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Measures on a Foucault's pendulum for schools

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Abstract

We present some measures with the Foucault's pendulum located in the building housing the Physics and Astronomy Department of our University. We shot a movie of the pendulum motion, whose frames have been later analyzed to extract information about the trajectory, for 1 hour. Thanks to this method, the rotation of the oscillation plane has been reconstructed with great accuracy. The educational value of this experiment is pointed out, also for secondary school's students.

Keywords: Foucault's pendulum, Coriolis force, latitude.



Fig. 1 — A couple of photos of our pendulum at the Physics and Astronomy Department, in Florence.

1. Introduction

The Foucault's pendulum has represented the first evident proof of the rotation of the Earth. It has been widely discussed in many articles, often with emphasis on its educational aspects [1-7]. For schools, the experiment represents a great cognitive acquisition, as it reveals the rotation of the Earth and shows the real effect of a fictitious force.

In our approach we used a time-lapse video to record the motion of the pendulum in one hour. Offline, we extracted from the video the positions of the pendulum bob to describe quantitatively the rotation of its oscillation plane, as expected for the action of the Coriolis force. The set-up is very simple and allows to be easily reproduced, for example in the high schools.

2. Details of the apparatus

The pendulum has been mounted in the stairwell at the Physics and Astronomy Department of the University of Florence (Fig. 1). The bob is a lead sphere with radius of 5 cm and mass of about 6 kg, which has been hung up by a 15.30 m harmonic steel wire, 0.50 mm diameter, tightened in a mandrel from above, without any special suspension. The period of the pendulum has been measured as $T = (7.84 \pm 0.01)$ s. The maximum displacement of the bob from its equilibrium position is about 50 cm, giving rise to a maximum angular amplitude of less than 2° .

For the start, the pendulum bob has been moved from its equilibrium position and tied by means of a thin wire to a fixed support; finally, the wire has been burnt. This allowed for a smooth start without any vibration.

The video has been shot in time-lapse mode with a standard videocamera, from a height of about 6 m above the sphere. Because the camera was not exactly on the vertical direction above the pendulum bob, this generated a parallax error, that was corrected offline, as illustrated in Fig. 2.

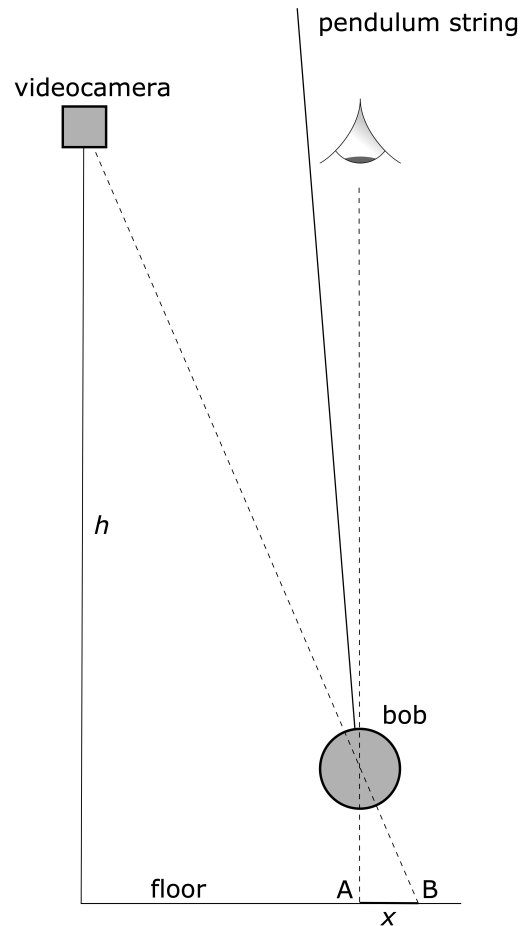


Fig. 2 — The projection of the center of the bob on the floor would be in A, if seen exactly from above. From the position of the videocamera, for a parallax error, the same point is seen in B; this error was corrected by software. The value of x is less than 2 cm in all cases.

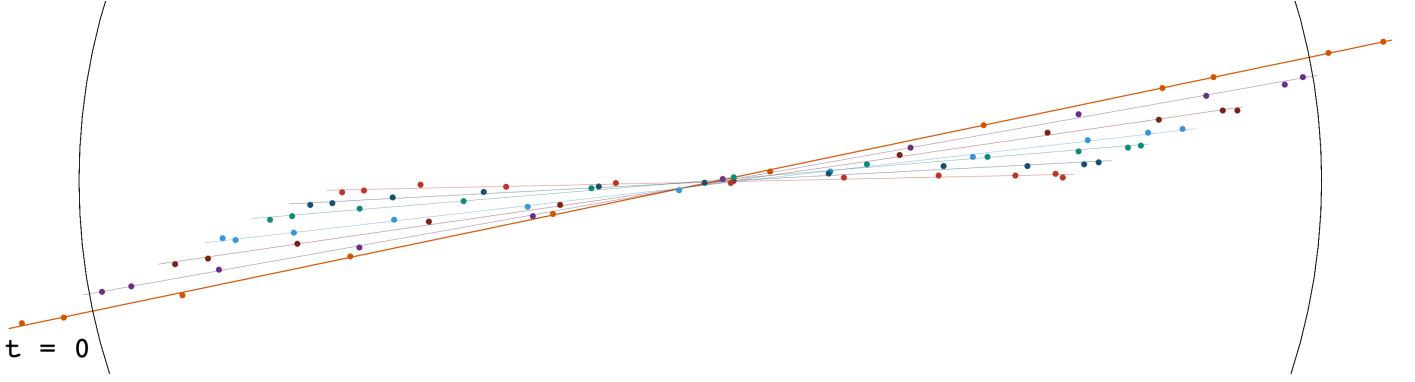


Fig. 3 — Tracks drawn every 10 min by the pendulum bob during a semi-oscillation, with linear fit on the trajectory. The oscillation plane rotates clockwise; points correspond to the positions measured in the screenshots extracted from the video.

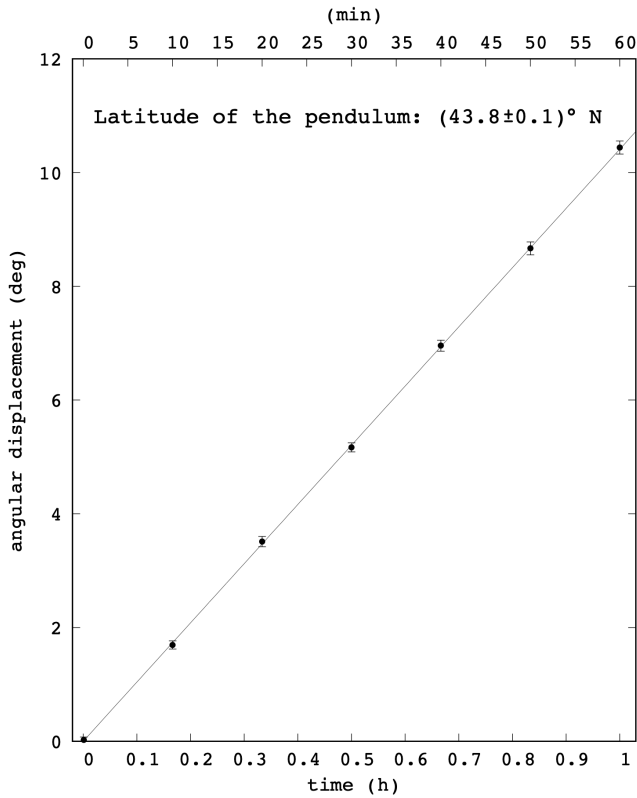


Fig. 4 — Angular displacement of the oscillation plane of the pendulum as a function of time.

The video frames, that are 30 every 4 s in time-lapse mode, have been saved and later opened with a free software (ImageJ [8]), which returns the coordinates of the points where the mouse is positioned. In this way the trajectory of the bob in a semi-oscillation can be drawn with great precision. We actually picked up one frame out of three, corresponding to about ten points in every semi-oscillation. The reconstructed trajectories of the pendulum are shown in Fig. 3 at some selected instants (every 10 min) for one hour of motion. The clockwise rotation of the oscillation plane and also the amplitude damping are clearly visible.

Distances, in pixels, can be converted in meters, just by measuring a reference object in the framed scene: it resulted $1 \text{ px} = 1.17 \text{ mm}$. The estimated uncertainty in the positioning is $\pm 1 \text{ px}$, which accordingly corresponds to about $\pm 1 \text{ mm}$.

3. Results

The angular coefficients obtained by the linear fits shown in Fig. 3 have been converted in angles to determine the rotation of the oscillation plane. In Fig. 4 the angular displacement of the oscillation plane is reported as a function of time. From the linear fit of the data reported in Fig. 4, $\vartheta = m \cdot t$, we determine m (deg/h), the angular displacement per hour. The time needed for a complete rotation of the pendulum in the absence of air friction would be $t_R(\text{h}) = 360^\circ / m$.

The local latitude φ can be calculated as:

$$\varphi = \arcsin [(23.93 \text{ h})/t_R]$$

with the duration of the sidereal day in the argument of the arcsine. The resulting latitude is $\varphi = (43.8 \pm 0.1)^\circ$, in excellent agreement with that of the location of our experiment (43.82° N , 11.19° E).

In Fig. 5 the maximum displacement of the pendulum bob from its equilibrium position is reported as a function of time. The damping follows an exponential behavior:

$$x(t) = x_0 e^{-k t}.$$

However, the description of the damping with Stokes' law applied to the pendular sphere does not return the correct value of the viscosity of the air: probably this model is too much simplified, because does not include the friction of the air also on the string.

4. Final remarks

In the last years of the high school, the programs must include the laws of motion and the discussion on inertial and non-inertial reference systems. This experiment is particularly suited in this context.

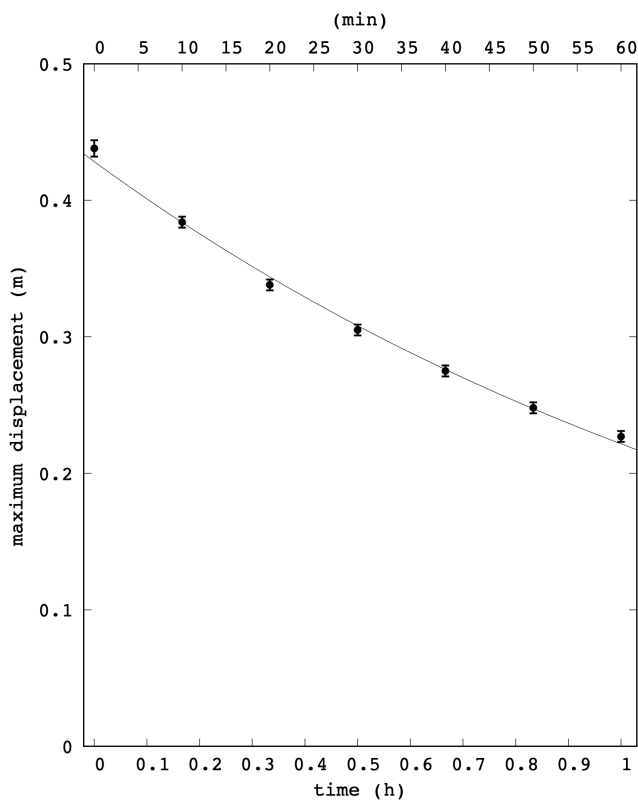


Fig. 5 — Amplitude damping with time.

From the analysis of the trajectories of the pendulum at some instants of the motion, by means of this method we can precisely measure the rotation of its oscillation plane.

Moreover, the experiment allows to determine the latitude at which the laboratory is located.

The experiment is also important for the development of the computer skills required to extract the data from the acquired images and transform them into meaningful graphics.

The experiment can be carried out both on site and remotely. In the first mode, students can be divided in groups and they will be able to actively participate in the experiment by providing themselves the camera (for example, that of a cell phone) with which to capture the motion of the pendulum.

Differently, students can see the video of the experiment at home and later analyze the positions extracted from the frames.

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