CREATIVE COMPUTER-BASED LABWORK ON ELECTRICITY

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ABSTRACT
A large series of computer-aided laboratory exercises based on the IP COACH system have been efficiently used in high-school learning. More recently, some of the labwork (particularly, on the topic of Direct Current) have been developed into creative experimental problems for university and high-school students to solve when studying Physics courses. Time-resolved measurements provided by COACH5 enabled the students to explore and explain an intriguing behaviour of filament bulbs connected into simple circuits.

KEYWORDS
Computer-aided experiment, microcomputer-based laboratory, laboratory work, IP COACH system, electricity.

INTRODUCTION

Laboratory exercises in physics belong to one of the most important parts of physics teaching. Students conducting laboratory exercises work on a certain physical topic exploring different physical phenomena. They are mentally and physically involved in their process of learning, so knowledge gained in this way should be deeper and more persistent. Moreover, nowadays there are modern computer tools available that can help in gaining data from real experiment as well as they can help in theoretical explanation of an explored physical phenomenon. The physical laboratory equipped with programmed computers interfaced with laboratory sensors and actuators is called a microcomputer-based laboratory. In such a lab students can measure different physical quantities like position, velocity, acceleration, force, temperature, light intensity, pressure, sound pressure, radiation, current, voltage, etc. In such an environment students can explore different physical phenomena that can be presented as creative experimental problems. In this paper we discuss a range of examples of traditional and new lab work designed for university or high school students.

WHAT IS A MICROCOMPUTER-BASED LABORATORY (MBL)

A microcomputer-based laboratory (MBL) is a laboratory where computers are equipped with an interface system, a set of sensors and appropriate software environment that enables to measure and graph physical quantities simultaneously as well as to process the acquired data. One such system is the IP COACH (CMA home page) that integrates several tools that enables:
- On-line measurement (with interface connected to the computer) and off-line measurement (interface can be disconnected from th;e computer) with all kinds of sensors and control systems.
- Data processing in spreadsheets, graphs with various advanced tools for analysis.
- Data video measurements on science video clips that helps students to make links to the real world. The computer can display video images on a screen and allow students to take data from them to study and analyse different phenomena from everyday life, such like different kinds of motion (basketball, football, collisions, projectile motion, etc).

- Creating dynamical models of different phenomena and simulations of processes. Modelling and measuring can be linked together and it can be shown that the theoretical model goes hand in hand with experimental data.

Such a system with all its possibilities can become very useful in physics education at the university or high school level. Its regular systematic use can bring positive influence upon certain fields that have been discussed by several researches (Thornton, 1990; Ješková, 2003). The main reasons for this statement in the field of real-time measurements, in particular are:
- MBL tools provide a genuine scientific experience for students: students gather and analyse real data. The students learn concepts by investigating the real world rather than only manipulating symbols. That brings positive influence on *students´ understanding* of certain physical concepts.
- Learning through MBL provides a real time link between a concrete experiment and the symbolic representation of that experience. It develops graphical skills concerning *interpretation of graphs*.
- MBL tools *eliminate the drudgery* of graph production and make the experiments easier to realize and to repeat under different conditions. The time saved is spent observing physical phenomena and analysing and interpreting abstract representations (graphs) of these phenomena.

STUDY OF THE BEHAVIOUR OF BULBS IN DIRECT ELECTRIC CIRCUIT WITH THE HELP OF MBL TOOLS

Studying the behaviour of different elements connected to direct circuit belongs to one of the basic laboratory activities at high school as well as at University level. This problem is usually realized as a lab activity aiming to measure VA characteristics of a bulb or other electrical elements (resistor, diode, electrolyte) and comparing the different behaviours of the elements placed in the circuit. With the help of the IP COACH system each measurement can be realized within several seconds. A typical set of findings generated by IP COACH is shown in fig. 1.
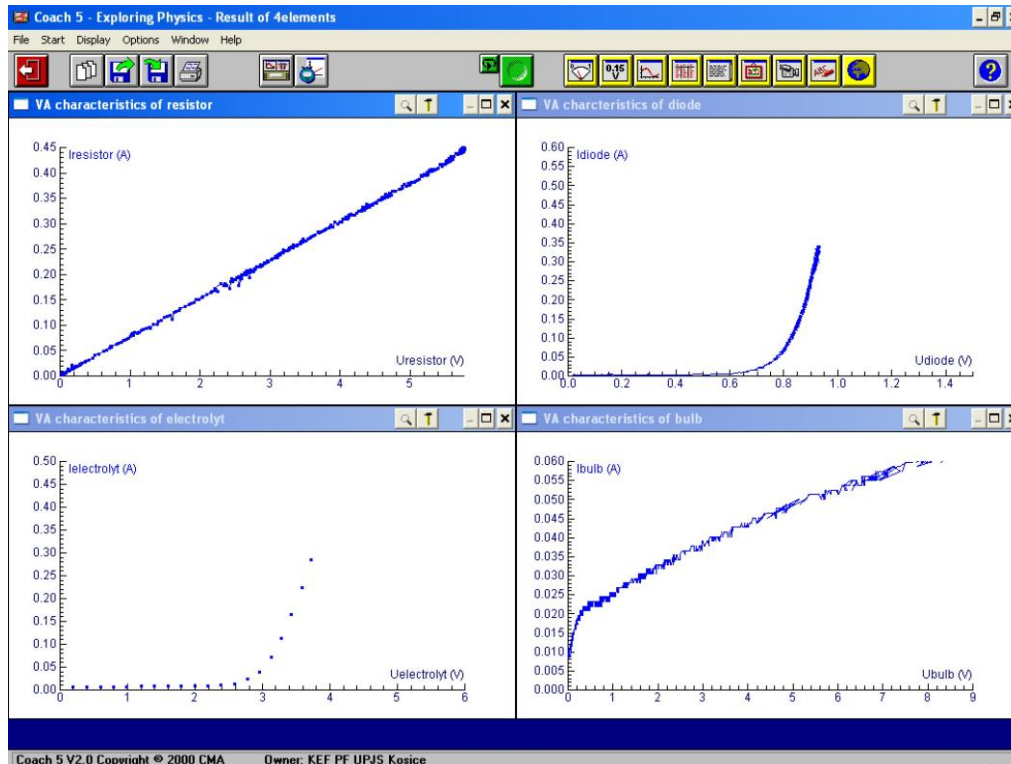

Figure 1. VA characteristics of different electric elements (resistor, diode, electrolyte, bulb)

VA CHARACTERISTICS OF BULB AND ITS THEORETICAL MODEL

The problem concerning non-linear characteristics of a bulb, as presented in fig.1 and explaining its non-linearity can be extended to a problem how to create a theoretical model of its behaviour. A simple model of the behaviour of tungsten filament is based on the following pieces of knowledge:

- The resistance of a conductor depends on temperature almost linearly with modest changes in temperature Δt: $R \approx R_0 (1 + \alpha \Delta t)$ (1).

- If the temperature related to a resistance R_0 equals 0^oC, than the equation is as follows: $R \approx R_0 (1 + \alpha t)$ (2), where R_0 is the resistance at 0^oC, α is the temperature coefficient of resistivity of the material.

- For most pure metals $\alpha \approx \dfrac{1}{273} K^{-1}$ (3).

- Using (3) in formula (2), we get $R = R_0 \alpha T$ (4) that means that the resistance of a material depends approximately linearly on the absolute temperature.

- The power dissipated in a resistance R can be expressed as $P_R = IU = RI^2 = R_0 \alpha T I^2$ (5).

- According to the Stefan-Boltzmann Law, the total power radiated is $P_{rad} = S\sigma T^4$ (6), where S is the area of the radiating surface, T is the absolute temperature and σ is a universal constant given as $\sigma = 5,6703 . 10^{-8}$ W/m^{2}K^4.

- Supposing that $P_R = P_{rad}$, we get $R_0 \alpha I^2 = S\sigma T^3 \sim R^3$, or $I^2 \sim (U/I)^3$. Consequently $I \sim U^{3/5}$.

- The model of the bulb characteristics is based on the relationship $I \sim U^{3/5}$. This mathematical model based on the formula $I = k.U^{3/5}$ (7) can be entered to the IP COACH modelling program. Presenting the experimental results simultaneously with the graphical representation of the formula (7) it can be shown that the experimental data approximately corresponds with the theoretical data gained from the model with appropriate constant. Furthermore, the physical meaning of the constant k can be found.

- The correspondence of experimental and theoretical data is highly positive at higher temperatures of the filament; at the room temperature the relationship is more complicated, since the equation $P_R = P_{rad}$ is not valid accurately.

In fig.2 there are examples of experimental and theoretical results for two different bulbs. There can be seen a good correlation at higher temperatures (high currents) and more complicated relationship at low temperatures (small currents).
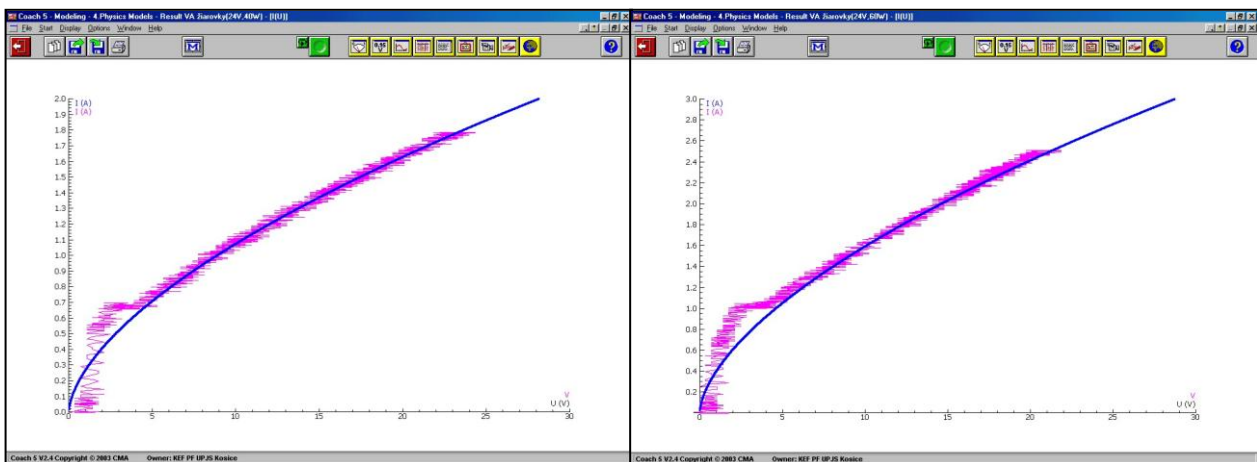

Figure2. Experimental and theoretical data for two different bulbs: 24V, 40W- left and 24V, 60W- right

TWO BULBS CONNECTED IN SERIES IN DIRECT ELECTRIC CIRCUIT

The problem of two bulbs connected in series in a direct electric circuit can become an interesting problem for students to solve. Supposing we have two different bulbs and a power source with voltage standard to light each separate bulb we can light the bulbs up separately as well as connecting them in series. From understanding these simple experiments, a new problem can emerge. This problem can be divided into two parts:

Problem 1: bulbs in steady state. If we put two identical bulbs (e.g. 40W) in the holders they shine equally brightly. If we put two identical bulbs (e.g. 20W) in the holders they also shine equally brightly. When we put one 40W and one 20W in the holders than the 20W bulb lights up and the other does not (or very faintly).

Problem 2: bulbs in transition state. If we put two different bulbs in the holders one of them will light up later than the other. There is a noticeable delay between the two bulbs.

What is the cause of this intriguing behaviour of bulb filaments? This question can become a good motivational question for student inquiry-based learning. With the help of MBL tools students can investigate the behaviour of different combinations of bulbs connected into simple direct circuits thus attempting to find the answer to these questions. Studying and analysing time–resolved measurements provided by MBL tools can help in explaining this mystery.

Explanation of problem 1: For the brightness of the bulb, the energy (or power) dissipated (expressed in formula 5) in a bulb is crucial. If two bulbs are connected in series, the power dissipated in each of them drops. In steady state the one that draws power closer to its normal condition will shine, the other one will barely glow at all.
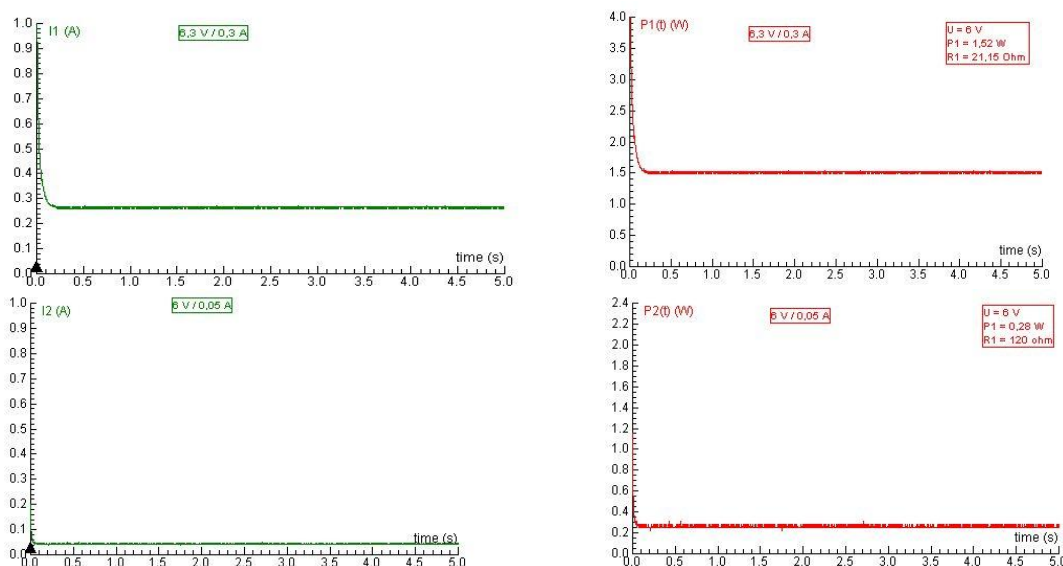
Figure3. Results of two different bulbs (current vs. time - left, power vs. time - right) connected to 6V power source separately (I_1=0,26A, R_1=21,15Ω, P_1=1,52W, I_2=0,048A, R_2=120Ω, P_2=0,28W)

This is proved experimentally with two small bulbs – 6,3V/0,3A, 6V/0,05A. Firstly the behaviour of single bulbs connected to the power source of 6V has been studied. The results are shown in fig. 3. Since the power dissipated in each bulb is different and the voltage is the same that means that the resistance of the bulb is different. The higher wattage bulb is the one with smaller resistance. If we connect the bulbs in series their combined resistance is bigger than either one separately. Therefore less current will flow through them as before and the power dissipated in each of them drops. According to

fig.4 the brightness of the bulb 2 is closer to its normal condition. That means that this bulb is bright (less than usual, because of smaller power) but the other one barely glows at all (since the power is a great deal smaller than usual).
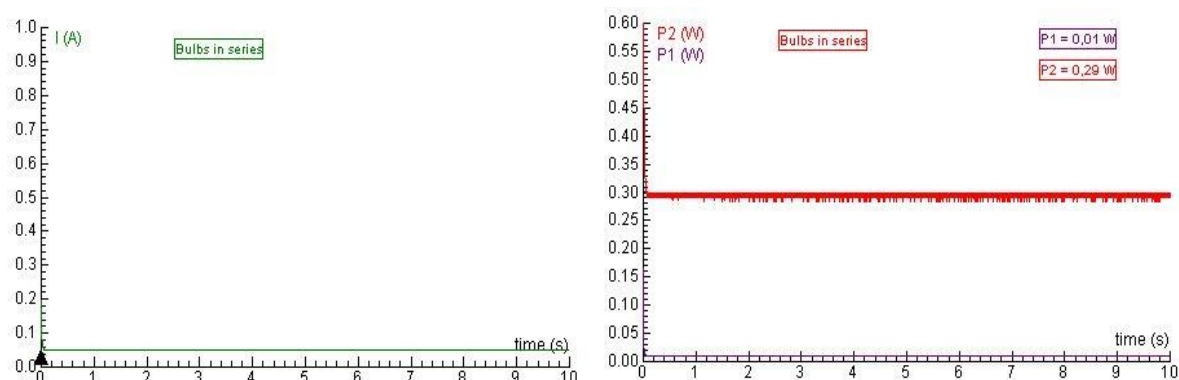

Figure 4. Results of two bulbs (current vs. time - left, power vs. time – right) connected in series to a 6V power source (I=0,05A, P_1=0,01W, P_2=0,29W)

Explanation of problem 2: When we switch on the circuit the current starts to flow. But initially the bulbs are at room temperature, so their resistance is quite low. When current flows through them, they are gradually heated according to Joule Law. Consequently, their resistance goes up and it causes the current drop. In fig. 5 there are current vs. time graphs for two different bulbs (24V/40W, 24V/60W) connected to 11V power source separately where decreasing current at the beginning can be clearly seen.
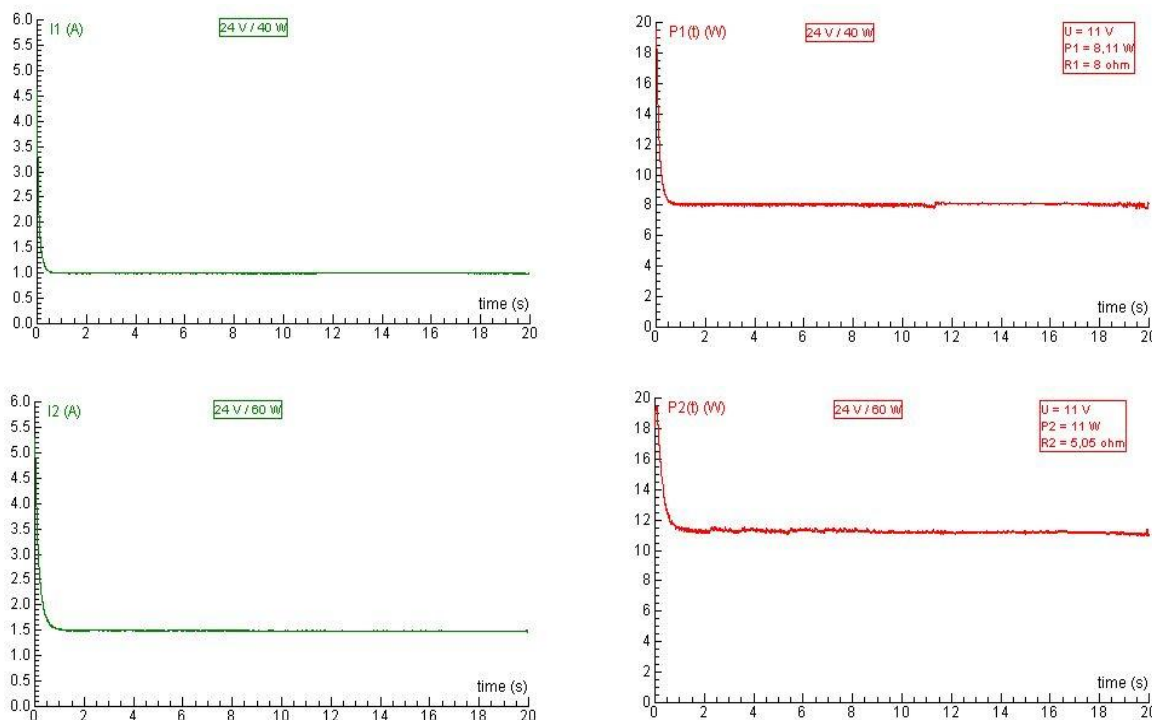

Figure 5. Current vs. time (left) and power vs. time (right) graphs for two different bulbs connected to 11V power source separately (I_1=1A, R_1=8Ω, P_1=8,11W, I_2=1,5A, R_2=5,05Ω, P_2=11W).

If the two bulbs differ noticeably, then connected in series the bulbs appear in essentially different conditions. If their initial resistances are e.g. $R_1>R_2$ the distribution of voltage is $U_1>U_2$. That means that

at the beginning the first bulb is nearly in a designed regime, while the other is under reduced voltage that causes low energy dissipation and underheating, consequently no emission of visible light. So it takes much time for Joule heat to increase the temperature of this bulb with the resistance increasing simultaneously. Consequently, bigger R_2 means voltage re-distribution between the bulbs ($U=U_1+U_2$, so when U_2 increases, then U_1 becomes smaller and first bulb fades) and the second gradually turns on.
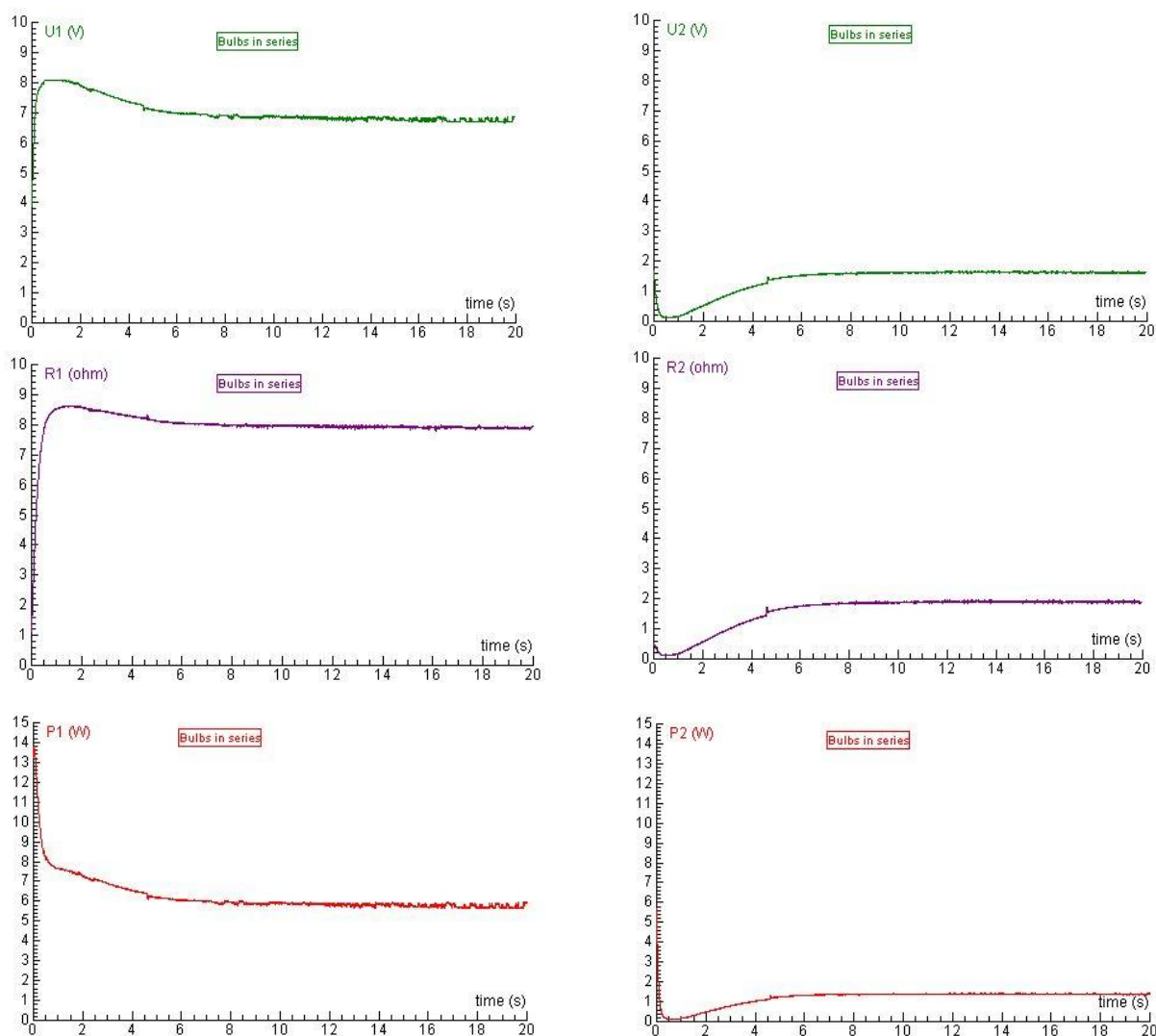

Figure 6. Graphs of current vs. time, voltage1 vs. time, voltage2 vs. time, resistance1 vs. time, resistance2 vs. time, power1 vs. time, power vs. time for two bulbs connected in series

In order to check and prove the above explanation of this strange behaviour of the bulbs we made measurements of different bulbs under different conditions (voltages). In fig. 6 there are results of measurements of two bulbs (24V/40W, 24V/60W) connected in series to 11V power source. Analysing the graphs of current vs. time (that is common for both bulbs), voltage vs. time (U_1(t), U_2(t)), resistance vs. time (R_1(t), R_2(t)), power vs. time (P_1(t), P_2(t)) the following conclusions can be done. At the beginning the bulb 1 has bigger resistance. That means the bigger voltage is across it. As a power vs. time graph shows this bulb is closer to its normal condition (fig.5 where the bulbs where connected separately) than the other one. That is the reason that this bulb lights up and the other one does not because of the small power dissipated, low temperature and no light emission. It takes time for Joule heat to increase the temperature and resistance, consequently. This late temperature (resistance) rise

causes redistribution of voltage and as the resistance of bulb 2 increases there is higher voltage across it. Because of this fact the bulb 2 gradually lights up while the bulb 1 fades a little.

CONCLUSIONS

In this paper we have attempted to give a few examples of how to use MBL tools in designing creative laboratory activities for students when they are studying the topic of electricity. Analysing single bulb behaviour as well as two bulbs connected in series can be extended to a problem of two bulbs connected in parallel and exploring their behaviour with the help of MBL tools. The lab activities examples mentioned show that MBL tools can change a physical laboratory into an environment where students can explore physical world around them, they can repeat the experiment several times under different conditions to see immediate reaction without too much effort being spent on processing. Comparing and analysing different results students deepen their physical knowledge that can lead to better understanding of the observing physical phenomenon (Thornton, 1990; Jeskova, 2003). How the experiments mentioned in the paper influence the students´ understanding of the concepts of electricity (resistance, electric power and work, etc) is the objective of further pedagogical research.

ACKNOWLEDGEMENTS

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