The Fine Tuning of the Universe: Evidence for the Existence of God?

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Investigations by cosmologists during the past sixty years have uncovered a remarkable new picture of our amazing universe and its incredible journey from the big bang to our "finely tuned" habitat. It appears that the initial conditions, the mathematical forms that nature takes, and the universal constants must each be precisely tuned to have a suitable habitat for complex, conscious life. Whether this fine tuning is evidence for a creator God is explored, while trying to avoid making fallacious "God of the gaps" claims and instead pointing appropriately to patterns in nature that provide legitimate evidence for a creator God.

Why is "Fine Tuning" such a popular subject today, as evidenced by the many books that have been written on this topic? Here are some examples: *The Anthropic Cosmological Principle*,[1] *Universes*,[2] *The Accidental Universe*,[3] *The Cosmic Blueprint*,[4] *Cosmic Coincidences*,[5] *The Anthropic Principle: Man as the Focal Point of Nature*,[6] *Universal Constants in Physics*,[7] *The Goldilocks Enigma: Why Is the University Just Right for Life?*,[8] *Cosmic Jackpot: Why Our Universe Is Just Right for Life*,[9] *The Constants of Nature: The Numbers That Encode the Deepest Secrets of the Universe*,[10] *Why the Universe Is the Way It Is*,[11] *Just Six Numbers: The Deep Forces That Shape the Universe*,[12] and *A Fine Tuned Universe: The Quest for God in Science and Theology*.[13]

There is good reason for these discussions. Fine tuning describes one of the great mysteries of the universe, and one that may have significant metaphysical implications. Even atheists such as Stephen Hawking note,

> To understand the universe at the deepest level, we need know not only how the universe behaves but why. Why is there something rather than nothing? Why do we exist? Why this particular set of laws and not some other?[14]

The universe is such a remarkable place of habitation for complex, conscious life that it is extremely difficult to believe that it is the result of a long series of cosmic accidents. The elegant mathematical forms that are encoded in nature, the twenty-two universal constants with values within very narrow ranges of exactly what they need to be,[15] and the multitude of initial conditions that must be within a very narrow bandwidth, which they are, would seem to suggest a universe that has been carefully crafted for our benefit.

This article will specifically explore the fine tuning of our universe, the mathematical forms that nature takes, the universal constants, and the precise initial conditions when the universe exploded into existence in the "big bang." Then this article will explore whether fine tuning provides significant warrant for belief in a creator God.

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Universal Constants, Initial Conditions, and the Laws of Nature "Work" Together

Important provisions for complex, conscious life in our universe are executed through the combination of natural laws, universal constants, and initial conditions. But how does this work? A simple example will be used to illustrate.

Suppose you are in Pisa, Italy, at the top of the Leaning Tower of Pisa and want to throw a water balloon timed to hit your friends as they walk on the plaza directly below you. The relevant natural law is expressed mathematically by Newton's differential equation for motion in a gravitational field. This law of nature (expressed in mathematical form) can be solved to give an algebraic equation, as seen in equation 1. The solution requires specification of a universal constant, G, for gravitational force; the mass of the earth, M; the height of the tower, h_0; and the initial velocity with which the water balloon is thrown, v_0, to determine how long, t, it will take for the balloon to reach the plaza:

$$h(t) = h_0 - (GMt^2)/2r^2 - v_0t \qquad (1)$$

This equation describes the fundamental law of nature that mass attracts mass with a force that we call the gravitational force of attraction between two masses (the water balloon and the earth in this case) scaled by the universal constant, G. In addressing various phenomena in nature, one must always know the appropriate law(s) of nature, expressed in mathematical form, with the initial conditions and the appropriate universal constants. If one sets h(t) = 0, then one can solve the equation to specify the time, t, that it will take for the balloon to reach the plaza below. Note that the drag force on the water balloon was not included in this calculation, in order to keep the equations in the illustration simple. There are many more-complicated phenomena in nature, but one can always predict the behavior of each phenomenon if one knows the appropriate law(s) of nature, the values of the associated universal constants, and the specification of initial conditions. It is worth noting the connectedness between the universal constants, the initial conditions, and the laws of nature. There are many different possible solutions (times) for h(t) = 0, depending on the values of the universal constants and initial conditions in combination with the mathematical form that the law of nature takes to prescribe h(t).

Requirements for a Universe to Support Complex, Conscious Life

Living systems may be distinguished from nonliving systems by their unique capacity to process energy from their surroundings (chemical or electromagnetic from the sun), store information, and replicate. In living systems, these remarkable capacities are executed by biopolymers such as DNA, RNA, and proteins. Living systems levitate above thermodynamic equilibrium, whereas nonliving matter will exist at, or very near, thermodynamic equilibrium.

Designing *a universe* is much more complicated than designing *in a universe*, as engineers and scientists do in our universe. When human beings design and create something, they are operating in a universe where the laws of nature have already been put into place and the universal constants have already been specified. Designing a universe requires that one specify the mathematical forms that the laws of nature take, defining the fundamental characteristics of the universe. Then, the universal constants which scale the characteristics of these laws of nature must be specified; for example, G as in $F = G[m_1m_2]/d^2$ where F is the force of attraction, the two m's are the two masses that have a gravitational attractive force between them, and d is the distance between the two masses. Our present universe is also the consequence of the initial conditions at the moment of the big bang such as the rate of expansion, which has a profound impact on the universe that unfolds. For example, if the post-big-bang rate of expansion is too rapid, then gravitational forces are insufficient to create stars and planets. If the initial rate of expansion is too slow, then the universe might simply expand briefly and then collapse so that all of the mass of the universe is in one place with an overwhelming gravitational force, precluding satisfying the list of design requirements given below.

A partial list of necessary requirements for a habitable universe for complex, conscious life similar to life forms that have been found in this universe must meet at least the following requirements suggested by Ward and Brownlee.[16]

1. The first requirement is a star that is located in a relatively "quiet" region of the universe where not too many neighbors are producing high-intensity, sterilizing radiation. This star needs to have its highest intensity of radiation in the range that is suitable to drive the chemical reactions

essential to life without destroying the products of these reactions. There must also be a means of transporting the energy from this star at the center of the solar system to planets where chemical reactions between the chemical building blocks in solution require energy to enable the chemical assembly of the building blocks into biopolymers.

2. There must be a planet or moon in the solar system of the star in requirement "1" that is terrestrial; in other words, solid rather than gaseous.
3. This universe must have sufficient chemical stability and elemental diversity to build the complex molecules necessary for essential life functions: namely, processing energy, storing information, and replicating.
4. There must be chemical reactions that allow predictable polymeric compounds like DNA, RNA, and proteins to form from various elements in simpler compounds.
5. There must be a "universal connector," an element that is essential to building the molecules of life. It must readily bond chemically with almost all other elements, including itself, forming bonds that are stable but not too stable so that disassembly is also possible. Only carbon in our naturally occurring 92 elements satisfies this chemical characteristic. This is the reason why, when we look for life on other planets, we begin by looking for carbon-based compounds. It is difficult to imagine living systems without a carbon-like element.
6. A "universal solvent" in which the chemical reactions can take place is essential, since chemical reactions in solids are much too slow and complex life could not be sustained as a gas. This solvent must readily dissolve both the reactants and the reaction products essential to living systems: that is, a liquid with the properties of water, which is very nearly a universal solvent.
7. The temperature range on the terrestrial planet or moon (see requirement 2) must maintain the universal solvent as a liquid rather than as a solid or as a gas for some portion of the year.
8. The right concentration of heavy (radioactive) elements must be present in the planet (see requirement 2) to heat the core of the planet and provide the necessary energy to drive plate tectonics to build up land mass in what would otherwise be a smooth round planet completely covered with the solvent.
9. The amount of solvent must be carefully coupled to plate tectonics activity to provide the planet with similar proportions of its surfaces as oceans and land mass.
10. The planet must have the right protection from the destructive forces in nature such as radiation and asteroids over a reasonable period of time.
11. The planet must have just the right stabilized axis tilt and angular velocity to give moderate, regular, and predictable seasons and moderate temperature fluctuations from day to night.

While one is tempted to think that these requirements are easily met, given the large number of stars, it should be noted that there are few places in the universe that are sufficiently free of sterilizing radiation to provide a suitable solar system. The number of candidate "neighborhoods" is further reduced by the requirement of a sun with the right amount of mass to give the right electromagnetic radiation spectrum. Furthermore, the occurrence of a suitable satellite in conjunction with such a star is even more problematic. Only Earth in our solar system of sixty-two satellites meets the above requirement for a "home" (Earth) in a safe neighborhood such as that of our sun and solar system, which are well placed in a quiet place in a suitable universe as described above.

In the following sections, how these universal and local needs (or design requirements) are met by the specific mathematical forms encoded in nature, the exact values of the universal constants in the universe, and the remarkable "coincidence" that initial (or boundary) conditions are exactly what they must be, will be presented. The developmental path that our universe navigated is consistently remarkable, making the origin of this place for life all the more wondrous and enigmatic. Unless *all* of these conditions, and many more not included in this list, are met, the universe would not allow for the development of complex, conscious life forms. Therefore, the above requirements for our universe are necessary conditions, but they are not by themselves sufficient for a habitat suitable for complex human life.

Ward and Brownlee express their wonder in their book, *Rare Earth*.

> If some god-like being could be given the opportunity to plan a sequence of events with the expressed goal of duplicating our "Garden of

> Eden," that power would face a formidable task. With the best of intentions, but limited by natural laws and materials, it is unlikely that Earth could ever be truly replicated. Too many processes in its formation involved sheer luck. Earth-like planets could certainly be made, but each outcome would differ in critical ways. This is well illustrated by the fantastic variety of planets and satellites that formed in our solar system. They all started with similar building materials, but the final products are vastly different from each other. Just as the more familiar evolution of animal life involved many evolutionary pathways with complex and seemingly random branch points, the physical events that led to the formation and evolution of the physical Earth also required an intricate set of nearly irreproducible circumstances.[17]

Mathematics and the Deep Structure of the Universe

Mathematics, in contrast to arithmetic, is an abstract intellectual activity that was developed by the Sumerians (in the region of Babylon) between the twentieth and the sixteenth century BC.[18] In Greece, Pythagoras was a key mathematician, as were his successors, Euclid and Archimedes between 400 BC and 200 BC.[19] Their studies focused especially on geometric objects, such as straight lines, circles, ellipses, and conic sections. In the third century BC, Apollonius of Perga wrote eight monumental volumes devoted to these curves, describing their properties as "miraculous."[20]

Because mathematics was considered to be an abstract idea, it came as a great surprise that the natural world was full of mathematical forms. Imagine the delight of Johannes Kepler (1571–1630) some eighteen centuries later, when he discovered that the orbits of planets around the sun conformed to these same beautiful but abstract mathematical forms. Kepler declared that the chief aim of all investigations of the external world should be to "discover the rational order and harmony which has been imposed on it by God and which he revealed to us in the language of mathematics."[21] Galileo Galilei (1564–1642) asserted that "the laws of nature are written by the hand of God in the language of mathematics."[22]

In his *Mathematics: The Loss of Certainty*, historian Morris Kline demonstrates that the religious mathematicians of the sixteenth and seventeenth centuries, including Newton, Galileo, Kepler, and Copernicus, all viewed the universe as orderly and capable of mathematical description precisely because a rational God had fashioned it that way.[23] These scientist-mathematicians believed that since God had designed the universe, then "all phenomena of nature would follow one master plan. One mind designing a universe would almost surely have employed one set of basic principles to govern all related phenomena."[24]

Only in the twentieth century have we come to fully understand that the incredibly diverse phenomena that we observe in nature are the outworking of a very small number of physical laws, each of which may be described by a simple mathematical relationship. Indeed, so simple in mathematical form and so small in number are these fundamental physical laws that they can all be written on one side of one sheet of paper, as seen in figure 1. It is truly remarkable that the wide diversity of phenomena in nature can be described by a few simple mathematical relationships.

Nobel laureate physicist Eugene Wigner in his widely quoted paper, "The Unreasonable Effectiveness of Mathematics in the Physical Sciences," notes that scientists often take for granted the remarkable—

The Fundamental Laws of Nature

- Mechanics (Hamilton's Equations)

$$\dot{p} = -\frac{\partial H}{\partial q} \qquad \dot{q} = -\frac{\partial H}{\partial p}$$

- Electrodynamics (Maxwell's Equations)

$$F^{\mu\nu} = \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu} \qquad \partial_{\mu} F^{\mu\nu} = j^{\nu}$$

- Statistical Mechanics (Boltzmann's Equations)

$$S = -k \int f \log f \, dv \qquad \frac{dS}{dt} \geq 0$$

- Quantum Mechanics (Schrödinger's Equations)

$$I\hbar \left| \psi \right\rangle = H \left| \dot{\psi} \right\rangle \qquad \Delta X \Delta P \geq \frac{\hbar}{2}$$

- General Relativity (Einstein's Equation)

$$G_{\mu\nu} = -8\pi G T_{\mu\nu}$$

Figure 1. The Five Essential Fundamental Laws of Nature for Life

even miraculous—effectiveness of mathematics in describing the real world. Wigner muses:

> The enormous usefulness of mathematics is something bordering on the mysterious … There is no rational explanation for it … The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.[25]

Albert Einstein was also struck by the wondrous orderliness of the world as he explained it:

> You find it strange that I consider the comprehensibility of the world (to the extent that we are authorized to speak of such comprehensibility) as a miracle or as an eternal mystery. Well a priori, one should expect a chaotic world, which cannot be grasped by the mind in any way … The kind of order created by Newton's theory of gravity, for example, is wholly different. Even if man proposes the axioms of the theory, the success of such a project presupposes a high degree of ordering of the objective world and this could not be expected a priori. That is the "miracle" which is being constantly reinforced as our knowledge expands.[26]

The splendid orderliness of the cosmos, expressed in the mathematical forms seen in figure 1, is remarkable in many additional ways to enable a universe with a suitable place for habitation by complex, conscious life. The particulars of the mathematical forms themselves are also critical.

Consider the problem of stability at the atomic and cosmic levels. Both Hamilton's equations for nonrelativistic Newtonian mechanics and Einstein's theory of general relativity (fig. 1) are unstable for a sun with planets unless the gravitational potential energy is proportional to the radius "r^{-1}," a requirement that is met only for a universe made with three spatial dimensions. Newtonian mechanics describe a crucial feature of the physical world, Newtonian gravitational attraction, that makes possible the peculiar behavior of planets having very stable orbits around their respective star, their sun.

For Schrödinger's equations for quantum mechanics to give stable, bound energy levels for atomic hydrogen (and by implication for all of the various types of atoms), the universe must have no more than three spatial dimensions. Furthermore, the physical reality captured in Schrödinger's equations makes possible a universe with 92 different elements. If nature did not have the characteristics implicit in Schrödinger's equations, all atomic orbitals would collapse, with the electrons being attached to the atomic nuclei, meaning no chemistry, no periodic chart, and no life. Maxwell's equations for electromagnetic energy transmission also require that the universe be no more than three-dimensional. Maxwell's equations describe a facet of nature without which life could not exist, since getting the energy from the sun to planets where life can exist is essential.

Furthermore, Richard Courant illustrates this felicitous meeting of natural laws with the example of sound and light:

> The actual physical world in which acoustic or electromagnetic signals are the basis of communication seems to be singled out among the mathematically conceivable models by its intrinsic simplicity and harmony.[27]

Boltzmann's equation for the second law of thermodynamics provides an essential predictability to the behavior (directionality) of chemical reactions.

To summarize, for life to exist, an orderly (and by implication, intelligible) universe is needed. Order at many different levels is required. For instance, to have planets that circle their stars, Newtonian mechanics operating in a three-dimensional universe is essential. For there to be multiple stable elements of the periodic table to provide a sufficient variety of atomic "building blocks" for life, an atomic structure to be constrained by the laws of quantum mechanics is necessary. The orderliness in chemical reactions that is the consequence of Boltzmann's equation for the second law of thermodynamics is essential for chemical reactions to "go" in predictable ways. For an energy source like the sun to transfer its life-giving energy to a habitat like Earth, the laws of electromagnetic radiation, which Maxwell's equations describe, must describe and compel this essential feature of our universe.

The universe is indeed orderly, and in precisely the ways necessary for it to serve as a suitable habitat for complex, conscious life. The wonderful internal ordering of the cosmos is matched only by its extraordinary economy. Each one of the fundamental laws of nature is essential to life itself. A universe lacking any one of the laws shown in figure 1 would almost certainly be a universe without life. Many modern scientists, like the mathematicians centuries before them, have been awestruck by the evidence

for intelligent design implicit in nature's mathematical harmony and the internal consistency of the laws of nature. Arizona State astrophysicist Paul Davies declares:

> All the evidence so far indicates that many complex structures depend most delicately on the existing form of these laws. It is tempting to believe, therefore, that a complex universe will emerge only if the laws of physics are very close to what they are … The laws which enable the universe to come into being spontaneously, seem themselves to be the product of exceedingly ingenious design. If physics is the product of design, the universe must have a purpose, and the evidence of modern physics suggests strongly to me that the purpose includes us.[28]

British astronomer Sir Fred Hoyle likewise comments:

> I do not believe that any scientist who examines the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed with regard to the consequences they produce inside the stars. If this is so, then my apparently random quirks have become part of a deep-laid scheme. If not, then we are back again to a monstrous sequence of accidents.[29]

Nobel laureates Eugene Wigner and Albert Einstein have respectfully evoked "mystery" or "eternal mystery" in their meditations upon the brilliant mathematical encoding of nature's deep structures. But as Kepler, Newton, Galileo, Copernicus, Davies, Hoyle, and many others have noted, the mysterious coherency of the mathematical forms underlying the cosmos is solved if one recognizes these forms to be the creative intentionality of an intelligent creator who has purposefully designed our cosmos to be a habitat for *Homo sapiens*.

Universal Constants

When scientists use the term "fine tuning" today, they generally are talking about the fine tuning of the universal constants, though the term has been used more broadly so far in this article. The deepest level of cosmic harmony and coherence is that of the elemental forces and universal constants that govern all of nature. The universe is embodied in the scaling of the various physical phenomena such as the gravitational force, the rest mass of the electron, and the speed of light.

The crucial role of universal constants can be illustrated by an example. If I were designing the first automobile, I would need to select an engine size for this car. Having no idea of how much horsepower the car will need, I might choose an engine with one horsepower. I install this engine into my first prototype and discover much to my dismay that the car will barely move. To rectify this problem, I replace this engine with one with 10,000 "horse power." Now I barely touch the accelerator and the car takes off like a rocket, causing a nonfatal crash that totally destroys my prototype. After building a new prototype, I equip it with a 100 horsepower engine which works just fine. Scaling the optimal engine size for a vehicle and many other components, is an example of what engineers do in their design work. It is quite analogous to the relative scaling of the universal constants in nature.

One of the remarkable discoveries of the past twenty years is that a functional universe suitable for complex, conscious life requires that the many universal constants in nature must be very nearly what we now know them to be. Many journal articles and books have documented this remarkable and surprising new insight, which has come to be known as the "fine tuning" of the universe. Table 1 provides an illustrative set of examples of important "universal constants" that must have values that are essentially what they are to provide a universe that is suitable for complex, conscious life: for example, the speed of light; the gravitational-force constant; the rest masses of the protons, electrons, and neutrons; the unit charge for the electron or proton; the weak nuclear force; the strong nuclear force; the electromagnetic coupling constants; Plank's constant; and the Boltzmann constant. These are all universal constants that are indispensable in the mathematical description of the universe.

When cosmological models were first developed in the mid-twentieth century, cosmologists naively assumed that the selection of a given set of constants was not critical to the formation of a suitable habitat for life. Through subsequent parametric studies using mathematical models that varied these constants, scientists now know that relatively small changes in any of the universal constants produce a dramatically different universe that is not hospitable to life of any imaginable type.

Let us examine several examples that constrain the selection of the universal constants to a remarkable degree. Twentieth-century physicists have identified four fundamental forces in nature. These may each be expressed as dimensionless numbers to allow a comparison of their relative strength. These values vary by a factor of 10^{41} or 41 orders of magnitude. Yet modest changes in the relative strengths of any of these forces and their associated constants would produce dramatic changes in the universe, rendering it unsuitable for life. Several examples to illustrate this fine-tuning of our universe are presented next.

Balancing Electromagnetism and Gravitational Forces

The electromagnetic force is 10^{38} times stronger than the gravitational force. Gravity draws hydrogen into stars, creating a high-temperature plasma. The protons in the plasma must overcome their electromagnetic repulsion to fuse. Thus, the relative strength of the electromagnetic force to the gravitational force determines the rate at which stars "burn" by fusion. If this ratio of strengths were altered to 10^{32} instead of 10^{38} (i.e., if gravity were much stronger than it actually is), stars would be a billion times less massive and would burn a million times faster.[30]

Electromagnetic radiation and the light spectrum also depend on the relative strengths of the gravity and electromagnetic forces and their associated constants. Furthermore, the frequency distribution of the electromagnetic radiation produced by the sun must be precisely tuned to the energies of the various chemical bonds on Earth. Excessively energetic photons of radiation such as the ultraviolet radiation emitted from a blue giant star, destroy chemical bonds and destabilize organic molecules. Insufficiently energetic photons, such as infrared and longer wavelength radiation from a red dwarf star, would result in chemical reactions that are either too sluggish or would not occur at all. Most life on Earth depends upon fine-tuned solar radiation, which requires, in turn, a very precise balancing of the electromagnetic and gravitational forces.

As previously noted, chemical bonding energy relies upon quantum mechanical calculations that include the electromagnetic force, the mass of the electron, the speed of light (c) and Planck's constant (h). Matching the radiation from the sun to the chemical bonding energy in plants on earth requires that the magnitude of six constants be selected to satisfy the following inequality, with the caveat that the two sides of the inequality are of the same order of magnitude, guaranteeing that the photons are sufficiently energetic, but not too energetic.[31]

$$(m_p^2\, G)/(hc) \geq [e^2/\{hc\}]^{12}[m_e/m_p]^4 \qquad (2)$$

Table 1. An abbreviated list of fundamental constants of physics and chemistry based on the values provided by CODATA.

Quantity	Symbol	Numerical Values	Unit
speed of light in vacuum	c	299 792 458	$m\ s^{-1}$
magnetic constant	μ_0	12.5664×10^{-7}	NA^{-2}
electric constant	ε_0	$8.854\ 187\ 817 \times 10^{-12}$	$F\ m^{-1}$
gravitational constant	G	6.6738×10^{-11}	$m^3kg^{-1}s^{-2}$
Planck's constant	h	$6.626070040 \times 10^{-34}$	Js
elementary charge	e	$1.6021766208 \times 10^{-19}$	C
magnetic flux quantum	φ_0	$2.067833831 \times 10^{-15}$	Wb
conductance quantum	G_0	$7.7480917310 \times 10^{-5}$	S
electron mass	m_e	$9.10938356 \times 10^{-31}$	kg
proton mass	m_p	$1.672621898 \times 10^{-27}$	kg
fine-structure constant ($e^2/4\pi\varepsilon_0 hc$)	α	$7.2973525664 \times 10^{-3}$	
inverse fine-structure constant	1/α	137.035999139	
Avagadro constant	N_A	$6.022140857 \times 10^{23}$	mol^{-1}
Faraday constant $N_A e$	F	96485.33289	C/mol
molar gas constant	R	8.3144598	$J/mol^{-1}\ K^{-1}$
Boltzmann constant, R/N_A	k	$1.38064852 \times 10^{-23}$	JK^{-1}

Substituting the values in equation 2 for h, c, G, m_e, m_p and e (with units adjusted as required) allows equation 2 to be evaluated to give

$$5.9 \times 10^{-39} > 2.0 \times 10^{-39} \quad (3)$$

In what is either an amazing coincidence or careful design by an intelligent Creator, these constants have the very precise values relative to each other that are necessary to give a universe in which radiation from the sun is tuned to drive the necessary chemical reactions that are essential for life. This result is illustrated in figure 2, where the intensity of radiation from the sun and the biological utility of the radiation are shown as a function of the wavelength of radiation.[32] While thermal energy from the sun is the primary source of energy for living systems on planet Earth, it is worth noting that there are several less common sources as well. Hot thermal vents in the oceans, for example, have provided the energy needed to supply simple life forms that are beyond the reach of sunlight. Other less common sources of energy for living systems include chemical gradients in oceans, gravitational interactions between two bodies like those found around "black smokers" on the ocean floor, or thermal gradients due to radioactive decay. However, the greatest intensity of radiation from the sun occurs at the place of greatest biological utility. Is this another remarkable coincidence, or another example of carefully crafted design in the functionality of the universe?

Happily, our star (the sun) emits radiation (light) that is finely tuned to drive the chemical reactions necessary for life. But there is still a critical potential problem: getting that radiation from the sun to the place where the chemical reactions occur. Passing through the near vacuum of space is no problem. However, absorption of light by either the earth's atmosphere or by water where the necessary chemical reactions occur, could render life on Earth impossible. It is remarkable that both the earth's atmosphere and water have "optical windows" that allow visible light (just the radiation necessary for life on Earth) to pass through with very little absorption, whereas shorter wavelength (destructive ultraviolet radiation) and longer wavelength

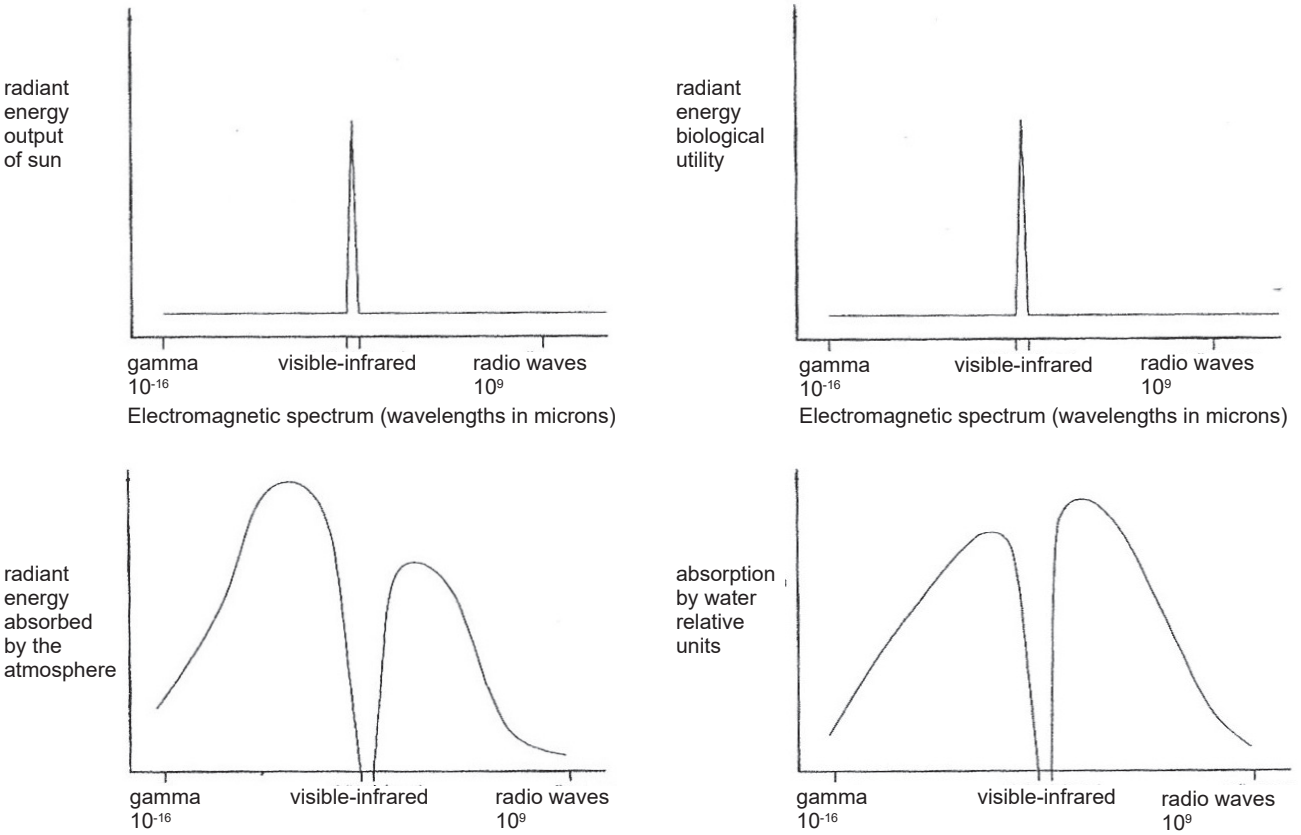

Figure 2. The visible portion of the electromagnetic spectrum (~ 1 micron) is the most intense radiation from the sun (upper, left): has the greatest biological utility (upper, right); and passes through the atmosphere of Earth (lower, left) and water (lower, right) with almost no absorption. It is uniquely this same wavelength of radiation that is ideal to foster the chemistry of life. This is either a truly amazing series of coincidences or else the result of careful design.

(infrared) radiation are both highly absorbed, as seen in figure 2. This allows solar energy in the form of light to reach the reacting chemicals in the universal solvent, which is water. The *Encyclopaedia Britannica* observes in this regard, "Considering the importance of visible sunlight for all aspects of terrestrial life, one cannot help being awed by the dramatically narrow window in the atmospheric absorption … and in the absorption spectrum of water."[33]

It is remarkable that the optical properties of water and of our atmosphere, the chemical bonding energies of the chemicals of life, and the radiation from our sun are all precisely harmonized to allow living systems to utilize energy from the sun, without which life could not exist. It is analogous to your car, which can run using only gasoline as a fuel. Happily, but not accidentally, the service station has an ample supply of exactly the right fuel for your automobile. But someone had to drill for and produce the oil, someone had to refine it into liquid fuel (gasoline) that has been carefully optimized for your internal combustion engine, and others had to truck it to your service station. The production and transportation of the right energy from the sun for metabolic motors of plants and animals is much more remarkable.

Finally, without this unique window of light transmission through the atmosphere of Earth and through water, made possible by the intricate framework of "just right" universal constants, vision would be impossible and sight-communication would cease, since living tissue and eyes are composed mainly of water.

Nuclear Strong Force and Electromagnetic Force

The nuclear strong force is the strongest force within nature, occurring at the subatomic level to bind protons and neutrons within atomic nuclei.[34] Were we to increase the ratio of the strong force to electromagnetic force by only 3.4%, the result would be a universe with no hydrogen, no long-lived stars that burn hydrogen, and no water (a molecule composed of two hydrogen atoms and one oxygen atom), our "universal solvent" for life. Likewise, a decrease of only nine percent in the strong force relative to the electromagnetic force would decimate the periodic table of elements. Such a change would prevent deuterons from forming from the combination of protons and neutrons. Deuterons, in turn, combine to form helium, then helium fuses to produce beryllium, and so forth.[35]

Within the nucleus, an even more precise balancing of the strong force and the electromagnetic force allows for a universe with an abundance of organic building blocks, including both carbon and oxygen.[36] Carbon serves as the universal connector for organic life and is an optimal reactant with almost every other element, forming bonds that are stable but not too stable, allowing compounds to readily be formed and also to be disassembled. Oxygen is a component of water, the necessary universal solvent in which life chemistry can occur. This explains why people first look for signs of organic molecules (ones containing carbon atoms) and signs that Mars once had water when they speculate about life on Mars.

Quantum physics examines the most minute energy exchanges at the deepest levels of the cosmic order. Only certain energy levels are permitted within nuclei-like steps on a ladder. If the mass-energy for two colliding particles results in a combined mass-energy that is equal to or slightly less than a permissible energy level on the quantum "energy ladder," then the two nuclei will readily stick together or fuse on collision, with the energy difference needed to reach the step being supplied by the combined kinetic energy of the colliding particles. If this mass-energy level for combined particles is exactly right, then the collisions are said to have resonance, which is to say that there is a high efficiency within the collisions. On the other hand, if the combined mass-kinetic energy results are a value that is slightly higher than one of the permissible energy levels on the energy ladder, then the particles will simply bounce off each other rather than fusing (i.e., sticking together).

It is clear that the step sizes between quantum nuclear energy levels depends on the balance between the strong force and the electromagnetic force, and these steps must be tuned to the mass-energy levels of various nuclei for resonance to occur and give an efficient conversion by fusion of lighter elements into carbon, oxygen, and heavier elements.

Distinguished cosmologist George Ellis concluded his article in *Scientific American* as follows: "The laws of nature exhibit an incredibly unlikely degree of fine tuning that is required to produce a life-friendly universe."[37]

In 1953, Sir Fred Hoyle et al. predicted the existence of the unknown resonance energy level for carbon, and it was subsequently confirmed through experimentation.[38] In 1982, Hoyle offered a very insightful summary of the significance he attached to his remarkable predictions.

> From 1953 onward, Willy Fowler and I have been intrigued by the remarkable relation of the 7.65 MeV energy level in the nucleus of 12 C to the 7.12 MeV level in 16 O. If you wanted to produce carbon and oxygen in roughly equal quantities by stellar nucleo-synthesis, these are the two levels you would have to fix, and your fixing would have to be just where these levels are actually found to be. Another put-up job? Following the above argument, I am inclined to think so. A common sense interpretation of the facts suggests that a super intellect has "monkeyed" with the physics as well as the chemistry and biology, and there are no blind forces worth speaking about in nature.[39]

Rest Masses of Elemental Particles

Scientists have been surprised to discover the extraordinary tuning of the masses of elementary particles to each other and to the forces of nature. Stephen Hawking has noted that the difference in the rest mass of the neutron and the rest mass of the proton must be approximately equal to twice the mass of the electron. The mass-energy of the proton is 938.28 MeV and the mass-energy of the neutron is 939.57 MeV. The mass-energy of the electron is 0.51 MeV, or approximately half of the difference in neutron and proton mass-energies, just as Hawking indicated it must be.[40] If the mass-energy of the proton plus the mass-energy of the electron were not slightly smaller than the mass-energy of the neutron, then electrons would combine with protons to form neutrons, with all atomic structures collapsing, leaving an inhospitable world composed only of neutrons.

On the other hand, if this difference were larger, then neutrons would all decay into protons and electrons, leaving a world of pure hydrogen, since neutrons are necessary for protons to combine to build heavier nuclei and the associate elements. As things stand, the neutron is just heavy enough to ensure that the big bang would yield one neutron to every seven protons, allowing for an abundant supply of hydrogen for star fuel and enough neutrons to build up the heavier elements in the universe.[41] Again, a meticulous inner "design" assures a universe with long-term sources of energy and elemental diversity.

Balancing the Nuclear Weak Coupling Force

The weak force governs certain interactions at the subatomic or nuclear level. If the weak force coupling constant were slightly larger, neutrons would decay more rapidly, reducing the production of deuterons, and thus of helium and elements with heavier nuclei. On the other hand, if the weak force coupling constant were slightly weaker, the big bang would have burned almost all of the hydrogen into helium, with the ultimate outcome being a universe with little or no hydrogen and many heavier elements instead. This would leave no long-lived stars and no hydrogen-containing compounds, especially water. In 1991, Reinhard Breuer noted that the appropriate mix of hydrogen and helium to provide hydrogen-containing compounds, long-term stars, and heavier elements is approximately 75% hydrogen and 25% helium, which is just what we find in our universe.[42]

This is obviously an illustrative—but not exhaustive—list of cosmic "coincidences." Clearly, the four forces in nature and the universal constants must be very carefully calibrated or scaled to provide a universe that satisfies the key requirements for life that have been enumerated on the original initial "needs statement": for example, elemental diversity, an abundance of oxygen and carbon, and a long-term energy source (our sun) that is precisely matched to the bonding strength of organic molecules with a minimal absorption by water in Earth's terrestrial atmosphere. John Wheeler, Professor of Physics at Princeton, in discussing these observations claimed: "The necessity to produce life lies at the center of the universe's whole machinery and design … Slight variations in physical laws such as gravity or electromagnetism would make life impossible."[43]

Initial Conditions

The "big bang" follows the physics of any explosion, though on an inconceivably large scale. The critical boundary condition for the big bang is its initial velocity. If the velocity is too fast, the matter in the universe expands too quickly, and never condenses into planets, stars, and galaxies. If the initial velocity is too slow, the universe expands only for a short time and then quickly collapses under the influence of gravity. Well-accepted cosmological models tell us that the initial velocity must be specified to a precision of $1/10^{60}$. Newer models tell us that the initial velocity needs to be specified to $1/10^{123}$.[44] Furthermore, the ratio of the gravitational energy to

the kinetic energy must be equal with a variation of no more than one part in 100,000. While these numbers may change over time, all possible models of the big bang will contain boundary conditions of a remarkably specific nature that cannot simply be described as "fortuitous." It is clear that the initial conditions for a "big bang beginning" for the universe are very demanding in their required precision.

By Many Measures, Nature Appears to Be Finely Tuned

There are literally hundreds of examples of fine tuning that seem to be essential to enable the universe to have the many features that are essential for complex, conscious life. What remains to be explained is how the universe just happens to have this remarkable combination of particular laws of nature with (1) just the right mathematical form, (2) universal constants that must be and are remarkably precise, and (3) mind-boggling initial conditions that our universe satisfies with amazing specificity.

Metaphysical Implications of Fine Tuning

"Finely tuned" is a description of how our universe appears that is widely accepted in the scientific community. This observation raises the very interesting question of why the universe is finely tuned. Is there a fine tuner? The remainder of this article will explore this metaphysical question: namely, does fine tuning point to an intelligent agency, a supernatural fine tuner?

Richard Dawkins, a British zoologist and one of the world's foremost apologists for classical Darwinism and atheism, addressed the question of design in his 1996 book *Climbing Mount Improbable*, by comparing particular, designed artifacts with similar accidents in nature.[45] Dawkins illustrates the concept of design by comparing the example of Mount Rushmore upon which are carved the clearly recognizable images of Presidents George Washington, Thomas Jefferson, Abraham Lincoln, and Theodore Roosevelt (fig. 3) to a naturally occurring rock in Hawaii that casts a shadow that resembles President John F. Kennedy (fig. 4), illustrating the difference between an accidental occurrence and an artifact that was the result of design and execution. Obviously, one could confirm this interpretation by carefully examining the surfaces of both images. One would have marks from chisels and dynamite utilized by the sculptor Gutzon Borglum, while the other would have a surface that was the result of natural weathering since there was no designer. The sheer number of details in which the Mount Rushmore sculptured faces resemble the four presidents testifies to the presence of an intelligent agent, a human sculptor. No one could seriously attribute these magnificent faces to the "creative" forces of wind, rain, sleet, and hail.

Generally, design is associated with complexity, which can sometimes be quantified with information content. To specify the three-dimensional topography of Mount Rushmore requires orders of magnitude more pieces of information than that required to create a two-dimensional silhouette with minimum features that looks like John Kennedy, but only when viewed from a certain direction. What does the nature of nature previously presented in this article suggest about the origin of our magnificent universe?

This second level of examination to be used to interpret the fine-tuning data is called "abduction,"[46] or

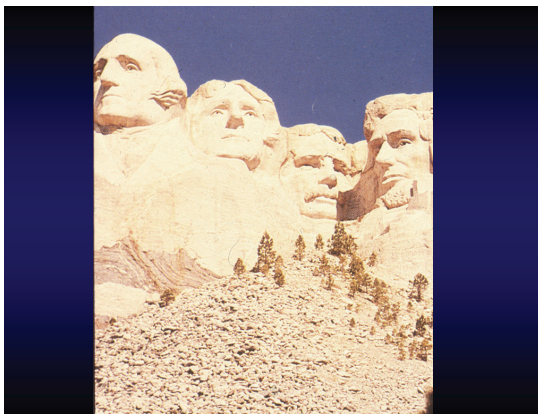

Figure 3. Mount Rushmore

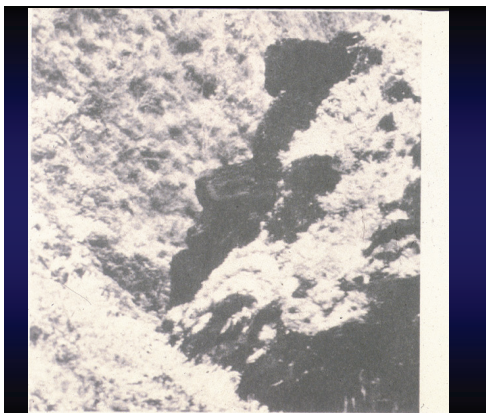

Figure 4. Rock in Hawaii

"inference to the best explanation," which is a means of justifying a hypothesis when there is insufficient data for the claim to have the warrant of an established theory. This approach allows one to posit a (maybe very) tentative hypothesis, while avoiding the erroneous claim that you cannot know anything about a question unless you have a much greater amount of data.

Proclivities of Theists and Atheists in Interpreting the Fine-Tuning Data

Theists believe that God can choose to act by performing miracles (God acting in some extraordinary, unpatterned ways that are not described by the laws of nature). They also believe that God can choose to act in his customary (patterned) ways, as described by the so-called laws of nature. Alternatively, God can choose to act in some combination of patterned and extraordinary ways to create a suitable habitat for human beings. Some theists believe that God chose to work only in his customary way (as described by the laws of nature) in the creation of our universe, while others believe that he chose to use some combination of miracles and processes.

Atheists believe that there is no God, and that all explanations of phenomena in nature will in due course be found to have "natural" explanations that describe the autonomous functioning of nature. Some, like Victor Stenger in his book *The Fallacy of Fine Tuning: Why the Universe Is Not Designed for Us,* seek to dispute the claims that the universe is fine tuned.[47] Michael Strauss has provided an excellent critique of Stenger's book, showing in detail why Stenger's claim that there is no fine tuning is clearly wrong.[48]

Many scientists (including atheists) seem to implicitly accept the evidence for fine tuning in the universe, responding to the overwhelming evidence for fine tuning by embracing the idea of a multiverse. If there actually are 10^{500} universes produced by inflation and if each universe has a different set of "natural laws," universal constants, and initial conditions, then fine tuning by accident becomes more plausible. However, there are serious questions about the existence of a multiverse, since it is impossible to "see" outside our own universe. In an editorial entitled "A Crisis at the Edge of Physics," in *The New York Times* (June 5, 2015), Adam Frank and Marcelo Gleiser (based on a recent article in *Nature)*, highlight the growing criticism of positing a multiverse, asserting that it is an audacious claim that can be neither confirmed nor refuted by experimental observations.[49] Alan Lightman, a professor of physics at MIT, confesses in his excellent book, *The Accidental Universe,* that he is an atheist who accepts the existence of a multiverse because he finds the arguments for fine tuning very persuasive and the multiverse seems to be the only alternative, acknowledging that this must be taken by faith as we cannot see outside our own universe.[50] This is an example of how the remarkable fine tuning in our universe is taken seriously by a thoughtful atheist.

One of the most compelling arguments for fine tuning comes from a leading string theorist, Leonard Susskind, in the foreword to his 2005 book *The Cosmic Landscape.*

> The real mystery raised by modern cosmology concerns a silent "elephant in the room," an elephant in the room I might add, that has been a huge embarrassment to physicists: why is it that the universe has all of the appearances of having been specially designed just so that life forms like us can exist. This puzzled scientists and at the same time encouraged those who prefer the false comfort of a creationist myth … In the past most physicists (including me) have chosen to ignore the elephant—even to deny its existence. They preferred to believe that nature's laws follow from some elegant mathematical principle and that the apparent design of the universe is merely a lucky accident. But recent discoveries in astronomy, cosmology, and above all, String Theory have left theoretical physicists little choice but to think about these things.[51]

Paul Steinhardt, Albert Einstein Professor in Science (Princeton) and Director of the Princeton Center for Theoretical Science, made some extraordinary claims in an interview with science writer John Horgan that was published in *Scientific American*, December 1, 2014.[52] Steinhardt complained that inflation theory, which he helped to create in 1982, was "developed" in part to "create" a multiverse that was in turn motivated by the desire to account for "fine tuning" in our universe by predicting an almost infinite number of alternative universes besides our own, with one or more having universal constants with the necessary values to permit life. Steinhardt said, "The fact that we had to introduce fine tuning (into the inflation model) to remove the "fine tuning" (that

we see in our universe) was worrisome. This problem has never been resolved." Since inflation theory requires new physical laws and new finely tuned constants, it did not resolve the challenge of accounting for fine tuning. It only pushes fine tuning down one level.

What about the "God-of-the-Gaps" Problem?

It is difficult to do justice to this extremely important question in the limited remaining space for this essay. Fortunately, this topic has been thoughtfully addressed in articles in this journal, *Perspectives on Science and Christian Faith*. Randy Isaac highlights his reasons for avoiding fine-tuning arguments as his primary support of biblical theism, but sees fine tuning as consistent with and reinforcing his faith commitment to biblical theism.[53] Ron Larson, Jack Collins, and David Snoke argue in different ways that we should be mindful of the God-of-the-gaps mistakes that can and have been made in the past so as not to repeat them. They offer clear directions on ways that this can be done.[54] I would add one additional approach that I have used in this article. If one frames the discussion of God's work in nature more carefully, the God-of-the-gaps concern can be minimized. God's work in nature in his customary patterned way (what we call the laws of nature), should be distinguished from God working in some extraordinary way, which may be viewed as a miracle.

Features in nature such as fine tuning can tentatively be assumed to be the consequence of God working in an extraordinary way. However, the discovery of the Grand Theory of Everything would not change my belief in God, but only my view of how God created and operates creation. It changes the question, "Did God do it or did nature do it autonomously?" to an a priori assumption that God did it, with the remaining question, "How did God do it—in his customary way (sometimes called the laws of nature), or in some extraordinary way (sometimes called a miracle)?"

Conclusion

Does our universe look more like Mt. Rushmore (fig. 3) or the rock in Hawaii (fig. 4)? The "nature of nature," especially fine tuning, provides clear and compelling evidence for our all-powerful, loving Creator God, who can be seen through "the things that have been made, so that those who do not believe are without excuse" (Rom. 1:20). ✧

Notes

[1]John D. Barrow and Frank J. Tipler, *The Anthropic Cosmological Principle* (New York: Oxford University Press, 1988).
[2]John Leslie, *Universes* (New York: Routledge, 1989).
[3]Paul Davies, *The Accidental Universe* (Cambridge, UK: Cambridge University Press, 1982).
[4]Paul Davies, *The Cosmic Blueprint* (Portsmouth, NH: Heinemann, 1988).
[5]John Gribbin and Martin Rees, *Cosmic Coincidences* (New York: Bantam Books, 1989).
[6]Reinhard Breuer, *The Anthropic Principle: Man as the Focal Point of Nature*, trans. Harry Newman and Mark Lowery (Cambridge, MA: Birkhäuser Boston, 1991).
[7]Gilles Cohen-Tannoudji, *Universal Constants in Physics,* trans. Patricia Thickstun (New York: McGraw-Hill, 1993).
[8]Paul Davies, *The Goldilocks Enigma: Why Is the Universe Just Right for Life?* (New York: Penguin Books, 2006).
[9]Paul Davies, *Cosmic Jackpot: Why Our Universe Is Just Right for Life* (Boston, MA: Houghton Mifflin, 2007).
[10]John D. Barrow, *The Constants of Nature: The Numbers That Encode the Deepest Secrets of the Universe* (New York: Vintage Books, 2002).
[11]Hugh Ross, *Why the Universe Is the Way It Is* (Grand Rapids, MI: Baker Books, 2008).
[12]Martin Rees, *Just Six Numbers: The Deep Forces That Shape the Universe* (New York: Basic Books, 2000).
[13]Alister E. McGrath, *A Fine Tuned Universe: The Quest for God in Science and Theology* (Louisville, KY: John Knox Press, 2009).
[14]Stephen Hawking and Leonard Mlodinow, *The Grand Design* (New York: Bantam Books, 2010), 9–10.
[15]Peter J. Mohr, David B. Newell, Barry N. Taylor, "CODATA Recommended Values of the Fundamental Physical Constants: 2014," *Reviews of Modern Physics* 88, no. 3 (26 September 2016): 035009, https://link.aps.org/doi/10.1103/RevModPhys.88.035009.
[16]Peter D. Ward and Donald Brownlee, *Rare Earth: Why Complex Life Is Uncommon in the Universe* (New York: Copernicus Books, 2000).
[17]Ibid., 37.
[18]George F. R. Ellis, "Does the Multiverse Really Exist?," *Scientific American* 305, no. 2 (August 2011): 38–43.
[19]Richard Dawkins, *Climbing Mount Improbable* (New York: Norton, 1996), 2–4.
[20]Ibid.
[21]Johannes Kepler, *De Fundamentis Astrologiae Certioribus,* Thesis XX (1601).
[22]Galileo Galilei; this comment is widely attributed to Galileo, but without reference.
[23]Morris Kline, *Mathematics: The Loss of Certainty* (New York: Oxford University Press, 1980).
[24]Ibid., 52.
[25]Eugene Wigner, "The Unreasonable Effectiveness of Mathematics in the Physical Sciences," *Communications on Pure and Applied Mathematics* 13, no. 1 (1960): 1–14.
[26]Albert Einstein, *Letters to Solovine* (New York: Philosophical Library, 1987), 131.

[27]R. Courant and D. Hilbert, *Methods of Mathematical Physics*, vol. 2, *Partial Differential Equations* (New York: John Wiley & Sons, 1966), 765–66.
[28]Paul Davies, *Superforce: The Search for a Grand Unified Theory of Nature* (New York: Simon and Schuster, 1984), 243.
[29]Fred Hoyle, *Religion and the Scientists,* quoted in Barrow and Tipler, *The Anthropic Cosmological Principle*, 22.
[30]Leslie, *Universes*, 36–39.
[31]Barrow and Tipler, *The Anthropic Cosmological Principle,* 336.
[32]Michael Denton, *Nature's Destiny: How the Laws of Biology Reveal Purpose in the Universe* (New York: The Free Press, 1998), 54–57.
[33]*Encyclopaedia Britannica*, vol. 18, 15th edition (1994): 200.
[34]Barrow and Tipler, *The Anthropic Cosmological Principle,* 322.
[35]S. W. Hawking, "Is the End in Sight for Theoretical Physics?," *Physics Bulletin* 32, no. 32 (1981): 15–17.
[36]Leslie, *Universes,* 35–40.
[37]Ellis, "Does the Multiverse Really Exist?," 43.
[38]F. Hoyle et al., "The 7.68-MeV State in C^{12}," *Physics Review* 92 (1953): 649.
[39]F. Hoyle, "The Universe: Past and Present Reflections," *Annual Review of Astronomy and Astrophysics* 20 (1982): 16.
[40]Hawking, "Is the End in Sight for Theoretical Physics?," 15.
[41]Barrow and Tipler, *The Anthropic Cosmological Principle*, 371.
[42]Breuer, *The Anthropic Principle*, 102.
[43]John Wheeler, quoted in John Boslough, "Inside the Mind of John Wheeler," *Reader's Digest* (September 1986): 107.
[44]William Lane Craig, "Design and the Anthropic Fine-Tuning of the Universe," in *God and Design,* ed. Neil A. Manson (New York: Routledge, 2003), 157.
[45]Dawkins, *Climbing Mount Improbable*, 5.
[46]*Stanford Encyclopedia of Philosophy*, substantive revision, April 28, 2017, s.v. "Abduction."
[47]Victor J. Stenger, *The Fallacy of Fine Tuning: Why the Universe Is Not Designed for Us* (Amherst, NY: Prometheus), 2011.
[48]Michael Strauss, blog, http://www.michaelgstrauss.com/2017/07/is-fine-tuning-fallacy.html.
[49]Adam Frank and Marcelo Gleiser, "A Crisis at the Edge of Physics," *New York Times*, June 5, 2015, New York edition, SR5, https://www.nytimes.com/2015/06/07/opinion/a-crisis-at-the-edge-of-physics.html.
[50]Alan Lightman, *The Accidental Universe: The World You Thought You Knew* (New York: Vintage Books, 2014), 1–22.
[51]Leonard Susskind, *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design* (New York: Little, Brown & Company, 2005), x, xi.
[52]John Horgan, "Physicist Slams Cosmic Theory He Helped Conceive," *Scientific American* (December 1, 2014), https://blogs.scientificamerican.com/cross-check/physicist-slams-cosmic-theory-he-helped-conceive/.
[53]Randy Isaac, "From Gaps to God," *Perspectives on Science and Christian Faith* 57, no. 3 (2005): 230–33.
[54]Ronald Larson, "Revisiting the God of the Gaps," *Perspectives on Science and Christian Faith* 61, no. 1 (2009): 13–22; ___, "Design or the Multiverse?," *Perspectives on Science and Christian Faith* 63, no. 1 (2011): 42–47; Jack Collins, "Miracles, Intelligent Design, and God-of-the-Gaps," *Perspectives on Science and Christian Faith* 55, no. 1 (2003): 22–29; David Snoke, "In Favor of God-of-the-Gaps Reasoning," *Perspectives on Science and Christian Faith* 53, no. 3 (2001): 152–58.

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