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# LISTENING TO GRAVITY

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2. Spring.
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How can you use the computer sound card for measuring the aceleration due tu gravity $g$?

We present three experiments (spring, pendulum and parabolic throw) for measuring the acceleration due to gravity g, using a computer sound card.
In each case, a device is connected to the audio input and an audio editing software is used for recording the electric signal generated by the device. This method allows time measurements with an accuracy of about $10^{-4}$ s.

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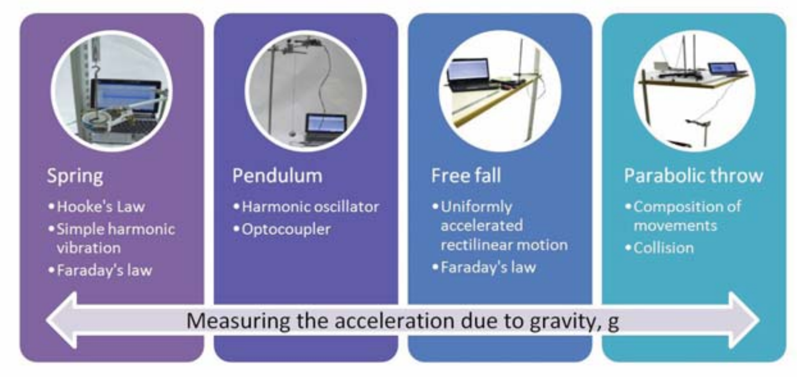
- In the mass-spring system, the signal comes from the electric current generated in a coil by a magnet attached to the mass hanger.
- In the pendulum case, the signal comes from an optocoupler that detects the motion of the thread.
- In the parabolic throw case, the signal comes from the sound generated by a steel ball, stroked by another ball, from a known height.

These experiments are enriched with other physical phenomena that contribute to learning with the support of new technologies.



**Spring**
- Hooke's Law
- Simple harmonic vibration
- Faraday's law

**Pendulum**
- Harmonic oscillator
- Optocoupler

**Free fall**
- Uniformly accelerated rectilinear motion
- Faraday's law

**Parabolic throw**
- Composition of movements
- Collision

Measuring the acceleration due to gravity, g

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## SPRING.- INTRODUCTION

A small neodymium magnet, a copper coil, a laptop and a sound analysis software program (for instance *Audacity* [1]) are used to determine the period of a oscillating mass-spring system [2] and therefore the spring constant $k$.

It is possible to calculate $g$ using previously *Hooke's Law* [3] to find out the ratio $k/g$.

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## SPRING.- OBJECTIVES

- To calculate the spring constant.
- To measure the period of a oscillating mass-spring system.
- To determine the acceleration due to gravity, $g$.

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## SPRING.- MATERIAL

- A coil spring.
- A stand with a ruler.
- Support for mass with neodymium magnet and circular masses.
- A plastic tube with a copper coil connected to the audio input of a computer.
- A PC and audio recording software.

# SPRING.- THEORETICAL BACKGROUND.

Hooke's Law $F = -kz$ allows to determine the ratio $k/g$ measuring, at equilibrium, the displacement $z$ due to different masses $m$ hanging spring:

$$0 = -kz + mg \Rightarrow m = \frac{k}{g} z\,. \tag{1}$$

The spring oscillation period $T$ is given by:

$$T = 2\pi\sqrt{\frac{m}{k}} \Rightarrow k = 4\pi^2 \frac{m}{T^2}\,. \tag{2}$$

Known $k$ from the expression (2) and $k/g$ from (1) is easy to deduce $g$:

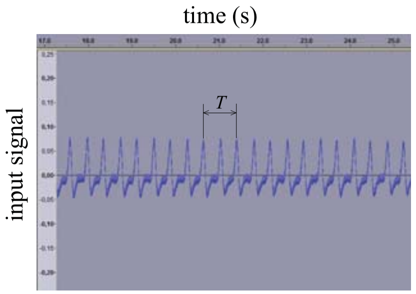
$$g = \frac{k}{k/g} = \frac{4\pi^2 m/T^2}{k/g}\,. \tag{3}$$

# SPRING.- EXPERIMENTAL METHOD (I).

A coil spring is hanged over a clamp and stretched with a (non-magnetic) mass hanger and slotted masses.
The magnet is glued to the bottom of the hanger.
A coil of 15 turns of enamelled copper wire (0.01 cm diameter) is wound around a plastic tube 2 cm long, with an inner diameter of 4,9 cm and a thickness of 0,15 cm.
The plastic tube is horizontally clamped with an aluminium alloy pincer, so that the magnet is located in the coil centre.
The coil ends are connected to the audio input of a laptop. A free software program for recording and editing sounds is available in the laptop.

# SPRING.- EXPERIMENTAL METHOD (II).

Once the mass-spring system is put to oscillate vertically, the recording button is activated. According *Faraday's law* of magnetic induction, the oscillation of the magnet through the coil generates a periodic electric signal that is recorded by the laptop.



# SPRING.- EXPERIMENTAL METHOD (III).

The period of the oscillating mass-spring system is given by the time between two alternated peaks ($i$ and $i+2$): $T = t_{i+2} - t_i$.
This is because the magnet passes through the coil twice in one cycle.
The time of a peak is measured by placing the cursor in the peak (a horizontal zoom of the signal can be useful to determine the location of the peak).
In order to reduce errors associated with the location of the peaks, it is advisable performing the measurement of the times of the peaks $i$ and $i+20$, so that $T = \frac{t_{i+20}-t_i}{10}$.

# SPRING.- RESULTS

The experiment was performed by first year students of the Physics Degree in Salamanca, Spain.

| **Magnitud** | **Value ± uncertainty** |
|---|---|
| Ratio $k/g$ | $k/g = 0{,}302 \pm 0{,}004\,\mathrm{kg/m}$ |
| Oscillation period $\Delta m = 10\,\mathrm{g}$ | $T = 0{,}59907 \pm 0{,}00002\,\mathrm{s}$ |
| Oscillation period $\Delta m = 20\,\mathrm{g}$ | $T = 0{,}70531 \pm 0{,}00002\,\mathrm{s}$ |
| Oscillation period $\Delta m = 30\,\mathrm{g}$ | $T = 0{,}79238 \pm 0{,}00002\,\mathrm{s}$ |
| Spring constant | $k = 2{,}94 \pm 0{,}05\,\mathrm{N/m}$ |
| Acceleration of gravity* | $g = 9{,}74 \pm 0{,}03\,\mathrm{m/s^2}$ |

* Note that the acceleration due to gravity in Salamanca, as reported by Instituto Geográfico Nacional of Spain is $g = 9{,}8004662\ \mathrm{m/s^2}$.

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# SPRING.- DATA FROM THE EXPERIENCE (I)

Hooke's Law $F = -kz$ allows to determine the ratio $k/g$:

$$0 = -k\Delta l + \Delta m \cdot g \Rightarrow \frac{k}{g} = \frac{\Delta m}{\Delta l} \tag{4}$$

| $m\,(\mathrm{g})$ | $l\,(\mathrm{cm})$ | $\Delta l\,(\mathrm{cm})$ |
|---|---|---|
| $m_0$ | | |
| $\Delta m =$ | | |

$$\frac{k}{g} = \underline{\hspace{3cm}} = \qquad\qquad kg/m \tag{5}$$

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# SPRING.- DATA FROM THE EXPERIENCE (II)

The spring oscillation period $T = 2\pi\sqrt{m/k}$

| $\Delta m\,(\mathrm{g})$ | $T\,(\mathrm{s})$ | $T_2^2 - T_1^2$ |
|---|---|---|
| 10 | | |
| 20 | | |

$$k = 4\pi^2 \frac{\Delta m_2 - \Delta m_1}{T_2^2 - T_1^2} \Rightarrow k = 4\pi^2 \underline{\hspace{2cm}} = \qquad\qquad N/m \tag{6}$$

Known $k$ from the expression (6) and $k/g$ from (5) is easy to deduce $g$:

$$g = \frac{k}{k/g} \Rightarrow \frac{k}{k/g} = \underline{\hspace{2cm}} = \qquad\qquad m/s^2 \tag{7}$$

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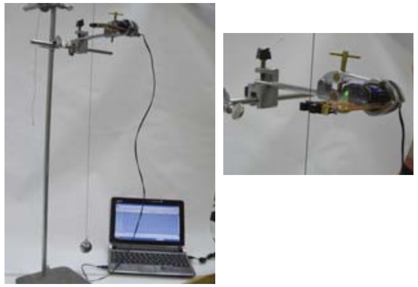
# PENDULUM.- INTRODUCTION

In order to calculate the period of a simple pendulum we utilize an U shaped optocoupler and a free audio recording software [4] (for instance *Audacity* [1]).

In this way it is possible to detect the periodic electric signal induced in the optocoupler and to measure periods with much more precision (around $10^{-5}$ s) than a classical chronometer.



# PENDULUM.- OBJECTIVES

- To determine the acceleration due to gravity, $g$, by measuring the period of a simple pendulum.

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# PENDULUM.- MATERIAL

- Tripod and supporting bar, unextendable thread, and ruler.
- Metallic sphere (pendulum bob).
- Optocoupler connected to the audio plug of a computer.
- PC and audio recording software.

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# PENDULUM.- THEORETICAL BACKGROUND.

It is well known that for small amplitudes the period of a simple pendulum depends only on the length of the pendulum, $L$ and on the acceleration of the gravity, $g$, through the equation:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{L}{g}}\,. \qquad (8)$$

Thus, measuring the length $L$ with a ruler and determining the period $T$ is easy to obtain $g$.

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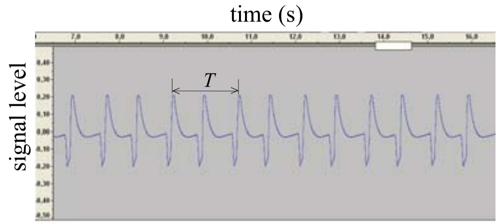
# PENDULUM.- EXPERIMENTAL METHOD (I).

We use an U-shaped optocoupler working both as a transmitter and receiver, that was recycled from a mechanical PC mouse. After suspending the pendulum bob from the supporting bar, the optocoupler is placed 7 or 8 cm below the axis with the help of a clamp in such a way that the thread crosses the center of the optocoupler during the swinging back and forth of the pendulum bob. Thus, the pendulum oscillates along the axis of the U-shaped optocoupler.

## Pendulum.- Experimental method (II).

When the pendulum is oscillating (even with very low amplitude oscillations), the recording mode of the audio software is activated. The thread crosses the optocoupler beam and the output signal changes. This change is detected by the sound card of the PC and the audio software producing periodic signals like that shown in this figure:



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## Pendulum.- Experimental method (III).

The period of the oscillating motion is given by the time distance between alternating signal peaks ($i$ and $i+2$), because the threat crosses twice the beam in a cycle.
The audio software (*Audacity* [1] in our case) allows to zoom the signal and to measure time distances by using the mouse as a pointer.
With the aim to reduce the uncertainties associated to the peaks location we suggest to measure the distance between non-consecutive peaks, for example, $i$ and $i+20$, so,
$T = \dfrac{t_{i+20} - t_i}{10}$.

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## Pendulum.- Data from the experience

Data from the metallic sphere (pendulum bob):
$m = 33,0$ g; $d_1/2 = 1{,}1\,\text{cm}$
Pendulum length (m):
$L =$ cm
Pendulum period $T$ (s):
$T =$ s

$$T = 2\pi\sqrt{\frac{L}{g}} \Rightarrow g = \frac{4\pi^2}{T^2}L = \frac{4\pi^2}{\qquad\qquad} = \qquad\qquad m/s^2 \tag{9}$$

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## Pendulum.- Results

Example of the measured periods with the corresponding uncertainties and the value obtained for $g$ after a least square fitting. The experiment was performed by first year students of the Physics Degree in Salamanca, Spain.

| **Pendulum length (m)** | **Period ± uncertainty (s)** |
|---|---|
| 0,4460 | $1{,}33979 \pm 0{,}00002$ |
| 0,5385 | $1{,}47215 \pm 0{,}00002$ |
| 0,6280 | $1{,}59057 \pm 0{,}00002$ |
| Acceleration of gravity*<br>$g = 9{,}78 \pm 0{,}02$ m/s$^2$ | |

* Note that the acceleration due to gravity in Salamanca, as reported by Instituto Geográfico Nacional of Spain is $g = 9{,}8004662$ m/s$^2$.

# PARABOLIC THROW.- INTRODUCTION

The method consists of throwing, with the help of a pendulum, a stainless steel ball from a known height onto the floor and measuring the fall time by recording the sounds produced by the collisions with the pendulum and the floor [4].
A free audio recording software (for instance *Audacity* [1]) is used to detect the signal and measure time more accurately (around $10^{-5}$ s) than a classical chronometer.

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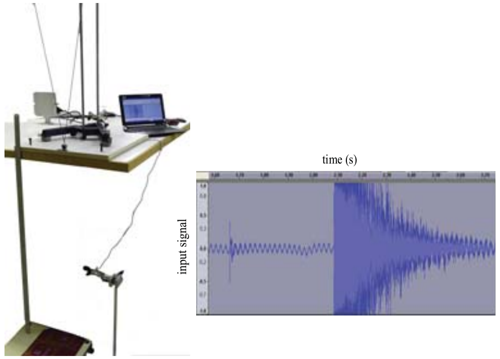
# PARABOLIC THROW.- OBJECTIVES

- To determine the acceleration due to gravity, $g$.



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# PARABOLIC THROW.- MATERIAL

- Two tables with leveling screws.
- Two stainless steel balls of known mass and radius, one of them forming a pendulum.
- A PC and audio recording software.
- A ruler (1 meter long). A tracing paper (carbon paper).

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# PARABOLIC THROW.- THEORETICAL BACKGROUND.

If $\mathrm{v}_{\mathrm{A}}$ is the initial horizontal velocity of ball A after the collision with the ball B, its trajectory in the gravitational field is given by equations:

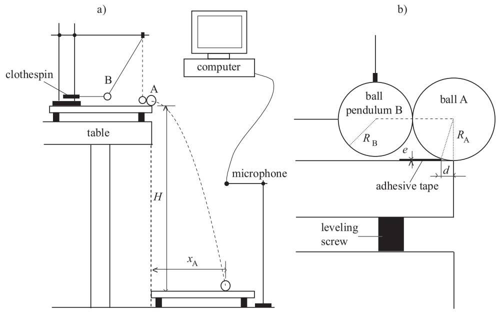
$$x = x_0 + \mathrm{v}_{\mathrm{A}} t \qquad \text{and} \qquad y = y_0 - \frac{1}{2} g\, t^2 \,, \tag{10}$$

where $g$ is the acceleration due to gravity and $(x_0, y_0)$ the coordinates of the object at $t = 0$
Taking $x_0 = 0$ and $y_0 = H$, the value of the fall time, $t_{\mathrm{A}}$, allows determining the acceleration of gravity by expression:

$$g = \frac{2H}{t_{\mathrm{A}}^2} \qquad \text{and} \qquad \mathrm{v}_{\mathrm{A}} = \frac{x_{\mathrm{A}}}{t_{\mathrm{A}}} \,, \tag{11}$$

while measuring the horizontal distance, $x_{\mathrm{A}}$, allows the knowledge of the initial speed of the ball A.

# PARABOLIC THROW.- EXPERIMENTAL METHOD (I).



The falling ball is placed in its starting point according to the scheme of this figure.

The pendulum is suspended in the air by clamping the thread with the clothespin.

After opening the clothespin, the pendulum moves and collides with ball A throwing it onto the floor, where the impact point is marked (for example, by using carbon paper).

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# PARABOLIC THROW.- EXPERIMENTAL METHOD (II).

A standard microphone connected to a PC is then suspended in the air just above the impact point and equidistant from the starting point of the falling ball in order to cancel the time delays due to the limiting speed of sound. Next, one repeats the experiment and records the sound of impact.

The height $H$ is measured with a 1-m steel ruler, as well as the horizontal distance, $x_A$, to be recorded in the table at the ground, due to the footprint of tracing paper.

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# PARABOLIC THROW.- EXPERIMENTAL METHOD (III).

An improvement of the precision and accuracy of the experiment can be obtained by analyzing and evaluating the principal sources of error, mainly the initial placement of the falling ball, the air buoyancy and drag effects.

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# PARABOLIC THROW.- RESULTS

The experiment was performed by first year students of the Physics Degree in Salamanca, Spain:

| **Magnitude** | **Value ± uncertainty** |
|---|---|
| Height | $H = 0{,}8760 \pm 0{,}0005\,\mathrm{m}$ |
| Mean drop time | $t_A = 0{,}42469 \pm 0{,}00009\,\mathrm{s}$ |
| Horizontal displacement | $x_A = 0{,}194 \pm 0{,}001\,\mathrm{m}$ |
| Horizontal speed of the ball A | $\mathrm{v}_A = 0{,}457 \pm 0{,}003\,\mathrm{m/s}$ |
| Acceleration of gravity | $g = 9{,}714 \pm 0{,}011\,\mathrm{m/s^2}$ |
| Acceleration of gravity* (with correction) | $g = 9{,}771 \pm 0{,}011\,\mathrm{m/s^2}$ |

* Note that the acceleration due to gravity in Salamanca, as reported by Instituto Geográfico Nacional of Spain is $g = 9{,}8004662\ \mathrm{m/s^2}$.

# PARABOLIC THROW.- DATA FROM THE EXPERIENCE

Height $H$:
$H =$ m
Horizontal displacement $x_A$:
$x_A =$ m
Drop time $t_A$:

| $t_{A1}$ (s) | $t_{A2}$ (s) | $t_A = t_{A2} - t_{A1}$ (s) |
|---|---|---|
| | | |

$$g = \frac{2H}{t_A^2} = \frac{2}{\qquad\qquad} = \qquad\qquad m/s^2 \qquad (12)$$

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# FREE FALL

Here we propose a method to determine $g$ based on the observation of a falling neodymium magnet in a free-fall. A well-known experiment for the measurement of the acceleration of gravity $\boldsymbol{g}$ is carried out on a personal computer using standard software (*Audacitiy* [1]) for a sound card, which provides an improved, more accurate, result and is a useful teaching method for a traditional classroom experiment. This method allows time measurements with an accuracy of about $10^{-4}$ s.
The original idea of this experience comes from Ganci [6], but we've improved it by reducing the size of the coils and adding a battery to the neodymium magnet.

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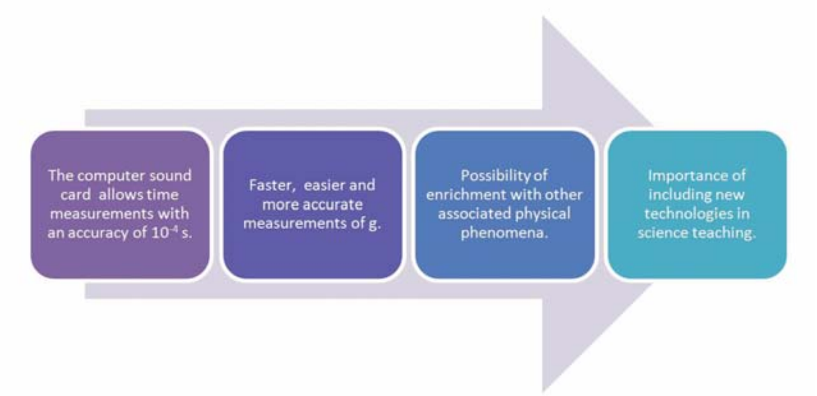
# ADVANTAGES OF THE EXPERIENCES

Special qualities that make this presentation spectacular:


The computer sound card allows time measurements with an accuracy of $10^{-4}$ s.

Faster, easier and more accurate measurements of g.

Possibility of enrichment with other associated physical phenomena.

Importance of including new technologies in science teaching.

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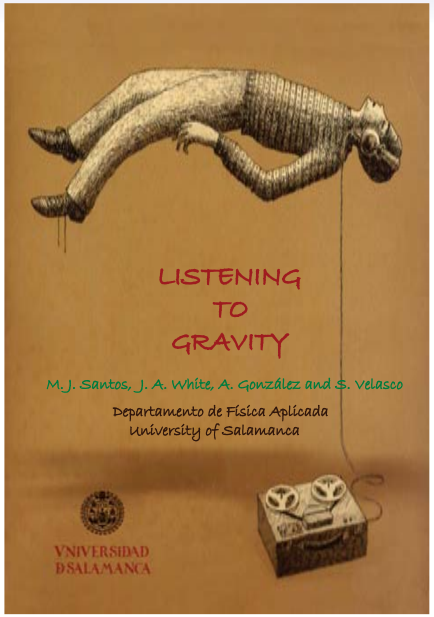
- The simplicity and accessibility to reproduce these experiences.
- Very high accurate measurements of time (of the order of $10^{-4}$ s).
- It provides an alternative procedure to the software that is presented by the commercial laboratories for the same purpose.
- Faster measurements than using standard methods.
- Possibility of enrichment with other associated physical phenomena to each experience.
- Importance of including new technologies in the education of sciences.
- The major advantages are the very low cost of the proposed experiments and they are easy to understand for students due to their familiarity with the software when it is used 'properly' for editing musical tracks.

1. http://www.softonic.com/s/audacity-gratis
2. J. A. White, M. J. Santos, A. González & S. Velasco, "*Timing the oscillations of a mass-spring system*," *The Physics Education*, (in press).
3. L. Hmurcik, A. Slacik, H. Miller, and S. Samoncik, "Linear regression analysis in a first physics lab," Am. J. Phys. 57(2), 135 (1989)
4. S. Velasco, M. J. Santos, A. González & J. A. White, "*Timing the oscillations of a pendulum*," *The Physics Education*, 46(3) 133-134 (March 2011)
5. J. A. White, A. Medina, F. L. Román, and S. Velasco, "*A measurement of g listening to falling balls*," The Physics Teacher, vol. 45, pp. 175–177, (2007)
6. S. Ganci, "*Quantitative measurements of acoustical beats by means of the 'improper' use of sound card software*," Eur. J. Phys. 28, L45 (2007)



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