Joule's Experiment as a Probe into Micro-World

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***Abstract*—Joule´s experiment has both the historical and pedagogical importance in the building of the bridge between macro and micro-world. Dissipative forces and their work as a transformation of the macroscopic mechanical energy into the energy of thermal motion are decisive in the study of mechanical phenomena of real world. In this work we introduce the ISES Joule´s remote experiment that qualitatively and quantitatively describes the transformation of macroscopic kinetic energy into heat and shows the quantities, active in the transformation. The remote experiment represents a new generation of ISES remote experiments, equipped with a module, providing diagnostic information on remote experiments, both for the client and the provider.**

***Index Terms*—Joule´s experiment; macro and micro-world equivalence; probe into micro-world; remote experiment with diagnostics; Phywe Joule experiment**

I. Introduction

The Joule´s experiment played the decisive role in the insight into micro-world of the 19th Century and proved the equivalence of the concept of energy for both micro- and micro-world. This is the reason to build the Joules´ experiment for contemporary teaching, as insight into micro-world is difficult point for the teacher to explain. The remote experiment (RE), though relying on the original concept, uses modern experimental parts of the standard setup of ISES RE [1], [2]. In Fig. 1 is the arrangement of the laboratory experiment with its constituent parts.

II. Joule´s Experiment

A. Principle

The Joule´s experiment, which dates back to 1840, was originally designed as a system of rotating paddles in a thermally isolated vessel filled with water, arranged so that they can revolve. The rotation was due to the system of two weights moving downwards, so that the transformation of the potential energy of the gravity of the weights to the kinetic energy of the rotating paddles takes place with a successive transformation into heat.

B. Laboratory Joule´s experiment

The arrangement of the Joule´s laboratory experiment is in Fig. 1, based on the components of Phywe. The adjustable friction force by the weight (8) and measured by the dynamometer (1) is exerted by the plastic belt, which is wound on the rotating cylindrical metallic body (3). The generated heat is increasing the temperature of the metallic body, measured by the ISES thermometer (5). The driving force for the rotation of the cylindrical body is exerted by the motor (8) (DC 12V) driven and controlled by a DC source.

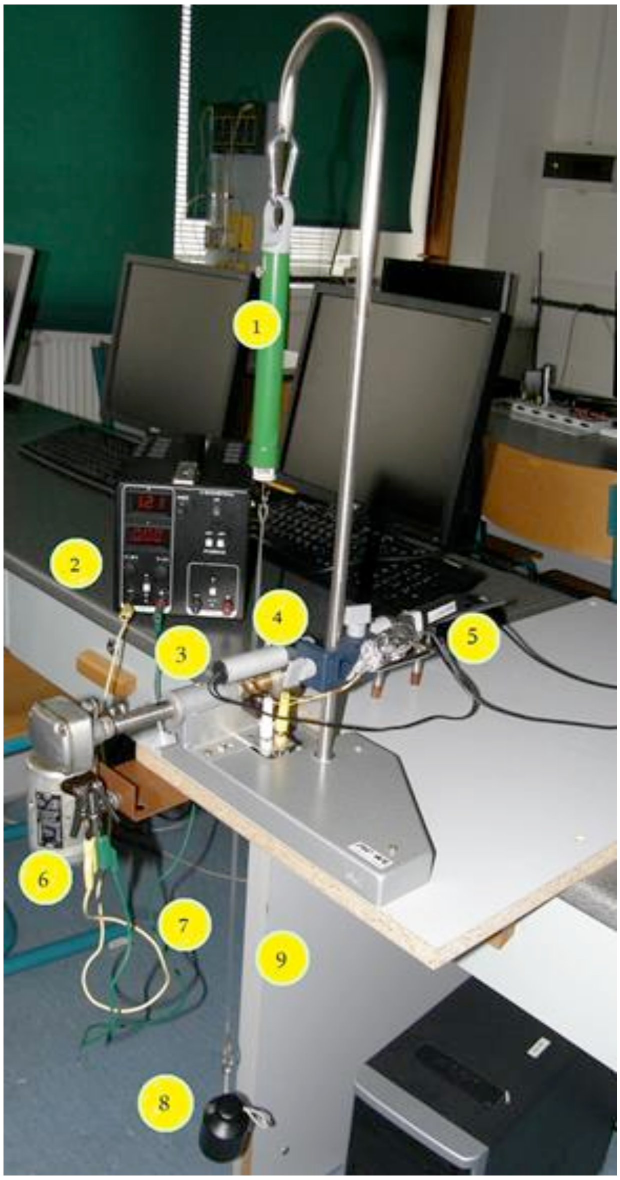

Figure 1. Joule´s laboratory experiment setup (1 – the ISES dynamometer, 2 – the voltage source, 3 – a heated cylindrical metallic body, 4 – the ISES optical gate, 5 – the ISES thermometer, 6 – the driving motor (12 V; 2,2 A), 7 – leads, 8 –the loading weight, 9 – the plastic tape (photo: Z. Kratka)

C. Data collection

The data collection system is based on the Internet School Experimental System (ISES) [1] where the ISES modules for the temperature measurements and the optical ISES gate for the No of revolutions elapsed are used. In Fig. 2 are samples of the experimental data. In the upper part is the record of the signal from the optical gate for the measurement of the number of revolutions during the experiment serving for the calculation of the covered path. Beneath is the recorded signal from the ISES thermometer, measuring the increase of the temperature on the time during the experiment (3-5°C).

III. REMOTE JOULE´S EXPERIMENT

A. *Construction of remote experiment*

The transformation of the laboratory experiment (Fig.1) to its remote counterpart (see Fig. 3) was accomplished using the modules of the ISES thermometer, the ISES optical gate, and the ISES relay for the supply of the driving motor. The ISES RE is based on the state machine principle with the .pds controlling file, and the controlling program in Javascript, compiled using the Easy Remote ISES (ER-ISES) environment [3][4].

The experiment has been connected via our Remote laboratory management system (RLMS) REMLABNET (http://remlabnet.eu) for the general use of EU in the FP7 project Go-lab portal, http://www.golabz.eu) (see [5]).

B. *Two types of diagnosti systems*

The crucial drawback of the existing REs is the lack of feedback of their proper functioning. The clients are then disgusted and are repelled from the regular use of REs as a result. In our current Measureserver two types for the diagnosis of the RE were built in ([5]).

One system (Fig. 4) signals by the “traffic lights” the available experiment ((a) green light), occupation of the experiment (temporary or permanent) ((b) orange light) and out of order experiment – not available for the service (red light (c)).

The second, more sophisticated diagnostic system, watches for the proper functioning of all the components of the RE. In Fig. 5 are displayed the continuous reports in regular time intervals on the state of the physical hardware. By the green color are denoted the correct set up and functions and two typical fault events, indicated by the red color. If the range or the sensitivity of any modules changes (see the event A in Fig. 5, red color), or if any module is disconnected (see the event B in Fig. 5, the red color), the corresponding report occurs and e-m message is sent to the experiment owner and to REMLABNET as a service request.

At the beginning of the remote experiment programming the ISES components and modules of the experiment are collected in the reference list with their sensitivity or ranges (see more details in [5]).

IV. RESULTS AND EVALUATION

Let us present a piece of the theory of the Joules´ experiment. The friction force between the belt and the cylindrical metallic body surface is equal to the difference between the force F_2 measured by the force meter and the weight of the used weight F_1.

$$F_T = F_2 - F_1 \tag{1}$$

The work of friction forces is equal to the friction force multiplied by the path covered by the rotating body

$$W = 2\pi r n\left(F_2 - F_1\right) \tag{2}$$

Where r is the cylinder radius and n is the number of revolutions. This work is compared with the heat

$$Q = mc\Delta T \tag{3}$$

absorbed by the rotating body, where m is the mass of the body and ΔT is its temperature increase the specific heat c that may be determined and compared with that from the tables

$$c = \frac{2\pi\, n(F_2 - F_1)}{m\Delta T}. \tag{4}$$

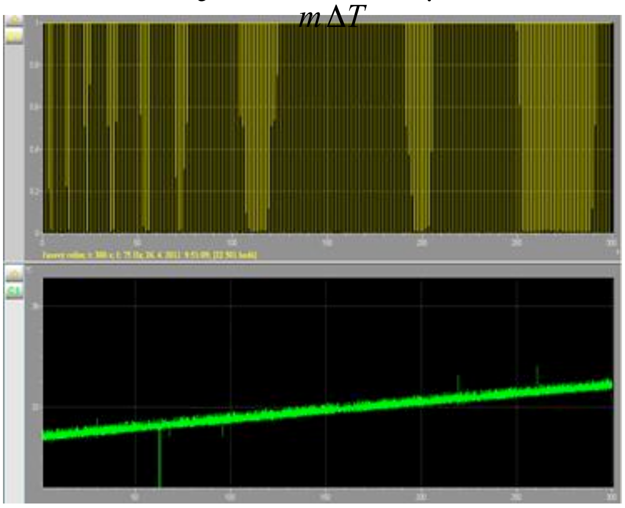

Figure 2. ISES Example of Joule´s experimental data - number of revolutions (upper graph) and the temporal dependence of the temperature increase (lower graph)

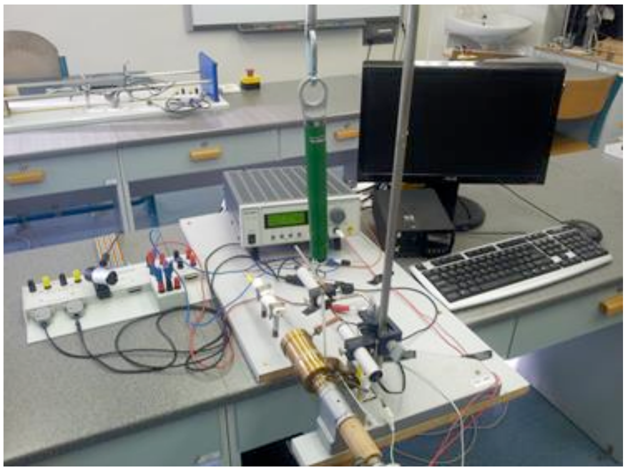

Figure 3. Arrangement of the RE „Joules´ experiment“; ISES control panel (left) with the modules of the ISES thermometer, the ISES optical gate, and the ISES relay for the supply of driving motor

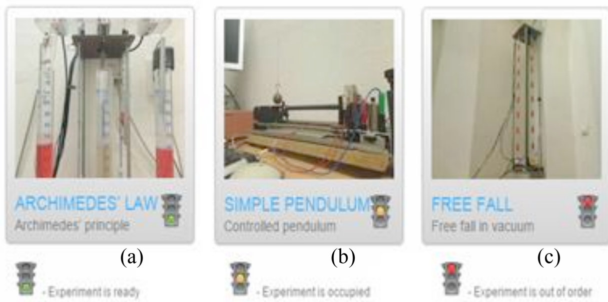

Figure 4. Remote experiments diagnostics I-the “traffic lights” signal availability of the experiment (green) (a), occupation of the experiment (orange) (b) and out of order experiment – not available (red) (c)

[10:29:00] [Measureserver is running] [10:29:30] [Measureserver is running] [10:29:50] [Measureserver is running]
(A) [10:30:30] [PORT:B, NAME:AMPERMETR, ID:000001, UNIT:A, MIN:-0.50, MAX:0.50, STATUS:Connected with wrong reference]
[10:31:00] [Measureserver is running] [10:31:10] [Measureserver is running] [10:31:20] [Measureserver is running]
(B) [10:32:00] [PORT:B, NAME:AMPERMETR, ID:000001, UNIT:A, MIN:-0.50, MAX:0.50, STATUS:Diconnected]
[10:33:30] [PORT:B, NAME:AMPERMETR, ID:100001, UNIT:mA, MIN:-5.00, MAX:5.00, STATUS:Connected]
[10:35:00] [Measureserver is running] [10:35:20] [Measureserver is running] [10:35:30] [Measureserver is running]

Figure 5. Remote experiments diagnostics II record, correctly running (green) and two faults (red) the setup of the remote experiment changed (range of A-meter) (A), one module A-meter disconnected (B)

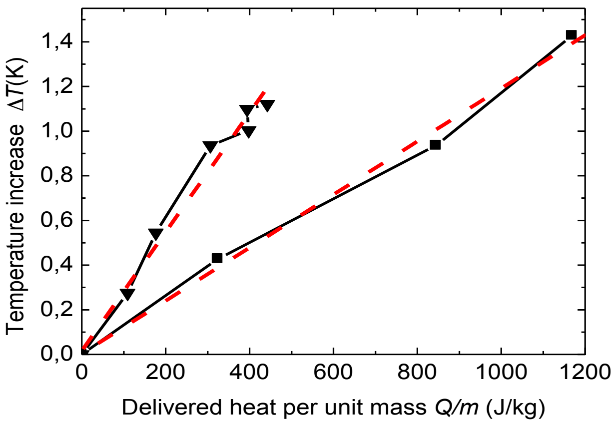

Figure 6. Specific heat evaluation: for brass (▼) and aluminium (■) for various paths covered, various mass of the heated body and variousfriction forces

In Fig. 6 are collected the results of the experiments on both aluminium (table value c_{Al}= 841 J K^{-1} kg^{-1} c_{brass}= 375 J K^{-1} kg^{-1}) cylinders of different weight and weight loads measured at different total No of revolutions. The results gave the values of the specific heat for both aluminium c_{Al} = 841 J K^{-1} kg^{-1} and brass c_{brass} = 375 J K^{-1} kg^{-1} with a very plausible correspondence with the table data.

V. RESULTS AND EVALUATION

The presented remote experiment “Joule´s experiment” constitutes an important tool for teaching physics in general and the teaching of micro-world in particular. The conclusions may be formulated:

The ISES framework both on the level of physical hardware and ISES remote experiments software (ER-ISES) is suitable for the easy construction of a rather wide range of remote experiments, including Joules´ remote experiment

1. The Joules´ experiment was built and optimized as to heat transport, heat losses and running parameters of the experiment and gives reliable results.
2. The new series of remote experiments with diagnostics was initiated, sensing and reporting both the availability of the remote experiment and its functioning.

The remote experiment “Joule´s experiment” was connected and made available via our RLMS REMLABNET network (http://remlabnet.eu) and also to the EU FP7 portal Go-lab (http://www.golabz.eu)

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