Open Access
Journal of Human Thermodynamics
ISSN 1559-386X
HumanThermodynamics.com/Journal.html

Article

A Thermodynamic Description of Life and Death in Biosystems

Nasif Nahle

Biological Cabinet: Institute of Scientific Research and Education on Biology, 614-C S. Business IH 35, New Braunfels, Texas, 78130 USA; email: scientists@biocab.org

Received: 30 December 2008; Published: 01 January 2009

Abstract

One of the challenges of biology has been the definition of life. Most of our attempts on defining 'life' have finished in a catalogue of properties which, more or less, describe only the living beings' functions, not life. Our problem begins when we lose the notion of reality provided by nature and go off the point with personal ideas. In this article, the operational definition of life and a meaning of death, based on empirical and observational data, will be expanded on, utilizing concepts from thermodynamics.

Introduction

It is commonly said that the five key attributes of life are: structure, complexity, order, evolution, and reproduction. We cannot say, however, that life is reproduction because many non-living beings reproduce spontaneously, for example prions, microspheres and crystals. Prions are a particular kind of defective protein which can expand at expenses of the normal proteins produced by the invaded organism. Prions are abiotic inert molecules that replicate simply by coming into contact with normal molecules. Normal proteins turn into prions when they 'touch' abnormal proteins; however, prions do not have any kind of nucleic acid because they are not cells, but secluded proteins or fragments of proteins. [1]

Prions also evolve similarly to any other complex molecules. This was deduced from the facility with which prions can break the species barriers for invading the tissues of other species, i.e. from bovines to humans and from humans to cats. [2]

We cannot assure that owning a complex molecular structure is an exclusive attribute of living beings. There are inert structures which are more intricate than those of a living being, a galaxy, for example. If we observe a corpse of a tree or a dog, we would observe that its molecular structure is identical to the molecular structure of that being when it was alive. Nevertheless, we distinguish with relative competence when a tree is dead and when it is alive.

What we observe, however, in the example above, is that the energy of dead beings is dispersed or relocated into more microstates than when they were alive, i.e. their local entropy production:

$$\sigma = \frac{dS}{dt}$$

increases, in such form that all their thermodynamic processes become irreversible ($\sigma > 0$). Biologically, reversibility refers to the possibility of inverting a provisional inhibition of a metabolic process. [3]

Some researchers have said that living beings are characterized by the order of their structures and that their order is maintained through non-spontaneous processes. [4] Nevertheless, we find abiotic systems which acquire autonomously more order than living beings. The universe's evolution is a good example. [5]

Another characteristic which has been attributed to living beings is their capability to evolve. [6] However, there are not systems in the knowable universe which do not evolve.

Other theoretical scientists have tried to unify the five attributes of the living beings by saying that the five attributes must be present in a single system for being considered alive. However, what could we say about mammals' erythrocytes, which don't replicate? [7]

Nucleic acids are not 'living molecules' which some authors have mentioned repeatedly. [8] Isolated nucleic acids do not maintain a quasi-stable state of its enthalpy. Conversely, ATP synthase performs all its functions even if it is isolated from a biomembrane. On the other hand, any cell deprived of its ATP synthases, does not survive. So life is maintained by the electrodynamics generated by these tiny molecular complexes.

Let us consider the virus. Viruses reproduce and have order and complex structures; besides, they evolve; however, viruses don't replicate spontaneously, as every other organisms do. Viruses must make contact with living cells, invade them and take control of the synthesis of proteins and nucleic acids of the host cells. If there are not living cells available, the viruses will not reproduce. [9]

Viruses illustrate the counterpart of the essential characteristics of living beings: viruses do not interchange energy autonomously with the environment and they cannot manipulate their internal energy to avoid the spontaneous deterioration of their structures. They are like dust, or rather, like crystals. *Viruses are not living beings*. [9]

To expound on this statement, via thermodynamics, it is argued here that the Gibbs' fundamental algorithm does not apply with viruses. Gibbs' formula permits the calculation of the differential of the internal energy *dU* of a biosystem or any living being, which is determined by several differentials that are translated into work, as shown below:

$$\mathrm{d}U = T\mathrm{d}S - P\mathrm{d}V + F\mathrm{d}l + \sum_{i=1}^{m} \mu_i \,\mathrm{d}n_i + \psi \mathrm{d}q$$

where T is the temperature of the system, dS is the local entropy of the system, P is the compression pressure, dV is the differential of volume caused by the compression, F is a given force exerted on the system, dl is the differential of elongation or size change, m is a determined number of molecules, i is a unit vector in a given direction, μ_i is the chemical potential of the unit vector, dn_i is a certain number of atoms or molecules, ψ is an electrodynamic potential, and dq is any amount of electrical charge.

Now, let us consider mammals' erythrocytes (blood cells). Mammals' erythrocytes don't possess nucleic acids; nevertheless, we say that the erythrocytes are alive. Mammals' erythrocytes lack mitochondria but they experience apoptosis, or programmed cell death. Mammals' erythrocytes have not a single opportunity of replication; though, we say that mammals' erythrocytes are alive; there is no doubt about it because they are obliged to die when getting old and obsolete (other cells induce apoptosis to erythrocytes). [10]

Evidently, mammals' erythrocytes fill all the parameters of the Gibbs' fundamental equation at any given time, except when the erythrocytes die.

We can also look at the criterion of life in terms of what is called a thermodynamic process. A thermodynamic process may be defined as the progression of energy changes taking place between an initial state and a final state. On this definition, it can be argued that viruses are not living beings because their thermodynamic processes belong to inert beings (abiotic systems), even if they may reproduce under favorable conditions. However, the mammals' red blood cells' thermodynamic processes match with those of living systems. Hence, we consider the mammals' red blood cells alive, although they cannot reproduce. [11]

In conclusion, life is not structure, complexity, order, evolution or reproduction, or either these characteristics taken as a whole; they are only characteristics of living beings. The first living beings on earth were not well-organized and complex organic bubbles which could replicate autonomously, but systems which possessed suitable mechanisms for capturing the energy from the environment, storing it into a controlled cascade of physicochemical reactions for using it when it was necessary in other biological processes, such as the maintenance of their structures, their reproduction, and the reversibility of the inhibition or the exhaustion of thermodynamic processes; only living beings can do that. [12]

In biophysics, one often talks about 'fields of energy'. In chemical systems, one can trace the path of quantums or units of energy when they are transferred from one molecule to another. A frequent confusion about the concept of *quantum energy* in larger systems, such as biosystems, however, is that the term tends to be viewed as a type of mysterious substance that cannot be verified by known methodologies. Nevertheless, here we refer exclusively to the state of energy characterized by quantum numbers. [13]

We can also know where and how much energy is stored by a living system (biosystem) and what a given biosystem can do with that load of energy stored. Now let us focus on the definitions of life and death.

What is Life?

We have seen that life is not the structure, order, complexity, evolution or reproduction of a molecular arrangement. Then, what is life?

To answer that question, we must make use of observation and experimentation. The clue for the correct answer resides in the energetic events which occur inside a biosystem.

First of all, we observe that the way by which a living being obtains its energy is different from the way by which the non-living beings obtain energy. Although the energy flows always from high density energy systems towards lower density energy systems, we could say that the living beings 'force' the energy to flow non-spontaneously toward their inner compartments; understanding the term compartment to be any structure capable of capturing, storing and releasing energy, i.e. open subsystems forming part of an open thermodynamic system. [12]

Secondly, we observe that the response of the living systems towards the fluctuations of the energy density of the environment is independent from the flux of entropy given in abiotic systems. A rock, for example, takes a portion of the incident energy on it incoming from the sun during daytime and loses this energy during nighttime, while living beings conserve, in a relatively stable manner, their internal energy density twenty-four hours day, no matter if it is a bacterium, a protozoan, a worm, a human being or an oak.

Finally, we observe that not all the structures of a cell are capable of producing an energy field in energetic equilibrium, but only some minuscule molecular complexes distributed along the biomembranes which are known as ATP synthase.

Any cell, whether it is a prokaryotic cell or a eukaryotic cell, possesses ATP synthase, without which, the cell would not survive. Then the unique cells' structure that is capable of producing and maintaining an energy gradient and an electrodynamic field is the ATP synthase. [14] If we deprive a cell, any cell, of its ATP synthase molecules, that cell irremediably will die.

In this view, we conclude that there are then three basic features intimately related with life:

- A non-spontaneous absorption, manipulation and storing of environmental energy. [12]
- The conservation of a quasi-stable internal energy density inside of the biosystems' compartments. [9]
- ATP synthase is the unique molecular complex capable of producing and maintaining an energy gradient and an electrodynamic field at the biomembranes, i.e. cellular membrane, mitochondria's membranes, chloroplasts' membranes, etc., of all living beings. [14]

Consequently, we can deduce that biosystems are capable of delaying the flux of their internal energy towards more available microstates, that is, the maintenance of an internal entropic equilibrium without violating any law of thermodynamics. At this point, we clarify that the entropic equilibrium is different from the thermal equilibrium because the living organisms must keep themselves in energetic non-equilibrium states to be capable of capturing and manipulating the energy from the environment, while the non-living beings are always in thermal equilibrium, to be precise, the abiotic systems take and release the same amount of energy, always. A locust, for instance, stores amounts of energy larger than the loads of energy that it would release towards the environment.

From these conceptions, we deduce a reductionist definition of life: [15]

> *Life is the interruption or delay of the spontaneous diffusions or dispersions of quantum energies of the biosystems toward more potential or available microstates.*

In this view, life is the complete set of microstates, i.e. positions and motions of the energy, produced by the flow of the energy which is caused by the proton motive force performed by specialized molecules called ATP synthase attached to biomembranes. Consequently, life is a *state of the energy* experienced by specific structures. Thanks to the oscillations of the electrochemical field of a biomembrane, some thermodynamic systems are able to holdup the dispersion of their internal energy toward more potential microstates and maintain an internal quasi-stable energy state.

Definition of Biological Death

Once we have obtained a reductionist definition of life, the definition of biological death evolves in parallel: [16]

> *Biological death is the reintegration of the spontaneous diffusion or dispersion of the quantum energy of the biosystems towards more available microstates*.

As such, death is the state of a thermodynamic biosystem in which that thermodynamic system cannot obtain non-spontaneously energy from the environment and organize non-spontaneously the energy obtained from the environment. Consequently, a dead biosystem discontinues the forcing of the energy into the biosystem's compartments; which, in the living case, would transform into internal energy that could be used for the progression of the processes that permits the biosystem to maintain a quasi-stable entropic state.

When a living thermodynamic system dies, it reintegrates the differential of the entropy between it and its environment, i.e. the local entropy of the biosystem will be higher than zero and it won't be transferred to the environment, but the biosystem will take entropy from the environment.

Apparently, the maintenance of a quasi-stable entropic state of a biosystem contradicts the second law of thermodynamics; however, we argue that it does not because the entropy of the biosystem increases at levels higher than the entropy of the environment, consequently, the entropy of the biosystem will be transferred to the environment, that is, from the system in a higher entropic state (the biosystem) to the system at a lower entropic state (the environment).

A violation to the second law of thermodynamics would imply that the entropy flowed from a system with a lower entropic state to a system with a higher entropic state. It doesn't occur in biosystems because the universe is always in a lower entropic state than as compared to biosystems.

Conclusion

Life is not defined by its molecular structure, or its order, its complexity, its evolution or its reproduction. Life and biological death are entropic states of some thermodynamic systems. The energy state of life permits biosystems to maintain a quasi-stable entropic state, while the energy state of death allows a biosystem to reintegrate the entropic differential between that biosystem and the universe.

We could say that the Gibbs' fundamental equation is the 'equation of life', of such form that we could determine whether a system is biotic or not by simply trying to apply the formula on the work *W* done by that biosystem and on the amount of heat used by that system for doing work. Any of the Gibbs' fundamental equation parameters can be adjusted by expanding or reducing them according to the studied bioprocess or according to the biosystem's physiology.

The entropic state of a biosystem is always increasing; however, the biosystem is capable of transferring the gained entropy towards any other system with a lower entropy state. If we consider some alternate phases of the entropy, like order and complexity, we would find that the universe is always more ordered and complex than any biosystem. Hence, the universe entropic state is always lower than the entropic state of the biosystems.

References

1. Prusiner, S. B. (1991). *Molecular Biology of Prion Diseases*. Science. Vol. 252, pgs. 1515, June 14.
2. Callen, Jean-Claude. (1999). *Biologie Cellulaire. Des Molécules aux Organismes. Cours et Questions de Révision*. Paris, France: Dunod.
3. Bakken, G. S., Gates, D. M., Strunk, Thomas H. and Kleiber, Max. (1974). "Linearized Heat Transfer Relations in Biology." *Science*. Vol. 183; pgs. 976-978. March 08.
4. (a) Campbell, Neil A., et al. (1999). *Biology*. Menlo Park, CA.: Addison Wesley Longman, Inc.
(b) Kestenbaum, David. (1988). "Gentle Force of Entropy Bridges Disciplines". *Science*, March 20, Vol. 279, pg. 1849.
5. Zuckerman and Malkan. (1996). "The Origin and Evolution of the Universe". *A UCLA Center for the Study of the Evolution and Origin of Life (CSEOL) Symposium*. Los Angeles, CA.: Jones and Bartlett Publishers.
6. (a) Campbell, Neil A., et al. (1999). *Biology*. Menlo Park, CA.: Addison Wesley Longman, Inc.
(b) Curtis, Helen. (1983). *Biology*. New York: Worth Publishers.
7. (a) Ham, Arthur W., Axelrad, Arthur A., Cormack, David H. (1979). *Blood Cell Formation and the Cellular Basis of Immune Responses*. New York: Lippincott Company.
(b) Nakano, Toru, Kodama, Hiroaki, Honjo, Tasuku. (1996). "In Vitro Development of Primitive and Definitive Erythrocytes from Different Precursors". *Science*, Vol. 272, Issue 5262, pgs. 722-24, May 03.
8. Anon. (2009). "RNA as a 'Living Molecule'", *Breaker Laboratory,* Yale University.

URL: http://breaker.research.yale.edu/index_files/RNATutor.htm
9. Callen, Jean-Claude. (1999). *Biologie Cellulaire. Des Molécules aux Organismes. Cours et Questions de Révision*. Paris: Dunod.
10. Walsh, Melanie, Lutz, Robert J, Cotter, Thomas G, and O'Connor, Rosemary. (2002). "Erythrocyte Survival is Promoted by Plasma and Suppressed by a Bak-derived BH3 Peptide that Interacts with Membrane-associated Bcl-XL", *Blood,* May 01. Vol. 99, No. 9, pgs 3439-48.
11. (a) Ham, Arthur W., Axelrad, Arthur A., Cormack, David H. (1979). *Blood Cell Formation and the Cellular Basis of Immune Responses*. New York: Lippincott Company.
(b) Ham, Arthur W. (1974). *Histology*. New York: J. B. Lippincott Company.
12. Glaser, Roland. (2005). *Biophysics*. Berlin Heidelberg, Germany: Springer-Verlag.
13. Hutchenson, John S. (2005). "Quantum Energy Levels in Atoms", *Connexions*, Module. URL: http://cnx.org/content/m12451/latest
14. Lodish, H., Berk, Arnold, et al. (1999). *Molecular Cell Biology* (pg. 617). New York: W. H. Freeman and Company.
15. Nahle, N. (1999). "Life". *Biology Cabinet*. New Braunfels, TX.
URL: http://biocab.org/Life.html
16. Nahle, N. (1999). "Biological Death". *Biology Cabinet*. New Braunfels, TX.
URL: http://biocab.org/Biological_Death.html
