Discussion on Second Law of Thermodynamics Oct. 10, 2017

Web Address for the Essay: **http://www.shawangunk.com/scichr/essays/thermo.html**

Background Questions:

1) What qualifications does the author have that makes allows him to address this issue?

2) What is the difference between an isolated system, a closed system, and an open system?

3) State the three laws of thermodynamics in your own words.

Discussion Questions:

4) According to the author what is the first flaw in using the second law in creation arguments?
   a) How would you rate the strength of this argument?
      (Poor, weak, neutral, good, strong)
   b) What questions and responses would you make to the author with
      respect to this first statement?

5) According to the author what is the second flaw in using the second law in creation arguments?
   a) How would you rate the strength of this argument?
      (poor, weak, neutral, good, strong)
   b) What questions and responses would you make to the author with
      respect to this first statement?

6) According to the author what is the third flaw in using the second law in creation arguments?
   a) How would you rate the strength of this argument?
      (poor, weak, neutral, good, strong)
   b) What questions and responses would you make to the author with
      respect to this first statement?

7) Summarize in two or three sentences your view of the discussion today as well as the impact of the article.

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The Second Law of Thermodynamics in the Context of the Christian Faith

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Introduction

This essay was written in response to the many questions that come up on the Science and Christianity mailing list that touch on issues of entropy and/or the second law of thermodynamics. I found myself writing the same things repeatedly to straighten out various misconceptions. So, with the permission of the moderator, I have written what is intended to be something between a personal essay and a FAQ on the topic. Since this is written from my personal viewpoint, I will start by stating my background and personal convictions which cannot help but influence what I write.

I have a Ph.D. in Chemical Engineering (UC-Berkeley, 1988), specializing in "Molecular Thermodynamics," which combines classical and statistical thermodynamics to describe the thermophysical properties of fluids. I then did two years of postdoctoral work, more or less in Chemical Physics, followed by four years in private industry. I am now with the Physical and Chemical Properties Division of the National Institute of Standards and Technology in Boulder, Colorado. [By the way, nothing I say here should be construed as representing NIST or the US Government.] I do not consider myself a specialist in the second law, but my overall expertise in thermodynamics is such that I feel I can shed light on the relevant issues.

I am an evangelical Christian. I believe the Bible to be entirely trustworthy in conveying the messages God wants it to. Where people get into trouble is when, for example, they take the message of Genesis 1 (that God created everything, including us) and try to read it as something it is not (*i.e.*, an astronomy text). I sometimes get annoyed at the silly arguments of "creation science," but what is more annoying is when non-Christians see those arguments and get the false impression that the age of the Earth (rather than Christ) is what Christianity is all about. I do believe that God created everything, but how and when and to what extent that involved his governance of "natural" processes are secondary questions that should not divide the church.

Finally, I should add that God seems to have given me a passion for truth. Truth in all things, since all truth is God's truth. I therefore welcome any correction and/or constructive criticism with regard to this document. These may be sent to aharvey@boulder.nist.gov.

What are the Laws of Thermodynamics?

To begin this nonrigorous exposition, we need a few definitions. In thermodynamics, we must refer to a clearly defined *system*. Textbooks commonly consider the system to be the contents of a box-like container. But we could also define the system to be a specific cubic meter of the atmosphere above Phoenix, or the Earth (provided we define the boundary precisely), or my left kidney. Everything in the universe that is not a part of the system is the *surroundings*. Systems are divided into three categories: an *isolated system* can exchange neither matter nor energy with its surroundings, a *closed system* can exchange energy but not matter, and an *open system* can exchange both energy and matter. The Earth, for example, is an open system, but might be considered closed if one neglected meteorites, space probes,etc. It is *not* an isolated system because, among other things, it receives radiant energy from the Sun. [NOTE: this categorization is not universally used; in particular it is not uncommon to hear an isolated system as defined above described as "closed."]

The first law of thermodynamics, also known as the law of conservation of energy, states that the total energy of any system remains the same, except to the extent it exchanges energy with its surroundings. This exchange can be in the form of heat transfer (perhaps by placing a hot body in thermal contact with the system) or work (perhaps by compressing the system via a piston). This gets modified a little to account for matter/energy conversion (important if the system is the Sun), but it is basically the simple idea that energy is never created or destroyed.

The second law is trickier. There are many statements of it; perhaps the simplest is that it is impossible for there to exist any process whose only effect is to transfer energy from a system at a low temperature to one at a higher temperature. In other words, heat flows downhill. The 2nd law is also formulated in terms of *entropy*, a well-defined quantity in

terms of heat flows and temperature. Another statement of the 2nd law is that, for any isolated system, the entropy remains the same during any reversible process and increases during any irreversible process. The 2nd law also places bounds on the entropy change in a non-isolated system in relation to the temperatures of the system and the surroundings and the amount of energy leaving or entering it, but it is important to note that a system can experience a decrease in entropy if it is exchanging energy with the surroundings. There is also a definition of entropy (and therefore a statement of the 2nd law) in the context of statistical physics; that will be dealt with later. The important thing to remember is that the 2nd law is ultimately a statement about heat flows, work, and temperature, and also about the direction of time. It states that, as time goes forward, the overall effect is for energy to dissipate from hot things to cold things, and talks about the amount of work that can be done in the process.

The third law concerns changes in entropy as the temperature approaches absolute zero, and indirectly can be used to show the impossibility of attaining absolute zero. It does not come up in the contexts of concern in this essay, so we will not discuss it further.

For those who want to learn more, I recommend *The Second Law*, by P.W. Atkins, Scientific American Books, New York, 1994. This is a marvelous popular introduction to the subject. The reader is cautioned, however, that Atkins has a bias toward metaphysical naturalism which sometimes leads him to extrapolate from the science to unfounded metaphysical conclusions. If you can ignore the philosophy and stick to the science, you will learn a lot from his book. A good exposition at a higher technical level is given in the introductory chapters of *Entropy*, by J.D. Fast, McGraw Hill, 1962. [NOTE: Fast's classic work should not be confused with a book of the same title written around 1980 by notorious gadfly Jeremy Rifkin.] Of course any college textbook on thermodynamics will cover these topics.

A Brief History of the Second Law

Some of the following information is adapted from Ira N. Levine, *Physical Chemistry*, McGraw-Hill, 1978. Something that was roughly the 2nd law was stated by French engineer Sadi Carnot in 1824 with regard to the efficiency of steam engines. [Carnot may also have been the first to postulate the 1st law, but he never published that and got no credit until long after his death.] Carnot's work was almost universally ignored, but was rediscovered (and stripped of its tie to the pre-1st-law "caloric" theory of heat) in the 1840's. Around 1850 came the first rigorous statements of the 2nd law by William Thomson (Lord Kelvin) and Rudolph Clausius. It was Clausius who first defined the quantity entropy and coined the word (from a Greek word meaning "transformation"). He made the often-quoted brief statement of the first and second laws: "*Die Energie der Welt ist Konstant. Die Entropie der Welt strebt einem Maximum zu*." [rough translation: The energy of the world (more properly, an isolated system) is constant. The entropy of the world strives toward a maximum.] Maxwell made his contributions a little later, followed by Boltzmann. Their main contributions here were in tying things to the concept of molecules (including the science of statistical mechanics, which they basically invented though Gibbs brought it to maturity), which was not a part of the thinking of people like Kelvin and Clausius.

The Second Law and Creation

Now we address the context in which the 2nd law arises in creation arguments. The usual argument goes something like this: "The 2nd law says everything tends toward increasing entropy (randomness and disorder). But the evolution of life involves the development of great complexity and order. Therefore, evolution is impossible by the 2nd law of thermodynamics." While it sounds simple, there are major flaws in this argument that render it worthless.

Flaw #1: The Earth is Not an Isolated System

We must remember that it is only in isolated systems that entropy is forced to increase. Systems that can exchange energy with their surroundings have no such restriction. For example, water can freeze into ice (becoming more ordered and decreasing its entropy) by giving up heat to its surroundings (this increases the entropy of the surroundings, of course). In the case of the Earth, the Sun is a major source of energy, and the Earth also radiates energy into space. One consequence of thermodynamics is that, when energy comes from a "hot" source (like the Sun) and is output to a "cold" reservoir (like space), it can be used to do work, which means that "complexity" or "order" can be produced. The main point is that, for a non-isolated system, an increase in "complexity" (assuming for the moment that one can connect that concept with entropy - see the next section) does not necessarily indicate a violation of the 2nd law. A good example is the development of a human fetus into an adult; this is the production of a more complex system but involves no violation (as far as we know) of the laws of thermodynamics.

Flaw #2: How do You Measure a Planet's Entropy?

We have a vague intuition about "disorder" corresponding to entropy and "complexity" corresponding to a decrease in entropy. But the 2nd law is not about vague intuitions; it is a rigorous statement about quantifiable flows of energy at different temperatures. And we cannot even begin to compute the thermodynamic quantities that would be required to talk intelligently about the 2nd-law implications of the development of life on Earth.

I can think of two (related) reasons why we can't apply 2nd-law analysis in any meaningful way. The first is that it is a practical impossibility to quantify the entropy of any living creature. We can intuitively guess that a human is more thermodynamically "complex" than the equivalent mass of amoebae or prebiotic soup, and that would probably even be correct. But we are not isolated (or even closed) systems, and humans certainly add to the entropy of our surroundings (more than the amoebae do), for example as we digest complex foods. How do all these factors balance out? Nobody knows, and it would take advances of many orders of magnitude in several branches of science (not to mention computing power) to come close to quantifying them sufficiently. Second is the large number of factors and processes involved. Considering humans - or even all life on Earth - in isolation is not valid. Why? Because life also interacts with the soil, the atmosphere, the oceans, heat from the Sun, and even heat from the Earth's interior. If we want to apply 2nd-law analysis to the development of life, we must look at the NET effect of ALL these interactions. Again, we can't quantify these factors enough to say how they balance out.

While physics does not tell us directly whether the development of life has violated the 2nd law, a simple thought experiment described in the next section suggests that it has not.

Flaw #3: An Internal Inconsistency

Some creationists assert that advanced (especially human) life represents a decrease in entropy which violates the 2nd law, and they therefore invoke intervention by God, who is outside the laws of thermodynamics. They also, however, generally assert that this particular "intervention" stopped with the creation of man, and that (with the exception of the occasional miracle) God has allowed things to develop in accordance with the laws of thermodynamics and other physical laws since then.

These two assertions are, however, mutually inconsistent. The reason is that entropy is strictly an additive quantity. If the 2nd law has not been violated as the number of humans grew from two to 5 billion, it is ridiculous to assert that it was violated in the comparatively minuscule change from zero to two. If we say that the first two humans represented a violation of the 2nd law, the only logical conclusion would be that God must be continually intervening in violation of the 2nd law in order to increase the number of humans on Earth. While God is certainly capable of this, there is no evidence to suggest that such gross violations of the 2nd law are happening as complex life forms like humans reproduce and increase in number. [NOTE: All this is not to say that God's creation of human life was not miraculous. My only point is that the specific assertion that the existence of human life in and of itself violates the 2nd law is unfounded.]

What About the Universe?

An occasional creationist response to flaw #1 mentioned above is to say that, while the Earth is not an isolated system, the universe as a whole is. That is, of course, correct in that the universe is the ultimate example of an isolated system. However, this does not help the argument they are trying to make. Astrophysicists, using data such as the cosmic background radiation, have verified that the universe has obeyed the second law of thermodynamics very well since the time of the big bang. The 2nd law predicts that something small and hot should become larger and colder, and that is just what has happened. The existence of some ordered life in a little corner of the universe like ours is a drop in the bucket - when the whole system is considered (which one must always do), there is no violation of the second law in the development of the universe.

So what about "before" the inception of the universe? Can it be said that bringing into existence the hot, pointlike early universe from nothing was a violation of the 2nd law? While that argument has a certain appeal, and I believe the creation of the universe to have been miraculous, I think a 2nd-law argument is inappropriate here as well. The 2nd law is an attribute of the physical universe, describing how systems go with time. Modern physics tells us that the physical universe is not just space but also contains time as a fundamental dimension. The process by which all that came to be is not something that can be addressed by the laws (including the laws of thermodynamics) characterizing the resulting universe.

What About Information Theory?

Flaw #2 above is sometimes attacked by referring to information theory, which contains a quantity called "entropy." While I am no expert in information theory, I can say enough to deal with that particular argument.

As a preliminary, we must talk about the definition of entropy from statistical physics. This definition is mostly due to Boltzmann, and is even engraved on his tombstone. Boltzmann defined the entropy of a system in terms of the number of different states available to it. So, for example, the expansion of a gas into double its original volume at constant temperature would represent an increase in entropy, because each molecule would have twice as much volume (and therefore twice as many "states") accessible to it. It is this definition that causes entropy to be thought of in terms of "disorder," because a highly ordered system like a crystal has fewer available states. Boltzmann's identification of this quantity with the thermodynamic entropy is now universally accepted.

More recently, a field has arisen called information theory. This deals with, among other things, quantifying the "information content" of various systems. Some of the results of information theory resemble the results of statistical physics, so much so that in certain well-defined conditions a quantity can be defined that is labeled "entropy" and that obeys something analogous to the 2nd law. While the identification of the information entropy with its thermodynamic counterpart is controversial, it is plausible enough to be taken seriously.

So some creationists, recognizing that their argument does not apply to the thermodynamic entropy, assert that it does make sense in terms of the information entropy. This is because information theory talks about things more directly related to "complexity" and "disorder." But Flaw #2 above (in addition to Flaws #1 and #3) applies equally to the information entropy. If the 2nd law is to be applicable at all in this context, we must be able to make the rigorous definitions of information content required by the theory. But, just as we cannot measure the thermodynamic entropy of a person or of the Earth, we cannot begin to quantify the "information content" either. Whatever definition of entropy we use, we simply don't have enough information (no pun intended) to apply 2nd-law analysis in any sensible way to the question of the development of life on Earth.

What about "Energy Conversion Mechanisms"?

A few of those invoking the 2nd law to oppose evolution have seemed to recognize Flaw #1 above, and responded by saying that for work and structure to be produced in a system, it is not enough to have energy inflow, one must also have an "energy conversion mechanism." This statement is actually correct, but it does not help the anti-evolution cause. The biochemistry of life is full of such mechanisms (a more standard name is "dissipative structures"). Photosynthesis is one example, as are various pieces of the biochemistry of the cell. With these structures in place (in other words, once the first life exists), there is then no obstacle from the standpoint of thermodynamics to the evolution of more and different life.

One might, of course, ask about the origin of these dissipative structures. This is a legitimate question, though not really one of "evolution" (which normally refers to the development of life from other life) but instead one of "abiogenesis." Whether or not the biochemistry of life could arise "naturally" is one where the evidence is not so clear, and legitimate arguments can be made here. However, at this level the arguments are not primarily about thermodynamics (and those who use them should not say their position is based on thermodynamics), so they are outside the scope of this essay.

Other Abuses of the Second Law

A common misuse of the 2nd law occurs in connection with events that are highly improbable. An example is the hypothetical origin of life from normal chemical processes, which has been compared to unlikely occurences such as the assembly of a 747 by a tornado passing through a junkyard. That may or may not be an appropriate analogy, but the misuse comes in when it is asserted that, simply because it is ridiculously unlikely, the scenario would represent a violation of the 2nd law. The important point is that, while violations of the 2nd law are highly improbable (this improbability is the essence of the 2nd law in the statistical-mechanical formulation), not every improbable event is a violation of the 2nd law. For example, if I flipped a coin 1000 times and came up "heads" each time, it would be highly improbable but would not violate any laws of thermodynamics.

Finally, there is the use of "entropy" in situations where thermodynamics is simply not relevant. One hears entropy invoked as an explanation for everything from my messy desk to the decline of American society. And that is tolerable and perhaps even useful as a metaphor; certainly there is some similarity between the "decay" and "disorder" in these situations and the thermodynamic consequences of the 2nd law. But we must not mistake metaphor for real physical law. To do so can lead to false and even harmful conclusions, such as when "relativity" is invoked to argue against the idea of absolute right and wrong.

The Second Law, Evil, and the Fall

My final topic is the occasional identification of entropy with "evil" or "death," an identification often accompanied by the assertion that the 2nd law is a consequence of the Fall. I believe that this is wrong for several reasons. [NOTE: I am neutral with regard to the literalness of the Biblical account of the Fall. I am open to the idea that it is a figurative account of mankind's collective rejection of God's authority. For simplicity, this section uses terminology that presumes the literal interpretation. But the arguments are not significantly affected if one takes a less literal view.]

First, I believe the identification of the 2nd law with "evil" is a consequence of some of the misconceptions mentioned above. We identify God (and therefore good) with "order," but mistakenly identify the ungodly "disorder" in the world with the thermodynamic entropy. Certainly entropy is a factor in some of the world's "disorder," such as the degradation of the environment. But gravity, electromagnetism, and the 1st law are all involved as well, and there are no grounds for assigning any special "evil" role to the 2nd law. Calling the 2nd law evil because it is involved in, for example, the decay that accompanies physical death is as unfounded as calling gravity evil when somebody falls off a cliff.

Second, the physical evidence strongly indicates that, like all God's other physical laws, the 2nd law has been operating since creation. Entropic processes are involved in the burning of the Sun and other stars (many of which emitted the light we see today longer ago than the 6000-20,000 years ago usually assigned to the Fall), and would have been involved as Adam and Eve walked, ate and digested their food, etc. While it is not impossible that God had an entirely different set of physical laws in place before the Fall, such speculation is not supported by any scientific or Biblical evidence.

Third, we need to deal with Romans 8.18-23, which talks about (in the context of the final fulfillment of the Kingdom) how "the creation itself will be set free from its bondage to decay and obtain the freedom of the glory of the children of God" (v. 21, NRSV). The "bondage to decay" is sometimes taken to refer to the 2nd law. That interpretation is at best incomplete. The Bible teaches (cf. Rev. 21) that, when all is said and done, God will throw out the current physical laws and create something that transcends all the limitations we now know. So while the "repeal" of the 2nd law may be a part of what the passage refers to, it is at most only a small portion of a much greater transformation. As to when the "bondage to decay" began, the passage says nothing to suggest it began with the Fall. Some of it, in fact, seems to imply that this bondage has been an aspect of creation from the beginning.

There may be an additional logical (and theological) fallacy at work in those who attribute the 2nd law to the Fall. The (faulty) line of reasoning goes something like, "Since the 2nd law will not exist in God's final Kingdom, it must not have existed before the Fall." This simply does not follow. Nowhere in the Bible does it suggest that the final Kingdom will simply be a restoration to pre-Fall conditions. Instead, it is pictured as something brand new and infinitely more glorious than what Adam and Eve experienced in the Garden.

With all that said, I should add that I do believe that the Fall has consequences. The primary result, of course, is our separation from God and resultant need for salvation. But Scripture does teach (Gen. 3.17) that there was also some negative consequence for our surroundings. I do not deny that, in some sense, the ground (and maybe all of Earth or even all of creation) is "cursed" because of our sin. What I do deny is that the 2nd law of thermodynamics is any more a part of that curse than is gravity or any of the other physical laws God has chosen to impose on His creation.

Final Thoughts

I used to think about entropy childishly. When I was about 20 and a fairly new Christian, I even wrote a poem called "The Second Law" in which I invoked entropy to explain decay of the human soul, of human society, and of Christ's church. [I later saw a "Life in Hell" cartoon listing "Entropy" as a topic about which all bad poets must eventually write.] Since then, I have learned more about thermodynamics and about God. I know how alluring the simplistic entropy arguments sound. But God calls us to truth, and that sometimes requires abandoning simplistic concepts.

My main purpose here is to dissuade my fellow followers of Christ from pursuing incorrect arguments based on a lack of understanding of the second law. One might ask whether it is really important for Christians to think about entropy in a mature manner. For many, it probably isn't. But for those who engage in apologetics, and for those who might find themselves defending the faith to those who are scientifically literate, I think it is important for three reasons.

The first is that, by abandoning these mistaken views, we can focus more effectively on legitimate arguments for the faith. While I do not subscribe to the notion that one can arrive at Christianity through pure reason, I do believe that it is reasonable in all respects. With regard to origins, there are reasonable arguments that the universe and human life did not come about through random Godless chance. But none of these arguments is based on thermodynamics, and it can only confuse the issues and obscure God's truth when the 2nd law is inappropriately dragged in.

The second reason is the special responsibility to truth we have as people of God. There is no room for falsehood in God's kingdom, even in the defense of the Gospel. We should be diligent in our efforts to avoid bearing false witness,

whether the victim is our next-door neighbor or Ludwig Boltzmann. Those who argue from a worldly position (like politicians) may be able to say "I don't mind using a little falsehood as long as it helps me persuade my audience," but that is an unacceptable position for a Christian. We who serve the God of truth should make a special effort to cleanse our words of all falsehood.

Finally, there is the issue of the Christian witness to the world. A small but not insignificant segment of the world is scientifically literate. It is tragic that many of these people think of Christians only as "those people with the crackpot arguments about a young Earth and entropy." I fear that many do not even consider the Gospel because of the mistaken notion that it requires them to believe things they know to be as silly as a flat Earth. The myth that Christianity is only for stupid people is widespread, and part of the blame must rest on some Christians. This harm to our witness will only be overcome if Christians refocus their message on central truths (like the fact that God created everything) rather than trivial side issues (like how He did it), and repudiate those arguments (like the misuse of the 2nd law) that are simply incorrect. We know many will still reject and belittle Christ and those who follow Him. But if the world is going to laugh at us, let it at least be for a central doctrine like the Resurrection or for our insistence on loving everybody, not for mistaken pseudoscientific arguments on peripheral issues.