Negative Entropy Living System Models and a Fifth Law of Thermodynamics

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Abstract

This paper will describe some basic negative entropy models for living system growth and repair. In so doing we will find that the laws of thermodynamics are unable to explain why growth and repair would spontaneously occur in nature. The models will show that the Second Law is not able to justify growth and repair without a Fifth Law.

A Fifth law is needed to include tendencies of living systems to create order from available work and matter. In this paper, the Second Law short comings are exposed and the need for a Fifth Law is demonstrated and proposed.

Key Words: Negative Entropy, Spontaneous Negative Entropy, Entropy damage, Schrödinger paradox, Fifth Law of Thermodynamics, Living Systems, Critical Environmental Interference, Irreproducibilities

1. Introduction - Basic Spontaneous Negative Entropy Growth & Repair Overview

While devices and systems that we use every day will not spontaneously repair themselves, living systems have this capability. Growth requires negative entropy change

$$\Delta S_N < 0 \qquad (1)$$

performed with available work and matter. The overall entropy generated is positive by the Second Law

$$dS_{Generated} = dS_{Environment} - dS_{N\ System\ Growth} > 0 \qquad (2)$$

Furthermore, when living systems sustain an injury; the system will try and repair the damage creating a spontaneous amount of negative entropy equal to or greater than the entropy damage.

$$\left|\Delta S_{\text{Repair}}\right| \geq \left|\Delta S_{\text{Damage}}\right| \qquad (3)$$

(where entropy damage causes system damage or internal irreversibility, as compared to non entropy damage flow [1]). The equal sign indicates a highly efficient repair process where the inequality represents an inefficient repair process [1].

In the reference frame of the living system

$$\Delta S_{\text{damage}} \geq 0,\ \Delta S_{\text{N System-Repair}} \leq 0,\ \text{so}\ \ \Delta S_{\text{damage}} + \Delta S_{\text{N System-Repair}} \approx 0 \qquad (4)$$

Therefore, the systems change in entropy has essentially decreased; its free energy has increased. However, by the Second Law the repair process generated at least this same amount of entropy damage or greater to the environment often in the form of pollution.

The question is, why does repair occur? If work is available, by the Second Law, we expect entropy to be maximize and spontaneous disrepair to be more favorable in order to decrease the system's free energy and come to environmental equilibrium

$$\Delta S_{\text{System-Disrepair}} \geq 0, \quad \Delta F_{\text{System}} < 0 \tag{5}$$

We state the obvious,

$dS_{Generatedrepair} = dS_{env} - dS_{N\,Sys\,Growth} > 0$ compared to disrepair $dS_{Generateddisrepair} = dS_{env} + dS_{Sys\,disorder} > 0$

We have $dS_{Generateddisrepair} > dS_{Generatedrepair}$ which is more favorable condition by the Second Law. This tells us that the second law is misleading without some new law to clarify why living systems have a stronger tendency for growth and repair over disrepair and disorder.

Negative entropy was first introduced by Erwin Schrödinger in a non technical field in his 1944 popular-science book *What is Life* [2]. Schrödinger uses it to identify the propensity of the living system to want to organize, which is contrary to the second law. That is, for most of us, we like to build houses, build cities, and organize our way of life. This is also observed in lower life forms.

In the book, *Principles of Biochemistry*, Lehninger [3] argues that the order produced within cells as they grow and divide is more than compensated for by the disorder they create in their surroundings in the course of growth and division. In short, according to Lehninger, "living organisms preserve their internal order by taking from their surroundings free energy, in the form of nutrients or sunlight, and returning to their surroundings an equal amount of energy as heat and entropy. However, the preference for order is not justified.

2. Repair of Closed Systems

Whenever a system can exchange either heat or matter with its environment, an entropy decrease of that system is entirely compatible with the Second Law [4]. The problem of organization in living systems increasing despite the Second Law is known as the Schrödinger paradox [5].

Complicating this issue is that closed systems are frequent opened for repair by man.

Consider a repair to a system that requires a certain amount of heat entropy $\frac{-\delta Q_{\text{Repair}}}{T}$. This is the repair entropy equivalent. A simple example is a failed solder joint. The repair amount of heat entropy reflow to the solder joint is [1]

$$dS_{Generated} = dS_{Environment} - \frac{\delta Q}{T}\Big)_{Sys-repair} \tag{6}$$

The entropy generated in repair is the sum of the environmental entropy and heat needed for repair. By the second law $\Delta S_{Generated} \geq 0$ and

$$TdS_{Environment} \geq \delta Q\big)_{Sys-repair} \tag{7}$$

Therefore, the repair process generates equal or more disorganized energy to the environment than the amount of organized energy needed for the repair process as expected.

Now it is second nature why this repair takes place to fix the solder joint so the system will operate again in its prior thermodynamic state. The system in a sense had become inefficient; the repair then restores the efficiency of the system to operate in its environment.

The fact that man tends to fix a broken closed system, supplying energy for the repair process, is not a reasonable conclusion of the Second Law. It does not violate the Second Law, but is a surprising conclusion. That is, why create order, why not let things fall apart in accordance with the Second Law coming to a minimum energy state?

3. A Repair Subsystem

In repair, time is not reversed; repair is done by removing the damaged area and re-grows the cells as close to their original state as nature permits. To be in agreement with the Second Law there still must be a natural tendency "to come to some sort of thermodynamic equilibrium state". Therefore, Mother Nature must use available work to create a "repair subsystem" that encourages negative entropy flow in order for the sub-system to come to some sort of ordered rather than disordered equilibrium state. This means that creating such a "repair system" takes energy that is part of the entropy production. In the non equilibrium state

$$\frac{d\Delta S_{System-Growth\,or\ \mathrm{Re}pair}}{dt} < 0 \quad , \quad \frac{d\phi_{System-Growth\,or\ \mathrm{Re}pair}}{dt} > 0 \tag{8}$$

Growth or repair then stops when the system is in the new "thermodynamic equilibrium state" with an increase in system and subsystem free energy.

We can hypothesize the repair tendency. At the repair site matter likely diffuse into the area driven both by a concentration gradient and an electrical charge across the repair area (see for example Becker, *Body Electric* [6]). A possible scenario to create negative entropy flow is [1]

$$-dS_{\mathrm{Re}pair} = \left(\frac{1}{T_R} - \frac{1}{T_{en}}\right)dU + \left(\frac{E}{T_{en}} - \frac{V_R}{T}\right)dq, + \left(\frac{\mu_{en}}{T_{en}} - \frac{\mu_R}{T}\right)dn \tag{9}$$

Here energy flow will go from the higher temperature area $T_R > T_{en}$ so that the repair internal energy increases $dU>0$, for $V>E$ then $dq>0$, the repair area is charged, and for $\mu_R > \mu_{en}$, $dn>0$, so the matter flows to the repair site. When $T=T_{en}$, $E=V$, and $\mu_{en}=\mu$, the repair process is completed and we are in thermodynamic unstable equilibrium state where free energy is available for useful work. The result is a more organized area.

4. Growth and Self-Repair Description

Growth and self-repair have similarities since the living system becomes more ordered,

$$\Delta S_{\mathrm{Living\ System}} < 0, \text{ for } 0 < \text{time} < \text{human growth phase} \tag{10}$$

In the case of repair,

$$\Delta S_{\mathrm{Living\ System\ Repair}} < 0, \text{ for Repair starts} < \text{time} < \text{Repair completed} \tag{11}$$

The exchange of entropies in repair is

$$\Delta S_{Gen} = \Delta S_{environment} + \Delta S_{\text{Repair}} > 0 \tag{12}$$

The total entropy of any repair process increases, in keeping with the Second Law. Since $\Delta S_{\text{Repair}} < 0$, than the entropy damage to the environment must be positive and greater than the negative repair entropy by the Second Law

$$|\Delta S_{en}| \geq |\Delta S_{\text{Repair}}| \tag{13}$$

Since the repair process is in itself cyclic, this means that the internal energy needs to be restored to its original state, where its change due to damage portion of the cycle is

$$\Delta U_{Change\text{-}due\text{-}to\text{-}damage} = \int_0^{Damage} dU = U_{Damage} - U_{Non\text{-}Damage} \tag{14}$$

In this simplified view, the internal energy change in a damage-repair cycle by the combined first and second law is [1]

$$\oint dU = \oint \delta W + T \oint dS + \Delta U_{un\text{-}repaired} = 0 \tag{15}$$

That is for a perfect repair, the internal energy in the cycle is unchanged and the imperfect repair leaves us with some inefficiency and permanent change to the internal energy. Daily living system use, we know causes damage. The unrepaired portion builds up causing fatigue and damage and living system efficiency decreases with time

$$\eta_{System}(t) = \frac{W_{actual}}{W_{actual} + W_{irr}(t)}, \quad W_{irr}(t+\tau) > W_{irr}(t) \tag{16}$$

It is hard to understand what drives the repair or growth process. Efficiency improves with repair and growth which is related to the systems free energy increase. The efficiency of the system and the subsystem being repaired must be related. This also relates to environment since work is done on or by the system and efficiency is needed. This suggests a non stationary entropy repair process with a subsystem repair that is correlated to the system. Given that the system is dependent on the subsystem's efficiency infers that in fact the living system seeks to maximize its free energy by using any available work to repair any broken subsystem. This is an area of science that is not well understood but part of our experiences.

Living systems are complex and the free energy of such a system is likely best described with that aid of a partition function

$$Z(T) = \sum_i^N \exp\{-\varepsilon_i / K_B T\} \tag{17}$$

which is an ensample, having a number of different internal energy states. The partition function near a true equilibrium state will have the free energy at a minimum, when the free energy is at a minimum, the value and the partition function will be at a maximum value. Thus growth and repair seek to minimize the partition function value of the complex living systems made up of numerous potential subsystem degradations each with its own relative minimum free energy equilibrium state potentially needing repair. The partition function may be another alternative tool in modeling negative entropy flow. However, ensample function typically becomes minimize for the free energy in accordance with the Second Law. *Therefore, we see that repair again in living systems, according to the Second Law is not easily justified.*

5. Living System Repair Work and Efficiency

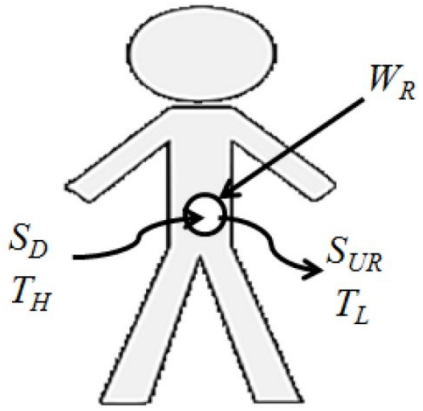

Figure 1 Simplified body repair

We can make a simplified thermodynamic repair model. The repair process is shown in Figure 1. An injury occurs, after a few hours the entropy is at a maximum where the entropy damage is S_D and the area has a temperature rise T_{High} (T_H). Repair work is done W_R, and the injury is almost completely repaired, the unrepaired entropy is S_{UR}. The change to the internal energy from repair cycle is ΔU due to the unrepaired damage. In this case, from the First and Second Law the minimum repair work is

$$W_{R-\min} = T_h S_D - \Delta U_{Damage\text{-}Unrepaired} = T_h S_D - T_L S_{UR} \tag{18}$$

The negative entropy generated for the repair process is

$$S_G = S_D - S_{UR} = -S_R \tag{19}$$

Where S_R is the negative entropy needed for the repair process. That is, in the case of repair

$$S_D - S_{UR} + (-S_R) = 0 \text{ and } S_{UR} = S_D + (-S_R) \tag{20}$$

So that the minimum work in the repair process is found by combining these equations

$$W_{R-\min} = S_D(T_H - T_L) - T_L(-S_R) \tag{21}$$

In the case of perfect repair S_D=-S_R, the minimum repair work is

$$W_{R-\min} = S_D T_H = Q_H \tag{22}$$

where Q_H is the heat dissipated prior to repair which can be measured.

The efficiency of repair is [1]

$$\eta_H = \frac{W_{actual}}{W_{actual} + W_{irreversible}} = \frac{W_{R-\min}}{W_{R-\min} + T_L S_{UR}} = 1 - \frac{T_L}{T_H}(1 + \frac{S_R}{S_D}) \tag{23}$$

In the case of perfect repair where S_R=-S_D, the efficiency is 1. Since S_R=-f S_D a fraction f of S_D , then their ratio will lead $(1+\frac{S_R}{S_D})$ to a value between 0 and 1, and this obeys the relation $\eta \le 1-\left(\frac{T_{Min}}{T_{Max}}\right)$ similar to cyclic heat engine process. Again, the improved efficiency is not anticipated by the Second Law.

6. Repair Aging Rate – An RC Electrical Model

We can look at the rate of negative repair entropy flow as it relates to entropy damage to within an aging factor *f(t)*

$$\frac{dS_{\text{Repair}}}{dt} = f(t)S_{Damage} \tag{24}$$

Here as aging increases in the living system, we expect that *f(t)* decreases where *0<f(t)<1*. Therefore, the rate of change of *f(t)* is some function of the unrepaired entropy damage $S_{UD}(t)$ that builds up over our lifetime and reduces our ability repair a living system. If this was not the case and we had perfect repair, we would not age. The model is simple but illustrates a possible view of aging. From our experience, *f(t)* must be a slow function of time compared to the repair rate, i.e.

$$\frac{d\Delta S_{\text{Re}pair}}{dt} >> \frac{df(t)}{dt} \tag{25}$$

Therefore we can write

$$\Delta S_{\text{Repair}} = -f\, S_{Damage} \tag{26}$$

and treat *f* as a constant over the repair time period, when we look at the entropy repair rate.

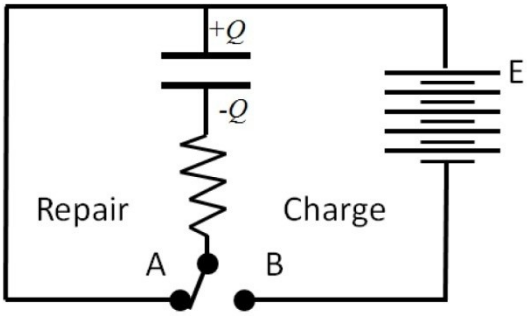

Figure 2 Charge and repair RC Model for the human body

Equation 24 can be compared to the well known RC circuit shown in Figure 2. The notion that the body charges up (switch B) in order to energize the repair area, and then the energy is discharged (switch A) has a similar differential equation given by

$$I = \frac{dQ}{dt} = -\frac{Q_o}{RC}e^{-t/RC} \tag{27}$$

Therefore in this model comparing to Equation 24, S_{Repair}=-S_{Damage} and charge flow equates to entropy flow. The fractional repair and repair time are f(t)~1/R(t)C(t) [1] and I is then the entropy current. For *f(t)* to decrease, *R* and *C* would need to increase. We would need at this point a

biological model for *R* and *C*. Perhaps it makes sense that the internal bodies resistance increase with time as the unrepaired entropy disorder builds up over a lifecycle and we associate entropy production with resistance. As well C would increase if the dielectric constant increases or the repair distance is reduced; this needs some thought on why that would occur if disorder were to increase over time.

7. A Proposed Fifth Law of Thermodynamics

In all types of models provided here for repair and growth, we see that living systems utilize available work to create negative entropy flow creating order. This effort makes little sense by the Second Law. For example we have shown that disrepair entropy is larger than repair entropy which should prohibit a repair processes. We see that none of the repair models described here violates the Second Law. However they certainly do not maximize generated entropy. The only answer that makes sense is to have a Fifth Law of Thermodynamics to justify the everyday occurrence of order observed in nature.

The proposed ***Fifth Law of Thermodynamics*** on negative entropy as implied by the arguments here is:

> *Mother Nature has a natural tendency to create system order from available work and matter attempting to maximize system work efficiency with its neighboring environment (i.e., attempting to maximize the system's free energy in the working environment).*

We have used the term Mother Nature which is a broader term that includes living systems and the environment. We might note that the environment needs to be included as it has a tenancy to organize, for example in weather systems. Associated with created order of course is free energy increase. Therefore the proposed law may alternately be expressed in terms of free energy.
Corollaries to help explain the Fifth law:

i. *Mother Nature is defined to include all living systems and the environment*

ii. *Systems are defined to include all living systems and inanimate objects.*

iii. *We use the term Mother Nature but we understand it takes work and matter to order a system. Therefore, it is understood that Mother Nature supplies the work. The fact that Mother Nature supplies and creates a certain type of system configuration is likely associated with efficiency of the created thermodynamic ordered system state with the neighboring environment. This makes sense since systems must function with the neighboring environment. The available energy used to create the order changes to disorganized energy, heat, in accordance with the Second Law so the overall entropy still increases.*

Similar to the Second Law, there is no formal proof of the Fifth Law. All we can say is, based on our experiences; this law has validity with system order appearing universally in nature in a way so as to maintain work efficiency between the system and the environment. We know by the Second Law that the overall entropy must increase as the available work, energy, used to create system order changes into disorganized energy, heat. Finally we see with the inclusion of this law, completes our attempt to describe all of nature not just closed systems.

8. Fifth Law Warning on Critical Environmental Interference

Although a bit philosophical, we might assert that human nature does not always agree with Mother Nature's instinct. Fifth Law can be violated due to an act of critical environmental interference from a strong environment-system destructive interaction. Then Mother Nature tendency will be lost or hindered due to a lack of available work and/or matter to generate enough negative entropy for the purpose of reproducing, repairing, or evolving related systems. All related systems to the destroyed environment will be irreproducible and will eventually become extinct.

The largest threat to system growth, repair and reproduction is when human nature interferes significantly with Mother Nature tendencies with the use of atomic and chemical weapons which could likely deplete our environment and cause multiple irreproducibilities. This is critical environmental interference. An additional example of such interference is that our environment is also aging as we humans pollute it. Therefore, Mother Nature cannot repair a number of systems like the ice caps and related systems will be affected as the ocean's volume changes. Critical Thermodynamic Interference has consequences that can obviously cascade to many systems.

9. Summary

A number of negative entropy models have been described for living systems. In each case, issues are demonstrated to show that the Second Law would not expect order to be favorable but a preferred disorder state would be more probable to drive the living system away from repair and growth towards a free energy minimum to achieve true equilibrium with the environment. Based on these models, we can conclude the need for a Fifth Law of thermodynamics and are able to provide a suggested Fifth Law to adequately resolve the Second Law paradox of for occurrence for order created by living systems. Finally, we provide a warning related to the Fifth Law that relates to mans ability to interfere with Mother Nature with atomic weapons and pollution that could threaten system order.

References

1. Feinberg, A., Thermodynamic Degradation Science, Physics of Failure, Fatigue, Reliability, and Accelerated Testing Applications, 2016, John Wiley.
2. E. Schrödinger *What is Life?* Cambridge University Press, Cambridge, 1944.
3. Lehninger, Albert (1993). Principles of Biochemistry, 2nd Ed. Worth Publishers. ISBN 0-87901-711-2.
4. Denbigh, K, *The Principles of Chemical Equilibrium*, Cambridge University Press 1955.
5. Schneider, Eric D.; Sagan, Dorion (2005). *Into the Cool: Energy Flow Thermodynamics and Life*. Chicago, United States: The University of Chicago Press. p. 15.
6. R.O. Becker and G. Selden, *The Body Electric*, Electromagnetism and the foundation of Life, William Morrow Publisher (1985).
7. Peter Schnohr, MD, DMSc[*]; James H. O'Keefe, MD[†]; Jacob L. Marott, MSc[*]; Peter Lange, MD, DMSc[*]; Gorm B. Jensen, MD, DMSc, Dose of Jogging and Long-Term Mortality, Journal of the American College of Cardiology, Vol. 65, Issues 5, pp. 411-419, Feb. 2015.