Evolution and the Second Law of Thermodynamics

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Why is it that the most vocal opponents of Darwinism often are not biologists or geologists, but physicists, computer scientists, engineers or mathematicians, like myself? The obvious answer would be that we don't understand the issues as well, but I have another explanation. You really don't need to know any biology or paleontology to understand the real problem with Darwinism: it is simply that it is extremely improbable. I realize that the development of life took millions of years, that there is an "evolutionary chain" of similarities connecting all species, and that many things about the process give the appearance of natural causes, but none of this diminishes the main problem.

In a Fall 2000 opinion piece in the Mathematical Intelligencer [1] I made the assertion that the underlying principle behind the second law of thermodynamics is that natural forces do not do extremely improbable things. An unfortunate choice of words: I should have said, the underlying principle is that natural forces do not do macroscopically describable things which are extremely improbable from the microscopic point of view. I argued that this principle seems to have been violated on Earth, because it seems extremely improbable that the four fundamental forces of Nature would rearrange the fundamental particles of Nature into encyclopedias and computers, even if the Earth does receive energy from the Sun. The argument from the second law of thermodynamics seems pretty compelling to the layman, but it has never seemed to impress many scientists, and my arguments did not seem to impress the mathematicians who wrote in to criticize my essay. Jason Rosenhouse, in his published reply [2], repeated the standard argument that the second law of thermodynamics "only applies to closed systems, which the Earth is not".

One of the predictions of the second law is that in a closed system where nothing but heat conduction is going on, thermal entropy–which measures randomness in the distribution of heat–can only increase, as heat energy becomes more randomly distributed (more uniformly distributed). If "thermal order" is defined to be the opposite (negative) of thermal entropy, then we can say that the thermal order can only decrease in a closed system. We can define another "entropy" and another "order" to measure randomness in the distribution of any other diffusing substance, for example, we can talk about the ”carbon order” in a solid, and the second law similarly predicts that the carbon order can only decrease in a closed system (assuming only diffusion is operative). More generally, the second law predicts that, in a closed system where only natural forces are at work, every type of order is unstable and will eventually decrease, as everything tends toward more probable (more random) states–not only will carbon and temperature distributions become more random, but the performance of all electronic devices will deteriorate, not improve. Natural forces, such as corrosion, erosion, fire and explosions, do not create order, they destroy it. The second law is all about probability. The reason natural forces may turn a spaceship into a pile of rubble but not vice-versa is probability: of all the possible arrangements atoms could take, only a very small percentage could fly to the moon and back.

But the Earth is an open system, and it is often argued that any increase in order is allowed in an open system, as long as the increase is ”compensated” somehow by a comparable or greater decrease outside the system. S. Angrist and L. Helper [3], for example, write, ”In a certain sense the development of civilization may appear contradictory to the second law... Even though society can effect local reductions in entropy, the general and universal trend of entropy increase easily swamps the anomalous but important efforts of civilized man. Each localized, man-made or machine- made entropy decrease is accompanied by a greater increase in entropy of the surroundings, thereby maintaining the required increase in total entropy.”

According to this logic, then, the second law does not prevent scrap metal from reorganizing itself into a computer in one room, as long as two computers in the next room are rusting into scrap metal–and the door is open. The spectacular increase in order seen here on Earth does not violate the second law because order is decreasing throughout the rest of this vast universe, so the total order in the universe is surely still decreasing.

So I wrote a reply, ”Can ANYTHING Happen in an Open System?” [4] to my critics which was published in the Fall 2001 issue of The Mathematical Intelligencer. In that reply, I first showed (see Appendix) that the second law does not simply require that any increase in thermal order in an open system be compensated for by a decrease outside the system, it requires that the increase in thermal order be no greater than the thermal order **entering** the open system. The thermal order in an open system can decrease in two different ways: it may be converted to disorder (first term on the right in equation (4) of the Appendix) or it may be exported through the boundary (second term). It can increase in only one way–by importation through the boundary. An identical analysis shows the same to be true of carbon (or any other diffusing substance): the increase in carbon order in an open system cannot be greater than the carbon order entering the system. In these simple examples, I again assumed nothing but heat conduction or diffusion was going on, but for more general situations I offered the tautology that "if an increase in order is extremely improbable when a system is closed, it is still extremely improbable when the system is open, unless something is entering which makes the increase **not** extremely improbable." The fact that order is disappearing in the next room does not make it any easier for computers to appear in our room–unless this order is disappearing **into** our room, and then only if it is a type of order that makes the appearance of computers not extremely improbable, for example, computers. Importing thermal order will make the temperature distribution less random, and importing carbon order will make the carbon distribution less random, but neither makes the formation of computers more probable.

As I wrote in [4], "order can increase in an open system, not because the laws of probability are suspended when the door is open, but simply because order may walk in through the door...If we found evidence that DNA, auto parts, computer chips, and books entered through the Earth's atmosphere at some time in the past, then perhaps the appearance of humans, cars, computers, and encyclopedias on a previously barren planet could be explained without postulating a violation of the second law here (it would have been violated somewhere else!). But if all we see entering is radiation and meteorite fragments, it seems clear that what is entering through the boundary cannot explain the increase in order observed here." What happens in an open system depends on the initial and boundary conditions; what happens in a closed system depends only on the initial conditions.

According to the traditional argument, the second law does not prevent atoms from reorganizing themselves into spaceships and computers here because the Earth is an open system. According to a new argument, however, advanced by recent critics of my article, this is not prohibited even in a closed system. Several of these have argued that everything Nature does can be considered extremely improbable–the exact arrangement of atoms at any time at any place is extremely unlikely to be repeated, argued one e-mail. Tom Davis, in his published reply [5], made an analogy with coin flipping and argued that any particular sequence of heads and tails is extremely improbable, so something extremely improbable happens every time we flip a long series of coins. If a coin were flipped 1000 times, he would apparently be no more surprised by a string of all heads than by any other sequence, because any string is as improbable as another. Davis concedes that it is extremely unlikely that humans and computers would arise again if history were repeated, "but something would".

I should have been more careful with my wording in the first article: I should have said that the underlying principle behind the second law is that natural forces do not do **macroscopically** describable things which are extremely improbable from the **microscopic** point of view. A "macroscopically describable" event is just an event which can be described without resorting to an atom-by-atom (or coin-by-coin) accounting. Carbon distributes itself more and more uniformly in a closed solid because there are many more arrangements of carbon atoms which produce nearly uniform distributions than produce highly nonuniform distributions. Natural forces may turn a spaceship into a pile of rubble, but not vice-versa–not because the exact arrangement of atoms in a given spaceship is more improbable than the exact arrangement of atoms in a given pile of rubble, but because (whether the Earth receives energy from the Sun or not) there are very few arrangements of atoms which would be able to fly to the moon and return safely, and very many which could not. TV sets represent order because very few arrangements of atoms allow one to see and hear what is happening on the opposite side of the Earth.

If we toss a billion coins, it is true that any sequence is as improbable as any other, but most of us would still be surprised, and suspect that something other than chance is going on, if the result were "all heads", or even "all tails except for coins $3i^2 + 5$, for i=1,2,3...". When we produce simply describable results like these, we have done something "macroscopically" describable which is extremely improbable. There are so many simply describable results possible that it is tempting to think that all or most outcomes could be simply described in some way, but in fact, there are only about 2^{30000} different 1000-word paragraphs, so the odds are about $2^{999970000}$ to 1 that a given result will not be that highly ordered–so our surprise would be quite justified. There may be many different types of order present in a new deck of cards, but every type of order will decrease as the deck is shuffled and re-shuffled, at least if there is a very large number of cards in the deck. In the real world it is sometimes much harder to say what the laws of probability predict than in a coin-flipping experiment (for example, now a regular pattern may not be improbable at all), and thus even harder to define and measure order, but sometimes it is easy. In any case, with 10^{23} molecules in a mole of anything, we can be confident that the laws of probability at the microscopic level will be obeyed (at least on planets without life) as they apply to **all** macroscopic phenomena; this is precisely the assumption–the **only** common thread–behind all applications of the second law. Everything the second law predicts, it predicts with such high probability that it is as reliable as any other law of science–tossing a billion heads in a row is child's play compared to appreciably violating the second law in any application. Jason Rosenhouse [2] writes ”His claim that ’natural forces do not cause extremely improbable things to happen’ is pure gibberish. Does Sewell invoke supernatural forces to explain the winning numbers in last night’s lottery?” But getting the right number on 5 or 6 balls is not extremely improbable, in thermodynamics ”extremely improbable” events involve getting the ”right number” on 100,000,000,000,000,000,000,000 or so balls! If every atom on Earth bought one ticket every second since the big bang (about 10^{70} tickets) there is virtually no chance than any would ever win even a 100-ball lottery, much less this one. And since the second law derives its authority from logic alone, and thus cannot be overturned by future discoveries, Sir Arthur Eddington [6] called it the ”supreme” law of Nature.

It may be argued that ”macroscopically (simply) describable”, is a concept that is too ”fuzzy” or too ”anthropomorphic” to use in scientific discussions, and thus the whole concept of ”order” is too vague to be taken seriously. If we measure the degree of order produced in a coin tossing experiment by the minimum number of words or characters required to describe it, as suggested above, then obviously an Englishman and a German will sometimes disagree about which outcomes are more ordered. But everyone will agree that ”all heads” or ”alternating heads and tails” are much more highly ordered than the vast majority of possible outcomes– these are simply describable in any language, because they are simple concepts. If an outcome cannot be described in 1000 English words and symbols, it isn’t very simply describable. (These are not new ideas: see www.mdl-research.org for a list of references to the statistical ”Minimal Description Length” principle, in which the degree of order in a data set is measured by the length of the shortest computer program that could generate the data; in fact, it has been proven that this measure does not depend too much on the computer language used.)

A good random number sequence is generally defined as one which cannot be described more concisely than by listing the numbers; those who design random number generators put a lot of effort into minimizing the ”order” shown by the sequences generated, yet they do not consider their efforts meaningless because order is too nebulous a concept, and they do not produce different versions of their programs for different languages or cultures.

There are indeed many macroscopically describable phenomena, but it is not true that there are so many that the second law cannot be expected to hold when applied to all of them–there are **relatively** few simply describable phenomena. It is not true, as the new argument asserts, that there are so many types of order that computers and TV sets need no explanation. ”Atoms will rearrange themselves into a machine that can travel to the moon and back”, or ”atoms will rearrange themselves into a machine that can add, subtract, multiply and divide real numbers with high accuracy", are macroscopic statements which have different lengths in different languages, but so is "carbon atoms will become less uniformly distributed", yet no one doubts that the second law can be applied in the latter situation. The question is really only, are these macroscopically describable events extremely improbable from the microscopic point of view (extremely improbable after taking into account what is entering from outside the system, naturally).

The evolutionist, therefore, cannot avoid the question of probability by saying that anything can happen in an open system, nor can he avoid it by saying that order is an entirely anthropomorphic concept and thus meaningless. He is finally forced to argue that it only seems extremely improbable, but really isn't, that atoms would rearrange themselves into spaceships and computers and the Internet. Darwinists are convinced that they already have an explanation for how all this happened, so let's look at their theory.

The usual argument against Darwinism, outlined in the first part of [1], is that natural selection cannot guide the development of new organs and new systems of organs through their initial useless stages, during which they provide no selective advantage. Consider, for example, the aquatic bladderwort, described in [7]:

> "The aquatic bladderworts are delicate herbs that bear bladder-like traps 5mm or less in diameter. These traps have trigger hairs attached to a valve-like door which normally keeps the trap tightly closed. The sides of the trap are compressed under tension, but when a small form of animal life touches one of the trigger hairs the valve opens, the bladder suddenly expands, and the animal is sucked into the trap. The door closes at once, and in about 20 minutes the trap is set ready for another victim."

The development of any major new feature presents similar problems, and according to Lehigh University biochemist Michael Behe, who describes several spectacular examples in detail in "Darwin's Black Box" [8], the world of microbiology is especially loaded with such examples of "irreducible complexity."

Although I cannot imagine any uses for the components of this airtight insect trap before the trap was almost perfect, a good Darwinist will imagine 2 or 3 far-fetched intermediate useful stages, and consider the problem solved. I believe you would need to find thousands of intermediate stages before this example of irreducible complexity has been reduced to steps small enough to be bridged by single random mutations–a lot of things have to happen behind the scenes and at the microscopic level before this trap could catch and digest insects. But I don't know how to prove this. I am furthermore sure that even if you could find a long chain of useful intermediate stages, each would present such a negligible selective advantage that nothing as clever as this insect trap could ever be produced, but I can't prove that either. More importantly, that natural selection seems even slightly plausible depends on the fact that while species are awaiting further improvements, their current complex structure is "locked in", and passed on perfectly through many generations. This is inexplicable–I don't see any reason why all living organisms do not constantly decay into simpler components–as, in fact, they do as soon as they die.

When you look at the individual steps in the development of life, Darwin's explanation is difficult to disprove, because some selective advantage can be imagined in almost anything. Like every other device designed to violate the second law, it is only when you look at the net result that it becomes obvious it won't work. Sometimes only an observer who is not so caught up in the details can see the broader picture–a mathematician, for example.

Darwin's defenders constantly point to the similarities between fossil species as conclusive proof that the development of life was guided by natural selection, when, in truth, these similarities do not tell us anything about the causes of the changes. In fact, the fossil record does not even support the idea that new organs and new systems of organs arose gradually; new orders, classes and phyla consistently appear suddenly [1]. For example, in November 1980, a New York Times News Service report contained the following:

> "Biology's understanding of how evolution works, which has long postulated a gradual process of Darwinian natural selection acting on genetic mutations, is undergoing its broadest and deepest revolution in nearly 50 years. At the heart of the revolution is something that might seem a paradox. Recent discoveries have only strengthened Darwin's epochal conclusion that all forms of life evolved from a common ancestor. Genetic analysis, for example, has shown that every organism is governed by the same genetic code controlling the same biochemical processes. At the same time, however, many studies suggest that the origin of species was not the way Darwin suggested...Exactly how evolution happened is now a matter of great controversy among biologists. Although the debate has been under way for several years, it reached a crescendo last month, as some 150 scientists specializing in evolutionary studies met for four days in

> Chicago's Field Museum of Natural History to thrash out a variety of new hypotheses that are challenging older ideas...No clear resolution of the controversies was in sight. This fact has often been exploited by religious fundamentalists who misunderstood it to suggest weakness in the fact of evolution rather than the perceived mechanism. Actually, it reflects significant progress toward a much deeper understanding of the history of life on Earth. At issue during the Chicago meeting was macroevolution, a term that is itself a matter of debate but which generally refers to the evolution of major differences...Darwin knew he was on shaky ground in extending natural selection to account for differences between major groups of organisms. The fossil record of his day showed no gradual transitions between such groups, but he suggested that further fossil discoveries would fill the missing links. "The pattern that we were told to find for the last 120 years does not exist," declared Niles Eldridge, a paleontologist from the American Museum of Natural History in New York. Eldridge reminded the meeting of what many fossil hunters have recognized as they trace the history of a species through successive layers of ancient sediments. Species simply appear at a given point in geologic time, persist largely unchanged for a few million years and then disappear. There are very few examples–some say none–of one species shading gradually into another."

Of course, none of the authors of the very angry letters the journal and I have received are going to be impressed by the above arguments. When these people discover that all of the basic constants of physics, such as the speed of light, the charge and mass of the electron, Planck's constant, etc., had to have almost exactly the values that they do have in order for any conceivable form of life to survive in our universe, they propose the "anthropic principle" and say that there must be many other universes with the same laws, but random values for the basic constants, and one was bound to get the values right. When you ask them how a mechanical process such as natural selection could cause human consciousness to arise out of inanimate matter, they say "human consciousness–what's that?", and they talk about human evolution as if they were outside observers, and never seem to wonder how they got inside one of the animals they are studying. And now, when you ask how the fundamental forces of Nature could rearrange the basic particles of Nature into libraries full of encyclopedias, science texts and novels, and computers, connected to laser printers, CRTs and keyboards, they say, well,

something had to happen.

There are no doubt other phenomena in Nature, not involving living things, where macroscopically describable things happen which appear–until they are studied more closely–to be extremely improbable from the microscopic point of view. But there is no other phenomenon anywhere that gives such an **extreme** impression of violating the second law; the development of life on Earth is completely unique. I believe the development of life has indeed violated the ”supreme” law of Nature, in a most spectacular way, but perhaps I am wrong. Perhaps it only seems extremely improbable, but really isn't, that, under the right conditions, the influx of stellar energy into a planet could cause atoms to rearrange themselves into computers and nuclear power plants and spaceships. But one would think that at least this would be considered an open question, and people who argue that it really **is** extremely improbable, and thus contrary to the basic principle underlying the second law, would be given a measure of respect, and taken seriously by their colleagues, but we aren't.

References

1 Granville Sewell, ”A Mathematician's View of Evolution,” The Mathematical Intelligencer 22 (2000), no 4, 5-7.

2 Jason Rosenhouse, ”How Anti-Evolutionists Abuse Mathematics,” The Mathematical Intelligencer 23 (2001), no 4, 3-8.

3 S. Angrist and L.Hepler, ”Order and Chaos,” Basic Books, 1967.

4 Granville Sewell, ”Can ANYTHING Happen in an Open System?,” The Mathematical Intelligencer 23 (2001), no 4, 8-10.

5 Tom Davis, ”The Credibility of Evolution,” The Mathematical Intelligencer 23 (2001), no 3, 4-5.

6 Arthur Eddington, ”The Nature of the Physical World,” McMillan, 1929.

7 R.F.Daubenmire, ”Plants and Environment,” John Wiley & Sons, 1947.

8 Michael Behe, ”Darwin's Black Box,” Free Press, 1996.

Appendix

Consider the diffusion of heat in a solid, R, with (absolute) temperature distribution U(x,y,z,t). The first law of thermodynamics (conservation of energy) requires that

$$Q_t = -\nabla \bullet J \tag{1}$$

where Q is the heat energy density and J is the heat flux vector. The second law requires that the flux be in a direction in which the temperature is decreasing, i.e.,

$$J \bullet \nabla U \leq 0 \tag{2}$$

(In fact, in an isotropic solid, J is in the direction of greatest decrease of temperature, that is, $J = -K\nabla U$.) Note that (2) simply says that heat flows from hot to cold regions–because the laws of probability favor a more uniform distribution of heat energy.

Now the rate of change of ”thermal entropy”, S, is given by the usual definition as:

$$S_t = \int\int\int_R \frac{Q_t}{U} \tag{3}$$

Using (3) and the first law (1), we get:

$$S_t = \int\int\int_R \frac{-J \bullet \nabla U}{U^2} - \int\int_{\partial R} \frac{J \bullet n}{U} \tag{4}$$

where n is the outward unit normal on the boundary ∂R. From the second law (2), we see that the volume integral is nonnegative, and so

$$S_t \geq -\int\int_{\partial R} \frac{J \bullet n}{U} \tag{5}$$

From (5) it follows that $S_t \geq 0$ in an isolated, closed, system, where there is no heat flux through the boundary ($J \bullet n = 0$). Hence, in a closed system, entropy can never decrease.

However, equation (5) still holds in an open system; in fact, the boundary integral in (5) represents the rate that entropy is exported across the boundary (notice that the integrand is the outward heat flux divided by temperature). Thus in an open system, (5) means the decrease in entropy cannot be more than the entropy exported through the boundary.

The above analysis can be repeated exactly for any other diffusing substance, for example we can let U(x,y,z,t) represent the concentration of carbon diffusing in a solid (Q is just U now), and again we can show that in an open system, the ”carbon entropy” thus defined cannot decrease faster than it is exported through the boundary.