NOT SO FINE TUNED AFTER ALL?

Introduction

This paper discusses one particular objection to the design argument from cosmic fine-tuning: the objection which says that the universe is not so fine tuned after all. It looks at a specific version of this objection, made by professor Steven Weinberg.

This paper is longer and more technical than most on this site. There really isn't any way to get to the argument without the technicalities. However, if you just want to see the conclusion, you can get this by reading the last few paragraphs.

The problem

Your body is made from organic chemicals – complicated chemicals containing carbon. The only place carbon atoms are made is inside stars. You are made of star dust.

Carbon, mass number 12, is made inside stars by the fusion of three helium nuclei, mass number 4. (Helium nuclei are also called alpha particles, **α.**) Along the way to producing carbon, two helium nuclei combine together to make a nucleus of beryllium, mass number 8.

Beryllium is pretty unstable – a beryllium nucleus will break down again into two helium nuclei in a tiny fraction of a second, unless a third helium nucleus is added before this happens.

The problem is that this reaction shouldn't happen, because the beryllium nucleus and helium nucleus together have more energy than a carbon nucleus. The amount of carbon produced in stars should be very small – and this means you and I shouldn't be here at all.

Hoyle's prediction

In the 1950s, the astronomer and physicist Fred Hoyle[1] was working on how the elements are made inside stars. He couldn't account for the production of carbon, because of the problem described above.

Because the universe contains astronomers and physicists, and other complicated things made from carbon atoms, Hoyle reasoned that there must be something that made the carbon reaction go faster than expected. He predicted the existence of an excited energy state (called a resonance) in the carbon 12 nucleus, at just the right energy level – just above the combined energies of the ^{8}Be and ^{4}He nuclei. This would allow the reaction making carbon to go ahead much more quickly.

So Hoyle predicted the existence of a resonant energy level at about 7.68 MeV in ^{12}C. Researchers looked for this energy level, and found it just where he said it should be.[2]

To make the picture a bit more complicated, oxygen is made by adding another helium nucleus to carbon. If *this* reaction had a resonance, all the carbon would be converted to oxygen, which would also be bad for the existence of complicated things made from carbon. Fortunately, the appropriate energy level in oxygen is just *below* the combined energy of carbon and helium, and the reaction cannot be resonant.

If these energy levels were not exactly as they are, either very little carbon would be produced, or all the carbon that is produced would be turned into oxygen. Our existence depends on the universe having significant amounts of both carbon and oxygen.

Hoyle's response

To Hoyle, the presence of this energy level in carbon seemed to be a case of remarkable fine-tuning. Hoyle – an out-and-out atheist - would later say that nothing had shaken his atheism as much as this discovery. He said:

> 'A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question.'[3]

And:

> 'I do not believe that any scientist who examines the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed with regard to the consequences they produce inside stars. If this is so, then my apparently random quirks have become part of a deep-laid scheme. If not, then we are back again at a monstrous sequence of accidents.'[4]

The objection

So much for the physics and the original fine-tuning argument. What of the objection?

In April 1999, Professor Steven Weinberg gave a lecture to the 'Cosmic Design' conference of the American Association for the Advancement of Science, His lecture was called 'Designer Universe?'

(Weinberg won the Nobel Prize in Physics in 1979. He is the author of 'The First Three Minutes,' which is one of the best popular accounts of the physics of the Big Bang. He is also a well-known atheist.)

In his talk, he claimed that the placing of the energy level in carbon 12 is not much of a case for cosmic fine-tuning, because it does not have to be especially precisely adjusted after all.

Although it looks as if the energy has to be very finely tuned with relation to the ground state of carbon 12 (within about 1%), the critical issue is really how it relates to the combined energies of the beryllium and helium nuclei. Looked at like this, it only has to be 'fine-tuned' to within about 20% - which is nowhere near so precise. (See the extended quotation from Weinberg's talk below.)

In discussion with John Polkinghorne, Weinberg said:

> [I] am not terribly impressed by the examples of fine-tuning of constants of nature that have been presented. To be a little bit more precise about the case of carbon, the energy levels of carbon, which is the most notorious example that's always cited, there is an energy level that is 7.65 MeV above the ground state of carbon. If it was .06 of an MeV higher, then carbon production would be greatly diminished and there would be much less chance of life forming. That looks like a 1% fine-tuning of the constants of nature ... However, as has been realized subsequently after this 'fine-tuning' was pointed out, you should really measure the energy level not above the ground state of carbon but above the state of the nucleus Beryllium 8 (^{8}Be) plus a helium nucleus ... In other words, the fine-tuning is not 1% but it's something like 25%. So, it's not very impressive fine-tuning at all.[5]

So Weinberg's argument is that the energy levels are not really as fine-tuned as Hoyle originally thought. Perhaps they are adjusted with an accuracy of only ±25%, rather than ±1%

‘The first step in the sequence of nuclear reactions that created the heavy elements in early stars is usually the formation of a carbon nucleus out of three helium nuclei. There is a negligible chance of producing a carbon nucleus in its normal state (the state of lowest energy) in collisions of three helium nuclei, but it would be possible to produce appreciable amounts of carbon in stars if the carbon nucleus could exist in a radioactive state with an energy roughly 7 million electron volts (MeV) above the energy of the normal state, matching the energy of three helium nuclei, but (for reasons I'll come to presently) not more than 7.7 MeV above the normal state.

This radioactive state of a carbon nucleus could be easily formed in stars from three helium nuclei. After that, there would be no problem in producing ordinary carbon; the carbon nucleus in its radioactive state would spontaneously emit light and turn into carbon in its normal nonradioactive state, the state found on earth. The critical point in producing carbon is the existence of a radioactive state that can be produced in collisions of three helium nuclei.

In fact, the carbon nucleus is known experimentally to have just such a radioactive state, with an energy 7.65 MeV above the normal state. At first sight this may seem like a pretty close call; the energy of this radioactive state of carbon misses being too high to allow the formation of carbon (and hence of us) by only 0.05 MeV, which is less than one percent of 7.65 MeV. It may appear that the constants of nature on which the properties of all nuclei depend have been carefully fine-tuned to make life possible.

Looked at more closely, the fine-tuning of the constants of nature here does not seem so fine. We have to consider the reason why the formation of carbon in stars requires the existence of a radioactive state of carbon with an energy not more than 7.7 MeV above the energy of the normal state. The reason is that the carbon nuclei in this state are actually formed in a two-step process: first, two helium nuclei combine to form the unstable nucleus of a beryllium isotope, beryllium 8, which occasionally, before it falls apart, captures another helium nucleus, forming a carbon nucleus in its radioactive state, which then decays into normal carbon. The total energy of the beryllium 8 nucleus and a helium nucleus at rest is 7.4 MeV above the energy of the normal state of the carbon nucleus; so if the energy of the radioactive state of carbon were more than 7.7 MeV it could only be formed in a collision of a helium nucleus and a beryllium 8 nucleus if the energy of motion of these two nuclei were at least 0.3 MeV—an energy which is extremely unlikely at the temperatures found in stars.

Thus the crucial thing that affects the production of carbon in stars is not the 7.65 MeV energy of the radioactive state of carbon above its normal state, but the 0.25 MeV energy of the radioactive state, an unstable composite of a beryllium 8 nucleus and a helium nucleus, above the energy of those nuclei at rest. This energy misses being too high for the production of carbon by a fractional amount of 0.05 MeV/0.25 MeV, or 20 percent, which is not such a close call after all.’[6]

- Steven Weinberg

The research

Weinberg based his argument on some research published in 1989. A group of physicists modelled how the development of stars would change if the resonant energy level in carbon was different. They found that the energy level could be varied quite a bit without disastrously affecting the production of carbon. In fact, if the energy level is reduced slightly, much *more* carbon is produced.[7]

From this they concluded that the tuning is not as precise as it at first appears, and therefore the ‘coincidence’ is not so significant.

Responding to the objection

So is Weinberg's objection convincing? I don't think so. Here are three reasons why:

(1) The fine tuning discovered by Hoyle isn't just about a single energy level in carbon: it also involves the 'coincidence' that the energy level in oxygen is too low to allow resonance. If this level was a bit higher, all the carbon that is produced would be burned into oxygen. Of course, we need *both* carbon and oxygen, in roughly equal amounts. As Barrow and Tipler say:

> 'Hoyle realized that this remarkable chain of coincidences – the unusual longevity of beryllium, the existence of an advantageous resonance level in C^{12} and the non-existence of a disadvantageous level in O^{16} – were necesssary, and remarkably fine-tuned, conditions for our own existence and indeed the existence of any carbon-based life in the Universe. '[8]

The argument that by decreasing the energy of the resonant level a little bit, much more carbon could be produced, seems to miss this point: it is not just carbon, but also oxygen that we need.

> 'The whole balance of the elements carbon and oxygen is critical not only for the chemistry of living organisms but for the distribution of the planets…And the balance of carbon and oxygen depends not only on the properties of Be^8, but on certain very fine details of the energy level schemes of C^{12} and O^{16}… You notice that a level exists in C^{12} slightly above the sum of the rest-mass energies of Be^8 and the α-particle. This means that C^{12} can be formed in a resonant reaction, a property that speeds up the helium burning, tending to compensate for the instability of Be^8. In fact by the combination of this resonance with the instability of Be^8, a sort of compromise situation is reached. Had Be^8 been stable, the helium-burning reaction would have been so violent that stellar evolution – with its consequent nucleosynthesis- would have been very limited in scope, less *interesting* in its effects. Had there not been a favorably placed resonance in the C^{12} nucleus, the rate of carbon production would be so slow that very little carbon would exist in the world; the opposite to the graphite planet situation. To refer lastly to O^{16}, if a similar favorably placed resonance existed in O^{16}, the conversion of C^{12} to O^{16} by α-particle addition would be so enhanced that once again there would be little carbon in the world. When we examine the O^{16} nucleus we see that a level exists very close to the sum of the rest masses of C^{12} and an α-particle, but fortunately the level is *below*, so that an actual resonance can never occur. I say fortunately, because if there was little carbon in the world compared to oxygen, it is likely that living creatures could never have developed.
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> The upshot of these remarks is that the further evolution of stars leading to the synthesis of still more complex nuclei, combined with an approximately equal balance between carbon and oxygen depends on three apparently more or less random accidents – that Be^8 is unstable, that a resonant level exists in C^{12} at exactly the right place, and that a potentially dangerous resonance in O^{16} happens to be just below threshold.'[9]
>
> *- Fred Hoyle*

(2) Weinberg is almost certainly mistaken about the fine tuning only needing to be 20 or 25%: The 1989 research varied the resonant energy level in carbon in an ad-hoc

way, and investigated the effect on carbon formation. However, in a paper published in Science in 2000, three scientists investigated how the rate of production of carbon would be affected by small changes in the fundamental forces that lie behind the carbon resonance - the strong nuclear force and the electromagnetic force. Their conclusion was that a change of just 0.5% in the strong nuclear force or 4% in the electromagnetic force would reduce the production of carbon or oxygen by between 30 and 1000 times:

> ‘We conclude that a change of more than 0.5% in the strength of the strong interaction or more than 4% change in the strength of the Coulomb force would destroy either nearly all C or all O in every star. This implies that irrespective of stellar evolution the contribution of each star to the abundance of C or O in the ISM would be negligible. Therefore, for the above cases the creation of carbon based life in our universe would be strongly disfavored.’[10]

So it looks as if there is still a strong case for fine tuning in the production of carbon and oxygen, looked at in terms of the strengths of the fundamental physical reactions involved.

(3) However, even if for the sake of argument we allow Weinberg’s central point – that the resonant energy level in carbon is only ‘fine-tuned’ to, say, 20%, rather than 1%, he has still not succeeded in his project of explaining away cosmic fine tuning:

The resonant energy level in carbon was one of the first, and one of the most specific cases of cosmic fine-tuning to be discovered. But it is only one example. Scientists now know of a number of other cases of cosmic fine-tuning. Some of these have to be much more precisely tuned than the carbon and oxygen energy levels.

To take just one example, the mathematical physicist Sir Roger Penrose[11] says that the initial conditions of the Big Bang are so special that the odds of their coming about by chance are less than one part in 10 to the power of (10 to the power of 123). That is 1 in 1 followed by 10^{123} successive 0's.[12] To give some idea of just how ridiculously small a number this is, there are only 10^{80} particles of any kind in the observable universe. As Penrose says,

> ‘… try to put one zero on every particle in the observable universe and you would be way short.’

Penrose concludes

> 'There has got to be fine tuning. This is fine tuning, this is incredible precision in the organisation of the initial universe.'

There are several other examples of fine tuning besides the energy level in carbon. Some of these involve much more precise fine tuning. For Weinberg's objection to carry through, he would have to explain away all of them, and he has not done that.

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[1] http://en.wikipedia.org/wiki/Fred_Hoyle
[2] Dunbar, D N F, Pixley, R E, Wenzel, W A and Whaling, W: 'The 7.68 MeV State in C12,' Physical Review vol. 29 Number 3, November 1st, 1953,
[3] Hoyle, F, 'The Universe: Past and Present Reflections.' in Engineering and Science, November, 1981. pp. 8–12
[4] Hoyle, F, in 'Religion and the Scientists' (1959) quoted in Barrow and Tipler p. 22
[5] http://skepticwiki.org/index.php/Triple_Alpha_Process
[6] http://www.physlink.com/Education/essay_weinberg.cfm
[7] Livio, M, Hollowell, D, Weiss, A & Truran, J W: 'The anthropic significance of the existence of an excited state of 12C,' Nature vol 340, No. 6231, 27 July 1989
[8] Barrow J D and Tipler F J: 'The Anthropic Cosmological Principle', 1986. pp 251 to 254
[9] Hoyle, F, 'Galaxies, Nuclei and Quasars' Heinemann 1966, pp 147-150
[10] Oberhummer, H, Csótó, A, and Schlattl, H: 'Stellar Production Rates of Carbon and Its Abundance in the Universe,' Science, vol 289, p. 88-90 (2000);
[11] http://en.wikipedia.org/wiki/Roger_Penrose
[12] http://www.youtube.com/watch?v=WhGdVMBk6Zo