Is Carbon Production in Stars Fine-Tuned for Life?

For years theists have claimed that the constants of physics had to have been finely tuned by God for life in the universe to be possible. In my June 2009 column I showed that many of these claims are based on an improper analysis of the data. Even some of the competent scientists who write on this subject commit the fallacy of varying just one parameter and holding all the others constant. When you allow all parameters to vary, you find that changes to one parameter can be easily compensated for by changes to another, leaving the ingredients for life in place. This point is also made nicely in a recent *Scientific American* cover story by Alejandro Jenkins and Gilad Perez. In this column I will discuss perhaps the most cited example of claimed fine-tuning, the Hoyle resonance.

In 1953 the famous astronomer Fred Hoyle calculated that the production of carbon would not occur with sufficient probability unless that probability was boosted by the presence of an excited nuclear state of C12 at about 7.7 MeV. In what appeared to be a remarkable victory for anthropic reasoning, the existence of such a state was quickly confirmed experimentally. Anthropic reasoning is inferring that some property of nature must exist for life, as we know it, to be possible. The Hoyle prediction has been regarded by theists and others as a miraculous example of the fine-tuning of the constants of physics needed to make life possible. As Hoyle, a professed atheist, remarked:

> 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.

You will find the Hoyle resonance, usually accompanied by the above quotation, prominently included in every discussion about fine-tuning. Let us examine the scientific facts in more detail.

Fig. 1(a) shows two energy levels: (1) the amount by which the total rest energy of Be^8 + He^4 exceeds that of C^{12}, which is 7.3367 MeV; (2) the excited state of C^{12} predicted by Hoyle and observed at 7.656 MeV. Note that Hoyle did not predict this value exactly but estimated that the energy level should be around 7.7 MeV.

Now it is often claimed that this excited state has to be fine-tuned to precisely this value in order for carbon-based life to exist. This is not true. Life might be possible over a range of carbon abundances.

In 1989 Mario Livio and his collaborators performed calculations to test the sensitivity of stellar nucleosynthesis to the exact position of the observed C^{12} excited state. They determined that a 0.06 MeV increase in the location of the level to 7.716 MeV would not significantly alter the carbon production in stellar environments. A decrease by the same amount to 7.596 MeV was needed before the carbon production increased significantly above its value in our universe. This range is shown in Fig. 1(b). Already we can see the excited state is not very fine-tuned.

Finally, we note that the problem is not to obtain the exact amount of carbon in our universe but just sufficient carbon production for life. We get more carbon when the Hoyle energy level is even lower. Furthermore, Livio et al. showed that the energy level can be increased by as much as 0.277 MeV to 7.933 MeV before insufficient carbon is produced. As Fig. 1(c) shows, an excited state anywhere from this energy down to near the minimum energy would produce adequate carbon. In short, no fine-tuning was necessary to produce sufficient carbon in stars for life as we know it to be possible. While nuclear theorists are unable to calculate the precise energy level of the Hoyle resonance, they know enough about how the carbon nucleus is formed to show that a resonance in the allowed region is very likely. □

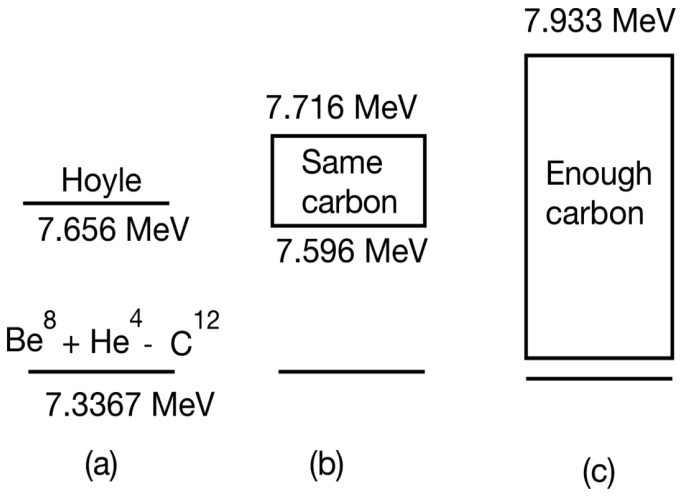

Fig. 1 (a) energy levels of carbon showing the amount by which the total rest energy of Be^8 + He^4 exceeds that of C^{12} (7.3367 MeV) and the excited state predicted by Hoyle; (b) the allowed range of the excited state that would yield the same amount of carbon; (c) the range of energy for an excited state that would produce carbon adequate for life.

Further Reading

F. Hoyle, et al., "A State in C12 Predicted From Astronomical Evidence," *Physical Review Letters* 92 (1953): 1096.

M. Livio, et al., "The Anthropic Significance of the Existence of an Excited State of C12," *Nature* 340 (1989): 281–86.

Alejandro Jenkins and Gilad Perez, "Looking for Life in the Multiverse: Universes with Different Physical Laws Might Still Be Habitable," *Scientific American* (January, 2010): 42–49.

Vic Stenger's latest book is The New Atheism: Taking a Stand for Science and Reason. *His Web site is at www.colorado.edu/philosophy/vstenger/.*