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Measurement of $g$ by means of the ‘improper’ use of sound card software: a multipurpose experiment

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Abstract
A well-known experiment for the measurement of the acceleration of gravity is carried out on a personal computer using standard software for a sound card in a non-canonical way, which provides an improved, more accurate, result and is a useful teaching method for a traditional classroom experiment.

Introduction
A traditional classroom experiment to measure the acceleration due to gravity, $g$, is carried out by dropping a magnet in a glass or plastic tube which has three or more identical coils of enamelled copper wire wound round it at equal distances [1]. A pattern of induced emf proportional to the change of magnetic flux in time is shown on an oscilloscope screen with a suitable time-base setting. Since the same magnet is passing through identical coils, it should be possible to investigate the major features of Faraday’s magnetic induction law, providing an interesting multipurpose experiment.

A standard storage oscilloscope cannot give measurements under 20% of relative uncertainty, but improved experimental results can be obtained by using a PC-based oscilloscope or dataloggers.

This note describes the use of standard PC software for a sound card used in an ‘improper’ way [2]. The major advantages are the very low cost of the proposed method and the ease of understanding for students due to their familiarity with the software when it is used ‘properly’ for editing musical tracks. The experiment can also be carried out at home, with further suggestions for more quantitative investigations on Faraday’s law of magnetic induction.

Experimental set up and measurement
The proposed experimental set up is shown in figure 1(a). It consists of a glass tube about 0.78 m long with a diameter of about 7 mm, into which a small hard magnet from a popular toy is dropped. Three identical coils of ten turns of enamelled copper wire spaced 0.3 m apart are wound around the glass tube and connected together, as shown in figure 1(b). In the laboratory, the tube, connected with two supports to a wooden strip, can be hung against a wall, so that it can be vertically adjusted. As a home experiment, a similar tube can be simply held at the top in an upright position with two fingers. A light cable is used to connect the coil ends to the audio input.
socket of a PC on which is running ‘Creative Wave Studio’\(^1\).

After having activated the recording button, the magnet is dropped through the tube; the stop button is then pushed and the recorded trace is shown and viewed as in figure 2. The time intervals between the first and second coils and second and third coils are identified and marked (i.e. at the central point of the signals), and the time intervals are directly read in a window at the bottom right-hand side of the screen with a maximum uncertainty of 0.002 s.

From the equations of linear motion with constant acceleration \(g\), it is easily shown that

\[
g = \frac{2 \left( \frac{h_2}{t_2} - \frac{h_1}{t_1} \right)}{t_1 + t_2}, \tag{1}
\]

where \(h_1\) and \(h_2\) are the space between the first and the second coil and the second and the third coil, respectively, and \(t_1\) and \(t_2\) denote the corresponding times of transit. In our case \(h_1 = h_2 = 0.30 \text{ m} \pm 0.001 \text{ m}\) and the times of transit are respectively \(t_1 = 0.135 \text{ s} \pm 0.002 \text{ s}\) and \(t_2 = 0.091 \text{ s} \pm 0.002 \text{ s}\). No significant casual errors are evidenced from the various measurements so, within the uncertainties claimed, a single measurement is sufficient for our purpose. By substituting the above data in equation (1), we find

\[
g = 9.5 \text{ m s}^{-2} \pm 0.5 \text{ m s}^{-2}
\]

with about 5% relative uncertainty.

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\(^1\) The Creative Wave Studio software is part of the various software furnished in a CD-ROM enclosed in any ‘Creative Sound Blaster’ card package. Another software (Sigview) has identical features and more functions. It is freely downloadable as shareware and licenced at very low cost after 21 days at: http://www.sigview.com.
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Figure 2. Screenshot of the traces due to the magnet dropping. The three markers point to the centre of each peak. Selecting the times between these markers, these times are directly read on the little window near the bottom right-hand side of the screen. The resolution in time of this software is 1 ms.

Figure 3. Graphical work of cut/paste of three peaks in figure 2 with 1:1 zoom and grid superposition using ‘Paint’ package of Windows.
Conclusion

In an Italian ‘Liceo’ curriculum, this experiment was run in two different contexts. The first time was at the beginning of the study of kinematics; the second time was two years later, when Faraday’s law was being studied: this had the twofold goal of providing a quantitative verification of Faraday’s law and of reinforcing the concept of ‘definite integral’. In this second discussion the following quantitative analysis of the areas of the three peaks was proposed.

Let

\[ Q = \int_{\Delta t} dq \propto \int_{\Delta t} V(t) \, dt \quad (2) \]

where \( Q \) is the total charge induced in a time interval \( \Delta t \) and \( V(t) \) the instantaneous induced emf. Obviously, a good graphical analysis requires a 1:1 zoom of figure 2 and a copy/paste of the half peaks from ‘Creative Wave Studio’ using the ‘Paint’ software tool on a fine grid. Figure 3 shows a copy/paste view with a convenient choice of a fine square grid. By defining \( S_1, S_2 \) and \( S_3 \) as the areas of the trapezoids in the first, second and third peak, respectively, it is easy to establish that

\[ 82 < S_1 < 118; \]
\[ 83 < S_2 < 123; \]
\[ 84 < S_3 < 117, \]

where the integer numbers refer to internal and external ‘unit area’ squares approximating area. Areas are therefore seen to be equal within a few per cent of uncertainty.

From a pedagogical point of view, students have found this approach to a delicate concept in mathematics useful.

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References


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