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Negative Entropy of Living Systems and a Thermodynamic Fifth Law

Key Words: *Negative Entropy, Spontaneous Negative Entropy, Entropy damage, Fifth Law of Thermodynamics, Living Systems, Law of Living System Negative Entropy*

ABSTRACT

The Carnot cycle, instrumental in the second law, is modified for living system yielding higher efficiency. Thus, the Second Law has shortcomings when trying to determine the thermodynamic state of a living system and a Fifth Law of Thermodynamics is needed to explain the effect of spontaneous repair and growth.

Introduction - Spontaneous Tendency

One way of phrasing the second law is that *"the spontaneous tendency of a system to go towards thermodynamic equilibrium cannot be reversed without at the same time changing some organized energy, work, into disorganized energy, heat."*

> *The problem with this statement is that living systems have a spontaneous tendency for growth and repair. An event that is also very common in nature. Therefore, which spontaneous tendency in effect are we to use in the Second Law? The one that causes order or the one that creates disorder. Or do we somehow have to prove that they are one and the same. Certainly, we can prove that the net result is increased disorder. However, that net results is much different when we take away the spontaneous effect of growth and repair as described here for a type of Carnot cycle for living systems. Lastly, there is the problem of the concept of spontaneous – it applies clearly to disorder in the Second Law, yet living systems uncontrollably spontaneously grow and repair, creating order.*

Negative entropy was first introduced by Erwin Schrödinger in a non technical field in his 1944 popular-science book *What is Life* [1]. 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 [2] 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, in his argument the preference for order is still not justified.

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

$$\Delta S_N < 0 \tag{1}$$

Here S is entropy and subscript N for negative entropy. This is performed with available work and matter. However, creating order cause disorder to the environment (waste) and the overall entropy change is positive (i.e., more disorder is created than order) in keeping with the Second Law

$$\Delta S_{Generated} = \Delta S_{Environment} + \Delta S_{N\ System\ Growth} > 0 \tag{2}$$

Furthermore, many living systems that sustain damage, will try and repair it creating a spontaneous amount of negative entropy equal to or greater than the entropy damage [3]

$$\left|\Delta S_{\text{Repair}}\right| \geq \left|\Delta S_{\text{Damage}}\right| \tag{3}$$

The equal sign indicates a highly efficient repair process where the inequality represents an inefficient repair process [3].

A living system seeks to balance damage with repair

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

improving its reliability. Therefore, the systems change in entropy has essentially decreased; its free energy (which equates to the ability to do useful work) has increased. However, by the Second Law the repair process generates at least this same amount of entropy damage or greater to the environment often in the form waste.

Growth and Self-Repair Description

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

$$\Delta S_{N\text{-Living System}} < 0, \text{ for } 0 < time < \text{human growth phase} \quad (5)$$

In the case of repair,

$$\Delta S_{N\text{-Living System Repair}} < 0, \text{ for Repair starts} < \text{time} < \text{Repair completed} \quad (6)$$

The exchange of entropies in repair is

$$\Delta S_{Gen} = \Delta S_{Environment} + \Delta S_{Repair} > 0 \quad (7)$$

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

$$\left|\Delta S_{Environment}\right| \geq \left|\Delta S_{Repair}\right| \quad (8)$$

The daily damage-repair process can be viewed as cyclic, this means that the internal energy U needs to be restored to its original state. Damage portion of the cycle is

$$\Delta U_{Change-due-to-damage} = \int_0^{Damage} dU = U_{Damage} - U_{Non-Damage} \quad (9)$$

In this simplified view, the internal energy change in a damage-repair cycle by the combined First and Second Laws is [3]

$$\oint dU = \oint \delta W + T\oint dS + \Delta U_{un-repaired} \geq 0 \quad (10)$$

That is, for perfect repair, the internal energy in the cycle is unchanged and for imperfect repair, yields some inefficiency and permanent change to the internal energy. The unrepaired portion builds up causing aging and living system efficiency η decreases, some repair work W, gets wasted, if W_{rev} is work needed for perfect repair, than $W_{irr}=W_{actual}-W_{rev}$ which increases with aging

$$\eta_{System}(t) = \frac{W_{actual}}{W_{actual} + W_{irr}(t)}, \quad W_{irr}(t+\tau) > W_{irr}(t) \quad (11)$$

Statement 1: *Living systems in daily use create internal damage. There is uncontrollable propensity to spontaneously repair this damage. However, since repairs are not 100% efficient, damage cumulates over time creating system aging decreasing efficiency.*

Living System Repair Work and Carnot Efficiency

We can make a simplified thermodynamic spontaneous repair model. The repair process is shown in Figure 1. An injury occurs, at some point, the entropy is at a maximum where the entropy damage is S_D and the repair area has a temperature rise T_{High} (T_H) due to inflammation and increased blood flow. Spontaneous repair work is done W_R, and the injury is almost completely repaired, the Un Repairable entropy damage is S_{UR}.

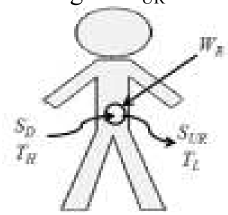

Figure 1 Simplified body repair

The change to the internal energy ΔU from repair cycle is due to the unrepaired damage. In this case, from the First and Second Law the minimum repair work is (see Eq. 10) and Fig. 1

$$W_{R-\min} = T_h S_D - \Delta U_{Damage-Unrepaired} = T_h S_D - T_L S_{UR} \quad (12)$$

The negative entropy needed for the repair process is

$$S_G = S_D - S_{UR} = -S_R \quad (13)$$

That is, in the case of repair

$$S_D - S_{UR} + S_R = 0 \text{ and } S_{UR} = S_D + S_R \quad (14)$$

So that the minimum work in the repair process is found by combining equations 12 and 14

$$W_{R-\min} = S_D(T_H - T_L) - T_L S_R \quad (15)$$

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

$$W_{R-\min} = S_D T_H = Q_H \quad (16)$$

where Q_H is the repair heat which can be measured.

The efficiency of living system spontaneous repair is

$$\eta_{L-Carnot} = \frac{W_{actual}}{W_{actual} + W_{irreversible}} = \frac{W_{R-\min}}{W_{R-\min} + T_L S_{UR}}$$
$$= 1 - \frac{T_L}{T_H}(1 + \frac{S_R}{S_D}) = 1 - \frac{T_L}{T_H}(1 - f) \quad (17)$$

We use the symbol $\eta_{L\text{-}Carnot}$ for a living system. Here we let $S_R=-f\,S_D$ a fraction f of S_D , a value between 0 and 1. In the case of perfect repair where $S_R=-S_D$, f=1 and the efficiency is 1. In the case of no repair f=0, the relation looks like the Carnot efficiency $\eta_H \le 1 - \left(\frac{T_{Min}}{T_{Max}}\right)$. In repair, the human body, behaves somewhat like a heat engine but has better efficiency compared to a Carnot Cycle

$$\eta_{L-Carnot} \ge \eta_{Carnot} \quad (18)$$

Having a higher efficiency than a Carnot cycle actually is not possible for heat engines, a Second Law limit.

It is important to note both the Carnot cycle and the living system Carnot cycle efficiency are the results of spontaneous occurrences in nature. They then conflict without definition. *We cannot simply say that by the Second Law we have added spontaneous work and explain it away because there is no provision in the second law to add spontaneous type work.* We see this is no ordinary work; it is specific to the living system and is truly spontaneous as it is uncontrollable, but has limits. It is a result of a living system's aging rate, repair quality, and damage amount [4]. Therefore, the repair rate helps us to measure a natural tendency and the well being of a Living system's thermodynamic state. We can boldly state

> ***Statement 2****: Living systems thermodynamic state (aging) can be measured by its repair or growth rate. This rate decreases with aging time. This decrease should be a good indication of the life span of any living system and a measure of its reliability or said another way, its negative entropy capability.*

Statement 2 is supported in the literature [4] as repair time, quantity and quality declines with age.

Living Systems Without Feedback

Many living systems such as trees and plants cannot repair damage as there is no feedback mechanism to identify damage. Therefore prior to ultimate failure, they are in a constant thermodynamic growth state that is not so different then the repair process which also creates growth as it does not reverse time. Many such non repairable systems outlive repairable living system. For example, trees commonly live many more years than people.

If we replace S_R with $S_{Growth}=S_G$ in Eq.17, we have

$$\eta_{L-Growth} = 1 - \frac{T_L}{T_H}(1 + \frac{S_G}{S_D}) = 1 - \frac{T_L}{T_H}(1 - f) \quad (19)$$

And S_D is then the maximum entropy that would be created to replace a full grown system.

A Proposed Fifth Law of Thermodynamics

We propose a Fifth Law of Thermodynamics, to help explain the discrepancies identified in this paper

> ***A living system spontaneous growth/repair rate is dependent on its L-Carnot efficiency.*** *Alternately, the "natural" thermodynamic state (its reliability) of a living system is dependent on its spontaneous growth/repair rate. This is a measurable quantity.*

Reference 4 is an example of the Fifth law where bone growth in old versus young mice has been measured.

Although this statement of the fifth law looks at first limiting to internal growth and repair, it could be extended to the external environment. Living systems have a propensity to organize by growing and repairing their environment building houses and cities, repairing damage roads and bridges as an example. Thus, living system organize to survive both internally and externally which creates higher reliability for a living system.

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