Could Magnetic Monopoles Cause Accelerated Decay?

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Abstract

We study the effect of superheavy magnetic monopoles on nuclei such as Aluminum-26 and Potassium-40, to see if the rate of beta decay is enhanced by the nearby passage of a magnetic monopole. Following an idea of Carrigan (1980a, 1980b), we consider the possibility that monopoles are trapped in the earth's interior by a balance between gravitational and magnetic forces from the earth's fields. Magnetic reversals such as those considered by Humphreys sent the monopoles to the surface during the Genesis Flood, causing nuclear decay rates to seem to accelerate. We use theory developed by Lipkin in the 1980s to treat the theory of perturbation of the decay rates by the monopoles. We show that the monopole velocities attained during a field reversal are sufficient for them to escape during the Flood, but not large enough to produce tracks in rocks and minerals similar to fission tracks.

Introduction

Any amateur scientist who has studied magnets has noticed that a bar magnet has two opposite poles that cannot be separated. In particle physics, theory says that particles made of a single north pole or a single south pole may exist in isolation (Figure 1), and these hypothetical particles are called *magnetic monopoles*, or *monopoles* for short.

Magnetic monopoles are associated with magnetic field lines. A magnetic monopole is either a south or a north pole. The field lines of these monopoles are affected by the magnetic charge that a north or south monopole may have. A south magnetic monopole has an isolated negative magnetic charge, which causes the magnetic field lines to converge toward the

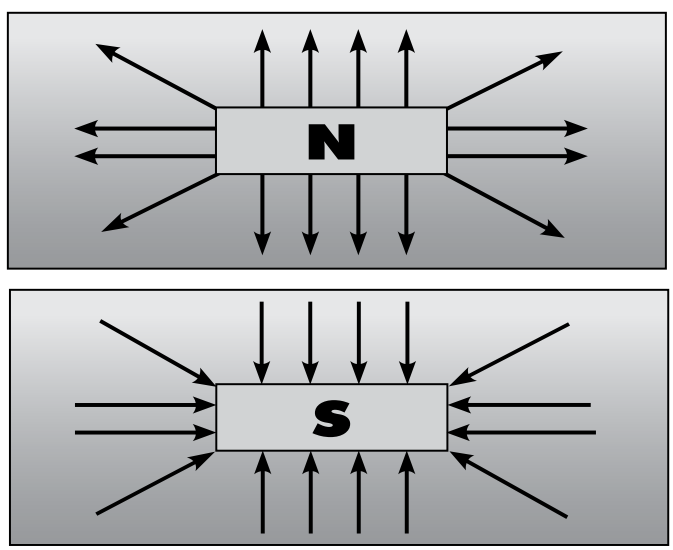

Figure 1. (a) North magnetic monopole containing a positive magnetic charge causes magnetic field lines to radiate away from the pole.

(b) South magnetic monopole containing a negative magnetic charge causes magnetic field lines to radiate toward the pole.

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pole. A north magnetic monopole has an isolated positive charge, which causes the magnetic field lines to radiate away from the pole. Since magnetic monopoles have a strong charge, they will cause ionization of surrounding atoms. The strong magnetic charges that these monopoles carry may also instigate a huge disturbance to the nuclei of atoms as the monopoles pass nearby and affect nuclear decay. The magnetic field lines of monopoles may cause the nucleus to be excited to higher energy levels, may trigger the angular momentum of the nucleus to change, and may generate a faster nuclear decay process.

In modern physics, the concept of a magnetic monopole was considered by Dirac (1931), who concluded that the magnetic charge had to be quantized in order to be consistent with quantum theory. There have been numerous experimental attempts to detect magnetic monopoles coming from space or to detect the tracks they may have left in rocks (Alvarez, 1975; Cabrera, 1982; Fleischer et al., 1969; Fleischer, Price, and Woods, 1969; Fleischer and Walker, 1975; Kolm et al., 1971; Malkus, 1951; Price et al., 1975; Price and Salamon, 1986; Ross, 1976; Ullman, 1981). Kolm et al. (1971) showed an emulsion track 1875 microns long with suspicious characteristics. The maximum length of fission tracks, tracks produced by the fission fragments coming from fission of uranium, is about 16 microns in the minerals, such as mica and obsidian (Fleischer et al., 1969). Price et al. (1975) reported monopole detection in a balloon-borne detector, but the claim was later withdrawn. Cabrera (1982) reported the detection of a single monopole in a superconducting loop detector, but this failed to be confirmed by other experiments.

In the 1970s, the prospects for magnetic-monopole hunters suddenly improved. Theoretical treatments appeared, giving monopole solutions without the singularities in Dirac's mathematical treatment. Working independently, Gerard 't Hooft of the University of Utrecht in the Netherlands and Alexander M. Polyakov of the Landau Institute for Theoretical Physics near Moscow found certain theories that not only allow magnetic monopoles but also demand them.

Further work by other particle theorists led to so-called grand unified theories combining electromagnetic, weak, and strong nuclear forces. These theories predict the existence of magnetic monopoles, although their mass-energy is of the order of 10^{11} GeV (Rubakov, 1981a, 1981b; Preskill, 1979, 1984; Carrigan and Trower, 1982). This is a large value, beyond the capabilities of present-day accelerators.

Experiments at Fermilab (Abbott et al., 1998) have ruled out monopoles with mass-energies less than 600 GeV. The Large Hadron Collider (LHC) is now operational, but the mass of the monopoles predicted by the grand unified theories is so large that there is not much hope that a monopole will be detected. Interestingly, the interaction of a magnetic monopole with a magnetic field is much more robust than the interaction of an electric charge with an electric field. In the early 1980s, Carrigan and Trower (1982) were able to write: "A magnetic monopole traversing a superconducting coil one meter long would gain more energy than a proton acquires in the largest particle accelerator ever built." The largest accelerator of 1982 was the FermiLab accelerator before its upgrade to the present 1 TeV capability. The beam energy then was about 200 GeV. Superconducting magnets made with current technology can produce magnetic fields with a strength in the tens of Teslas range (1 Tesla = 10^4 gauss). The LHC particle accelerator employs niobium-titanium (Nb-Ti) magnets operating at 1.9 K, which allows them to run safely at 8.3 Teslas. Calculation shows that a 10 Tesla (100,000 gauss) superconducting magnet would accelerate a monopole to a kinetic energy of 200 GeV.

If the superheavy monopoles predicted by theory exist, where would they be found? Parker (1970) noted that if free monopoles exist in space, they would be accelerated to very high energies by the magnetic fields. He established what is now known as the *Parker bound* on the abundance of free monopoles in space. Too many monopoles would absorb too much energy from the interstellar and intergalactic magnetic fields, causing these magnetic fields to disappear. If the galactic magnetic field is not dissipated or distorted, then the monopoles cannot be present at a density of more than one per 10^{21} cm^3. Thus, the Parker bound placed severe limits on the flux of magnetic monopoles that would be able to impinge upon the earth.

Carrigan (1980a, 1980b) proposed that gravity can become an important consideration in the fate of monopoles and that monopoles could be trapped inside the earth's core. Energetic monopoles would slow down by causing ionization trails as they pass through the earth and would concentrate at a radius inside the earth's core, where magnetic forces on the monopoles would be cancelled by the gravitational attraction. In section 2, we will present our calculations of the radius inside the earth at which this would occur.

Lipkin (1983, 1984) examined whether monopoles passing near to a nucleus could induce a beta decay to occur. Ordinary beta decays are thought to be spontaneous, but in the high magnetic field produced by the monopole, the decay rate is accelerated. Lipkin (1949) and Merzbacher (1951) showed that high-energy photons could not accelerate decays to any appreciable extent. However, the theory allows monopoles to succeed where other candidate particles do not.

Quantum theory gives certain selection rules, the rules for changes in spin and parity that must be obeyed if a transition between two energy levels is to have a large probability. However, these selection rules are generally not obeyed in the decays employed in radioisotope dating techniques. For such techniques, nuclei with a large half-life are needed; hence the so-called forbidden transitions are normally of importance in such cases. When a monopole approaches a nucleus, it can lead to a way to bypass the normal routes for the transitions involved. The monopole induces the nucleus to transition to an excited state with a different spin and parity than the ground state, which then has a larger probability of beta decay. Lipkin presented calculations for the deuteron and for the Al-26 nucleus. If the monopole passed within a few femtometers (1 femtometer = 1 fermi $=10^{-15}$ meters), the decay was accelerated. We have applied Lipkin's method for the decay of K-40, the nucleus used in potassium-argon dating. We discuss these calculations in section 3.

The Interaction of Monopoles with the Earth's Magnetic Field

Carrigan (1980a, 1980b) proposed that the monopoles could be trapped inside the earth's core at a radius of $R = 0.18R_E$, where R_E is the radius of the earth (Figure 2). At this radius, the inward gravitational force on a superheavy monopole of mass 0.06 micrograms (corresponding to a mass-energy of 10^{16} GeV) would equal the outward magnetic force. Carrigan did not give the model he assumed for the magnetic field inside the earth. We have repeated the calculation using the magnetic field equation in the model of Barnes (1973), yielding $R = 0.02R_E$. Energetic monopoles would slow down by causing ionization trails as they pass through the earth and become thermalized. By "thermalized," we mean that they have the same average kinetic energy as the atoms of the surroundings. Once thermalized they would drift slowly toward this point where the gravitational force would cancel the magnetic force (Carrigan, 1980a).

By solving Maxwell's equations for a model in which the earth has a conducting, spherical core, and matching the interior solutions to the exterior solutions at the boundary between core and mantle, Barnes (1973) obtained the following equation for the radial equation for the magnetic field inside the core:

$$B_r = \frac{\pi^2 \left(\frac{R_E}{R_C}\right)^3 B_0}{\left(\frac{\pi r}{R_C}\right)^2} \left(\frac{\sin\left(\frac{\pi r}{R_C}\right)}{\frac{\pi r}{R_C}} - \cos\left(\frac{\pi r}{R_C}\right) \right) \cos(\theta) \tag{1}$$

Here B_0 is the earth's magnetic field at the pole and the equation is valid only inside the core. The angle θ is the spherical coordinate angle between the z-axis and the line to the field point. Outside the core, one has:

$$B_r = \frac{B_0 R_E^3 \cos(\theta)}{r^3} \tag{2}$$

Using Carrigan's value for the mass of the monopoles, we find that the gravitational force balances the magnetic force at a radius $r = 0.02\ R_E$, which is inside the earth's inner core.

In the Humphreys (1987, 1988) scenario for magnetic field reversals, rapid field reversals take place during the Genesis Flood. During such field reversals, the predominate component of the earth's magnetic field is no longer the dipole component (Humphreys, 2002), and the chaotic behavior of the field lines during reversals has been established by the computer simulations of Glatzmaier (Ladbury, 1996; Olson et al., 1999; Glatzmaier and Roberts, 1995a, 1995b). Thus, during the rapid field reversals, the monopoles would no longer be confined inside the core, and could be expected to escape to larger radii and to impinge upon radioactive nuclei contained in surface rocks.

In the Glatzmaier simulations, the magnetic field inside the earth's core can be as large as 560 gauss (Glatzmaier and Roberts, 1995b). This would move the point where the magnetic monopoles concentrate from the $0.02R_E$ radius outward to a point closer to Carrigan's $0.18R_E$ value. During a reversal, the monopoles could be launched outward by the chaotic behavior of the magnetic field lines, causing the monopoles to interact with nuclei inside the crustal rocks. In the next section we will examine the effect that the monopoles would have on some radioisotopes, and hence on radioisotope dating.

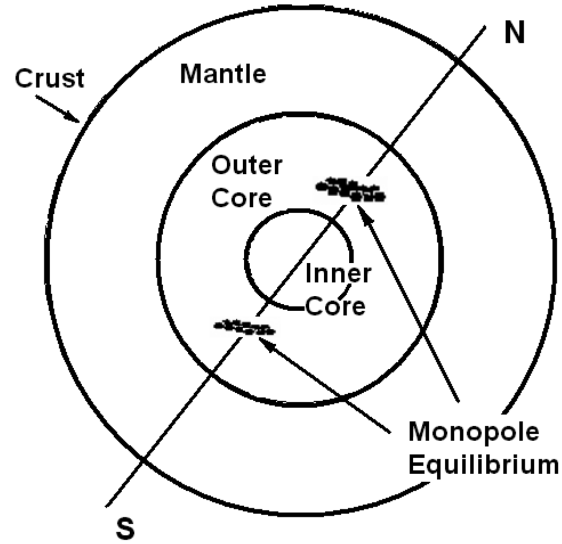

Figure 2. The earth's interior showing the inner and outer cores, and the mantle, with the equilibrium point for the magnetic monopoles.

Calculation of the Effect of a Monopole on Beta-Decay

The dating of radioisotopes relies heavily on beta decay and/ or alpha decay. Beta-minus decay is a process whereby a neutron turns into a proton and emits an electron and an antineutrino (Figure 3). The process whereby a nucleus undergoes beta decay has to do with the quarks that make up a proton and a neutron. Modern studies show beta decay occurs when a quark changes flavor from down to up. The W^- particle is the particle that decays into an electron and an antineutrino. Allowed and forbidden decay are involved in radioisotope dating (Chaffin, 2005). An allowed decay is one in which the parity change is zero and the spherical symmetry is conserved. Forbidden decay occurs when isotopes violate several factors, such as change in parity and spherical symmetry, or the angular momentum changes by more than one quantum number. Nuclear beta decay transitions of isotopes proceed at rates that depend on the squares of quantities known as *matrix elements*. These *matrix elements* are usually derived from perturbation theory, which is used to find solutions to complicated quantum systems. Perturbation theory is very useful for comparing or mixing different types of systems. Lipkin used perturbation theory for explaining the mixing of nuclear wave functions by a super-heavy monopole with a strong magnetic field as it approaches the nucleus of an atom (Lipkin, 1983, 1984). He predicted that the closer a monopole approaches the nucleus, the faster the nucleus would decay. He first explained his theoretical approach by using the parameters and properties of a deuteron, which is a simple nucleus containing a proton and a neutron. The proton and neutron that make up the nuclei of a deuteron were involved in solving the electric and magnetic matrix elements for the transitions. Lipkin also considered the effect of a magnetic monopole passing near an Aluminum-26 nucleus. Aluminum-26 is of interest in studies of the solar system, where evidence of extinct radioactivity due to the Al-26 exists (Lee et al., 1976). The estimates of beta-decay matrix elements needed for Lipkin's calculation were obtained with nuclear wave functions by a method known as the "shell model method," along with experimental data of the values of magnetic moments. These experimental values were taken from ^{25}Al and ^{25}Mg, thus providing input data to give accurate calculations within Lipkin's theoretical treatment. The experimental values included the magnetic moments, which Lipkin used as follows:

$^{25}Mg = -0.9$ and $^{25}Al = 3.6$ nuclear magnetons (Lipkin, 1983).

The shell method usually incorporates shells denoted as: s, p, d, and f (Figure 4), corresponding to different orbital

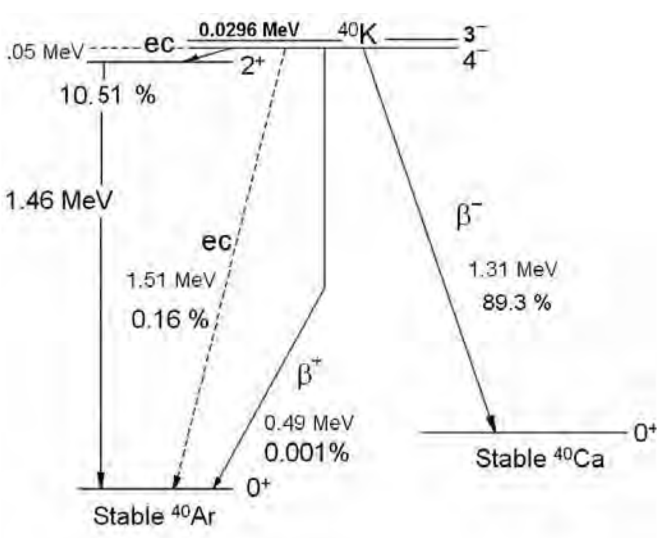

Figure 3. Decay scheme of ^{40}K, showing the electron capture (ec), beta-minus (β^-), and beta-plus (β^+) branches.

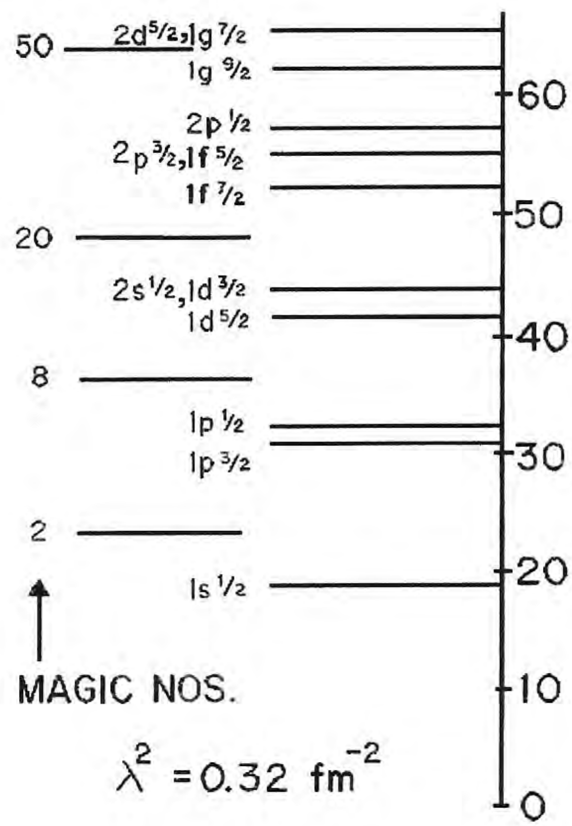

Figure 4. Energy levels according to the nuclear shell model, showing the s, p, d, f orbital angular momentum designations as well as the half-integral total angular momentum of the level. The scale at the right gives the energy in MeV, and the closed shell occupation numbers (magic numbers) are shown at the left.

angular momenta quantum numbers. These shells help to describe the single-particle states a proton or neutron will occupy. Lipkin also focused on using the nuclear properties of ^{26}Al. The spin states of ^{26}Al were predicted from an unpaired or missing neutron and an unpaired or missing proton both in the "d" 5/2 shell, where 5/2 is the spin of the single-particle state of the last particle outside the shell. The beta-plus decay of ^{26}Al to ^{26}Mg involved transitions that could be accelerated by a monopole, if the monopole caused the Al-26 to first transition to excited states. These magnetic effects caused by the monopole thus yield a shorter lifetime for ^{26}Al. Lipkin used "log ft" values to predict how close a monopole would have to be in order to cause this accelerated decay. Lipkin's final results were expressed in terms of the equations:

$$\log ft(5^+ - 0^+) = 7.4 + 16 \log r \tag{3a}$$

$$\log ft(\,^+5 - 2^+) = 6.8 + 8 \log r \tag{3b}$$

where r is the distance of the monopole from the nuclear center in fermis (Lipkin, 1983).

These results were compared with the normal or undisturbed log ft value of 14.2 in order to obtain the amount of acceleration of the decay (Lipkin, 1983). Lipkin's method of explaining how close a monopole must be to a nucleus is the same method we used for determining whether or not our isotope would experience accelerated decay. As Lipkin proposed, we also imagine a fixed distance that a monopole has to be within near the nucleus in order to allow an accelerated decay. Since we are exciting the nucleus with a monopole moving with respect to time, we used time-dependent perturbation theory. Radioisotope dating is one of the main methods used in dating how old certain rocks are. Different isotopes that have significant configurations will yield acceptable dates of rocks. Potassium-40 (^{40}K) is an isotope used commonly in radioisotope dating. We chose to examine Potassium-40 as our isotope for study. This isotope has two main branches of decay. Potassium-40 can undergo beta-minus decay to produce Calcium-40 or ^{40}K can undergo electron capture, which produces Argon-40. Nuclear isotopic stability is related to two factors. When both the atomic mass and the atomic number are even integers, there is more likelihood of stability. When the nuclear spin changes by zero or plus or minus one and the parity does not change, the beta decay is said to be an allowed decay. Since potassium in general has only nineteen protons and twenty-one neutrons, special shell model procedures must be taken into consideration. In the nuclear shell model, the designations s, p, d, f, g, and h represent different shells that the protons and neutrons can go into. Once a shell contains the maximum number of neutrons (or protons), we call the shell a "closed shell." In our case we needed to balance our atomic mass and atomic number in order to get a stable isotope. For the shell model configuration we find that we have one hole in the proton $d_{3/2}$ shell and one neutron into the neutron $f_{7/2}$ shell. These neutron and proton configurations were used to find the lowest and highest spin states that Potassium-40 could attain. The following algebra for our spin states, where J represents spin state, was used to find the lowest and highest spin states: $J = J_1 + J_2 = |3/2 - 7/2|, \ldots\ldots, 3/2 + 7/2 = 2, 3, 4, 5$. These possible spin states are considered in order to calculate the fixed distance that a monopole must be within in order to cause accelerated decay. For low-lying energy levels of K-40, the outer or valence protons and neutrons occupy the $d_{3/2}$ shell and the $f_{7/2}$ shell, respectively. We must add the total wave function of our proton hole and neutron in order to get the total angular momentum that is needed to explain the existing energy levels. The "4" spin state for ^{40}K is the ground state, thus we only needed the angular momenta that could explain the energy levels from the 2^- - 3^- states. Figure 5 shows the low-lying energy levels of K-40. The coefficients used for adding the total angular momentum for two wave functions were called "Clebsch-Gordon coefficients." These coefficients, often given in tables in reference works for quantum-mechanical calculations, are the numbers needed to combine two wave functions of definite angular momentum to give an overall wave function of a given total angular momentum, J and angular momentum projection M.

To calculate the probability of the monopole causing the nucleus to decay, we use time dependent perturbation theory (see Griffiths, 2005, Chapter 9). The main effort involves finding a so-called "matrix element" of the monopole perturbation operator between two states, the ground state and the intermediate state that the monopole excites the nucleus to before it undergoes beta decay to an energy level of the daughter nucleus

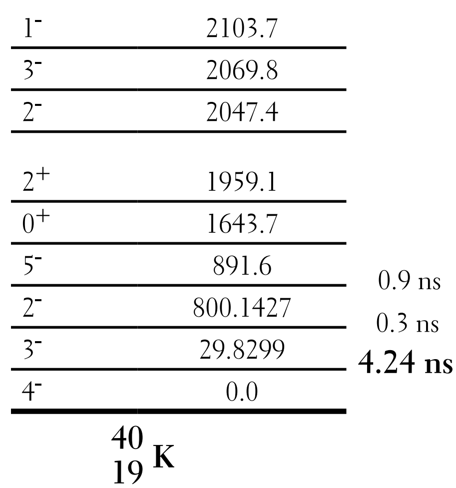

Figure 5. Low-lying levels of K-40, showing spins and parity, energies in keV, and lifetimes in nanoseconds.

Argon-40. We find the largest contribution to the transition probability comes from the 4^- ground state being excited to the low-lying 3^- and 2^- intermediate states.

The Clebsch-Gordon coefficients for combining the proton-hole 3/2 states with the outer neutron's 7/2 states become part of the following expressions for finding the matrix elements for the $<4^- \rightarrow 2^->$ and $<4^- \rightarrow 3^->$ transitions:

$$\sum_{m_1 m_2} C^{3/2\ 7/2\ 2}_{m_1\ m_2\ M}\ C^{3/2\ 7/2\ 4}_{m_1\ m_2\ M'}\ (m_1 - m_2)^2 \tag{4a}$$

$$\sum_{m_1 m_2} C^{3/2\ 7/2\ 3}_{m_1\ m_2\ M}\ C^{3/2\ 7/2\ 4}_{m_1\ m_2\ M'}\ (m_1 - m_2) \tag{4b}$$

For these two quantities, we were able to calculate the values 5.714 and 1.914.

These values were substituted into the standard perturbation theory equations to get the "log ft" value, for an assumed distance of closest approach of the monopole. In order to determine our log ft, we needed the most recent, and the best experimental value of log ft of ^{40}K, which is 11.55. By using this value, we were able to predict whether the $<4^- \rightarrow 2^->$ and $<4^- \rightarrow 3^->$ transitions yielded the most effect on the transition rate. By using the experimental value of the log ft (11.55, see National Nuclear Data Center web site, http://www.nndc.bnl.gov/chart/), we obtained the following distances:

The transition $<4^- \rightarrow 2^->$ gives an appreciably enhanced transition rate when the monopole approaches within r = 0.61 to 1.5 fermis.

The transition $<4^- \rightarrow 3^->$ gives an appreciably enhanced transition rate, but the monopole must approach closer, to within r = 0.1 to 0.6 fermis.

Thus the $<4^- \rightarrow 2^->$ transition had the largest effect, and we may use it to obtain the order of magnitude of the monopole's effect of the K-40 nuclear decay.

Wechsung, Strassheim, and Bass (1971, p. 567) calculated wave functions for the low-lying odd-parity states of K-40, using nuclear shell model techniques involving mixing of different orbital configurations in the single-particle wavefunctions. The ground state of the K-40 nucleus is predominately the $(d_{3/2})^{-1}(f_{7/2})^1$ configuration, that is, one hole in the proton $d_{3/2}$ orbital and one neutron in the $f_{7/2}$ orbital (Gorringe, 2006; Dieperink et al., 1968; Klotz et al., 1972; Southon et al., 1976; Wakatsuki et al., 1970). Wechsung et al., (1971) included shell-model configurations where there was one neutron in the $1f_{7/2}$ orbital and one hole in the proton $1d_{3/2}$ orbital, as well as configurations where the neutron occupied the $2p_{3/2}$ orbital or the proton hole was in the $2s_{1/2}$ orbital. Their Table 5 gave the results of calculations of the coefficients of different configurations contributing to the wavefunctions of the low-lying states of K-40. In order to calculate the effect of the monopole exciting the K-40 nucleus to higher energy levels, we adopted the Wechsung et al (1971) wave functions for the spin and parity 3^- states and also calculated an extra 3^- state beyond the two they gave in their paper. This enabled us to estimate the contribution of these excited states to the transition to states of Ar-40 by beta-plus and electron capture. We find by direct calculations that the excited states of K-40 higher than the ones already included contribute very little to the transition probability, due to the fact that conflicting configurations begin to dominate the wavefunctions as the excitation energy increases.

Discussion

In a FermiLab preprint, Carrigan (1980b) wrote:

> For a monopole in thermal equilibrium with the liquid core at a temperature of 4000°K, the monopole thermal velocity is on the order of 10^{-2} cm/sec. Likewise the average mass drift velocity in the core is on the same order. On the other hand if an axial field of 100 gauss is present the characteristic monopole velocity might be 10^5 cm/sec based on extrapolating the Ahlen energy loss formula to low beta values. With the complex coiled field geometry fully on, monopoles would move to equilibrium positions probably near the surface of the solid core or the inner surface of the mantle in about one year.

We have checked Carrigan's statement using the energy loss formula of Lindhard quoted in Ahlen and Kinoshita (1982), and we also find a velocity of approximately 10^5 cm/s for a monopole in the core, which loses energy by ionization at the same rate at which it gains energy by acceleration in a 100-gauss magnetic field. For this order of magnitude of monopole speed, the monopoles could reach the earth's crust well inside the time frame of a yearlong, worldwide flood. Hence, magnetic reversals during the Flood seem to be capable of causing the monopoles to pass near and thereby to influence crustal rocks in accord with our general scenario.

Are the monopoles energetic enough to produce tracks in rocks and minerals similar to those left by fission fragments? If they are, then our paradigm would be falsified by the fact that such tracks are not found in Earth rocks. However, Price and Salamon (1986, p. 1226), in discussing the stopping power S_n for monopoles by elastic collisions with nuclei and the stopping power S_e for ionization and electronic excitation, wrote:

> At $v < 10^{-2}$ c most of the energy lost by a heavy ion goes into elastic collisions with nuclei, producing displaced atoms directly. This "nuclear" component of energy loss, S_n, has its peak value for ion velocities $\sim 10^{-3}$ c. For a bare monopole, S_n is far too small to form a track[4] and S_e is also too small except at velocities $v \sim c$.

Since our characteristic velocity of 10^5 centimeters per second is about 10^{-5} times the speed of light, c, these monopoles moving with this speed will not produce permanent tracks in rocks and minerals.

Our calculation discussed earlier indicates that a K-40 nucleus must approach within a radius of 1.5 fermis or 1.5×10^{-15} meters to be induced to transform to Ar-40, giving a cross section of $\pi r^2 = 7.069 \times 10^{-26}$ cm^2. If 50% of the K-40 atoms are to be passed by a monopole within the one year of the Flood, then this would indicate that the flux would have to be 2.242×10^{17} monopoles/(cm^2 s). This is a relatively large flux and indicates that a large number of monopoles would have to have been trapped inside the earth and brought to the surface by the field reversals during the Flood.

Conclusion

In conclusion, our research has not uncovered any reason why magnetic monopoles, released via magnetic field reversals of the earth during the Genesis Flood, could not have caused a significant amount of accelerated decay. Our study shows that magnetic monopoles can attain velocities in the right ranges to be able to escape the earth's interior during magnetic field reversals, but yet slow enough that they do not cause permanent tracks in rocks. They could provide an important mechanism for causing rocks that contain potassium-40 to undergo an accelerated decay. Our cross section and flux values show that numerous amounts of monopoles would have increased the accelerated decay of potassium-40. The small time factor for monopoles to reach the surface shows that they could contribute to accelerated decay during magnetic field reversals and thus during the Genesis Flood.

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