atoms by emitting energy and/or particles. This decay process usually consists of a sequential series of decay stages to reach the stable element form. The original unstable, radioactive form is known as the "parent element." The final stable form is known as the "daughter element."
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> Radioactive Decay Dating determines the proportion of radioactive parent element to stable daughter element…. The half-life is extrapolated backwards through time to a date at which no stable daughter element would be present. That date is usually considered to be the starting point representing the time that rock solidified….
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> [One assumption made] is that only one variety of each radioactive isotope is generated and the half-life of that variety can be exclusively used to extrapolate back to the starting point. Boudreaux and Baxter have recently demonstrated that different varieties of radioactive isotopes with different half-lives form in predictable portions. The short half-life varieties may decay from parent to daughter isotope within seconds, minutes, hours, or days. Because the parent isotope of these short half-life isotope varieties was no longer present in samples, it was previously assumed that only the long half-life variety ever existed. Therefore, radioactive decay rates were calculated exclusively from the long half-life variety of the isotope.
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> If a short half-life isotope variety was originally present, extrapolations based exclusively on the long half-life variety of isotope would yield excessively old radiometric age date estimates. Rapid production of daughter isotope from the short half-life variety of parent isotope potentially explains why recently solidified rocks consistently date several magnitudes of order too old….
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> The traditional Potassium Argon Radiometric Decay Dating Method has a problem. There are not one, but two varieties of the radioactive isotope potassium-40 that decay into argon. The nucleus of the more stable variety contains five neutrons in the second shell, inducing a spin state of 4. The nucleus of the less stable variety contains one neutron in the first shell and four neutrons in the second shell, inducing a spin state of 2. Therefore, the two varieties of potassium-40 have different half-life decay rates.
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> The Spin State 4 variety of potassium 40 is produced only 28 percent of the time and has a half-life of 1.3 billion years. The Spin State 2 variety is produced the remaining 72 percent of the time and has a half-life of only [15] hours. Therefore, the half-life of both potassium-40 configurations calculated together would be only 795 years. Radiometric Decay Dating Methods have traditionally utilized half-life calculations based exclusively

> upon the more stable, long half-life variety because stable isotope longevity obscured detection of the less stable, short half-life variety.
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> Radioactive decay age extrapolations for potassium-40 and perhaps…other radioactive isotopes will potentially shrink rock dates to a tiny fraction of present estimated ages. [6]

Unusual Property of ^{40}K. In a previous report, [5] Boudreaux pointed out that the trend observed in a plot of *decay energies vs. decay constants* (Sargent's Rule) for the radiogenic isotopes of potassium (atomic mass 41-49) beta emitters and the radiogenic isotopes of potassium (atomic mass 35-39) beta absorbers did not fit ^{40}K. The enormously long half-life on the order of a billion years for ^{40}K decay does not match the reported decay energy on a plot of Sargent's Rule. Thus, Boudreaux recommended that a reliable method be developed for computing nuclear binding energies and decay rates.

Nuclear Models of Quantum Theory (QT). As a professor and researcher, Boudreaux was already skilled in making calculations by means of QT models:

> Three important nuclear models are the Liquid Drop Model, the Shell Model (developed by Maria Goeppert-Mayer and Hans Jensen), which emphasizes the orbits of individual nucleons in the nucleus, and the Collective Model (developed by Aage Bohr and Ben Mottleson), which complements the shell model by including motions of the whole nucleus such as rotations and vibrations.
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> The Liquid Drop Model treats the nucleus as a liquid. Nuclear properties, such as the binding energy, are described in terms of volume energy, surface energy, compressibility, etc.—parameters that are usually associated with a liquid. This model has been successful in describing how a nucleus can deform and undergo fission.
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> The Nuclear Shell Model is similar to the atomic model where [orbiting and spinning] electrons arrange themselves into shells around the nucleus….
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> The Collective Model emphasizes the coherent behavior of all the nucleons. Among the kinds of collective motion that can occur in nuclei are rotations or vibrations that involve the entire nucleus….
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> The Shell Model and the Collective Model represent the two extremes of the behavior of nucleons in the nucleus. More realistic models, known as unified models, attempt to include both shell and collective behaviors. [7]

It is true that "A goal of nuclear physics is to account for the properties of nuclei in terms of mathematical models of their structure and internal motion." [7] But Dr. Boudreaux knew that none of the QT models could be considered a realistic description of the nucleus. So, to resolve the discrepancy of NBE for ^{40}K, he enlisted Eric Baxter to calculate the NBEs of selected nuclei by calculating NBEs based on the Lucas Model of Nuclear Structure.

Methodology of Modeling and Computation. In the new description of the nucleus, nuclear particles are modeled after the proposals of Lucas [1, 2] and Bergman [3, 4] in which all interactions are between protons and proton/electron pairs producing neutrons. Each particle is regarded as a torus of electrostatic charge, negative or positive for an electron or proton respectively.

Boudreaux knew that the radii are 3.87×10^{-13} meter for the electron and 2.11×10^{-15} meter for the proton, as *free particles*. [8] But the ring model requires ring particles to change size as they approach each other and exchange energy by flux coupling. Thus, Boudreaux found that the binding of nuclear particles reduces the electron radius by two orders of magnitude and expands the proton radius some 183 per cent. (This same deformation was already predicted on a theoretical basis by Bergman.) [4] If these optimized adjustments are not made, the computed nuclear binding energies are a hundred times lower than required for acceptable values.

The toroidal rings are so infinitesimally thin (some 10^{-200} meter), that they can be adequately regarded as electro/magnetostatic current loops having fixed dimensions, charges and magnetic moments. In the computations of NBE, a small error was introduced by regarding the self-energy of nuclear electrons and protons as constant. However, the exact nuclear potential energy from mutual interactions was calculated for the electromagnetic interactions. The equation derived by Eric Baxter gives the total nuclear binding energy (NBE) as a function of particle charge, magnetic moment, and dimensions.

The required number of nucleons for each nuclide was initially distributed within shells, using either the conventional *magic numbers* or the *ring model* scheme. In the case of ^{40}K, for example, there are 19 protons for the atomic number plus 21 protons and 21 electrons producing 21 neutrons. If magic numbers are employed for initial shell occupancies, the order of assignments is 2, 8, 10, & 20 protons and 1, 5, 10 & 5 electrons. While the methodology of these calculations is independent of any initial particle assignments (energy minimization via a variational routine ultimately yields the correct particle distribution), a more accurate initial estimate allows fewer iterations to attain convergence. Furthermore, the *ring model* is preferred, since it accurately reproduces nuclear spins observed for all measured isotopes; whereas, the *magic numbers* are correlated with the Quantum Mechanical Shell Model, which has only 65-70 percent accuracy in reproducing observed nuclear spins. [5]

All computations were conducted with a computer program (in Pascal) written by Eric Baxter. The "nuclear radius" was used to locate the maximum shell position from the nucleus and was divided proportionately into segmented regions for accommodating the required number of shells. The order of filling nucleons in shells is often from the outermost shells inward. These outer shells are the most energetically stable, while the least stable regions are the inner shells closest to the origin.

Each particle was specified by five coordinates: three positional Cartesian coordinates (x, y, z) internal to each loop, and two angular coordinates defining the tilt orientation of

each loop. The coordinate positions and angular orientation of each particle were allowed to fluctuate, and the total energy was minimized according to the variational principle, for which the change of energy with respect to a change in position is zero.

To obtain decay energies, say the β^- emission, an electron was "removed" from a neutron in the shell of least stability. Then, the total energy was recalculated and minimized as done for the parent isotope. The difference in energies (NBEs) of this final structure and the original one is the *decay energy*.

The calculated NBEs seem to duplicate the observed values with an accuracy of only some 80 to 90 percent, based on the few limiting test cases calculated thus far (see Table 1). Although the equation for computing NBEs is thought to be exactly correct, it does not contain all energy contributions, and the variable contributions to total nuclear binding energy from particle self-energies were included as fixed, constant energies. Nor were electrostatic polarization energies included in the present model with fixed loop dimensions. Including these adjustments would have enormously complicated the conditions for convergence and calculations of NBE. However, accurate NBEs are not essential for purposes of calculating accurate decay energies, as is demonstrated by the data reported in Table 1 where predictions match experimental data within the range of 90 to 99 percent accuracy.

TABLE 1
CALCULATED vs. REPORTED LITERATURE VALUES
E. A. Boudreaux and E. Baxter

Element	Atomic Number	Mass Number	Decay Mode	Decay Energy Calculated (MeV)	Decay Energy Reported (MeV)	Half-Life Calculated	Half-Life Reported
Be	4	8	2α	0.051	0.046	———	1.7×10^{-16} s
Na	11	24	$\beta-$	5.7	5.51	1.0 day	.63 day
K	19	40	$\beta-$, $\beta+$	1.3, 1.5	1.32, 1.50	1.3×10^{9} yr	1.3×10^{9} yr
K	19	40	$\beta-$	3.2[a]	———	15 hr[a]	———
K	19	42	$\beta-$	3.5	3.52	12 hr	12.4 hr
K	19	44	$\beta-$	5.9	5.66	22 min	22.1 min
K	19	46	$\beta-$	7.1	7.72	120 s	107 s
K	19	48	$\beta-$	11.4	(12.1) ?	7.2 s	6.8 s
Th	90	231	$\beta-$	0.4	0.389	24 hr	25.2 hr
Th	90	234	$\beta-$	0.3	0.270	23 day	24.1 day
Sm	62	147	α	2.2	2.23	9.6×10^{10} yr	1.06×10^{11} yr
Th	90	232	α	4.0	4.081	1.2×10^{10} yr	1.4×10^{10}yr
U	92	235	α	4.7	4.679	6.5×10^{8} yr	$7.08\ 10^{8}$ yr
U	92	238	α	4.2	4.185	4.3×10^{9} yr	4.46×10^{9} yr
———	114	298	α	8.215[b]	———	10-100 yr	?
———	116	300	α	10.432[b]	———	30 s	———

a. Calculated alternate ground state. Not reported elsewhere.
b. Original calculations limited to a precision of two significant figures. Most recent calculations have been refined to a three decimal significance.

Results and Discussion. Nuclide ^{8}Be was found to dissociate readily into two alpha particles, while ^{24}Na and ^{40}K are beta emitters (expulsion of an electron) producing stable daughter products via one mode of decay. However, ^{40}K also decays by positron emission (sometimes called "beta absorption") producing ^{40}Ar, but this is only 11 percent of the total decay process. Thus, beta emission accounts for the major portion of the decay.

Pertinent NBE, decay energies and half-lives are presented in Table 1. Boudreaux showed in a previous report [5] that the decay energies of radiogenic potassium isotopes followed a smooth trend in relation to the decay constants, according to Sargent's Rule. Boudreaux reanalyzed this trend and found that the slopes of the curves are dependent upon isotopic nuclear spins. The nuclear spins of even isotopes, ^{N}K for N = 42, 44, 46, & 48 were all found to be 2, but ^{40}K has two spin states. According to the *ring model*, the following is obtained for ^{40}K:

Shell Number	1	1	2	2	3	3	4	4	Spin	Calculated β^- Decay Energy (MeV)
Particle Types*:	p	n	p	n	p	n	p	n		
Number of Particles:	–	1	3	4	….	….	16	16	2	3.180
	–	–	3	5	….	….	16	16	4	1.312
* p = protons										
* n = neutrons										

Hence, ^{40}K has two spin states with different decay energies. Naturally this has a profound impact on the actual decay time of ^{40}K. Note that only the decay energy for Spin 4 State is reported experimentally (see Table 1).

Conclusions. Boudreaux validated the calculated results by various comparisons to the experimental data. He concluded that "As shown in Table 1, all calculated data were found to be in excellent agreement with the observed data." [5]

And he believes "*these results offer a significant breakthrough in providing a sound scientific solution for answering those nagging questions regarding long-lived radiogenic isotopes.* In fact, we are confident that in cases reporting long half-lives for other specific isotopes, those nuclides will display decay energy states for at least two different spin states. The existence of these phenomena will be undetectable by any direct measurement, because the long-lived state will mask the detection of the short-lived state. Thus the computational approach [described above] is the only recourse for studying this problem." [5]

Future Research. Common Sense Science and Origins Resource Association both plan to perform more analysis and research on nuclear structure and radiogenic processes. Continued research projects will be conducted independently and in collaboration. Multiple approaches are already being pursued. First, equations of the self-energies of

both electrons and protons must be derived and used to obtain total nuclear binding energies.

Second, the "triggering mechanism" that initiates nuclear disintegration must be rigorously described and incorporated into a theory of radioactivity to improve prediction of decay rates. The current approach relies upon an expected relationship between nuclear binding energy and decay rate—without specifying the trigger that causes the nucleus to eject a particle. The following decay triggering mechanisms should be analyzed and evaluated:

1. *Quantum Tunneling Effect*. According to Quantum Theory, the fundamental origin of physical processes and process rates is the so-called "quantum tunneling effect"—an unproven hypothesis that suggests particles move and emit other particles and/or energy spontaneously. This imagined effect is credited with causing an alpha or beta particle to escape the forces that restrain its location within the nucleus and escape the atom completely. The effect is well-described mathematically by using certain non-physical assumptions (*e.g.* point-like particles) and has been adapted to accurately predict many physical processes including a process of triggering radioactive decay.

2. *Bombardment*. Moving particles that originate either outside the nucleus (*i.e.* cosmic particles) or within the nucleus (*e.g.* free neutrons in uranium) can trigger a radiogenic event by "colliding" with a particle in the nucleus, thereby breaking the internal bond and "knocking" a particle outside the nucleus. The rate of radioactive decay caused by bombardment will, of course, depend upon the number and energies of bombarding particles.

3. *Collective Motions*. The Collective Model, described above, identifies various collective motions that can occur in nuclei (*e.g.* rotations or vibrations) that involve the entire nucleus. Such sources of energy may even trigger the ejection of a particle associated with radioactive decay.

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