Free fall in vacuum: an educational Lab-experiment

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Abstract

Free fall experiments, based on various methods and technologies, can be found in every educational Physics laboratory. The proposed apparatus allows the study of the effect of air resistance in the movement of the falling body. The apparatus is relatively simple and easy to construct, and consists of a tube in which a ping pong ball is dropped. Various conditions of air pressure in the tube, measured with a sensor, can be realized through the use of an air-pump. The motion of the ball is monitored via a series of LED-photo resistor gates which are placed along the tube, and which take measurements of the position of the ball at various points of its path. As the ball falls, it passes through successive photo resistor gates, the signals of which can be collected and analyzed with a common computer program. Taking and analyzing data with the proposed apparatus may be considered as an interesting and useful educational activity for first semester students. In this paper, we present a description of the apparatus, together with some experimental results exhibiting the role of air resistance in the motion of the ball. The experimental data presented were obtained during a typical student laboratory session.

Introduction

Modern technologies of sensors, in combination with the use of personal computers and computer programs gain ground more and more in educational physics laboratories, often providing an alternative, easily accessible and, most importantly, reliable solution for setting up an experiment [1].
In the experiment presented in this work, the aforementioned technologies are implemented for the study of a typical motion: the free fall of a body. This characteristic motion constitutes a beloved subject of educational experiments, mainly because of its relative simplicity in combination with the opportunities it offers for further investigation from the student as an exercise project. Free fall has been the subject of numerous educational experiments, implementing various methods, traditional or more modern ones, as for example the follow-up of the falling body with a video camera [1], by means of a motion sensor [2, 4, 6] or the CCD technique [3].

Materials and Methods

The proposed experimental set up is a simple and inexpensive construction, designed to make it possible for a student to monitor the motion of a falling body in conditions of variable pressure (quasi in vacuum) for educational purposes. The student can directly collect data, and investigate the effect of air friction through the study of the motion of a falling body.

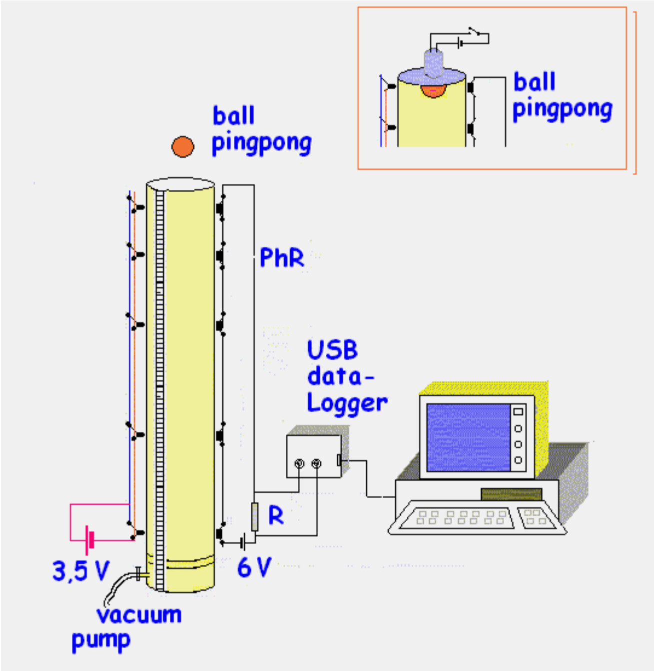

Fig. 1a: A schematically draw of the experimental set up used for the measurements

The proposed set-up :

Cylindrical Plexiglas tube (~2 m long, 10 cm diameter), a set of 7 gates (LED-Photo-resistors), an electro-magnet for holding the falling bodies (ping pong balls), the laboratory vacuum pump and a digital sensor of voltage (PS-2115) and pressure (PS-2107) with the appropriate PC interface (PS-2100) and Software (DataStudio) of Pasco company [6].

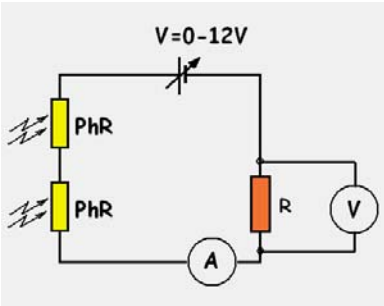

Fig. 1b: The series circuit of the photo-resistors

This set up is based on an older version, by which instead of photo gates was used a system with coils, while the falling body was a little magnet bar [5].

The measurement method is as follows:

In this experiment, the falling body is a ping pong ball initially held at the upper end of the tube by an electromagnet via a small metal pin. Through a control panel, the ball is released. Prior to that, and with the aid of the vacuum pump connected to the tube, airs pressure within the tube is set to the desired value (as measured by a sensor). As the ball falls in the tube, it shadows successively the photo gates which are placed along the tube at certain positions, leading to variations of the voltage across the resistor R of the Photo-resistors circuit. This voltage is measured by a voltage sensor and a typical signal obtained is presented in Fig. 2. Each peak corresponds to the passage of the ball through a photo gate. Knowing the time instant the ball has passed each photo gate and the exact position of each photo gate, one can determine various quantities related to the motion of the ball. The measurements can be repeated under various conditions of airs pressure. Results of the data processing are shown in Fig. 3-7.

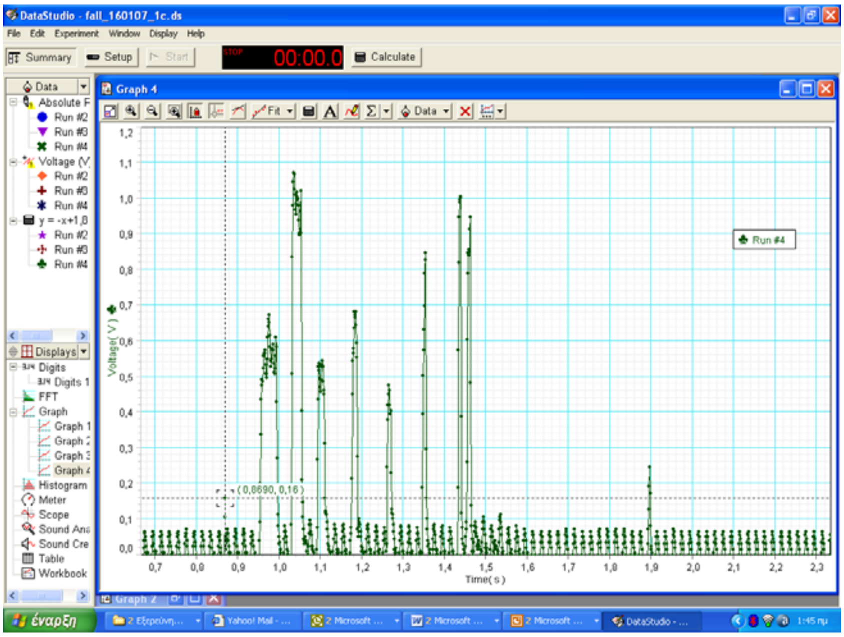

Fig. 2: A print screen produced by the measurement software presenting voltage changes within the circuit vs time.

Results and Discussion

The results of our data analysis presented in the graphs of this section are straightforwardly understood, since they indeed agree with the well known laws and relations governing the fall of a body in air for different values of airs pressure p (Fig. 3 and Fig. 4).

For p = 760 mmHg, the acceleration, a, of the falling body is found smaller than the acceleration due to gravity (g = 9,80 m/s2), since a non-negligible force of friction, T, is exerted on the body by the air apart from its weight W (Fig. 5). As the airs pressure becomes smaller, T decreases and a increases towards g. (Fig. 5 and Fig. 6). Assuming a turbulent flow of the air around the falling ball, the force of friction, T, exerted on the ball is proportional of the square of the instantaneous velocity u of the ball.

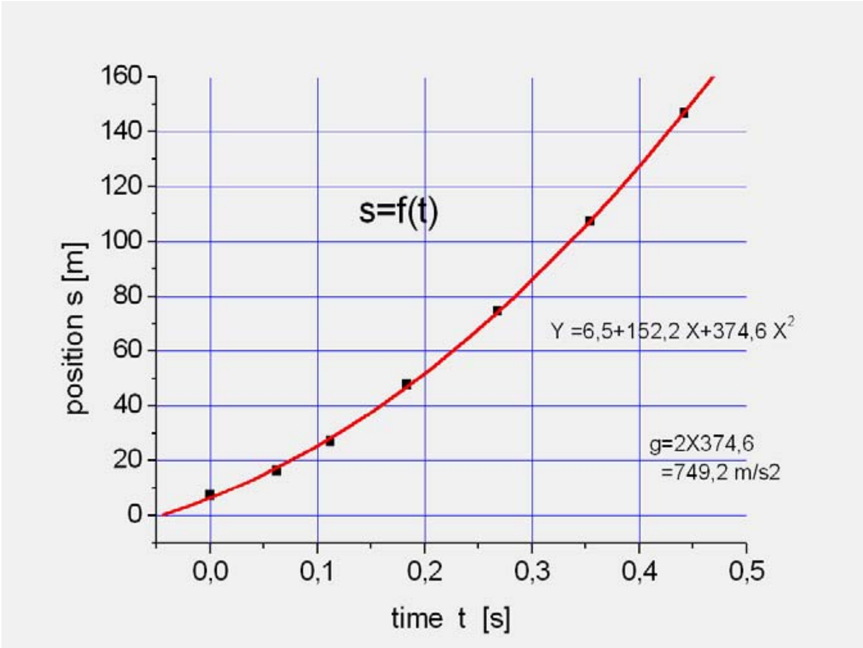

Fig. 3: The position S of the falling body as a function of time t, for eight different values of the airs pressure within the Plexiglas tube in the range 760-20 mmHg.

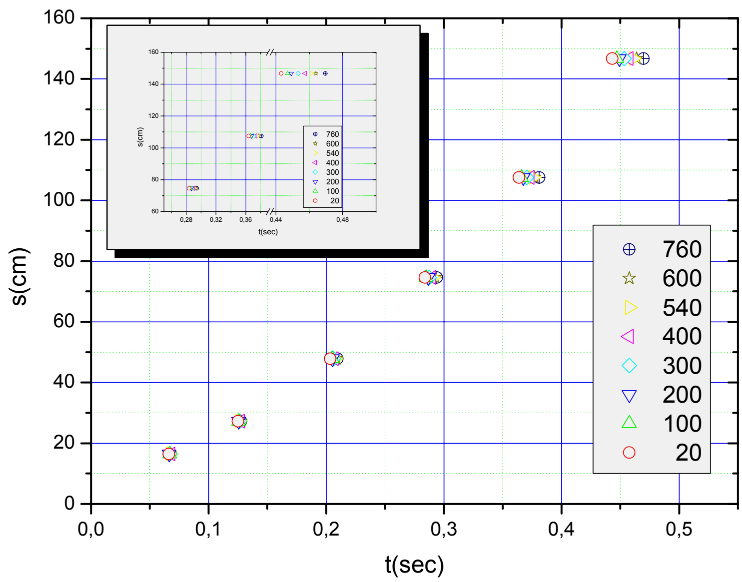

Fig. 4: The position S of the falling body as a function of time t, for airs pressure within the Plexiglas tube equal to 600mmHg.

$$T = \frac{1}{2} d \cdot \eta \cdot S \cdot c_w \cdot v^2$$

where d is airs density, η is the friction coefficient, S is the surface of the body's area facing the air, c_W is a coefficient which in the case of a spherical body takes the value 0.24, and u is the instantaneous velocity of the falling body

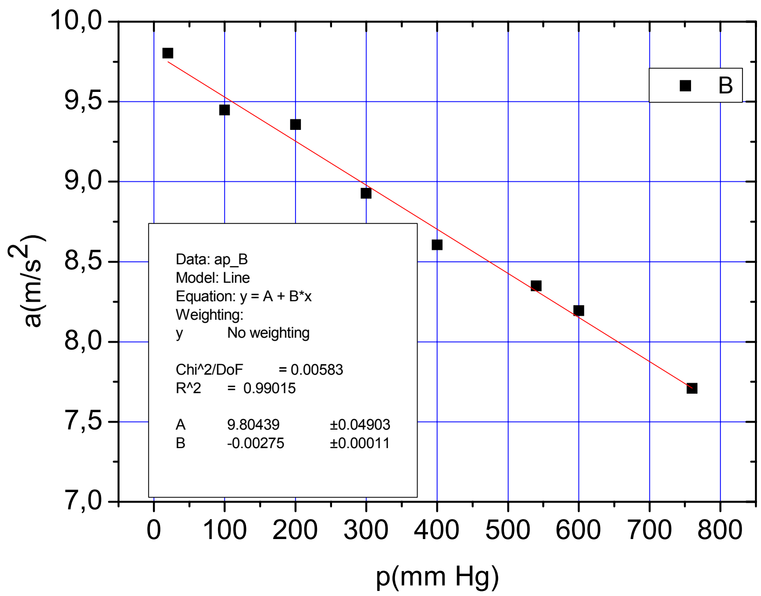

Fig. 5: The acceleration, a, of the falling ball as a function of airs pressure, p, within the Plexiglas tube.

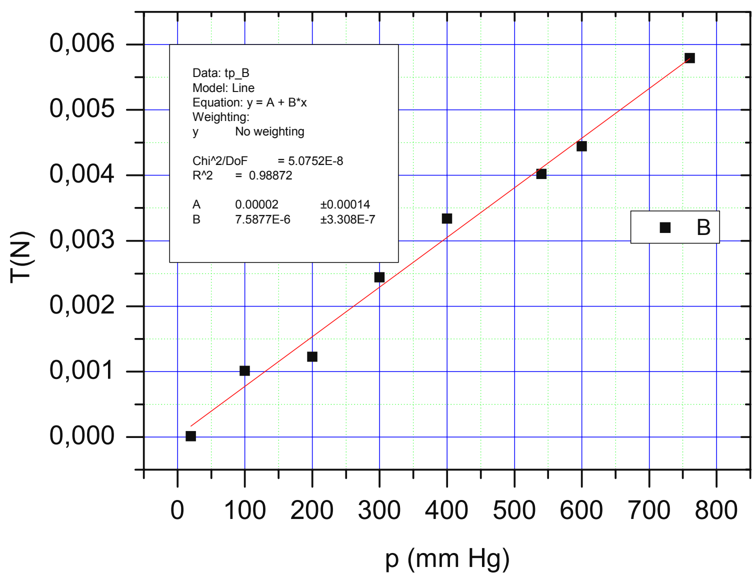

Fig. 6: The force of friction, T, exerted on the ball as a function of airs pressure, p, within the Plexiglas tube

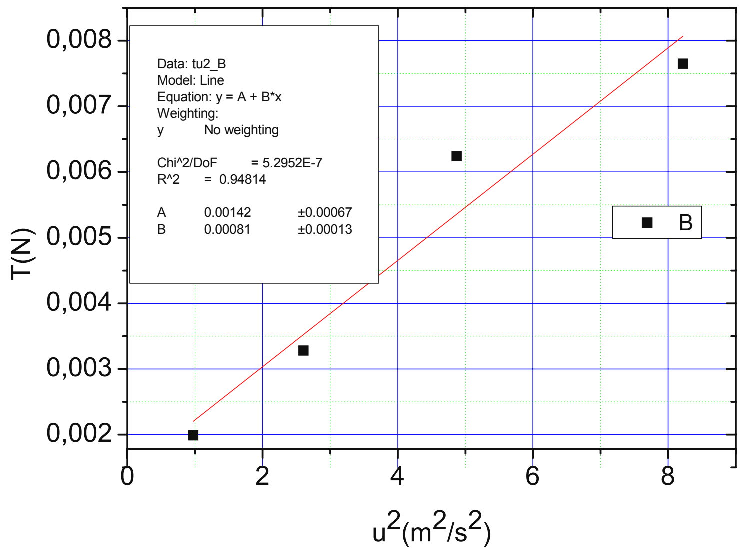

Fig. 7: The force of friction, T, exerted on the ball vs the square of velocity of the falling ball

Further on, one can investigate the dependence of the force of friction T on the instantaneous velocity through the following procedure.
For a given value of the airs pressure P, the first three pairs of time, t, and position, S, of the falling body are used to calculate the initial velocity and the acceleration of the falling body through a best-fit curve. The same procedure is applied for the consecutive three pairs of time, t, and position, S, and so on, until all data values have been exploited. One ends up with four pairs of values for the velocity and the acceleration, and for each such pair one can calculate the force of friction.

Conclusions

In this work, we have presented a computer-aided experiment for studying an object's free-fall and fall within air. The experiment provides a way of calculating the acceleration due to gravity, as well as the acceleration and friction exerted on a body falling within air for different values of airs pressure.
The experimental setup can be built up in any educational Physics Laboratory in a relatively simple and inexpensive way. Data collection and analysis are performed with the aid of modern means of data acquisition (sensors, personal computer, data acquisition and analysis software). This procedure enables students to improve their skills in modern technologies, and, on the other hand, to acquire a more profound understanding of the physical phenomena investigated by this experiment.
We, of course, are aware of the limitations of our relatively simple experimental and theoretical approach. Further refinements on both levels are currently in progress and are going to be presented elsewhere. Nevertheless, we believe that the proposed experiment constitutes a useful educational activity for first semester students, since it can improve their skills in modern technologies and

offer a profound knowledge of the physical phenomena investigated by this experiment.

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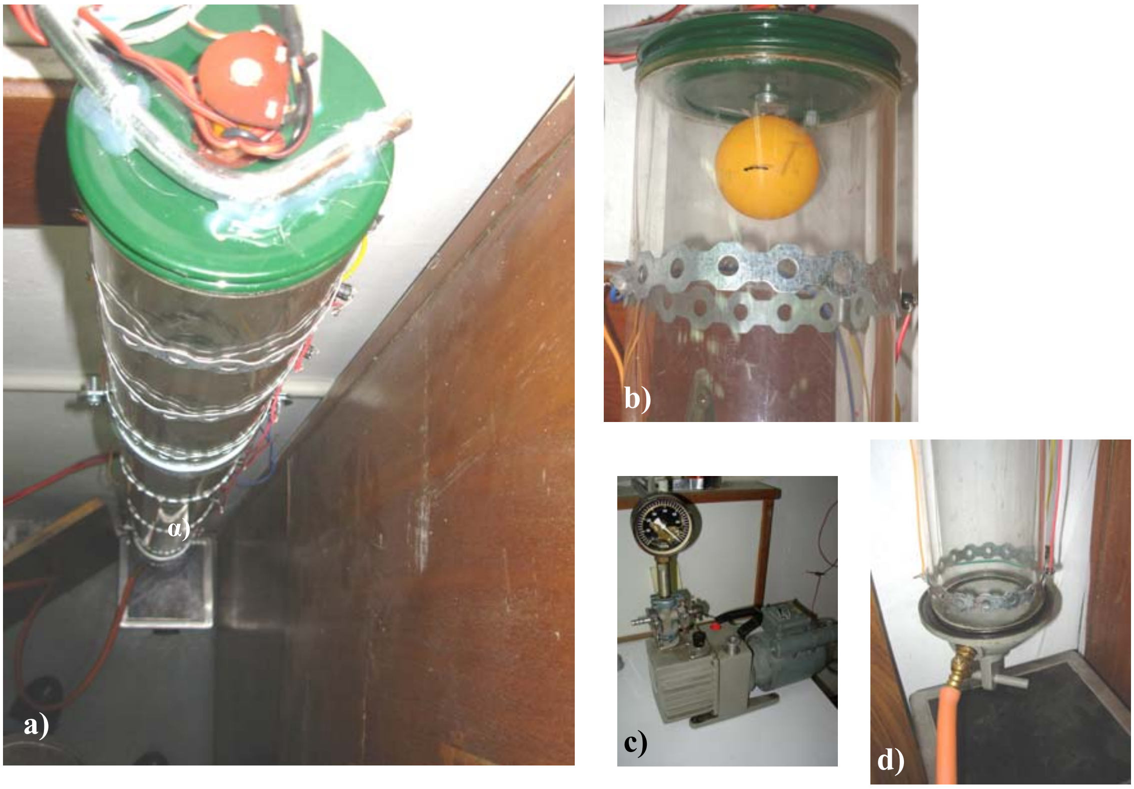

Photos: a) the Plexiglas tube, where free fall in vacuum takes place, b) the electromagnet holding the ping pong ball, c) the pump and d) the air outlet valve.