Generating structural, interactional and processual order through synergetic entanglement is the essence for understanding and using Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System

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Abstract. Recently, we invented a new branch of irreversible processes by studying the interaction between Heart and Lungs through thousands of measurements of the heart frequency, lung frequency and oxygen content in the blood for many people of different age. Based on these measurements we discovered a surprisingly simple but powerful formula correlating the two frequencies in any stationary state through a quantum number $N$, that has an integer value for healthy people, but non integer for ill persons. Actually, the formula states that the interaction between Heart and Lungs, considered as two macroscopic oscillators, is quantized, which means that it is very much ordered or highly organized. We believe that this discovery has no connection with Quantum Mechanics, that describes the behavior of microscopic systems. Thus, the aim of the paper is to explain and understand why the quantization of the Cardio-Pulmonary Interaction occurs in macroscopic biological system. We present two diagrams invented by us for describing the quantized stationary states and processes with or without quantum jump between different stationary states depending on person activity. Based on the above mentioned formula and these diagrams, we show that our discovery is in accordance with the new branch of science, Synergetics.

1. Introduction

Recently, we extended the Thermodynamics with Finite Speed applied to Thermal Machines [1-13] to “Biological Machines”, thereby inventing and building a new branch of irreversible processes [10, 14 - 24] that studies the interaction between Heart and Lungs, and called by us Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System (QBTFSCS).

After doing thousands of measurements of the Heart frequency $F_H$, Lung Frequency $F_L$ and oxygen content in the blood for many children, young, adult and old persons, we have discovered a very simple correlation of the two frequencies in any stationary state, as a function of a quantum number $N$: 

\[ F_H / F_L = N \]
where $N$ is an integer number for healthy people, but not an integer for ill persons (with heart or lung problems).

The fact that this formula is very simple actually shows that the interaction between Heart and Lungs, viewed as two macroscopic oscillators is very well organized, and because of that is quantized, similarly to the interaction between the electron and proton in the hydrogen atom. Despite of this similarity, we do believe that this discovery has nothing to do with Quantum Mechanics, which describes the behaviour of microscopic systems.

Similar research regarding the cardio-pulmonary components functioning and interaction are found in the literature. Some of them correlate the shift in heart rate variability with postures and walking by time–frequency analysis [25]. The reported results based upon eighteen subjects performing four sequential 5-min physical activities (supine, sitting, standing and spontaneous walking) showed heartbeat frequency fluctuations when changing the posture, and that the ratio of low- to high-frequency fluctuation during standing was significantly higher than during supine and sitting.

Another study [26] aimed to detect and compare the changes of heart rate and respiratory frequency during high altitude mountain ascent. Results showed that this activity differently affected the heart rate and the respiration frequency variability, concluding that the respiration frequency had more randomness than the heart rate and altitude increased this difference.

Important results confirming our discovery are provided by the analysis of a set of nonlinear dynamic models for the interactive respiration/cardiovascular mechanism by employing equivalent electric circuits [27]. The authors have found that for a specified activity mode (e.g., sleeping, walking or resting), the heart beat rate can be assumed to be proportional to the breath frequency through a value of constant that is determined by the mode of human body activity.

The present paper will try to explain and argue why the quantization of the Cardio-Pulmonary Interaction appears in macroscopic biological systems.

The diagrams that we have invented [10, 14 - 24] and used here to describe the quantized stationary states and processes with or without quantum jump between different stationary states corresponding to different posture of the person emphasize the correlation between the heart and lungs frequencies and the associated quantum number.

The explanation regarding the quantized macroscopic interaction between Heart and Lungs is presented in section 3 based on the idea of the synergetic entanglement of the two oscillators and also, by using experimental measurements regarding the oscillation periods of these two subsystems.

Conclusions and perspectives are discussed in the last section.

2. Diagrams for describing stationary states and processes with and without quantum jump in the cardio-pulmonary system

Inspired from Thermodynamics with Finite Speed [1-13] we invented 5 diagrams for describing Stationary States and Processes with and without quantum jump between them, in the Cardio-Pulmonary System which are used now in QBTFSCPS, in a similar way like in Thermodynamics of Thermal Machines, in order to describe cyclic diurnal processes of persons of different ages (child, young, adult, old).

In this paper we present only 2 diagrams (Figures 1 and 2), which are the most important, in which we can represent stationary states (0, 1, 2, 3,…13, 14, 15, 16) and processes between stationary states (0-1, 1-2, 2-3, 3-4,…12-13, 13-14, 14-15, 15-16) with or without quantum jump, and the quantum number corresponding to each state.

In these figures starting from state 0, one can read the values of the frequency ratio $R_i = F_i / F_{0i}$ and the quantum integer number $N$ for each stationary state, as function of $F_{0i}$, in one diagram (figure 1) and as function of $F_{0i}$ in the second diagram (Figure 2), for different postures of a person (SP).

Each of the two diagrams has its importance given by the distribution of the stationary states and processes on the frequency variation range. There is a clear separation of the stationary states on the
frequency variation range of each biological machine, and the frequency values $F_H$ and $F_L$ increase progressively with the posture changing. Regarding the processes between stationary state, the diagrams reveal iso-rhythm (1-2, 2-3, ..., 12-13) or iso-pulse processes (6-7).

Figure 1. Diagrams $R_f, N = f(F_L)$ (for SP).

Figure 2. Diagrams $R_f, N = f(F_H)$ (for SP).
Figure 3. Power $\dot{W}_t = f(F_L)$ and total entropy source $\dot{S}_t$ (for SP).

Figure 4. Power $\dot{W}_t = f(F_L)$ and total entropy source $\dot{S}_t$ (for SP).

Based on these diagrams we were capable to compute the variation of the power consumed by heart and lungs, $\dot{W}_t$, and the total source of entropy generated in each stationary state, $\dot{S}_t$, (Figures 3 and 4). Note that the same separation previously mentioned appears here in a more obvious way, being question of the increasing demand in energy (power) consumption and consequently, in entropy generated.
3. The essence for Understanding and using Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System Order is through synergetic entanglement

The explanation regarding the quantized macroscopic interaction between Heart and Lungs is based on the idea that the essence of generating structural, interactional and process order between these two oscillator subsystems (Heart and Lung) is an effect of synergetic entanglement discovered by Hacken [28] when trying to explain how the lasers works.

![Diagram showing ordered correlations between Heart and Lungs periods](image)

**Figure 5.** Intuitive explanation of the ordered correlations between oscillations of Heart and Lungs for processes with $R_f = 3$ and $R_f = 3.5$ (for SP).

Based on that discovery he created a new branch of science called Synergetics. In Synergetics he has shown that between two oscillators either microscopic or macroscopic, an interactional relation can appear which introduce a degree of order, expressed quantitatively by certain relations between the frequencies of the two oscillators.

An intuitive explanation of the ordered correlation between the frequency of Heart and frequency of Lungs oscillation is presented in figures 5 and 6.

In figure 5 we show the correlation between Lungs and heart periods by considering one oscillation of the Lungs for different variation of the volume from $V_{min}$ to $V_{max}$ and back to $V_{min}$ in two stationary states, corresponding to $R_f =$ integer: $3$, and to $R_f =$ not integer: $3.5$.

Figure 6 illustrates the similar correlation for another person (BB), corresponding to an integer $R_f =$: $6$, and to a not integer $R_f =$: $5.5$.

One can see that when the number of the complete oscillations of the Heart corresponds to only one oscillation of the Lungs, the ratio between the Periods of these oscillations ($P_H/P_L = F_H/F_L$) will correspond to integer numbers of $R_f = F_H/F_L$.

The explanation of the not-integer numbers of $R_f$, but increasing with $0.5$ from an integer number consists in the fact that a complete oscillation of the Lungs corresponds (for these cases) to not a
complete oscillation, but to \textit{an integer number of oscillations plus a half fraction of the last oscillation} of the Heart.

Thus, in both figures, to one oscillation of the lung corresponds either an integer number (3 for SP and 6 for BB), either a fractional number (3.5 for SP and 5.5 for BB) of heart oscillations.

It is quite obvious that in both cases, despite of the difference in the frequency ratio values $R_f$ and in corresponding values of the quantum number $N$, that are 4 and 6 respectively (for SP, 79 years old), and 14 and 16 respectively (for BB, 29 years old), the organized interaction of oscillations is similar.

4. Conclusions and perspectives
The discovery of the quantized formula that correlates the frequency of the heart - $F_H$ with frequency of the lungs - $F_L$ through a quantum number, which is an integer in stationary states of healthy people was the beginning of inventing of a new branch of Irreversible Thermodynamics called by us: Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System (QBTFSCPS), as an extension of Thermodynamics with Finite Speed applied to Thermal Machines.

We have shown that generating structural, interactional and processual order through synergetic entanglement is the essence for understanding and using Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System.

Two of the five new diagrams that we have invented, where the stationary states and processes between stationary states with or without quantum jump can be studied, are presented. They emphasize the correlation of the heart/lungs frequency ratio with the quantum number in different stationary states that are changing according to the person’s posture. Furthermore, a thermodynamic approach of the two biological machines allowed to compute the power consumed by heart and lungs and the total source of entropy generated in each stationary state.

These diagrams drawn by persons in the period of life when they are healthy can help the designers to build quite soon personalized artificial hearts and lungs with a correlated functioning.
Our discovery and the new branch called by us Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System (QBTFSCS) provide a thermodynamic and synergetic approach of the two components of an important biological system. We intend to extend it in the near future to a triple interaction: heart, lungs and brain.

References
[1] Stoicescu L and Petrescu S 1964 The First Law of Thermodynamics for Processes with Finite Speed in Closed Systems Sci. Bull. UPB Bucharest 26(5) 87-108
[2] Stoicescu L and Petrescu S 1964 Thermodynamic Processes Developing with Constant Finite Speed Sci. Bull. UPB Bucharest 26(6) 79-119
[3] Stoicescu L and Petrescu S 1965 Thermodynamic Processes with Variable Finite Speed Sci. Bull. UPB Bucharest 27(1) 65-96
[4] Stoicescu L and Petrescu S 1965 Thermodynamic Cycles with Finite Speed Sci. Bull. UPB Bucharest. 27(2) 82-95
[5] Stoicescu L and Petrescu S 1965 The Experimental Verification of the New Expression of the First Law for Thermodynamic Processes with Finite Speed Sci. Bull. UPB Bucharest. 27(2) 97-106
[6] Petrescu S 1969 Contribution to the study of thermodynamically non-equilibrium interactions and processes in thermal machines PhD Thesis University Politehnica of Bucharest Romania
[7] 1991 New Sources of Energy (Helsinki: Helsinki University of Technology)
[8] Petrescu S et al 2006 Advanced Energy Conversion – Vol I – II (Lewisburg: Bucknell University
[9] Petrescu S, Costea M, et al 2011 Development of Thermodynamics with Finite Speed and Direct Method (Bucharest: AGIR Publishing House)
[10] Petrescu S et al 2015 Advanced Thermodynamics of Irreversible Processes with Finite Speed and Finite Dimensions, (Bucharest: AGIR Publishing House)
[11] Petrescu S et al 1993 A Comparison between Optimization of Thermal Machines and Fuel Cells based on New Expression of the First Law of Thermodynamics for Processes with Finite Speed Proc 1st Int. Thermal Energy Congress ITEC’93 (Marrakech)
[12] Petrescu S et al 2002 Application of the Direct Method to Irreversible Stirling Cycles with Finite Speed Int. J. Energy Research 26 589-609
[13] Petrescu S et al 2013 Effect of irreversibilities estimated with the direct method on the Stirling engine performance, Proc. Rom. Acad. Tech. Sci Conf. Brașov (Bucharest: AGIR Publishing House)
[14] Petrescu S et al 2014 Means for Qualitative and Quantitative Description of the Cardio-Pulmonary System Operation within Irreversible Thermodynamics with Finite Speed Proc. Rom. Acad. Tech. Sci Conf. Brașov (Bucharest: AGIR Publishing House)
[15] Petrescu S et al 2014 Discovery of Quantum Numbers in the Cardio-Pulmonary Interaction Studied in Thermodynamics with Finite Speed Proc. Rom. Acad. Tech. Sci Conf. Brașov (Bucharest: AGIR Publishing House)
[16] Petrescu S et al 2015 From Thermodynamics with Finite Speed towards Biological Quantum Thermodynamics with Finite Speed Proc. Nat. Conf. on Thermodynamics NACOT’15 Iasi
[17] Petrescu S et al 2015 Stationary Quantum States in Cardio-Pulmonary System, Proc. Rom. Acad. Tech. Sci Conf. Galati
[18] Petrescu S et al 2015 Processes with Quantum Jumps in the Cardio-Pulmonary System Proc. Rom. Acad. Tech. Sci Conf. Galati
[19] Petrescu S et al 2016 Diagrams Describing Stationary States and Processes in Cardio- Pulmonary System Proc. Rom. Acad. Tech. Sci Conf. Targu-Mures
[20] Petrescu S et al 2016 Complete Circadian Cycle of Cardio-Pulmonary System Studied in Quantum Biological Thermodynamics with Finite Speed, Proc. Rom. Acad. Tech. Sci Conf. Targu-Mures
[21] Petrescu S et al 2016 Quantum Biological Thermodynamics with Finite Speed of the cardio-respiratory system as a new extension of Thermodynamics with Finite Speed Proc. Francophone Coll. on Energy and Thermodynamics COFRET 2016 Bucharest

[22] Petrescu S et al 2016 How different we are in terms of Heart-Lung interaction: discovery and description in Quantum Biological Thermodynamics with Finite Speed Proc. Francophone Coll. on Energy and Thermodynamics COFRET 2016 Bucharest

[23] Petrescu S et al 2018 What is quantum biological thermodynamics with finite speed of the cardio-pulmonary system: a discovery or an invention Proc. Romanian Acad. Series A – Math. Physics Tech. Sci. Information Science. 19 249-254

[24] Borcila B et al 2018 Effect of flue on Stationary States and Processes in the Cardio-Pulmonary System described in Quantum Biological Thermodynamics with Finite Speed IOP Conference Series: Materials Science and Engineering. 444(8) 082023

[25] Chan H L et al 2007 Correlates of the shift in heart rate variability with postures and walking by time–frequency analysis Computer Methods and Programs in Biomedicine. 86(2) 124-130

[26] Wesfreid E and Billat V 2012 Randomness and changes of heart rate and respiratory frequency during high altitude mountain ascent without acclimatization Physica A: Statistical Mechanics and its Applications. 391(4) 1575-1590

[27] Tsai N C and Lee R M 2011 Interaction between cardiovascular system and respiration Appl. Mathem. Modelling 35 5460–5469

[28] Haken H 1983 Advanced Synergetics, Instability Hierarchies of Self-Organizing Systems and Devices (Berlin Heidelberg New York Tokyo: Springer Verlag)