Can ANYTHING Happen in an Open System?

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1 The Second Law of Thermodynamics

Consider the diffusion (conduction) 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

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

where Q ($Q = c\rho U$) 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.,

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

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

"Thermal entropy" is a quantity that is used to measure randomness in the distribution of heat. The rate of change of thermal entropy, S, is given by the usual definition as:

$$S_t = \iiint_R \frac{Q_t}{U} dV \tag{3}$$

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

$$S_t = \iiint_R \frac{-\mathbf{J} \bullet \nabla U}{U^2} dV - \iint_{\partial R} \frac{\mathbf{J} \bullet \mathbf{n}}{U} dA \tag{4}$$

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

$$S_t \geq - \iint_{\partial R} \frac{\mathbf{J} \bullet \mathbf{n}}{U} dA \tag{5}$$

From (5) it follows that $S_t \geq 0$ in an isolated, closed, system, where there is no heat flux through the boundary ($\mathbf{J} \bullet \mathbf{n} = 0$). Hence, in a closed system, entropy can never decrease. Since thermal entropy measures randomness (disorder) in the distribution of heat, its opposite (negative) can be referred to as ”thermal order”, and we can say that the thermal order can never increase in a closed system.

Furthermore, there is really nothing special about ”thermal” entropy. We can define another entropy, and another order, in exactly the same way, to measure randomness in the distribution of any other substance that diffuses, 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 through an identical analysis show that the ”carbon order” thus defined cannot increase in a closed system. It is a well-known prediction of the second law that, in a closed system, every type of order is unstable and must eventually decrease, as everything tends toward more probable (more random) states—not only will carbon and temperature distributions become more random (more uniform), 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, it uses probability at the microscopic level to predict macroscopic change: the reason carbon distributes itself more and more uniformly in an insulated solid is, that is what the laws of probability predict, when diffusion alone is operative. The reason natural forces may turn a spaceship, or a TV set, or a computer into a pile of rubble but not vice-versa is also probability: of all the possible arrangements atoms could take, only a very small percentage could fly to the moon and back, or receive pictures and sound from the other side of the Earth, or add, subtract, multiply and divide real numbers with high accuracy.

The discovery that life on Earth developed through evolutionary ”steps”, coupled with the observation that mutations and natural selection—like other natural forces—can cause (minor) change, is widely accepted in the scientific world as proof that natural selection—alone among all natural forces—can create order out of disorder, and even design human brains, with human consciousness. Only the layman seems to see the problem with this logic. In a recent Mathematical Intelligencer article [Sewell 2000], after outlining the specific reasons why it is not reasonable to attribute the major steps in the development of life to natural selection, I asserted that the idea that the four fundamental forces of physics alone could rearrange the fundamental particles of Nature into spaceships, nuclear power plants, and computers, connected to laser printers, CRTs, keyboards and the Internet, appears to violate the second law of thermodynamics in a spectacular way. Anyone who has made such an argument is familiar with the standard reply: the Earth is an open system, and order can increase in an open system, as long as it is "compensated" somehow by a comparable or greater decrease outside the system. The argument that the second law of thermodynamics "only applies to closed systems, which the Earth is not" was repeated in one published response to my article [Rosenhouse 2001]. S. Angrist and L. Hepler in "Order and Chaos" [Angrist and Hepler 1967], 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 reasoning, 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. A closer look at equation (5), which holds not only for thermal entropy, but for the "entropy" associated with any other substance that diffuses, shows that this argument, which goes unchallenged in the scientific literature, is based on a misunderstanding of the second law. Equation (5) does not simply say that entropy cannot decrease in a closed system, it also says that in an open system, entropy cannot decrease faster than it is exported through the boundary, because the boundary integral there represents the rate that entropy is exported across the boundary: notice that the integrand is the outward heat flux divided by absolute temperature. (That this boundary integral represents the rate that entropy is exported seems to have been noticed by relatively few people [for example, Dixon 1975, p202], probably because the isotropic case is usually assumed and so the numerator is written as $-K\frac{\partial U}{\partial n}$, and in this form the conclusion is not as obvious.) Stated another way, the order in an open system cannot increase faster than it is imported through the boundary. According to (4), the thermal order in a system can decrease in two different ways, it can be converted to disorder (first integral term) or it can be exported through the boundary (boundary integral term). It can increase in only one way: by importation through the boundary. Similarly, the increase in "carbon order" in an open system cannot be greater than the carbon order imported through the boundary, and the increase in "chromium order" cannot be greater than the chromium order imported through the boundary, and so on.

The above analysis was published in my reply "Can ANYTHING Happen in an Open System?" [Sewell 2001] to critics of my original Mathematical Intelligencer article. In these simple examples, I 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 it **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. What happens in a closed system depends on the initial conditions; what happens in an open system depends on the boundary conditions as well.

As I wrote in [Sewell 2001], "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."

2 Many Types of Order

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. In the original Mathematical Intelligencer article [Sewell 2000] I made the assertion that the underlying principle behind the second law is that natural forces do not do extremely improbable things. The journal and I received several replies arguing 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, noted one e-mail. In another published reply [Davis 2001], the author 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. This critic concedes that it is extremely unlikely that humans and computers would arise again if history were repeated, "but something would".

Obviously, 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 any 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 an insulated 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.

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 "alternating heads and tails", or even "all tails except for coins $3i^2 + 5$, for integer i". 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. And if it can't be described in 1000 English words and symbols, it isn't very simply describable.

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. One critic [Rosenhouse 2001] wrote "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 [Eddington 1929] called it the "supreme" law of Nature.

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.

3 Darwin's Explanation

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 there are so many types of order that order is a meaningless concept. 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 us look closer at their theory. The traditional argument against Darwinism, outlined in the first part of [Sewell 2000], is that natural selection cannot guide the development of new organs and new systems of organs—i.e., the development of new orders, classes and phyla—through their initial useless stages, during which they provide no selective advantage. French biologist Jean Rostand [Rostand 1956], writes "I believe firmly in the evolution of organic Nature," yet says

> "It does not seem strictly impossible that mutations should have introduced into the animal kingdom the differences which exist between one species and the next...hence it is very tempting to lay also at their door the differences between classes, families and orders, and, in short, the whole of evolution. But it is obvious that such an extrapolation involves the gratuitous attribution to the mutations of the past of a magnitude and power of innovation much greater than is shown by those of today."

Consider, for example, the aquatic bladderwort, described in [Daubenmire 1947]:

> "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" [Behe 1996], 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. Finally, that natural selection seems even remotely 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 phenomenon is observed, but 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.

Darwinists point to the similarities between species (fossil and living) as evidence that the development of life was guided by natural selection, but these similarities do not really tell us anything about causes. In fact, the fossil record does not even support the idea that new organs and new systems of organs arose gradually: orders, classes and phyla consistently appear suddenly. For example, Harvard paleontologist George Gaylord Simpson [Simpson 1960] writes:

> ”It is a feature of the known fossil record that most taxa appear abruptly. They are not, as a rule, led up to by a sequence of almost imperceptibly changing forerunners such as Darwin believed should be usual in evolution...This phenomenon becomes more universal and more intense as the hierarchy of categories is ascended. Gaps among known species are sporadic and often small. Gaps among known orders, classes and phyla are systematic and almost always large. These peculiarities of the record pose one of the most important theoretical problems in the whole history of life: Is the sudden appearance of higher categories a phenomenon of evolution or of the record only, due to sampling bias and other inadequacies?”

4 Conclusions

Modern man has decided that science can explain everything, and anything that doesn't fit into this model is simply ignored. When he discovers 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, he proposes the "anthropic principle" [e.g., Leggett 1987] and says 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 him how a mechanical process such as natural selection could cause human consciousness to arise out of inanimate matter, he says "human consciousness—what's that?", and he talks about human evolution as if he were an outside observer, and never seems to wonder how he got inside one of the animals he is studying. And now, when you ask how the four 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 and the Internet, he says, well, **something** had to happen.

The development of life may have only violated one law of science, but that was the "supreme" law of Nature, and it has violated that in a most spectacular way. At least that is my my opinion, 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 nuclear power plants and spaceships and computers. 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.

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