Particle Physics and Paley's Watch

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Abstract

This review of particle physics illustrates the energy-matter relationship in nature and describes the building blocks of the physical world. Particle physics research reveals that matter is far more complex than scientists imagined just decades ago. This poses a major challenge to naturalistic interpretations of the origin, existence, and maintenance of the universe. Various theories have been developed to account for the living world, including natural selection and genetic drift, but these mechanisms are not applicable to the inorganic world revealed by particle physics. The failure of naturalism to explain the universe has resulted in a revival of Paley's watch hypothesis. It has also resulted in new attempts by philosophical naturalists to deal with these discoveries. This includes the blind watchmaker hypothesis, an attempt to show how a universe that looks like it was created by intelligence actually came into being spontaneously. However, evidence shows that the universe, and especially the earth, was clearly designed to support human life.

Introduction

The *teleological* argument, often called the argument from design, has always been a major evidence for the Creator's existence. The best known illustration of teleology is Paley's watch analogy, first introduced in his *Natural Theology* in 1802. If a traveler finds a watch beside a path, its specific complexity will convince him that it has an intelligent maker. This analogy has traditionally been used to argue for theism in the biological world, and now is used to argue for theism in the atomic world as well (DeYoung, 1985).

A century ago it was thought that atoms were simple, small, and homogeneous masses of uniform shape, or perhaps a specific set of definite shapes. The last century of research on submicroscopic matter has revealed a new and far more complex watch-like atomic and subatomic structure than anyone earlier imagined, especially in the realm of elementary particles. These research findings eloquently support the Paley's watch hypothesis (see Barrow and Tipler, 1986).

The implications for theology of the level of complexity in the subatomic world has long been recognized by many leading scientists such as Arthur H. Compton:

> Who is there who has not asked himself, 'What is this world around me?' Rocks, trees, people—what are the parts of which they are made, and how are these parts put together? ... When we take apart this infinitely complex mechanism which we call dirt, or perhaps a diamond, or it may be a flower, we find it made up of a myriad of tiny molecules. Each of these molecules is itself complex but is more perfectly formed than the wheels of a watch, and has continued to run . . . without winding and without wear. We find that the molecules which make up matter in all its endless variety of forms are themselves built up of a few hundred kinds of atoms (Compton, 1929, p.110).

Physics research has discovered a whole new world consisting of many elementary particles, but scientists are still unable to explain *why* these particles exist and exactly how they work to produce the world at the macro-molecular level.

A person can take apart a watch to study its intricate movements, can graph its motions and formulate laws that describe the relationships of the hundreds of parts observed, and still not understand *its origin* at the most basic level. Likewise, scientists have observed, measured, charted, analyzed, and graphed the atomic and subatomic world but still do not understand how it works at the most fundamental level nor can they explain its origin.

Attempts have been made to use mutations and natural selection as an explanation for the origin of complexity in the living world. Conversely, analogies to mutations and natural selection—most commonly the "many universes hypothesis"—have failed to explain the order, complexity,

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and design existing in the submicroscopic world researched by particle physics. Electrons, protons, neutrons, and smaller particles undergo rearrangement due to both external and internal forces, but because they do not reproduce or mutate as do genes, evolution by natural selection is not involved in their creation (Lahav, 1999). These particles have maintained their physical properties since the Creation. Like a watch, atomic particles produce an intricate mechanical system which enables life to exist. The most that researchers achieve is a description of the submicroscopic world and a mathematical analysis of it.

Research has produced an enormous body of knowledge that helps scientists to formulate laws and delineate patterns and relationships, but comparatively little understanding exists of the *why* of that which is discovered (Feynman, 1985). Physical laws only summarize what we observe, they do not explain it. Many phenomenon happen in a lawful, probabilistic way, but without a known reason or identifiable cause. The complexity of the building blocks of matter is such that even the long-established law of causality has been questioned by some. Of course, because the cause of something is unknown does not prove that a cause does not exist, only that we have not yet identified it.

The law of gravity is a good example. Scientists can accurately describe gravity but they cannot adequately *explain* how gravity "works." The four fundamental forces—gravity, electromagnetic, and the strong and weak nuclear forces—are "fundamental" because "they cannot be accounted for in terms of anything else" (Beiser, 1992). Scientists do not know their cause. The original goal of particle physics was to discover the most basic building blocks of the universe by breaking matter into smaller and smaller pieces, eventually arriving at the smallest units possible. However, the results have produced so much data that most particle physicists spend the majority of their time attempting to make sense of the findings.

The Structure of the Atom

The atom was once believed to be a unit of indivisible mass as the word ατομοσ (Greek for *cannot cut*) implies. Then when the atom was discovered to contain inner "parts" that were emitted during radioactive decay, it was viewed as a container with its parts somewhat randomly joined together. Researchers have now revealed the atom to be an incredibly intricate mechanical structure (see Cox, 1989). Even minor changes in this structure can radically modify the properties of the atomic unit called an element. The formation of isotopes, isomers, and ions are excellent examples. The precision of the total structure, including its mass and energy, is extremely critical. Yet within this precision exists a measure of adaptive ability, a trait that is also common to living things. One basic example of this plasticity, yielding, or adaptivity ability, is covalent bonding between many kinds of atoms.

Probability is a major design feature of the universe because it can be used to ensure that a system works. The atom's behavior is fully predictable not because electrons are in a specific place at a specific time as required of a watch, but because given a large number of atoms, enough electrons will be within a certain region to guarantee the system works. Precision follows from probability because only a high probability is required for the system to work properly. The total unit functions only because the atom's workings as a *whole* are precise.

As watch parts must be machined within certain tolerances to function properly in the assembled unit, in like manner the subatomic particles' characteristics must be within certain narrow tolerances. The mass of each electron is 9.1094×10^{-31} kg and does not measurably deviate from this value. As far as we are able to determine, every particular subatomic particle is identical, i.e., every proton is perfectly identical to every other proton and every atom is identical to every other one of that isotope. Although *The Handbook of Chemistry and Physics* provides ranges for the characteristics of subatomic particles, these are *measurement errors* and not tolerances of the particles themselves. All subatomic particles are clearly identical to an incredible degree, manifesting clear evidence of unity.

Subatomic particles are not only identical but also carefully selected for their purpose. One example of this precision is the mass of the proton. If the proton mass was *slightly* greater or less, the universe as we know it could not exist (Fritzsch, 1983; DeYoung, 1985). The proton's mass must be slightly less than the neutron's mass. If proton mass was larger by just 0.2 percent, it would be unstable, rapidly decaying into a neutron, a positron, and a neutrino:

$$p \rightarrow n + e^{+} + \nu$$

All hydrogen nuclei (which consist of a single proton) then would decay within minutes. Furthermore, hydrogen is a major component of our bodies, as well as water molecules, the sun, and all the other stars. Hydrogen is, after all, the dominant element in the universe. Therefore the proton's mass has been wisely chosen to prevent the collapse of the entire universe. Likewise, if the properties of the other stable particles were slightly altered, the biomolecules of life could not exist.

The atom's nucleus and the electrons revolving around it form a definite structure consisting of complex orbitals and suborbitals. If the nucleus were the size of a tennis ball, the diameter of the atom would be from two to twenty miles, depending upon the particular element. Hydrogen is the smallest atom, and meitnerium (number 109) is currently the largest known and named atom. Fully 99.95 percent of an atom's mass exists in the nucleus, a structure that is only 0.001 of the entire volume of the atom. This nucleus is very densely packed together so that a pin-head size piece of pure nuclear matter would weigh about a million tons.

The electrons travel around the nucleus at a speed estimated at about six thousand miles per second (3 percent of light speed). They produce an energy cloud and a force field which totally surrounds the nucleus (Sutton, 1984). The nucleus itself was once believed to be simply a set of parts held together in a spherical shape, but it is now known to be a complex, ordered structure (Flam, 1994). Its components are assembled according to very definite energy levels and the behavior and properties of each chemical element ultimately depends upon this specific structure. To achieve stability and carry out their role, the protons and neutrons likely travel in "orbits" within the nucleus at enormous speeds. Three nuclear models that help us understand how the nucleus behaves will be described here.

1. The nuclear *shell model* focuses on the nucleus as a tiny solar system. The protons and neutrons move in subnuclear orbits similar to those of electrons, with paths determined by their energy. The nucleons themselves travel at speeds estimated up to 100,000 miles per second, over 50 percent of light speed (Penrose and Isham, 1986). The shell model is consistent with a hierarchy of similarly *created* patterns of orbital motion: the nucleus, atom, solar system, galaxies, and galaxy clusters.

2. The *optical model* views the nucleus as a *collective unit*. When a stream of bombarding particles collides with a nucleus, a small portion is reflected, some are refracted, and others are absorbed somewhat like the passage of light through a clouded crystal ball. This model is several decades old and is fairly successful in predicting many physical results.

3. The *liquid drop model* was developed by several theorists including Niels Bohr, Lise Meitner, Otto Hahn, J. A. Wheeler, and others in the 1930s to explain the process of nuclear fission. This model focuses on the nucleus as a group of tightly packed spheres. If one is hit, all the others respond and move in a predictable way, as if coupled by springs. The vibration is such that if enough force or a high enough level of instability exists the nuclei can separate in two, much like a liquid drop separating into smaller droplets.

Although the nucleus is tightly packed, its nucleons apparently slide over each other without touching and without friction, meaning that the nucleus as a whole behaves as a superfluid (Bertsch, 1983). This is an "ideal fluid" which exhibits frictionless flow somewhat like superconductivity. Pairs of nucleons also spin in opposite directions as they travel in their defined orbits. If the number of both neutrons and protons is even, the nucleus as a whole has no net unbalanced internal rotational angular momentum.

The entire nucleus generally rotates relatively slowly in contrast to the individual nucleons' rapid rotation. As with a spinning raw egg, if stopped and then released, the rotational inertial motion of the fluid inside the egg will cause it to again resume spinning. The nucleus shows similar rotational behavior. This description gives a brief glimpse into one frontier of physics concerning the nucleus. On a deeper level, the nuclear force that holds the nucleons tightly together remains poorly understood. Only the Creator knows the ultimate details of the ever smaller components of His created matter.

The Particle Zoo

According to current theory, all known matter is built from two basic kinds of elementary particles, called *quarks* and *leptons*. The quarks are trapped inside larger particles (usually protons and neutrons) and have not been demonstrated to exist in isolation, even in accelerator collisions. Conversely, leptons can travel outside of and commonly exist independently of an atom. Quarks respond to the strong nuclear force while leptons do not (Fritzsch, 1983).

The six kinds of leptons are the electron, electron neutrino, muon, muon neutrino, tau, and tau neutrino. Each also has an antiparticle, bringing the total number of particles in this family to twelve. Of the six leptons, the electron is by far the best known. Except for the neutrino, we do not yet know why the other four leptons exist; they have been called the "vestigial organs" of physics (Maddox, 1991). The term *lepton* is Greek for small or light.

There are six kinds of quarks called *up*, *down*, *strange*, *charmed*, *bottom*, and the *top* or *truth* quark. These six quark variations are sometimes called *flavors*. Each quark further has three varieties or *degrees of freedom*, labeled by the colors red, green and blue to distinguish them. Actual colors do not exist on this level since quarks are much smaller than the wavelength of visible light. Each quark variety also has an antiparticle equivalent, identical except for electrical charge. Altogether then there are 36 distinct quarks (Figure 1). The proton consists of two up and one down quark (uud), and the neutron consists of two down and one up quark (ddu). An anti-proton ($\overline{\text{p}}$) consists of two anti-up and one anti-down quarks.

Researchers have probed quarks to distance scales below 10^{-18} meter and find evidence that quarks themselves may consist of still smaller particles. Ferris (1988, p. 295) uses an illustration to show how small this is: "If a single atom was enlarged to the dimension of the earth, any subcomponents of quarks and leptons would have to be smaller than a grapefruit to have escaped detection." Although this is very small, we still have a long way to go because smallness extends to infinity. However, there is a theoretical conclusion that the Planck-length, or 10^{-35} m,

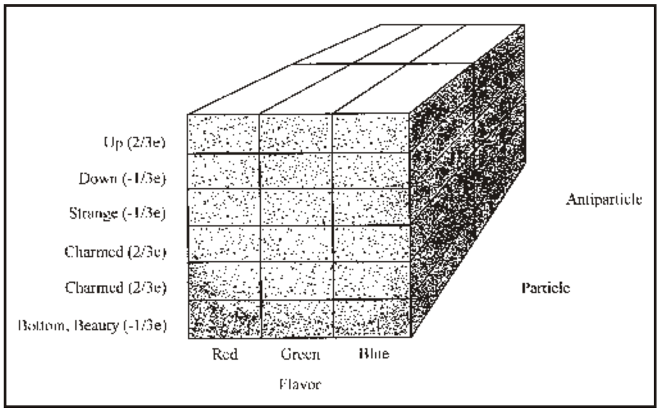

Figure 1. A graphical summary of the 36 distinct types of quarks.

is the ultimate lower limit on detectable, measurable lengths.

Matter and Force Carrying Particles: As another way to categorize particles, the micro-world is composed of two particle types, *fermions* after Enrico Fermi (1901–1954) and *bosons* after Satyendra Nath Bose (1894–1974). The fermions include all matter particles, and the bosons all force-carrying particles (Weinberg, 1996). Fermions include the proton, electron, and neutron. Bosons include the photon and gluon particles.

When traveling through a vacuum, neutrinos and photons move at the speed of light, never slower or faster. When photons travel through matter, they slow down due to absorption and reradiation. But neutrinos do not interact with any of the four forces except the weak nuclear force, and are much more penetrating. Thus the estimated ten-billion neutrinos that zip through every square inch of the earth every second rarely interact with anything (Winter, 1992).

The neutrino was first hypothesized by Pauli to account for the difference between the calculated mass energy from a beta decay reaction and the actual energy level measured (Tayler, 1981). The particle was named *neutrino* (Italian for *little neutral one*) by Fermi in 1934. Three types of neutrinos exist: electron neutrinos, muon neutrinos, and tau neutrinos (Asimov, 1992). The reactions that produce the sun's energy are believed to convert hydrogen to helium, releasing electron neutrinos in the process. This is also the hypothesized origin of neutrinos that come from outer space. Because so many of them exist, if they turn out to have a rest-mass above zero, as now indicated, their collective mass may outweigh the entire mass of visible galaxies.

Anti-Particles: Anti-particles are so named not because they are *against* anything but because each known particle type has a companion particle that is identical but opposite in charge and certain other traits. Matter and anti-matter both have mass, take up space, and can be discerned by the human senses. Anti-matter was first predicted from Paul Dirac's symmetry theory and later confirmed in the laboratory. Anti-matter is influenced by gravity just as is matter.

The mate of an *electron* (e^-) is a *positron* (e^+), of a *proton* (p^+), an *anti-proton* ($\overline{p}$), and of a *neutron* (n), an *anti-neutron* ($\overline{n}$). A neutron is a *neutral particle* and has no charge. Instead the anti-neutron has a *magnetic moment* sign opposite to that of a neutron. Magnetic moment is the magnetic field that results from the spin of a particle. All of the known subatomic particles have corresponding anti-particles.

As ordinary anti-matter, a positron usually has an extremely short existence because soon after it forms in a reaction it is attracted to an electron and annihilated. Collisions between a positron and an electron result in the conversion of their masses into energy according to the famous $E = mc^2$ relationship. This process produces high energy electromagnetic gamma radiation (g) shown by:

$$e^+ + e^- \rightarrow 2\gamma.$$

The inverse reaction, namely *electron-positron* creation or "pair production" ($\gamma \rightarrow e^- + e^+$) is commonly used to produce positrons (Parker, 1988). The existence of anti-matter on the earth is limited primarily to that produced artificially in the laboratory. However, some older versions of the big bang model also predict equal amounts of matter and anti-matter in space. Anti-matter atoms are as stable as matter if they do not collide and react with matter. Some astronomers even hypothesize regions of "anti-universe" that consist of anti-planets, anti-stars, and anti-galaxies. If an *anti-matter* galaxy came in contact with a *matter galaxy*, large scale annihilation would result. No such energetic events are observed in space.

Cosmic Rays: To produce most anti-particles requires high energy collisions of about 30 gigaelectron (10^9) volts, such as is produced at the Brookhaven Synchrotron where much of the research on anti-matter was completed. Another event that naturally produces anti-matter is the collision of cosmic rays with atomic nuclei that regularly occurs in the upper atmosphere. Such collisions can be more energetic than anything produced by accelerators.

Almost all cosmic rays are *charged nuclei* of atoms. About 90 percent are single protons (hydrogen nuclei), and most of the rest are nuclei from stable elements, mostly light elements, but may include elements from helium to lead (Friedlander, 1989). Their energies vary from 10^9eV to as high as 10^{20}eV or more.

The relatively young Vela supernova is a prime contributor of cosmic rays that strike the earth (Erlykin and Wolfendale, 1997). Cosmic rays themselves rarely make it to the earth's surface unchanged. Our atmosphere is one of several protective shields provided for the earth. When cosmic rays enter the earth's atmosphere they collide with air atoms and the collision produces a shower of secondary particles, often *muons*. These are leptons similar to electrons but 207 times as massive. The secondary particles

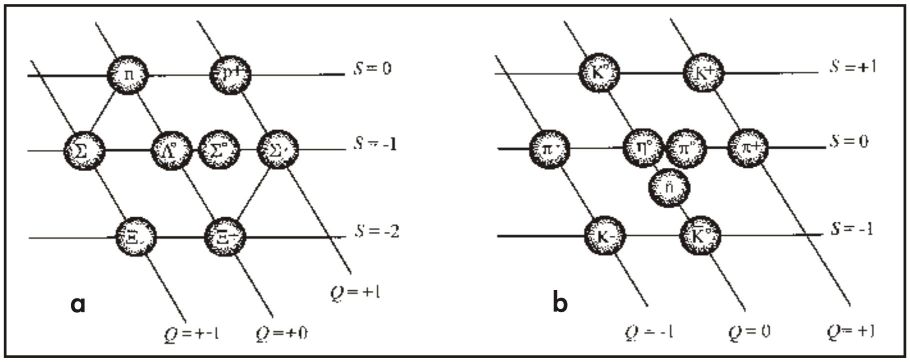

Figure 2. (a) The hexagonal Eightfold Way pattern for the eight spin-1/2 baryons. This strangeness versus charge plot uses a sloping axis for the charge number *Q*. (b) The Eightfold Way pattern for the nine spin-zero mesons.

collide with an increasing number of air particles as they move toward the earth, producing an ever enlarging cone shaped shower of new particles.

If the primary ray contains enough energy, the cascade effect will reach the earth's surface. The end of the flow is usually around one hundred yards in diameter and can contain up to a billion particles. Many of these particles are electrons, but large numbers are muons. A few muons from cosmic rays pass through every human on Earth every second.

Additional Particle Properties

Mass. Mass is determined by measuring the gravity force acting on an object, or by measuring the object's momentum which is the product of its mass and velocity. The mass of many particles is extremely small and can be given as the ratio of the particle to that of an electron, which may be set at a value of one. A proton has 1,836 times the mass of an electron, and the *omega hyperon* has fully 3,276 times an electron's mass.The mass value is also given in terms of the energy necessary to create the particle, measured in *electron volts* (eV). An eV is the energy needed to move an electron through a potential difference of one volt. Each molecular reaction in a typical flashlight battery produces about 1.5 electron volts of chemical energy.

Electric charge. All particles have either a positive, negative, or neutral electrical charge. Most hadron and lepton particles have a charge of +1, 0, or –1, but particles with a charge of +2, –2, +3, –3 and other multiples are known. Quarks have charges of +1/3, +2/3 and –1/3 and –2/3. Many particles exist in all three basic charge states. An example is a *pion* which can be either a *pion-plus*, *pion-minus*, or *pion-naught* (+1, –1, 0).

Magnetic moment. Magnetic moment describes the magnetic field that is always associated with a spinning charged particle. All spinning charged particles manifest the characteristics of a tiny magnet that allows them to line up and reorient themselves when placed in a magnetic field. The atom's spin is determined to be either in the direction of the magnetic field or in the opposite direction only, and thus it too is quantized. This conclusion was supported by the famous 1924 Otto Stern-W. Gerlach experiment.

Parity. Parity is a comparison between an object and its mirror image. There are two possibilities. A particle may look the same as its reflection, for example a sphere or cylinder. Or the particle may be obviously reversed, such as many written letters would be. Symmetric particles which do not change in mirror reflection are assigned the *even parity* number +1. Particles which are reversed are given the odd parity number –1. Parity is a quantum number, and is conserved in interactions when the parity of the products is equal to the parity of the initial reactant. The evidence indicates that parity is conserved in strong nuclear interactions, but in weak nuclear interactions such as beta decay, it is not conserved.

Half life. Half-life refers to the rate of decay or conversion of an unstable particle into other particle combinations. For short decay rates, this value is typically measured by calculating the distance that the particle travels before it decays and then dividing by its velocity (Weinberg, 1996).

Symmetry and Conservation

Several physical quantities in nature including energy, momentum, and electric charge display constancy or conservation. Why these conservation laws exist cannot be explained by natural science alone. Creationists would conclude that they display the profound dependability and predictability planned in the Creation.Conservation rules are multiplied in the realm of elementary particles. Consider two examples. The category of *strange* particles include kaons, lambdas, and sigmas. It is found experimentally that these strange particles are always produced in pairs. This property is called conservation of strangeness. Second, particle interactions usually obey conservation of quantum numbers including spin, baryon number, lepton number, strangeness, and electric charge. Fascinating diagrams result from these properties. For example suppose we plot strangeness (S) against electric charge (Q) for the eight baryon particles that all have a spin of one half. Figure 2a shows the result, a hexagon. Likewise one can group the nine mesons which all have spin zero, and a similar picture results (Figure 2b). These symmetric patterns are called the *eightfold way*, first shown by Murray Gell-Mann in 1961.

Alternate grouping produces other patterns, for example a ten pin bowling pattern. Some researchers even have tried to connect these patterns with New Age concepts or Eastern Mysticism. Instead, however, physicists are actually discovering the partial, poorly understood picture of the elegant symmetry of the created building blocks of matter.

Exotic Matter

The basic building blocks of the universe can be assembled to produce new types of atoms with unusual characteristics. For example, a *negative muon*, since it is similar to an electron, can take the place of an electron and orbit around a deuterium nucleus (Parker, 1988). As a muon orbits two-hundred times more closely to the nucleus than an electron, a pair of deuterium nuclei with an orbiting muon can come so close together that the two nuclei fuse, expelling the muon, which then soon orbits another nucleus, causing another fusion and another expelling (Flam, 1994). The process then continues until the building blocks are exhausted.

Conclusions

The goal of particle research is to understand the universe and to learn how it functions. We have come a long way from the simple conception of a universe consisting only of a few types of solid atoms. The existence of an estimated 500 subatomic particles shows that our attempts to simplify the universe by formulating a few basic laws that explain a large amount of information have been thwarted by a high level of complexity. The purpose or function of most of these particles in the universe is not yet understood, but we maintain that all of these subatomic particles will eventually be found to have a critical function in the universe to support life.

> Why are there twelve leptons, when the Universe seems to contain only electrons and electron neutrinos in appreciable numbers? Electron antineutrinos are produced only in radioactive transformations, which are few in number in the Universe as a whole. Positrons are produced in some radioactive transformations, but less often even than electron antineutrinos. The heavier leptons and their neutrinos are produced, as far as we know, only in the laboratory by such things as cosmic-ray bombardment. Why, then, doesn't the Universe get by on just electrons and electron neutrinos? Why needlessly complicate things? (Asmiov, 1992, p.251).

Asimov concludes that the complexity discovered by particle physics exist for a reason and are not needless.

> *The universe is built in such a way that every interaction must play its role.* We might not see what possible use the tauon has, for instance, but I have the strong feeling that whatever it is that makes the Universe work as it does requires the tauon's existence; that *without the tauon the Universe would not be the Universe we live in and might not even have the capacity to exist* (Asimov, 1992, p. 252 emphasis ours).

The theory that the entire particle zoo is constructed from complex fundamental particles called quarks and leptons does not explain their source . And both quarks and leptons have shown evidence of having an internal structure below 10^{-18} meters. Will these subquarks also show evidence of yet smaller particles? We now know that the multiple levels of hierarchical structure, from subatomic particles to galaxy clusters, are all integrated and functional because of the other levels (DeYoung, 1987).

All of the particles so far identified have very definite traits which indicate that each one has a watch-like structure. The description of the particle traits show that they are quantized, meaning they exist in discrete units. The conclusion that they were all designed to produce a universe that can support life is a logical deduction. Although we understand the role of only a few of these particles, hundreds more could exist, all of which no-doubt play a role in creation just as all body parts play a role in life (Breuer, 1991). Particle physics research has revealed the fact that properties are such that only slight modifications would not allow stable atoms to exist. According to theorists including particle physicists John Polkinghorne, this new knowledge of particle physics

> constitutes a triumphant new natural theology . . . the new natural theology is different from that of Saint Thomas Aquinas and the eighteenth-century English theologian and philosopher William Paley—who argued, famously, that the mechanism of the eye could be understood only as the creation of an intelligent designer. By contrast, the new natural theology, Polkinghorne says bases "its arguments not on particular occurrences (the coming-to-be of the eye or of life itself), but on the character of the physical fabric of the world which is the necessary ground for the possibility of any occurrence." For Polkinghorne, then, the very existence and nature of the physical universe is testimony both to its divine origin and to its inherent cosmic purposefulness (Wertheim, 1999 p. 40).

Physicists believe that every subparticle of the same species is exactly alike—every electron is exactly like every other electron in the universe, and the same is true of all subatomic particles. Further, their behavior is so orderly we summarize it in statements called laws. Why do patterns, symmetry, and laws exist in nature? Some experts might answer that the task of science is to find out only *how* nature works, not *why*. But this response reveals the incompleteness of natural science alone. Ultimate truth about the universe must also deal with God's construction and continuing oversight of His creation.

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Book Review

The Call of Distant Mammoths by Peter D. Ward
Springer-Verlag, New York. 1997, 241 pages, $26

Author Ward is a faculty paleontologist living in Seattle. He has written several excellent previous books about natural history. This time he tackles the question of what killed off the mammoths just "10,000 years ago." There are two competing ideas: a gradual, cold climate change or extinction from human hunting. Ward visits earth locations in the past using an imaginary time machine. There are good descriptions of dinosaur habitat, the hypothesized Chixulub impact event, and early American Clovis people.

Scientist Don Fisher has made careful analysis of mammoth tusks and they provide a "diary" of the animals' life (p.216). This data reveals mammoth diet, health, and even the birth rate for females. The conclusion is that mammoths lived during a cooler period, but they show little sign of stress or starvation. Ward therefore concludes that mammoths along with 50 other large North American mammal species were hunted to extinction by people over a rapid 1,000 year period. Mammoths may have been slowly *dying out*, but mankind made them *die out* (p.191).