

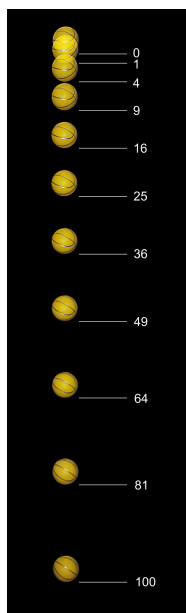
Free Falling

An experiment proposed by:

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Overview

This experiment is devoted to the study of free falling. We are going to investigate how bodies fall within the Earth's gravitational field and, in particular, we are interested in studying the combination of motions in two dimensions and to quantify the acceleration due to gravity g . To perform this experiment we will make use of a smartphone equipped with PHYPHOX, a free App available for major operating systems in their corresponding App stores. Among the possible measurements that can be done with PHYPHOX there is the option of recording the time elapsed between two acoustic events. This measurement is made using the "Acoustic Stopwatch". It starts measuring time when it detects, through the microphone, a sound whose intensity is higher than a user-defined threshold; the chronometer stops when a second event is detected. From physics textbooks we know that the bodies in a uniform gravitational field follow a parabolic trajectory whose equation of motion, in a bidimensional reference frame with a horizontal x -axis and a vertical y -axis, is



$$\begin{cases} x(t) = x_0 + v_x(0)t \\ y(t) = y_0 + v_y(0)t - \frac{1}{2}gt^2 \end{cases}$$

with $g \simeq 9.8 \text{ m/s}^2$. The initial position and velocity of the body are (x_0, y_0) and $(v_x(0), v_y(0))$, respectively. According to these equations, the motion along the x and y directions are completely decoupled and independent on each other. In the following we suppose to ignore the above and we design an experiment to learn that from experience.

Materials & Requirements

1. A smartphone with PHYPHOX installed
2. Few coins of different values
3. A tape measure or a ruler
4. Supports of different heights, with flat surfaces (tables, chairs, boxes, etc.)
5. A stick (a pen, a fork, a ruler, etc.)
6. A scale
7. A computer to record data and produce plots, and optionally data analysis and fitting.

Using the Acoustic stopwatch

You can find the Acoustic stopwatch among the tools in the TIMERS section of PHYPHOX. The threshold, expressed in arbitrary units, should be adjusted such that it is above the environmental noise. The minimum delay avoids having a stop trigger for times shorter than the one given. It can be useful to prevent echoes of the first event, for example, to reach the microphone before the second event happens. Usually default values are ok.

Clicking on the small pulsing triangle on the top-right of the display (start button) the smart-phone starts listening. Clap your hands to start the stopwatch. Claps again to stop it and read the time elapsed between events on the display.

The SEQUENCE tab shows up to five times. After the first event, the time is recorded for the second and successive four events in sequence. Time n shows the time elapsed between event $n-1$ and event n . In the PARALLEL view the same times are shown with respect to the starting event 0. In the MANY tab you can see a graph of the time recorded for each event since the beginning of the experiment together with some statistics. Try clapping several times to see what happens in each view.

You can stop the experiment using the pause button and throw the measurements clicking on the bin icon.

Fall time as a function of initial speed

Put a coin close to the border of a table. Start the acoustic stopwatch, then hit the coin with the tip of the stick. The noise should be sufficient to start the stopwatch. If not, adjust its threshold.

When the coin hits the floor, the noise should stop the chronometer. Read the elapsed time t_i and take note of it. Measure the horizontal distance x_i reached by the coin with respect to the table and note it.

Repeat the experiment at least five times, giving the coin different speeds. The initial speed v_i of the coin must be related with x_i : the longer x_i , the higher v_i .

Make a plot of t_i vs x_i and draw a conclusion from it. Does the time of flight depend on the initial speed of the coin? If not, how long it takes to fall? Express the measurements properly.

Fall time as a function of the height

Repeat the experiment with the coin starting from the border of objects of different heights h_i . For each height take few measurements, then average them.

Make a plot of t_i vs h_i . Does the time of flight depend on h ? How? Try to make a plot of t_i^2 as a function of h . Is the plot consistent with expectations?

Fit the experimental data with a straight line and obtain the parameters. Check if they are consistent with expectations.

Fall time as a function of the mass

Repeat the above experiment with coins of different weight. Estimate the parameters of the line and make a plot of the slope as a function of the coin mass, measured with a scale. Does the time of flight depend on the mass?

General remarks _____

Always try to estimate the uncertainties of each measurement properly. Can you spot any source of systematic error? Can you estimate its size?

Before starting any series of measurements, make few tests to train your ability to perform operations seamlessly. Note the measurements neatly and in a complete way (indicating values, uncertainties and units). Use tables and graphs appropriately.

For the instructor

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1. A simple way to treat the data is to log it on a google spreadsheet. At university level, it would be appropriate to save data in text files, and retrieve the files via python scripts for plotting and fitting.
 2. Check that echoes do not interfere with the measurement. Echoes can trigger the stop of the counter, if intense enough. To evaluate their effects set the delay of the acoustic stopwatch to zero, then produce the trigger sound. If echoes are important, the stopwatch stops before the coin touches the floor. Take note of the time recorded in few experiments and set a delay t_d high enough to avoid echoes. Then, given that $h = \frac{1}{2}gt^2$, set the minimum height of the coin as $\frac{k}{2}gt_d^2$ with $1 < k < 2$.
 3. This experiment has been tested with success at Sapienza Università di Roma, 1st-year physics course, 2020.

Objectives, Level of deployment, and Duration

1. Primary objective: Enjoyment and practice in empirical experiments.
2. Primary objective: Obtaining data that can be plotted and fitted, without requirement of much analysis.
3. Secondary objective: Introduction to digital hardware methods of experimenting.
4. Suitable for: high school; university first year sciences; first year physics. In high school and university first year science, data analysis can be relatively simple. In order to estimate the slope of a linear model $y = \alpha x + \beta$, we suggest to compute all the possible ratio of $\frac{\Delta y}{\Delta x}$ and take the average. Similarly, the intercept can be obtained computing the average of $y - \alpha x$.
5. Duration: 2 or 3 hours of data acquisition, + 1 hour of data plotting, + writing short report.

Further Info Online

Please leave feedback, suggestions, comments, and report on your use of this resource, on the channel that corresponds to this experiment on the Slack workspace “smartphysicslab.slack.com”. Instructors should register on the platform using the form on smartphysicslab.org to obtain login invitation to the Slack workspace, and/or to request being added to the mailing list of smartphysicslab.