EXPERIMENTAL METHOD OF JOULE'S EXPERIMENT IN PHYSICS FOR SECONDARY SCHOOL

Terézia Jindrová[1]

Abstract: Energy remains a problematic topic in the pedagogic sphere. One main issue in high-school teaching is the lack of practical examples. Such demonstrations are the most effective way of imparting knowledge. This article discusses a new modern version of the Joule's experiment as a practical demonstration for Physics classes. It models the specific thermal capacity and the transformation of mechanical energy into heat energy. As such, it represents an approach for teaching thermodynamics. The goal of this research is to verify the functionality of the new apparatus and its optimization for use in practical experiments during high-school classes. One main acquisition is the application of the Joule's experiment in teaching Physics within a lesson and to provide a methodical procedure on how to operate the experiment in a school. This practical example may help teachers incorporate other experiments and use inquiry-based science education in their teaching programs.

UDC Classification: 027.7; **DOI:** http://dx.doi.org/10.12955/cbup.v6.1225

Keywords: Joule's experiment, Inquiry-based school education, heat, energy, work

Introduction

A science teacher's role is to lead their students towards correctly solving problems. One didactic method for fulfilling this objective is the use of experiments in class. In this undertaking, teachers aim to guide their students towards active participation where students acquire knowledge by working with the data they have measured in the classroom. The students solve problems by formulating questions, developing a hypothesis, accumulating data, and then reaching conclusions (Pasch M. et al., 1998). These are the characteristics of inquiry-based science in education. The main concept involves an education program orientated towards students gaining practical skills. Hence, science teachers should aim to use experiments in the education of physics for this reason.

Experiments in class are suitable for high school, particularly second year when thermodynamics are taught and students are required to learn the concepts of energy, force, work, and friction. They need to perform analyses of data and glean an understanding of the basic principles of physics. The understanding of elementary mathematics is also important. Students need to know how to calculate the surface area of a circle and express it as a formula. An experiment integrates varying fields of science, such as physics, chemistry, mathematics, and informatics.

In this article, the demonstration of a basic natural law is examined, namely, the energy conservation law. Joule (1850) demonstrated the correlation between mechanical work and heat and subsequently provided the mechanical equivalent of heat. The Joule experiment is named after him.

Data and Methodology

This study used similar measurements to Joule (1850), but with modern experimentation equipment. The measurements were controlled by a computer. Data were obtained through 'hands-on' experiments and recorded under the Internet School Experimental System (ISES) module system, described below.

To achieve this experiment with students, one suitable didactic method is Inquiry-Based Science Education (IBSE). The students can interpret data, gain knowledge, and relate and apply rules. This type of education requires students to ask questions and then research, examine, and consider information as well as form hypotheses and reach conclusions. The typical objective is that students actively discover a generalization that illustrates an unidentified event or a series of data.

Generally, the experiment provides an answer to the question, given to every student undertaking the experiment: "What would happen if ..." The experiment generally allows them to investigate the relationship between causes and consequences. It is based on a physics method, calorimetry, used to investigate heat (in the narrower sense), and temperature measurement.

The program, ISES, was used to the collect the data and perform the analyses in this paper. This is an open-source program that was used under the Windows operating system with all its advantages (OLE and multitasking). The system is composed of an interface card, a set of variable modules and sensing elements, and a service graphical and evaluation software (Schauer, Ožvoldová & Lustig, 2006).

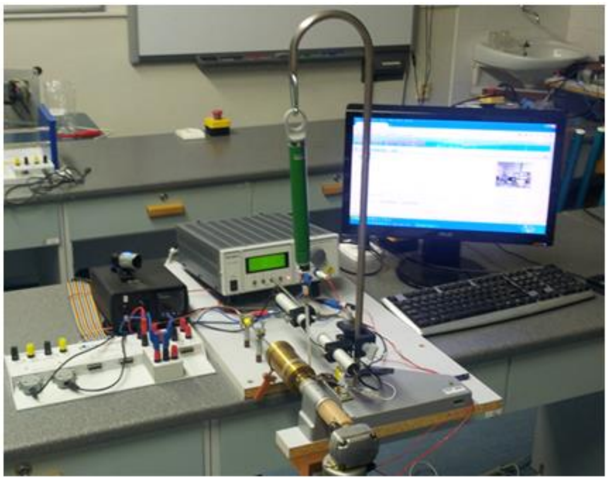
[1] Department of Physics, Constantine the Philosopher University in Nitra, Slovakia, terezia.jindrova@ukf.sk

Input modules used in the measurements were a thermometer and optic gate. The thermometer had a scale from −20 °C to 120 °C. The optic gate recorded the number of the cylinder revolutions. The principle was the reaction on the interrupted optic path. The optic beam was interrupted by shield rotation.

Experimental Apparatus

The whole experiment (Figure 1) was conducted on the board that served as the supporting surface for the entire apparatus. The engine was connected to the voltage source, which rotated the cylinder. The plastic tape was situated around the cylinder and fixed on the top with a dynamometer and weighed down. The mass of the weight was changeable, with three masses of weight 0.5 kg, 1.0 kg, and 1.5 kg. The plastic tape managed friction as the cylinder was warming up. In this experiment, measurements were taken from two cylinders, a small brass cylinder with mass (*m*) of 0.640 kg and a large brass cylinder with mass of 1.290 kg. The cylinder needed fixing to the plastic cylinder where a temperature sensor was set. The temperature receiver was connected with an electric ISES thermometer. A dynamometer and optic gate were fixed to the stand with the optic gate connected with ISES. Measurements were taken from the optic gate, which was recording the number and frequency of revolutions.

Figure 1: Experimental construction of apparatus

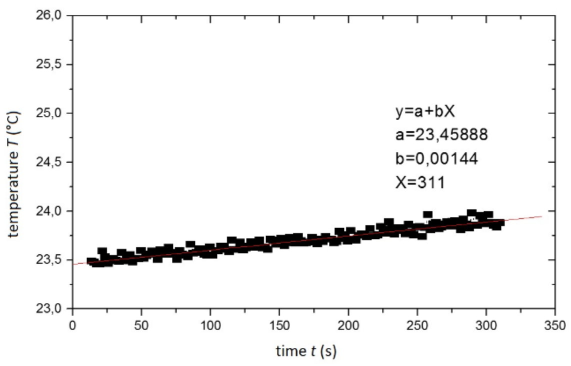


Source: Jindrová

Results and Discussion

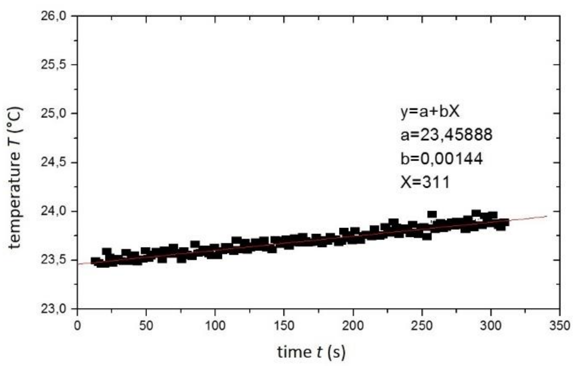
The study achieved the measurement and its evaluation for the verification of correctness of the experiment and on their base utilization the experiment in physics education.

Figure 2: Graph dependence of the temperature on time, small brass cylinder



Source: Jindrová

Figure 3: Graph dependence of the temperature on time large brass cylinder



Source: Jindrová

The main goals of this article were to measure and determine the equivalence of mechanical work and heat and to determine the specific thermal capacity of brass. The experiments involved a small cylinder of brass with a mass, $m_{1(Mo)}$, of 0.640 kg and an average (d) of 0.045 m. The large cylinder of brass had a mass ($m_{2(Mo)}$) of 1.29 kg, average (d) the same as a small cylinder 0.045 m. The ISES created a dependence of temperature on times for weights of 0.5 and 1.0 kg (Figure 2) and 1.5 kg (Table 2). The calculated data were compared with figures of the physical tables.

Table 1 shows data for the small brass cylinder. Table 2 shows data for the large brass cylinder.

Table 1: Data for the small cylinder of brass

č. m.	1.	2.	3.
b / $°C.s^{-1}$	0,001	0,003	0,007
m_z / kg	0,5	1	1,5
X / s	311	418	244
Δt_{mer} / °C	0,311	1,25	1,7
F_G / N	5	10	15
F_D / N	8,9	21	30
F_T / N	3,9	11	15
W / J	110	311	424
Q / J	110	307	420
c / $\frac{J}{kg\ K}$	391	389	390
Δc / $\frac{J}{kg\ K}$	7	5	6

Table 2: Data for the large cylinder of brass

č. m.	4.	5.	6.
b / $°C.s^{-1}$	0,003	0,004	0,004
m_z / kg	0,5	1	1,5
X / s	221	332	385
Δt_{mer} / °C	0,663	1,45	1,54
F_G / N	5	10	15
F_D / N	17,5	35,7	42,4
F_T / N	12,5	25,7	27,4
W / J	353	726	774
Q / J	347	718	763
c / $\frac{J}{kg\ K}$	391	388	390
Δc / $\frac{J}{kg\ K}$	7	4	6

b coefficient rising temperature , m_z mass of weight, X time, Δt_{mer} increase temperature, F_G gravitational force, F_D force of dynamometer, F_T force of friction, W mechanical work, Q heat, c specific heat capacity, Δc difference between specific heat capacity in table and measured

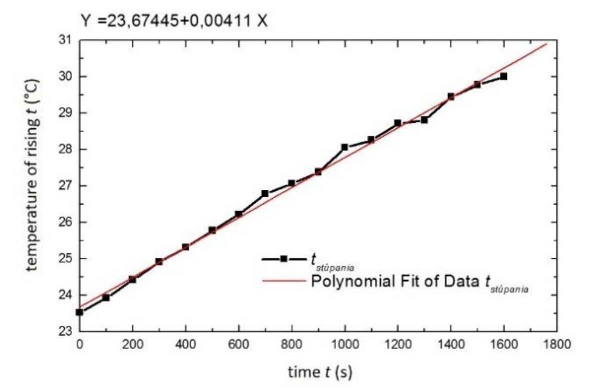
Source: Jindrová

With the apparatus operating for 2400 s (40 min), the results showed that heat dissipated during the experiment (Figure 4). The small brass cylinder with a weight of about 1 kg mass showed the dependence of temperature on time at 100 s (Figure 4). This dissipated during the measurement.

The experiment after several runs was disconnected from the source. The specimen after disconnection was allowed to cool (Figure 5).

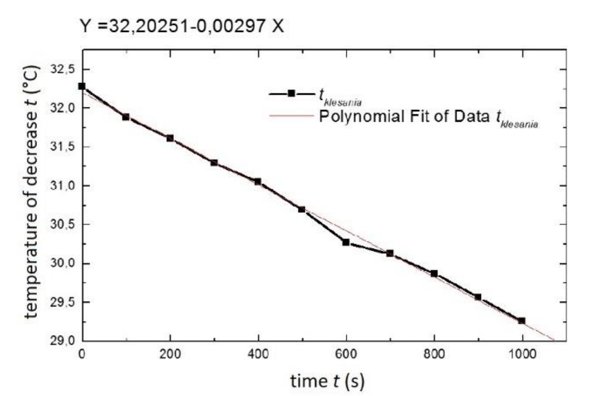
The results in Table 1 and 2 show work and heat are not precisely equal. This is due to various causes, for example, the impurity caused by dust. A clean plastic tape, cylinder, and thermometer's brass contacts on the plastic cylinder are needed for exact results by alcohol. It is necessary because dust impedes the smooth progress over time. The experiment was not situated in an isolated area and the heat dissipated. The result may have been influenced by the changing temperature in the classroom, the opening of a window, or running of the air-conditioner. By the nature of energy conservation law, these effects are valid resulting from the equivalence of mechanical work and heat.

Figure 4: Dissipate during measurement



Source: Jindrová

Figure 5: Cooling of the cylinder



Source: Jindrová

Application to the Education Process

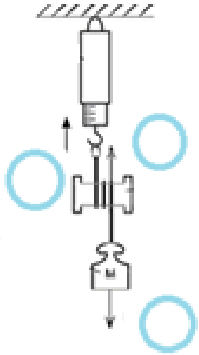
The study aimed to design a teaching lesson with IBSE with a 'hands-on' Joule's experiment. It is important to include practical experimentation into the teaching of Physics because students observe that the experiments in practice can at times differ to that presented in the theory. From this, the students learn logical thinking.

The textbooks for 2nd Year Secondary School Physics (Svoboda et al., 1985) describe an experiment within the laboratory exercise, based on the theoretical example of determining internal energy and mass-specific capacity. This present article provides an empiric IBSE procedure of knowledge, which is a new approach involving the Joule's experiment for teaching beyond a theoretical level. In this, the teacher uses questions oriented towards a hypothesis and then, asks the students to test the hypothesis by measurements in a demonstration component of the lesson. The second step focusses on the analysis and processing of the obtained data. The students deduce a conclusion and construct theoretical knowledge, at which point, it is necessary to discuss the result. The following example is related to the work of frictional forces in producing heat.

1. In the introduction lesson, the teacher describes both the historic and new Joule's experimental approaches and the motivation for performing the experiment. The teacher chooses and assigns the components of the experiment (Figure 1): dynamometer, thermometer, the source of electromotive force, cylinder, optical gate, and engine.
2. Which values are needed for calculating the heat and capacity of the materials? How is the work of the mechanical systems defined? Can you determine which path to take?
   Determine the diameter of the cylinder by using the movable meter. Calculate the radius of the cylinder and record the value.
   Determine the cylinder's mass by the scale and take note of the value.
3. Which components of the experimental apparatus are input modules?
   Open the ISES program. Connect the thermometer to the input module A and the optic gate to the input module B. Pre-set 200 spins for the optic's gate and sample at 150 Hz. Click the imaging, panel č.1, A3 for the smoothing the curve of the graph line temperature. In the panel, number 2 choose OFF1 that is recording spins.
4. Think about how to configure the constant number of revolutions in the ISES program.
   The optical gate B1 is marked with a function f (x). The function IFG (B1; 0.5; 1.0; 0) adjusts the signal. This function operates after the following instruction: If B1 exceeds 0.5, then it is 1, in other cases, it is 0. You are getting rectangle pulsation. After adjusting signal as an absolute value derive two peaks: ABS (X"/10). After that, every peak is summarized by an integral function. Then, divide that sum by two. This operation is necessary because up until to now the onset and drop of the signal of the cylinder's rotation were being considered. This part is realized by

function: dx§/2. After adjusting all the functions, the correct number of revolutions, N, is derived. In this case, N is equal to 200 revolutions.
5. Which type of forces are considered in the mathematical definition of the work? Which forces occur in the experiment? Write these in the blue circle.

Figure 6: Apparatus of Joule experiment



Source: Phywe Systeme GmbH und Co KG

6. Do you know how to assign these forces? What type of forces must be deducted?
7. Calculate the work of friction forces when you have prepared the experiment for 200 rotations.
8. Which parameters will be recorded to the sphere of the graph? What type of dependence is being recorded? How do you know that the cylinder is receiving 200 rotations?
   Switch on an experiment and control your prediction. Are your answers correct?
9. Do you know the mathematical formulation of a linear function?
   In this step, you will be required to obtain data by linear approximation of the function $y = ax+b$.
10. Did you know how you obtain this function?
    You must check ten points on the graph line of the time dependence on the temperature. You do approximation linear fitting and obtain values *a* and *b*. Did you know what are the means of *a* and *b*?
11. Specify the initial temperature of the cylinder when the experiment is running and the final temperature after the selected measuring time. How much did this temperature rise? Explain the temperature increase and determine it by calculation.
12. Select 50 revolutions and run the experiment. Export the data and create a chart. Do the same for 150 turns. Describe what you saw.
13. Look in the physical tables for the value of the specific heat capacity for brass and aluminum. Include the units of measure.
14. Calculate the amount of heat supplied to the brass cylinder for the measured values of temperature and the physical quantities detected, i.e. mass and capacity.
15. Next, predict how the temperature would increase depending on the same time duration when using an aluminum cylinder. Would the temperature increase be larger or smaller than the small brass cylinder? Write your assumption and verify by measurement.
16. What would be the amount of heat delivered to the aluminum cylinder compared to the small brass cylinder? Write your assumption and explain.

At the conclusion of the experiment, it is essential for the students to think independently and figure out the differences and various measurements. The teacher needs to summarize the essentials and the pupils' new concepts, laws, and relationships.

Conclusion

This study focused on performance, realization, and evaluation of measurements using a new version of Joule's experiment. The approach was oriented on verifying the correctness of the measuring apparatus, equality of work and heat, and the specific thermal capacity of the brass cylinder. The experiment demonstrated the elementary physical law of energy conservation. Based on worked examples, this experiment teaches the problematic of measuring heat. It is recommended that Joule's experiment is included in the teaching of physics and to increase the scope of experimentation in high schools. This article contributes to a proposal for the use of this experiment in teaching physics at high school.

Acknowledgments

This work is supported by University grand agency. I want to acknowledge my school tutor doc. RNDr. Peter Čerňanský PhD. for valuable advice.

References

Jindrová, T. (2015): *Disipatívne sily ako sonda do mikrosveta pomocou Joulovho pokusu*, [Dissipative forces as a probe into microworld using Joule's experiment], Trnavská univerzita v Trnave, Pedagogická fakulta, Katedra fyziky, 49 s

Joule, J. P. (1850) *On the Mechanical Equivalent of Heat*, Philosophical Transactions of the Royal Society of London, Royal society. JSTOR volume 140, pp. 61-82. Retrieved from https://archive.org/stream/jstor-108427/108427#page/n3/mode/2up

Pasch M. et al. (1998).*Od vzdelávacího programu k vyučovací hodině.* , [From the training program to the lesson] Praha: PORTÁL. 416 s.

Schauer F., Ožvoldová M., Lustig F., (2006). ISES-Internet School Experimental System for computer based laboratories in physics. *World Innovations in Engineering Education and Research iNEER Special Volume 2006*, chapter XX.

Schauer F., Ožvoldová M., Gerhátová Ž. Tkáč L., (2013) *Vzdialené laboratóriá pri diseminácii vedeckých poznatkov*, [Remote laboratories in the dissemination of scientific knowledge] Typi Universitatis Tyrnaviensis, ISBN 978-80-8082-770-0, vydavateľstvo SAV, monografia

Svoboda E., et al. *Fyzika pre 2. Ročník gymnázia.* ,[Physics for second Grammar School] Bratislava: SLOVENSKÉ PEDAGOGICKĚ NAKLADATEĽSTVO.279 s -283 s.

Trnová E., Trna J. (2015), IBSE PROFILES-*Modules in Science Teacher Education*, International Conference on Education and New Developments. (pp. 116-120). Porto (Portugal): World Institute for Advanced Research and Science (WIARS),

Phywe Systeme GmbH und Co KG. (2018) Available 28.1.2018 https://repository.curriculab.net/files/versuchsanleitungen/p2330200/p2