

# Determining Gravitational Acceleration Accurately and Simply

**Albino Rafael Pinto**, Agrupamento de Escolas da Lixa, Felgueiras, Portugal

**Carlos Saraiva**, Agrupamento de Escolas de Trancoso, Trancoso, Portugal

There are several ways in the literature to determine the value of gravitational acceleration.<sup>1-7</sup> In this article, we will present a way that allows us to determine the value of gravitational acceleration very accurately using everyday materials. For this, we will use an electromagnet, a coil, a steel sphere, a speaker, an audio cable (3.5-mm jack), a direct current power supply, connecting wires, a computer, and the Audacity software.

In this activity, we will view two electromagnetic signals on the computer monitor and measure the time between them using Audacity. These signals were produced the instant a sphere falls, after it is no longer attracted to an electromagnet, and the instant it hits a wooden plate that has a speaker. We made a short video to illustrate the experimental setup and explain how to measure the time.

Knowing the distance traveled, it is possible to determine the value of the gravitational acceleration. In this experiment we obtained the value of  $9.82 \text{ m/s}^2$  for the gravitational acceleration, with a relative error of approximately 0.20%.

## Procedure

We fixed an electromagnet we built to a support so that it was possible to vary its height. At its end we glued an iron screw with its pointed end facing downwards. Then, we wrapped an enameled copper wire around the electromagnet to form a coil with about five turns. Then, we fixed a speaker (reused from an obsolete device) to a wooden board. This speaker was placed on the ground. Finally, we connected the coil with five turns and the speaker to a computer through the microphone input, with Audacity installed (Figs. 1 and 2). For this,

we used an audio plug (3.5-mm jack) that can be reused from a computer speaker or microphone that are damaged. These types of plugs can also be purchased and are very cheap.

We connected the electromagnet to a direct current power supply and brought a steel ball close to the pointed end of the screw in order to be attracted to it. We started recording with Audacity. Then, we turned off the electromagnet (opening the circuit with the switch), the steel ball fell, and at the same time there was a variation in the magnetic flux (through the electromagnet, which was to induce an electric current in the coil). Audacity detected this induced current (signal 1). For this reason, this coil must have few turns so as not to damage the computer's sound card. If you do not intend to use the sound card of the computer, you can use an external sound card that costs about \$5.00.

When the sphere hit the wooden board, the vibration produced caused the speaker to create an induced current that was also detected by Audacity (signal 2). Finally, we stopped Audacity and measured the time interval between the two signals that corresponded to the time of the sphere's fall. Note: We used an iron screw with a pointed point because the residual magnetism of the electromagnet's iron core (remaining field), when using small mass spheres, can cause them to remain attracted to the electromagnet, even after disconnecting the circuit.

Audacity software is a sound editing program. The induction microphone has a membrane that vibrates when it receives a sound wave. A coil inside the microphone is attached to the membrane, which is assembled on a circuit with a fixed magnet. The oscillation of the membrane varies the flow of

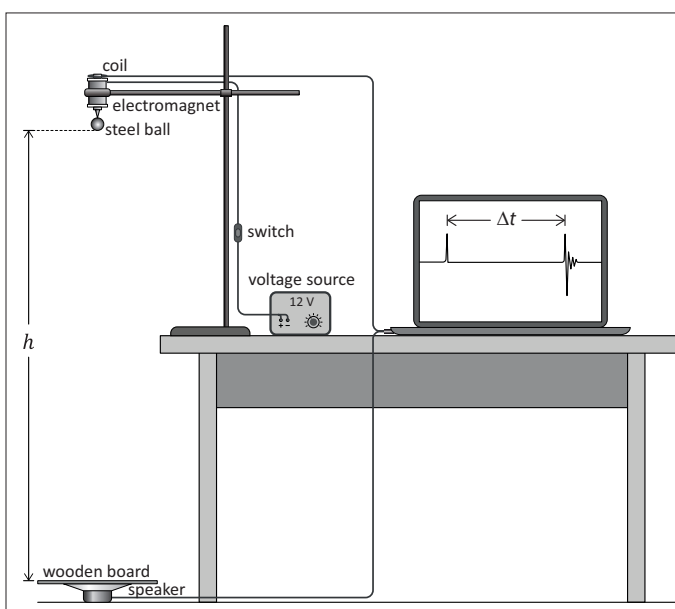
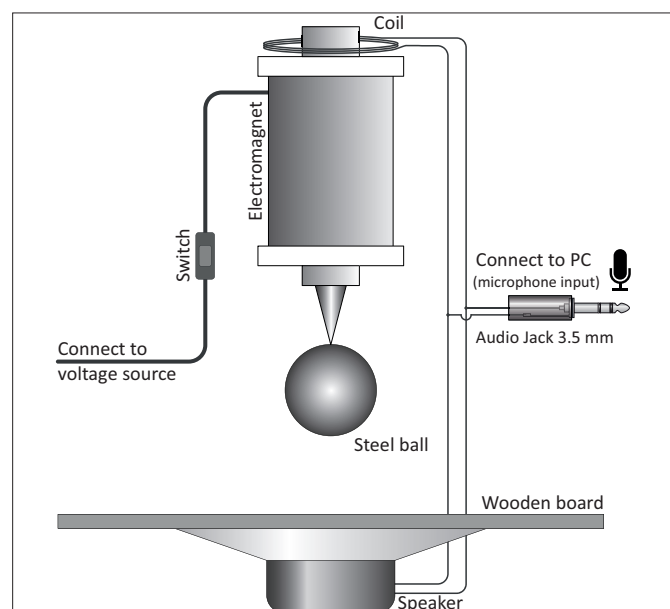


Fig. 1 and 2. Assembly specifications.

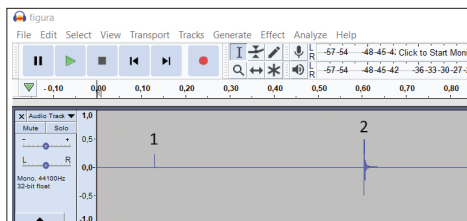


Fig. 3. Recording with Audacity.

Table I. Measured values.

Time / s	Height / m
0.215	0.2266
0.260	0.3286
0.300	0.4369
0.334	0.5433
0.369	0.6647
0.400	0.7819
0.436	0.9277
0.452	0.9980
0.473	1.0952
0.499	1.2192
0.521	1.3262
0.540	1.4267
0.557	1.5209
0.576	1.6315
0.606	1.7962

the magnetic field and creates an induced current that is then converted into a signal that can be recorded by Audacity. Instead of the microphone, we can create an induced current, varying the magnetic field, which is what we did in both situations (when we dropped the sphere and when it hit the wooden board). The software allows you to measure time with a resolution of milliseconds.

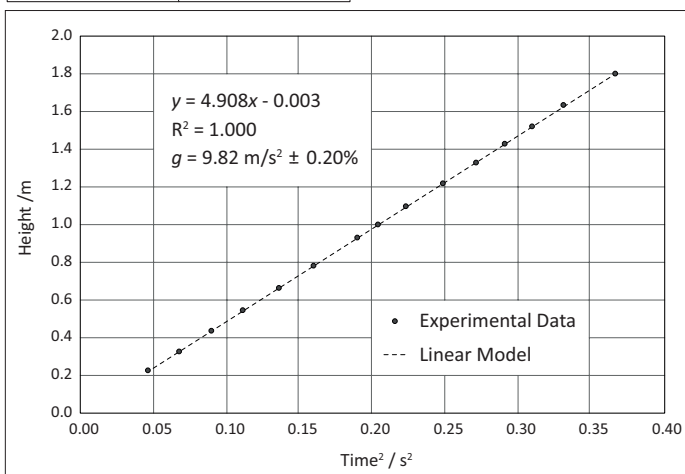


Fig. 4. Graphical depiction of the measured values.

## Results

When the electromagnet is turned off, an electric current is created, which translates into the appearance of a signal on the computer monitor. This instant must be recorded as the start of the fall time. When the sphere hit the wooden board, another sign was created and that moment was recorded as the end. Using the program's zoom function, we can easily measure the fall time that corresponds to the interval between the two signals. To record the time, we only need to click on the graph. We did several tests with different heights and determined the fall time. The records are shown in Table I.

Based on the graph of height as a function of the square of time, we determined the slope of the line whose value corre-

sponds to half the value of gravity:

$$y = 4.908 t^2 = \frac{1}{2} g t^2. \quad (1)$$

Therefore, the value of the gravitational acceleration is:

$$g = 2 \times 4.908 \text{ (m/s}^2\text{)}, \quad (2)$$

approximately 9.82 m/s<sup>2</sup>. Thus, the percent relative uncertainty will be:

$$\%e = \frac{g_{\text{exp}} - g_{\text{teo}}}{g_{\text{teo}}} \times 100\% = \frac{9.82 - 9.80}{9.80} \times 100\% = 0.20\%. \quad (3)$$

This process that we present has the advantage of using spheres of different masses and also allows us to vary the fall height quickly. It is important that students can vary these two factors to conclude that the value of the gravitational acceleration is constant.

We made a short video to illustrate the experimental setup and explain how to measure the time: <https://www.youtube.com/watch?v=CcJlrWz393M&feature=youtu.be>.

## References

1. J. Kim et al., "A measurement of gravitational acceleration using a metal ball, a ruler, and a smartphone," *Phys. Teach.* **58**, 192–194 (March 2020).
2. Unofre Pili, Renante Violanda, and Claude Ceniza, "Measurement of  $g$  using a magnetic pendulum and a smartphone magnetometer," *Phys. Teach.* **56**, 258–259 (April 2018).
3. Florian Theilmann, "Going nuts: Measuring free-fall acceleration by analyzing the sound of falling metal pieces," *Phys. Teach.* **54**, 182–183 (March 2016).
4. Oliver Schwarz, Patrik Vogt, and Jochen Kuhn, "Acoustic measurements of bouncing balls and the determination of gravitational acceleration," *Phys. Teach.* **51**, 312–313 (May 2013).
5. Patrik Vogt, Jochen Kuhn, and Sebastian Müller, "Experiments using cell phones in physics classroom education: The computer-aided  $g$  determination," *Phys. Teach.* **49**, 383–384 (Sept. 2011).
6. J. A. White, A. Medina, F. L. Román, and S. Velasco, "A measure of  $g$  listening to falling balls," *Phys. Teach.* **45**, 175–177 (March 2007).
7. James L. Hunt, "Five quantitative physics experiments (almost) without special apparatus," *Phys. Teach.* **43**, 412–416 (Oct. 2005).
8. M. B. Hunt and K. Dingley, "Use of the sound card for datalogging," *Phys. Educ.* **37**, 251–253 (May 2002).
9. The Audacity sound editor is freeware and available for download at <http://audacity.sourceforge.net>.

Agrupamento de Escolas da Lixa, Portugal;  
albinorafaelpinto@gmail.com