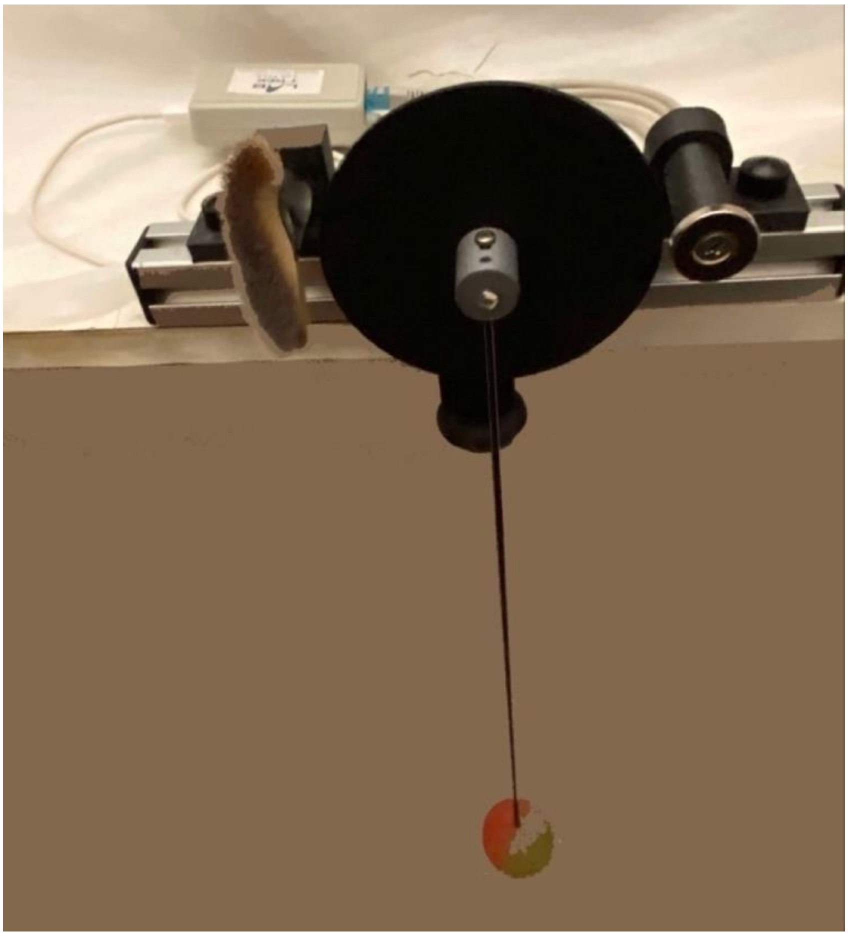
Pendulum with different types of friction
Motion at large/small amplitudes
Smartphone/Tablet compatible



A simple didactic tool that uses real-time data acquisition via smartphone or tablet and a pendulum coupled to a low-friction rotation sensor, with variable effective length and mass, and with two different types of adjustable damping: "*sliding*" friction and "*Viscous*" friction (proportional to the angular velocity).
A dedicated datalogger allows using the *Phyphox* App for Android-IOS to acquire data that can be transferred to a PC for detailed analysis.

The experiments can consist in verifying that:

- the period for small oscillations does NOT depend on the value of the mass *M* (trying with rubber balls of different diameter or attached disc),
- the period for small oscillations depends on the square root of the effective length (by sliding the ball/disc along the rod)
- that the period for large oscillations depends on the amplitude (experimental data can be compared with theoretical predictions)
- that the damping is LINEAR for SLIDING friction
- that the damping is EXPONENTIAL for VISCOUS friction

The experiments can consist in the study of various behaviors of the system:

1) Study of the period for small oscillations (harmonic motion).

- Dependence of the period on the value of the mass *M*. To do this, the pendulum can be loaded with rubber balls of different sizes, or with discs.
- Dependence of the period on the length *L*. To do this, the masses (ball or discs) are made to slide along the shaft.

2) Study of the period for large oscillations (anharmonic motion).

When the maximum elongation of the pendulum (amplitude) is greater than about 10°, the behavior of the pendulum becomes particularly interesting for intermediate or advanced students.
- On the one hand, the period depends on the amplitude and the oscillations of the pendulum are no longer harmonics.
- Many properties of the system associated with its non-linearity become evident and this creates new challenges for its study.
- This device is particularly suitable and flexible to carry out this type of study, the results of which can be compared with various theoretical models.

3) Motion analysis for various types of damping.

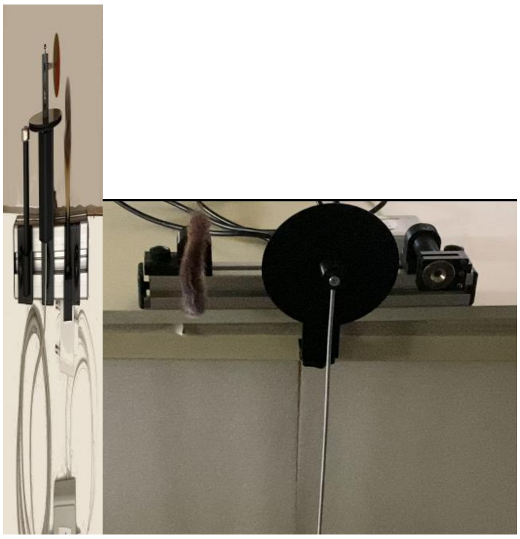
- Study of motion with sliding friction. A LINEAR decrease in amplitude is observed with time. The extent of this damping can be varied.
- Study of motion with viscous friction, ie proportional to speed. An EXPONENTIAL decrease in amplitude is observed with time. The amount of damping can be varied.

The kit includes:

- datalogger with **USB** and **bluetooth** connection
- **small friction rotary sensor**
- thin **carbon fiber rod**
- 2 perforated **rubber balls**
- 2 aluminum **disks**
- **device** to suspend a disc to the rod
- **magnet** mounted on slide
- **brush** mounted on slide
- aluminum **rail**, equipped with a **table-vice**

The experimental apparatus

In this device we use an angle sensor connected to a dedicated data logger, equipped with *bluetooth and USB connections*, which can be controlled from a PC or a *smartphone or tablet*.



The elements that make up the device are: *datalogger*, *rotation sensor*, *rod*, *rubber ball*, *aluminum disks*, *magnet* mounted on slide, *brush* mounted on slide. The sensor and the two slides are mounted on an *aluminum rail*, equipped with a *vice* that allows it to be fixed to the edge of a table (see Figure 1).
The pendulum consists of a rubber ball inserted on a thin (carbon-fiber) rod attached to the pivot of an angle-sensor with *very little friction*.
In order to study both *viscous* and *sliding* friction, an *aluminum disk* is fixed to the sensor axis. In this way the oscillation of the pendulum can be damped by a *resisting torque* M_R produced by two types of forces: a *viscous force* produced by a *magnet* faced to the disk (the eddy currents due to the relative motion of the disk-magnet produce a resisting torque proportional to the angular velocity $M_R = -\gamma\omega$, or a constant resisting torque (sliding friction) produced by a soft brush touching the disk $M_R = -A\ \mathrm{sign}(\omega)$.
- The *intensity* of each friction torque can be varied by adjusting the position of the magnet or brush with respect to the disc.
- The *effective length* of the pendulum can also be changed by sliding the ball along the rod.
- Finally, the *mass* value M can be *modified* by changing the type of rubber ball or disc attached to the rod.

2. The use of phyphox for data acquisition

LabTrek has developed an application for Android and IOS based on the *PhyPhox* application, which can be downloaded for free on the internet.

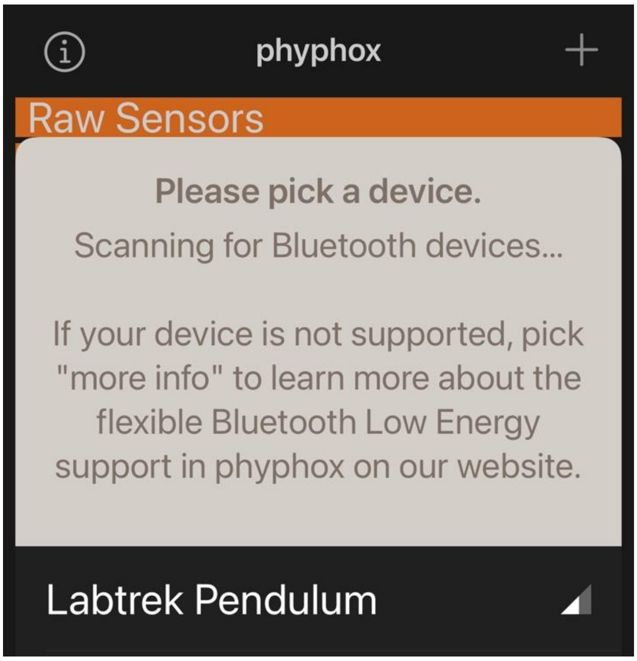


Figure 3 Adding a Bluetooth experiment to PhyPhox and selection of Labtrek Pendulum

To install the LabTrek PhyPhox submenu for the pendulum, just start PhyPhox on the smartphone or tablet, click on the + at the top right, select the option “*Add experiment for Bluetooth device*”.
PhyPhox immediately search for available Bluetooth devices.
You must select “*Labtrek Pendulum*”. Obviously the Labtrek datalogger must be located not too far from the smartphone/tablet that is searching it, since the protocol Bluetooth communication has a range of no more than ten meters.
As soon as the Labtrek datalogger for pendulum has been detected, you may save the Labtrek experiment to the Phyphox list (Fig. 4).

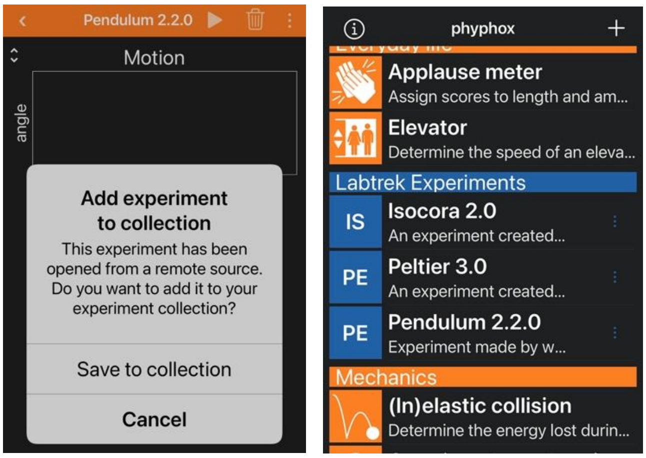


Figure 4 Saving the experiment in a new List of Phyphox experiments

When the data logger is identified, the "Pendulum" window opens for data acquisition (Fig. 5 above). In this window, by clicking on the "arrow" symbol at the top left, you access the version with the "Zoom", "Selection" and "Other tools" options (Fig. 5 below):

The graph of the angle as a function of time might seem at first sight that of a harmonic motion (Fig. 6)

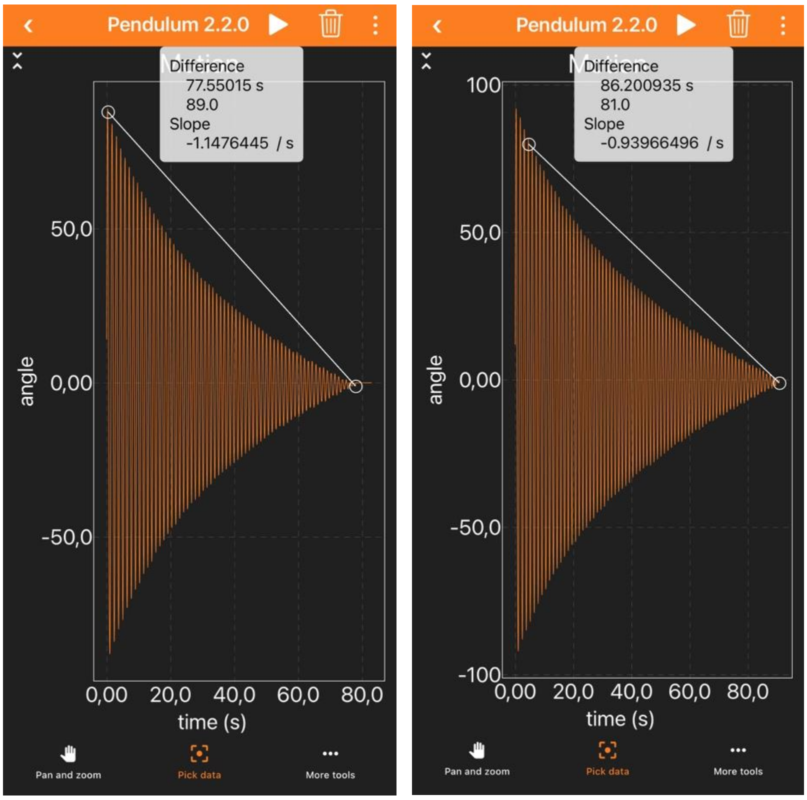


Figure 6 "Free" (left) and magnet damped (right) oscillations

An interpolation of the amplitude at two points reveals that the pendulum dulls in a non-linear fashion (Figure 6 left). Damping, on the other hand, is exponential, due to the viscous friction of the air on the oscillating sphere, and becomes more evident if the "viscous" braking is increased by bringing a magnet close to the aluminum disc (Figure 6 right).

The shape of the graph changes a lot if you brake the disc by touching it with a brush (Figure 7): in this case a linear damping is observed.

The shape of the graph changes a lot if you brake the disk by touching it with a brush (*linear damping*)

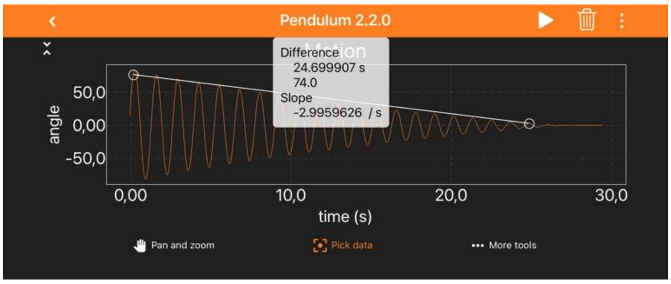


Figure 7. Friction due to the brush (*dry friction*)

The application allows very few manipulation actions of the acquired data: *Zoom*, (for *y* axis and *x* axis) and *Selection* of two acquired points (for which *linear interpolation* is drawn and the *time interval* = $\Delta x = x_2 - x_1$ and *amplitude variation* = $\Delta y = y_2 - y_1$ and *slope* of the interpolating line).
For other manipulations the user must use an external data analysis system (for example Excel©): a click on the word "*More tools*" in the lower window opens the window where you can select "*Export this data set*"

However, even within the PhyPhox-Labtrek application it is possible to do a first data analysis: for example, by selecting a positive peak in the graph and then a second adjacent peak, from the value in the "Difference" field (temporal distance of the two points), the period is obtained. By performing this operation on portions of the graph at different amplitudes, the dependence of the period on the amplitude can be demonstrated (Figure 9).

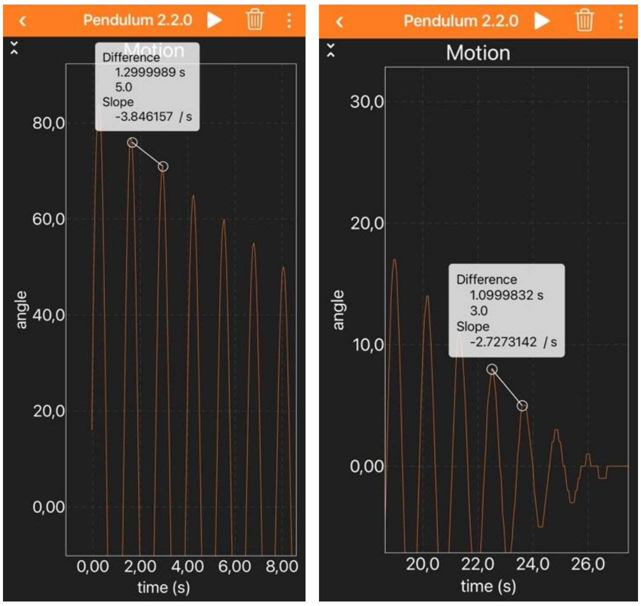


Figure 9 Measurement of the period at different amplitudes

In order to obtain the graphs of Figure 9 in Phyphox, the "Zoom" and "Selection" options must be used.
In the illustrated case we see that the period passes from 1.3 seconds for amplitude about 80 degrees), to 1.1 seconds for amplitude about 10 degrees.
An alternative is to use the "enable remote access" option and command the acquisition from a PC (Figure 10).

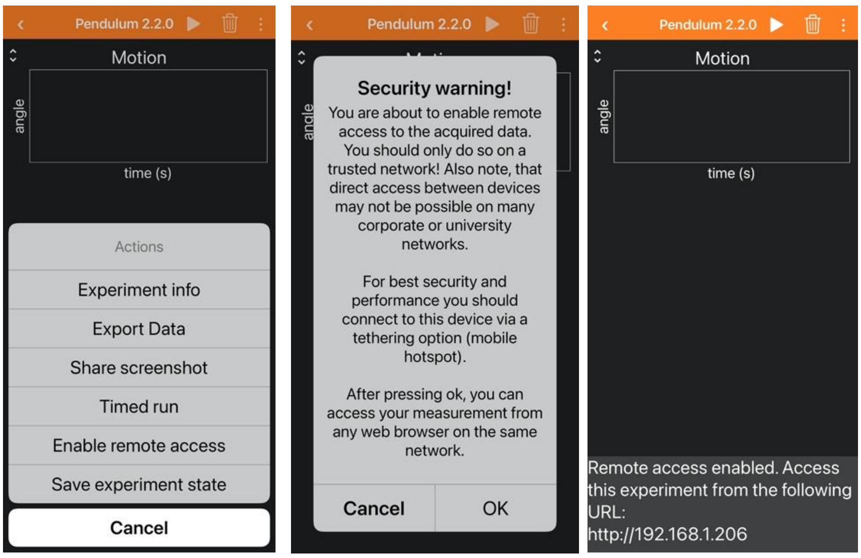
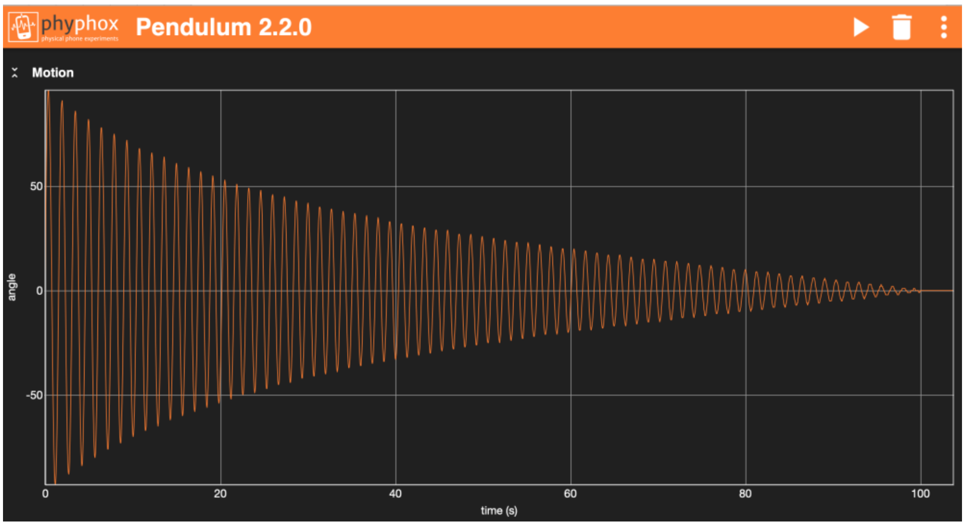
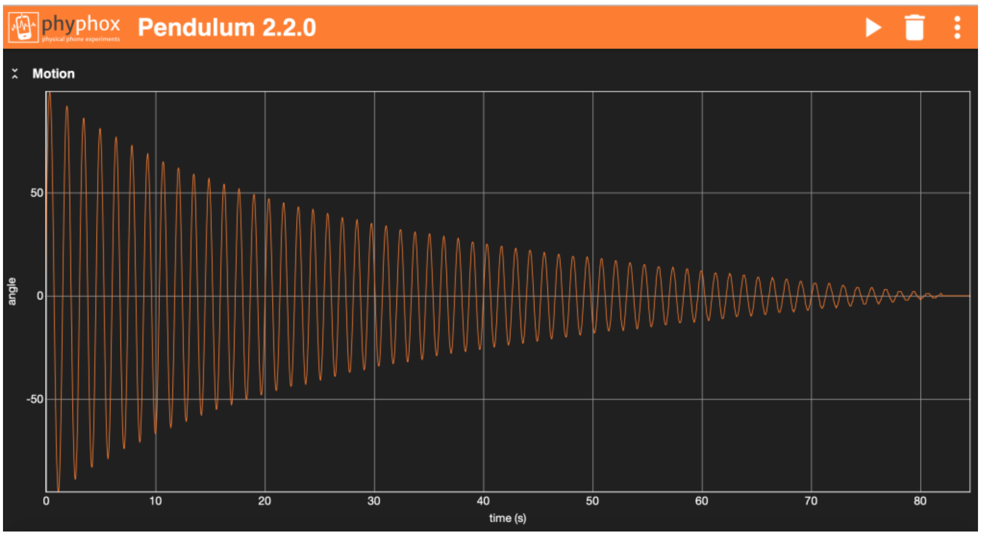


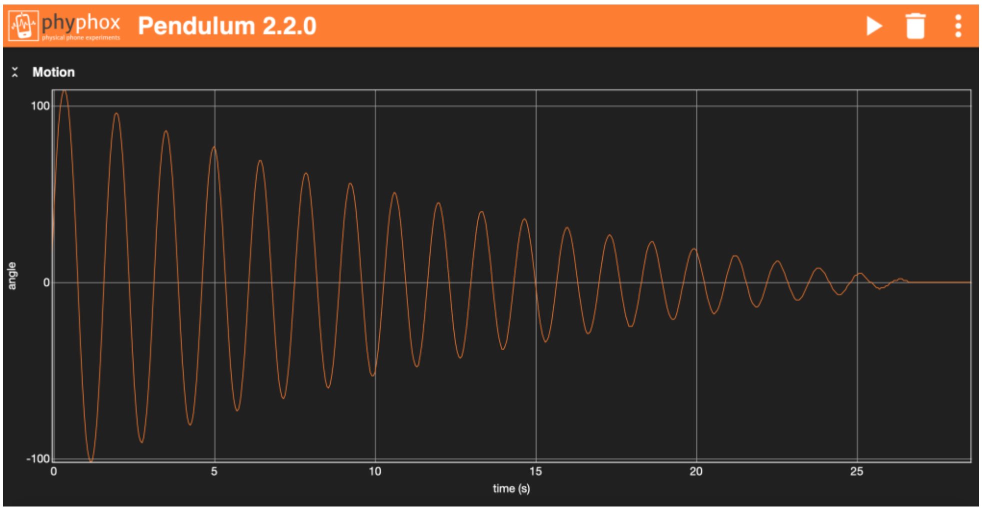
Figure 10 Info window and Remote access from PC



PC screen: Acquisition of free oscillations (viscous friction of air only)



PC screen: Acquisition of oscillations with magnet (higher viscous friction)



PC screen: Acquisition of oscillations damped by the brush (sliding friction)

3. Data acquired replacing the ball with a disc

One example of two data sets acquired with an oscillating disc instead of an oscillating ball (see figure 10) is shown in figure 11.

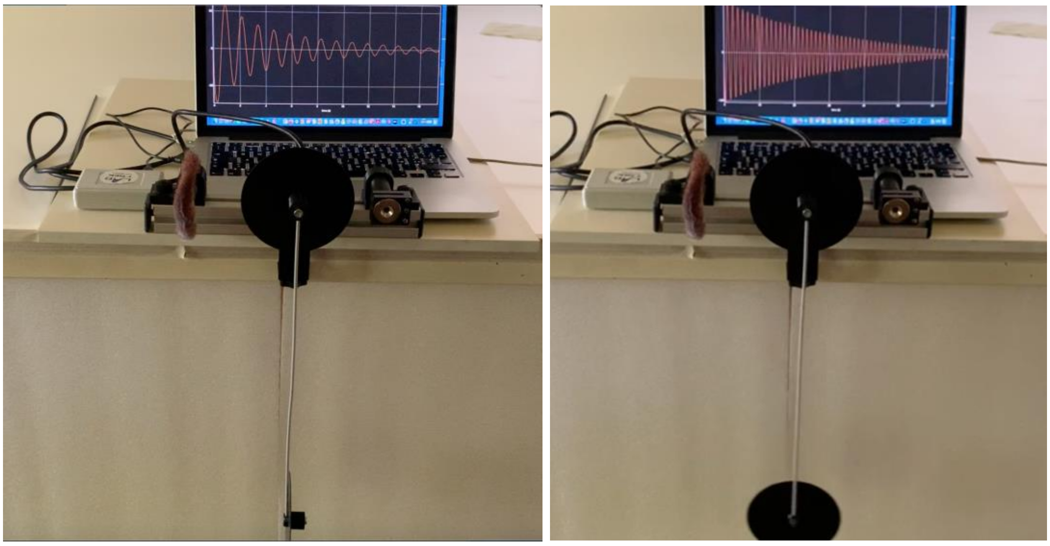


Figure 10 : A disc may replace the ball, using a fitting tool

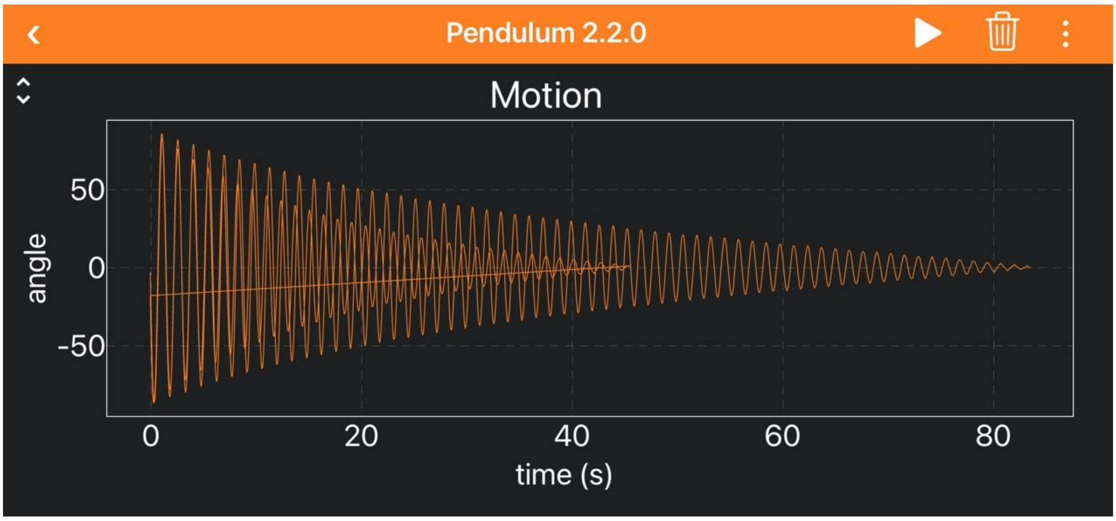


Figure 11 : Two data sets acquired with an oscillating disc.

In figure 11, the longer trace was acquired with the disc in-plane with oscillation plane (smaller viscous friction). The shorter trace was acquired with the disc tilted by an angle of 30 degrees (larger viscous friction). It is evident that by tilting the disc we obtain a stronger damping due to the increased form-factor of the oscillating body.