

Anthropic principle

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In astrophysics and cosmology, the **anthropic principle** (from the Greek, *anthropos*, human) is the philosophical consideration that observations of the physical Universe must be compatible with the conscious life that observes it. Some proponents of the anthropic principle reason that it explains why the Universe has the age and the fundamental physical constants necessary to accommodate conscious life. As a result, they believe it is unremarkable that the universe's fundamental constants happen to fall within the narrow range thought to be compatible with life.^[1]

The strong anthropic principle (SAP) as explained by Barrow and Tipler (see variants) states that this is all the case because the Universe is compelled, in some sense, for conscious life to eventually emerge. Critics of the SAP argue in favor of a weak anthropic principle (WAP) similar to the one defined by Brandon Carter, which states that the universe's ostensible fine tuning is the result of selection bias: i.e., only in a universe capable of eventually supporting life will there be living beings capable of observing any such fine tuning, while a universe less compatible with life will go unhehld.

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Definition and basis

The principle was formulated as a response to a series of observations that the laws of nature

and parameters of the Universe take on values that are consistent with conditions for life as we know it rather than a set of values that would not be consistent with life on Earth. The anthropic principle states that this is a necessity, because if life were impossible, no one would know it. That is, it must be possible to observe *some* Universe, and hence, the laws and constants of any such universe must accommodate that possibility.

The term *anthropic* in "anthropic principle" has been argued ^[2] to be a misnomer.^[3] While singling out our kind of carbon-based life, none of the finely tuned phenomena require human life or some kind of carbon chauvinism.^{[4][5]} Any form of life or any form of heavy atom, stone, star or galaxy would do; nothing specifically human or anthropic is involved.

The anthropic principle has given rise to some confusion and controversy, partly because the phrase has been applied to several distinct ideas. All versions of the principle have been accused of discouraging the search for a deeper physical understanding of the universe. The anthropic principle is often criticized for lacking falsifiability and therefore critics of the anthropic principle may point out that the anthropic principle is a non-scientific concept, even though the weak anthropic principle, "*conditions that are observed in the universe must allow the observer to exist*",^[6] is "easy" to support in mathematics and philosophy, i.e. it is a tautology or truism. However, building a substantive argument based on a tautological foundation is problematic. Stronger variants of the anthropic principle are not tautologies and thus make claims considered controversial by some and that are contingent upon empirical verification.^{[7][8]}

Anthropic coincidences

Main article: Fine-tuned Universe

In 1961, Robert Dicke noted that the age of the universe, as seen by living observers, cannot be random.^[9] Instead, biological factors constrain the universe to be more or less in a "golden age," neither too young nor too old.^[10] If the universe were one tenth as old as its present age, there would not have been sufficient time to build up appreciable levels of metallicity (levels of elements besides hydrogen and helium) especially carbon, by nucleosynthesis. Small rocky planets did not yet exist. If the universe were 10 times older than it actually is, most stars would be too old to remain on the main sequence and would have turned into white dwarfs, aside from the dimmest red dwarfs, and stable planetary systems would have already come to an end. Thus, Dicke explained the coincidence between large dimensionless numbers constructed from the constants of physics and the age of the universe, a coincidence which had inspired Dirac's varying-G theory.

Dicke later reasoned that the density of matter in the universe must be almost exactly the critical density needed to prevent the Big Crunch (the "Dicke coincidences" argument). The most recent measurements may suggest that the observed density of baryonic matter, and some theoretical predictions of the amount of dark matter account for about 30% of this critical density, with the rest contributed by a cosmological constant. Steven Weinberg^[11] gave an anthropic explanation for this fact: he noted that the cosmological constant has a remarkably low value, some 120 orders of magnitude smaller than the value particle physics predicts (this

has been described as the "worst prediction in physics").^[12] However, if the cosmological constant were more than about 10 times its observed value, the universe would suffer catastrophic inflation, which would preclude the formation of stars, and hence life.

The observed values of the dimensionless physical constants (such as the fine-structure constant) governing the four fundamental interactions are balanced as if fine-tuned to permit the formation of commonly found matter and subsequently the emergence of life.^[13] A slight increase in the strong nuclear force would bind the dineutron and the diproton, and nuclear fusion would have converted all hydrogen in the early universe to helium. Water, as well as sufficiently long-lived stable stars, both essential for the emergence of life as we know it, would not exist. More generally, small changes in the relative strengths of the four fundamental interactions can greatly affect the universe's age, structure, and capacity for life.

Origin

The phrase "anthropic principle" first appeared in Brandon Carter's contribution to a 1973 Krakow symposium honouring Copernicus's 500th birthday. Carter, a theoretical astrophysicist, articulated the Anthropic Principle in reaction to the Copernican Principle, which states that humans do not occupy a privileged position in the Universe. As Carter said: "Although our situation is not necessarily *central*, it is inevitably privileged to some extent."^[14] Specifically, Carter disagreed with using the Copernican principle to justify the Perfect Cosmological Principle, which states that all large regions *and times* in the universe must be statistically identical. The latter principle underlay the steady-state theory, which had recently been falsified by the 1965 discovery of the cosmic microwave background radiation. This discovery was unequivocal evidence that the universe has changed radically over time (for example, via the Big Bang).

Carter defined two forms of the Anthropic Principle, a "weak" one which referred only to anthropic selection of privileged spacetime locations in the universe, and a more controversial "strong" form which addressed the values of the fundamental constants of physics.

Roger Penrose explained the weak form as follows:

"The argument can be used to explain why the conditions happen to be just right for the existence of (intelligent) life on the earth at the present time. For if they were not just right, then we should not have found ourselves to be here now, but somewhere else, at some other appropriate time. This principle was used very effectively by Brandon Carter and Robert Dicke to resolve an issue that had puzzled physicists for a good many years. The issue concerned various striking numerical relations that are observed to hold between the physical constants (the gravitational constant, the mass of the proton, the age of the universe, etc.). A puzzling aspect of this was that some of the relations hold only at the present epoch in the earth's history, so we appear, coincidentally, to be living at a very special time (give or take a few million years!). This was later explained, by Carter and Dicke, by the fact that this epoch coincided with the lifetime of what are called main-sequence stars, such as the sun. At any other epoch, so the argument ran, there would be no intelligent life around in order to measure the physical constants in question — so the coincidence had to hold,

simply because there would be intelligent life around only at the particular time that the coincidence did hold!"

—*The Emperor's New Mind, Chapter 10*

One reason this is plausible is that there are many other places and times in which we can imagine finding ourselves. But when applying the strong principle, we only have one Universe, with one set of fundamental parameters, so what exactly is the point being made? Carter offers two possibilities: First, we can use our own existence to make "predictions" about the parameters. But second, "as a last resort", we can convert these predictions into *explanations* by assuming that there *is* more than one Universe, in fact a large and possibly infinite collection of universes, something that is now called a multiverse ("world ensemble" was Carter's term), in which the parameters (and perhaps the laws of physics) vary across universes. The strong principle then becomes an example of a selection effect, exactly analogous to the weak principle. Postulating a multiverse is certainly a radical step, but taking it could provide at least a partial answer to a question which had seemed to be out of the reach of normal science: "why do the fundamental laws of physics take the particular form we observe and not another?"

Since Carter's 1973 paper, the term "Anthropic Principle" has been extended to cover a number of ideas which differ in important ways from those he espoused. Particular confusion was caused in 1986 by the book *The Anthropic Cosmological Principle* by John D. Barrow and Frank Tipler,^[15] published that year which distinguished between "weak" and "strong" anthropic principle in a way very different from Carter's, as discussed in the next section.

Carter was not the first to invoke some form of the anthropic principle. In fact, the evolutionary biologist Alfred Russel Wallace anticipated the anthropic principle as long ago as 1904: "Such a vast and complex universe as that which we know exists around us, may have been absolutely required ... in order to produce a world that should be precisely adapted in every detail for the orderly development of life culminating in man."^[16] In 1957, Robert Dicke wrote: "The age of the Universe 'now' is not random but conditioned by biological factors ... [changes in the values of the fundamental constants of physics] would preclude the existence of man to consider the problem."^[17]

Variants

Weak anthropic principle (WAP) (Carter): "we must be prepared to take account of the fact that our location in the universe is *necessarily* privileged to the extent of being compatible with our existence as observers." Note that for Carter, "location" refers to our location in time as well as space.

Strong anthropic principle (SAP) (Carter): "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. To paraphrase Descartes, *cogito ergo mundus talis est*." The Latin tag ("I think, therefore the world is such [as it is]") makes it clear that "must" indicates a deduction from the fact of our existence; the statement is thus a truism.

In their 1986 book, *The Anthropic Cosmological Principle*, John Barrow and Frank Tipler depart from Carter and define the WAP and SAP as follows:^{[18][19]}

Weak anthropic principle (WAP) (Barrow and Tipler): "The observed values of all physical and cosmological quantities are not equally probable but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirements that the Universe be old enough for it to have already done so."^[20]

Unlike Carter they restrict the principle to carbon-based life, rather than just "observers." A more important difference is that they apply the WAP to the fundamental physical constants, such as the fine structure constant, the number of spacetime dimensions, and the cosmological constant —, topics that fall under Carter's SAP.

Strong anthropic principle (SAP) (Barrow and Tipler): "The Universe must have those properties which allow life to develop within it at some stage in its history."^[21]

This looks very similar to Carter's SAP, but unlike the case with Carter's SAP, the "must" is an imperative, as shown by the following three possible elaborations of the SAP, each proposed by Barrow and Tipler.^[22]

- "There exists one possible Universe 'designed' with the goal of generating and sustaining 'observers'."

This can be seen as simply the classic design argument restated in the garb of contemporary cosmology. It implies that the purpose of the universe is to give rise to intelligent life, with the laws of nature and their fundamental physical constants set to ensure that life as we know it will emerge and evolve.

- "Observers are necessary to bring the Universe into being."

Barrow and Tipler believe that this is a valid conclusion from quantum mechanics, as John Archibald Wheeler has suggested, especially via his idea that information is the fundamental reality, see *It from bit*, and his **Participatory Anthropic Principle (PAP)** which is an interpretation of quantum mechanics associated with the ideas of John von Neumann and Eugene Wigner.

- "An ensemble of other different universes is necessary for the existence of our Universe."

By contrast, Carter merely says that an ensemble of universes is necessary for the SAP to count as an explanation.

'Modified anthropic principle (MAP) (Schmidhuber): The 'problem' of existence is only relevant to a species capable of formulating the question. Prior to Homo sapiens intellectual evolution to the point where the nature of the observed universe - and humans' place within same - spawned deep inquiry into its origins, the 'problem' simply did not exist.^[23]

The philosophers John Leslie^[24] and Nick Bostrom^[25] reject the Barrow and Tipler SAP as a fundamental misreading of Carter. For Bostrom, Carter's anthropic principle just warns us to make allowance for **anthropic bias**, that is, the bias created by anthropic selection effects (which Bostrom calls "observation" selection effects) — the necessity for observers to exist in order to get a result. He writes:

"Many 'anthropic principles' are simply confused. Some, especially those drawing

inspiration from Brandon Carter's seminal papers, are sound, but... they are too weak to do any real scientific work. In particular, I argue that existing methodology does not permit any observational consequences to be derived from contemporary cosmological theories, though these theories quite plainly can be and are being tested empirically by astronomers. What is needed to bridge this methodological gap is a more adequate formulation of how observation selection effects are to be taken into account."

—*Anthropic Bias*, Introduction., ^[26]

Strong self-sampling assumption (SSSA) (Bostrom): "Each observer-moment should reason as if it were randomly selected from the class of all observer-moments in its reference class." Analysing an observer's experience into a sequence of "observer-moments" helps avoid certain paradoxes; but the main ambiguity is the selection of the appropriate "reference class": for Carter's WAP this might correspond to all real or potential observer-moments in our universe; for the SAP, to all in the multiverse. Bostrom's mathematical development shows that choosing either too broad or too narrow a reference class leads to counter-intuitive results, but he is not able to prescribe an ideal choice.

According to Jurgen Schmidhuber, the anthropic principle essentially just says that the conditional probability of finding yourself in a universe compatible with your existence is always 1. It does not allow for any additional nontrivial predictions such as "gravity won't change tomorrow." To gain more predictive power, additional assumptions on the prior distribution of alternative universes are necessary.^{[23][27]}

Playwright and novelist Michael Frayn describes a form of the Strong Anthropic Principle in his 2006 book *The Human Touch*, which explores what he characterises as "the central oddity of the Universe":

"It's this simple paradox. The Universe is very old and very large. Humankind, by comparison, is only a tiny disturbance in one small corner of it - and a very recent one. Yet the universe is only very large and very old because we are here to say it is... And yet, of course, we all know perfectly well that it is what it is whether we are here or not."

___^[28]

Character of anthropic reasoning

Carter chose to focus on a tautological aspect of his ideas, which has resulted in much confusion. In fact, anthropic reasoning interests scientists because of something that is only implicit in the above formal definitions, namely that we should give serious consideration to there being other universes with different values of the "fundamental parameters" — that is, the dimensionless physical constants and initial conditions for the Big Bang. Carter and others have argued that life as we know it would not be possible in most such universes. In other words, the universe we are in is fine tuned to permit life. Collins & Hawking (1973) characterized Carter's then-unpublished big idea as the postulate that "there is not one universe but a whole infinite ensemble of universes with all possible initial conditions".^[29] If this is granted, the anthropic principle provides a plausible explanation for the fine tuning of our universe: the "typical"

universe is not fine-tuned, but given enough universes, a small fraction thereof will be capable of supporting intelligent life. Ours must be one of these, and so the observed fine tuning should be no cause for wonder.

Although philosophers have discussed related concepts for centuries, in the early 1970s the only genuine physical theory yielding a multiverse of sorts was the many worlds interpretation of quantum mechanics. This would allow variation in initial conditions, but not in the truly fundamental constants. Since that time a number of mechanisms for producing a multiverse have been suggested: see the review by Max Tegmark.^[30] An important development in the 1980s was the combination of inflation theory with the hypothesis that some parameters are determined by symmetry breaking in the early universe, which allows parameters previously thought of as "fundamental constants" to vary over very large distances, thus eroding the distinction between Carter's weak and strong principles. At the beginning of the 21st century, the string landscape emerged as a mechanism for varying essentially all the constants, including the number of spatial dimensions.^[31]

The anthropic idea that fundamental parameters are selected from a multitude of different possibilities (each actual in some universe or other) contrasts with the traditional hope of physicists for a theory of everything having no free parameters: as Einstein said, "What really interests me is whether God had any choice in the creation of the world." In 2002, proponents of the leading candidate for a "theory of everything", string theory, proclaimed "the end of the anthropic principle"^[32] since there would be no free parameters to select. Ironically, string theory now seems to offer no hope of predicting fundamental parameters, and now some who advocate it invoke the anthropic principle as well (see below).

The modern form of a design argument is put forth by Intelligent design. Proponents of intelligent design often cite the fine-tuning observations that (in part) preceded the formulation of the anthropic principle by Carter as a proof of an intelligent designer. Opponents of intelligent design are not limited to those who hypothesize that other universes exist; they may also argue, anti-anthropically, that the universe is less fine-tuned than often claimed, or that accepting fine tuning as a brute fact is less astonishing than the idea of an intelligent creator. Furthermore, even accepting fine tuning, Sober (2005)^[33] and Ikeda and Jefferys,^{[34][35]} argue that the Anthropic Principle as conventionally stated actually undermines intelligent design; see fine-tuned universe.

Paul Davies's book *The Goldilocks Enigma* (2006) reviews the current state of the fine tuning debate in detail, and concludes by enumerating the following responses to that debate:

1. The absurd universe: Our universe just happens to be the way it is.
2. The unique universe: There is a deep underlying unity in physics which necessitates the Universe being the way it is. Some Theory of Everything will explain why the various features of the Universe must have exactly the values that we see.
3. The multiverse: Multiple universes exist, having all possible combinations of characteristics, and we inevitably find ourselves within a universe that allows us to exist.
4. Intelligent Design: A creator designed the Universe with the purpose of supporting complexity and the emergence of intelligence.
5. The life principle: There is an underlying principle that constrains the Universe to evolve

towards life and mind.

6. The self-explaining universe: A closed explanatory or causal loop: "perhaps only universes with a capacity for consciousness can exist." This is Wheeler's Participatory Anthropic Principle (PAP).
7. The fake universe :We live inside a virtual reality simulation.

Omitted here is Lee Smolin's model of cosmological natural selection, also known as "fecund universes," which proposes that universes have "offspring" which are more plentiful if they resemble our universe. Also see Gardner (2005).^[36]

Clearly each of these hypotheses resolve some aspects of the puzzle, while leaving others unanswered. Followers of Carter would admit only option 3 as an anthropic explanation, whereas 3 through 6 are covered by different versions of Barrow and Tipler's SAP (which would also include 7 if it is considered a variant of 4, as in Tipler 1994).

The anthropic principle, at least as Carter conceived it, can be applied on scales much smaller than the whole universe. For example, Carter (1983)^[37] inverted the usual line of reasoning and pointed out that when interpreting the evolutionary record, one must take into account cosmological and astrophysical considerations. With this in mind, Carter concluded that given the best estimates of the age of the universe, the evolutionary chain culminating in *Homo sapiens* probably admits only one or two low probability links. Antonio Feoli and Salvatore Rampone dispute this conclusion, arguing instead that the estimated size of our universe and the number of planets in it allows for a higher bound, so that there is no need to invoke intelligent design to explain evolution.^[38]

Observational evidence

No possible observational evidence bears on Carter's WAP, as it is merely advice to the scientist and asserts nothing debatable. The obvious test of Barrow's SAP, which says that the Universe is "required" to support life, is to find evidence of life in universes other than ours. Any other universe is, by most definitions, unobservable (otherwise it would be included in *our* portion of *this* universe). Thus, in principle Barrow's SAP cannot be falsified by observing a universe in which an observer cannot exist.

Philosopher John Leslie^[39] states that the Carter SAP (with multiverse) predicts the following:

- Physical theory will evolve so as to strengthen the hypothesis that early phase transitions occur probabilistically rather than deterministically, in which case there will be no deep physical reason for the values of fundamental constants;
- Various theories for generating multiple universes will prove robust;
- Evidence that the universe is fine tuned will continue to accumulate;
- No life with a non-carbon chemistry will be discovered;
- Mathematical studies of galaxy formation will confirm that it is sensitive to the rate of expansion of the universe.

Hogan^[40] has emphasised that it would be very strange if all fundamental constants were strictly determined, since this would leave us with no ready explanation for apparent fine

tuning. In fact we might have to resort to something akin to Barrow and Tipler's SAP: there would be no option for such a universe *not* to support life.

Probabilistic predictions of parameter values can be made given:

1. a particular multiverse with a "measure", i.e. a well defined "density of universes" (so, for parameter X , one can calculate the prior probability $P(X_0) dX$ that X is in the range $X_0 < X < X_0 + dX$), and
2. an estimate of the number of observers in each universe, $N(X)$ (e.g., this might be taken as proportional to the number of stars in the universe).

The probability of observing value X is then proportional to $N(X) P(X)$. (A more sophisticated analysis is that of Nick Bostrom.)^[41] A generic feature of an analysis of this nature is that the expected values of the fundamental physical constants should not be "over-tuned," i.e. if there is some perfectly tuned predicted value (e.g. zero), the observed value need be no closer to that predicted value than what is required to make life possible. The small but finite value of the cosmological constant can be regarded as a successful prediction in this sense.

One thing that would *not* count as evidence for the Anthropic Principle is evidence that the Earth or the solar system occupied a privileged position in the universe, in violation of the Copernican principle (for possible counterevidence to this principle, see Copernican principle), unless there was some reason to think that that position was a necessary condition for our existence as observers.

Applications of the principle

The nucleosynthesis of carbon-12

Fred Hoyle may have invoked anthropic reasoning to predict an astrophysical phenomenon. He is said to have reasoned from the prevalence on earth of life forms whose chemistry was based on carbon-12 atoms, that there must be an undiscovered resonance in the carbon-12 nucleus facilitating its synthesis in stellar interiors via the triple-alpha process. He then calculated the energy of this undiscovered resonance to be 7.6 million electron-volts.^{[42][43]} Willie Fowler's research group soon found this resonance, and its measured energy was close to Hoyle's prediction.

However, a recently released paper argues that Hoyle did not use anthropic reasoning to make this prediction.^[44]

Cosmic inflation

Main article: Cosmic inflation

Don Page criticized the entire theory of cosmic inflation as follows.^[45] He emphasized that initial conditions which made possible a thermodynamic arrow of time in a universe with a Big Bang origin, must include the assumption that at the initial singularity, the entropy of the

universe was low and therefore extremely improbable. Paul Davies rebutted this criticism by invoking an inflationary version of the anthropic principle.^[46] While Davies accepted the premise that the initial state of the visible Universe (which filled a microscopic amount of space before inflating) had to possess a very low entropy value — due to random quantum fluctuations — to account for the observed thermodynamic arrow of time, he deemed this fact an advantage for the theory. That the tiny patch of space from which our observable Universe grew had to be extremely orderly, to allow the post-inflation universe to have an arrow of time, makes it unnecessary to adopt any "ad hoc" hypotheses about the initial entropy state, hypotheses other Big Bang theories require.

String theory

Main article: String theory landscape

String theory predicts a large number of possible universes, called the "backgrounds" or "vacua." The set of these vacua is often called the "multiverse" or "anthropic landscape" or "string landscape." Leonard Susskind has argued that the existence of a large number of vacua puts anthropic reasoning on firm ground: only universes whose properties are such as to allow observers to exist are observed, while a possibly much larger set of universes lacking such properties go unnoticed.

Steven Weinberg^[47] believes the Anthropic Principle may be appropriated by cosmologists committed to nontheism, and refers to that Principle as a "turning point" in modern science because applying it to the string landscape "...may explain how the constants of nature that we observe can take values suitable for life without being fine-tuned by a benevolent creator." Others, most notably David Gross but also Lubos Motl, Peter Woit, and Lee Smolin, argue that this is not predictive. Max Tegmark,^[48] Mario Livio, and Martin Rees^[49] argue that only some aspects of a physical theory need be observable and/or testable for the theory to be accepted, and that many well-accepted theories are far from completely testable at present.

Jurgen Schmidhuber (2000–2002) points out that Ray Solomonoff's theory of universal inductive inference and its extensions already provide a framework for maximizing our confidence in any theory, given a limited sequence of physical observations, and some prior distribution on the set of possible explanations of the universe.

Ice density

When water freezes into ice, the ice floats because ice is less dense than liquid water. This is one possible example of the anthropic principle, because if ice did not float, it might have been difficult or impossible for living organisms to have existed in water; without the insulating properties of a top ice layer, lakes and ponds would tend to freeze solid and thaw very little during warmer periods. This principle has been criticized as neglecting the existence of the tropical zone and other warmer climates.

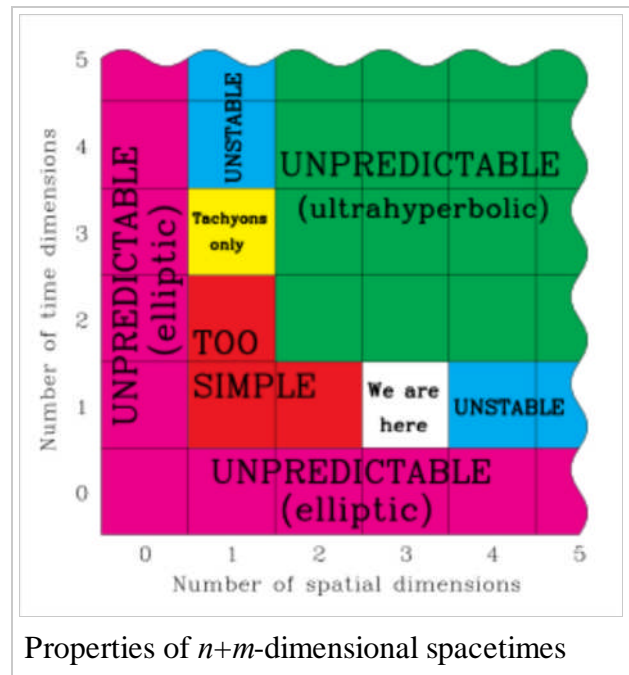
Ice is unusual in that it is approximately 9% less dense than liquid water. Water is the only known non-metallic substance to expand when it freezes. The density of ice is 0.9167 g/cm³ at

0°C, whereas water has a density of 0.9998 g/cm³ at the same temperature. Liquid water is densest, essentially 1.00 g/cm³, at 4°C and becomes less dense as the water molecules begin to form the hexagonal crystals^[50] of ice as the freezing point is reached. This is due to hydrogen bonding dominating the intermolecular forces, which results in a packing of molecules less compact in the solid.

Spacetime

Main article: Spacetime

In 1920, Paul Ehrenfest showed that if there is only one time dimension and greater than three spatial dimensions, the orbit of a planet about its sun cannot remain stable. The same is true of a star's orbit around the center of its galaxy.^[51] Ehrenfest also showed that if there are an even number of spatial dimensions, then the different parts of a wave impulse will travel at different speeds. If there are $5 + 2k$ spatial dimensions, where k is a whole number, then wave impulses become distorted. In 1922, Hermann Weyl showed that Maxwell's theory of electromagnetism works only when with three dimensions of space and one of time.^[52] Finally, Tangherlini showed in 1963 that when there are more than three spatial dimensions, electron orbitals around nuclei cannot be stable; electrons would either fall into the nucleus or disperse.^[53]



Max Tegmark expands on the preceding argument in the following **anthropic** manner.^[54] If T differs from 1, the behavior of physical systems could not be predicted reliably from knowledge of the relevant partial differential equations. In such a universe, intelligent life capable of manipulating technology could not emerge. Moreover, if $T > 1$, Tegmark maintains that protons and electrons would be unstable and could decay into particles having greater mass than themselves (This is not a problem if the particles have a sufficiently low temperature).

The Anthropic Cosmological Principle

A thorough extant study of the anthropic principle is the book *The Anthropic Cosmological Principle* by John D. Barrow, a cosmologist, and Frank J. Tipler, a theosophist and mathematical physicist. This book sets out in detail the many known anthropic coincidences and constraints, including many found by its authors. While the book is primarily a work of theoretical astrophysics, it also touches on quantum physics, chemistry, and earth science. An entire chapter argues that *Homo sapiens* is, with high probability, the only intelligent species in the Milky Way.

The book begins with an extensive review of many topics in the history of ideas the authors deem relevant to the anthropic principle, because the authors believe that principle has important antecedents in the notions of teleology and intelligent design. They discuss the writings of Fichte, Hegel, Bergson, and Alfred North Whitehead, and the Omega Point cosmology of Teilhard de Chardin. Barrow and Tipler carefully distinguish teleological reasoning from *eutaxiological* reasoning; the former asserts that order must have a consequent purpose; the latter asserts more modestly that order must have a planned cause. They attribute this important but nearly always overlooked distinction to an obscure 1883 book by L. E. Hicks.^[55]

Seeing little sense in a principle requiring intelligent life to emerge while remaining indifferent to the possibility of its eventual extinction, Barrow and Tipler propose the:

"Final anthropic principle (FAP): Intelligent information-processing must come into existence in the Universe, and, once it comes into existence, it will never die out."
__^[56]

Barrow and Tipler submit that the FAP is both a valid physical statement and "closely connected with moral values." FAP places strong constraints on the structure of the universe, constraints developed further in Tipler's *The Physics of Immortality*.^[57] One such constraint is that the universe must end in a big crunch, which seems unlikely in view of the tentative conclusions drawn since 1998 about dark energy, based on observations of very distant supernovas.

In his review^[58] of Barrow and Tipler, Martin Gardner ridiculed the FAP by quoting the last two sentences of their book as defining a Completely Ridiculous Anthropic Principle (CRAP):

"At the instant the Omega Point is reached, life will have gained control of *all* matter and forces not only in a single universe, but in all universes whose existence is logically possible; life will have spread into *all* spatial regions in all universes which could logically exist, and will have stored an infinite amount of information, including *all* bits of knowledge which it is logically possible to know. And this is the end."
__^[59]

Criticisms

Carter has frequently regretted his own choice of the word "anthropic," because it conveys the misleading impression that the principle involves humans specifically, rather than intelligent observers in general.^[60] Others^[61] have criticised the word "principle" as being too grandiose to describe straightforward applications of selection effects.

A common criticism of Carter's SAP is that it is an easy *deus ex machina* which discourages searches for physical explanations. To quote Penrose again: "it tends to be invoked by theorists whenever they do not have a good enough theory to explain the observed facts."^[62]

Carter's SAP and Barrow and Tipler's WAP have been dismissed as truisms or trivial tautologies, that is, statements true solely by virtue of their logical form (the conclusion is identical to the premise) and not because a substantive claim is made and supported by observation of reality. As such, they are criticized as an elaborate way of saying "if things were different, they would be different," which is a valid statement, but does not make a claim of some factual alternative over another.

Critics of the Barrow and Tipler SAP claim that it is neither testable nor falsifiable, and thus is not a scientific statement but rather a philosophical one. The same criticism has been leveled against the hypothesis of a multiverse, although some argue that it does make falsifiable predictions. A modified version of this criticism is that we understand so little about the emergence of life, especially intelligent life, that it is effectively impossible to calculate the number of observers in each universe. Also, the prior distribution of universes as a function of the fundamental constants is easily modified to get any desired result.^[63]

Many criticisms focus on versions of the Strong Anthropic Principle, such as Barrett and Tipler's *anthropic cosmological principle*, which are teleological notions that tend to describe the existence of life as a *necessary prerequisite* for the observable constants of physics. In a lecture titled "The Confusion of Cause and Effect in Bad Science," the paleophysicist Caroline Miller said:^[64] WARNING: this quotation is attributed to a talk given at Piffard College, but Piffard College seems not to exist.

"The Anthropic Principle is based on the underlying belief that the universe was created for our benefit. Unfortunately for its adherents, all of the reality-based evidence at our disposal contradicts this belief. In a nonanthropocentric universe, there is no need for multiple universes or supernatural entities to explain life as we know it."

Similarly, Stephen Jay Gould,^{[65][66]} Michael Shermer,^[67] and others claim that the stronger versions of the Anthropic Principle seem to reverse known causes and effects. Gould compared the claim that the universe is fine-tuned for the benefit of our kind of life to saying that sausages were made long and narrow so that they could fit into modern hotdog buns, or saying that ships had been invented to house barnacles. These critics cite the vast physical, fossil, genetic, and other biological evidence consistent with life having been fine-tuned through natural selection to adapt to the physical and geophysical environment in which life exists. Life appears to have adapted to physics, and not vice versa.

Some applications of the anthropic principle have been criticized as an argument by lack of imagination, for tacitly assuming that carbon compounds and water are the only possible chemistry of life (sometimes called "carbon chauvinism", see also alternative biochemistry).^[68] The range of fundamental physical constants consistent with the evolution of carbon-based life may also be wider than those who advocate a fine tuned universe have argued.^[69] For instance, Harnik et al.^[70] propose a weakless universe in which the weak nuclear force is eliminated. They show that this has no significant effect on the other fundamental interactions, provided some adjustments are made in how those interactions work. However, if some of the fine-tuned details of our universe were violated, that would rule out complex structures of any kind — stars, planets, galaxies, etc.

Lee Smolin has offered a theory designed to improve on the lack of imagination that anthropic principles have been accused of. He puts forth his fecund universes theory, which assumes universes have "offspring" through the creation of black holes, and that these offspring universes have values of physical constants that depend on these of the mother universe.^[71] Some versions of the anthropic principle are only interesting if the range of physical constants that allow certain kinds of life are unlikely in a landscape of possible universes. But Lee Smolin assumes that conditions for carbon based life are similar to conditions for black hole creation, which would change the a priori distribution of universes such that universes containing life would be likely. In ^[72] the string theorist Leonard Susskind disagrees about some assumptions in Lee Smolin's theory, while Smolin defends his theory.

The philosophers of cosmology John Earman,^[73] Ernan McMullin,^[74] and Jesus Mosterin contend that "in its weak version, the anthropic principle is a mere tautology, which does not allow us to explain anything or to predict anything that we did not already know. In its strong version, it is a gratuitous speculation".^[75] A further criticism by Mosterin concerns the flawed "anthropic" inference from the assumption of an infinity of worlds to the existence of one like ours:

“The suggestion that an infinity of objects characterized by certain numbers or properties implies the existence among them of objects with any combination of those numbers or characteristics [...] is mistaken. An infinity does not imply at all that any arrangement is present or repeated. [...] The assumption that all possible worlds are realized in an infinite universe is equivalent to the assertion that any infinite set of numbers contains all numbers (or at least all Gödel numbers of the [defining] sequences), which is obviously false.”

See also

- Big Bounce
- Biocentrism (theory of everything)
- Doomsday argument
- Final anthropic principle
- Fine-tuned Universe
- The Great Filter
- Infinite monkey theorem
- Inverse gambler's fallacy
- Mediocrity principle
- Metaphysical naturalism
- Neocatastrophism
- Nick Bostrom
- Puddle thinking
- Quark Mass and Congeniality to Life
- Rare Earth hypothesis
- Selection bias
- Triple-alpha process
- Teleology

Footnotes

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