

THE STUDY OF THE PERIODICAL PHENOMENA *

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Abstract. A traditional teaching method, that physics teacher are using in our days, is the lecture method. This means that teachers transmit in a passive way the knowledge to the students and for this reason the pupils are not active participants to the lesson. In order to motivate the students and to determine them to assume an active participation to the physics lessons, modern educational tools are used. The aim of this study is to illustrate periodical phenomena presented in an interactive way. The periodical phenomena could be seen in everyday life and in many fields of activity. Such examples are: the moon phases, the seasons changing, the heart beats the alternation of the breathing phenomena. The characteristic of a periodical phenomenon is its periodicity and the fact that during the evolutionary course there is at least one physical quantity associated with the system that varies between a maximum value and a minimum one. From the periodical phenomena the gravitational oscillations of the pendulum and heart beats were chosen to be illustrated, using the COBRA 3 system of acquisition and data processing provided by PHYWE Company (Germany), two heart rate sensors, and an EKG sensor connected at NOVA LINK (Fourier Education-USA). Passing from the compulsory courses presented in the syllabus to the examples from the real life this could make physics more attractive, gathering the interest and the behavior of the students regarding the subject.

Key words: pendulum's oscillations, heart rate sensor, pulse wave, EKG sensor.

1. INTRODUCTION

Physics is the closest discipline to the real life, offering the possibility to scientifically study the processes in the surrounding world. Teaching physics is based more on theory and less on practical applications [1]. The study of physics involves the development of logical thinking and the acquisition of skills that are useful in disciplines such as chemistry, biology and medicine. The concepts of physics can be applied in the medical field, in understanding the functioning of

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certain instruments and devices such as the pacemaker, the defibrillator etc. [2]. Teachers should use those teaching strategies and those means of education which determine the student to see physics as a system of concepts that must be applied in practice [3]. The interactive whiteboard and the equipment provided with boards of acquisition and data processing are instruments that, when used during physics lessons, allow an interdisciplinary approach of different subjects. The present paper aims to study two periodic phenomena, namely the gravitational pendulum's oscillations using the COBRA 3 system of acquisition and data processing provided by PHYWE Company (Germany), and the heart beats using equipment NOVA LINK, Heart Rate / Pulse Sensor, Heart Rate (Exercise) Sensor and EKG Sensor (Fourier Education USA). By conducting the experiments mentioned above, the students had the possibility to represent the resulted data on a graph and to determine some characteristics of the signals, for example: the period, the frequency and the amplitude.

2. THE THEORETICAL FRAMEWORK

The periodic phenomenon is the phenomenon which identically reproduces itself at equal intervals of time. To a system that evolves in a periodic manner one can attach at least a physical quantity that varies periodically between a minimum and a maximum value. The variation in time of such a physical quantity is a periodic signal. The periodical signals are characterized by frequency, period and amplitude. The functioning of the human body is largely based on periodic phenomena such as heart beats, breathing phenomena etc. The study of these phenomena in medicine contributes to the establishment of a correct diagnosis. In this way, the study of the electrical signals recorded during an electrocardiogram, can identify abnormal heart rate known as arrhythmias. The biological phenomena are not strictly periodic. However, these phenomena could be considered periodic if the study duration is not too long.

2.1. THE OSCILLATIONS OF THE GRAVITATIONAL PENDULUM

The equation which describes the oscillatory motion of the gravitational pendulum, provided by the fact that the angular amplitude is small enough, it is given by the following equation [4]:

$$\frac{d^2\theta}{dt^2} + \frac{g}{l}\theta = 0, \quad (1)$$

where θ is the angular elongation, g is the gravitational acceleration and l is the wire's length. The solution of this equation is given by the relation (2):

$$\theta = \theta_0 \sin \sqrt{\frac{g}{l}} t. \quad (2)$$

This is the equation of harmonic oscillatory motion having the θ_0 amplitude. The pulsation is given by relation (3):

$$\omega_0 = \sqrt{\frac{g}{l}}. \quad (3)$$

2.2. THE HEART BEATS

The heart rate represents the number of cardiac cycles per minute or the number of heart beats per minute, being an important parameter for the cardiovascular system.

The structure of the heart consists of two pumps, each of them composed of one atria and one ventricle, one situated on the right side, that ensures the pulmonary circulation, and the other one located on the left side that ensures the systemic circulation. The mechanical activity of the heart implies the contraction of the myocardial cells, the opening and the closing of the valves and the blood flow to and from the heart's chambers.

Cardiac muscle is specialized for complex periodic electrical activity and repetitive contractions [5].

The efficient pumping of blood is realized only through the coordination of the two atria' and the ventricles' contractions [6]. The heart is an oscillator. The heart has a regular activity. One can talk about a cardiac cycle [7]. The cardiac cycle includes a systole and a diastole.

The systole is the active part of the cardiac cycle. During this stage, the arterial pressure is the highest and, in the same time, the blood from the ventricles is pumped in the aorta and in the pulmonary arteries. The diastole is the period when the heart relaxes. During the first stage of the diastole, the veins fill with blood the right and the left atria, while the two ventricles are relaxed. In the next stage, the cardiac muscle of the two atria contracts and pumps blood through the semilunar valves in the right and in the left ventricle at the same time [8]. For a healthy adult, the period of the cardiac cycle is 0.8 s. The pump function of the heart is performed by the electrical action of the heart muscle.

The electrical activity of the heart is controlled by a system of impulses generation and electrical conduction which includes: the sinoatrial node (SA), the atrioventricular node (AV), the atrioventricular septum and the Purkinje fibers and which assures the cardiac automatism. The SA node is located in the left atria's wall. Inside these structures there are electrical stimulating cells which generate the heart rate. These cells initialize spontaneously electrical impulses which are rapidly distributed to the other heart cells [8].

The sinoatrial node acts as an electronic multivibrator, releasing one electric pulse at every cardiac cycle [9]. The excitation signal is rapidly transmitted at the atrioventricular node which is located at the right atria's base. The AV node slows the transmission of the signal to the ventricle in order to assure the appropriate filling of the ventricles. This delay always allows the atria to contract before the ventricles so that when the ventricles contract the atria relax. The electrical signal is transmitted from the AV node to the AV septum which is located in the wall that separates the two ventricles. The AV septum splits into two branches, one for each ventricle. As these branches reach the top of the heart, they start to branch in structures called Purkinje fibers [9].

The electrocardiogram (EKG) is the graphical record of electrical impulses in the cardiac conduction system. The electrodes connected to the skin transmit the heart's electrical impulses, which are recorded as a continuous line [10]. Each heart beat generates a pattern, which is denoted by the letters P, QRS and T. A healthy heart produces a characteristic pattern of voltage changes. A typical electrocardiogram includes wave P, QRS complex and T wave. P wave represents the electrical impulse traveling across the atria. QRS complex represent the spread of the electrical impulse down the septum and around the ventricles in the Purkinje fibres. The T wave marks the end of the activity in the ventricles [10]. Figure 1 shows a normal EKG recording.

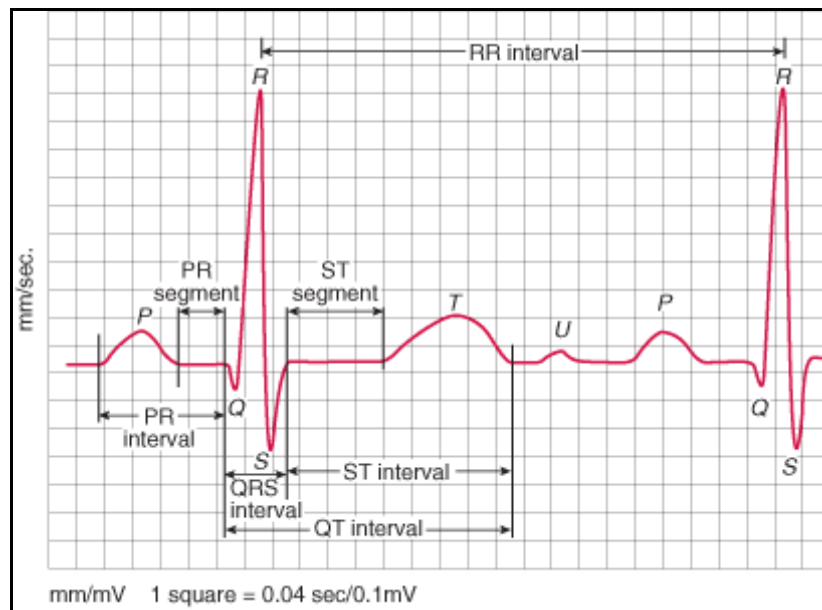


Fig. 1 – A normal EKG recording [11]. The colored versions could be accessed at <http://www.infim.ro/rfp/>.

Due to the action of pumping made by the heart, the blood enters in the arteries in jets or pulses [12]. The flow of the fluids in tubes with elastic walls allows the explanation of the flow regime of the blood in the circulatory system.

An increase in the pressure of a fluid that is in an elastic tube determines the expansion of the tube's walls. After the pressure is reduced, the deformed elastic tube comes to his initial shape and pushes the additional amount of fluid which was deposited through the elastic rebound of the tube's walls [13].

After every systole, a wave of deformation propagates from the heart to the peripheral blood vessels in the same way as a perturbation propagates alongside an elastic rope or at the surface of the water when an object is thrown in it [14]. If the pressure at the entrance in an elastic tube varies in an oscillating way, the result is a train of wave crests which moves along the tube [15]. The propagation of the waves inside an elastic tube is the simplest model of an artery [16].

The pressure generated by the heart increases and decreases in a periodic manner. The propagating wave of deformation of the artery walls is a pulse wave [15].

At every arterial or venous section affected by the pulse wave, it can be observed the following three coherent phenomena: the flow of the blood alongside the axis of the blood vessel (flow pulse), the increase of the blood pressure (pressure pulse), the extension of the transversal profile of the blood vessel (profile or volume pulse) [17].

The propagation of a wave in an elastic tube has as an effect the possibility for the wave to reflect when it encounters an unevenness of the medium in which it propagates or a narrowing of the tube [16]. The direct wave and the reflected one can interfere. The interference can be constructive if both waves are in phase or destructive if they are in opposition phase.

Starting from the heart to the periphery, the diameter of the arteries decreases while it continues to branch. Thus, at the closed end of the blood vessels it can be produced the reflection of the direct wave created by the ventricular contraction [16].

The arterial pressure waveform consists of the direct pressure wave created by the ventricular contraction and of the wave reflected at the periphery, especially in the lower part of the body [16]. If the reflected wave is present then it overlays the direct wave and the pressure that is measured is the result of the overlay of the two waves. The waveform of the pulse is determined by the phase difference between the direct wave and the reflected one [18]. Thus, if both waves are in phase, their interference will be constructive, having as a result the amplification of measured pressure whereas, if the two waves are in opposite phase, their interference will be destructive and the measured pressure will be diminished [16]. The pressure pulse wave is similar to the volume pulse wave [19]. Figure 2 shows a representation of a radial arterial pulse wave and a volume pulse wave.

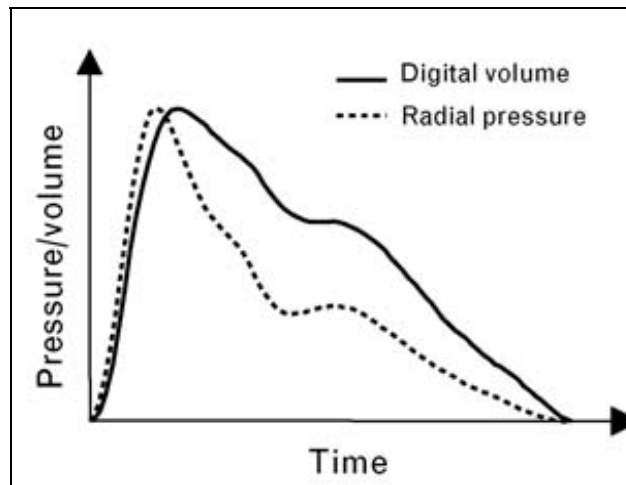


Fig. 2 – The waveform of the pressure /volume pulse [19]. The colored versions could be accessed at <http://www.infim.ro/rrp/>.

The peripheral pulse is an extension of the arterial pulse. The volume pulse wave can be detected at the finger. The method used is based on the detection of the cardiovascular pulse wave which propagates through the body using a source of IR radiations and a detector. The information about the volume pulse wave can be obtained by measuring the intensity of the IR radiation transmitted through the finger. The technique is used for detecting the changes in the blood's volume in the in the microvascular tissue of the finger. The amplitude of pulsations of the volume with every heart beat of the heart is correlated with the flow of blood [20].

The wave generated by the regular heart beats is periodical and pulsatile, but it is not a sinusoidal wave. The Fourier transform can be used to study the pulse wave form [15]. The Fourier transform transfers the signal from time domain to the frequency domain. The pressure pulse generated by the heart is actually a composite wave consisting of many so called harmonic components. The pressure pulse's frequency generated by the heart represents the fundamental frequency. The frequency of the second harmonic is double the fundamental frequency; the frequency of the third harmonic is three times the fundamental frequency. The fundamental frequency of the heart is 1 Hz [15].

3. THE METHOD

3.1. PENDULUM OSCILLATIONS WITH COBRA 3

The experiment was conducted assisted by the computer and using the equipment with acquisition boards and data processing, provided by Cobra 3 from

Phywe System GMBH&Co.KG (Germany). Figure 3 depicts the equipment used. The graphic of angular amplitude versus time is visualized on interactive whiteboard and is presented in Fig. 4.

The graphic was displayed on the interactive whiteboard and with the aid of the cursors lines, the period can be determined, and also the signal's amplitude.



Fig. 3 – Gravitational pendulum. The colored versions could be accessed at <http://www.infim.ro/rp/>.

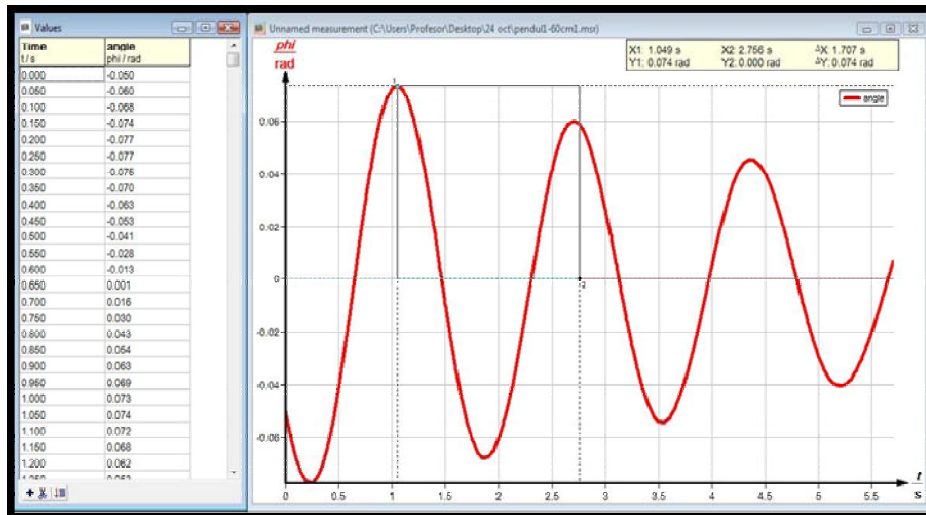


Fig. 4 – Gravitational pendulum's oscillations. The colored versions could be accessed at <http://www.infim.ro/rp/>.

3.2. HEART BEATS

We pass on then to the study of the second periodical phenomenon, respectively the heart beats.

a. The study of the heart beats using the Heart Rate/Pulse Sensor of Fourier Education Company (USA). An experiment was then conducted to determine the heart rate. For this reason, the “Fourier Heart Rate/Pulse Sensor” of Fourier Education Company (USA) was used, which was connected through Nova Link to the computer. The determination of the heart rate is based on the modification of an IR radiation’s intensity transmitted through the blood vessels at the fingers. During the systole, the heart forces the blood in the vessels and the blood volume changes through time and along with these changes the radiation’s intensity absorbed by the finger is also modified [21]. The MultiLab-Fourier Systems software allows the visualization of the graphics that depict the volume wave in real time. By analyzing these graphics the period, the signal amplitude and the heart rate could be determined. The MultiLab-Fourier Systems software also allows the visualization of the Transform Fourier of the initial signal. Figure 5 shows The Heart Rate/Pulse Sensor of Fourier Education Company (USA) and Fig. 6 shows an image during the experiment.

Measurements were taken in different conditions: in rest state, in conditions of effort and of apnea. For each graphic, with the aid of MultiLab software, it can be visualized the Fourier transform and could be determined the period, the frequency, the signal amplitude and the average of the amplitude and standard deviation. The graphics were visualized at the interactive whiteboard, where with the help of the cursor line some characteristics of the signal could have been determined as period and amplitude.

Figure 7 presents a typical example of a pulse wave measured as a function of time in a rest state.



Fig. 5 – The Heart Rate Sensor and NOVA LINK. The colored versions could be accessed at <http://www.infim.ro/rp/>.



Fig. 6 – Image during the recording data. The colored versions could be accessed at <http://www.infim.ro/rp/>.

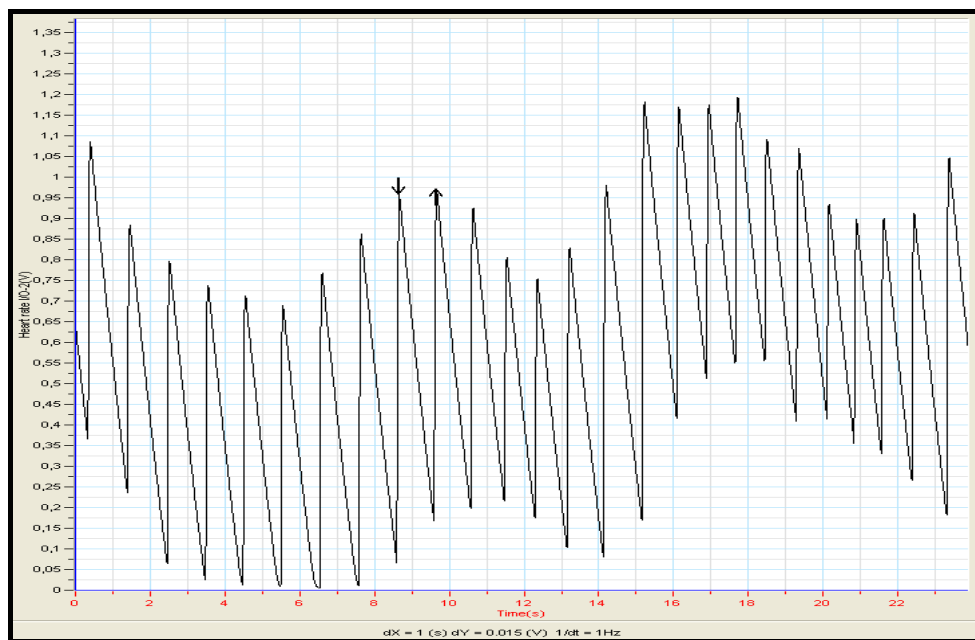


Fig. 7 – The graphic in rest state. The colored versions could be accessed at <http://www.infim.ro/rp/>.

In Fig. 8 is presented the Fourier Transform of the signals depicted in Fig. 7.

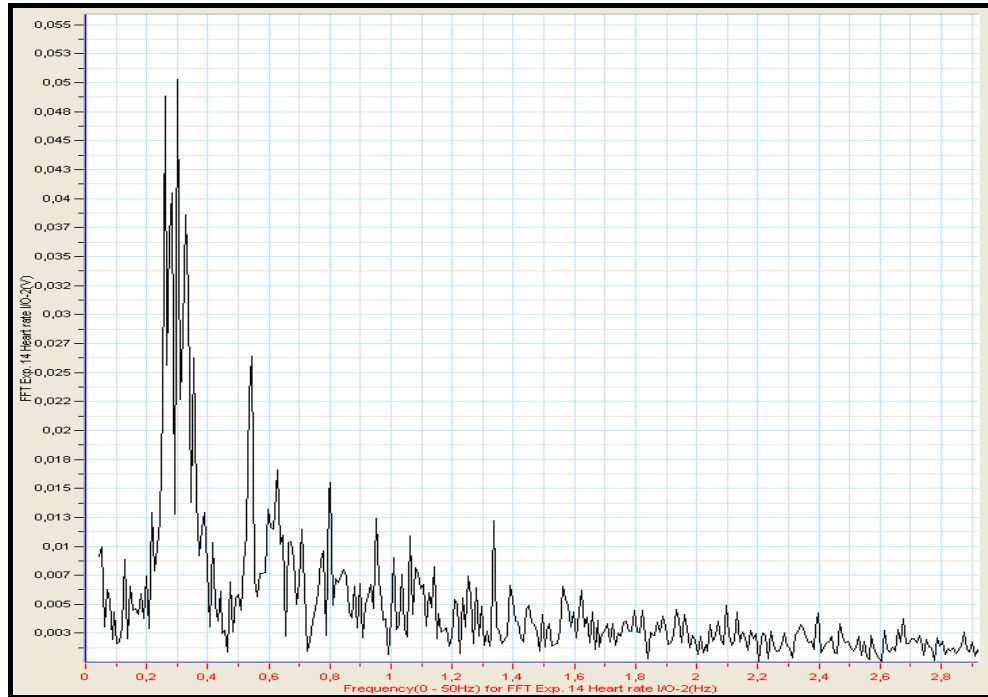


Fig. 8 – Fourier Transform (rest state). The colored versions could be accessed at <http://www.infim.ro/rfp/>.

In Table 1 are indicated the values of signal period, the frequency, the average value of the amplitude and standard deviation for different experimental conditions. The first experiment was done with the index finger at room temperature. The second measurement was realized after the index finger was kept in hot water for 2 minutes. The next experiments were done before the effort and then during the effort. The last set of measurements was realized in apnea conditions for 1 minute and then during normal breathing. One can observe that the signal amplitude is greater when the skin temperature is higher due to vasodilatation that can increase skin blood flow. In cold conditions the signal amplitude is lower, because a localized vasoconstriction could be produced and this can decrease the skin blood flow [20]. The increase of signal amplitude during effort, was greater than before effort. It also notes that the heart rate accelerates during an exercise to allow better oxygenation of the muscles involved in this activity.

Table 1

The values of signal period, the frequency, the average value of the amplitude and standard deviation for different experimental conditions

EXPERIMENTAL DATA					
Experimental conditions	Period T [s]	Frequency ν [Hz]	Amplitude U [V]	Average Amplitude U_m [V]	Standard Deviation [V]
Cold finger	0.950	1.014	0.410	0.071	0.093
Hot finger	0.880	1.136	1.250	0.930	0.230
Before effort	1.020	0.960	0.960	0.470	0.25 0
During effort	0.560	1.818	1.230	1.009	0.140
After effort	0.680	1.471	1.080	0.490	0.240
Apnea	1.140	0.877	0.240	0.030	0.049
Normal breathing	1.170	0.855	0.440	0.095	0.120

b. The study of the heart beats using the Heart Rate (Exercise) Sensor of Fourier Education Company (USA). The sensor is comprised of a wireless transmitter belt and a Pulse Receiver module that plugs into NOVA LINK. Transmitter belt is placed below the chest. The transmitter belt senses the electrical signals generated by the heart. The transmitter sends electrical signals from the heart to the receiver module. With the help of this module there was recorded the heart rate, measured in heart beats per minute (bpm) and pulse waveform at rest, in terms of effort and then back to the normal period of rest [22]. Figure 9 shows the Heart Rate (Exercise) Sensor of Fourier Education Company.



Fig. 9 – Heart Rate (Exercise) Sensor. The colored versions could be accessed at <http://www.infim.ro/rrp/>.

Figure 10 shows a typical graph which represents heart rate recording in bpm in rest conditions.

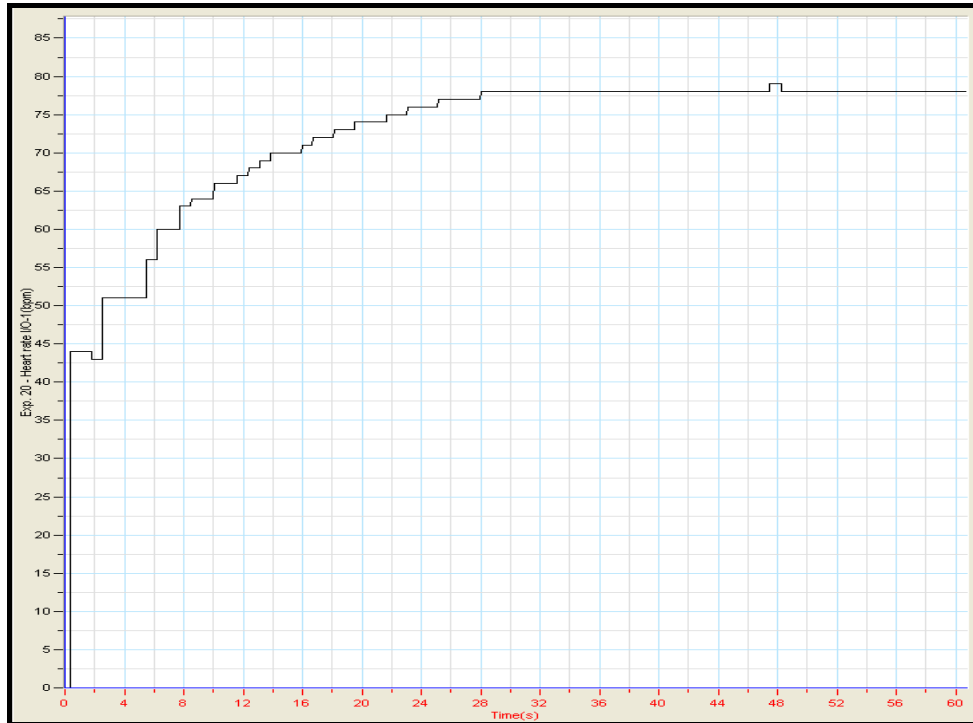


Fig. 10 – Monitoring heart rate in bpm in rest condition. The colored versions could be accessed at <http://www.infim.ro/rfp/>.

In Table 2 are indicated the average of the heart rate, the minimum and maximum value of the heart rate and the standard deviation for different experimental conditions.

Table 2

The average of the heart rate in bpm, the minimum and maximum value of the heart rate and the standard deviation for different experimental conditions

EXPERIMENTAL DATA				
Experimental conditions	Average Heart rate [bpm]	The minimum heart rate [bpm]	The maximum heart rate [bpm]	Standard deviation [bpm]
Rest state	72.50	43	79	9.16
During effort	107.97	78	154	21.24
After effort	101.01	82	153	20.99

Using the same sensor one could get the pulse waveform in the same experimental conditions. Figure 11 shows the pulse waveform recorded at rest conditions.

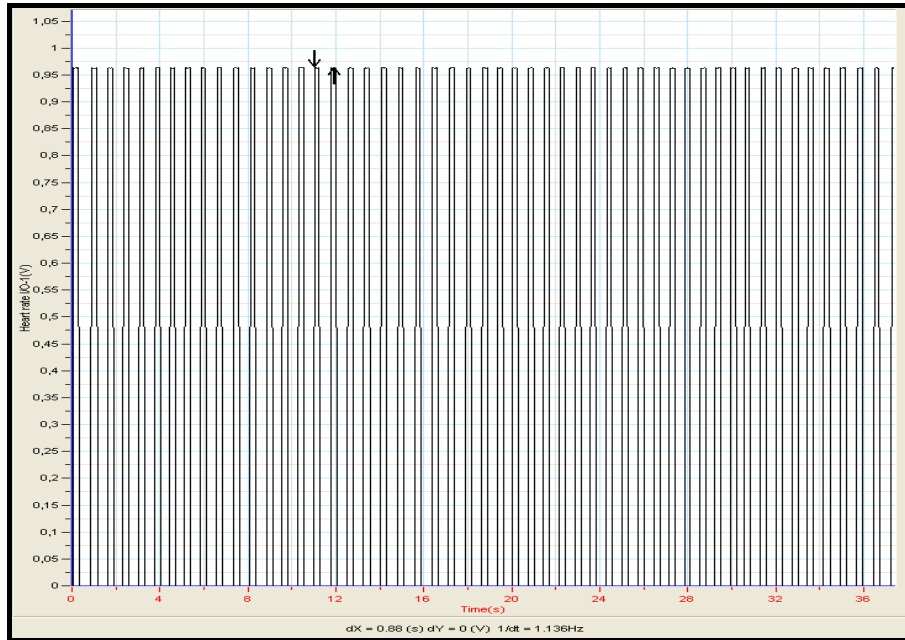


Fig. 11 – Monitoring waveform in rest state. The colored versions could be accessed at <http://www.infim.ro/rfp/>.

Table 3 shows the experimental data.

Table 3

The values of the pulse waveform period, the frequency, the average value of the amplitude and standard deviation for different experimental conditions, recorded with The Heart Rate (Exercise) Sensor

EXPERIMENTAL DATA					
Experimental conditions	Period T [s]	Frequency ν [Hz]	Amplitude U [V]	Average Amplitude U_m [V]	Standard Deviation [V]
Rest state	0.80	1.25	0.32	0.96	0.45
Effort state	0.52	1.92	0.41	0.96	0.48

In this experiment, as in the previous one, students were able to find that the heart rate is higher during exercise than at rest.

c. The study of the heart beats using the EKG Sensor. The EKG Sensor measures cardiac electrical potential waveforms. This sensor enables to investigate the electric activity of the heart. The sensor consists of Fourier Systems plastic sensor case and three electrode leads. The first electrode is placed on the right wrist. A second electrode is placed a few centimeters above the first one and a third electrode is placed on the inside of the left wrist [23]. Figure 12 shows the

recording an EKG and Fig. 13 presents a typical example signal obtained from EKG recording with the corresponding sequence representation cardiac cycle (from P wave to T wave). The graph show a pattern repeated with each beat of the heart.

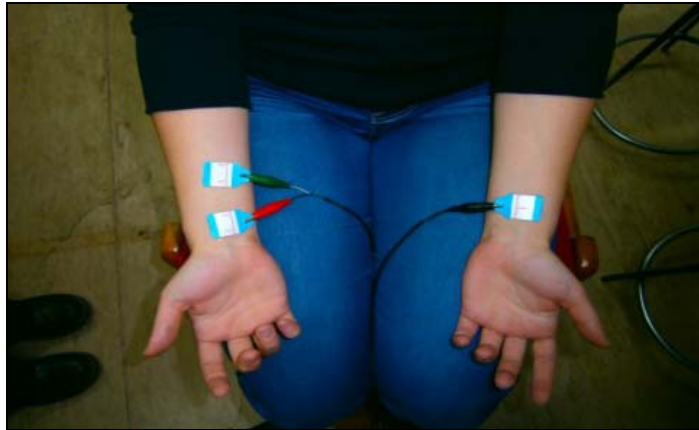


Fig. 12 – Recording data during EKG. The colored versions could be accessed at <http://www.infim.ro/rfp/>.

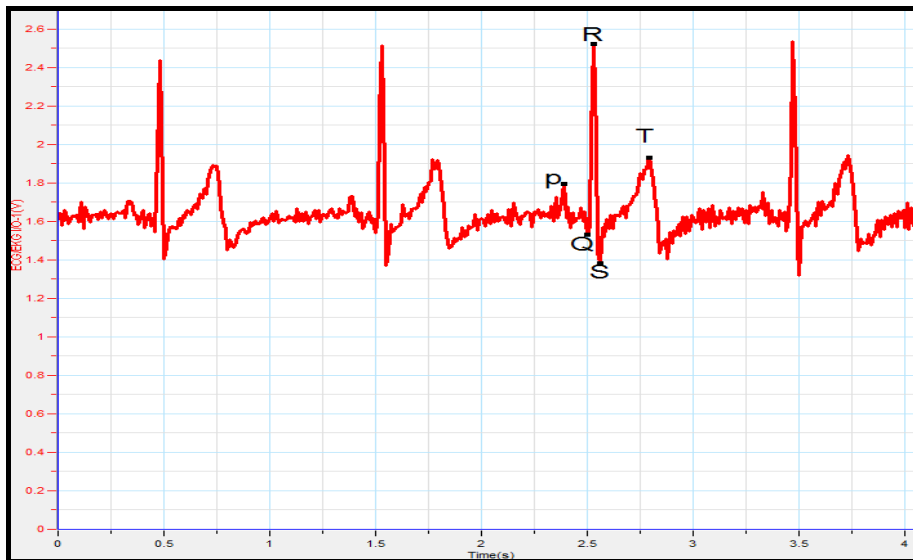


Fig. 13 – EKG data. The colored versions could be accessed at <http://www.infim.ro/rfp/>.

The sequence of the P wave to T wave is a cardiac cycle. The period and the frequency of this cycle can be determined.

At rest, the frequency was 1.176 Hz and in the effort condition, the frequency was 2.632 Hz.

4. CONCLUSIONS

The aim of the present study was to show the fact that physics notions can be applied in different spheres of activity such as human physiology. So, with the aid of the physics notions such as the propagation of the waves and their interference could be explained the flow of the blood in the circulatory system. The electricity concepts learned, can be applied in the study of electrical activity of the heart. The students could find that, any periodic waveform can be represented as the superposition of harmonics according to Fourier's theorem. Using the interactive whiteboard and computer assisted experiment realization, led to the involvement of students during class. They were able to make connections with the notions of anatomy related to the circulatory system and the heart function and the trigonometry concepts related to the Fourier transform. Conducting such experiments arouse the interest of students to study Physics, participating actively in their implementation. Teachers may use particular instruments: real experiment [24–26], virtual experiments [27] and interactive whiteboard and computer assisted experiment [28].

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