Electricity

Induction

Faraday's Law of Induction

GENERATING A VOLTAGE PULSE IN A CONDUCTING LOOP BY THE MOTION OF A PERMANENT MAGNET

- Observing the motion of a permanent bar magnet through a set of induction coils connected in series.

- Measuring the induced voltage as a function of time.

- Calculating the magnetic flux as a function of time.

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GENERAL PRINCIPLES

Any change of the magnetic flux through a closed conducting loop induces in it an electrical voltage. Such a change is produced, for example, when a permanent bar magnet moves through a stationary conducting loop. (Fig. 2).

In this case it is instructive to consider not only the time-dependent induced voltage

$$(1) \quad U(t) = -\frac{d\Phi}{dt}(t),$$

where Φ: magnetic flux

but also its integral over time, viz. the voltage pulse

$$(2) \quad \int_{t_1}^{t_2} U(t) \cdot dt = \Phi(t_1) - \Phi(t_2)$$

This corresponds to the difference between the magnetic flux at the beginning (t_1) and that at the end (t_2) of the observed process.

In the experiment, a permanent bar magnet is allowed to fall through six identical induction coils that are connected in series. The induced voltage is recorded as a function of time (green curve in Fig. 3).

The voltage amplitude increases from coil to coil as the magnet moves through each coil, because the velocity of the magnet increases steadily.

The areas under all the positive and negative voltage signals are equal. They correspond to the maximum flux Φ produced by the permanent magnet inside each individual coil.
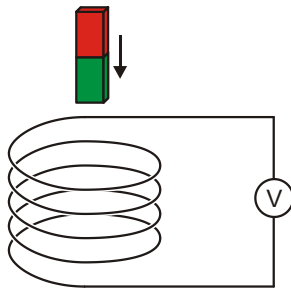
Fig. 1: Experiment set-up

Fig. 2: Principle for measurement

LIST OF EQUIPMENT

1	Induction Tube Apparatus with 6 Coils	1001005 (U8511200)
1	Voltage Sensor 500 mV, Differential	1021681 (UCMA-BT32i)
1	Sensor Cable	1021514 (UCMA-BTsc1)
1	Data Logger WiLab	1022284
1	Software Coach 7	

More information about digital measurement can be found on the experiment's webpage in the 3B Webshop.

SET-UP AND CONFIGURATION

Induction Tube Apparatus

Note:
Bumps, knocks or any lateral forces acting on the tube may damage the instrument.

- Do not subject the tube to any mechanical stress.
- Put the base on a horizontal, level working surface.
- Set up the tube in the socket of the plinth using gentle pressure.
- Place the cork board under the base.

Data Logger, Voltage Sensor and Software

- Install the software on the computer you will be using for the measurement.
- Connect the data logger to the computer.
- Connect the voltage sensor to the appropriate 4-mm sockets of the induction tube with the help of the 4-mm experiment lead and use the sensor cable to connect it to the data logger.
- Start the software. Press the [Oᴡ] button and select the "User level: Author" from the drop-down menu in the "Log-in" window which opens. Enter the password for "Author key" and confirm it with OK.
- Click the [✳] button. The "Activity Options" window will open. Confirm the pre-selected settings by clicking OK.

The software will establish a connection to the data logger. A graphic representing the data logger with a pictogram of the voltage sensor connected to it will appear in the bottom left of the four windows.

- In the window displaying the data logger graphic click the [⌖] icon for the voltage sensor with the right mouse button. In the menu which opens select "Set to zero" and confirm with "OK".
- Click the [⏱] button, enter the following parameters and then confirm with OK:

Method

Type: Time-based

Duration of measurement: 0.3 seconds

Frequency: 1000 per second

Number of measurements: 300

Triggering

Trigger channel: Differential voltmeter

Trigger level: 0.1 mV

Direction: up

Pre-trigger time: 0.01 seconds

Note:
For The purposes of evaluation, it is particularly important to select an optimum duration for the measurement (here: 0.3 s) while the measurement parameters are being entered.

- Click the [▦] button.
- The data table will appear in the top right window. It will have columns for time t and voltage U, both initially empty.
- Click the [◠] button. In the menu which opens select "Add new", then move the mouse cursor to the top left window and click on it.

The window will then display a trace plot (initially blank)

- Click the time symbol "t(s)" in the header for the first column of the data table and, keeping the mouse button down, drag it to the axis button for the bottom of the plot, then click on the border when it lights up blue. Click the voltage symbol "V(mV)" in the header for the second column and, again keeping the mouse button held down, drag it to the axis button for the left of the plot, then click on the border when it lights up blue.

This assigns the x-axis of the trace to be time and the y-axis to be voltage.

The data logger and the software are now fully configured for the measurement.

EXPERIMENT PROCEDURE

The experiment set-up is such that the induced voltage is positive when the magnet is introduced into the coil. It may be necessary to carry out the measurement procedure described below twice, since the sign of the voltage is dependent on the orientation of the magnet as it falls down the tube, i.e. with the north or south pole facing down (Fig. 2).

- Start the measurement in the software by clicking the [▷] button. A "Waiting for trigger event" window opens.
- Hold the magnet in the opening at the top of the tube and then let it go. Measuring starts automatically as soon as the set trigger level is reached and stops automatically once the configured measurement duration has elapsed.
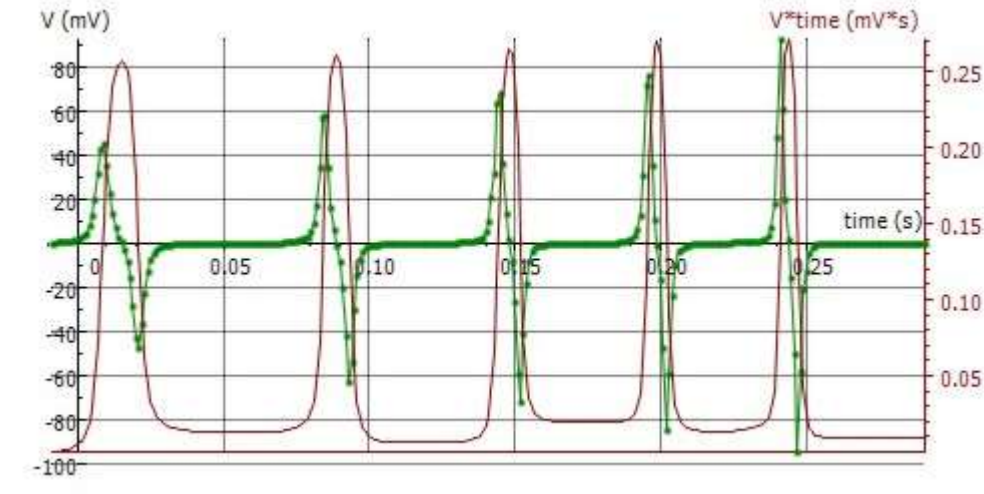
Fig. 3: Change in induced voltage *U* and magnetic flux Φ over time

SAMPLE MEASUREMENT AND EVALUATION

Induced Voltage

The green curve in Fig. 3 shows the trace of how voltage changes over time.

As described in the procedure, a positive voltage is induced as the magnet enters an induction coil. This induced voltage goes back to zero when the magnet reaches the centre of the coil. During the subsequent exit of the magnet from the coil, a negative voltage is induced. Since the speed of the magnet increases as it progresses from coil to coil along the tube, the magnitude of the voltage signals gets higher and higher, but the width of the peaks becomes narrower, i.e. the area of the surfaces under all the positive and negative signal peaks remains the same in absolute terms.

Magnetic Flux

*   Click the ⬚ button for the trace and choose "Integral" from the menu. In the "Integral" window which opens click "Plot".

The plot in the "Integral" window shows the variable "V*t" in units of "mV*s" (violet curve in Fig. 3). This corresponds to the magnetic flux Φ in equation (2)

*   Close the "Integral" window by clicking "OK".

A third column "V*t (mV*s)" appears in the data table and the symbol "〰 V*t" is shown beneath the cursor.

*   Click on the still empty window at the bottom right.

A plot of the variable "V*t (mV*s)" will now be shown as a trace. To show the induced voltage and and magnetic flux simultaneously in the top left window, proceed as follows:

*   Click the symbol "V*t (mV*s)" in the header for the third column of the data table and, keeping the mouse button held down, drag it to the active axis region for the right of the plot, then click on the border when it lights up blue.

The y-axis on the right-hand side of the plot is now assigned to the magnetc flux. To display the curve in optimum fashion, proceed as follows:

*   Click with the right mouse button on the background of the trace and select "Zoom to Fit" from the menu which opens.

Scaling of the axes is modified automatically in such a way that the curve is optimally displayed. For subsequent measurements both the induced voltage and magnetic flux will be displayed at their best automatically on the trace.

The magnetic flux reaches a maximum when the induced voltage returns to zero (Fig. 3), i.e. when the magnet has reached the centre of the coil. The area of the surfaces under all the positive and negative signal peaks remains the same in absolute terms (see above). This correponds to the maximum magnetic flux Φ of the permanent magnet inside an individual coil. The maximum magnetic flux therefore reaches the same value of $\Phi_{max} \approx 250$ μVs within the given measurement tolerances.