A Model for the Variation of the Fermi Constant with Time

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Abstract

Genesis, chapter one, is discussed in terms of whether half lives could have been smaller early in creation week. Radioactive equilibrium of uranium is discussed in terms of such a scenario, along with U-235 and Pu-244 abundances. The discussion is related to evolutionary thoughts about element production in stars. I discuss the possibility of variation of coupling constants and particle masses within modern string theory. Finally, a concrete, numerical approach is given for the possible variation of the Fermi constant over the history of the earth.

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 in this journal (Chaffin, 2000a), have developed in recent years into multidimensional string theory. These theories attempt to explain the existence of electromagnetic, gravitational, 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, I will consider the possibility that string theory may be relevant to the age of the earth question.

In particular, I 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. I will consider how scriptural evidence can best be interpreted, in terms of a young-earth model. I will discuss isotopic abundances of uranium and a few other elements, as indicative of the types of data we would like to be able to explain. Then I will progress to some modern particle physics, in a search for possible mechanisms for changing half lives. In particular, I will give a model for 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 do I 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. 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. Hence, I will discuss some examples which are directly related to nuclear decay rates.

The work in this paper will begin with a short discussion of biblical interpretation as it relates to the sequence of events during creation week. Is accelerated radioactive decay, with the associated large radiation densities, consistent with the Genesis account? From there I will move to the interpretation of some uranium isotopic abundances and their explanation in terms of a young-earth model. This will be related to recent evolutionary ideas about the production of nuclei in stars and possible creation alternatives. Then I discuss some ideas about multidimensional topology and how this relates to the quantities in physics which most directly determine decay rates, the so-called "coupling constants." I 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 and Yamaguchi (1999).

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Genesis Interpretation

The Genesis account, when taken straightforwardly, seems to imply an age of the universe of thousands rather than millions of years. In some early *CRSQ* articles, John Whitcomb, Jr., offered evidence in terms of the meanings of the original Hebrew language of Genesis one (Whitcomb, 1965; 1967). Many Christians, especially some from the earlier generations of the 1900's, advocated the view that an extensive time gap of millions of years existed between the first two verses of Genesis. To address these concerns, Whitcomb discussed the meanings of the original language, suggesting that Genesis 1:2, should read essentially the way it has been traditionally translated.

For example, the King James Version translation of Genesis 1:1–2 is:

> 1 ¶ In the beginning God created the heaven and the earth.
> 2 And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters.

The "was without form and void" in verse two is correctly translated according to Whitcomb. The contrary view is that the verb "was" should be translated "became," implying that some pre-Adamic judgment destroyed the original perfection of God's creation. Other biblical creationists have also expressed similar opinions to that of Whitcomb. Robert L. Reymond (1967; 1998) advocated the same view of *ex nihilo* creation, the historicity of the universal deluge, the tower of Babel incident, God's covenant arrangement with Adam, the resultant effects on the race of Adam's fall, and the decrease in longevity of the patriarchs following the Flood. Fields (1973; 1994) wrote a Master of Divinity thesis on this and related questions which later became a book. B. K. Waltke (1975a, b , c, d; 1976) wrote a series of articles in *Bibliotheca Sacra* discussing the cultural background of the Genesis account, the meanings of the original words, etc., and arrived at a view of creation very close to that of these other conservative scholars.

In an earlier article (Chaffin, 2000a), I gave a model in which accelerated radioactive decay occurred early in creation week, before the creation of man. This avoids abnormal radiation doses which living things would receive from an accelerated decay episode. In private discussions, some have expressed reservations about whether radioactive decay could have occurred before the fall of man (Genesis 3), since God's creation was then "very good." As a rebuttal to this view, one might note that radioactive decay is simply the emission of particles by nuclei, with some particles changing into other types of particles. It does not necessarily follow that this could not occur before the Fall. Also, the creation as described in Genesis is not an instantaneous one, but a stepwise process of six days. Hence, although a creation with an inordinate amount of radioactive decay would certainly not be "very good," it still may have occurred as a part of this stepwise creation in the first two and one-half days, before creation of life.

The authorities cited above have commented on the stepwise nature of the Genesis creation. Reymond (1998, p. 391), in discussing the meaning of Genesis 1: 1–3, offered what he thought was the best meaning. He has God creating a "well-ordered universe" in verse one. Then verse two begins the chronological sequence of telling how God did it, with the earth being empty and formless at first. Reymond wrote (p. 391):

> Some object that this construction has God originally creating a "chaos"—an ascription insulting, it is said, to the divine nature. But such an objection is based on an unwarranted *a priori* perception of what God should or should not do in keeping with the perfections of his nature. The objection presumes that an originally unformed earth as a first creative act on his part is unbecoming to his character. But this cannot be demonstrated and therefore must not be assumed.

Whitcomb (1967, p. 71) commented on the state of the earth at the point of verse 2:

> The crust, however, had no significant features, such as continents, mountains, and ocean basins, for these were formed on the third day. . . . As a planet, it [the earth] was perfect in every way, but at this stage of creation week it was not yet an appropriate home for man. It was "without form and void" (*tohu wabohu*).

Fields (1973, pp. 128–129) describes and agrees with the views of Calvin, Luther, and others that "the step in Genesis 1:2, was merely a step in the process of creation."

After an extensive discussion of the gap theory and variations of the gap theory, Waltke concluded (1975c, p. 226):

> ...verse 1 [Genesis 1:1] is a summary statement, or formal introduction, which is epexegeted in the rest of the narrative. It appears to this author that this is the only viewpoint that completely satisfies the demands of Hebrew grammar.

Thus, regarding these subjects, these authors, who have graduate training in bible fields, seem to express a consistent opinion, which opinion will be adopted in this work.

Isotopic Distributions of Uranium

Uranium isotopes U-238, U-235, and U-234 occur in the per cent abundances 99.27, 0.72, and 0.0055%, with other isotopes only occurring in trace amounts. The half lives of these isotopes are 4.47×10^9 years for U-238, 7.04×10^8 years for U-235, and 2.47×10^5 years for U-234. A condition known as *radioactive equilibrium* occurs when the activities of successive members of a decay chain are equal. The activity is defined as the decay constant (which is the natural logarithm of two divided by the half-life) times the number of atoms in the sample.

Figure 1 shows an analogy between fluid flow and the decay of the atoms in the U-238 to U-234 series. The level of the fluid in a bucket is a balance between the rate of inflow and the rate of outflow. For a given level of fluid in the bucket, a proportional amount of pressure is produced at the bottom of the bucket, where the valves are located. This is analogous to the amounts of radioactive parent atom present. However, the rate of decay also depends on how wide open the valve is, which is analogous to the half life. The most probable decay mode of U-238 is alpha decay, which produces Th-234. Thorium-234 undergoes beta minus decay with a half life of 24.1 days, producing Protactinium-234. Pa-234 then also undergoes beta minus decay with a half life of 6.69 hours producing Uranium-234. Thus U-234 is in the decay chain of U-238, and radioactive equilibrium does exist because 0.0055 times the decay constant of U-234 is the same as 99.27 times the decay constant of U-238. Departures from radioactive equilibrium exist in some samples (Chalov and Merkulova, 1966; 1968; Chalov, Merkulova, and Tuzova, 1966; Thurber, 1962) but the departures are relatively small.

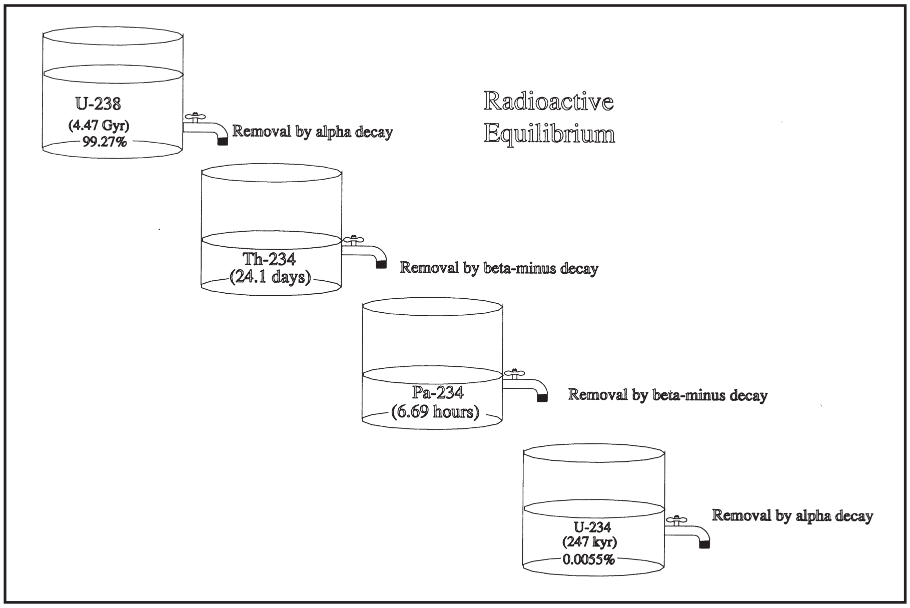

Figure 1. An analogy between fluid flow and the decay of the atoms in the U-238 to U-234 series.

The variations may possibly be explained in terms of the difference in relative solubility of U-234 and U-238 starting from hexavalent and tetravalent uranium in compounds and their decomposition products (Chalov and Merkulova, 1966; 1968). Thus, a fraction of the U-234 atoms present in a mineral lattice will have formed by radioactive decay starting from U-238. Due to the recoil of a nucleus during alpha decay, a significant number of daughter nuclei will lose their former link with the mineral lattice. These daughter U-234 nuclei will as a result be, on the average, found in different linkages as compared to the U-238 nuclei. This was Chalov and Merkulova's explanation for why they found different rates of dissolution of U-234 and U-238 in their laboratory experiments. Working together with T.Z. Tuzova, Chalov and Merkulova attempted to use this difference in solubility to obtain an age of the Aral Sea (southern Kazakhstan and northern Uzbekistan). Their result was 150 ± 30 thousand years. However, some fragile assumptions were needed to arrive at this number, and such ages are not well accepted even among evolutionists.

From a young-earth viewpoint, it is easy to point to these fragile assumptions to invalidate age determinations such as those just mentioned. However, with an earth of only some thousands of years old, it is difficult to explain the bulk of the approximately equal ratios without an episode of accelerated decay. Starting from an arbitrary initial state, it takes more than one half life of U-234 to establish equilibrium, implying an age of the samples very much larger than straightforward Biblical interpretation would indicate. Figure 2 shows the graph of the U-234 abundance versus time, assuming the U-234 starts with a 100% abundance, or was equal in abundance to that of U-238. One sees that, for this starting assumption, and assuming no accelerated decay, an age of the earth of at least four million years is implied. A possible alternative assumption is to assume that there was no U-234 at all at the start. Figure 3 shows the result of that calculation. Assuming no acceler-

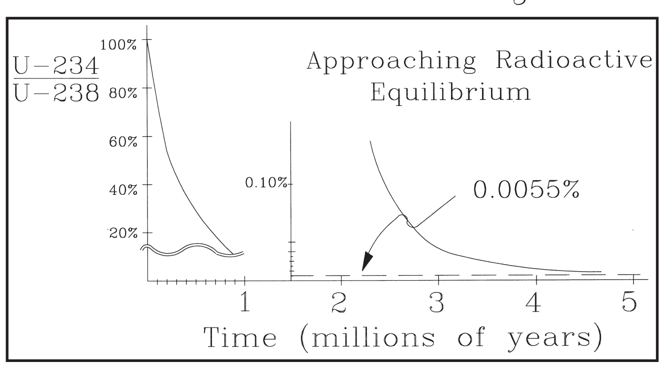

Figure 2. Graph of the U-234 abundance versus time, assuming the U-234 starts with a 100% abundance, or was equal in abundance to that of U-238. The time scale shown assumes that no accelerated decay occurred.

ated decay, this assumption thus implies an earth age of at least 1.2 million years.

To justify the young-earth viewpoint, one would be logically correct in claiming that the rocks may have been created already in a state of radioactive equilibrium, with no time needed to reach that state. However, a more natural explanation seems to be provided by accelerated radioactive decay. We do not know the original ratio of U-234 to U-238 in the created materials of the early earth, but if we make some reasonable guesses, then a period of accelerated decay would adjust this ratio to the 0.0055 % ratio presently found in the bulk of earth materials. This may be evidence that such accelerated decay did, in fact, occur. Furthermore, by the time of the Garden of Eden, radioactive equilibrium would have been in existence, and decay rates of uranium much smaller, possibly even zero.

The U-235 abundance, compared to U-238, also seems to support this point of view. If the initial abundances of these two isotopes were of the same order of magnitude, then several half lives of U-235 are needed to establish the present 0.72% and 99.27% isotopic abundances, implying sample ages of a few billion of years (Chaffin, 1985). As in the U-234 cases, we do find slight variations in U-235 percent abundances between different minerals collected at different sites (see for example Malyshev et al., 1977). However, the variations are small. To advocate a young earth without accelerated decay or very rapid initial decay after the creation of the elements, one seems forced to assume that the uranium isotopes were created in isotopic per cent abundances approximating those found today (Chaffin, 1985).

When considering evidence for the presence of plutonium-244 in solar-system rocks (Chaffin, 2000b), evolutionary astronomers have concluded that a supernova must have occurred close in time and space to the existence of the hypothetical pre-solar nebula. Although young-earth assumptions would not favor the solar nebula idea, the rock data on Pu-244 nevertheless should be considered. If these rocks did in fact contain Pu-244 (half life 8.0 x 10^7 years), this would be additional evidence for accelerated decay.

Dating with Stars

In recent years, astronomers have attempted to date the universe independently of the assumed models of inflationary expansion and other assumptions (Meyer and Truran, 2000; Arnould and Takahashi, 1999). One of the ideas is to measure the abundance of U-238. Another idea uses Th-232. Now Th-232 is the starting element of the *thorium series*, while U-238 is the starting member of the so-called *uranium series*, so they are in different decay chains and do not decay into each other. The method em-

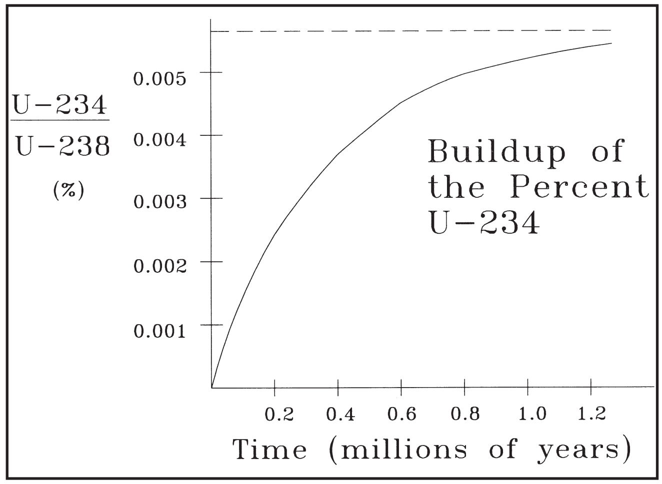

Figure 3. Graph of a possible alternative assumption—that there was no U-234 at all at the start. Assuming no accelerated decay, this leads to an earth age of at least 1.2 million years.

ploys *measured* abundance ratios in a large number of ultra-metal-poor (UMP) stars, and compares the present-day, *measured* abundances to theoretical values to calculate the age of the star. For UMP stars, studies have shown that s-process model abundances are under-represented as compared to r-process stars. The s[slow]-process is a build up of heavy elements by capture of neutrons in nuclei, with enough time in between captures for beta decays to take their course. The r[rapid]-process is a rapid capture of neutrons with no time in between captures. Many evolutionary astronomers now think that large-mass, Type II supernovas are a likely location for the r-process type of nucleosynthesis.

Actually, the idea of using U-238 or Th-232 abundances to date stars is not a recent one (Butcher, 1987). However, measurements have only recently begun to provide the type of data in UMP stars that is needed (Westin, Sneden, Gustafsson, and Cowan, 2000) According to a news story ("Dating a star like a rock," 2000) and a press release on the web site of the European Southern Observatory (www.eso.org), a paper is in preparation by Gustafsson, Mitzuno-Weidner, Hill, Primas, Bonifacio, Molaro, and Nissen which will report a new observation of uranium in a spectral line of the UMP star CS22892-52. What is done is to compare the measured abundance of uranium or thorium to that of europium to extract an age, based on the r-process model for initial abundances. The press release stated that the lower limit for the age, based on the U-238 measurement, is determined for the CS22892-52 star as 12 billion years. For the star HD115444, a lower limit of 11 billion years is already in print (Westin, Sneden, Gustafsson, and Cowan, 2000).

The r-process model can only be applied to stars which are thought to be very old stars, such as these galactic halo stars, CS22892-52 and HD115444. Stars of that "age" are thought to have been produced before much s-process material was mixed into the interstellar medium. Any admixture would ruin the whole method. It is possible that, after around 20–30 stars have been measured, the results may not be uniform and these assumptions will therefore be proven wrong. Meanwhile, this remains an active area of research. Interestingly, the high-temperature environments of stars are known to alter half lives, particularly those of elements such as Re-187 (Meyer and Truran, 2000). However, attempts are made to factor these effects into the equations.

The r-process models produce initial abundance ratios for U-235/U-238 of 1.35 ± 0.14 and for Th-232/U-238 of 1.58 ± 0.15, where the errors are the standard deviations based on the eight different models reported by Pfeiffer, Kratz, and Thielemann (1997). Thus, according to these models, slightly more U-235 is initially produced than U-238, and after 12 billion years, radioactive decay will have reduced the abundance ratio of U-235/U-238 considerably. Since the half-life of U-235 is 7.04×10^8 years, and of U-238 is 4.47×10^9 years, calculations show that the present-day U-235/U-238 ratio in these UMP stars should be about 6.4×10^{-3}%. Hence, it will be interesting to see if some future measurements will be able to determine U-235 abundances in these stars. On earth the ratio is 0.72%. Since the evolutionary model has more recent r-process material contributing to the solar material, this does not necessarily disprove the stellar evolution scenario. But it does not prove it either.

Accelerated nuclear decay, if it occurred uniformly throughout the galaxy, would of course destroy the validity of these methods of calculation. It would also change rates of nuclear processes in the cores of stars. Hence, although we may reject the evolutionary assumptions for stars, it is a field of future research to determine exactly which assumptions we reject or accept in a young-earth model.

With these data in mind, we now turn again to the subject of how accelerated decay could occur. In Chaffin (2000a), a sketch of a mechanism was presented. We now attempt to provide some possible further details for the sketch.

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 is defined to be smooth, or 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; Pontryagin, 1999). For example, the surface of a sphere is a two-dimensional manifold, which mathe-

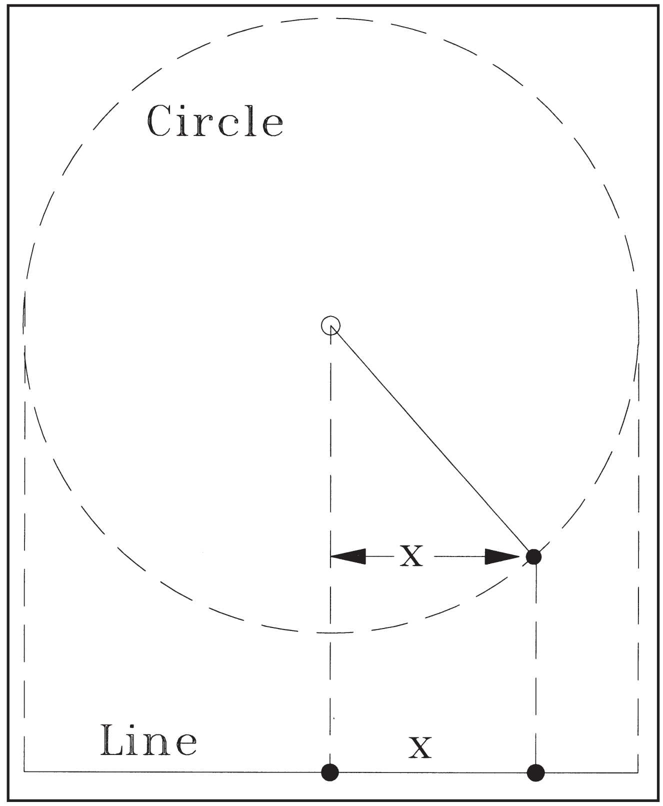

Figure 4. The position of a pendulum bob, confined to move in a single vertical plane, can be completely specified by a single linear coordinate x, provided the pendulum does not swing over the support's level. If the pendulum is free to swing higher than the support, then the circular topology is needed to specify the position. (Figure drawn after Rourke and Stewart, 1986).

maticians 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 4). 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 1890's up to his death in 1912. Poincaré analyzed different surfaces by thinking in terms of 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 5 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.

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 6). 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, and Polchinsky, 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 which gives 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), it was speculated that, contrary to previous thought (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 (Nath and Yamaguchi, 1999).

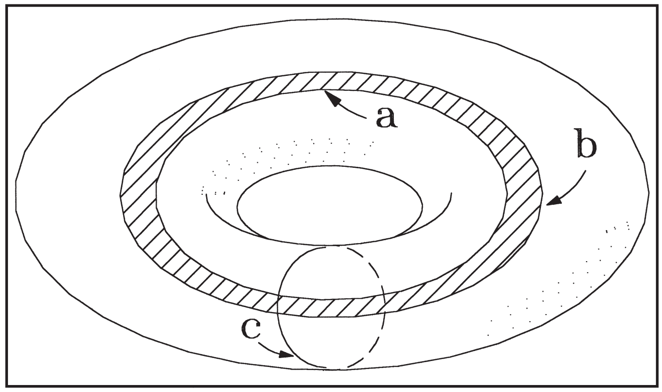

Figure 5. Three closed curves on the surface of a doughnut (torus) illustrate inequivalent and equivalent closed paths. Curves a and b, which bound the hatched area, can be smoothly distorted into each other, whereas curve c winds around a different direction and cannot be distorted into a or b, without cutting and pasting the ends (Figure drawn after Eguchi, Gilkey and Hanson, 1980).

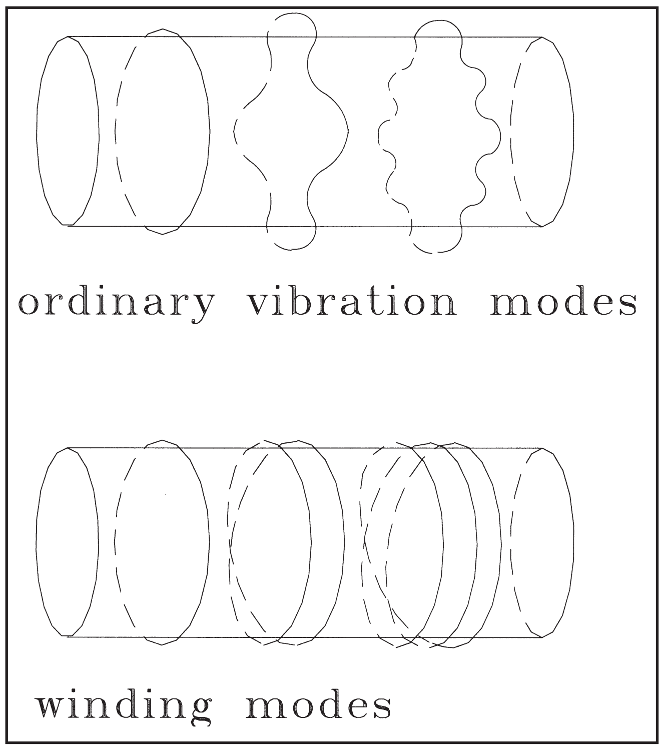

Figure 6. The ordinary vibration modes of closed strings (above) and the winding modes (below). In the equations of string theory, these two modes carry energy, and exchange roles when the radius of the compactified dimension moves from small to large.

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 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 SO(N+1), the group of rotations, contiguous to the "leave-it-alone" or identity rotation, in N+1 dimensional space.[1] This gave the result for the SO(N+1) coupling constant:

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

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.

Weinberg also considered an example having the symmetry SU(3), the group of all unitary 3x3 matrices with determinant plus one. In this example there are two different possible values for coupling constants g and g',

$$g = \frac{\sqrt{2}\kappa}{R}$$

and

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

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 and 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 and 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 $(\text{separation})^{-4/3}$; i.e. much more slowly than the Casimir pressure.

Candelas and Weinberg (1984), and before them Rubin and 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

[1]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.

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 are 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).

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 $p = nh/(2\pi R)$, $n = 0, 1, 2, 3, \ldots$, 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, and 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 and 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 1800's. 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)xSU(2)xU(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 (Georgi and Glashow, 1974; Georgi, Quinn, and 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 a 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, 1989). 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, 1989, 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:

$$m = m_0 + \frac{4}{15}\frac{\mu_0 e^2}{a} \tag{3}$$

where e is the charge, a is the radius of the sphere, and μ_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 (Georgi, 1989, p. 434; Bjorken and Drell, 1964, section 8.2). 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 10^{29} 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 and Tye (1998) discussed the possible suppression of proton decay by an additional symmetry, while Dienes, Dudas, and Gherghetta (1998) 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 and 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

Humphreys (2000) provided a model for accelerated beta decay. However, his approach involved different assumptions than will be addressed here. Nath and 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 and 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 $G^{eff}{}_F$ is given by

$$G_F^{eff} \cong G_F^{SM}\left(1 + \frac{\pi^2}{3}\frac{M_W^2}{M_R^2}\right) \tag{4}$$

Here, $G_F{}^{SM}$ is the value of the Fermi constant which may be calculated from the standard model of quantum field theory (Nath and Yamaguchi, 1999, comment that the standard model agrees very well with experiment), which does not involve any assumptions about extra dimensions. For the case of more than one extra dimension, Nath and 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 and Stuart, 1999), Nath and 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 2005 or so, evidence for these extra dimensions may be found (see Kane, 2000, for a semi-fictitious account of expectations).

Now, because we are interested in the possiblity of accelerated decay in the early universe, we need to take the discussion a step further than Nath and 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

We have seen that 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.

I have also discussed the explanation of uranium and plutonium-244 abundances using accelerated decay, and given explicit equations for the determination of 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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Book Review

Origins: Linking Science and Scripture by Ariel A. Roth
Review and Herald Publishing Association, Hagerstown, MD. 1998, 384 pages, $29.99

This is an impressive book for its depth of scholarship, its clarity of expression, and its perceptive analysis of the current principal theories of origins: young-earth creation and old-earth evolution. The writer is respectful of the claims of evolution, but he shows through careful analysis and many literature references how far short these claims fall in agreement with the evidence. In contrast, the same evidence from biology and geology is shown to be eminently compatible with the concept of an earth filled with life by God some thousands of years ago.

Dr. Roth opens the discussion with a section entitled "The Questions" giving some historical background on the origins controversy. A chapter called "Fashions in Thinking" describes various paradigms which have been dominant in the past, only to go out of fashion when prevailing opinion changed. Paradigms come and go, and may be true of false.

> As we search for truth, we can avoid letting ourselves be trapped by erroneous paradigms by practicing both independent thought and thorough investigation. We must always base our conclusions only on the firmest data (p.44).

Succeeding sections of the book include "Living Organisms" which is a detailed description of the biosphere and theories of its origin; "The Fossils," a study which essentially falsifies the theory of evolution; and "The Rocks," in which evidence indicates that sedimentary rocks were deposited rapidly by flood waters rather than slowly over eons of time.

One section is entitled "An Evaluation of Science and Scripture" in which the author points out that science deals with only part of reality. Naturalistic science can tell us nothing of morality, freedom of choice, consciousness, or purpose. "There exists a vast realm beyond the simple cause-and-effect explanations of science" (p. 286). Likewise the investigation of historical events is largely outside the purview of science since these are non-repeatable, in contrast to experiments in physics or chemistry.

A chapter entitled "Scripture: Something Unusual" deals with authentication of the Bible. Evidences includes independent historical records, archaeological discoveries, the prevalence of flood stories among all peoples, and the remarkable fulfillment of prophecies centuries after they were first written. A further chapter discusses some questions on scripture interpretation, and a final chapter is entitled "Is Science in Trouble?" Here Dr. Roth quotes the philosopher Malcolm Muggeridge, who stated: "It is time to try to reestablish an equilibrium between science and spirituality, allowing mankind to find again a place in the universe" (Note 32). Dr. Roth goes on to say,

> The problem is not just evolution. In a sense, evolution is only an important symptom of a more deep-seated issue. The real difficulty is more whether naturalistic science is going to persist in trying to provide answers to all questions within its own closed system of explanations. How did science get into this intellectual straitjacket? Science made its greatest error when it rejected God and everything else except mechanistic explanations… Science would not now be facing apparently insurmountable challenges to evolution if it had not adopted such a strong exclusive, naturalistic stance. Concepts of the creation life would still offer a possible explanation as they did for the pioneers of modern science (p. 334).

As a comprehensive and extremely well-researched book, this volume should be attractive to anyone interested in the subject of origins. It would be especially suitable as a textbook for high schools and colleges where the evidence for creation and criticism of evolution are allowed to be taught. The book includes numerous illustrations, a glossary of technical terms, and an index.

Carol Armstrong
(deceased)