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# Accelerated Decay: Theoretical Models

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## Abstract

I discuss the possibility of variation of coupling constants and particle masses within modern physics. Quantum mechanical calculations are presented giving the decay constant for alpha decay and its variation with depth of the nuclear potential well. Finally, a concrete, numerical approach is given for the possible variation of the Fermi constant over the history of the earth.

## Keywords

Accelerated Decay, Age of the Earth, Tunneling, Beta Decay, Alpha Decay

## Introduction

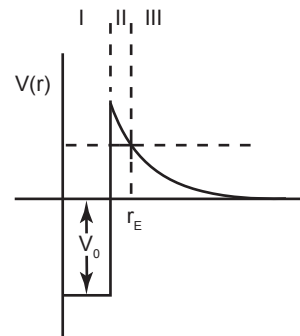
Modern physics involves more abstraction than the physics of even 20 years ago. Hence, it becomes an endeavor which may lead researchers into false starts and/or require us to solve the same problem in several different ways. However, it appears that physics research needs to involve different approaches in order to succeed. Kaluza-Klein theories, which were previously discussed (Chaffin, 2000a), have developed in recent years into multidimensional string theory. These theories attempt to explain the existence of gravitational, electromagnetic, weak nuclear and strong nuclear forces within a single theoretical framework. The development of string theory provides many examples of false starts. However, new understandings of mathematics and physics have enabled reasons and explanations to be given in particle physics which had not been previously possible. Attempting to take advantage of these new descriptive capabilities, let us consider the possibility that string theory may be relevant to the age of the earth question.

In particular, consider the subject of accelerated radioactive decay, which is the study of the possibility that radioactive half lives had smaller magnitudes earlier in history than today. Some concepts from modern particle physics lead to possible mechanisms for changing half lives. In particular, they lead to possible variation of the Fermi constant, which is the number in beta decay theory which most directly fixes the rate of nuclear decay by transmutations of neutrons to protons and vice versa.

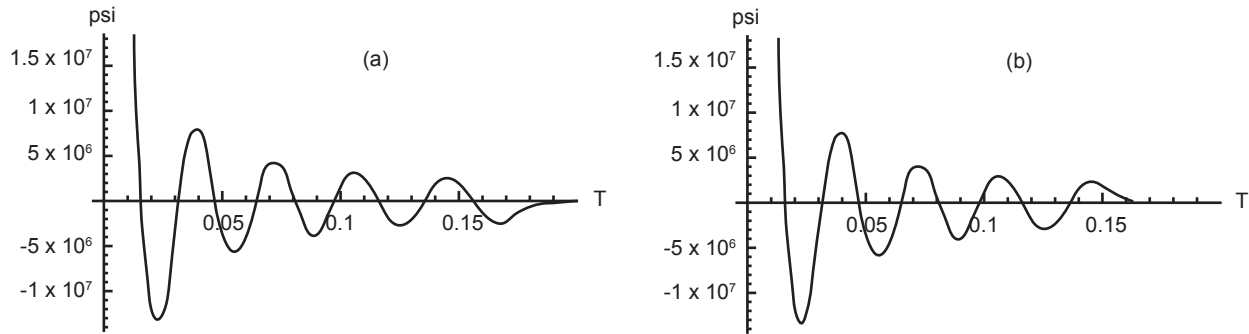
If the age of the earth is measured in thousands

rather than billions of years, then how does one explain the isotopic abundances of, for example, uranium, as found in geological samples? If half lives have varied over earth history, then nuclear physics must be altered in some way, and the altered theories could lead to new explanations for the isotopic abundance variations with time (Chaffin, 2000b, 2001). If there has been accelerated decay at some points in earth history, it will be impossible to successfully explain the data without recognizing and modeling this fact. Examples of “constants” which are no longer considered to have remained constant over the history of the universe are found in great quantity in recent physics literature. A common denominator of many of these examples is multidimensional string theory.

In this paper, some examples which are directly related to nuclear decay rates will be examined. Then we will discuss some ideas about multidimensional topology and how this relates to the quantities in physics which most directly determine decay rates,



**Figure 1.** The square-well potential with Coulomb Barrier



**Figure 2.** Sudden change in the number of nodes. The harmonic oscillator wave function for well depths of 58 MeV (a) and 54 MeV (b). The x-axis is the radial coordinate of the alpha particle,  $T = \rho / (2\eta)$ , where  $\rho$  and  $\eta$  are defined in Green & Lee (1955). Figure 2a shows the harmonic oscillator wave function for a well depth of 58 MeV. Figure 2b shows what happens when the well depth is changed to 54 MeV, without changing the alpha particle energy. If one counts the number of nodes in Figure 2a, there are nine, not counting the ones at zero and infinity. For Figure 2b, there are eight nodes, a reduction by one.

the so-called “coupling constants.” Then we consider their allowed variability according to modern theories, principally relying upon some work of Weinberg (1983) and then progressing to a somewhat different approach starting with the paper by Nath & Yamaguchi (1999).

### Alpha Decay and Variation of the Nuclear Force Strength

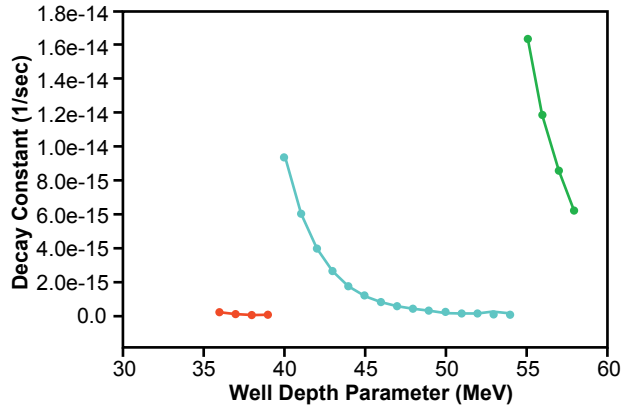
Historically, the numerical treatment of alpha decay has relied on quantum mechanics and the tunneling theory (Pierronne & Marquez, 1978; Preston, 1947). Figure 1 shows the usual scheme where the potential felt by an alpha particle is modeled by a square well for the interior of the nucleus and a Coulomb repulsion outside. Classically, a particle could not occupy region II of the figure; thus it could not have the negative energy that would be required for it to have only a few MeV of kinetic energy when it escapes to infinity. However, a wave such as that used in quantum theory can leak through, even though the particle would have a negative energy for radius less than the  $r_E$  value shown in the figure.

Although the changes in physical “constants” suggested in recent physics literature are very small (Chaffin, 2000b), alpha decay rates are very sensitive to small changes in well depths or shapes. At the Third International Conference on Creationism, Chaffin (1994) discussed results of a numerical study, using a simple computer program, which allowed the depth of the nuclear potential well to vary. The radius of the nucleus and the depth of the potential well represent two variables which are tied to the energy of the emitted  $\alpha$ -particle and the decay constant. In this simple model a constraint is needed, which may be taken to be the approximate constancy of radioactive halo radii (Chaffin, 2000b; Gentry, 1992; Humphreys, 2000; Snelling, 2000). If the energy of the  $\alpha$ -particle is held constant, then the halo radius

will also be constant. Since the radius of a halo ring is slightly dependent on the dose of radiation and the size of the halo inclusions, an exact constraint on the  $\alpha$ -particle energy cannot be maintained. For a 5 MeV change in the potential well depth, with the  $\alpha$ -energy held exactly constant the computer program showed that the decay constant will change by only one power of ten. If the  $\alpha$ -energy is allowed to change by 10% or so, then the decay constant changes by about 105. If the accelerated decay needed to explain the data is restricted to about one year or so, then a change in the decay constant of 109 or so may be required (DeYoung, 2000). Thus these considerations seemed to indicate that a one-year episode of accelerated decay at the time of the Flood may not be enough.

To test the variability of the decay constant, the computer program mentioned above, which was a Fortran program, was rewritten using *Mathematica*, a very powerful, modern software package which facilitates numerical work of this sort. For the square well potential on the inside of the nucleus, the *Mathematica* notebook gave essentially the same answers as the earlier work. In collaboration with Gothard and Tuttle, Chaffin modified the notebook to use a harmonic oscillator potential for the interior region, where the nuclear potential is felt by the alpha particle (Chaffin, Gothard, & Tuttle, 2001). In the course of this work, it was discovered that, as the nuclear potential well depth is changed, and the nuclear radius changes slightly, it is possible to have a sudden change in the number of nodes of the real part of the alpha particle’s wavefunction. This was modeled for both the harmonic oscillator and square well potentials, with nearly the same results for either notebook.

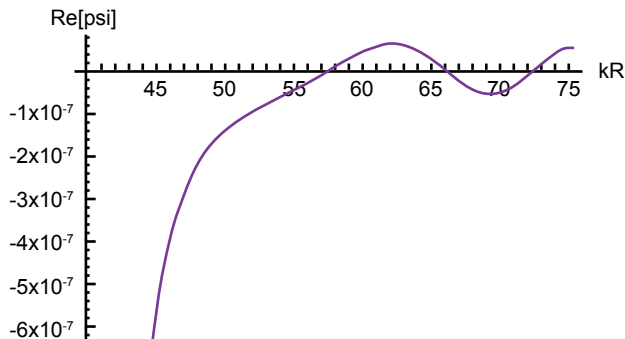
The change in the number of nodes causes the probability of tunneling to change by about a factor of ten, as shown by the discontinuity in the graph of Figure 3. Tunneling probabilities depend on the



**Figure 3.** The decay constant versus well depth for the harmonic oscillator interior potential. The graph shows a discontinuity, which occurs when the wavefunction changes the number of nodes as the radius slowly increases.

size of the wavefunction at infinity. The two graphs of Figure 2a, b show the wavefunction decreasing to zero at infinity. However, the probability of alpha decay for a nucleus such as uranium-238 is very low, hence the wavefunction will have small oscillation of both its real and imaginary parts, too small to show on this scale. Figure 4 shows a plot of the real part of the wavefunction for well depth parameter of 54, done with Mathematica. The x-axis shows a dimensionless variable  $T$  (defined in Fröberg, 1955), whose size represents the distance from the nucleus.

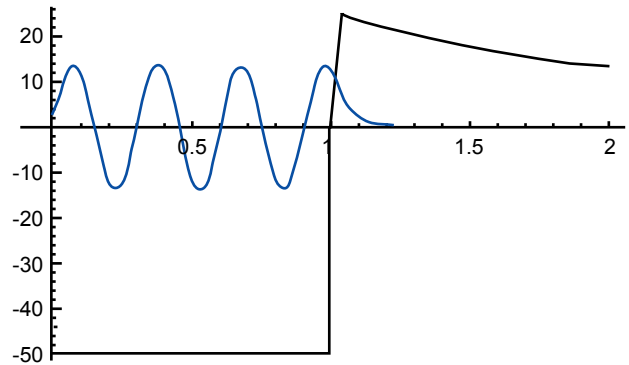
The use of potentials with a sharp boundary between the interior and exterior of the nucleus is not realistic. Consequently, in collaboration with Daniel Banks (Chaffin & Banks, 2002), a *Mathematica* notebook was written to use the exponentially diffuse boundary square well for the interior of the nucleus. This interior potential was originally investigated in a classic work by Green & Lee (1955), although they did not apply it to alpha decay. Figure 5 shows the potential well and the corresponding wavefunction for this case.



**Figure 4.** The real part of the Coulombic wavefunction outside the Coulomb barrier. The oscillatory behavior shows that the probability of escape is not zero for the alpha particle. The x-axis is the dimensionless radial coordinate  $p$  defined in Green & Lee (1995).

The use of this potential allows the potential energy to increase gradually as the distance increases outward and the nuclear force yields to the Coulomb repulsion. The treatment is somewhat complicated, in that now the wavefunction is a spherical Bessel function on the interior of the well, whose logarithmic derivative is matched to a Bessel function of nonintegral order for the changeover region, and then to a Coulomb wavefunction for the exterior region. There is now an interior radius for the changeover region, as well as an exterior radius. Either one can be varied to see what the effect is. In summary, it is found that the size of the variations is about what we obtained for the simpler cases of the square well or harmonic oscillator well.

The depth of the nuclear potential well is determined directly by the strength of the strong nuclear force, hence by the “strong coupling constant.” A coupling constant is a number inserted in a theory to fix the strength of a force. We determine it experimentally, but theories exist which indicate that it may not be a constant over the history of the universe. Hence, we will discuss the relevant parts of these theories in the next few sections.



**Figure 5:** The exponentially diffuse boundary potential and the corresponding wavefunction. The vertical axis is energy in MeV and the horizontal axis is the radius  $\rho$ . For the wavefunction, the vertical axis is the real part of the wavefunction multiplied by ten.

### Topology and Strings

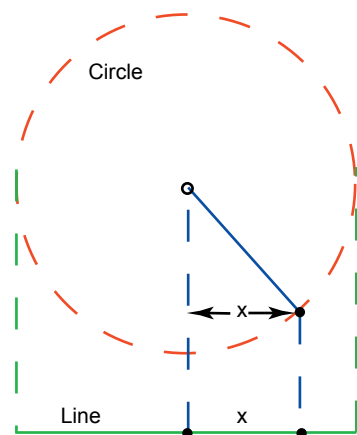
Multidimensional string theories quickly lead to the branch of mathematics known as *topology*. This, of necessity, is what happens when one takes these extra coordinates, or dimensions, seriously. An *n-dimensional manifold* is a space which can be transformed into a connected polyhedron, and such that every point can be surrounded by a collection of other points which is equivalent to the interior of an  $n$ -dimensional ball (Alexandroff, 1961; Nash & Sen, 1983; Pontryagin, 1999). For example, the surface of a sphere is a two-dimensional manifold, which mathematicians write as  $S^2$  (pronounced S-two, not S-squared). One needs two numbers to specify a point on this manifold, hence the number 2 means it is two-

dimensional. Another two-dimensional manifold is the surface of a torus,  $T^2$ . For precise, mathematical purposes, the sphere  $S^2$  and the torus  $T^2$  are distinct entities, and should not be confused.

For example, suppose we are trying to describe the motion of a pendulum (Figure 6). Initially, let us suppose that the pendulum is swinging back and forth, staying perfectly within the confines of a vertical plane. Then we could draw a line, or projection, down to the point on a flat, horizontal surface directly below the pendulum ball. A single coordinate  $x$  would then suffice to specify the position of the pendulum ball, this coordinate specifying the position on a straight line. However, for large oscillations of the pendulum, and if the pendulum was fixed by a universal joint at the top, the pendulum could swing over the top. Our single coordinate would then not suffice to distinguish positions above the support from positions below the support. Hence, a more correct mathematical model for the pendulum would be the circle. If, in addition, the pendulum were now able to swing in all directions, and not confined to one vertical plane, then the circular topology becomes inadequate, and a more correct model is the sphere,  $S^2$ .

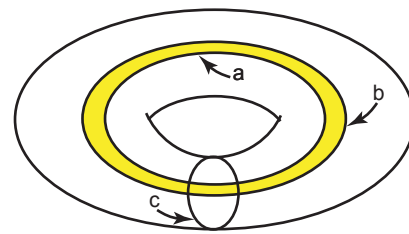
Suppose now that the problem is that of two pendulums, each confined to move in a vertical plane but allowed to swing over the top. The two pendulums move independently of each other, assuming positions on two different circles. The combined coordinates now have a different topology, the topology of the torus,  $T^2$ .

One of the early pioneers of topology was Henri Poincaré, whose active work on the subject occurred during the 1890s up to his death in 1912. Poincaré analyzed different surfaces by thinking in terms of



**Figure 6.** The position of a pendulum bob, confined to move in a single vertical plane, can be completely specified by a single linear coordinate  $x$ , provided the pendulum does not swing over the support's level. If the pendulum is free to swing higher than the support, then the circular topology is needed to specify the position. (Figure drawn after Rourke & Stewart, 1986).

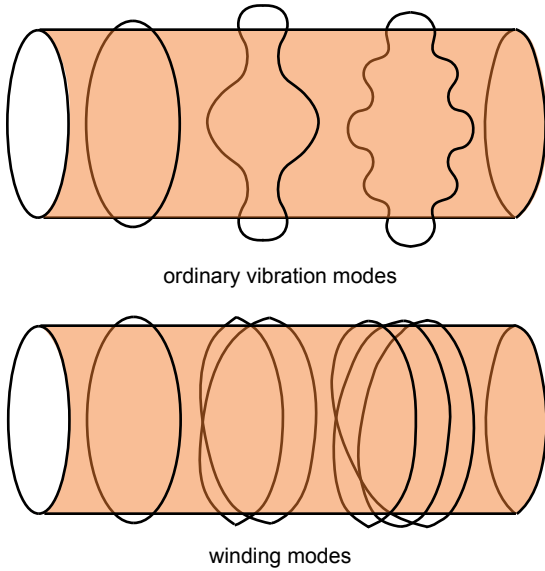
deformations of loops, which links to what are now called homology and homotopy. In mathematical topology, homology theory concerns itself with the question of the number of holes in the space. Shown in Figure 7 are three curves,  $a$ ,  $b$ , and  $c$  on the surface of a torus. The curves  $a$ ,  $b$ , and  $c$  have something in common, they cannot be shrunk to a point by continuous sequence of deformations. For curves  $a$  and  $b$  it is because the hole is there. For curve  $c$  it is because the curve is wound around a closed circumference and cannot be shrunk unless one cuts the curve, moves it, and then pastes the ends together. In topology, this is described by stating that  $a$  and  $b$  belong to the same homology class, whereas  $c$  belongs to a different class. Similarly, the concept of homotopy concerns itself with deforming loops. Two loops are homotopic if they can be continuously deformed into each other. These concepts, and others, become important tools in analyzing topology and ultimately multidimensional string theory.



**Figure 7.** Three closed curves on the surface of a doughnut (torus) illustrate inequivalent and equivalent closed paths. Curves  $a$  and  $b$ , which bound the hatched area, can be smoothly distorted into each other, whereas curve  $c$  winds around a different direction and cannot be distorted into  $a$  or  $b$ , without cutting and pasting the ends (Figure drawn after Eguchi, Gilkey, & Hanson, 1980).

Within the last five to ten years research has uncovered numerous dualities relating different limits and formulations of string and membrane theories. Greene (2000, pp.231–262) and Duff (1998) have discussed the duality between ordinary vibrational modes and winding modes of a string (see Figure 8).

A value of the radius for compactified dimensions leads to the same results or equivalent results for a different radius, in which the winding modes and ordinary vibrational modes change roles in the equations of the theory (Dai, Leigh, & Polchinski, 1989). Another type of duality relates the strong coupling limit of one theory to the weak coupling limit of another. A coupling constant is a number giving the strength with which an elementary particle is coupled to the field that it experiences. For example the coupling constant for interaction with the electromagnetic field is the electric charge. In some work by Witten (1996) and Lykken (1996), these authors was speculated



**Figure 8.** The ordinary vibration modes of closed strings (above) and the winding modes (below). In the equations of string theory, these two modes carry energy, and exchange roles when the radius of the compactified dimension moves from small to large.

that, contrary to previous thought (see Kaplunovsky, 1988, 1992), strong coupling limits of certain string theories were more relevant to accelerator physics. This led to some more realistic applications of string theory than had been previously been possible (see Nath & Yamaguchi, 1992).

### Compact Circumferences and Coupling Constants

Weinberg (1983) used generalized Kaluza-Klein models having  $4+N$  dimensions to find a relation between coupling constants and the root-mean-square (rms) circumferences of the compactified dimensions. As discussed in reference (Chaffin, 2000a), the original Kaluza-Klein model had only one extra dimension besides the usual four of ordinary spacetime. Witten (1981) discussed the generalization to the case where there are more compact dimensions. Weinberg applied this idea to reduce some assumed higher-dimensional equations of gravitation theory to the four-dimensional case, and worked out the results of his equations for some simple examples. These examples assign an assumed topology to the compactified dimensions, and then calculate the rms circumferences. For one example, he assumed that the topology corresponded to the symmetry group  $\mathbf{SO}(N+1)$ , the group of rotations, contiguous to the “leave-it-alone” or identity rotation, in  $N+1$  dimensional space. (A *group* is a set of elements plus a rule of combination of pairs of elements, satisfying certain requirements, including that every element has an inverse.) This gave the result for the  $\mathbf{SO}(N+1)$  coupling constant:

$$g = \left( \frac{\kappa}{R} \right) \left[ \frac{1}{2} (N+1) \right]^{\frac{1}{2}} \quad (1)$$

Here,  $\kappa^2 = 16\pi G$ , where  $G$  is Newton’s gravitation constant,  $R$  is the radius of this  $(N+1)$ -dimensional shape with topology analogous to that of a sphere. Thus, for a highly symmetrical topology such as this, all the coupling constants would be the same. In the real world, we know that the strong, electroweak, and gravitational constants are different, but here we are dealing with a simplified example to illustrate possible “real” behaviors.

Weinberg also considered an example having the symmetry  $\mathbf{SU}(3)$ , the group of all unitary  $3 \times 3$  matrices with determinant plus one. In this example there are two different possible values for coupling constants  $g$  and  $g'$ ,

$$g = \sqrt{\frac{2\kappa}{3}} \quad (2a)$$

and

$$g' = \sqrt{\frac{2}{3}} \frac{\kappa}{R} \quad (2b)$$

Thus, the ratio of the two coupling constants is the square root of three, and does not depend on the radius  $R$  of the extra dimensional shape.

Candelas & Weinberg (1984) generalized these results to include the effects of quantum fluctuations of matter fields on the vacuum, and found slightly modified versions of the earlier relations between the radii  $R$  of the compactified dimensions and the coupling constants. They also generalized some considerations of Rubin & Roth (1983) which attempted to relate the radii of the compactified dimensions to the average temperature of the matter fields contained in the universe.

The change of the compactified radii with temperature can be understood physically through the Casimir effect (Chaffin, 2000a, Hawking, 1996). The Casimir effect is a force between two parallel conducting plates caused by differences in zero-point energy of the electromagnetic field. In a similar manner, at zero temperature, the gravitational zero-point energy of the Kaluza-Klein ground state leads to the collapse of the fifth dimension, but in that case we deal with the topology of the compactified dimensions, not with parallel plates. In the parallel-plate case, if a gas of photons at fixed temperature is introduced between the plates, the net pressure on the plates will be the sum of two contributions: the positive pressure from thermal photons, of constant magnitude, and the negative Casimir pressure, varying in inverse proportion to the fourth power of the plate separation.

The negative Casimir pressure arises because the short distance between the plates prevents standing waves of certain wavelengths from existing between the plates. If the plates start out close together, the negative Casimir pressure is stronger than that of the thermal photons and the plates collapse. If they start out at a distance such that the Casimir pressure is weaker, then the plates will fly apart with nothing to stop the separation. The thermal photon pressure changes as the plate separation changes, but only as (separation)<sup>-4/3</sup>; that is, much more slowly than the Casimir pressure.

Candelas & Weinberg (1984), and before them Rubin & Roth (1983), attempted to extrapolate from the parallel-plate case to a realistic Kaluza-Klein model. Such a model would remove the artificial constraints of an assumed external geometry and an assumed time-independent internal geometry. Realistic models would also involve more than just one compact dimension with compactification brought about by vacuum expectation values (VEVs) for non-gravitational fields, and would include fermionic (half-integral spin) fields. The presence of curvature in both the compact and non-compact dimensions, the response of the VEVs to changes in temperature, and fermion degeneracy pressure might well all contribute to behavior very different from that observed in the parallel-plate case.

This idea provides a possible mechanism for changing the radii of the compact dimensions as the universe expands and its background temperature changes. Early in creation week, it may be that the mechanism could also work in a young-earth model.

### Kaluza-Klein Excitations

In superstring theory, we need to link a 10-dimensional “manifold,” which is simply a framework which can be smoothly described by 10 independent coordinates, with our observed four-dimensional spacetime. If the extra six dimensions are curled up into a compact space, this simply means that every point of four-dimensional spacetime has one of these compact six-dimensional spaces associated with it (In more recent theory, 11 dimensional membranes are wrapped up to make ten-dimensional superstrings, but that is just an unneeded complication as far as we will be concerned.). If the size of the compactified six-dimensional space is small compared to the scale of everyday life, we would not directly detect the effect of these extra dimensions (Chaffin, 2000a, Hawking, 2001).

At high enough energies, higher even than those of the abortive superconducting supercollider, the SSC—which began but did not complete construction in Texas, a particle accelerator would be likely to detect the presence of the so-called Kaluza-Klein excitations

or Kaluza-Klein modes. In quantum mechanics, waves are associated with all particles. When we consider string theory, we find that if a spatial dimension is curled up, then the momentum  $p$  associated with the waves wrapping around this dimension will be quantized, with values  $p = nh/(2\pi R)$ ,  $n = 0, 1, 2, 3, \dots$ , and  $h$  is Planck’s constant, while  $R$  is the radius of the compactified dimension. In this picture the masses of the quantized excitations, the masses  $m_n$  of the particles, are given by  $m_n^2 = m_0^2 + n^2 h^2 / (4\pi^2 R^2 c^2)$ , where  $m_0$  is the mass of the mode with zero momentum and  $c$  is the speed of light.

Particles can be divided into fermions (half-integral spin) and bosons (integral spin). It is possible that the fermions or some of the fermions may not have Kaluza-Klein excitations Dienes, Dudas, & Gherghetta (1999). This is dependent on exactly how the extra dimensions are compactified. If the fermion corresponds to excitations located at the fixed points of an orbifold, then no Kaluza-Klein excitations exist. In mathematically precise formulations of topology, an orbifold is a way of smoothing over or “blowing up” certain fixed points at which different coordinates must be joined (Dixon, Harvey, Vafa, & Witten, 1985).

In the actual multidimensional string theories, we need to make contact with the “real” world of four spacetime dimensions. The 10-dimensional superstring theory must compactify six of the dimensions on a six-dimensional compact manifold. Particle physicists have, in the last 15 years, spent a great deal of time studying just how to do this. Fortunately, mathematicians have been studying topology since the time of Poincaré in the late 1800s. While they have not fully developed all the machinery needed by the string theorists, two mathematicians, Eugenio Calabi and Shing-Tung Yau had studied a type of six-dimensional space, known as a Calabi-Yau space (pronounced cah-lah'-bee-yah'-oo) which particle theories needed (Greene, 2000). The topology of this space, with the requisite number of “holes,” seems to be right to allow the known quarks and leptons to be described in terms of string theory. The quarks and leptons are grouped into three “families,” which are allowed by these Calabi-Yau shapes. They allow description in terms of representations of the  $SU(3) \times SU(2) \times U(1)$  group of the so-called standard model.

### Unified Theories

In 1974 the  $SU(5)$  theory of combined strong, weak, and electromagnetic interactions was proposed (see Georgi & Glashow, 1974 and Georgi, Quinn, & Weinberg, 1974). The  $SU(5)$  theory receives its name because it is modeled after five by five special unitary matrices (hence the nickname **SU** standing

for special unitary), special meaning they have determinant plus one. This theory allowed all the families of quarks and leptons to be combined into representations of the  $SU(5)$  group, which means that we only needed particles called gluons,  $W^+$ ,  $W^-$ ,  $Z^0$  bosons, and the photon to describe the forces between the quarks and leptons (Georgi, 1989; has given a popular-level description of how this theory was formulated.). Basically, the  $SU(5)$  theory had only one “coupling constant.” In accord with previous discussion, “coupling constant” may be thought of as a number which describes how much force originates from placing particles of known type a certain distance apart. Each type of force has its own coupling constant, but the  $SU(5)$  theory implied that the coupling constants for strong, weak and electromagnetic forces all originated from a single constant, diverging into their various values as the energy of the interactions is lowered from high energies down to low energies. The reason for the divergence of these values has to do with what is called renormalization, and with the effective field theory which results from performing the renormalization appropriate to a given energy scale. In quantum field theory, a particle is surrounded by a cloud of virtual particles, which cloud will be penetrated to varying degrees by a second particle interacting with it (Georgi). A more energetic particle penetrates further. For example, a real particle with positive electric charge will be surrounded by pairs of virtual electrons and positrons. On the average, the virtual positrons are pushed farther away from the real particle, while the virtual electrons are nearer to it. So on the average, the real particle has more negative charge near to it than far from it. A second real particle, depending on its energy, will penetrate this cloud to a lesser or greater degree. For this reason, the effective interaction depends on the particle energy, and the coupling constant of electromagnetic interactions is less for smaller energies. In the case of the strong force, the gluons cause the force to get weaker at larger energies (Georgi, p. 432).

Renormalization theory says that not only the coupling constants, but also the masses of particles appear to vary on different energy scales (Nelson, 1985). While quantum theory connects this effect to varying energy scales, the basic ideas are actually much older. J.J. Thomson discovered the so-called electromagnetic mass in 1881 (Thomson, 1881). Thomson correctly noted that a charge moving through a dielectric experiences a resistance, which is non-dissipative, and hence is best described by an additional contribution to the mass. The resistance is comparable to that of a sphere moving through a perfect fluid. Motion of the sphere is impeded by the presence of the fluid. Using James Clerk Maxwell’s theory of electricity and magnetism, Thomson

showed that the charged sphere, moving through the dielectric, would experience an additional mass. Thomson’s equation for the new mass  $m$  is:

$$m - m_0 + \frac{4}{15} \frac{\mu_0 e^2}{a} \quad (3)$$

where  $e$  is the charge,  $a$  is the radius of the sphere, and  $\mu_0$  is the magnetic permeability. While quantum theory does not assign a radius to the electron, the “vacuum polarization” effect is nevertheless a real effect (Bjorken & Drell, 1964, section 8.2; Georgi, 1989, p. 434). In many lab experiments, the particles have low energy and are nowhere near the large energies that bring out these effects. However, for experiments involving modern particle accelerators, these effects become evident: the effective coupling constants and effective masses vary with energy.

The  $SU(5)$  theory of Georgi and colleagues had an unfortunate failure. It predicted the decay of the proton, with a half-life greater than 1,029 years. As a result of this prediction, experiments were set up to detect this proton decay, and no conclusive evidence for such decays was found. The half-life of the proton, if not infinite, was shown to be higher than the range which the  $SU(5)$  theory seems to allow. Other unified theories based on other groups or on string theory are possible, and this is still an active field of research. For example, Shiu & Tye (1998) discussed the possible suppression of proton decay by an additional symmetry, while Dienes et al, (1998a, 1998b) discussed a higher-dimensional mechanism involving selection rules for the Kaluza-Klein excitations which allow all proton-decay processes to have vanishing probability. In the  $SU(5)$  theory and in similar theories allowing proton decay, there are particles, either X-bosons or Higgs particles, which are responsible for the proton’s decay. In the Dienes, Dudas, & Gherghetta theory, however, the proton does not have Kaluza-Klein excitations which leads to a zero probability for its decay (Technically, the proton is said to be restricted to the fixed points of an orbifold, at which point the probability for interacting with the X-bosons or Higgs particles is zero.). Of course, these theories are untested at present, so the correct explanation for the lack of proton decay is still undecided.

Unfortunately, this also leaves open the question of whether or not the  $SU(5)$  theory was correct in predicting that there is only one coupling constant at high energies. If the radii of compactified dimensions varied over the early history of creation, then a related question also seems to be unanswered for us. Could the rates of alpha and beta decay vary relative to each other over the history of the universe? This is an interesting question, and needs to be answered in order to correctly interpret radioisotope data. A start in this direction will be provided in the next section.

## Kaluza-Klein Excitations and the Fermi Coupling Constant

Nath & Yamaguchi (1999), considered the question of whether Kaluza-Klein excitations contribute to the so-called Fermi constant, which determines the fundamental rates of beta decays. Enrico Fermi, the Italian-American of the Manhattan project, was responsible for the first realistic theories of beta decay, so this coupling constant  $G_F$ , as applied in beta decay theory, is named after him. For the case of one extra dimension, Nath & Yamaguchi showed that to leading order in the ratio of the W boson mass  $M_W$  to the mass proportional to  $1/R$  (the compactification scale mass  $M_R$ ), the effective Fermi constant  $G_F^{eff}$  is given by

$$G_F^{eff} \cong G_F^{SM} \left( 1 + \frac{\pi^2}{d} \frac{M_W^2}{M_R^2} \right) \quad (4)$$

Here,  $G_F^{SM}$  is the value of the Fermi constant, which may be calculated from the standard model of quantum field theory (Nath & Yamaguchi (1999) comment that the standard model agrees very well with experiment) without any assumptions about extra dimensions. For the case of more than one extra dimension, Nath & Yamaguchi derived a simple formula similar to the above but depending on the extra dimensions. From the results of standard model calculations, plus experimental measurements (Abachi et al, 1996; van Ritbergen & Stuart, 1999), Nath & Yamaguchi showed that the energy  $M_R c^2$  was at least 1.6 TeV. This encourages particle physicists to hope that, with the completion of the Large Hadron Collider (LHC), expected in 2006 or so, evidence for these extra dimensions may be found (see Kane (1998) for a semi-fictitious account of expectations).

Now, because we are interested in the possibility of accelerated decay in the early universe, we need to take the discussion a step further than Nath & Yamaguchi did. In their paper, they only considered present-day measurements. Because of our interest in explaining radioisotope data in terms of a young earth, we may think as follows. If, over the early history of the universe, the radius of compact dimensions should change, then so would the mass scale  $M_R$ , and hence the value of the Fermi constant. Under the simplifying assumption that other factors in the equation do not change as radically as  $M_R$  does, decreases in the sizes of extra dimensions would increase  $M_R$ , and hence decrease the values of  $G_F$ . This in turn would mean that half-lives for beta decays of nuclei would become larger as the extra dimensions became smaller. Thus, one would expect accelerated decay to have occurred early in the history of the creation.

## Conclusion

A straightforward biblical interpretation does not rule out a period of accelerated decay early in creation

week. Since life does not appear until some time on day three, the cessation of the accelerated decay at that point prevents life from receiving abnormally large radiation doses. The models presented depend on the compactification of extra dimensions, with the compactification being completed early in creation week. Other models may lead to accelerated decay at other points, for instance during the Fall of Genesis 3 or during the Flood of Noah, but it would seem that these other episodes would probably have to be explained using alternative models, and could not allow as much accelerated decay as could be accommodated early in creation week.

Since God is the origin of physical principles, it would be wrong to state that He must act in a certain way. However, Scripture is a reliable record of His actual creation. The models considered here merely point out some unnecessary assumptions involved in interpreting radioactive decay: half lives may not have been constant.

Although extended Kaluza-Klein and string theories must be considered as highly tentative theories, in this work we find some explicit equations showing the variation of the Fermi constant. These results enable one to conjecture about how much the variation must have been in order to explain present-day isotopic abundances. Since there is no precise number to match with theory, and since various approaches to the final, present-day abundances are possible, these results remain explanatory in nature. Perhaps future studies will be able to connect more precisely with the data.

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