Can ANYTHING Happen in an Open System?

Granville Sewell
Mathematics Dept.
University of Texas El Paso
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Critics of my Opinion piece,"A Mathematician's View of Evolution," [1] have focused primarily on my first point, which deals with the question of whether or not major evolutionary improvements can be built up through many minor improvements. It is clear to me that they cannot, but this question is the traditional front on which most battles over Darwinism have been fought since 1859, and I did not imagine that my arguments would constitute the last word on this topic. I consider that the main point in my article was the second one.

Mathematicians are trained to value simplicity. When we have a simple, clear proof of a theorem, and a long, complicated, counter-argument, full of hotly debated and unverifiable points, we accept the simple proof, even before we find the errors in the complicated argument. That is why I prefer not to extend here the long-standing debate over the first point, but to dwell further on the much simpler and clearer second point of my article, which is that the increase in order observed on Earth (and here alone, as far as we know) violates the laws of probability and the second law of thermodynamics in a spectacular fashion.

Evolutionists have always dismissed this argument by saying that the second law of thermodynamics only dictates that order cannot increase in an isolated (closed) system, and the Earth is not a closed system–in particular, it receives energy from the Sun. The second law allows order to increase locally, provided the local increase is offset by an equal or greater decrease in the rest of the universe. This always seems to be the end of the argument: order can increase (entropy can decrease) in an open system, therefore, ANYTHING can happen in an open system, even the rearrangement of atoms into computers, without violating the second law.

It requires only a modicum of common sense to see that it is extremely improbable that atoms should rearrange themselves into mammalian brains, computers, cars, and airplanes, even if the Earth does receive energy from the Sun. We will see that the idea that anything can happen in an open system is based on a misunderstanding of the second law; that 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. Let us look first at a form of "order" that is easy to measure.

Consider heat conduction in a solid, R. If R is a closed system (no heat crosses the boundary), we can define a ”thermal entropy” in the usual way, to measure randomness in the heat distribution, and show using the second law of thermodynamics that the total entropy in R can never decrease, and will in fact increase until the temperature distribution is uniform throughout R. If R is open, the thermal entropy in R can decrease, but it is easy to show (see Appendix) that the decrease cannot be greater than the entropy exported through the boundary of R. Because a decrease in thermal entropy is associated with an increase in ”thermal order”, this can be stated in another way: in an open system, the increase in order cannot be more than the order imported through the boundary.

According to the second law, then, the order in the universe is continually decreasing, but what is left of it at any time can be transported from one open system to another. For example, if a rod of uniform, moderate, temperature is used to connect a hot and a cold reservoir, the entropy of the rod will decrease, as one end becomes hotter and the other becomes colder. The temperature will become less uniformly distributed in the rod–something that would be extremely unlikely to happen without help from outside. The rod is simply importing order from the outside world, where order is now decreasing as the temperatures of the two reservoirs approach each other.

If we look at the diffusion of, say, carbon, in a solid instead of the conduction of heat, and take $U(x, y, z, t)$ now to be the carbon concentration instead of the temperature, we can repeat the analysis in the Appendix for ”carbon entropy” (Q is just U now), showing again that in a closed system (no carbon crosses the border) this entropy cannot decrease, while in an open system, the decrease in entropy cannot be greater than the entropy exported through the boundary. But it is important to notice that now ”entropy” measures the randomness of the distribution of carbon, not heat, so the amount of thermal entropy exported is not relevant to the change in carbon entropy in the solid. For example, if a steel rod of uniform temperature and uniform carbon concentration is placed between two steel blocks of unequal temperatures but carbon concentrations identical to that in the rod, the rod may import ”thermal order” (export thermal entropy), but the ”carbon order” will be unaffected. In the scientific literature, thermal entropy is usually referred to simply as ”entropy”, but in fact there are many entropies (depending on what we choose to measure: see [2], p. xiii) and many kinds of order: any macroscopic feature or property that is improbable from the microscopic point of view can be considered order. For example, of all the possible configurations that atoms could take, very few would allow the transmission of pictures or air transportation of packages over long distances, so television sets and airplanes can be considered to be improbable, and to represent order. The second law predicts that–in a universe in which only natural processes are at work–every type of order is unstable and must decrease, as everything tends toward more probable (more random) states. But just because two things are both improbable does not necessarily mean that the importation of one (say, TV sets) into an open system can explain the appearance there of the other (say, airplanes). Rather,

> 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 it NOT extremely improbable.

Although it is not as easy to quantify the order associated with airplanes and computers as the order associated with a carbon or temperature distribution, it is clear that life and human creativity are responsible for some very large increases in order here. Contrary to common belief, however, the ”thermal order” imported from the Sun does not help explain the formation of humans, jet airplanes, TVs and computers. If we add sunlight to the computer model hypothesized in [1], would we expect that the simulation would NOW predict that the basic forces of Nature would rearrange the basic particles of Nature into libraries full of encyclopedias, science texts and novels, or computers connected to laser printers, CRTs and keyboards? If we take a book of random letters and blow vowels into the front of the book (pretend letters can diffuse!) and suck them out the back, we can import order into the book, if randomness of the vowel distribution is used to measure order. Vowels are essential for words, just as solar energy is essential for life, but this process is not going to produce a great novel–that is a different KIND of order.

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. Many scientists seem to have the idea that ”entropy” is a single number which measures order of all types, so if entropy decreases locally when computers appear–no problem, entropy is increasing all over the rest of the universe, so the total entropy is surely increasing, and the second law is satisfied. For example, S. Angrist and L. Hepler [3] 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."

What is the conclusion then–that the explosion of new order on Earth has violated the laws of physics in a supernatural way? Not necessarily–since the advent of quantum mechanics, the laws of physics cannot be used to predict the future with certainty, and they do not really say that anything is absolutely impossible, they only provide us the probabilities. Thus one could argue that the origin and development of life may not have violated any of the laws of physics–only the laws of probability. The conclusion is only this: contrary to what Charles Darwin believed, and contrary to to the majority opinion in science today, the development of intelligent life is not the inevitable or reasonably probable result of the right conditions, it is extremely improbable under any circumstances.

References

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

2. R. Carnap, "Two Essays on Entropy," University of California Press, 1977.

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

Appendix

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

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

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

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

(In fact, in an isotropic solid, $\mathbf{J}$ is in the direction of greatest decrease of temperature, that is, $\mathbf{J} = -K\nabla U$.) 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:

$$S_t = \iiint\limits_R \frac{Q_t}{U} dV. \tag{3}$$

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

$$S_t = \iiint\limits_R \frac{-\mathbf{J} \bullet \nabla U}{U^2} dV - \iint\limits_{\partial R} \frac{\mathbf{J} \bullet \mathbf{n}}{U} dA,$$

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

$$S_t \geq - \iint\limits_{\partial R} \frac{\mathbf{J} \bullet \mathbf{n}}{U} dA. \tag{4}$$

From (4) it follows that $S_t \geq 0$ in an isolated, closed system, where there is no heat flux through the boundary ($\mathbf{J} \bullet \mathbf{n} = 0$). Hence, in a closed system, entropy can never decrease.

However, equation (4) still holds in an open system; in fact, the boundary integral in (4) 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, (4) means the decrease in entropy cannot be more than the entropy exported through the boundary.