Electricity

Electromagnetic induction

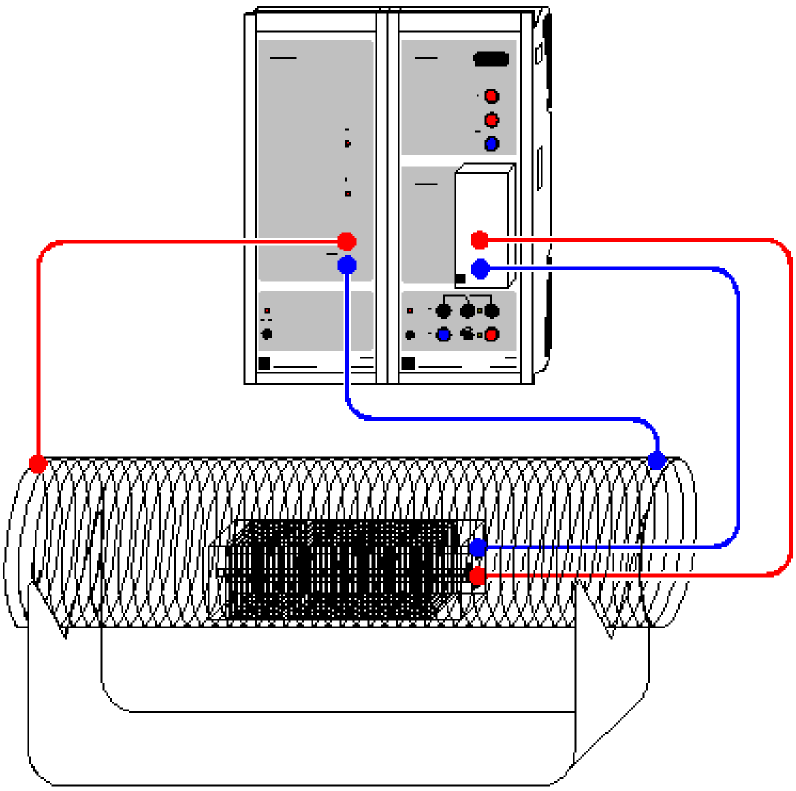
Induction by means of a variable magnetic field

Measuring the induction voltage in a conductor loop for a variable magnetic field - with Power-CASSY as variable source of current

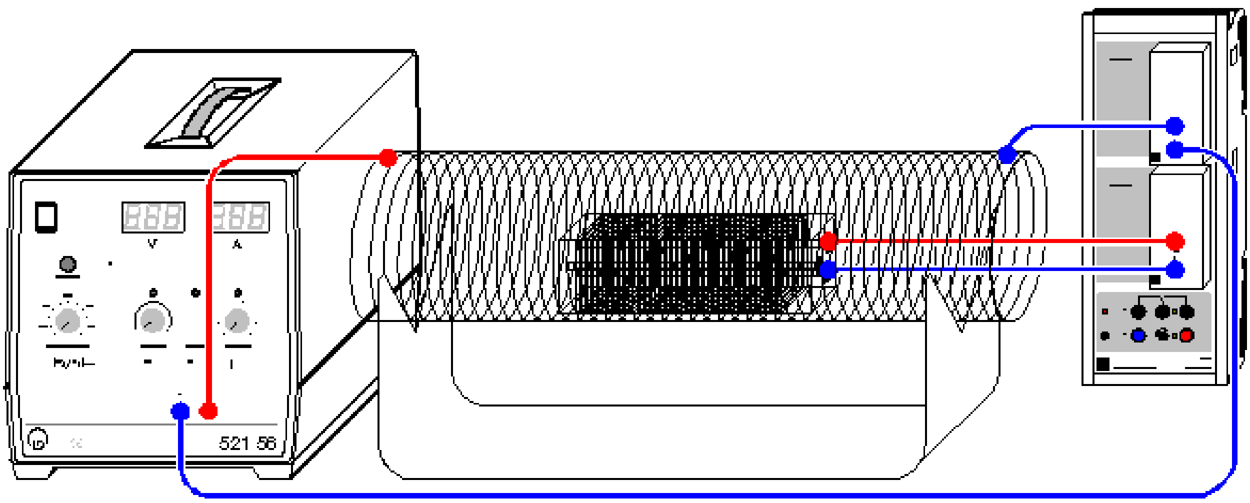
Description from CASSY Lab 2

For loading examples and settings, please use the CASSY Lab 2 help.

Induction in a variable magnetic field



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY and Mobile-CASSY

Experiment description

Voltages and currents which are produced as a result of variations in magnetic fields are called induction voltages and currents, and the phenomenon itself is referred to as electromagnetic induction. When a conductor loop is placed within a magnetic field **B**, the magnetic flux permeating the loop is determined by the integral of the conductor loop area:

$$\Phi = \int_A \mathbf{B} \cdot d\mathbf{A}$$

If instead of a conductor loop we use a coil with N_1 turns, all perpendicular to the magnetic field, Φ increases correspondingly to

$$\Phi = B \cdot A \cdot N_1.$$

If the magnetic field B does not vary, the magnetic flux Φ remains constant. When the magnetic field, and thus the magnetic flux through the area of the coil, changes over time, a voltage and consequently a current as well are induced in the coil; their magnitude and direction depend on how the field varies. Faraday's law of induction applies:

$$U = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

and thus

$$U = -\frac{\mathrm{d}B}{\mathrm{d}t} \cdot A \cdot N_1 .$$

Conversely, an electric current generates a magnetic field, e.g. when a current I flows through a coil. For the magnetic field inside a large cylindrical coil with the length L and the number of turns N_2, the following applies:

$$B = \mu_0 \frac{N_2}{L} I$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am (magnetic field constant).

This experiment uses a large cylindrical coil as a field coil through which a varying current I(t) flows, which generates a varying magnetic field B(t) within the coil. Rectangular induction coils having different cross-sections (areas) A and numbers of turns N_1 are placed inside this field coil. A voltage U is induced in these coils, which can be calculated as:

$$U = -\frac{\mathrm{d}I}{\mathrm{d}t} \cdot \mu_0 \cdot A \cdot \frac{N_2}{L} \cdot N_1$$

This experiment verifies the proportionalities between the induced voltage U and the change over time dI/dt of the field-coil current I, the area A of the induction coils and the number of turns N_1 of the induction coils. Power-CASSY (524 011) or the triangular wave form power supply (521 56) are particularly suitable for this experiment, as the output current I over time can be controlled so that the slope | dI/dt | is constant. The slope | dI/dt | is continuously adjustable from 0.2 A/s to 2.2 A/s. Three induction coils are also provided, with N_1 = 300 turns each. Coil 1 has the cross-section A = 50 × 50 mm^2, coil 2 A = 30 × 50 mm^2 and coil 3 A = 20 × 50 mm^2. Coil 1 is also provided with additional taps at N_1 = 100 and N_1 = 200 turns.

Equipment list

1	Sensor-CASSY	524 010 or 524 013
1	Power-CASSY	524 011
1	CASSY Lab 2	524 220
1	µV box	524 040
1	Field coil, d = 120 mm	516 244
1	Stand for tubes and coils	516 249
1	Set of induction coils	516 241
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows XP/Vista/7/8	

Alternatively (without Power-CASSY)

1	Sensor-CASSY	524 010 or 524 013
1	CASSY Lab 2	524 220
1	µV box	524 040
1	30-A box	524 043
1	Field coil, d = 120 mm	516 244
1	Stand for tubes and coils	516 249
1	Set of induction coils	516 241
1	Triangular wave form power supply	521 56
1	Connecting lead, 50 cm, blue	501 26
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows XP/Vista/7/8	

Experiment setup (see drawing)

The large coil is supplied with a constant | dI/dt | using either Power-CASSY or the triangular wave form power supply. In the latter case, the flowing current must be measured at input A of Sensor-CASSY using the 30 A box. The induced voltage of the induction coils is measured using the µV box at input B.

Carrying out the experiment

a) Measuring the induction voltage U as a function of the area (cross-section) A of the induction coils

- Load settings
- Place coil 1 ($A = 0.0025\ m^2$, N_1 = 300 turns) in the large field coil and connect it to the µV box.
- Execute the measurement with .
- Repeat the measurement with coils 2 ($A = 0.0015\ m^2$) and 3 ($A = 0.0010\ m^2$).

b) Measuring the induction voltage U as a function of the number of turns N_1 of the coils

- Load settings
- Connect coil 1 (N_1 = 100 turns) in the large field coil to the µV box.
- Execute the measurement with .
- Repeat the measurement with N_1 = 200 and N_1 = 300 of coil 1.

c) Measuring the induction voltage U as a function of dI/dt

- Load settings
- Connect coil 1 (N_1 = 300 turns) in the large field coil to the µV box.
- Execute the measurement with .
- Repeat the measurement with the reduced maximum current I_{max} or dI/dt respectively; to do this, move the pointer of the display instrument to the desired position using the mouse.

Alternatively (without Power-CASSY)

a) Measuring the induction voltage U as a function of the area (cross-section) A of the induction coils

- Load settings
- Place coil 1 ($A = 0.0025\ m^2$, N_1 = 300 turns) in the large field coil and connect it to the µV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{max}) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with (the measurement begins with a rising edge of the induction voltage U_{B1}; you may need to deactivate the trigger).
- Stop the measurement with after a few current periods.
- Repeat the measurement with coils 2 ($A = 0.0015\ m^2$) and 3 ($A = 0.0010\ m^2$).

b) Measuring the induction voltage U as a function of the number of turns N_1 of the coils

- Load settings
- Connect coil 1 (N_1 = 100 turns) in the large field coil to the µV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{max}) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with (the measurement begins with a rising edge of the induction voltage U_{B1}; you may need to deactivate the trigger).
- Stop the measurement with after a few current periods.
- Repeat the measurement with N_1 = 200 and N_1 = 300 of coil 1.

c) Measuring the induction voltage U as a function of the frequency of the excitation field

- Load settings
- Connect coil 1 (N_1 = 300 turns) in the large field coil to the µV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{max}) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with (the measurement begins with a rising edge of the induction voltage U_{B1}; you may need to deactivate the trigger).
- During the measurement increase dI/dt in steps of about 0.4 A/s.
- Stop the measurement with .

Evaluation

Depending on the experiment section, activate the appropriate display (click on **Area**, **Number of Turns** or **dI/dt**) with the mouse. A further table is filled out in which the induction voltage is determined for the respective parameter A, N_1 or dI/dt (by entering via the keyboard; dI/dt can be determined by fitting a straight line). You can find the induction voltage U e.g. by determining the mean value. You can then use the mouse to drag this value from the status line and drop it into the table (drag & drop). The desired diagram is generated as you enter the values.

All three diagrams confirm the proportionalities between the induction voltage U and the area A, number of turns N_1 and dI/dt.

In this example, we obtain the proportionality factor U/A = 101 mV/m^2 (or 129 mV/m^2 without Power-CASSY) between the induction voltage U and the coil cross-section A. Theory expects the proportionality factor

$$\frac{U}{A} = -\frac{\mathrm{d}I}{\mathrm{d}t} \cdot \mu_0 \cdot \frac{N_2}{L} \cdot N_1 .$$

By comparison, the number of turns of the induction coil N_1 = 300 and N_2 = 120 of the air coil, the air coil length L = 0.41 m, the calculated current increase dI/dt = 1.00 A/s (resp. 1.19 A/s) and the magnetic field constant $\mu_0 = 4\pi\cdot10^{-7}$ Vs/Am taken together give us the proportionality factor U/A = - 110 mV/m^2 (resp. -131 mV/m^2), which agrees with the experiment result. The sign depends on the direction of the turns and the connection to the µV box.

Notes

The µV box may have a slight offset, which can be corrected in Settings by selecting **Correct**, setting value 0 mV and choosing **Correct Offset**; be sure to interrupt the circuit of the air coil first.

Power-CASSY can also output a significantly higher frequency, and thus make the µV box unnecessary. However, note that in this case the current regulation of Power-CASSY tends to slight overshoots at higher frequencies and inductive loads, which negatively affect the induced voltage (1st derivation of the current). You can resolve this by connecting a resistor of around 10 Ω in series.