

The Anthropic Principle

(Also list under The Fine-Tuning argument)

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The Anthropic Coincidences

In 1919, mathematician and physicist Hermann Weyl puzzled why the ratio of the electromagnetic force to the gravitational force between two electrons is such a huge number, $N_1 = 10^{39}$.¹ Weyl wondered why this should be the case, expressing his intuition (and nothing more than that) that "pure" numbers, like π , that is, numbers that do not depend any system of units, when occurring in the description of physical properties, should most naturally occur within a few orders of magnitude of unity. Why 10^{39} ? Why not 10^{57} or 10^{-123} ? Some principle, Weyl thought, must select out 10^{39} .

In 1923, astronomer Arthur Eddington agreed: "It is difficult to account for the occurrence of a pure number (of order greatly different from unity) in the scheme of things; but this difficulty would be removed if we could connect it to the number of particles in the world—a number presumably decided by accident."² He estimated that number, now called the "Eddington number," to be $N = 10^{79}$. Well, N is not too far from the square of N_1 .

In 1937, physicist Paul Dirac noticed that N_1 is the same order of magnitude as another pure number N_2 that gives the ratio of a typical stellar lifetime to the time for light to traverse the radius of a proton.³ That is, he found two seemingly unconnected large numbers to be of the

same order of magnitude. If one number being large is unlikely, how much more unlikely is another to come along with about the same value?

In 1961, astrophysicist Robert Dicke pointed out that N_2 is necessarily large in order that the lifetime of typical stars is sufficient to generate heavy chemical elements such as carbon. Furthermore, he showed that N_1 must be of the same order of N_2 in any universe with heavy elements.⁴ Thus, this became the first of what are called the *anthropic coincidences*, connections between physical constants that seem to be necessary for the existence of life in the universe.

While many examples of claimed anthropic coincidences can be found in the literature, here are the most significant:

1. The electromagnetic force is 39 orders of magnitude stronger than the gravitational force. If they were more comparable in strength, stars would have collapsed long before life had a chance to evolve.
2. The vacuum energy density of the universe is at least 120 orders of magnitude lower than some theoretical estimates. If at any time it were as large as these calculations suggest, the universe would have quickly blown apart.
3. The electron's mass is less than the difference in the masses of the neutron and proton. Thus, a free neutron can decay into a proton, electron, and anti-neutrino. If this were not the case, the neutron would be stable and most of the protons and electrons in the early universe would have combined to form neutrons, leaving little hydrogen to act as the main component and fuel of stars.
4. The neutron is heavier than the proton, but not so much heavier that neutrons cannot be bound in nuclei, where conservation of energy prevents the neutrons from

decaying. Without neutrons we would not have the heavier elements needed for building complex systems such as life.

5. The carbon nucleus has an excited energy level at around 7.65 million electron-volts (MeV). Without this state, insufficient carbon would be manufactured in stars to form the basis for life. Using anthropic arguments, astronomer Fred Hoyle predicted this energy level before it was confirmed experimentally.⁵

The Three Anthropic Principles

In 1974, astronomer Brandon Carter introduced the notion of the *anthropic principle*, which hypothesized that the anthropic coincidences are not the result of chance but somehow built into the structure of the universe.⁶ He proposed two versions. His *weak anthropic principle* (WAP) states that

We must be prepared to take into account the fact that our location in the universe is necessarily privileged to the extent of being compatible with our existence as observers.

Carter's *strong anthropic principle* (SAP) says that

The Universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage.

Other authors have presented their own versions of anthropic principles, over thirty being available in the literature. I will just mention three more versions—those proposed by mathematician John Barrow and physicist Frank Tipler in their tome on the subject.⁷ The first two are rephrases of Carter's wording. The Barrow and Tipler WAP reads:

The observed values of all physical and cosmological quantities are not equally probable but take on values restricted by the requirement that there exist sites

where carbon-based life can evolve and by the requirement that the Universe be old enough for it to have already done so.

Note that Barrow and Tipler require the existence of “carbon-based life” while Carter simply refers to the existence of “observers.” This is better phrasing since many of the coincidences have to do with carbon, directly or indirectly.

Barrow and Tipler’s SAP reads:

The Universe must have those properties which allow life to develop within it at some stage in its history.

Note that all three authors say that the universe “must” have the properties that allow for the creation of life, or, at least, observers. Thus, the SAP seems to imply some intent or purpose within the universe.

Barrow and Tipler round out their various anthropic principles with the *final anthropic principle* (FAP):

Intelligent, information processing must come into evidence in the Universe, and, once it comes into existence, it will never die out.

Note that the term "anthropic principle" is a misnomer, as is "anthropic coincidence." While singling out our kind of carbon-based life, none of the coincidences require human life or demand that carbon-based life develop intelligence.

Implications

The WAP is considered by most physicists and cosmologists to be a simple tautology. Of course the constants of nature are suitable for our form of life. If they were not, we would not be here to talk about it. For a study of selection effects, see Bostrom.⁸

Still, the anthropic coincidences strike most people as puzzling and they wonder what might imply about the nature of the universe. Barrow and Tipler suggest three different possible implications of the SAP:

(A) There exists one possible universe "designed" with the goal of generating and sustaining "observers."

(B) Observers are necessary to bring the Universe into being.

(C) An ensemble of other different universes is necessary for the existence of our universe.

Authors with religious agenda have interpreted (A) as evidence for a creator God, in particular, the God they happen to worship. They ask: How can the universe possibly have obtained the unique set of physical constants it has, so exquisitely fine-tuned for life as they are, except by purposeful design—design with life and perhaps humanity in mind?^{9,10}

However, nothing in the above discussion requires that this God be the one of any particular faith. Indeed, “design” might be interpreted as a purely natural process, perhaps an evolutionary one akin to the design inherent in Darwinian natural selection or just some structure built into the universe that science has not yet explained.¹¹

Possibility (B) arises from a mystical misinterpretation of quantum mechanics. Though it has formed the basis of a large popular literature in recent years, few physicists take it very seriously.¹²

Possibility (C) presents the notion that multiple universes exist and so we happen to just live in that universe which is suitable for the evolution of our kind of life. We will consider this possibility below.

Fine-tuning in the Eye of the Beholder

The strength of the electromagnetic force is determined by the value of the unit electric charge—the magnitude of the charge of an electron—designated by e . The claim is that e is a constant that has been fine-tuned far from its natural value in order that we have stars sufficiently long-lived for life to evolve (coincidence 1 above).

However, e is not a constant. We now know from the highly successful *standard model* of particles and forces that e and the strengths of the other elementary forces vary with energy and changed very rapidly in the first moments of the big bang. According to current understanding, in the very high-energy environment at the start of the big bang, the four known forces were unified as one force, just as Weyl anticipated should happen "naturally." That is, e began with its natural value. Then, as the universe cooled, the forces separated by a process called *spontaneous symmetry breaking* into the four basic kinds we experience at much lower energies today, with e and the other force strengths having evolved to their current stable values. Stellar formation, and thus life, had to simply wait for the forces to separate sufficiently. Actually the wait was a just tiny fraction of a second.

Only four parameters are needed to specify the broad features of the universe, as it exists today: the masses of the electron and proton and the current strengths of the electromagnetic and strong interactions.¹³ I have studied how the minimum lifetime of a typical star depends on the first three of these parameters. Varying them by ten orders of magnitude around their present values, I find that over half of the stars will have lifetimes exceeding a billion years.¹⁴

Large stars need to live tens of millions of years or more to allow for the fabrication of heavy elements. Smaller stars, such as our sun, also need about a billion years to allow life to develop within its solar system of planets. Earth did not even form until nine billion years after

the big bang. The requirement of long-lived stars is easily met for a wide range of possible parameters. The universe is certainly not fine-tuned for this characteristic.

One of the many major flaws with most studies of the anthropic coincidences is that the investigators vary a single parameter while assuming all the others remain fixed. They further compound this mistake by proceeding to calculate meaningless probabilities based on the grossly erroneous assumption that all the parameters are independent.¹⁵ In my study I took care to allow several parameters to vary at the same time.

In a very impressive paper, physicist Anthony Aguire has independently examined the universes that result when six cosmological parameters are simultaneously varied by orders of magnitude and found he could construct cosmologies in which "stars, planets, and intelligent life can plausibly arise."¹⁶

The standard model contains about twenty parameters that are not determined by the theory but must currently be inferred from experiments. However, only four are needed to specify most properties of matter. These are the masses of the electron and the two quarks ("up" and "down") that constitute protons and neutrons, and a universal strength parameter from which the value e and the other force strengths are determined. Ultimately, it is hoped that all the basic parameters will be determined by theories that unify gravity with the standard model, for example, *string theory*.¹⁷ We must wait to see if the calculated masses of the electron and neutron come out to satisfy coincidences 3 and 4 above. Another possibility, which we will consider below, is that these parameters are random.

Many of the examples of anthropic coincidences found in theological literature result from simple misunderstanding of physics. For example, any reference to the fine-tuning of constants like the speed of light c , Planck's constant, h , or Newton's gravitational constant, G , are

irrelevant since these are all arbitrary constants whose values simply define the system of units being used.

Also, some of the "remarkable" precision people talk about is highly misleading, depending on the arbitrary choice of units. For example, theologian John Jefferson Davis asserts, "If the mass of neutrinos were 5×10^{-34} instead of 5×10^{-35} kg [kilogram], because of their great abundance in the universe, the additional gravitational mass would result in a contracting rather than expanding universe."¹⁸ This sounds like fine-tuning by one part in 10^{35} . However, as philosopher Neil Manson points out, this is like saying that "if he had been one part in 10^{16} of a light-year shorter (that is, one meter shorter), Michael Jordan would not have been the world's greatest basketball player."¹⁹ Incidentally, Davis' estimate of the neutrino mass is not accurate. In fact, the individual masses are not known, with experiments so far measuring only mass differences. Furthermore, if the mass of neutrinos were ten times greater, there likely would be ten times fewer of them in the cosmos and the gravitational effect would be the same. So this fine-tuning claim collapses on several fronts.

Let us next consider coincidence 5, which asserts fine-tuning is needed to produce carbon. Nobel laureate physicist Steven Weinberg has shown that the production of carbon in stars is not very dependent on the 7.65 MeV nuclear energy level predicted by Hoyle. Rather it hinges on the radioactive state of a carbon nucleus formed out of three beryllium nuclei. This misses being too high for carbon production by 20 percent, which, as he says, "is not such a close call after all."²⁰

In short, much of the so-called fine-tuning of the parameters of microphysics is in the eye of the beholder, not always sufficiently versed in physics, who plays with the numbers until they seem to support a prior belief that was based on something other than objective scientific analysis.

The Vacuum Energy Problem

Although we normally think of the vacuum as empty of matter and energy, gravitational energy can be stored in the curvature of empty space. Furthermore, quantum mechanics implies that a vacuum will contain a minimum *zero-point energy*.

Weinberg was perhaps the first to highlight the *vacuum energy problem* (coincidence 2). He referred to it as the *cosmological constant problem*, since any vacuum energy density is equivalent to the parameter in Einstein's theory of general relativity called the cosmological constant that relates to the curvature of empty space.²¹

Calculations gave a value for the vacuum energy density that is some 120 orders of magnitude greater than the maximum value possible from observations. Since this density is constant, it would seem to have been fine-tuned with this precision from the early universe, so that its value today allowed for the existence of life.

Until recently, it was thought that the cosmological constant was probably exactly zero, in which case there was no need for fine-tuning. However, in 1998, two independent research groups studying distant supernovae were astonished to discover that the current expansion of the universe is *accelerating*.²² More recent observations have confirmed this result. The universe is falling up! The source of this cosmic acceleration is some still-unidentified *dark energy*, which constitutes 70 percent of the mass of the universe. One possible explanation is gravitational repulsion by means of the cosmological constant, that is, by way of the vacuum energy field that is allowed by general relativity.

If that is the case, then the cosmological constant problem resurfaces. In the meantime, we now can argue plausibly that the original calculation was incomplete and a proper calculation will give zero for the vacuum energy density. Until these newer estimates are shown to be

wrong, we cannot conclude that the vacuum is fine-tuned for life and have no particularly strong need to invoke a designer deity.

But, then, what is responsible for cosmic acceleration? What is the nature of the dark energy? A cosmological constant is not the only possible source of gravitational repulsion. According to general relativity, any matter field will be repulsive if its pressure is sufficiently negative. Theorists have proposed that the dark energy may be a matter field, called *quintessence*, which requires no fine-tuning.

Is Our Form of Life the Only Possible?

Consider the fact that we live on Earth, rather than Mercury, Venus, Mars, or some other planet in the known solar system. Mercury and Venus are too hot and Mars is too cold. Mercury has no atmosphere, while the atmosphere of Venus is too thick for the sun's rays to penetrate to the surface and the atmosphere of Mars is too thin to provide sufficient oxygen and water.

The temperature range and other properties of Earth are just right for life. For example, Earth's atmosphere is transparent to the same spectrum of light to which our eyes are sensitive. Anthropoc reasoning would have it that the atmosphere was fine-tuned so that humans and other animals could see at a distance. The transparency also happens to match the spectral regions within which the electromagnetic radiation from the sun is maximal. Again, anthropic reasoning would attribute this to design with humans in mind.

But, rather obviously, life evolved on Earth because conditions here were right. The type of life that evolved was suitable for those conditions.

With 100 billion stars in 100 billion galaxies in the visible universe, and countless others, according to current cosmological theory, likely to lie beyond our horizon, the chances of some form of life developing on some planets seems very good. Indeed, many of the chemical

ingredients of life such as complex molecules have been observed in outer space. Of course, we will not know for sure until we find such life.

Still, we expect any life found in our universe to be carbon-based, or at least based on heavy element chemistry. The fine-tuning argument implies that this is the only form of life that is possible, and that is a huge, unwarranted assumption. Even if all the forms of life in our universe turn out to be of this basic structure, it does not follow that life is impossible under any other arrangement of physical laws and constants. This fact alone is fatal to the fine-tuning argument.

Carbon would seem to be the chemical element best suited to act as the building block for the type of complex molecular systems that develop lifelike qualities. Even today, new materials assembled from carbon atoms exhibit remarkable, unexpected properties, from superconductivity to ferromagnetism. However, we have no reason to assume that only carbon life is possible.

Given the known laws of physics and chemistry, we can imagine life based on silicon or other elements chemically similar to carbon. While carbon may be optimum for the parameters of our universe, silicon might be better if the parameters were slightly different. However, whatever elements are used, they still require cooking in stars and thus a universe old enough for stellar evolution.

We can only speculate what form life might take on another planet, with different conditions. It would be wonderful to have more examples of life, but we do not. And, any speculation about what form life might take in a universe with a different electron mass, electromagnetic interaction strength, or different laws of physics is even more problematical. We simply do not have the knowledge to say whether life of *some* sort would not occur under different circumstances.

Multiple Universes

We have seen that cosmological parameters, such as the cosmological constant, need not have been fine-tuned for life. We also have a plausible scenario in which the strengths of the four forces evolved to their current values and that long-live stars can be expected over a large range of these and other physical parameters. The hope is that a future theory that unifies gravity and microphysics will enable the calculation of the few parameters that are needed to define the fundamental structure of matter. However, even if this hope is not realized current theories already suggest another possible answer to the anthropic coincidences.

For example, our universe may be just one of a huge number other universes within some super universe called the *multiverse*. The fundamental parameters may be randomly distributed among universes and we live in the one where the parameters happen to be suitable for the evolution of our form of life.

Theists have scoffed at the idea of multiple universes, arguing that we have no evidence for the existence of any but our own. But, we have no evidence for their God, either. At least in the case of multiple universes we have physical theories, based firmly on empirical data within our own universe, pointing to their existence. The highly successful cosmological inflation model implies that the spontaneous event that created our universe would have been repeated many times.²³ While this may still be classified as speculation, it is speculation based on good science and observational data. The speculation that a Creator God exists is based on no science and no data.

Several commentators have argued that a multiverse cosmology violates Occam's razor.²⁴ This is wrong. The entities that Occam's law of parsimony forbids us from "multiplying beyond necessity" are theoretical hypotheses, not universes. Although the atomic theory of matter multiplied the number of bodies we must consider in solving a thermodynamic problem by 10^{24}

or so per gram, it did not violate Occam's razor. Instead, it provided for a simpler, more powerful, more economic exposition of the rules that were obeyed by thermodynamic systems.

The existence of many universes is in fact consistent with all we know about physics and cosmology. No new hypotheses are needed to introduce them. It takes an added hypothesis to rule them out—a super law of nature that says only one universe can exist. That would be an uneconomical hypothesis. Putting it another way, we have no basis for assuming that only a single universe exists. The theist argument requires two hypotheses that are unwarranted by data or theory: (1) only one universe exists and (2) God exists.

A Life Principle?

Despite the apparent uncongeniality of the universe to life, life is present and some people still insist that this is remarkable. Physicist Paul Davies suggests a *life principle* is "written into the laws of physics" or "built into the nature of the universe."

Of course, nowhere in current physics, chemistry, or biology do we see any sign of a fundamental life principle, some *élan vital* that distinguishes life from non-life. Davies speculates, "a felicitous mix of law and chance might be generalised to cosmology, producing directional evolution from simple states, through complex, to life and mind."²⁵

Davies shares this notion with Nobel laureate biochemist Christian de Duve²⁶ and biologist Stuart Kauffman.²⁷ These authors all seem to view the life principle as some previously unrecognized, holistic, teleological law of nature. Nancey Murphy and other theologians, who admit that the traditional notion of a separate soul and body is no longer viable given the evidence from neuroscience, have termed this notion "nonreductive physicalism." They think they can find a place for God and the soul therein.²⁸

However, computer simulations indicate that complexity evolves from simplicity by familiar, purely reductive physical processes without the aid of any overarching holistic guiding principle. The life principle, if it exists, may be one of the type of so-called "emergent principles" found in chaos and complexity theory that naturally arise from the nonlinear, dissipative, but still purely local interactions of material particles. These cannot be called new laws of physics since they follow from already existing laws, if not by direct, mathematical proof, then by computer simulation.

A Tiny Pocket of Complexity

Perhaps any random universe, regardless of its properties, will naturally develop at least some tiny pockets of complexity within a vast sea of randomness, which is just what we see in our universe. Complexity is not so ubiquitous in our universe as most people seem to think. The photons in the Cosmic Microwave Background, a billion times more common than hydrogen atoms, are random to one part in a hundred thousand. The visible matter we see around us and in the sky, which impresses us so much by its complexity, constitutes one-half of one percent of the mass of the universe. Perhaps we do not need either a designer or multiple universes to explain such small deviation from chance behavior.

I find it rather amusing that theists make two contradictory arguments for life requiring a creator. Sometimes you hear these from the same people. In the fine-tuning argument, the universe is so *congenial* to life that the universe must have been created. But, if it is so congenial, then we should expect life to evolve by natural processes. In the second argument, which one hears from creationists and anti-evolutionists, the universe is so *uncongenial* to life that life must have been created. In that case it is too unlikely for life to have evolved by natural

processes and so must have been produced by an intelligent designer. But, then life could very easily have been an improbable accident.

The universe looks just as it would be expected to look if it were not created by God. From this we can conclude, beyond a reasonable doubt, that such a God does not exist.

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