ANTHROPIC PREDICTION

JOHN LESLIE

I. The anthropic principle

Carter's anthropic principle (1974, 291) is "that what we can expect to observe must be restricted by the conditions necessary for our presence as observers". Despite its name, the principle applies not just to humans "but also to non anthropic observers" (1989a, 45). It has a "weak" version: that "our location" – time and place – "is *necessarily* privileged to the extent of being compatible with our existence as observers" (1974, 293). Also a "strong", that our universe "must be such as to admit the creation of observers within it at some stage" (294): it must obviously be observer-permitting since we are observers it permitted. This is important, Carter suggests, if there exist "many universes, of which only one can be known to us", "an ensemble of universes characterised by all conceivable combinations of initial conditions and fundamental constants", those with observer-permitting combinations forming "an exceptional *cognizable* subset" (295-298).

Ambiguity looms here, because the universes are perhaps not entirely separated. They may, e.g., be huge cosmic domains, touching at their edges, or successive cycles of an oscillating cosmos. Carter in one place writes that the strong principle means "the combination of the ordinary weak anthropic principle with a hypothesis of the existence of an ensemble of connected or disconnected branches of the universe" (1989a, 50). The distinction between *weak* and *strong* thus becomes vague. A branch, a domain, may be "just a place" to me, "a universe" to you. Similarly, an epoch such as an oscillatory cycle might or might not be "just a time". Indeed, even entirely separated systems might be called "places, not universes," on the excuse that the universe should be defined as Absolutely Everything. However, these are arbitrary verbal matters. More interesting is whether the anthropic principle has predictive power. Many agree with H.Pagels that it "never *predicts* anything" and "is not testable" (Leslie (ed.) 1990a, 177).

Pagels might be trivially right because the principle itself, as I prefer to formulate it, is as tautologous as that bachelors lack wives. It simply reminds us that every observer inhabits an observer-permitting time, place and universe. Unquestionably correct, it can predict nothing. It is not testable because it could never fail tests, any more than could the principle of bachelor-wifelessness. Now, as my first paragraph illustrated, Carter sometimes formulates the principle tautologically. It is unwise to disregard tautologies, though! If three sets of five tigers visited the thicket and only fourteen returned, steer clear of the thicket: the tautology is that three fives make fifteen. And if there exist many universes with differing characteristics, beware of assuming that your universe is ordinary in being life-permitting. Against various backgrounds, "anthropic" tautologies become important. Carter recognizes this when putting one such background into a statement of the strong principle. Remember, my second paragraph showed him saying in one place that this combines the weak principle with "the existence of an ensemble..".

The distinction between the tautological and the non-tautological formulations seems another arbitrary verbal matter. Little practical difference divides (a) saying that a tautologous anthropic principle is important because of some factual background and (b) putting this background into the principle itself, so that it becomes non-tautologous. What is of practical importance is that scientists often overlook the selection effects which may accompany inability to observe just any time, place or universe. It is a tautology that there might be such selection effects. The tautology *encourages* predictions while not itself *making* any. Logic does not force all times, places, universes, to be observer-permitting, and users of the anthropic principle make various predictions through supposing that not all of them are.

They do not suppose it groundlessly. There is much evidence that our universe is "fine tuned for life" in the following technical sense: slight changes in its properties – in its turbulence, or in the relative strengths of the forces operating in it, or the relative masses of its particles, etcetera – would have excluded living beings of any plausible kind. This suggests *that there exist many universes (i.e., largely or entirely separated spatiotemporal regions) and that turbulence, force strengths, particle masses and much else, vary widely from universe to universe.* It would then be unsurprising that at least one universe had characteristics fine tuned for being life-permitting; unsurprising, also, that we found ourselves in such a universe, not in a life-excluding one (Leslie 1982; 1983a,b; etc.). All this encourages, e.g., the prediction that fundamental physics will be found not to have dictated the force strengths and particle masses which we see. Elsewhere, gravity and electromagnetism might be of almost equal strength, instead of the first being 10^{39} times weaker than the second. Or the proton and the electron might have roughly equal masses so that life as we know it, chemical life, was impossible.

Pagels complains (ibid.) that "there is no way we can actually go to an imaginary universe and check for life". Yes; but neither can we travel to the Big Bang, and yet we can well judge there was no life then. Pagels's complaint could be forceful against someone who asked whether our universe was unusual *among all logically possible universes* in being life-permitting; but, I protest, one need ask no such question. The anthropic principle can have importance when applied just to the possible universes in "the local area", possible universes resembling ours in their fundamental physics but differing in such things as force strengths and particle masses. If, say, gravity's strength had been slightly different then, it can seem, our universe would have collapsed almost immediately or else would have expanded so quickly that there would soon have been only cold near-vacuum. Would anyone say it could still have contained observers? Observers evolving, perhaps, in a millisecond before collapse occurred (although in our universe life-encouraging thermal disequilibrium appeared only after a million years, when radiation began streaming through space freely)? If not, there would be grounds for thinking that, among the universes of the local area, ours was unusual in being life-permitting. We might then very reasonably conclude that – unless the explanation lay in a divine Fine Tuner or in neoplatonism's more abstract Creative Principle [possibilities which are defended in Leslie 1979, 1989 chapter

8, etc., but which have nothing whatever to do with the anthropic principle as Carter and I understand the words "anthropic principle"] – *there were many and varied universes*: sufficiently many to make it quite likely that at least one would be appropriately tuned. If a bullet hits a fly on a wall, where the local area of the wall was otherwise empty, one suspects that a marksman fired the bullet or that many bullets are hitting the wall. One need not ask whether *distant* areas of the wall are so thick with flies that almost any bullet landing *there* would be fly-hitting.

Perhaps a single fly, just one possible universe with life-permitting characteristics, should be replaced by a small group, or two or three small local-area groups (Rozental, Novikov and Polnarev 1982). Thus, seemingly life-excluding changes in gravity's strength might be compensated for by weakening or strengthening electromagnetism. But fine tuning remains fine tuning even when the local area of possible universes includes a tiny range (or two or three tiny ranges) of life-permitting universes.

II. Varying 'constants'

By "anthropic predictions" I mean predictions *encouraged* by the anthropic principle, even if not dictated by it. An early example – before Carter gave the principle a name – was Dicke's prediction *that Dirac's varying gravity would be found to be illusory*. Looking at various gigantic ratios, Dirac had theorized that they were necessarily the same at all times, one result being that gravity's weakness reflected the universe's great age, about 10^{10} years. Dicke instead saw an observational necessity here, a necessity placing the universe's observed age inside the period during which observers could exist. When the universe was younger than 10^8 years, there would be no stars like our sun, steadily burning and with planets bearing carbon etc. produced inside earlier stars. When it was older than 10^{12} years, virtually no sunlike stars would still shine. Observers could expect to find themselves only in the intervening period. Even without Dirac's varying gravity, they would then see such things as that the gravitational coupling constant roughly equalled the ratio of the proton Compton wavelength to the universe's Hubble radius. "The statistical support for Dirac's cosmology is found to be missing", Dicke concluded (1961; Carter 1976, 652; Tipler 1989, 28).

"Anthropic" reasoning like Dicke's might have been employed to predict *that the Steady State theory would be found to be wrong*. The fact that nobody thus employed it was merely a historical accident. The competing Big Bang theory makes it unsurprising that there is an epoch when the universe's age roughly equals the main sequence lifetime of a sunlike star. Dicke shows why we could have expected to live then. Big-Bang-theory calculations combine with actual observations to say that we do live then. Well, the universe's age, according to Big Bang theorists, essentially equals the Hubble time: the time elapsed since everything now visible to us was seemingly concentrated at one point, given its observed expansion. In a Steady State we again get expansion but we get no reason why Hubble time and main sequence lifetime should be comparable. Even a very rough equality between those times could seem very unlikely. Instead of swallowing the unlikelihood, one could well have rejected the Steady State (Rees 1972).

Dicke's reasoning applied the weak anthropic principle to our temporal location. How about predictions encouraged by the strong principle? The weak/strong distinction is, as I said, somewhat arbitrary because one writer's "universe" is "just a location" to another. Still, whenever it is natural to think of ourselves as investigating fundamental parameters *of our universe* we should bear the strong principle in mind. Take the case of another gigantic ratio, one to which Eddington had drawn attention: that the number of particles in the visible cosmos, about 10^{80}, roughly equals the inverse square of the gravitational coupling constant. This was understandable in conventional, non-Eddingtonian physics, Carter said. It was implied by the fact that space is no longer radiation-dominated so as to exclude galaxies and all plausible life-forms (Carter 1974, 293-294). Furthermore, gravity's strength had to be what it is, more or less exactly, for there to be long-lasting stable stars to encourage living beings to evolve (295-298). The first of these considerations suggested a prediction *that, like Dirac's, Eddington's physics would be found to be mistaken; the second, a prediction that gravity must have the* *strength we have long known it to have* (which makes the word "prediction" controversial: see below).

The strong anthropic principle says that our universe's fundamental parameters are observer-permitting. If fine tuning was needed, the parameters must in point of fact have been tuned appropriately — since we observers exist, do we not? Still, why was there an appropriately tuned universe? An ensemble of very varied universes could be the answer. Given "the *actual* existence of an ensemble" (Tipler 1989, 30) it could have been virtually inevitable that at least one universe would be observer-permitting, despite a need for fine tuning. Fine tuning could be powerful indirect evidence that universes exist in great number and variety. This encourages the expectation that proposed mechanisms for making many and varied universes will remain compatible with new scientific discoveries.

Many such mechanisms have been proposed (for references see Barrow and Tipler 1986 and Leslie 1989b, chapter 4). The anthropic prediction is *that* at least one such mechanism will survive advances in physics and cosmology. Maybe several will. Several mechanisms might actually have operated, creating universes inside universes —for this, remember, might be just a way of saying there were huge domains inside huge domains. [One mechanism splits; another then splinters.]

Oscillations – Bangs alternate with Squeezes – provide a possible mechanism, successive cycles counting as different universes. "Bounces" banned by classical physics might be allowed by quantum theory, or by gravity's becoming repulsive at extreme energies. Perhaps, as J.A.Wheeler proposed (Leslie (ed.) 1990a, 207-215), all fundamental parameters change randomly at each bounce. Entropy would then not have to grow so greatly with each new cycle that only the first could be life-permitting. Alternatively, total mass might increase enormously as each cycle ended, heavily diluting any entropy increase (Sikkema and Israel 1991).

A standard suggestion is that gravity, electromagnetism, and the nuclear forces, were unified into a single force early in the Bang. Cooling switched on a scalar field or fields which split the forces apart and produced particles with different masses ("symmetry breaking"). The potential energy of any such field perhaps had many minima of roughly equal depth but corresponding to different field values (Linde 1985, 16). It could have fallen to different minima in different cosmic regions or cycles, randomly. Particle masses, produced by interaction with the field or fields, would thus be randomized. So would force strengths, which reflect these masses. Hence oscillations could easily give us universes varying greatly – as could virtually all other mechanisms for generating multiple universes. Virtually all could incorporate randomized symmetry breaking, by scalar fields or other factors. Shaposhnikov and Tkachev (1990) note that recent discussion "of topological changes in quantum gravity has led to the suggestion that coupling constants...are in fact dynamical variables" in a superspace. They mention S.W.Hawking, S.Coleman and others, and "the baby universe picture of quantum gravity": universes give birth to others which influence the force strengths etc. of their mothers in ways perhaps unpredictable by anyone ignorant of just how the universes chance to be linked.

The cosmos might be "open", extending infinitely from its first seconds, for even an infinite space can expand (Ellis and Brundrit 1979). Regions well beyond the horizon set by how far light can have travelled towards us since the Bang could then count as "other universes". Similarly if the cosmos were closed like a sphere's surface, but still gigantic. The popular "inflationary" cosmos stretches immensely far and could well be split into domains with different overt properties, although obeying the same fundamental laws (Guth and Steinhardt 1984; Linde 1985).

Weinberg writes, "Fluctuations in scalar fields can trigger cosmic inflation in regions of the Universe where the fields happen to be large. Except near the edges, the inflationary region would appear to its inhabitants as a separate subuniverse"; or "Quantum fluctuations in the very early Universe may cause incoherence between different terms in the state vector of the Universe; each term would then in effect represent a separate universe" (1987, 2607). Again, H.Everett's Many-Worlds Quantum Theory (DeWitt and Graham 1973, 167-219) makes the cosmos divide continually into branches each representing a way the dice of quantum indeterminism fell.

Suggested mechanisms for making multiple universes are too numerous for listing here. The crucial point is that virtually all could permit the universes to vary greatly. One of the first was E.P.Tryon's: universes are quantum vacuum fluctuations "costing" nothing because their gravitational potential energy, a negative quantity, balances the mass-energy of their particles (Leslie (ed.) 1990a, 216-219). Tryon remarked, "Vacuum fluctuations on the scale of our universe are probably quite rare" but "observers always find themselves in universes capable of generating life, and such universes are impressively large". He could have added that if force strengths etc. varied among universes then even impressively large ones might only rarely be life-permitting.

Our inability to observe variation among universes "does not mean that this ...is irrefutable", for many physicists are optimistic about discovering "underlying physical mechanisms fixing what, at our present level of understanding, appear to be independent fundamental constants" (Carter 1989a, 50). The constants would then be "constants" in the fullest sense, the same everywhere. But the semblance of fine tuning is nowadays vivid enough to give grounds for predicting *that the optimistic physicists will be found to be wrong*. Otherwise [unless God tuned indirectly, by selecting the physics?] the semblance would be "a mystery" (51).

Another anthropic prediction is *that the inflationary theory will be found to be right*. The "smoothness problem" concerns how the visible universe escapes immense turbulence, when it could seem to have begun as some 10^{83} unco-ordinated regions: regions beyond one another's horizons. The answer may be that inflation, a brief period of exponentially rapid expansion, stretched everything by up to $10^{1,000,000}$ times (Linde 1985, 17) so that even regions tiny enough to be fully co-ordinated grew far huger than everything visible to us today. Well, this same inflation can appear essential to answering why physical constants, if settled randomly at early instants, were settled (as suggested by quasar studies) in the same way right out to our horizon. Without inflation, this could seem like having 10^{83} monkeys who all typed the same word.

Rees remarks (1987, 47) that given inflation plus randomization, with "oases where the constants, and so on, had propitious values" for life, "the desert regions beyond may be observable...when, perhaps a thousand billion years or more from now, light from the edges of our domain has had time to reach us". But such potential verification in the far future is inessential: the verifiability criterion of meaningfulness is defective, as most philosophers now agree. We need not even wait for laboratory evidence that constants are random, before treating a varied ensemble of universes seriously. Randomization of constants at early instants is already on a serious footing, thanks to the apparent fine tuning.

The existence of greatly many universes *would not* have made *this* universe – the one which became "ours" – *more likely to get* life-permitting constants when it underwent early random symmetry breaking or other randomizing processes. An ensemble of universes could only have made it likely that such constants would appear *somewhere or other* (Leslie 1986b, 1988a). Yet only where they had chanced to appear, could observers say "here" and "our universe".

III. Life's prerequisites

The anthropic principle encourages the prediction *that intelligent life is difficult to achieve,* for we cannot be elsewhere than where it was achieved. We may well be products of accidents unlikely to be repeated widely, either in this universe or among multiple universes. A "superweak" anthropic principle reminds us that if intelligent life's evolution, no matter how suitable the environment, always involves improbable happenings, then all observers evolved where such happenings happened (Leslie 1986a, 112-113). So we might feel encouraged to predict *that intelligent life would appear only rarely even in ideal locations.* Even if most planetary systems are lifeless, "our own...necessarily belongs to the subclass containing life" (Carter 1989b, 196-197). If only one planet chanced to enjoy a climate stable enough, and was lucky enough in escaping disastrously violent cometary impacts, for all the years needed for intelligence to evolve, we should be *there*. If life's origin depended on Nature patiently tossing "her tetrahedral dice...trying to line up 600 nucleotides...to make genesis DNA" in a process failing almost everywhere, *ours* would be a planet with beings "to view the film" (M.H.Hart in Leslie (ed.) 1990a, 265). This undercuts one of Hoyle's defences of a Steady State. Life's origin, he says, can seem so unlikely that $10^{1,000,000}$ galaxies would be needed to give it much chance of appearing even once, but in a Steady State universe there would be plenty of time for life to spread to our planet from wherever it did appear (Bertola and Curi (eds.) 1989, 82). Very well; but how, I ask, can the Steady State theory gain any advantage through this? A Big Bang universe, if open and infinitely large, or if closed but made gigantic by inflation, might easily contain $10^{1,000,000}$ galaxies -- and any galaxy in which life originated would be "here" to any observers into which that life developed there. There is thus no obvious need to join Hoyle in asking for enough time for life to spread *to here* from its lucky point of origin. We might well instead be *at* that lucky point.

We could feel encouraged to predict *that there are no exotic life-forms*: life-forms not dependent on whatever tuning is needed for life of familiar kinds. In this case we shall never encounter "something like Fred Hoyle's fictional black cloud" (Carter 1989a, 50), its dusts forming an intelligent whole. Life will not be found in frozen hydrogen, in Earth's molten interior, in our sun or in white dwarf or neutron star, or in any other of the curious locations defended by Feinberg and Shapiro (1980). It depends on fine tuning. In this connection, Hoyle made two dramatically successful anthropic predictions. Asking how the carbon so crucial to all known life-forms was produced copiously inside stars, he predicted "a particular resonance in the carbon nucleus, which allows carbon to form from ^{4}He plus ^{8}Be despite the instability of ^{8}Be" (Rees 1981, 122). Also that the ^{16}O nucleus *would not* resonate to destroy the carbon (Barrow and Tipler 1986, 253).

A common protest is that Hoyle made no true anthropic predictions. What was predicted concerned not life, but carbon. Carbon could be essential to life; but *so what?* We have long known that the universe contains much carbon, and therefore that some mechanisms produce it. Hoyle's account of those mechanisms is a credit to Hoyle but not to the anthropic principle! However, the protest is wrong. (i) Hoyle predicted very delicate tuning of resonance levels, yet was very confident. Why? Largely because such matters varied, he thought, from location to location, and "we can exist only in the portions of the universe where those levels happen to be correctly placed" (1965, 159). So "anthropic" considerations did influence him. Compare S.W.Hawking's confidence that galaxies could not have formed, had the early cosmic expansion rate been different by one part in a million.

The confidence was encouraged by Hawking's view that galaxies were among life's prerequisites: only in a universe expanding at the right rate "will there be beings to observe" (Longair (ed.) 1974, 283-286). (ii) While we have long known that much carbon exists, Hoyle's predictions were new. (iii) The distinction between prediction and *retrodiction* (i.e., showing that various theories would have made facts such as carbon's existence *predictable*: this is sometimes called "postdiction" instead, or "explanation") may have small importance. For one thing, every retrodiction involves a prediction that the retrodicted findings will not be shaken by new discoveries.

Some peope claim that theories retrodicting known facts are unsupported by them, because they have been tailored to fit them. Yet even if those facts had always been held in mind when generating the theories, it could have been hard to "tailor" suitably if you wanted simple theories meshing well with others you trusted. It often seems mere historical accident that observations preceded the simple, well-meshing theory which would have predicted them. Suppose the theory-builder was interrupted by sneezings, the delay turning a prediction into a retrodiction. Suppose it was instead the observer that sneezings delayed. Can much really hang on this? Seemingly not. Admittedly, scientists forming theories to fit observations are apt to fool themselves into thinking the theories simpler, better meshing, than they actually are. Because of this human weakness, predictions support theories better than retrodictions do -- but only slightly. So there is nothing too very wrong in saying *that all the fine tuning was not only "anthropically predictable" but even "predicted by the anthropic principle"*. It will be none too important whether this or that had in fact been predicted by someone like Hoyle, or whether scientists made only a "prediction" in scare-quotes, a retrodiction. What is important is that fine tuning was needed (at least in "the local area" of possible universes, as defined in this paper's first section) for there to be any observers. The more tuning there is, the more warranted a belief in multiple and varied universes.

Apparent evidence of fine tuning usually concerns facts which are already well known -- as is to be expected if they are facts crucial to our existence. What has often been unappreciated, however, is that many such facts are crucial not just to ourselves but to all plausible life-forms, in this universe or in any other "in the local area". Or it has been thought that rough tuning would suffice, when in fact great accuracy was needed. We have long known, e.g., that the cosmos has a density which makes space at least roughly flat, but we have only recently seen that early departures from flatness corresponding to density changes of one part in 10^{60} could have been life-excluding through making galaxies unable to form (B.J.Carr in Leslie (ed.) 1990a, 143). Again, we have known still longer that electromagnetism is far stronger than gravity, without realising that changes in their relative strengths by one part in 10^{40} could have banished long-lasting stable stars like the sun (Davies 1984, 242).

Some claims which people have made about fine tuning are less well established than others, of course, yet it can seem unlikely that all of them are wrong. Chapter 2 of Leslie 1989b discusses various of them, with references. [See also Atkins 1981; Davies 1983; Barrow and Tipler 1986.] They include these:

(i) As already mentioned, tremendous turbulence could have resultedwhen regions coming out of the Bang made contact. Placing a pin to select our orderly world from the possibilities, God needed accuracy to one part in 10 raised to the power of 10^{123}, R.Penrose has calculated, unless early orderliness was dictated by physical principles yet to be discovered.

(ii) Many think that early inflation guarantees a life-permitting expansion rate and cosmic density, also smoothing away any roughness (though Penrose challenges this). Yet such inflation could itself require tuning: bare and quantum lambda, components of an inflation-driving cosmological constant, need to cancel out to one part in $10^{50.}$ The masses of numerous scalar particles appear crucial to the cosmological constant's being right for inflation to occur life-encouragingly, and to its later becoming vanishingly small (failing which, space would expand or contract violently). And inflation yields fluctuations appropriate for galaxy formation only if a grand unified force has a coupling constant as tiny as 10^{-7}.

(iii) With the nuclear weak force slightly stronger, the Bang burns p all hydrogen (essential for making water and long-lived stable stars). A slight weakening again destroys the hydrogen (since early neutrons do not decay into protons) or later prevents the proton-proton and carbon-nitrogen-oxygen cycles which make stars sources of heat, light, and elements beyond helium.

(iv) With a strength increase of perhaps 1% in the nuclear strong force, almost all carbon converts to oxygen inside stars. One of perhaps 2% blocks the formation of protons or else binds them into diprotons so that suns burn 10^{18} times faster. With a somewhat greater increase, quite small bodies become miniature neutron stars. *De*creasing the strength by about 5% (or increasing Planck's constant by over 15%, or making the neutron slightly heavier or the proton slightly lighter) unbinds the deuteron, rendering stellar burning impossible. With even a 1% decrease, practically no carbon forms.(v) As noted earlier, the relative strengths of gravity and electromagnetism may need tuning to one part in 10^{40} for there to be stable sunlike stars — a main ground for this being that a star's luminescence depends on its surface transparency, which varies markedly with ionization. Again, a slight strengthening of electromagnetism destroys atoms by transforming quarks into leptons, or makes protons repel one another so powerfully that hydrogen is the only element. Further, electromagnetism needs to be fairly weak for protons to avoid decay, and for chemical changes to be easy: with a doubled strength, such changes are so slowed that intelligence perhaps cannot evolve in under 10^{62} years.

(vi) Superheavy particles dominate at early moments. Small changes in their masses so greatly alter the ratio of matter particles to photons that almost all matter collapses into black holes, or is transformed into light. [A recent further argument (Campbell *et al.* 1991, 457) is that Majorana neutrino masses have to be below 50 keV for any early excess of matter over antimatter not to be washed away.

The superheavies need to be 10^{14} times heavier than the proton, for protons to be life-permitting stable. Proton lifetimes even of 10^{16} years would be brief enough for you to die from your body's own radioactivity. (vii) The existence of solids and of chemistry demands that the electron be much less massive than the proton.

(viii) Space's topological and metrical properties, including its dimensionality and signature, may vary among cosmic regions. Without three dimensions and signature +++- [where the minus sign comes with the $-(ct)^2$ of special relativity] there can be nothing comparable to stable atoms, stable suns, or any particle-like states whatsoever, while waves propagate only with severe distortion.

(ix) A top-quark mass much above 125 GeV (roughly the actual figure) could mean that cosmic ray collisions cause a "vacuum metastability disaster": scalar field alterations make space collapse rapidly.

The above list gives known cases of apparent fine tuning. We could feel encouraged to predict *that today's lists are incomplete.*

IV. Not too much tuning

Often the observed value of some physically or cosmologically important parameter seems "unnatural" in the following sense: some well trusted theory, containing a probabilistic element, places this value "far from the peak of the probability curve", i.e., far from the values which the theory says were most likely. We might nevertheless understand it through reflecting that in a large ensemble of universes the majority, where the parameter took "more natural", "more expected", "less special" values, could be hostile to life. But then, D.W.Sciama points out, "we would not expect our universe to be a more special number of the ensemble than is needed" (Bertola and Curi (eds.) 1989, 111).

Sciama's point is enough to destroy one early anthropic explanation. Boltzmann imagined a cosmos extending so far, temporally or spatially, that it would be bound to contain epochs or domains ("worlds", he called them) far from thermal equilibrium just by chance. In these entropy could be expected to increase, he said. Increasing entropy being life's prerequisite, we observe one of these worlds. Alas, Boltzmann places you and me in an entropy fluctuation *much larger* than would be necessary to explain our present conscious states. It would be far more likely that our cerebral activity-patterns, together with anything else that was absolutely necessary, resulted from random particle collisions, than that Earth and solar system and all the stars were products of a monstrous fluctuation (Penrose 1979, 634).

Likewise with one explanation of why the universe observed by us has much more matter than antimatter. In most universes, G.Steigman proposed (Longair (ed.) 1974, 355), Chance produces matter and antimatter in almost exactly equal amounts, matter-antimatter annihilations then destroying the stuff from which observers could be made. Observable universes are tremendous flukes! Like Boltzmann, Steigman has violated the following restriction. The probability that a world or universe taken randomly from an ensemble would have the properties you seem to see *must exceed* the probability that you do not really see what you seem to (Leslie 1989b, 99-100).

In general, when our theories make the probabilities of various values of some parameter *rise steeply to a peak outside* the "anthropogenesis region" of values observable by living organisms, then these theories are probably wrong unless the observed value *is at or near the region's edge*, about as close to the peak as anthropogenesis permits. [I am assuming a typical case, where the steep rise begins inside the region.] Weinberg applies this to the cosmological constant. If our universe will never recollapse then an anthropic understanding of the constant's vanishingly small value seems mistaken: the value is too far below the region's upper edge in a universe of this sort (1987; 1989, 8). [The values with peak likelihoods seemingly lie hugely above that edge –™unless something forces the constant to be zero, no anthropic explanation then being needed.] But if the universe is instead such that it will recollapse, then the constant could well be understood anthropically (1989, 9).

Suppose it were proved that the cosmological constant's observed value lies at or near an edge to the anthropogenesis region while the values "intrinsically most probable" (but unobservable except by angels) peak sharply beyond this edge. Could the *being at or near the edge* be evidence of multiple universes? Seemingly not, for it would be predicted also by scientists believing in just one universe. While not classifying any values as *the values taken in most universes*, these scientists could still classify various values as *most probable* -- and would of course accept that they should not be expected by observers, if incompatible with anthropogenesis. They would expect to observe a value about as near the peak as observably possible. Regrettably, one of the anthropic principle's best-respected defenders challenges this. After writing that our universe, if drawn from an ensemble, should be expected to be no more "special" than necessary, Sciama adds that "by contrast a unique universe might be expected to be characterised by very special initial conditions". But, I object, very special initial conditions are those we should expect *not* to observe unless the less special were unobservable. Multiplicity of universes does not affect this. Sciama's philosophical thesis may be that probabilities cannot apply to a unique universe (so that no such universe could be "special" in a full-blooded sense). The thesis seems mistaken. It suggests that if in such a universe the ratio between proton and electron masses, expressed decimally, were a succession of ones, twos and zeros spelling "Designed by God" in Morse code's dots, dashes, spaces, then there would be nothing improbable even in *that*!

The truth of the matter is instead as follows. *Multiple universes help it to be believable* that an observed value really is intrinsically improbable, *provided that* the supposedly more probable values are observer-excluding (a proviso which typically demands being-at-or-near-the-edge, as discussed above). In a large and varied universe-ensemble, genuinely improbable values could well be present somewhere. Maybe only such a somewhere is observer-permitting. This inspired Shaposhnikov and Tkachev (1990) who hoped that the Higgs boson had a mass of 45 GeV. In some cosmological models 45 GeV would be highly improbable, but anthropically predictable thanks to a link with whether a life-permitting amount of matter survived early matter-antimatter annihilations. However, experiments now suggest a greater mass. Any model in which 45 GeV is anthropogenetically crucial seems wrong.

V. Mankind's future

Weinberg's arguments about the cosmological constant exploited the point that when a first observable value is far more likely than a second, then you should *prima facie* expect to observe the first, while when you in fact observe the second then, *prima facie*, the first was not genuinely far more likely. Now, similar considerations have been applied to *predicting how long humankind will survive*. Two things are at issue here. The first is the epoch at which *the human race* originated, inside the total available period: perhaps the period in which Earth's climate would have been hospitable. Is it likely that it arrived only late during the period? The second is where, inside the race's total lifetime, *an individual human* could have expected to live. Could he or she at all have expected to be as early in that lifetime as, say, the 1990s?

Looking at the first issue, Carter (1983, 1989a,b) considers the time humans took to evolve, around four billion years, and our sun's life-encouraging main sequence lifetime. These coincide within about a factor of two. Why are they at all comparable? [Cf. Rees (1972) on the Steady State, discussed earlier.] Carter answers that when a process involves one or more highly improbable steps and is very unlikely to be completed in the period available, then its completion, if it does chance to be completed, will most probably occur *after a time roughly comparable to that period.* Our galaxy could contain hugely many earthlike planets where crucial steps towards intelligence will never be taken because the typical time needed would be 10^{10} times longer than taken on Earth. Even if humanlike intelligence chanced to evolve fast enough (before their suns became red giants?) on only one or two planets in 10^{20}, anthropic "self-selection", the fact that observers can observe only situations where all steps towards observership have been taken, would ensure "that ours must be one of the exceptional cases". Intelligence like ours could easily be "unique in the visible Universe". Carter fairly confidently predicts *that such intelligence is unique in our galaxy* (1983, 352-360).

Carter's coincidence is only rough. Now, when a process (e.g., accumulating twenty double-sixes when two dice are tossed repeatedly) is unlikely to be completed in the period available because involving many highly improbable steps, then the most likely time of completion inside that period is when it has elapsed almost entirely. Our sun, though, will burn steadily for several billion more years -- so Carter predicts *that the highly improbable steps towards our level of intelligence will prove to have been few.* One avoids this conclusion if Earth's climate, "had we not emerged to retard or accelerate the process" (1983, 362), would have overheated or overcooled long before the sun's main sequence lifetime ended; but Carter dislikes this suggestion and rejects an argument Barrow and Tipler give for it. Admiring C.O.Lovejoy's thesis that "traits essential to any intelligent species are so uniquely human in the animal kingdom that the probability of the evolution of *any* intelligent terrestrial species is *equal* to the probability of the evolution of...*Homo sapiens*", and estimating that the number of crucial steps towards human intelligence was at least 110,000, Barrow and Tipler calculate a probable figure of no more than 41,000 years for "the length of time the biosphere will exist in the future" (1986, 564-567). Yet their argument seems faulty on three counts. (i) Carter's reasoning concerns Earth's biospheric degradation only "had we not emerged to retard or accelerate the process". (ii) Lovejoy is unconvincing. Carter protests (1989b, 204) that Barrow and Tipler severely underestimate "the number of alternative ways of achieving similar results (as evidenced by the rich diversity of known life-forms)". (iii) Their calculation is Bayesian. This looks appropriate; however, Bayesian calculations should only *shift some prior estimate* of the probability that, say, Earth would soon have overheated or overcooled. The prior estimate might be reached through M.Hart's computer simulations which suggest that Earth's climate has been only marginally stable. Yet Barrow and Tipler discuss Hart's findings *just after* their calculation, not prior to it.

Now for the second, quite separate issue. Where could an individual human at all expect to find him/herself inside humankind's total lifetime? And in view of where you do find yourself, what conclusions might you draw about the lifetime? Again one might use Bayesian reasoning, taking account of any prior probability that humans would destabilize Earth's climate, or of their colonizing the galaxy so that even the sun's death throes would not mean Doom.

As illustrated by Carter's treatment of the first issue, "anthropic" arguments can be applied to observership's likely circumstances. Indeed, when Carter rediscovered the argument Dicke had used against Dirac, his calculations concerned when *most* life-giving stars burn (1989b, 189): the epoch he thought most likely to contain observers, or to contain most observers. It might be hard to state circumstances where observers could not possibly exist. They might conceivably exist early in the Bang, flying out of black holes. A black hole emits particles randomly: hence, Hawking and Israel remark (1979, 19), it might emit "a television set or Charles Darwin". But even if, in a gigantic universe, a few observers were generated like this, nobody should expect to find that he/she/it had been thus generated. Similarly if our universe's temporal entirety contained numerous technological civilizations of sizes rivalling ours: we should not expect to find ourselves *in the very earliest, or among the earliest 0.1%.* [So failures to detect extraterrestrial intelligence suggest that when our universe ends it will have had only few such civilizations, or else that they typically self-destruct too quickly to be readily detectable. This encourages predictions about what future searchers will discover.] And likewise, as Carter noticed early in the 1980s, a human should not expect to find him/herself *among the earliest 0.1% of all humans. Which gives some grounds for predicting that the human race will not continue at its present size for many more centuries,* and still more for predicting *that it will not colonize its entire galaxy.*

Though investigating this theme in a lecture of 1983, Carter did not develop it in the lecture's printed version. He merely hinted at it in an appended Discussion (Carter 1983, 363), saying that "something like a man made ecological disaster...might well be discussed with reference to the anthropic principle". While he has defended it ever since, it has only recently reached print through me and Nielsen (Leslie 1989a etc.; Nielsen 1989, 454-459). Nielsen's presentation of it may, however, be flawed by not recognizing that it yields only *a Bayesian shift* in any estimate of how likely our race is to end soon: compare what was said just a moment ago about Barrow and Tipler. At any rate, Carter has written to me that my Bayesianism correctly represents his reasoning.

Its essence is this. If the human race is to end soon, you and I are positioned fairly ordinarily inside the race's total lifetime. Population has grown so markedly that of all humans so far, roughly 10% are alive today. But if the race will flourish for many more centuries, and particularly if it will colonize the galaxy, we could be very extraordinarily early humans. We could be in the first 0.01%, or the first 0.00001%. Fed into Bayesian calculations, our observed temporal position might therefore much increase estimates of the likelihood that the race will end soon (or else shrink to a tiny size and remain there). Compare how one can reason when winning one of a lottery's first three prizes. No matter how many names were in the hat, *some* had to be winners (just as, no matter how many humans there would be, *some* would be born earliest). Still, when my name is a winner I have reason to suspect that only a few remain in the hat.

Suppose a 2% probability that a hat with my name in it has ten names, a 98% probability that it has a thousand. These "prior" probabilities are my estimates before names are drawn. If my name is among *the earliest three* to be drawn then, Bayes's Rule tells me, the "posterior" probability that there were ten names is (2% x 3/10) divided by (2% x 3/10) + (98% x 3/1000). Which is about 67%.

Suppose the sole alternatives are that our race will end by AD 2100, and that it will last many more centuries. Simplifying again, suppose that the probability of a human's finding him/herself in the 1990s is 10% in the case of the short-lasting race; otherwise it is 0.1% (which could be far too high). You initially estimate, e.g., that the probability of the race ending by 2100 is 1%. That is to say, it is 1% prior to considering your observed temporal position. You next consider it. If you can use Bayes's Rule as in the previous case, the re-estimated probability of Doom Soon exceeds 50%.

It could be wrong to treat the cases similarly. Our universe might be radically indeterministic. Then there would not yet be any firm fact of how long our race will continue, similar to the fact that a hat still contains, say, seven names. Yet (i) some physicists still hold that, in the last analysis, the world is deterministic; (ii) any indeterminism could be unlikely to influence, e.g., whether humankind would survive today's pollution crisis; and (iii) Carter's reasoning at least acts powerfully against the theory that it is highly probable that the race will survive many thousand more years (since calling this "highly probable" means that any indeterministic factors truly would be unlikely to prevent it).

Do not object that your birth time was not decided with a hat; or that everybody is extraordinary *somehow*; or that Stone Age men (who, let me interject, did not face our pollution crisis) could have been led by Carterian reasoning to conclude that humankind would soon vanish; or that we *know* we live in the 1990s and would be equally certain of it, no matter what our views about our race's future; or that our genes are of kinds common only around the 1990s; or that humans of the future *cannot yet* observe their temporal positions. These objections (and many more) fail, although I shall not here repeat why (Leslie 1989a; 1989b, 214; 1990b,c; 1992a,c,d). Particularly in need of countering, though, is this. Suppose a gigantic universe contains two human races: one ending in AD 2100, and the other lasting immensely longer. The chances that you are in the short-lasting race would equal those of your being pre-2100 in the long-lasting one, if equally many humans were in those two positions. My counterargument is that in this scenario a human could expect to be post-2100 in the long-lasting race -- but you are not, which suggests that the scenario is wrong.

Carter's reasoning is of course sensitive to new evidence of risk-reduction efforts. And determinism is not fatalism — so do not argue that the determinism needed for the argument to run really smoothly *would make efforts futile.* What risks, then, could efforts minimize? Might the "jolts" of incautious high-energy experiments produce the vacuum metastability disaster mentioned earlier, which we could anyhow be lucky to have escaped if the top-quark mass is high? Here risk-taking could be controlled by scientists, able to understand Carter's reasoning. Could it encourage a prediction *that, if we make no effort to avoid extreme energies, a vacuum metastability disaster will occur?*

Vacuum metastability is poorly understood, and nobody knows what energies physicists could attain. Still, one might judge that nuclear war, pollution, deadly viruses, would all leave survivors who would regenerate a huge population, and that the main risk of irrevocable doom lay in the vacuum.

"True vacuum" nowadays means that fields are at their lowest potential energy. We may be in the "false vacuum" of an only-metastable scalar field, held above a barrier over which it might be jolted. In a high-energy experiment a bubble of true vacuum might form. The bubble would expand unstoppably "at close to the speed of light, with enormous energy release. ..We can ask whether a new generation of particle accelerators could trigger such an unfortunate event" (Hut and Rees 1983, 508). It would change Nature's constants, destroy all protons, produce gravitational collapse "in microseconds or less" (Coleman and De Luccia 1980, 3314; Turner and Wilczek 1982, 634). Hut and Rees judged the danger minimal: colliding cosmic rays had reached energies far higher than humans could foreseeably attain. However, Lederman and Schramm think they might be attained before AD 2100 with "something radically different from present technology" (1989, 232). Already, wake-field accelerators have been proposed with field strengths 10,000 times those used now. And if one had a means, not involving vast energy losses, of repeatedly doubling laser beam frequencies, focussing might achieve enormous energies. The crystals presently used for such doubling could not serve here.

The particle physicist's "standard model" suggests that we live in a metastable vacuum if the top-quark mass exceeds 95 GeV plus six tenths the Higgs boson mass. It may, for recent tests place the first of these masses between 100 and 160 GeV, and leave the second of themΩ perhaps under 50 GeV (Ellis, Linde and Sher 1990, 203-205). If a "supersymmetric" model is right instead, "the proliferation of parameters makes any attempts to find limits meaningless" (Flores and Sher 1983, 1682). Either way, our sole security lies in keeping below estimated cosmic ray collision energies. Indeed, we must keep *well below* them. (i) The crux is: how lucky are we that no disastrous collision has occurred in our past light cone [the segment of spacetime inside which a bubble of true vacuum expanding at virtually the speed of light would have meant *no us*]? How often do very energetic cosmic rays collide head on? All estimates have involved simplifications: most notably, the assumption that the things to calculate are the collision probabilities inside *a typical* past light cone stretching backwards from today. Yet our existence guarantees that no disastrous collision has occurred in *our* past light cone, even if past light cones of this size typically include many such collisions! A possible anthropic selection effect has been disregarded. [Note, too, that another such selection effect might conceivably explain our failure to detect technologically advanced extraterrestrials. All over our universe, beings who develop technological civilizations may almost always perform disastrous high-energy experiments soon afterwards. Thereafter, no observers could exist inside their future light cones, i.e., at viewpoints from which they could be seen. (ii) Complex studies [Sher 1989 cites

465 other papers, yet warns that they may be "swept into the dustbin" by new findings] indicate that not just collision energies but the details of the resulting fireballs might be crucial. For instance: bubbles of true vacuum, particularly if extremely energetically produced, might shrink instead of expanding because they started off too small. Accelerators or other devices might generate fatal bubbles more efficiently than cosmic rays could. Accelerator luminosities are great, making it more probable that further high-energy particles, or very massive particles, would arrive after collisions to facilitate bubble growth, or that a subcritical bubble would exploit quantum uncertainties and grow: "it may not be likely, but it only takes one event.." (Sher 1989, 335-336 and reference 463).

As Ellis, Linde and Sher comment (205), "many people would not like even to consider the possibility that we live in an unstable vacuum", yet "one should be happy if it is stable enough". Carter's argument suggests, though, that stability sufficient in the absence of human intervention could well be insufficient in its presence. This applies to the vacuum just as much as to Earth's climate. Carter has written to me that while vacuum metastability is interesting, "given all the other more obvious dangers that surround us I cannot say it adds significantly to my alarm". But to this I reply that while clever folk might well shrug off those dangers, arguing that not even all-out nuclear war could put an end to the human race, shrugging would be far harder to justify in the case of vacuum metastability, where the physics is so difficult, the potential disaster so all-destroying. *Prior to* considering Carter's point about our observed position in human population history, one might still shrug. How about afterwards? Much depends on what weight one gives to such comments as that obviously Carter is wrong because anyone considering his argument now has to be alive now and not, say, in the thirty-fifth century.

VI. Were observers necessary?

Even the strong anthropic principle, I said, concerns only a possible observational selection effect. Many, however, have read Carter's statement that our universe *must be observer-admitting* (obviously, since we are in it) in a way he did not envisage. They have understood him as suggesting that our universe was forced to be observer-containing: perhaps because physics and philosophy teach that only what is observed can truly exist, or perhaps because God wants observers.

If one thought that the unobserved was the unreal, as various "idealistic" arguments maintain, then one might be inclined to predict that quantum theory's "collapse of the wave function" must always be observer-produced. Again, influenced both by idealism and by theism, Tipler suggests that intelligent life will continue at all future times. From this he derives such predictions as that the universe is closed and will collapse to a point, particle density diverging to infinity but no faster than the square of the energy (1989, 35). He even develops a fascinating picture of a final cosmic state where intelligently processed information has become infinite. But it is philosophically far from clear that *the real* is *the observed*, and a recent experiment at Rochester (reported in the November 1991 *Scientific American*) may well show that no observers are needed to collapse wave functions. Carter rejects "concepts such as 'anthropic finality' whose teleological nature is, as John Leslie has emphasised, quite contrary to the empirical, conventionally 'scientific', spirit of the anthropic ('ex post facto' selection) principle as I intended it to be understood" (1989a, 35-36). And why should a theist suppose that divine power could create *only one* universe, the divine benevolence then having to cram it with living intelligence until its very end?

UNIVERSITY OF GUELPH
ONTARIO N1G 2W1
CANADA

REFERENCES

Atkins, P.W. (1981), *The Creation*. Oxford: W.H.Freeman.

Barrow, J.D., and Tipler, F.J. (1986), *The Anthropic Cosmological Principle*. Oxford: Clarendon Press.

Bertola, F., and Curi, U. (eds.) (1989), *The Anthropic Principle*. Cambridge: Cambridge University Press.

Campbell, B.A., Davidson, S., Ellis, J., and Olive, K.A. (1991), "Cosmological baryon asymmetry constraints on extensions to the standard model", *Physics Letters B 256*: 457-464.

Carter, B. (1974), "Large Number Coincidences and the Anthropic Principle in Cosmology", in M.S.Longair (ed.), *Confrontation of Cosmological Theories with Observational Data*. Dordrecht: Reidel, pp.291-298. Reprinted in J.Leslie (ed.) 1990a, pages 125-133.

—. (1976), "Understanding the Fundamental Constants", in J.H.Sanders and A.H.Wapstra (eds.), *Atomic Masses and Fundamental Constants*. New York:

Plenum Press, pages 650-654.

—. (1983), "The Anthropic Principle and its Implications for Biological Evolution", *Philosophical Transactions of the Royal Society, London A 310*: 347-363.fi [fi

—. (1989a), "The Anthropic Selection Principle and the Ultra-Darwinian Synthesis", in F.Bertola and U.Curi (eds.), *The Anthropic Principle*. Cambridge: Cambridge University Press, pages 33-63. fi [fi

—. (1989b), "The anthropic principle: self-selection as an adjunct to natural selection", in S.K.Biswas, D.C.V.Mallik, C.V.Vishveshwara (eds.), *Cosmic Perspectives*. Cambridge: Cambridge University Press, pages 185-206.

Coleman, S., and De Luccia, F. (1980), "Gravitational effects on and of vacuum decay", *Physical Review 21*: 3305-3315.

Davies, P.C.W. (1983), "The anthropic principle", in D.Wilkinson (ed.), *Progress in Particle and Nuclear Physics*: Volume 10. New York: Pergamon Press, pages 1-38.

—. (1984), *Superforce*. New York: Simon and Schuster.

DeWitt, B.S., and Graham, N. (eds.) (1973), *The Many-Worlds Interpretation of Quantum Mechanics*. Princeton: Princeton University Press.

Dicke, R.H. (1961), "Dirac's Cosmology and Mach's Principle", *Nature 92:* 440-441. Reprinted in J.Leslie (ed.) 1990a, pages 121-134.

Ellis, G.F.R., and Brundrit, G.B. (1979), "Life in the Infinite Universe", *Quarterly Journal of the Royal Astronomical Society 20*: 37-41.

Ellis, J., Linde, A., and Sher, M. (1990), "Vacuum stability, wormholes, cosmic rays and the cosmological bounds on m_t and m_H", *Physics Letters B 252*: 203-211.

Feinberg, G., and Shapiro, R. (1980), *Life Beyond Earth*. New York: William Morrow.

Flores, R.A., and Sher, M. (1983), "Upper limits to fermion masses in the Glashow-Weinberg-Salam model", *Physical Review D 27:* 1679-1682.

Guth, A.H., and Steinhardt, P.J. (1984), "The inflationary universe", *Scientific American 250:* 116-128.

Hawking, S.W., and Israel, W. (eds.) (1979), *General Relativity*. Cambridge: Cambridge University Press.

Hoyle, F. (1965), *Galaxies, Nuclei and Quasars*. London: Heinemann.

Hut, P., and Rees, M.J. (1983), "How stable is our vacuum?", *Nature 308*: 508-509.

Lederman, L.M., and Schramm, D.N. (1989), *From Quarks to the Cosmos*. New York: W.H. Freeman.

Leslie, J. (1979), *Value and Existence*. Oxford: Basil Blackwell.

—. (1982), "Anthropic Principle, World Ensemble, Design", *American Philosophical Quarterly 19*: 141-151.

—. (1983a), "Cosmology, Probability and the Need to Explain Life", in N.Rescher (ed.), *Scientific Explanation and Understanding*. Lanham: University Press of America, pages 53-82.

—. (1983b), "Observership in Cosmology: the Anthropic Principle", *Mind 92*: 573-579.

—. (1985), "Modern Cosmology and the Creation of Life", in E.McMullin (ed.), *Evolution and Creation*. Notre Dame: University of Notre Dame Press, pages 91-120.

—. (1986a), "The Scientific Weight of Anthropic and Teleological Princi ples", in N.Rescher (ed.), *Current Issues in Teleology*. Lanham: University Press of America, pages 111-119.

—. (1986b), "Anthropic Explanations in Cosmology", in A.Fine and P.Mach amer (eds.), *PSA 1986: Volume One*. Ann Arbor: Edwards Brothers, pages 87-95.

—. (1987), "Probabilistic Phase Transitions and the Anthropic Principle", in J.Demaret (ed.), *Origin and Early History of the Universe*. Lieô ge: Presses of the University of Lieô`ge, pages 439-444.

—. (1988a), "No Inverse Gambler's Fallacy in Cosmology", *Mind 97*: 269 272.

—. (1988b), "The Prerequisites of Life in Our Universe", in G.V.Coyne, M.J.Heller and J.Zycinski (eds.), *Newton and the New Direction in Science.* Vatican City: Vatican Observatory, pages 229-258.

—. (1988c), "How to draw conclusions from a fine-tuned universe", in R.J.Russell, W.R.Stoeger and G.V.Coyne (eds.), *Physics,* *Philosophy and Theology*. Vatican City: Vatican Observatory, pages 297-311.

——. (1989a), "Risking the World's End", *Bulletin of the Canadian Nuclear Society 10* (3): 10-15. Reprinted in *Interchange* (1990) *21*: 49-58.

——. (1989b), *Universes*. London and New York: Routledge.

——. (1989c), "Demons, Vats and the Cosmos", *Philosophical Papers 18*: 169 188.

——. (1989d), "The Leibnizian Richness of Our Universe", in N.Rescher (ed.) *Leibnizian Inquiries*. Lanham: University Press of America, pages 139-146.

——.(ed.) (1990a), *Physical Cosmology and Philosophy*. New York: Macmillan. ——. (1990b), "Is the End of the World Nigh?", *The Philosophical Quarterly Ã Ã40:* 65-72.fi [fi

——. (1990c), "Time and the Anthropic Principle", for the plenary session of "The Problem of Time in Cosmology", Soviet Academy of Sciences, Leningrad, November, and published in Mind (1992) 101:521-40.

——. (1992a), "Doomsday Revisited", *The Philosophical Quarterly 42*: 85-89.

——. (1992b), "Design and the Anthropic Principle", to appear in *Biology and Philosophy*.

——. (1992c), "The Doomsday Argument", to appear in *The Mathematical Intelligencer*.

——. (1992d), "Bayes, Urns and Doomsday", to appear in *Interchange*.

——. (1992e), "Cosmology", "Cosmos", "Finite/Infinite", "World", "Why There Is Something", to appear in J.Kim and E.Sosa (eds.), *A Companion to Metaphysics*. Oxford: Basil Blackwell.

——. (1992f), "Multiple Universes", to appear in R.F.Kitchener (ed.), *The Origin of the Universe*.

Linde, A. (1985), "The Universe: inflation out of chaos", *New Scientist 105* (1446): 14-18. Reprinted in J.Leslie (ed.) 1990a, pages 239-247.

Longair, M.S. (ed.) (1974), *Confrontation of Cosmological Theories with Obs ervational Data*. Dordrecht: Reidel.

Nielsen, H.B. (1989), "Random Dynamics and Relations between the Number of Fermion Generations and the Fine Structure Constants", *Acta Physica Polonica B 20*: 427-468.fi [fi

Penrose, R. (1979), "Singularities and time asymmetry", in S.W.Hawking and W.Israel (eds.), *General Relativity*. Cambridge: Cambridge University Press, pages 581-638.

Rees, M.J. (1972), "Cosmological Significance of e^2/Gm^2 and Related 'Large Numbers'", *Comments on Astrophysics and Space Physics 4:* 179-185.

—. (1981), "Our Universe and Others", *Quarterly Journal of the Royal Astronomical Society 22:* 109-124.

—. (1987), "The anthropic Universe", *New Scientist 115* (1572): 44-47.

Rozental, I.L., Novikov, I., and Polnarev, A. (1982), "On Numerical Values of Fundamental Constants and the Anthropic Principle" (in Russian with English abstract), *Izvestiya Akademii Nauk Estonskoii SSR Seriia Fiziko-Matemati cheskii 31*: 284-289.

Shaposhnikov, M.E., and Tkachev, I.I. (1990), "Higgs Boson Mass and the Anth ropic Principle", *Modern Physics Letters A 5*: 1659-1661.

Sher, M. (1989), "Electroweak Higgs Potentials and Vacuum Stability", *Physics Reports 179*: 273-418.

Sikkema, A.E., and Israel, W. (1991), "Black-hole mergers and mass inflation in a bouncing universe", *Nature 349*: 45-47.

Tipler, F.J. (1989), "The Anthropic Principle: A Primer for Philosophers", in A. Fine and J. Leplin (eds.), *PSA 1988: Volume Two*. Ann Arbor: Edwards Brothers, pages 27-48.

Turner, M.S., and Wilczek, F. (1982), "Is our vacuum metastable?", *Nature 298*: 633-634.

Weinberg, S. (1987), "Anthropic Bound on the Cosmological Constant", *Physical Review Letters 59*: 2607-2610.

—. (1989), "The cosmological constant problem", *Reviews of Modern Physics 61:* 1-23.