Electricity

Electromagnetic induction
Induction in a moving conductor loop

Measuring the induction voltage in a conductor loop moving within a magnetic field

---

Objects of the experiment

■ To measure the induction voltage as a function of the speed of the conductor loop.

■ To measure the induction voltage as a function of the width of the conductor loop.

■ To measure the induction voltage as a function of the magnetic flux density.

Principles

When a conductor loop is placed within a magnetic field B, the magnetic flux permeating the loop is

$$\Phi = B \cdot A \qquad \text{(I)}$$

Here, A is the area enclosed by the conductor loop, which is oriented perpendicular to the magnetic field. When this loop is withdrawn from the magnetic field, the area A permeated by the magnetic field is reduced. When a rectangular conductor loop with the width b is moved by the distance dx, its area changes by the value $dA = -b \cdot dx$ and its magnetic flux density changes correspondingly by $d\Phi = B \cdot b \cdot dx$. Thus, the change in the magnetic flux per time interval dt is

$$\frac{d\Phi}{dt} = -B \cdot b \cdot \frac{dx}{dt} \qquad \text{(II)}$$

when an open conductor loop is used, the electrons are displaced until their own electrical opposing field compensates the lorentz force. A voltage U is induced at the ends of the loop which ist porportional to the change in the magnetic flux:
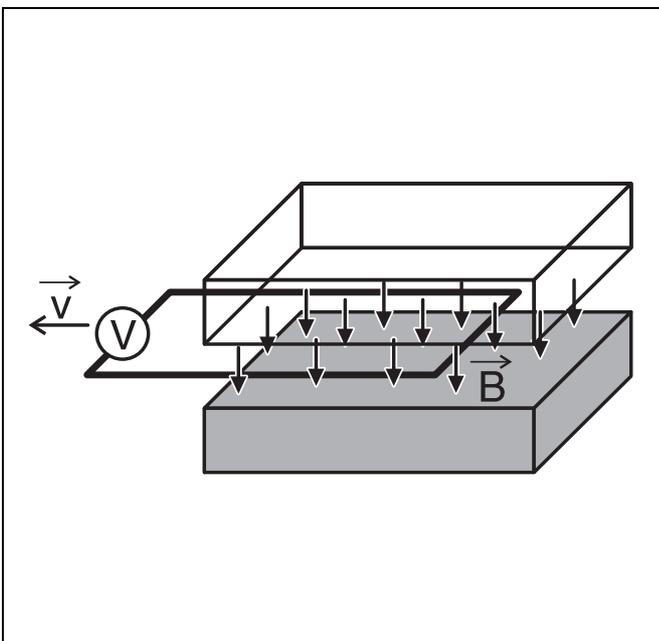
$$U = -\frac{d\Phi}{dt} \qquad \text{(III)}$$

The speed

$$v = \frac{dx}{dt} \qquad \text{(IV)}$$

of the conductor loop ultimately gives us the value of the induction voltage

$$U = B \cdot b \cdot v \qquad \text{(V)}$$

In this experiment, three induction loops of different widths are mounted on a sliding carriage. Two of the conductor loops are rectangular and have the widths $b = 4$ cm and $b = 2$ cm. The third is trapezoidal in shape and has an effective width $b = 4$ cm $\cdot \cos 45° = 2.8$ cm. The sliding carriage with the conductor loops is pulled though a magnetic field by a thread attached to an electric motor. You can vary the speed with which the sliding carriage is pulled through the magnetic field by winding the thread around a clutch with a stepped axle, i.e. one with different diameters, while running the motor at a constant speed. In this experiment, we do not measure the absolute motor speed of the sliding carriage; for a constant motor speed, the sliding carriage speeds have a ratio of 1:2:4.

The magnetic field is generated using paired cylindrical permanent magnets placed between two large parallel iron plates. Pole pieces are placed in the gaps between the magnets over the entire length of the plate, which ensure a sufficiently homogeneous magnetic field when the magnets are evenly distributed. You can vary the magnetic field strength by changing the number of permanent magnets.

Apparatus

1 Induction apparatus	516 40
6 Pairs of magnets, cylindrical	510 48
1 Experiment motor	347 35
1 Control unit for experiment motor	347 36
1 Microvolt meter	532 13

Setup

The induction apparatus is marked for the positions of the magnets. When using n magnet pairs (n = 2, 3, 4, 5, 6, 8), be sure to place one magnet at each of the points designated n.

Slight variations in the magnetic field B cannot be prevented entirely. To improve the homogeneity of the magnetic field, first place all magnets in the middle of the base unit and then slide them evenly to the position marks designated "8".

Make sure that the magnets' polarity between the iron plates is always the same. The poles are color-coded.

Set up the experiment as shown in Fig. 1.

– Extend the guide rail **(c)** for the sliding carriage of the induction apparatus.
– Place the pairs of magnets to the left and right of the sliding carriage, making sure that the polarity between the iron plates **(e)** is always the same.
– Mount the clutch **(a)** in the chuck of the experiment motor.
– Set up the experiment motor in front of the front end of the guide rail as shown in Fig. 1 and connect the control unit.
– Insert the thread attached to the sliding carriage **(d)** through the guide hole of end stop **(b)** and then lay it in slit **(a)** of the clutch (see Fig. 2).
– Wind the thread approx. one turn around the axle segment of the clutch with the smallest diameter. Be sure to observe the rotational direction of the motor and make sure that the thread runs as smoothly as possible.
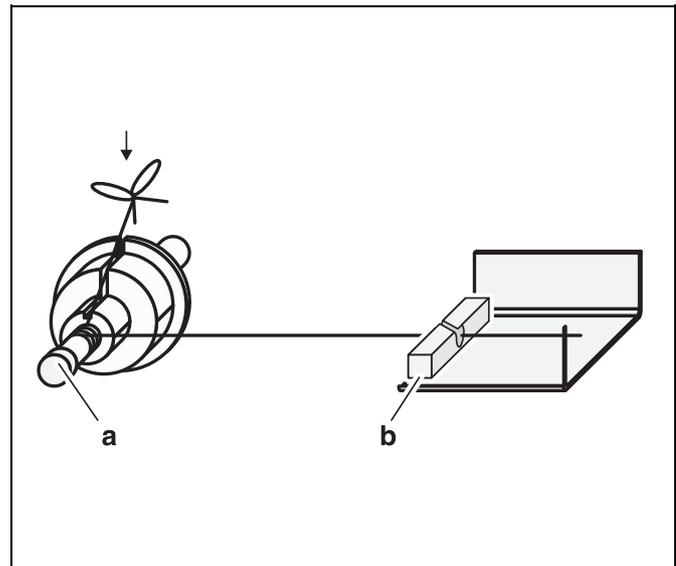
– Make a test run to be sure that the thread turns wind next to each other and not on top of each other, as otherwise the diameter of the axle, and thus the speed of the sliding carriage, will not remain constant during the experiment.
– Connect the screened cable **(f)** of the sliding carriage to the microvolt meter and select the measuring range 10^{-4} V.

Fig. 2   Inserting the thread through the guide hole of the end stop and attaching it to the slip friction clutch

Fig. 1   Experiment setup
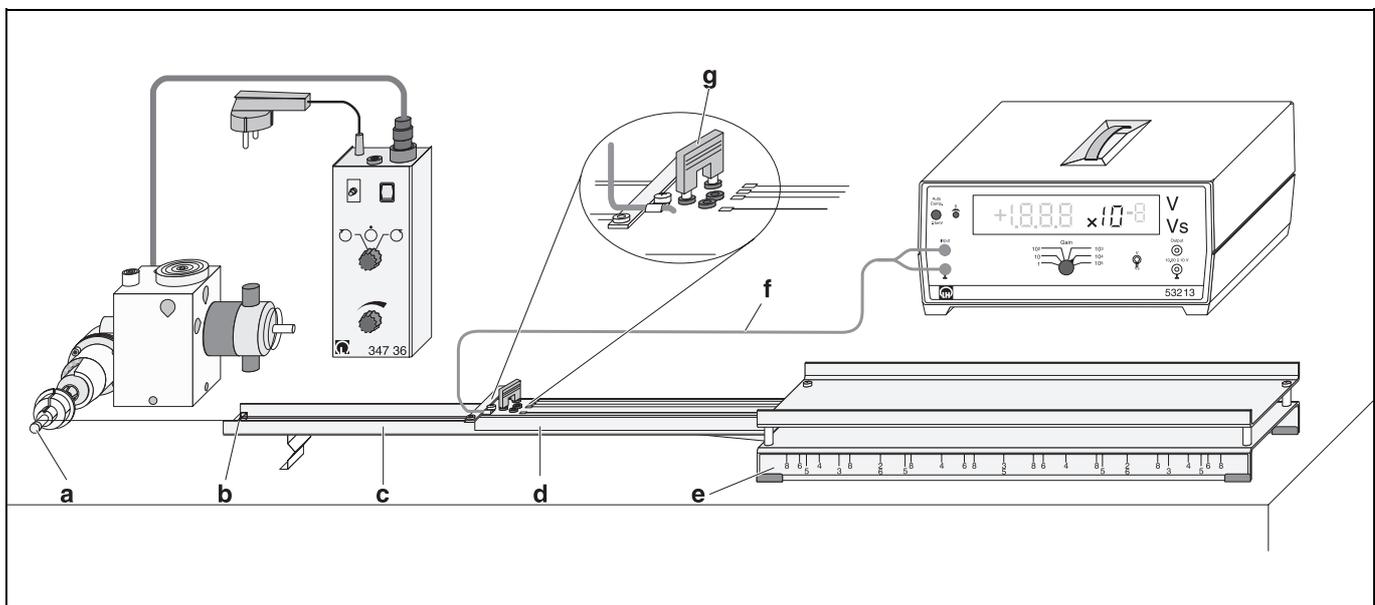
Carrying out the experiment

To protect the microvolt meter from voltage overloads when the sliding carriage is pushed back fast, a microswitch **(h)** *is attached to the front of the sliding carriage to disconnect the measuring instrument from the induction loops (see Fig. 3). Always hold down the microswitch when pushing the sliding carriage back.*

The clutch slips when the sliding carriage strikes the stop at the end of the guide rail. This prevents the thread from tearing and the experiment setup from being upset.
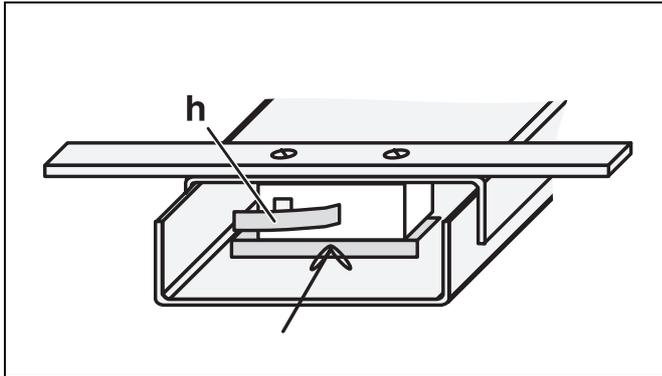

Fig. 3   Press the microswitch to electrically disconnect the micro-volt meter and the conductor loops before pushing the slid-ing carriage back.

a) Measuring the induction voltage as a function of the speed of the conductor loop:

Check the offset of the microvolt meter at the start of every experiment. If necessary, zero the instrument by pressing the AutoComp key (you may also need to carry out fine adjustment using the offset potentiometer; see the Instruction Sheet for your microvolt meter).

–   Connect the widest conductor loop ($b = 4$ cm) by plugging in bridging plug **(g)** on the sliding carriage (see Fig. 1).
–   Select the smallest axle diameter of the clutch, switch on the experiment motor and set the speed so that the micro-volt meter shows an induction voltage of about 50 mV. Switch off the experiment motor without changing the setting of the speed control knob; then hold down the microswitch on the sliding carriage and push the sliding carriage back to the starting point. Then write down the exact voltage value.
–   Select the medium axle diameter, switch on the experiment motor and measure and write down the induction voltage.
–   Repeat the measurement with the large axle diameter.

b) Measuring the induction voltage as a function of the width of the conductor loop:

–   Connect the trapezoidal conductor loop ($b = 2.8$ cm) by changing the position of the bridging plug **(g)**.
–   Use the largest axle diameter and switch on the experiment motor, then measure and write down the induction voltage.
–   Connect the narrow conductor loop ($b = 2$ cm) by changing the position of the bridging plug and repeat the measure-ment.

c) Measuring the induction voltage as a function of the magnetic flux density:

The homogeneity of the field decreases with the number of magnet pairs used. To keep the field as homogeneous as possible, be sure to place the permanent magnets exactly on the position marks.

–   Connect the wide conductor loop ($b = 4$ cm) by changing the position of the bridging plug **(g)**.
–   Remove two magnet pairs from the induction apparatus and place the remaining six magnet pairs at the position marks with the designation "6".
–   Use the largest axle diameter and switch on the experiment motor, then measure and write down the induction voltage.
–   Repeat the measurement for $n = 5, 4, 3$ and 2 magnet pairs; be sure to place the magnets at the appropriate markings each time!
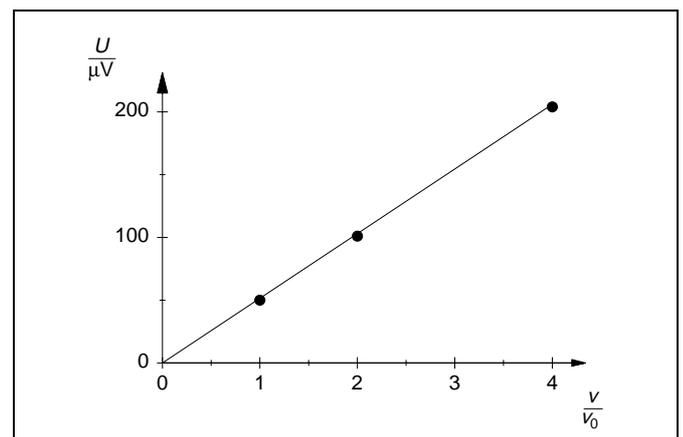
Measuring example and evaluation

a) Induction voltage as a function of the speed v of the conductor loop:

Table 1: Induction voltage U as a function of the speed v of the induction loop ($n = 8$, $b = 4$ cm)

$\dfrac{v}{v_0}$	$\dfrac{U}{\mu V}$
1	50
2	101
4	204

Fig. 4 confirms the proportionality between the induction volt-age U and the speed v of the loop.

Fig. 4   Induction voltage as a function of the speed

b) Induction voltage as a function of the width *b* of the conductor loop:

Table 2 : Induction voltage *U* as a function of the width *b* of the conductor loop ($n = 8$, $v = 4\ v_0$)

$\dfrac{b}{\text{cm}}$	$\dfrac{U}{\mu V}$
4	204
2.8	146
2	108

c) Induction voltage as a function of the magnetic flux density:

Table 3 : Induction voltage *U* as a function of the number of magnet pairs *n* ($v = 4\ v_0$, $b = 4$ cm)

n	$\dfrac{U}{\mu V}$
8	204
6	160
5	138
4	108
3	80
2	54

Fig. 5 confirms the proportionality between the induction voltage *U* and the width *b* of the loop.
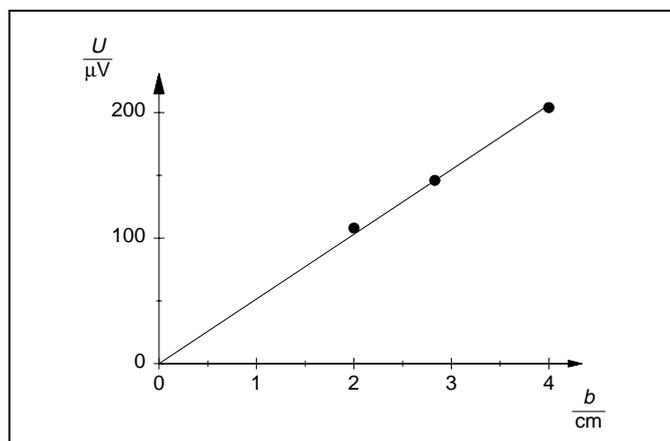

Fig. 5   Induction voltage as a function of the loop width

Fig. 6 confirms the proportionality between the induction voltage *U* and the magnetic field *B*.
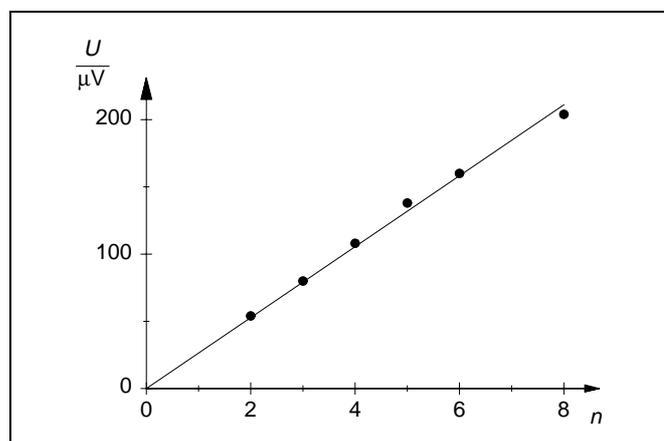

Fig. 6   Induction voltage as a function of the number of magnet pairs