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WHY (ALMOST ALL) COSMOLOGISTS ARE ATHEISTS

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Science and religion both make claims about the fundamental workings of the universe. Although these claims are not a priori incompatible (we could imagine being brought to religious belief through scientific investigation), I will argue that in practice they diverge. If we believe that the methods of science can be used to discriminate between fundamental pictures of reality, we are led to a strictly materialist conception of the universe. While the details of modern cosmology are not a necessary part of this argument, they provide interesting clues as to how an ultimate picture may be constructed.

Introduction

One increasingly hears rumors of a reconciliation between science and religion. In major news magazines as well as at academic conferences, the claim is made that that belief in the success of science in describing the workings of the world is no longer thought to be in conflict with faith in God. I would like to argue against this trend, in favor of a more old-fashioned point of view that is still more characteristic of most scientists, who tend to disbelieve in any religious component to the workings of the universe.

The title "Why cosmologists are atheists" was chosen not because I am primarily interested in delving into the sociology and psychology of contemporary scientists, but simply to bring attention to the fact that I am presenting a common and venerable point of view, not advancing a new and insightful line of reasoning. Essentially I will be defending a position that has come down to us from the Enlightenment, and which has been sharpened along the way by various advances in scientific understanding. In particular, I will discuss what impact modern cosmology has on our understanding of these truly fundamental questions.

The past few hundred years have witnessed a significant degree of tension between science and religion. Since very early on, religion has provided a certain way of making sense of the world — a reason why things are the way they are. In modern times, scientific explorations have provided their own pictures of how the world works, ones which rarely confirm the pre-existing religious pictures. Roughly speaking, science has worked to apparently undermine religious belief by calling into question the crucial explanatory aspects of that belief; it follows that other aspects (moral, spiritual, cultural) lose the warrants for their validity. I will argue that this dis-

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agreement is not a priori necessary, but nevertheless does arise as a consequence of the scientific method.

It is important from the outset to distinguish between two related but ultimately distinct concepts: a picture of how the world works, and a methodology for deciding between competing pictures. The pictures of interest in this paper may be labelled "materialism" and "theism." Materialism asserts that a complete description of nature consists of an understanding of the structures of which it is comprised together with the patterns which those structures follow, while theism insists on the need for a conscious God who somehow rises above those patterns. (These categories can be found, for example, in Richard Swinburne's *Is There a God?*[1] I don't mean to pick on the conference organizer, but this short book is a well-presented and paradigmatic example of the kind of view I want to contrast with mine.) Science is most often associated with a materialist view, but the essence of science lies as much in a methodology of reaching the truth as in any view of what form that truth might ultimately take. In particular, the scientific method is an empirical one, in contrast to appeals to pure reason or to revelation. For the purposes of this paper I will assume the validity of the scientific method, and simply ask what sorts of conclusions we are led to by its application.

Within this framework, there are two possible roads to reconciliation between science and religion. One is to claim that science and religion are not incompatible because they speak to completely distinct sets of questions, and hence never come into conflict. The other is to assert that thinking scientifically does not lead to rejection of theism, but in fact that religious belief can be justified in the same way that any scientific theory might be. I will argue that neither strategy succeeds: science and religion do speak to some of the same questions, and when they do they get different answers. In particular, I wish to argue that religious belief necessarily entails certain statements about how the universe works, that these statements can be judged as scientific hypotheses, and that as such they should be rejected in favor of alternative ways of understanding the universe.

Probably nothing that I say will be anything you have not heard elsewhere. My goals here are simply to describe what I think a typical scientist has in mind when confronted with the question of science vs. religion, even if the scientists themselves have not thought through these issues in any detail.

Worldviews

One of the most difficult tasks in discussing the relationship between science and religion is to define the terminology in ways that are acceptable to everyone listening. In fact, it is likely impossible; especially when it comes to religion, the terminology is used in incompatible ways by different people. I will therefore try to be as clear as possible about the definitions I am using. In this section I want to carefully describe what I mean by the two competing worldviews, materialism and theism, without yet addressing how to choose between them.

The essence of materialism is to model the world as a formal system, which is both unambiguous and complete as a description of reality. A materialist model may be said to consist of four elements.

First, we model the world as some formal (mathematical) structure. (General relativity describes the world as a curved manifold with a Lorentzian metric, while quantum mechanics describes the world as a state in some Hilbert space. As a more trivial example, we could imagine a universe which consisted of nothing other that an infinitely long list of "bits" taking on the values 0 or 1.) Second, this structure exhibits patterns (the "laws of nature"), so that the amount of information needed to express the world is dramatically less than the structure would in principle allow. (In a world described by a string of bits, we might for example find that the bits were an infinitely repeated series of a single one followed by two zeroes: 100100100100...) Third, we need boundary conditions which specify the specific realization of the pattern. (The first bit in our list is a one.) Note that the distinction between the patterns and their boundary conditions is not perfectly well-defined; this is an issue which becomes relevant in cosmology, and we'll discuss it more later. Finally, we need a way to relate this formal system to the world we see: an "interpretation."

The reader might worry that we are glossing over very subtle and important issues in the philosophy of science; they would be correct, but needn't worry. Philosophy of science becomes difficult when we attempt to describe the relationship of the formalism to the world (the interpretation), as well as how we invent and choose between theories. But the idea that we are trying, in principle, to model the world as a formal system is fairly uncontroversial.

The materialist thesis is simply: that's all there is to the world. Once we figure out the correct formal structure, patterns, boundary conditions, and interpretation, we have obtained a complete description of reality. (Of course we don't yet have the final answers as to what such a description is, but a materialist believes such a description does exist.) In particular, we should emphasize that there is no place in this view for common philosophical concepts such as "cause and effect" or "purpose." From the perspective of modern science, events don't have purposes or causes; they simply conform to the laws of nature. In particular, there is no need to invoke any mechanism to "sustain" a physical system or to keep it going; it would require an additional layer of complexity for a system to cease following its patterns than for it to simply continue to do so. Believing otherwise is a relic of a certain metaphysical way of thinking; these notions are useful in an informal way for human beings, but are not a part of the rigorous scientific description of the world. Of course scientists do talk about "causality," but this is a description of the relationship between patterns and boundary conditions; it is a derived concept, not a fundamental one. If we know the state of a system at one time, and the laws governing its dynamics, we can calculate the state of the system at some later time. You might be tempted to say that the particular state at the first time "caused" the state to be what it was at the second time; but it would be just as correct to say that the second state caused the first. According to the materialist worldview, then, structures and patterns are all there are — we don't need any ancillary notions.

Defining theism is more difficult than defining materialism, for the simple reason that theist belief takes many more forms that materialist belief, and the same words are often taken to mean utterly different things. I will partially avoid this difficulty by not attempting a comprehensive definition of religion, but simply taking belief in the existence of a being called "God" as a necessary component of being religious. (Already this choice excludes some modes of belief that are sometimes thought of as "religious." For example, one could claim that "the laws of physics, and their working out in the world, are what I hold to be God." I am not sure what the point of doing that would be, but in such a case nothing that I have to say would apply.)

The subtlety has therefore been transferred to the task of defining "God." I will take it to mean some being who is not bound by the same patterns we perceive in the universe, who is by our standards extremely powerful (not necessarily omnipotent, although that would count), and in some way plays a crucial role in the universe (creating it, or keeping it going, etc.). By a "being" I mean to imply an entity which we would recognize as having consciousness — a "person" in some appropriately generalized sense (as opposed to a feature of reality, or some sort of feeling). A rather concrete God, in other words, not just an aspect of nature. This notion of God need not be interventionist or easy to spot, but has at least the capability of intervening in our world. Even if not necessarily omnipotent, the relevant feature of this conception is that God is not bound by the laws of physics. In particular, I don't include some sort of superhero-God who is bound by such laws, but has figured out how to use them in ways that convey the impression of enormous power (even if it is hard to imagine ultimately distinguishing between these two possibilities). When I say that God is not bound by the laws of physics, I have in mind for example that God is not limited to moving more slowly than the speed of light, or that God could create an electron without also creating a corresponding positively-charged particle. (We are not imagining that God can do the logically impossible, just violate the contingent patterns of reality that we could imagine having been different.) Of course these are meager powers compared to most conceptions of God, but I am taking them to be minimal criteria. There are various types of belief which are conventionally labelled as religious, but inconsistent with my definition of God; about these I have nothing to say in this paper.

It should be clear that, by these definitions, materialism and theism are incompatible, essentially by definition. (The former says that everything follows the rules, the second says that God is an exception.) It does not immediately follow that "science" and "religion" are incompatible; we could follow the scientific method to conclude that a materialist description of the world was not as reasonable as a theistic one. On the other hand, it does follow that science and religion do overlap in their spheres of interest. Religion has many aspects, including social and moral ones, apart from its role in describing the workings of the world; however, that role is a crucial one, and necessarily speaks to some of the same issues as science does. Suggestions that science and religion are simply disjoint activities generally rely on a re-definition of "religion" as something closer to "moral philosophy."[2] Such a definition ignores crucial aspects of religious belief.

In judging between materialism and theism, we are faced with two possibilities. Either one or the other system is logically impossible, or we need to decide which of the two conceivable models better explains the world we experience. In my view, neither materialism nor theism is logically impossible, and I will proceed on the idea that we have to see which fits reality better. Of course arguments against materialism have been put forward which do not rely on specific observed features of our world, but instead on either pure reason or revelation; I won't attempt to deal with such arguments here.

Theory choice

Given this understanding of materialism and theism, how are we to decide which to believe? There is no right answer to this question, and sensible arguments can only be made after we agree on some basic elements of how we should go about choosing a theory of the world. For example, someone could insist on the primacy of revelation in understanding deep truths; in response, there is no logical argument that could prove such a person wrong. Instead, I would like to ask what conclusion we should reach by employing a more empirical technique of deciding between theories. In other words, we address the choice between materialism and theism as a scientist would address the choice between any two competing theories.

The basic scientific assumption is that there exists a complete and coherent description of how the world works. (This need not be a purely materialist description, in the language of the previous section; simply a sensible description covering all phenomena.) Although we certainly don't yet know what this description might be, science has been extremely successful at constructing provisional theories which accurately model some aspects of reality; this degree of success thus far convinces most scientists that there really is a comprehensive description to be found. This underlying assumption plays a crucial role in determining how scientists choose between competing theories which are more modest in their goals, attempting to model only some specific types of phenomena — in a nutshell, scientists choose those models which they feel are more likely to be consistent with the true underlying unified description.

We can make such a sweeping statement with some confidence, only because it avoids all the hard questions. In particular, how do we go about deciding whether a theory is more or less likely to be consistent with a single coherent description of nature? It is at this point that the judgment of the individual scientist necessarily plays a crucial role; the process is irreducibly non-algorithmic.

A number of criteria are employed, including fit to experiment, simplicity, and comprehensiveness. No one of these criteria is absolute, even fit to experiment; after all, experiments are sometimes wrong.

Let me give an example to illustrate the different criteria employed by scientists to judge theories. When we observe the dynamics of galaxies, we find that the apparent gravitational force exerted by the galaxy on particles orbiting far around it is inevitably much larger than we would expect by taking into account the combined mass of all the visible material in the galaxy. A straightforward and popular hypothesis to explain this observation is the idea of "dark matter," the notion that most of the mass in galaxies is not in stars or gas, but rather in some new kind of particle which has not yet been observed directly, and which has an average mass density in the universe which is approximately five times greater than that of ordinary matter. But there is a competing idea: that our understanding of gravity (through Einstein's general relativity) breaks down at the edges of galaxies, to be replaced by some new gravitational law. Such a law has actually been proposed by Milgrom, under the name of "Modified Newtonian Dynamics," or MOND.[3] At this point we don't know for certain whether the dark matter hypothesis or the MOND hypothesis is correct, but it is safe to say that the large majority of scientific experts come down in favor of dark matter. Why is that? On the one hand, there is a sense in which MOND is more compact and efficient: it has been demonstrated to accurately describe the observations of a wide set of galaxies, with only a single free parameter, while the dark matter idea is somewhat less predictive on this score. But there are two features working strongly in favor of dark matter. First, it makes detailed predictions for a wide class of phenomena, well outside the realm of individual galaxies: clusters of galaxies, gravitational lenses, large-scale structure, the cosmic microwave background, and more, while MOND is completely silent on these issues (there is no prediction to verify or disprove). The second (closely related) point is that MOND is not really a complete theory, or even a theory at all, but simply a suggested phenomenological relation that is supposed to hold for galaxies. Nobody understands how to make it part of a larger consistent framework. Therefore, despite the greater predictive power of MOND within its domain of validity, most scientists consider it to be a step backward, as it seems less likely to ultimately be part of a comprehensive description. (Nobody can say for sure, so the issue is still open, but the majority has a definite preference.)

It should be clear why choosing between competing theories is difficult — it's a matter of predicting the future, not of applying a set of unambiguous criteria. Nevertheless, it's not completely arbitrary, either; it's simply a matter of applying a set of somewhat ambiguous standards. Fortunately, cases in which a certain theory would be favored by applying one reasonable criterion while a different theory would be favored by applying a different reasonable criterion are both rare and typically short-lived; the acquisition of additional experimental input or increased theoretical understanding tends to ultimately resolve the issue relatively cleanly in favor of one specific model.

According to this description, the evaluation of a scientific theory involves both a judgment about the theory itself and about the more comprehensive theory which would ultimately describe nature. While a number of disparate factors are applied to concrete theories, the criteria relevant to judging competing comprehensive theories are much more straightforward: among every possible model which fits all of the data, we choose the simplest possible one. "Simplicity" here is related to the notion of "algorithmic compressibility": the simplicity of a model is judged by how much information is required to fully specify the system. There is no a priori reason why nature should be governed by a comprehensive model which is at all simple; but our experience as scientists convinces us that this is the case.

It should be clear how these considerations relate to the choice between materialism and theism. These two worldviews offer different notions of what form a comprehensive description will take. Acting as scientists, it is our task to judge whether it seems more likely that the simplest possible comprehensive theory which is compatible with what we already know about the universe will turn out to be strictly materialistic, or will require the introduction of a deity.

Cosmology and belief

If we accept the scientific method as a way to determine the workings of reality, are we led to a materialist or theist conclusion? Naively, the deck seems to be stacked against theism: if we are looking for simplicity of description, a view which only invokes formal structures and patterns would appear to be simpler than one in which God appeared in addition.

However, we are constrained to find simple descriptions which are also complete and consistent with experiment. Therefore, we could be led to belief in God, if it were warranted by our observations — if there were evidence (direct or otherwise) of divine handiwork in the universe.

There are several possible ways in which this could happen. Most direct would be straightforward observation of miraculous events that would be most easily explained by invoking God. Since such events seem hard to come by, we need to be more subtle. Yet there are still at least two ways in which a theist worldview could be judged more compelling than a materialist one. First, we could find that our best materialist conception was somehow incomplete — there was some aspect of the universe that could not possibly be explained within a completely formal framework. This would be like a "God of the gaps," if there were good reason to believe that a certain kind of "gap" were truly inexplicable by formal rules alone. Second, we could find that invoking the workings of God actually worked to simplify the description, by providing explanations for some of the observed patterns. An example would be an argument from design, if we could establish convincingly that certain aspects of the universe were designed rather than assembled by chance. Let's examine each of these possibilities in turn.

We turn first to the idea that there is something inherently missing in a materialist description of nature. One way in which this could happen would be if there were a class of phenomena which seemed to act without regard to any patterns we could discern, something that stubbornly resisted formalization into a mechanistic description. Of course, in such a case it would be hard to tell whether an appropriate formalism actually didn't exist, or whether we just hadn't yet been clever enough to discover it. For example, physicists have tried for most of the last century to invent a theory that described gravity while being consistent with quantum mechanics. (String theory is the leading candidate for such a theory, but it has not yet been fully developed to the point where we understand it well enough to compare it to experiment.) It is hard to know at what point scientists would become sufficiently frustrated in their attempts to describe a phenomenon that they would begin to suspect that no formal description was applicable.

However, it is safe to say that such a point has not been reached, or even approached, with any of the phenomena of current interest to physicists. Although there are undoubtedly unsolved problems, the rate at which successful theoretical explanations are proposed for these problems is well in accordance with expectation. In other words, there does not seem to be any reason to suspect that we have reached, or are about to reach, the fundamental limits of our ability to find rules governing Nature's behavior.

A more promising place to search for a fundamental incompleteness in the materialist program would be at the "boundaries" of the universe. Recall that a complete mechanistic picture involves not only patterns we discern in nature, but some boundary condition which serves to choose a particular realization of all the possible configurations consistent with such a pattern. In the realm of science, this is an issue of unique concern to cosmology. In physics, chemistry, or biology, we imagine that we can isolate systems in whatever initial state we like (within reason), and observe how the rules governing the system play themselves out from that starting point. In cosmology, in contrast, we are faced with a unique universe, and must face the issue of its initial conditions. One could certainly imagine that something like a traditional religious conception of God could provide some insight into why the initial state was the particular one relevant to our universe.

In classical cosmology initial conditions are imposed at the Big Bang, a singular region in spacetime out of which our universe was born. More carefully, if we take our current universe and run it back in time, we reach a point where the density and curvature of spacetime become infinite, and our equations (gravity described by Einstein's general relativity, and other fields described by the Standard Model of particle physics) cease to make sense. This initial moment must apparently be treated as a boundary to spacetime. (A boundary in the past, not in any direction in space.) As we now recognize, the conditions near the Big Bang are by no means generic; the curvature of space (as opposed to that of spacetime) was extremely close to zero, and widely separated parts of the universe were expanding at nearly identical rates. What made it this way? Do we need to accept the imposition of certain boundary conditions as an irreducible part of our worldview, or is there some way of arguing within a bigger picture that these conditions were somehow natural? Or do we simplify our description by invoking a God who brought the universe into existence in a certain state?

Nobody knows the answers with any certainty. The best we can do is to extrapolate from what we think we do know. In this context, modern cosmology does have something to teach us. In particular, we now know that the issue of boundary conditions is more complicated than it might appear at first. Indeed, we now understand that, despite appearances, the universe might not have a boundary at all. This could happen in one of two ways: either the Big Bang might actually be smooth and nonsingular, or it might represent a transitional phase in a universe which is actually eternal.

The first possibility, that the Big Bang is actually nonsingular, was popularized by the Hartle-Hawking "no boundary" proposal for the wave function of the universe.[4] Discussions of this proposal can be somewhat misleading, in that they frequently refer to the idea that the universe came into being out of nothing. This would be hard to understand, if true; what is this "nothing" that the universe purportedly came out of, and what caused it to come out? A much better way of putting the Hartle-Hawking idea into words would be to say that the apparent "sharp point" at the beginning of spacetime is smoothed out into a featureless surface. The mechanism by which the smoothing purportedly happens involves technical details of the geometry of the spacetime metric, and in all honesty the entire proposal is very far from being well-formulated. Nevertheless, the lesson of the Hartle-Hawking work is that we don't necessarily have to think of the Big Bang as an "edge" at which spacetime runs into a wall; it could be more like the North Pole, which is as far north as you can possibly go, without actually representing any sort of physical boundary of the globe. In other words, the universe could be finite (in time) and yet be unbounded.

The other way to avoid a boundary is more intuitive: simply imagine that the universe lasts forever. Like the Hartle-Hawking proposal, the idea of an eternal universe requires going beyond our current well-formulated theories of general relativity and particle physics. In the context of classical four-dimensional gravitation, it is well known that the conditions that we believe obtained in the very early universe must have originated from a singularity. Extensions of this picture, however, can in principle allow for smooth continuation through the veil of the Big Bang to an earlier phase of the universe. Within this scenario there are two possibilities: either what we see as the Big Bang was a unique event, about which the universe expands indefinitely in either direction in time; or it was one occurrence in an infinitely repeating cycle of expansions and recontractions. Both possibilities have been considered for a long time, but have received new attention thanks to recent work by Veneziano and collaborators (the "pre-Big-Bang" model[5]) and Steinhardt, Turok, and collaborators (the "cyclic universe" model[6]).

In either case, an attempt is made to circumvent traditional singularity theorems by introducing exotic matter fields, extra dimensions of space, and sometimes "branes" on which ordinary particles are confined. For example, in the model of a cyclic universe advocated by Steinhardt and Turok, our universe is a three-brane (three spatial dimensions, evolving in time, for a total of four spacetime dimensions) embedded in a background five-dimensional spacetime. Motion in the extra dimension, it is suggested, can help resolve the apparent Big-Bang singularity, allowing a contracting universe to bounce and begin expanding into a new phase, before eventually recollapsing and starting the cycle over again.

I don't want to discuss details of either the pre-Big-Bang scenario or the cyclic universe; for one thing, the details are fuzzy at best and incoherent at worst. Neither picture is completely well-formulated at this time. But the state of the art in early-universe cosmology is not the point; the lesson here is that we are not forced to think of boundary conditions being imposed arbitrarily at the earliest times. In any of the scenarios mentioned here, the issue of initial conditions is dramatically altered from the classical Big-Bang scenario, since there is no edge to the universe at which boundary conditions need to be arbitrarily imposed. Thus, one cannot argue that we require the initial state of the universe to be specified by the conscious act of a deity, or that the universe came into existence as the result of a single creative act. This is by no means a proof that God does not exist;

God could be responsible for the universe's existence, whether it is boundaryless or not. But these theories demonstrate that a distinct creation event is not a necessary component of a complete description of the universe. Although we don't know whether any of these models will turn out to be part of the final picture, their existence allows us to believe that a simple materialist formalism is sufficient to tell the whole story.

Being allowed to believe something, of course, is not the same as having good reasons for doing so. This brings us to the second possible way in which scientific reasoning could lead us to believe in God: if, upon constructing various models for the universe, we found that the God hypothesis accounted most economically for some of the features we found in observed phenomena. As noted, this kind of reasoning is a descendant of the well-known argument from design. A few centuries ago, for example, it would have been completely reasonable to observe the complexity and subtlety exhibited in the workings of biological creatures, and conclude that such intricacy could not possibly have arisen by chance, but must instead be attributed to the plan of a Creator. The advent of Darwin's theory of evolution, featuring descent with modification and natural selection, provided a mechanism by which such apparently improbable configurations could have arisen via innumerable gradual changes.

Indeed, modern science has provided plausible explanations for the origin of all the complex phenomena we find in nature (given appropriate initial conditions, as we just discussed). Nevertheless, these explanations rely on the details of the laws of physics, as exemplified in general relativity and the Standard Model of particle physics. In particular, when we consider carefully the particular laws we have discovered, we find them to be specific realizations of more general possible structures. For example, in particle physics we have various kinds of particles (fermions, gauge bosons, a hypothetical higgs boson), as well as specific symmetries among their interactions, and particular values for the parameters governing their behavior. Given that the universe is made out of fermions and bosons with particular kinds of interactions, to the best of our current knowledge we do not understand why we find the particular particles we do, or the particular symmetries, or the particular parameters, rather than some other arrangement. Is it conceivable that in the particular realization of particles and forces of our universe we can discern the fingerprints of a conscious deity, rather than simply a random selection among an infinite number of possibilities?

Well, yes, it is certainly conceivable. In fact, the argument has been made that the particles and interactions we observe are not chosen at all randomly; instead, they are precisely tuned so as to allow for the existence of human life (or at least, complex structures of the kind we consider to be necessary for intelligent life).

In order for this argument to have force, we must believe both that the physical laws are finely-tuned to allow for life (i.e., that the complexity required for life to form is not a robust feature, and would generally be absent for different choices of particles and coupling constants), and that there is no simpler alternative explanation for this fine-tuning. I will argue that neither statement is warranted by our current understanding, although both are open questions; in either case, there is not a strong reason for invoking the existence of God.

Let's turn first to the fine-tuning of our observed laws of nature. It is certainly true that the world we observe depends sensitively on the particular values of the constants of nature: for example, the strength of the electromagnetic and nuclear forces. If the strong nuclear force had a slightly different value, the balance which characterizes stable nuclei would be upset, and the periodic table of the elements would be dramatically altered.[7] We could imagine (so the argument goes) values for which hydrogen were the only stable element, or for which no carbon was formed in the life cycle of stars. In either case it would be difficult or impossible for life as we know it to exist.

But there are two serious holes in this argument, at least at our current level of expertise: we don't really know what the universe would look like if the parameters of the standard model were different, nor do we know what are the necessary conditions for the formation of intelligent life. (Both of these claims are open to debate, and there are certainly scientists who disagree; but if nothing else these are the conservative positions.)

To appreciate the difficulty of reliably determining what the universe would be like if the constants of nature took on different values, let us imagine trying to figure out what our actual universe should look like, if we were handed the laws of subatomic physics but had no direct empirical knowledge of how particles assembled themselves into more complex structures. A fundamental obstacle arises immediately, since quantum chromodynamics (the theory of quarks and gluons, which gives rise to the strong nuclear force) is a strongly-coupled theory, so that our most straightforward and trustworthy techniques (involving perturbation theory in some small parameter, such as the fine-structure constant of electromagnetism) are worthless. We would probably be able to conclude that quarks and gluons were bound into composite particles, and could even imagine figuring out that the lightest nearly-stable examples were protons and neutrons (and their antiparticles). It would be very hard, without experimental input, to calculate reliably that protons were lighter than neutrons, but it might be possible. It would be essentially impossible to determine accurately the types of stable nuclei that protons and neutrons would be able to form. We would have no chance whatsoever of accurately predicting the actual abundance of heavy nuclei in the universe, as these are formed in stars and supernovae whose evolution we don't really understand even with considerable observational input. Most embarrassingly, we would never have predicted that there was a significant excess of matter over antimatter, since the process by which this occurs remains a complete mystery (there are numerous plausible models, but none has become commonly accepted).[8] So we would predict a world in which there were almost no nuclei at all, the nucleons and anti-nucleons having annihilated long ago, leaving nothing but an inert gas of photons and neutrinos, in other words, a universe utterly inhospitable to the existence of intelligent life as we know it. Of course, perhaps life could nevertheless exist, of a sort radically different than we are familiar with. As skeptical as I am about the ability of physicists to accurately predict gross features of a universe in which the laws of nature are different, I am all the more skeptical of the ability or biologists (or anyone else) to describe the conditions under which intelligence may or may not arise. (Cellular automata, the simple discrete systems popularized by Wolfram and others[9], provide an excellent example of how extreme complexity can arise out of fundamentally very simple behaviors.) For this reason, it seems highly presumptuous for anyone to claim that the laws of nature we observe are somehow delicately adjusted to allow for the existence of life.

But in fact there is a better reason to be skeptical of the fine-tuning claim: the indisputable fact that there are many features of the laws of nature which don't seem delicately adjusted at all, but seem completely irrelevant to the existence of life. In a cosmological context, the most obvious example is the sheer vastness of the universe; it would hardly seem necessary to make so many galaxies just so that life could arise on a single planet around a single star. But to me a more pointed observation is the existence of "generations" of elementary particles. All of the ordinary matter in the universe seems to be made out of two types of quarks (up and down) and two types of leptons (electrons and electron neutrinos), as well as the various force-carrying particles. But this pattern of quarks and leptons is repeated threefold: the up and down quarks are joined by four more types, just as the electron and its neutrino are joined by two electron-type particles and two more neutrinos. As far as life is concerned, these particles are completely superfluous. All of the processes we observe in the everyday workings of the universe would go on in essentially the same way if those particles didn't exist. Why do the constituents of nature exhibit this pointless duplication, if the laws of nature were constructed with life in mind?

Beyond the fact that the constants of nature do not seem to be chosen by any intelligent agent, there remains the very real possibility that parameters we think of as distinct (for example, the parameters measuring the strength of the electromagnetic and nuclear forces) are actually calculable from a single underlying parameter. This speculative proposal is the goal of so-called grand unified theories, for which there is already some indirect evidence. In other words, it might turn out to be that the constants of nature really couldn't have had any other values. I don't think that, if we discovered this to be the case, it would count as evidence against the existence of God, only because I don't think that our present understanding of these parameters counts as evidence in favor of God.

But perhaps the parameters are finely tuned; we might imagine that our understanding of physics, biology, and complexity some day will increase to a degree where we can say with confidence that alternative values for these parameters would not have allowed intelligent life to evolve. Even in that case, the existence of God is by no means the only mechanism for explaining this apparently-unlikely state of affairs; a completely materialist scenario is provided by the well-known anthropic principle. Imagine that what we think of as the "constants of nature" are merely local phenomena, in the sense that there are other regions of the universe where they take on completely different values. This is a respectable possibility within our current conception of particle physics and cosmology. The idea that there are different, inaccessible regions of the universe is consistent with the theory of "eternal inflation," in which spacetime on large scales consists of innumerable distinct expanding universes, connected by regions of space driven to hyper-expansion by an incredibly high-energy field.[10] Within each of these separate regions, we can imagine that the matter fields settle into one of a large number of distinct metastable states, characterized by different values of all the various coupling constants. [Such a scenario is completely consistent with current ideas from string theory[11], although it is clearly at odds with the idea from the previous paragraph that all of the coupling constants might be uniquely calculable. The truth is that either scenario is possible, we just don't know enough at this point to say with confidence which, if either, is on the right track.]

In a universe comprised of many distinct regions with different values of the coupling constants, it is tautologous that intelligent observers will only measure the values that obtain in those regions which are consistent with the existence of such observers. This is nothing more fancy than the reason why nobody is surprised that life arose on the surface of the Earth rather than the surface of the Sun, even though the surface area of the Sun is so much larger: the Earth is simply a much more hospitable environment. Therefore, even if we were to be confident that tiny alterations in the particles and couplings we observe in our universe would render life impossible, we would by no means need to invoke intelligent design as an explanation.

Conclusions

The question we have addressed is, "Thinking as good scientists and observing the world in which we live, is it more reasonable to conclude that a materialist or theist picture is most likely to ultimately provide a comprehensive description of the universe?" Although I don't imagine I have changed many people's minds, I do hope that my reasoning has been clear. We are looking for a complete, coherent, and simple understanding of reality. Given what we know about the universe, there seems to be no reason to invoke God as part of this description. In the various ways in which God might have been judged to be a helpful hypothesis — such as explaining the initial conditions for the universe, or the particular set of fields and couplings discovered by particle physics — there are alternative explanations which do not require anything outside a completely formal, materialist description. I am therefore led to conclude that adding God would just make things more complicated, and this hypothesis should be rejected by scientific standards. It's a venerable conclusion, brought up to date by modern cosmology; but the dialogue between people who feel differently will undoubtedly last a good while longer.

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NOTES

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