Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System

I- Fundamental concepts, equations and diagrams

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The paper presents the Fundamental Concepts, Equations and Diagrams in a new domain which is the extension of Thermodynamics with Finite Speed (TFS), invented and called by us: Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System (QBTFSCPS). The new concepts are: Stationary States, parameters of Stationary States, Processes between Stationary States with or without Quantum Jump, Non-Stationary States. Essential parameters of the Stationary States are: Frequency of Heart Oscillations F_H, Frequency of Lungs Oscillations F_L and Quantum Number N - which characterize the Synergetic (ordered) Interaction between Heart and Lungs, in a Stationary State. We present also a Fundamental Equation discovered by us, based on experimental data, which describes any Stationary States and 4 Equations of the Processes between these States in the Cardio-Pulmonary System. Based on these new concepts and new equations we invented 6 Diagrams which describe graphically in synoptic images the Stationary States and Processes between them with or $_W$ithout Quantum Jump, between Quantum levels represented by the Quantum Number N (an integer number = 0, 1, 2, 3, 4, 5, 6, … etc.).

Keywords: Stationary States, Non-stationary States, Processes with Quantum Jump, Quantum Number in Cardio-Pulmonary Synergetic Interaction, Diagrams describing Processes in the Cardio-Pulmonary System

Thermodynamics with Finite Speed (TFS) and the *Direct Method* were invented by S. Petrescu and L. Stoicescu in the years 1964-1969 in their Seminal Papers [1-5], and in Stoian Petrescu PhD-Thesis, [6] advised by Prof. Lazar Stoicescu. After 1990, the *Thermodynamics with Finite Speed* and the *Direct Method* were further *developed* [7-13] and then *validated* for the most difficult Engines to model (in order to compute Efficiency, and Power), namely for 15 Stirling Engines (the most performant in the world: USA, Germany, Japan, Sweden, Holland, New Zeeland) [9, 12, 13]. This validation of TFS has attracted the interest of researchers in *Irreversible Thermodynamics* applied to Thermal Machines has become a very powerful concern because using the *Direct Method* from TFS we can now optimize the thermal machines at the design stage, much better in comparison with other methods. After the serious criticism of Thermodynamics in Finite Time by American Professors Gyftopulous and Moran [14, 15], in the last 10-15 years, the expressions, *Thermodynamics with Finite Speed and Direct Method,* became key words in very many papers regarding optimization of the Thermal Machines, all over the world [9-13]. In the last 5 years, we extended *Thermodynamics with Finite Speed* (TFS) from Thermal Machines to one of the most important Biological System in humans, namely for the *Cardio-Pulmonary System* and developed *a new branch of Irreversible Thermodynamics* called by us: *Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System.* (QBTFSCPS) [16-26]. We did take the courage to try this extension of TFS to a new and unexpected domain (a Biological System) only after *our Extension of TFS to Fuel Cells* [11] in 1993, and after *Validation of TFS for 12 Stirling Engines* [12], in 2002. Only based on these two achievements of TFS we considered to be prepared for the new extension of TFS to a Biological System (the Cardio-Pulmonary System). Our confidence that we will succeed in this courageous process of knowledge is based on the remark that there is a similarity between the functioning of the Cardio-Pulmonary System and Stirling Machines, and also on the findings that the muscles are similar to fuel cells with moving electrodes (the fibers of the muscles).

A recent paper [25] proposed the question: *What is Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System (QBTFSCPS):* An Invention or a Discovery? At the end of that paper we concluded that QBTFSCPS is both, namely: an *Invention (a Scientific Construction)* based on *an extremely interesting formula Discovered experimentally.* In order to do thousands of *experiments* with more than 180 people (children, adults, old man and women) we defined what we called *Stationary States* of the Cardio-Pulmonary System, when both *Frequencies, F_H-Frequency of the Heart* (pulse), and *F_L-Frequency of normal* (not controlled like in Yoga*) respiration process in the Lungs*, they remain constant for a few minutes or tens of minutes (as in the sleep process) if the person does not move, work or is at rest in 3 positions (horizontally in bed, sitting or standing upright). We have chosen these two *parameters of Stationary States* (F_H and F_L), as *fundamental concepts* in order to characterize the functioning (in a healthy person) of the Cardio - Pulmonary System. Before doing these measurements we believed that a *nice and simple formula* will be determined which would correlate the two properties of *all Stationary States* in a day, measured from time to time (for example every hour).

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The result was a catastrophe from the point of view of our initial expectations. It seems that the points in F_H-F_L diagrams were placed completely randomly, without any chance to draw a curve between these points. After very many (thousands) such measurements we invented *an extremely simple formula*, (but by no means what we expected: a line, a parabola, a hyperbola, a polynomial function, a logarithmic function, etc…) but a *Quantized Formula:*

$$R_f = F_H / F_L = (2 + N/4) \quad (1)$$

where: R_f is the state parameter that characterizes the Stationary State of the interaction between the two subsystems, the Heart and the Lungs; ***N*** is an integer for healthy people and not an integer for people with any Heart problems: (atrial fibrillation, ventricular fibrillation, arrhythmia, fluttering etc.). Studying the *Stationary States* and *Processes between these States* we discovered 4 types of processes which can be described quantitatively using formula (1) in a similar way like the *equation of state* from Classical Reversible Thermodynamics:

$$(P \cdot v)/T = R \quad (2)$$

where: Pressure - P, Specific volume - v and Temperature T are the (classical) parameters of State of a System in *Thermodynamic Equilibrium* (for example a gas in a cylinder of a Thermal Machine, when the piston is stationary). This means that the two Biological Machines (the heart and the lungs), as long as the person is alive are in a state of *Thermodynamic Equilibrium*. Because of that the *Classical Thermodynamics does not apply to such systems*, and it was necessary to invent an *Irreversible Thermodynamic* where *speeds of the two processes* (in the Heart and in the Lungs) are *two essential parameters of the Stationary States,* which affect fundamentally the performances of these two Bio - Thermal Machines (Efficiency and Power).

Because of that we started to build QBTFSCPS considering the two Frequencies of oscillations of the two Biological Machines - Heart and Lungs, in a continuous mechanical and hydraulic contact through the flowing the blood between them. Because of the similarity between the two formulas (1) and (2) we build/constructed/ invented *a new branch of Irreversible Thermodynamics,* like an *extension of Thermodynamics with Finite Speed to the Cardio-Pulmonary Systems* [18] called by us: *Quantum Biological Thermodynamics with Finite Speed of the Cardio-Pulmonary System* (QBTFSCPS) [16-19].

Using this formula (1) *we invented 6 diagrams* which describe all the *Stationary States* and *Processes between them* in a day measured based on several *experimental protocols invented by us* (for example measuring each hour, or measuring each time when a person is changing the position and activity). Using these diagrams we discovered *4 Fundamental processes between Stationary States* with or without Quantum Jump. Using these diagrams and the formula (1) we discovered the equations which describe these Processes, in a similar way like the Processes from Thermal Machines: isometric (v=ct.), isobaric (P=ct.) isothermal (T=ct.) and polytropic (when all parameters are variable). In QBTFSCPS we discovered and written the equations for 4 similar processes from Classical Reversible Thermodynamics, namely: *Iso - Heart Frequency* (Iso - pulse) when F_H = ct.; *Iso- Lungs Frequency* when F_L=ct.; *Iso - Quantum Number –N,* when N is constant.

Experimental part

Equations Describing Processes between Stationary States with or without Quantum Jump in the Cardio-Pulmonary System

Equation (1) can be written as follows:

$$F_H = F_L \cdot (2 + N/4) \quad (3)$$

It can be applied to two successive Stationary States, 1 and 2:

$$F_{H,1} = F_{L,1} \cdot (2 + N_1/4) \quad (4)$$

$$F_{H,2} = F_{L,2} \cdot (2 + N_2/4) \quad (5)$$

Similar with the equation of State of perfect gases written for two successive Equilibrium States:

$$P_1 \cdot v_1 = R \cdot T_1 \quad (6)$$

$$P_2 \cdot v_2 = R \cdot T_2 \quad (7)$$

The three equations of *reversible processes* from Classical Reversible Thermodynamics (CRT), are obtained dividing member by member Equations (6) and (7) and imposing also the condition that one of the *state parameters* (P, v, T) remains constant during the respective process. For example:

$$P_1/P_2 = T_1/T_2 \quad (8)$$

if: $v_1 = v_2$, isometric process;

$$v_1/v_2 = T_1/T_2, \quad (9)$$

if: $P_1 = P_2$, isobaric process;

$$P_1 \cdot v_1 = P_2 \cdot v_2, \quad (10)$$

if: $T_1 = T_2$, isothermal process.

In a similar way, from eqs. (4) and (5), we obtained the 3 equations of the processes between Stationary States in the human Cardio-Pulmonary System. Namely, for each one of the *parameter of Stationary State* (F_H, F_L, N) remaining constant during a Process of transition from a Stationary State 1 to a Stationary State 2 we get the following 3 equations:

$$\frac{F_{L,2}}{F_{L,1}} = \frac{8+N_1}{8+N_2}, \text{ at } F_H = \text{constant}, \quad (11)$$

we called this an *Iso-Pulse Process*

$$\frac{F_{H,2}}{F_{H,1}} = \frac{8+N_2}{8+N_1}, \text{ at } F_L = \text{constant}, \quad (12)$$

we called this an *Iso-Respiration Process*

$$\frac{F_{H,2}}{F_{H,1}} = \frac{F_{L,2}}{F_{L,1}}, \text{ at } N = \text{constant}, \quad (13)$$

we called this *an Iso-Quantum Number Process.*

In the Cardio-Pulmonary System does not exist a Process called *adiabatic*, because the System changes continuously heat with surrounding, as long as the person is alive. If we would isolate adiabatically a person the temperature will increase at a level when the person will die. The human body exchanges heat with surroundings continuously through the skin and trough the respiration process. We cannot stop the respiration process, neither the heat transfer through the skin. For these reasons an Adiabatic Process is impossible for a person alive. For another process which we called *Polytropic Process*, for which the heat transfer is not zero, and neither one of the 3 parameters of Stationary State remain constant we cannot obtain the equation of such a process, just using the

equation of Stationary States (1) but we have to introduce a *polytropic parameter*, similar with *polytropic exponent* in the equation of Polytropic Processes from Classical Reversible Thermodynamics. By definition this *polytropic parameter* is the ration between change of the *Quantum Number* between the two States (initial and final) $\Delta N = N_2 - N_1$) and the change of the Frequency of the Lungs $\Delta F_{L,} = F_{L,2} - F_{L,1}$, in a N-F_L diagram.

$$\mu = \frac{\Delta N}{\Delta F_L} \tag{14}$$

Starting from experimental measurements of F_H and F_L, and representing the Stationary States and Processes between them we invented 6 Diagrams. In these Diagrams we can identify all the *Polytrophic Processes* and compute the *polytrophic parameter (slope of the process)* μ with the formula (14). These Processes correspond to different *actions* i.e., *position change, eating, moving, doing gymnastics, running, working (physical or intellectual)*. For each such actions we take will correspond a certain *Polytrophic Process*, between two Stationary States (one in the situation before action and second state after that action). Essential is to do the measurement before the next action, and finally at several minutes after the action in order to obtain *Stationary States*. Otherwise either the *Heart Frequency* (pulse) F_H or the *Lungs Frequency* F_L will vary in time of the measurement. For persons with some *Heart problems* (ill) the Stationary States cannot be achieved or they do not respect the formula (1). The Equation for a *Polytrophic Process* between two *Stationary States* is expressed as:

$$F_{H2} = F_{L2} \cdot \left(2 + \frac{N_1}{4} + \mu \frac{F_{L2} - F_{L1}}{4} \right) \tag{15}$$

The Power consumption and Efficiency of such Processes may be calculated by relations similar to those used for the Polytrophic Process in the Classical Reversible Thermodynamics. Using equation (15) the *Power of the Heart* results as function only of F_L, similarly to the computations of the cycles in Thermal Machines. One can compute the daily Total Energy Consumption of the Heart – Lungs System and comparing the values for different days, depending of *action's* type that person did in that day (eating, walking, working, dancing, sport, etc.) [17, 18].

The new Pv/Px Diagram from Quantum Biological Thermodynamics with Finite Speed, improved version

The new *Pv/Px* diagram (fig. 1) invented within the QBTFS and used for explaining and calculating the Cardio-Pulmonary System performances was developed by revealing in more detail the sections that characterize Heart and Lungs specific functions and parameters.

The *Pv/Px* diagram presents schematically the large circulation (systemic) and small circulation (pulmonary). The large circulation realizes the circuit: the left ventricle $\longrightarrow$ arteries $\longrightarrow$ arterioles $\longrightarrow$ capillaries $\longrightarrow$ venules $\longrightarrow$ veins $\longrightarrow$ the right atrium, and the small circulation: the right ventricle $\longrightarrow$ the pulmonary artery $\longrightarrow$ Lungs $\longrightarrow$ the pulmonary veins the left atrium, where the oxygenated blood passes into the left ventricle and the circuit is resumed [27]. Also, the main functional parameters are highlighted in the diagram: volume changes of the four Heart compartments, ventricular and auricular pressures, pressure drops in the Heart valves (mitral and aortic, respectively tricuspid and pulmonary), heat exchange in the body due to circulation of the blood. At the same time, the diagram includes data on Lungs functions and gases exchange in Lungs alveoli membranes, including volume variations and pressure drops during breathing. Taking into consideration the presented aspects, the new *Pv/Px* diagram developed within QBTFS, results its special utility for the calculation of performance parameters (Mechanical Work and Power) of the Cardio-Pulmonary System based on the Direct Method from the Thermodynamics with Finite Speed.

Results and discussions

Intuitive explanation of the ordered correlation between the Frequency of Heart and Frequency of Lungs Oscillation

In the figure 2. we show on the top only one oscillation of the Lungs for different variation of the volume from V_{min} to V_{max} and back to V_{min} for different situations, corresponding to R_f = integers: 2, 3, 4, 5, 6 and for R_f = not

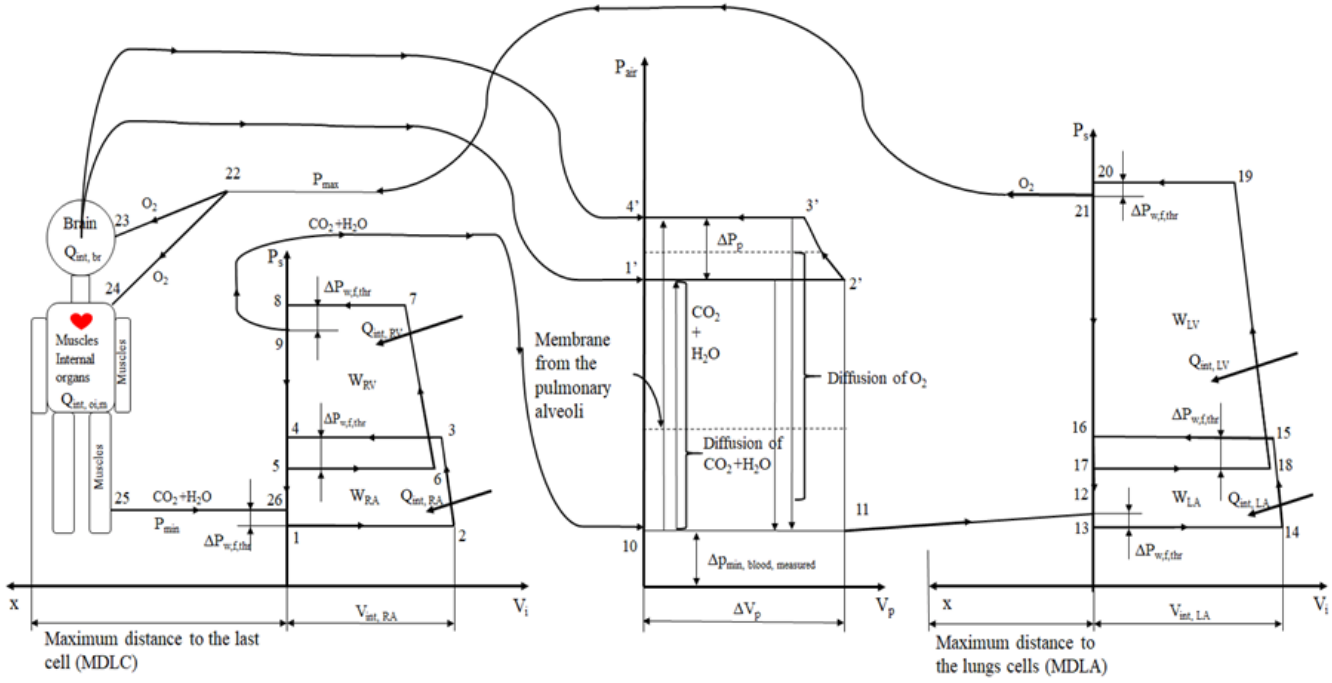

Fig. 1. The new *Pv/Px* Diagram developed for the Cardio-Pulmonary System

integer numbers: 3.25; 3.5; 3.75; 4.5. On the bottom there are many oscillations of the Heart corresponding to only one oscillation of the Lungs (for each case).

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 ($P_{e,L}/P_{e,H}$) will correspond to integer numbers of $R_f = F_H/F_L$. In the cases when for one oscillation of the Lungs does not correspond an integer number of oscillations of the Heart the ratio R_f will be not an integer, but a number as following: 3.25; 3.5; 3.75; 4.5.

The explanation of these not-integer numbers but increasing with 0.25 correspond to the fact that *a complete oscillation of the Lungs* correspond (for these cases) to not complete oscillations, but to *a fraction of the last oscillation* which can be 1/4=0.25; 2/4=0.5; 3/4=0.75 from the *Period* $P_{e,H}$ of one oscillation of the Heart.

In figure 3, the explanation for integer and not integer values of R_f are similar, but in this cases all the oscillations of the Lungs take place between the same volumes V_{min} and V_{max}. This situation corresponds to a respiration with the same change of volume but with different *Periods* or different *Frequencies*. This situation is different in comparison with figure 2, where the change of the volume of the Lungs in time of one oscillation varies and increasing at the same time with the value of R_f.

Figure 4 is similar with the case from figure 3 with respect to change of *Volume* of the Lungs in time of each oscillation being the same, for all rations R_f.

The difference between these figures is the fact that in figure 4. we represent several oscillations of the Lungs with different *Periods* $P_{e,L}$ in order to show that for each *Period* (time duration) of the Lungs oscillation corresponds exactly *the same integer number of Heart oscillations* (2; 3; 4 respectively).

The 6 Diagrams describing Stationary States and the Processes with or without Quantum Jump

We present here:

Symptomatology on a 72h period, of a person (78 years old-SP) who was ill with flu, (in the time of experimental measurements) based on the 6 Diagrams invented within the *Quantum Biological Thermodynamics of the Cardio-Pulmonary System.* These diagrams, in which *Stationary States* and *Processes* between them are represented, with or without *Quantum Jump,* illustrate variations of Heart (F_H) and Lungs (F_L) Frequencies, of the rate $R_f = F_H/F_L$, of the *percentage of oxygen* in the blood and of the *Quantum Number N* corresponding to each *Stationary State*. The analysis of the 6 diagrams provides interesting conclusions that reveals the *serious consequences of this disease* on the Cardio-Pulmonary System of the person concerned, in comparison with his *normal health condition*.

These diagrams, in which *Stationary States* and *Processes* with or without *Quantum Jump between them* are represented, illustrate variations of Heart (F_H) and Lungs (F_L) Frequencies, with the rate, $R_f = F_H/F_L = (2+N/4)$, where N is an integer, called by us the *Quantum Number* of the respective *Stationary State*.

In the figure 5-7 we present the 40 successive *Stationary States* (from 0 to 39) and corresponding Processes between them (with or without jump between *Quantum Numbers N levels*), for a person 78 years old with flu (SP-Stoian Petrescu).In all figure 5-7 we observe a very strong

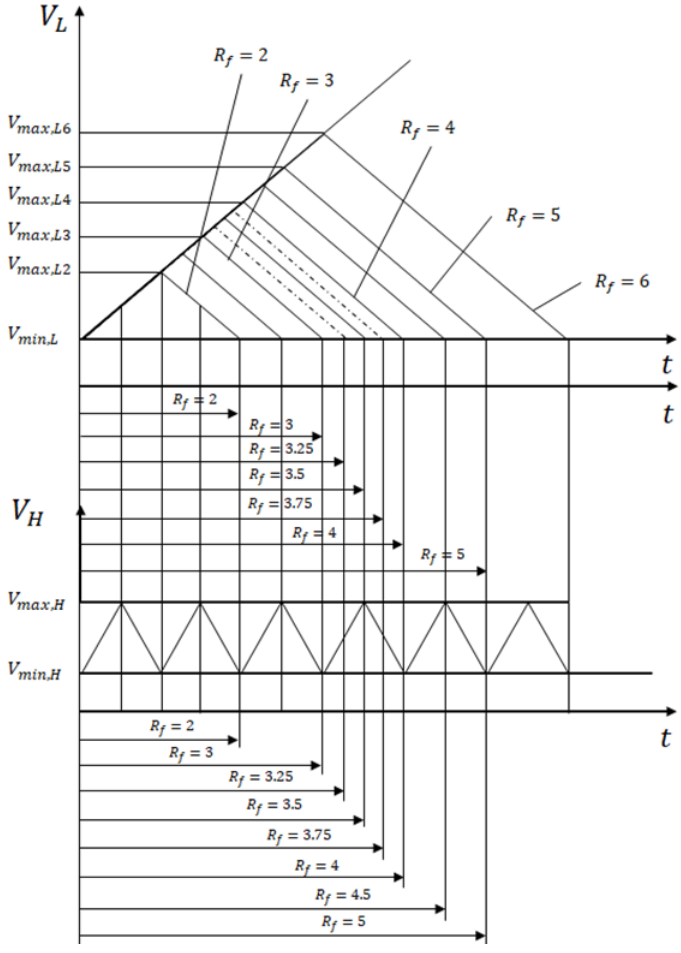

Fig. 2. Intuitive explanation of the ordered correlations between oscillations of Heart and Lungs for processes with R_f= integer number: 2, 3, 4, 5, 6 and R_f= not integer number: 3.25; 3.5; 3.75; 4.5.

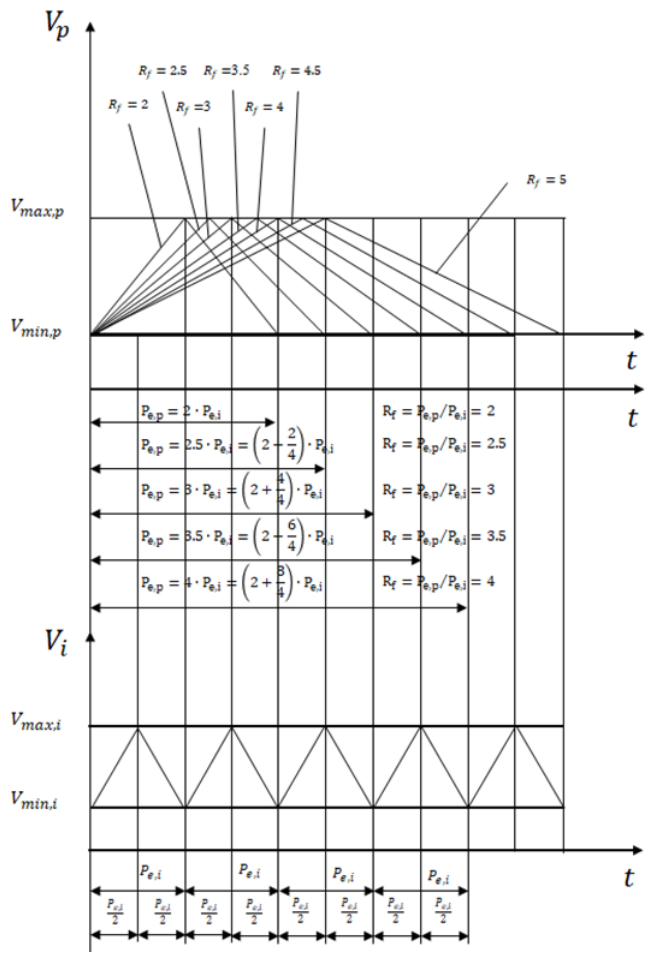

Fig. 3. Intuitive explanation of the ordered correlations between oscillations of Heart and Lungs for processes with R_f= integer number: 2, 3, 4, 5, and R_f= not integer number: 2.5; 3.5; 4.5.

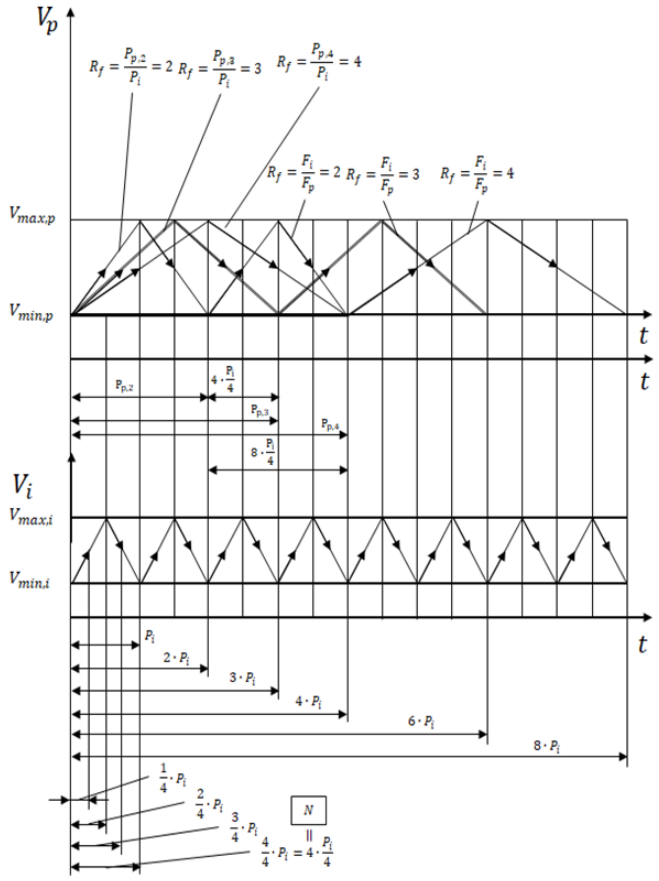

Fig. 4. Intuitive explanation of the ordered correlations between oscillations of Heart and Lungs for processes with R_i= integer number: 2, 3, 4.

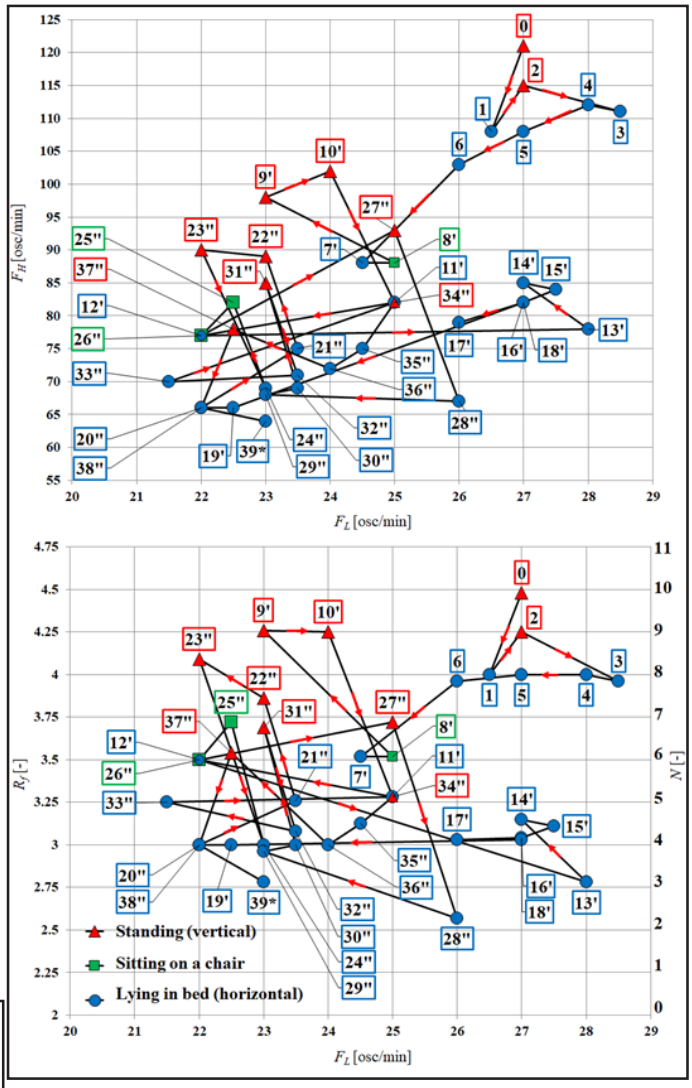

Fig. 5. Diagrams F_H = f(F_L) and R_f, N = f(F_L), with the effects of the flu. (for SP)

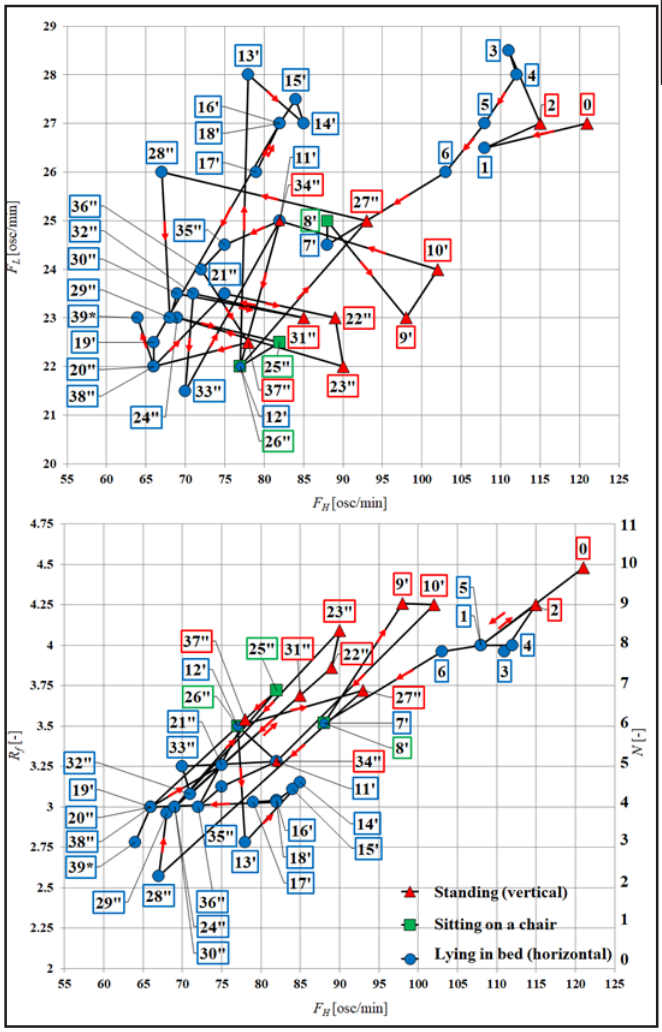

Fig. 6. Diagrams F_L =f(F_H) and R_f, N = f(F_H), with the effects of the flu. (for SP)

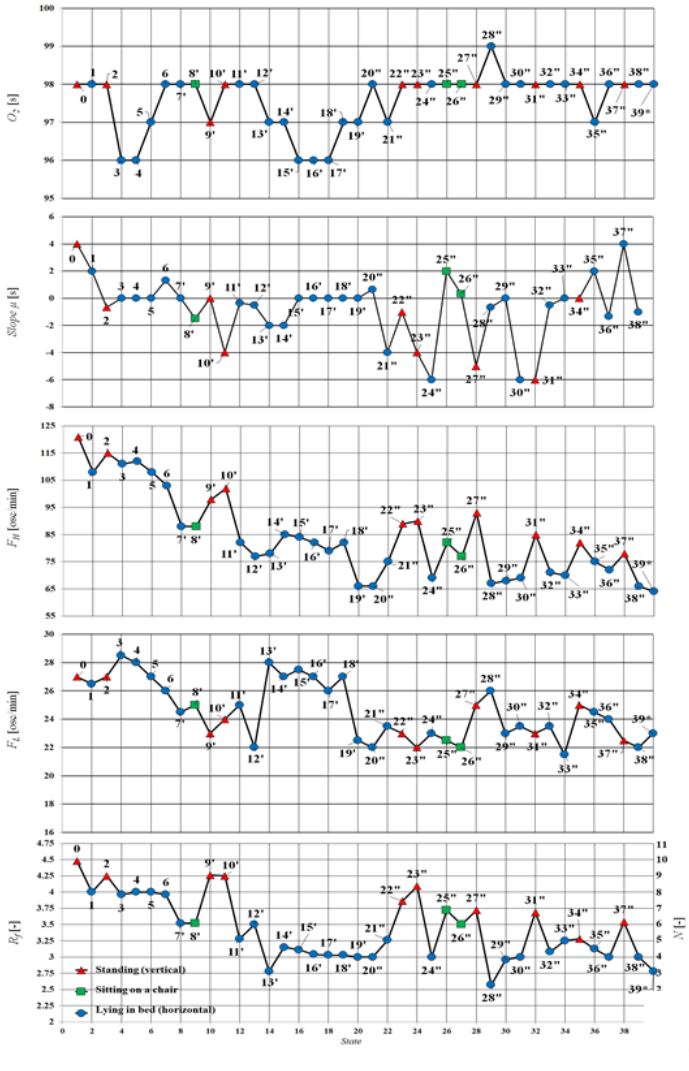

Fig. 7. Diagrams O_2 = f (Number of the state); F_H = f (Number of the state); F_L = f (Number of the state); Slope μ = f(Number of the state) and R_f, N = f(Number of the state), with the effects of the flu. (for SP)

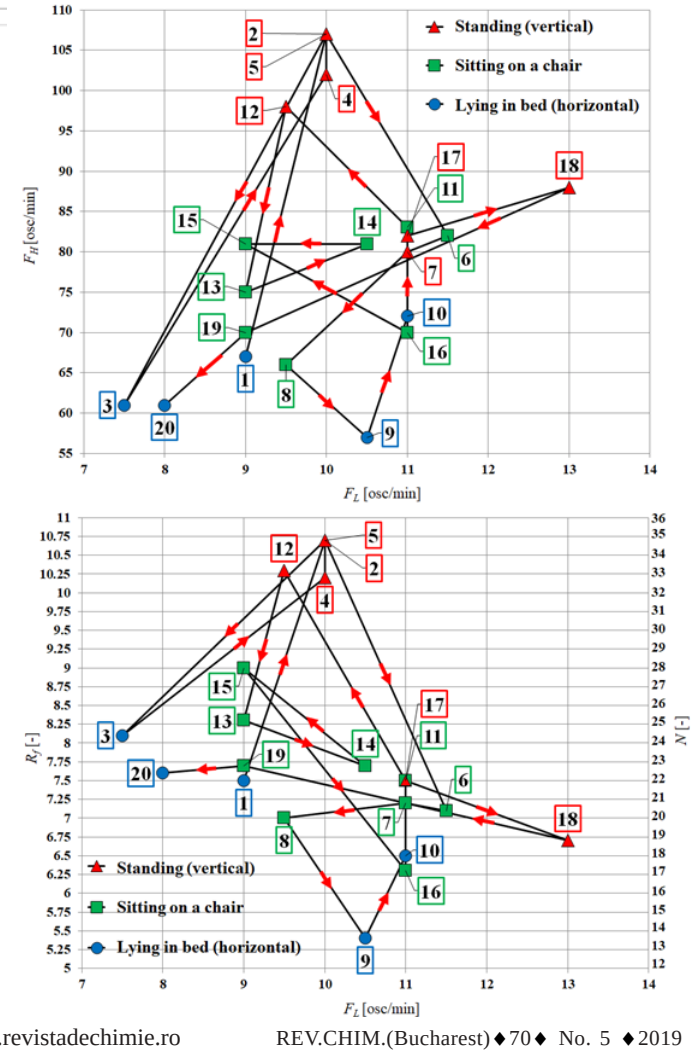

Fig. 8. Diagrams F_H = f(F_L) and R_f, N = f(F_L), for healthy state. (for BB)

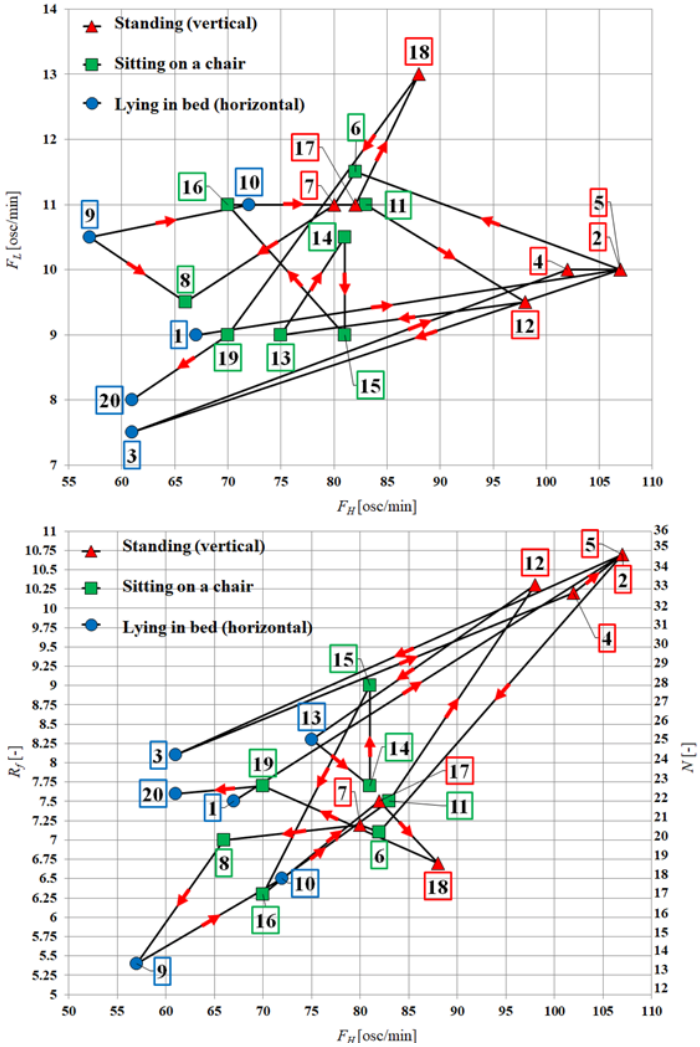

Fig. 9. Diagrams F_L =f(F_H) and R_f, N = f(F_H), for healthy state. (For BB)

and negative effect of the flu on the person. The successive states 0-6 are in the domain of very high values of F_H and F_L, situation in which the person does not feel well and have fever. After taking some medicine the situation is improved step by step (the states: 20", 21"… 39*) and the main parameters of the Cardio Pulmonary System F_H and F_L drop down to normal values. In figure 7., very interesting correlations are presented between changes in blood O_2 percentage, Heart rate F_H, pulmonary Frequency F_L, ratio of R_f and N Frequencies as Cardio-Pulmonary System's state number functions (0, 1, 2, 3 , 4, ... 39) during elementary processes without physical effort. The analysis of figure 7., reveals the tendency of decreasing the Heart / Lungs Frequencies and increasing the percentage of Oxygen in the blood, which shows in a good correlation between the two *machines*, the blood pump - the Heart and the air compressor - the whole of the two Lungs together with the return to a good state of health.

Similar figure 8-10 are for a young healthy person (BB-Bogdan Borcila). The values of the state fundamental parameters, F_H, F_L and of the percentage of O_2 in the blood tissue measured by the person BB are within normal limits, corresponding to the different elementary and complex Processes unfolded.

The diagrams analysis of figure 10. indicates that the BB person's Cardio-Pulmonary System works optimal given the good correlation of the status parameters F_H, F_L, R_f and N, as well as the constant maintenance of the O_2 percentage of blood tissue, which ensures the normal deployment of the vital processes in the body.

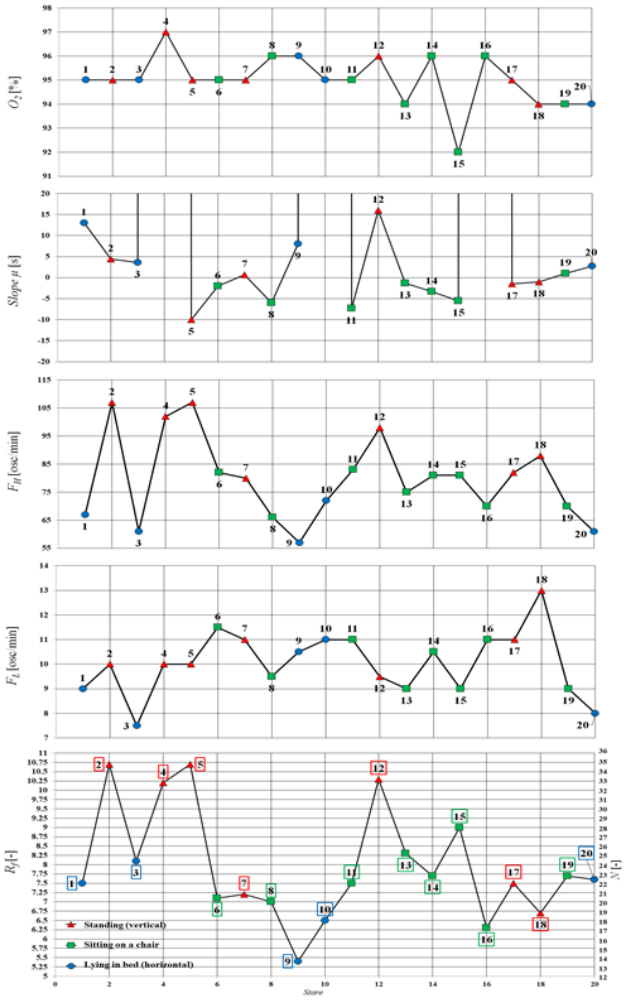

Fig. 10. Diagrams O_2 = f (Number of the state); F_H = f (Number of the state); F_L = f (Number of the state); Slope μ = f (Number of the state) and R_f, N = f (Number of the state), for healthy state. (for BB)

Conclusions

Using the 6 diagrams invented in QBTFS, presented above either in the normal health situation or in the illness one provides very important information regarding the functioning of the Cardio-Pulmonary System. This information could be very useful when such a person needs either a Pacemaker or even an artificial Heart. The two devices can now be designed on a personalized bases using such diagrams obtained by any person in healthy state. The pacemaker must be adjusted corresponding to the domain of Heart and Lungs Frequencies and the correlations between them through R_f and the Quantum Number N. In previous papers [21-26] we have presented similar Diagrams for many persons showing how different we are from the point of view of Heart-Lungs Interaction, which is a very strong indication that personalized pacemakers and personalized artificial Hearts must be designed in the future, based on such *Personalized Diagrams*, obtained by each person before he or she get ill.

References

1. STOICESCU, L., PETRESCU, S., The First Law of Thermodynamics for Processes with Finite Speed, in Closed Systems, Buletin I.P.B., Bucharest, Romania, **vol. 26**, no. 5, 1964, p. 87-108.
2. STOICESCU, L., PETRESCU, S., Thermodynamic Processes Developing with Constant Finite Speed, Bulletin I.P.B., Bucharest, Romania, **vol. 26**, no. 6, 1964, p. 79-119.

3. STOICESCU, L., PETRESCU, S., Thermodynamic Processes with Variable Finite Speed, Buletin I.P.B., Bucharest, Romania, **vol. 27**, no. 1, 1965, p. 65-96.
4. STOICESCU, L., PETRESCU, S., Thermodynamic Cycles with Finite Speed, Buletin I.P.B., Bucharest, Romania, vol. 27, no. 2, 1965, p. 82-95.
5. STOICESCU, L., PETRESCU, S., The Experimental Verification of The New Expression of the First Law for Thermodynamic Processes with Finite Speed, Bul. I.P.B., Bucharest, **vol. 27**, no. 2, 1965, p. 97-106.
6. PETRESCU, S., Contribution to the study of thermodynamically non-equilibrium interactions and processes in thermal machines, Ph.D. Thesis (Adviser: Prof. L. Stoicescu), I.P.B., Bucharest, Romania, 1969.
7. PETRESCU, S., New Sources of Energy, Helsinki University of Technology, Finland, 1991.
8. PETRESCU, S., ZAISER, J., HARMAN, C., PETRESCU, V., COSTEA, M., FLOREA, T., PETRE, C., FLOREA, T.V., FLOREA, E., Advanced Energy Conversion – Vol. I - II, Bucknell University, Lewisburg, PA, USA, 2006.
9. PETRESCU, S., COSTEA, M., et al., Development of Thermodynamics with Finite Speed and Direct Method, Bucharest, Romania. AGIR, 2011.
10. PETRESCU, S., COSTEA, M., FEIDT, M., GANEA, I., BORIARU, N., Advanced Thermodynamics of Irreversible Processes with Finite Speed and Finite Dimensions, Bucharest, Romania, AGIR, 2015.
11. PETRESCU, S., PETRESCU, V., STANESCU, G., COSTEA, M., 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, First International Thermal Energy Congress, ITEC - 93, Marrakech, Morocco, 1993.
12. PETRESCU, S., COSTEA, M., HARMAN, C., FLOREA, T., Application of the Direct Method to Irreversible Stirling Cycles with Finite Speed, International Journal of Energy Research **vol. 26**, USA, 2002, p. 589-609.
13. PETRESCU, S., COSTEA, M., BORCILA, B., FEIDT, M., Effect of irreversibilities estimated with the direct method on the Stirling engine performance, Conferina Zilele ASTR, Brasov-2013
14. GYFTOPULOUS, E. P., Fundamentals of analysis of processes, Energy Conversion & Management, **vol. 38**, 1997, p.1525-1533.
15. MORAN, M.J., A Critique of Finite time Thermodynamics, ECOS' 98, Nancy, France, Ed. by A. Bejan, M. Feidt, M.J. Moran and G. Tsatsaronis, Nancy, France, 1998, p. 1147-1150.
16. PETRESCU, S., COSTEA, M., TIMOFAN, L., PETRESCU, V., Means for Qualitative and Quantitative Description of the Cardio-Pulmonary System Operation within Irreversible Thermodynamics with Finite Speed, Proceedings of ASTR Conference, Sibiu, Romania, 2014.
17. PETRESCU, S., PETRESCU, V., COSTEA, M., TIMOFAN, L., DANES, S., BOTEZ, G., Discovery of Quantum Numbers In the Cardio-Pulmonary Interaction Studied in Thermodynamics with Finite Speed, Proceedings of ASTR Conference, Sibiu, Romania, 2014.
18. PETRESCU, S., COSTEA, M., PETRESCU, A.S., PETRESCU, V., From Thermodynamics with Finite Speed towards Biological Quantum Thermodynamics with Finite Speed, Proceedings of the National Conference of Thermodynamics NACOT'15, Iasi, Romania, 2015.
19. PETRESCU, S., COSTEA, M., PETRESCU, V., BOLOHAN, R., BORIARU, N., PETRESCU, A.S., BORCILA, B., Stationary Quantum States in Cardio-Pulmonary System, ASTR Conference, Galati, Romania, 2015.
20. PETRESCU, S., COSTEA, M., PETRESCU, A.S., PETRESCU, V., BORIARU, N., BOLOHAN, R., BORCILA, B., Processes with Quantum Jumps in the Cardio-Pulmonary System, ASTR Conference, Galati, 2015.
21. PETRESCU, S., BOLOHAN, R., PETRESCU, V., BORCILA, B., COSTEA. M., Diagrams Describing Stationary States and Processes in Cardio-Pulmonary System, ASTR Conference, Targu-Mures, 2016.
22. PETRESCU, S., PETRESCU, V., BOLOHAN, R., COSTEA, M., BORCILA, B., Complete Circadian Cycle of Cardio-Pulmonary System Studied in Quantum Biological Thermodynamics with Finite Speed, ASTR Conference, Targu-Mures, 2016.
23. PETRESCU, S., PETRESCU, V., BOLOHAN, R., BORCILA, B., COSTEA, M., Quantum Biological Thermodynamics with Finite Speed of the cardio-respiratory system as a new extension of Thermodynamics with Finite Speed, COFRET 2016 June 29-30, Proceedings of COFRET'16, Bucharest, Romania, 2016.
24. PETRESCU, S., PETRESCU, V., BOLOHAN, R., BORCILA, B., COSTEA, M., DANES, S., FEIDT, M., BOTEZ, G., HUMINIC, G., HUMINIC, A., BORIARU, N., POPESCU, G., MANITIU, N., DUMITRASCU, N., PANAITE, E., LOZONSCHI, T., GHEORGHIAN, A., How different we are in terms of Heart-Lung interaction: discovery and description in Quantum Biological Thermodynamics with Finite Speed, COFRET 2016 June 29-30, Proceedings of COFRET'16, Bucharest, Romania, 2016.
25. PETRESCU, S., BORCILA, B., PETRESCU, V., COSTEA, M., BOLOHAN, R., et. al, What is quantum biological thermodynamics with finite speed of the cardio-pulmonary system: a discovery or an invention, Constructal Law & Second Law, Conference, Romanian Academy, Bucharest, 2017.
26. BORCILA, B., PETRESCU, S., COSTEA, M., BOLOHAN, R., PETRESCU, V. and BOTEZ, G. - Effect of flue on Stationary States and Processes in the Cardio-Pulmonary System described in Quantum Biological Thermodynamics with Finite Speed -, The 8 th International Conference On Advanced Concepts In Mechanical Engineering, ACME 2018, June 7 - 8, Iasi, Romania, (ISI Journal).
27. ARTHUR, C., GUYTON, J., HALL, E., Textbook of Medical physiology, Twelfth edition, International edition: 978-0-8089-2400-5, 2011.

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