The Proceedings of the International Conference on Creationism

Volume 7 | Article 6

2013

Double-Beta-Decay - An Indicator of the History of Accelerated Decay?

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Proceedings of the Seventh International Conference on Creationism.
Pittsburgh, PA: Creation Science Fellowship

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KEYWORDS: Double-beta decay, Geochemical Half-life measurements, Half-life measurements, Nuclear phase transitions, Time variation of constants

ABSTRACT

Evidence that the half-lives for double beta decay have varied during the history of the earth are discussed. Data for Tellurium-130 and Selenium-82 indicate an episode of variation occurred in the geologic history, possibly just prior to the Genesis Flood. Possible change in the strength of the nuclear force could lead to an associated change in nuclear phase from isoscalar to isovector pairing, and indicators in the scientific literature are highlighted to show the relevance.

INTRODUCTION

Several isotopes are known to undergo double beta-decay, a process in which two neutrons change into two protons with the emission of two electrons and two antineutrinos. The half-lives for these processes are some of the longest half-lives ever measured, meaning that such decays happen only very slowly. In calculating these half-lives from theory, physicists assume that certain laws of physics have operated in a well-formulated manner. In inferring the age of a rock using these decays, one must assume that the laws of physics have operated the same over the lifetime of the rock. The purpose of the research discussed here is to examine double-beta-decay as a possible indicator of a change in half-lives, possibly caused by a change in the strength of the strong nuclear force. Tellurium-130 and Selenium-82 are isotopes for which the half-life has been measured by directly detecting the decays in specially constructed detectors and also by measuring the concentrations of the decay products and their precursors in rocks.

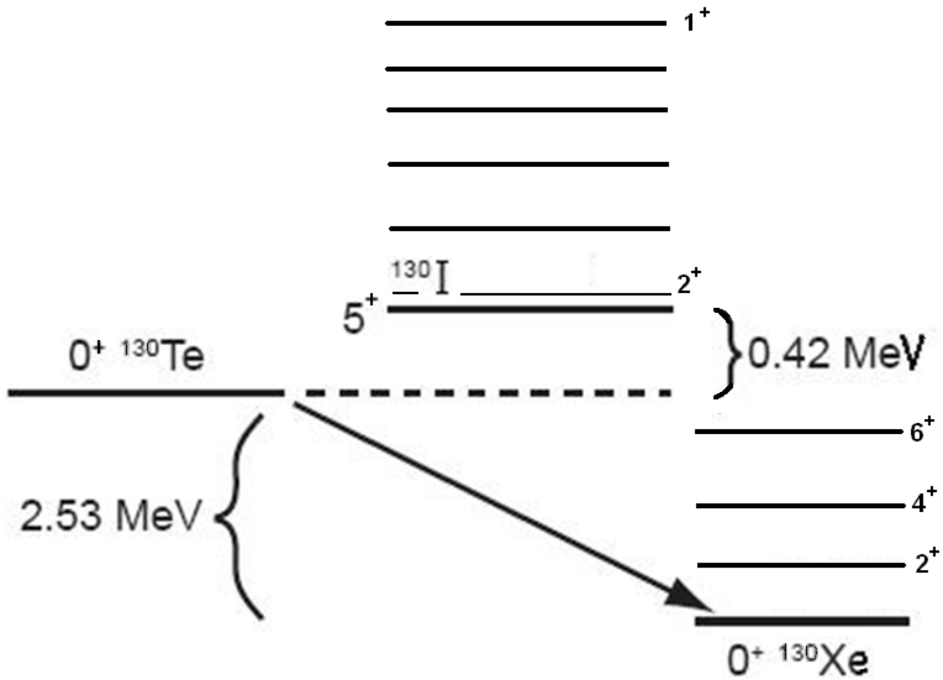

Figure 1. Tellurium-130 decay scheme. The ground state of the intermediate Iodine-130 nucleus is higher in energy, hence the decay cannot proceed as a two step process.

In science, and particular in physics, it is easy to fall into the trap of thinking that there are principles outside of God, which we call "laws" which God must necessarily be subject to. In a Sermon of July 3, 1881, Spurgeon addressed this subject:

> Our wise men are continually talking of the laws of nature, and we know that there are such laws, or, in other words, it is a fact that God usually acts in such and such a way; but to suppose that there is any power in the mere laws of nature is absolutely absurd. (Spurgeon, 1971, pp. 377-378)

The proposal that radioisotope decay rates may have been different in the past would be consistent with this viewpoint. The accelerated decay hypothesis asserts that half-lives of radioactive elements changed at certain periods in the history of the earth, including perhaps that decay rates were much larger during the Genesis Flood. As part of the research for the RATE project (RATE is an acronym meaning Radioisotopes and the Age of the Earth), it was shown that assuming that a certain number called the coupling constant for the strong nuclear force had changed leads to enhanced rates for alpha-decay via quantum mechanical tunneling, and enhanced rates for beta-decay by changing the nuclear spin thus changing the order of the so-called forbidden decays (Chaffin, 2005).

In single beta-minus-decay, a single neutron changes into proton with the emission of an electron and antineutrino. A double-beta-decay is not two single beta-decays following one another, since the states of the intermediate nuclei are higher in energy than either the parent or daughter nucleus. The two single beta-decays could only occur if the first decay created energy, which is impossible. Thus, when a double beta-decay is observed to occur, as in the case of Tellurium-130 decaying into Xenon-130, the decay must proceed in one step without involving the intermediate nucleus Iodine-130 which is higher in energy (Figure 1).

Since 1949, the half-life of Te-130 has been inferred from geological samples by measuring the amount of the decay product Xe-130 (the daughter nucleus) and the parent nucleus Te-130 (Inghram, and Reynolds, 1949, 1950). However, in recent years a direct measurement of the rate of decay has been performed at the *Neutrino Ettore Majorana Observatory (NEMO)* which is located underground in a tunnel on the French-Italian border. The results for the Te-130 half-life obtained by this NEMO collaboration were reported in 2011(Arnold *et al*., 2011):

$$\mathbf{T_{1/2} = (7.0 \pm 0.9\ (stat) \pm 1.1 (syst))\ x\ \ 10^{20}\ yr.}$$

Here the inferred statistical errors (stat) as well as systematic error limits (syst) are indicated. In Figure 2 we see the graph presenting the half-lives calculated for various samples plotted against conventional geological age shown on the uniformitarian time scale. The NEMO collaboration's recent measurement is also plotted (shown in green). It is seen that the values for the more recent samples agree with The NEMO collaboration result, but the older samples do not. The older samples show a larger result differing from recent samples by a statistically significant amount. Of course, if the accelerated decay hypothesis is correct, the x-axis of the figure would not represent a true age and only represents a relative age. However, the figure seems to indicate that a significant amount of accelerated decay occurred at the onset of the Flood, as represented by the dropping of the graph as one goes from right to left across the figure. This behaviour of the graph seems to offer evidence of when the half-life changed.

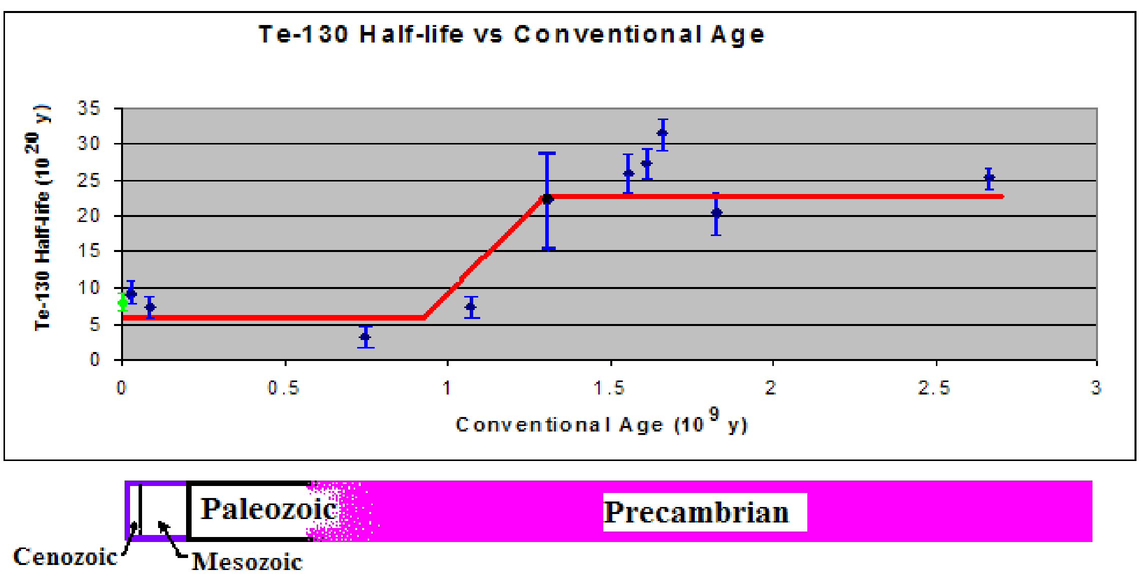

Figure 2. Half-life for double-beta-decay plotted against conventional sample age. Most of the data can be found in Bernatowicz et al. (1993) and references given therein, or see Table 1. The names of the eras of the standard geologic column are shown below the graph for comparison.

RETENTION AGES AS A PROPOSED EXPLANATION

Since the 1980's, various groups have noticed that the geochemical measurements of the half-life of Te-130 fall into two ranges, one centered around 22×10^{20} years and one centered around 7×10^{20} years (Kirsten, 1983; Manuel, 1986; Richardson, Manuel, Sinha and Thorpe, 1986; Lin, Manuel, Cumming, Krstic, and Thorpe, 1988; Lee, Manuel, and Thorpe, 1991; Manuel, 1991; Bernatowicz, T., J. Brannon, R. Brazzle, R. Cowsik, C. Hohenberg, and F. A. Podosek. 1992, 1993). For instance, Manuel (1986), by accepting K-Ar and U-He ages for some samples and rejecting the U-Xe ages which indicated an older time for recrystallization, argued that the "best" geochemical value for the Te-130 half-life was $(7 \pm 2) \times 10^{20}$ years. Thus Manuel found it necessary to be selective of the accepted data in order to support the smaller half-life value. This position was supported in the paper by Richardson, Manuel, Sinha and Thorpe (1986). These workers noted that the tellurium ores are likely to be recrystallized during metamorphism at a date after the original formation of the ore bodies. However, later work cast doubt on the reliability of the K-Ar ages for these samples (Manuel, 1991), and Bernatowicz *et al*. (1992) argued that techniques involving the lighter noble gases such as Ar or He were likely to be unreliable for such samples.

Bernatowicz *et al*. (1993) noticed the discrepancy in double-beta-decay half-lives obtained from different samples. In trying to explain the data, they proposed the possibility that analysis of some samples was discrepant due to retention of noble gases (Xenon or Argon) from previous decay of Tellurium-130 or Selenium-82 prior to the solidification of the rocks. Hence, they proposed that using noble-gas retention ages (K-Ar, U-Xe) was impractical due to possible inheritance of these gases. Instead they proposed to rely only on samples which were thought to form in well-understood processes. Bernatowicz *et al*. (1993, page 821), discussing volcanogenic massive sulfide deposits, wrote:

> [these deposits] are believed to have formed from hydrothermal circulation associated with oceanic spreading-center volcanism. . . . expected to be juvenile materials extracted from the Earth's mantle (without the potential complication of passage through the continental crust) – the situation for which . . . inheritance of radiogenic ^{130}Xe from any preexisting Te concentration is unlikely.

This reduced the samples that could be trusted to: 1. the 1.6 Gigayear-old Colorado Good Hope and Vulcan native Te ores, and 2. the 2.7 Gigayear-old Quebec Mattagami altaite, listed in Table 1.

Table 1. Measured Te-130 Half-lives for double beta decay, arranged by Conventional Age.

Reference	Sample origin and type	Conventional Age (10^9 y)	Te-130 Half-life (10^{20} y)	Quoted Error
Bernatowicz *et al*. (1993)	Cripple Creek, CO calaverite	0.028	8.94	±1.1
Bernatowicz *et al*. (1993)	Cripple Creek, CO krennerite	0.028	9.21	±1.1
Takaoka *et al*. 1996a,b	Oya Mine, Japan tellurobismuthite	0.0875	7.26	±1.1
Bernatowicz *et al*. (1993)	Kalgoorlie, Australia krennerite	0.75	3.23	±1.1
Lin *et al*. (1988)	New Zealand kitkaite	1.095	7.5	±0.3
Kristen *et al*. (1968)	Good Hope Mine, CO native Te	1.31	22.3	±6.9
Srinivasan *et al*. (1972a,b)	Boliden, Sweden tellurobismuthite	1.56	26	±2.7
Bernatowicz *et al*. (1993)	American Mine, CO native Te	1.66	31.6	±1.3
Bernatowicz *et al*. (1993)	Vulcan Mine, CO native Te	1.61	27.3	±1.3
Alexander *et al*. (1969)	Kirkland Lake, Ontario altaite	1.83	20.3	±3.0
Richardson *et al*. (1986)	Mattagami Lake, Quebec altaite	2.67	25.3	±0.8

However, one can see from Table 1 that these samples yield half-lives for double-beta decay of 22.3, 27.3, and 25.3 x 10^{20} years (one could use the prefix Zetayears =10^{21} years), and correspond to three points shown in Figure 1 which are the older samples, yielding half-lives larger than the value that has been directly measured in the NEMO-3 experiment and the experiment of Arnaboldi *et al*. (2003). In 1993, when Bernatowicz *et al*. proposed this, the direct measurements were not yet available, and hence they were proposing that the results from the more recent samples shown in Figure 1 were not reliable, instead favoring the results from the older samples in Table 1, which gave a larger half-life. This thus illustrates the danger of this type of analysis, since the direct measurements later supported the more recent results from the Cripple Creek Mine region of Colorado and from the Oya Mine, Japan. Perhaps a better interpretation of the data would involve a change in the Te-130 half-life over the history of the earth.

OTHER ISOTOPES

The geochemical method has been used successfully only in the case where the decay product is a noble gas isotope that would accumulate in rocks; Tellurium-130 decays to the noble gas Xenon-130 and Selenium-82 to the noble gas Krypton-82. The decay scheme of Selenium-82 is shown in Figure 3. The data available are more limited for Selenium-82 than for Tellurium-130. Not as many samples have been analyzed. Nevertheless, Barabash (1998, 2000, 2003) noticed that the data for Selenium-82 seemed to show a difference between the half-life measured by the geochemical method and the experimentally determined direct method. He attributed the change to a possible change in the strength of the weak nuclear force, or in the Fermi constant. This is possible, but such a change would not also affect alpha decays (Chaffin, 2005). Hence, the favorite hypothesis proposed in this paper is a change in the strength of the strong nuclear force. This will be discussed further below.

Uranium-238 also undergoes double beta decay, and the half life for this process has been measured by chemically isolating and measuring from the resultant alpha particles, the amount of plutonium (Pu-238) that had accumulated in 33 yr from 8.47 kg of purified uranyl nitrate (Turkevich, Economou, and Cowan, 1991). The uranyl nitrate had been sealed-up years before, with no thought of being used for that purpose. This is interesting, but since the decay in question occurred in recent times, it plays no role in determining whether half lives have changed over the history of the earth.

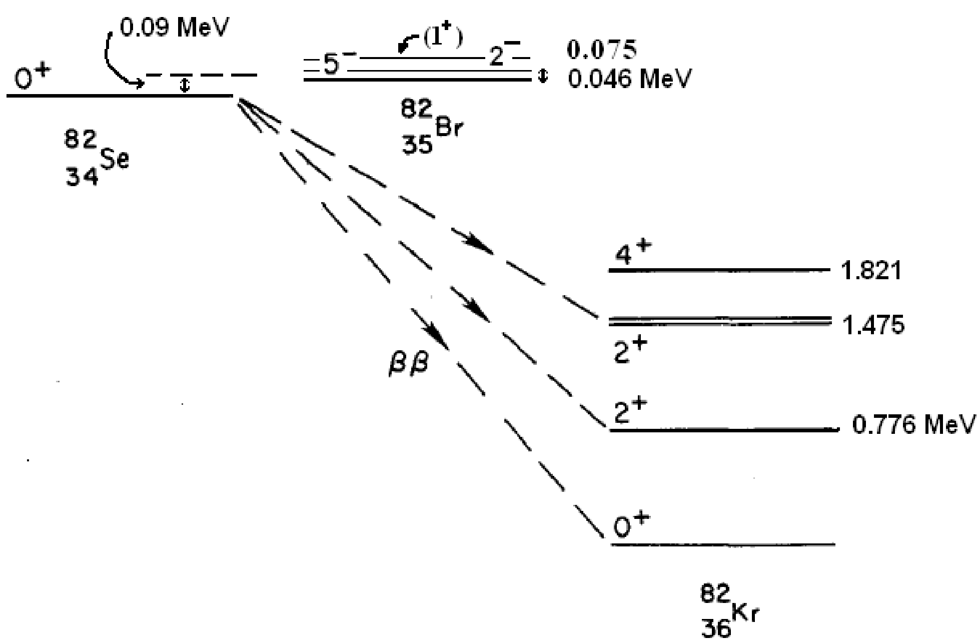

Figure 3. Selenium-82 Decay Scheme. Note that the decay product is Krypton-82, which is also a noble gas.

THE THEORETICAL DEPENDENCE OF THE HALF-LIFE ON THE STRENGTH OF THE STRONG NUCLEAR FORCE

The strong nuclear force is the term used in nuclear physics for the pushes or pulls that exist between neutrons or protons that hold the nucleus together, or also for the pushes or pulls that hold quarks inside the protons or neutrons. The number which determines how strong a force is needed is called the "strong coupling constant." To define a "coupling constant," one could compare Coulomb's Law for the electrical repulsion force between two protons:

$$F = \frac{ke^2}{r^2} . \qquad (1)$$

Here the product ke^2 plays the role of a "coupling constant." For the strong nuclear force, the interaction includes extra factors due to the short range of the nuclear force and the spin dependence of the interaction, but the coupling constant for the strong force is basically a coefficient similar to the ke^2 given above.

What would a change in the fundamental strong coupling "constant" do to double-beta-decay half-lives? The inverse of the half-life of a nucleus for two-neutrino (2ν) double-beta-decay, according to theory, is given by:

$$\frac{1}{T_{1/2}^{2\nu}} = G_F^4 \left| M_{GT} \right|^2 G^{2\nu}(E_0, Z) \quad , \qquad (2)$$

where, G_F = Fermi constant,
M_{GT} = Gamow-Teller Matrix Element,
$G^{2\nu}(E_0,Z)$ = phase space factor, a function of the kinetic energy release E_0 and the atomic number, Z.

The "matrix element" in the above equation is calculated by using some model to determine the wavefunctions of the protons and neutrons inside the nucleus, and then calculating the squares of these matrix elements of certain operators using these wavefunctions. Which operators are used determines different contributions to the overall decay probability. Transitions involving a flip of the spin of the neutron or proton are called Gamow-Teller matrix elements, M_{GT}, while those that do not involve a spin flip are Fermi matrix elements, M_F. The result for the matrix elements depends sensitively on the energy difference between the initial and final states of the nucleus for the double-beta-decay, which in turn depends on the strength of the nuclear force (Simkovic, 2006).

The phase space factor also depends on the amount of energy release, E_0, in the decay. Figure 4 shows a graph of the logarithm of the half-life versus kinetic energy release for nuclei for which double-beta-decay is possible, assuming that the Gamow-Teller matrix element M_{GT} = 1.0 while the Fermi matrix element M_F = 0. The Gamow-Teller matrix element varies considerably, as we will discuss later, but the graph is nevertheless useful for observing some general trends. For double-beta decay, the Fermi matrix element is usually very small compared to the Gamow-Teller matrix element, and hence can be taken to be approximately zero/

Theory also includes the possibility of double-beta-decay without the emission of any neutrinos, called neutrinoless double-beta-decay. The inverse half-life of a nucleus for neutrinoless double-beta-decay is given by:

$$\frac{1}{T_{1/2}^{0\nu}} = \left|m_{\beta\beta}\right|^2 G_F^4 \left|M_{GT}^{0\nu}\right|^2 G^{0\nu}(E_0, Z) \qquad (3)$$

Here $m_{\beta\beta}$ is the effective Majorana neutrino mass, depending on neutrino oscillation parameters.(Simkovic. 2006). The matrix element and phase space factors have a superscript 0ν to distinguish them as being different from the one defined before. The neutrinoless decays are generally less likely than the two-neutrino decays, and we will not discuss them further.

A variation in the strength of the fundamental strong coupling would manifest itself in terms of a change in the energy release in a double-beta decay. It would change not only the Gamow-Teller matrix element, but also the phase-space factor.

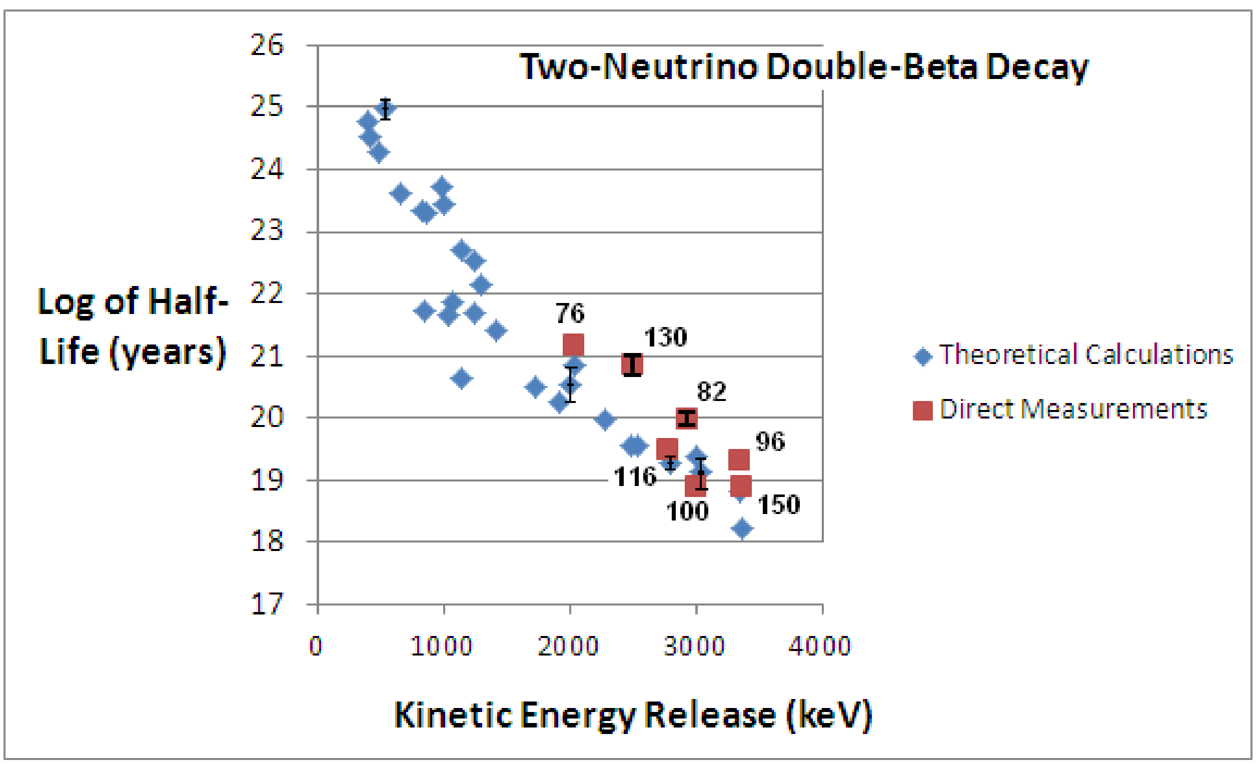

Figure 4. Systematics of half-life for double-beta decay versus energy release. After Haxton, and Stephenson (1984).

The simplified "theoretical calculations" for the graph of Figure 4 use M_{GT} = 1.0 and M_F = 0, and an approximation for the average energy level of the intermediate nucleus. One notices the following:

- The trend of the graph levels out for larger energy releases, hence the effect of a change in energy release on the half-life is not as great for Se-82 as for Te-130.
- Te-130 is situated above the trend line, hence changes in the strength of the nuclear force are likely to bring it back towards the trend line.
- Te-130 has a Gamow-Teller matrix element that is more suppressed than that of Se-82, hence it would be more sensitive to changes in the strength of the nuclear force.

THE DEPENDENCE ON THE MATRIX ELEMENT

The Quasiparticle Random Phase Approximation (QRPA) is a mathematical technique used by physicists to perform approximate calculations of the difficult to obtain wavefunctions and matrix elements for nuclei (Simkovic, 2006). Theoretical calculations of the $2\nu\beta\beta$-amplitude within the QRPA reveal a sensitive dependence on the strength g_{pp} of the charge-exchange triplet particle-particle (p-p) interaction (see Figure 5).

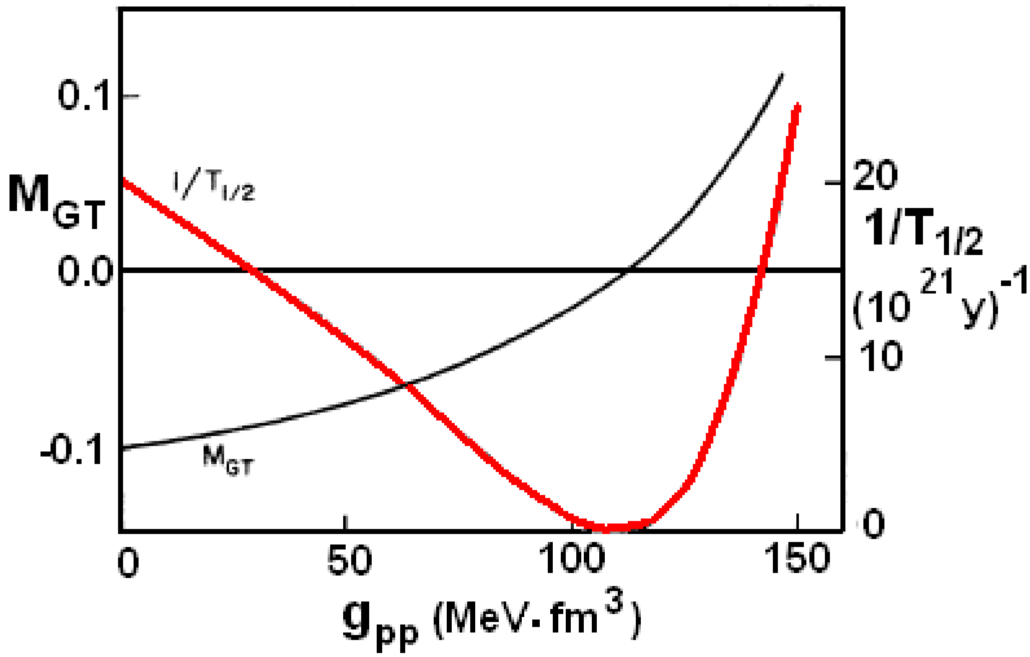

Figure 5. Inverse of ^{130}Te Half-life $1/T_{1/2}$ and Gamow-Teller Matrix Element M_{GT} versus Particle-Particle Interaction Strength g_{pp}. After Vogel and Zirnbauer (1986).

According to theoretical calculations of Rumyantsev and Urin (1998): For Te-130, the matrix element M_{GT} = 0.0468, and the Te-130 half-life $T_{1/2} = 9.4 \times 10^{19}$ years, while assuming the Bernatowicz *et al*. value of $T_{1/2} = 2.7 \times 10^{21}$ years would give M_{GT} = 0.0087. Thus, the calculations using present-day values give results an order of magnitude different half-life from the value implied by the Bernatowicz *et al*. half-life value obtained from geochemical data. For Se-82, the Te-130 matrix element is M_{GT} =

0.0295, the half-life $T_{1/2}$ = 2.6 x 10^{20} years, while assuming the experimental value of $T_{1/2}$ = 1.08 x 10^{20} years would give M_{GT} = 0.0459.

According to theoretical calculations of Rodin, Faessler, Simkovic and Vogel (2006): For Te-130, M_{GT} = 0.036 to 0.056 assuming the directly-measured Arnaboldi *et al*. (2003) value $T_{1/2}$ = (6.1 ± 1.4 stat.$^{+2.9}_{-3.5}$ sys.) × 10^{20} years rather than the geochemical Bernatowicz *et al*. value of $T_{1/2}$ = 2.7 x 10^{21} years. For Se-82, M_{GT} = 0.10 to 0.16 assuming the directly-measured experimental value of $T_{1/2}$ = 1.08 x 10^{20} years. These results indicate that level of accuracy attainable from present-day theory, but they also help to show that dependence of the result on the strength of the nuclear force.

If the strength of the nuclear force varies at some point in earth history, the g_{pp} value would also vary. The half-life for double-beta-decay depends very sensitively on the g_{pp} parameter, due to the proximity to the value leading to a phase transition involving isoscalar versus isovector pairing in the intermediate 1^+ state of the odd-odd transition nucleus. In nuclei which have more neutrons than protons, there exists an outer layer of the nucleus which is rich in neutrons compared to the inner core of the nucleus. In these nuclei, there can exist in some cases a competition between the stability of isoscalar and isovector Cooper pairs. Cooper pairs are the pairs of particles which interact closely and lead to the superfluid phase of a nucleus (Chaffin, 2008). Isospin is a quantum number used in nuclear physics to represent the state of the nucleon as being either a proton or a neutron, and the coupling together of the isospin quantum numbers of the two nucleons of a Cooper pair can lead to a state with a total isospin of zero (T=0) or one (T=1). The predominance of the T = 0 state is called isoscalar pairing and results in the two nucleons, one proton and one neutron, having parallel spins, as in the deuteron. The predominance of the T = 1 state is called isovector pairing and results in the two nucleons, two protons or two neutrons, having anti-parallel spins. As the nucleus changes from one state to another, there can be a change in phase from isovector pairing to isoscalar pairing, and vice versa (Vogel and Zirnbauer,1986; Civitarese, Hess,and Hirsch, 1997; Goodman, 1983). As shown in Table 5, the matrix element can pass through zero as the strength of the parameter g_{pp} representing this component of the nuclear force varies. Since one divided by the half-life is directly proportional to the square of the matrix element, there exists a value for which the half-life approaches infinity. Near this value, one has an extreme sensitivity of the half-life to the strength of the nuclear force.

CONCLUSION

The differences between the geochemical, theoretical, and directly measured half-lives speak to the question of a variation in the strength of the nuclear force over earth history. The older geologic samples yield a larger half-life for double beta decay of Te-130 than the more recent samples. If the strength of the nuclear force varied over the history of the earth, then all types of decay should change their half-lives. Since double-beta decay depends on the strength of the nuclear force in a different manner than single beta decay or alpha decay, one would expect to find its half-life to vary in the way noticed in this paper.

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