International Conference on Renewable Energies and Power Quality (ICREPQ'19)
Tenerife (Spain), 10th to 12th April, 2019
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.17 July2019

Is there any example of an isolated system in nature? What is the applicability of the second law of thermodynamics?

Oliveira, L. E.[1]

[1] Department of Conservation and Biodiversity
AI, Abepoli Institute
Center I – Santa Branca, 12380000 São Paulo (Brasil)
Phone/Fax number: +0055 12 991569448, e-mail: **levi_ezequiel@yahoo.com.br**

Abstract. In 1854, Rudolf Clausius developed the second law of thermodynamics, which measures the disorder of a system under investigation. According to that law, all isolated systems always increase in entropy over time. This conclusion was emerged by an empirical experiment of a confined gas that is released inside a vessel. The gas will always expand, thus increasing the entropy of the system. However, the question that remains is that if there is any isolated system in the Universe? This law is bringing several mistaken conclusions such as many examples showed by experts in this area. The purpose of this paper is to show misleading examples shown by the scientific authorities of the second law of thermodynamics. Despite the second law, the Universe has always produced more organized and complex systems over time. Actually, is impractical to show examples of the second law of thermodynamics because there is no isolated system throughout the Universe. The 13.7 billion year history of the Universe's existence shows that it evolves from a hot soup of energy and matter to complex systems like stars, planets, and living things.

Key words

Second law of thermodynamics, increase in entropy of isolated system, sand castle, evolving Universe.

1. Introduction

Thermodynamics is the science of heat flow between an object of study and its environment. To study the efficiency of any engine, it is vital to investigate the amount of energy required to produce an amount of work [1, 2].

The object under investigation is called the thermodynamic system. The system limit is called the boundary and everything else is the surroundings, which is the entire Universe excluding the system under observation [3].

The system could be a sample of gas inside a vessel with a movable piston, an entire steam engine, a cell, a living being, a star, a planet or even the entire Universe. Systems are free to exchange heat, work and other forms of energy with their surroundings [4].

The system boundary can allow the exchange of matter and / or energy with the environment. Depending on the boundary, the system under investigation can be classified as open, closed or isolated. The open system allows the exchange of matter and energy with its environment. The closed system only allows the exchange of energy. The isolated system does not allow the exchange of matter and energy with the environment [5].

In fact, all systems in the Universe are not isolated. Several examples can illustrate this condition, such as stars, planet and living things. The emergence of complexity in the Universe has been observed since the 13.7 billion years of its existence. This is because the flow of energy has ensured the emergence of ever more complex structures.

The aim of this work is to show misleading examples that pretended to show the second law of thermodynamics in practice. However, these examples are not isolated systems. Indeed, there is no isolated system in the Universe. There are real examples of systems that decreased in entropy over time like the snow flake formation and accretion process.

2. Discussion

A. The sand castle example

A clip from the BBC television series Wonders of the Universe shows a sand castle slowly disintegrated by the action of the wind. Thus, according to this clip, entropy always increases for any system (Figure 1).

Fig. 1. Sand castle dismantled by the wind [6].

The BBC channel of You Tube posted the following information:

"How a sandcastle reveals the end of all things. Professor Brian Cox builds sandcastles in the Namib Desert to explain why time travels in one direction. It is a result of a phenomenon called entropy; a law of physics that tells us any system tends towards disorder. From Wonders of the Universe, BBC2." [6].

The misconception of this information is that not all systems tend to disorder. There are several systems that tend to decrease in entropy because there are no known systems in the Universe. Therefore, for any system, the entropy may increase or decrease over time. In addition, this documentary also has a misleading report. The sand castle is not an isolated system because it suffers wind action that transports material into and out of that system (sand castle). Watch the documentary to observe the action of the wind: https://www.youtube.com/watch?v=uQSoaiubuA0.

In fact, the sand castle is an open system. In addition, there are other examples of open systems in the Universe, whose entropy decreases over time, such as the formation of snowflake (Figure 2).

Fig. 2. Snowflake [7].

A snow crystal appears when water vapour (high entropy) in the air converts to solid ice (low entropy) with highly organized and ornamented patterns in an arrangement of water molecules under the crystal form of ice (Figure 3).

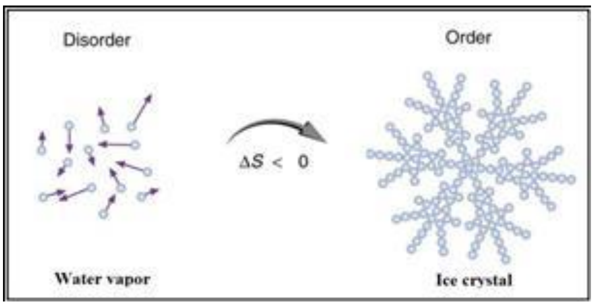

Fig. 3. Ice formation [8].

Other example of decrease in entropy of an open system is the planet formation by accretion process. The gravity force is responsible to clump the stardust together (Figure 4).

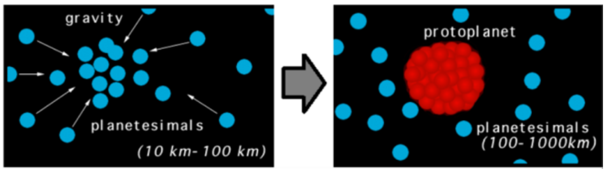

Fig. 4. Planet formation by accretion process [9].

In fact, all systems in the Universe are not isolated. Several examples can illustrate this condition, such as stars, planet, living beings and even sand castles. The increased complexity of the Universe is observed during the 13.7 billion years of its entire existence. This is because the flow of energy has ensured the emergence of ever more complex structures.

Professor Dr. David Cristian from Macquire University describes this possibility of increasing complexity of the Universe: "…we have a great storyline. That storyline is the appearance of more and more complex things in the universe, despite the Second Law of Thermodynamics Now let me explain that. One of the fundamental laws of physics is the Second Law of Thermodynamics, and that seems to be telling us that the general tendency of the Universe is to get simpler. So how is it possible to get more complex things? Well as we'll see, energy plays a crucial role in that story. So, how does the idea of energy help us explain this puzzle that more and more complex things seem to have appeared despite the Second Law of Thermodynamics? Well, as long as the universe is not perfectly disorganized, there will always be slight differences, slight gradients, and that means that energy will flow. And it's these flows of energy, free energy it's called technically, that allow the construction of more complex things where the conditions are just right. So energy is our first crucial concept."

David Cristian associated with the emergence of complexity because of the "Goldilocks Conditions", a term inspired by a fable of three bears and a girl. The conditions of Goldilocks are when conditions are "perfect" for something more complex to emerge, such as the fable of Goldilocks and the Three Bears. In this fairy tale, the girl named Goldilocks, goes out for a walk in the woods and finds a house where she enters and finds three bowls of porridge. The first one she tastes is very hot, the next one is very cold, but the third one is at the right temperature, so she eats everything.

These right conditions allow the action of free energy flow. However, Professor Cristian did not describe what conditions allowed the emergence of complexity, despite the second law of thermodynamics. So what are these conditions?

Actually, there is only one condition that allows the flow of free energy, which is only possible because there is no isolated system in the whole Universe. Therefore, there is no violation to the second law of thermodynamics.

In fact, this law of physics is null in predicting any thermodynamic process, since its model is only for isolated systems. This issue raises several scientific misunderstandings in the understanding of the thermodynamic behaviour of any system under investigation. Actually, the question is not whether nature is violating a physical law. It is the law that is not predicting the physical world.

The main misconception would be to accept that all the systems of the Universe always increase of entropy with the time. This is not true. Since there is no isolated system in the Universe, the entropy of a system can increase or decrease over time. This is a question that has remained since the birth of the science of thermodynamics in the late nineteenth century. The only system that can be considered as increasing in entropy over time is the Universe as a whole, because it is expanding and the galaxies are moving away from each other.

However, this increase in entropy is because the Universe is expanding and it is not because of the consequence of the second law. We still do not know if the Universe is an isolated system. There is no scientific evidence of energy exchange occurring across the boundary of the Universe. Furthermore, we do not know if there is a surrounding outside the Universe system.

Therefore, the idea that any system is meant to increase its entropy is just a fairy tale, like the fable of Goldilocks and the Three Bears. In fact, any system can increase or decrease overtime, since there is no isolated system. So the idea that any system always tends to increase overtime entropy is just like the sandcastle example, which is not good for illustrating a physical law, but it's great to be just fable.

B. The broken glass cup example

Many scientists like to demonstrate the second law of thermodynamics by showing the broken glass cup process as an example (Figure 5).

Fig. 5. Broken glass process [10].

The problem with ths example is to consider the glass cup as an isolated system. The collision of the glass with the floor releases energy that is responsible for breaking the glass. Therefore, the glass system is not insulated. This system is subject to external influence.

Even if we consider the glass cup + floor as only one system, there are other types of energy that is released by the impact of the collision out of this system such as heat and sound wave. Therefore, the glass + floor glass system is also not isolated either. So how can a glass decrease its entropy? The answer is that the transfer of energy is necessary and it is possible because the system is not isolated.

If sand, soda ash and limestone were collected from the soil and converted into a glass cup, the work to perform this process reduced the entropy of the glass cup system.

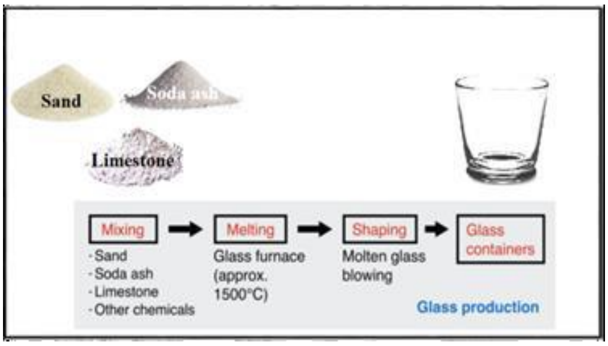

Fig. 6. Glass cup production [11].

Indeed, any steps of the process of glass cup production or the whole process are all open systems that allow the heat transfer.

The glass production process itself is much slower compared to the broken glass process which increases entropy very quickly by the action of the energy released by the collision with the ground. However, both processes, the brake and the production of the glass cup, occur because the glass cup is not an isolated system.

C. The broken egg example

The broken egg is an example of a natural system that will increase in entropy by the energy released by the impact of its collision with the floor (Figure 7).

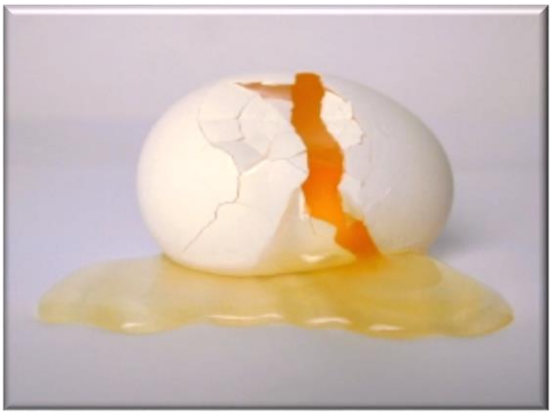

Fig. 7. Broken egg process [12].

The broken egg is not an isolated process, just like broken glass. Although egg breaking is a rapid phenomenon with an increase in entropy, the system is not isolated. The egg receives energy liberated from the egg collision on the ground.

There is also the process of egg formation, with nutrients provided by the mother chicken; it is possible to produce a highly organized system represented by the egg. Egg formation is possible because the egg system is not isolated as the glass cup system. There is energy exchange between the egg and the body of the chicken mother (Figure 8).

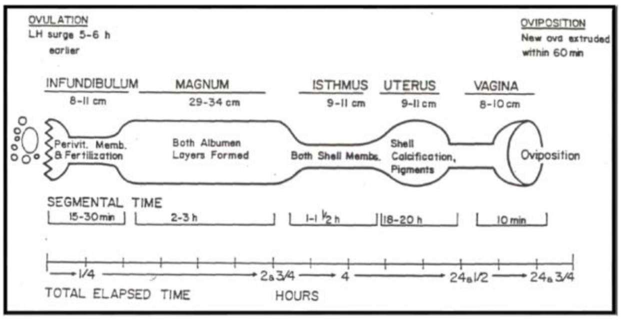

Fig. 8. Egg formation process [13].

D. The perfect machine example

Even the Science of Thermodynamics has already accepted the idea that there are no isolated systems. It is perfectly accepted that there is always energy exchange of the system with the environment.

The Carnot engine is a theoretical thermodynamic cycle proposed by the French physicist Sadi Carnot in 1824. It provides an upper limit to the efficiency that any classical thermodynamic engine can achieve. Therefore, it is impossible to build a 100% efficient machine. In fact, such a "perfect" engine is only theoretical (Figure 9).

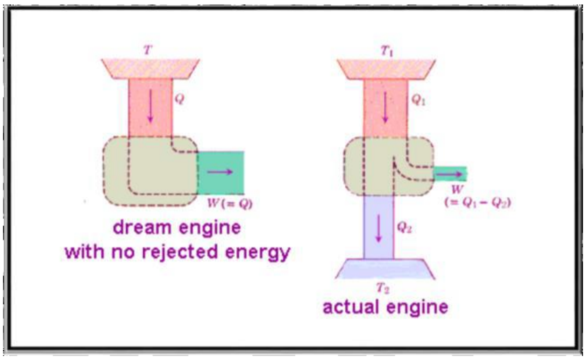

Fig. 9. Carnot engine and actual engine [14].

E. Other examples

There are several other examples of systems that are not isolated, such as stars, planets, galaxies, living organisms, clouds, etc. In fact, any system in the universe is not isolated.

The second law of thermodynamics predicts that entropy always increases in isolated systems. But there is no single isolated system throughout the Universe. Therefore, its prediction is null, since for any system, the entropy can increase or decrease with time.

F. The evolving Universe

The Universe becomes increasingly complex because of the formation of highly organized systems, with the emergence of atoms, molecules, stars, galaxies, planets, and even life systems (Figure 10).

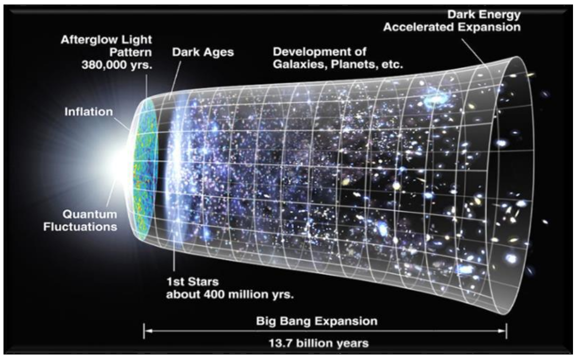

Fig. 10. Evolving Universe [15].

In the beginning, there was only a hot soup of particles and energy before the formation of the first atoms. The Universe was very homogeneous. Today, the Universe is formed from many open systems that evolved from a single hot soup, forming hydrogen and helium atoms shortly after the Big Bang. After the Big Bang it was formed all the known elements, through the release of huge amount of energy (Figure 11).

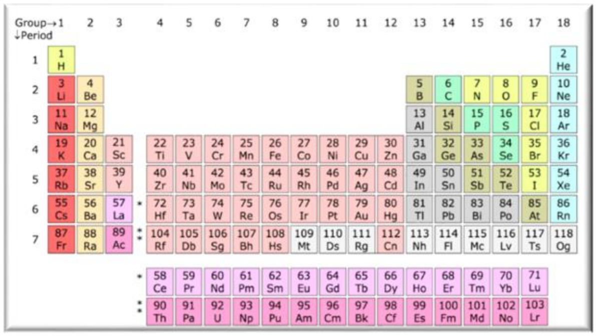

Fig. 11. Periodic table

Gravitational force plays an important role in the formation of organized structures, reducing the entropy of open systems in the Universe. The appearance of the first stars, 200,000,000 years after the Big Bang, was possible, because gravity agglomerated clouds of matter forming denser systems with higher temperatures.

The opposing forces between the energy released by the fusion of matter and the gravitational force were responsible for the appearance of the first stars. The emergence of stars allowed the formation of planets and eventually life.

The evolution of the Universe allowed the emergence of the most intriguing molecule that exists: the deoxyribonucleic acid (DNA). Figure 12, shows the highly organized structure of DNA molecule, which has all the information to build and maintain living organisms.

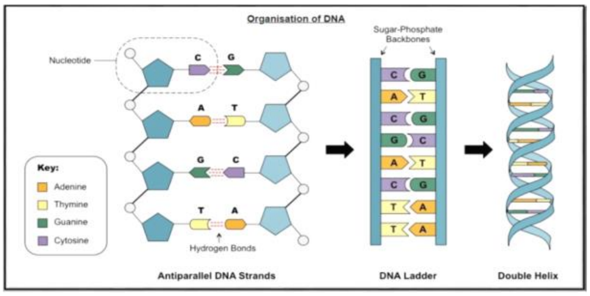

Fig. 12. DNA molecule.

G. The Second Law of Thermodynamics and the arrow of time

As any process advances in time and the second law of thermodynamics predicts that the entropy of an isolated system always increases, the measurement of entropy is a way of distinguishing the past from the future.

This is another misconception, because the Universe's 13.7 billion history shows only the emergence of increasingly complex systems (decreased entropy), from a homogeneous hot soup of energy and matter to atoms, molecules, and even DNA. The emergence of complex systems is only possible because there is no isolated system. Incidentally, this is a problem of the second law of thermodynamics, which asserts for the increase of entropy in isolated systems.

H. What is the applicability of the second law of thermodynamics?

In order for the end of the Universe to be true to thermodynamics, it would be necessary for the Universe to be an isolated system without any external influence. The problem is that we do not know if there is nothing beyond the limit of the Universe. If you it is isolated, it is isolated from what? If thermodynamics is applied to small systems, so it can be applied to systems as large and heterogeneous such as the Universe? It does not make much sense to consider the whole Universe as a system, because the definition of a system is that it is separated from the environment by a boundary. So what are the surroundings of the Universe? Is the limit of the Universe an adiabatic wall?

Nevertheless, the entire Universe as a system can be considered as increasing in entropy because it is expanding with galaxies moving away from each other (Figure 13).

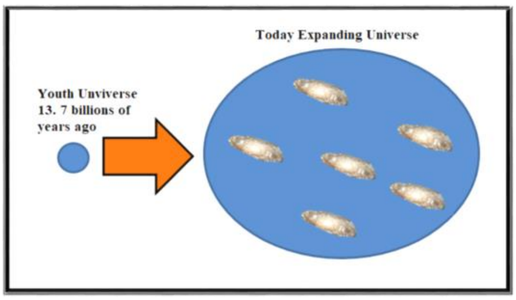

Fig. 13. Expanding Universe.

In fact, systems like stars, planet, and life have evolved to be highly organized structures, with much less entropy than the substances from which they originated. It is always possible that the entropy of one part of the Universe will decrease, so long as the total change in the entropy of the Universe increases. In equation form, it is possible to write this as $\Delta S_{\text{Universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings (rest of the Universe)}} > 0$.

In addition, the decreasing of entropy of one part of the Universe is only possible because there is no isolated system. The only reasonable prediction of the end of everything by the lenses of the Science of Thermodynamics is the heat death hypothesis derived from the second law of thermodynamics, which states that entropy tends to increase in an isolated system.

In fact, death by heat is a possible destination of the Universe because all systems are not isolated, allowing the exchange of heat. In the end, all free energy will be extinguished, because all systems will achieve a thermal equilibrium. Therefore, it is not a consequence of the second law of thermodynamics which makes predictions only for isolated systems.

3. Conclusion

Many people argue that the evolution of the Universe violates the second law of thermodynamics. In fact, over time, complex structures evolved from much simpler systems, representing a large decrease in entropy in various systems, such as atoms, stars, and living things.

Therefore, the entropy of any system tends to increase or decrease with time, since there is no isolated system except the Universe itself, which is increasing in entropy because it is expanding with the galaxies getting away from each other.

References

[1] Guggenheim, E.A., Thermodynamics. An Advanced Treatment for Chemists and Physicists, 1st edition 1949, 5th edition 1967, North-Holland, Amsterdam.

[2] Petrucci, R. H., William, S., Herring, H.F.G., Madura, J.D., General Chemistry: Principles & Modern Applications. 9th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2007. 791-796.

[3] Linden N, Popescu S, Skrzypczyk P. How small can thermal machines be? The smallest possible refrigerator. Phys Rev Lett. v. 105, p. 130-401, 2010.

[4] Adkins, C.J., Equilibrium Thermodynamics, (first edition 1968), third edition 1983, Cambridge University Press, ISBN 0-521-25445-0, pp. 18–20.

[5] Münster, A. (1970), Classical Thermodynamics, translated by E.S. Halberstadt, Wiley–Interscience, London, p. 22.in Proc.

[6] Professor Brian Cox builds sandcastles in the Namib Desert Wonders of the Universe - BBC Two https://www.youtube.com /watch?v=uQSoaiubuA0.

[7] Site visited on January 06, 2019: <https://www.redbrick.me/ top-5-snowflake-facts>.

[8] Site visited on January 06, 2019: < https://courses. lumenlearning.com/physics/chapter/15-6-entropy-and-the-econd-law-of-thermodynamics-disorder-and-the-unavailability-of energy>.

[9] Site visited on January 10, 2019: <http://zebu. uoregon.edu/ disted/ph121/l7.htm>.

[10] Site visited on January 12, 2019: < https://startsat60.com /discover/lifestyle/pick-up-broken-glass-easily-and-safely-with this- trick>.

[11] Site visited on January 10, 2019: <https://noahslist.com/ a/ielts-report -about-glass-production-nofl33-3684.html>.

[12] Site visited on January 14, 2019: https://ethicsalarms.com/ 2012/06/21/ethics-quiz-the-bank-the-addict-and-the-broken-egg/>.

[13] Site visited on January 10, 2019: < http://explainagainplease. blogspot.com/2013/04/egg-formation-and-quality.html>.

[14] Site visited on January 10, 2019: < http://heatengine kiechiko.blogspot.com/2017/06/carnot-heat-engine-youtube.html>.