Related topics

Maxwell's equations, electrical eddy field, magnetic field of coils, coil, magnetic flux, induced voltage.

Principle and task

A magnetic field of variable frequency and variyng strength is produced in a long coil. The voltages induced across thin coils which are pushed into the long coil are determined as a function of frequency, number of turns, diameter and field strength.

Equipment

Field coil, 750 mm, 485 turns/m	11001.00	1
Induction coils, 1 set	11006.88	1
consisting of		
Induction coil, 300 turns, dia. 40 mm	11006.01	1
Induction coil, 300 turns, dia. 32 mm	11006.02	1
Induction coil, 300 turns, dia. 25 mm	11006.03	1
Induction coil, 200 turns, dia. 40 mm	11006.04	1
Induction coil, 100 turns, dia. 40 mm	11006.05	1
Induction coil, 150 turns, dia. 25 mm	11006.06	1
Induction coil, 75 turns, dia. 25 mm	11006.07	1
Function generator	13652.93	1
Digital counter, 4 decades	13600.93	1
Digital multimeter	07134.00	2
Connecting cord, 750 mm, red	07362.01	4
Connecting cord, 750 mm, blue	07362.04	2
Connecting cord, 2000 mm, blue	07365.04	1

Problems

Determination of the induction voltage as a function

1. of the strength of the magnetic field,
2. of the frequency of the magnetic field,
3. of the number of turns of the induction coil,
4. of the cross-section of the induction coil.

Set-up and procedure

The experimental set-up is as shown in Fig. 1. The coil current and the induction voltage are measured with the digital multimeters. The effect of frequency should be studied between 1 kHz and 12 kHz, since below 0.5 kHz the coil practically represents a short circuit and above 12 kHz the accuracy of the measuring instruments is not guaranteed.

Theory and evaluation

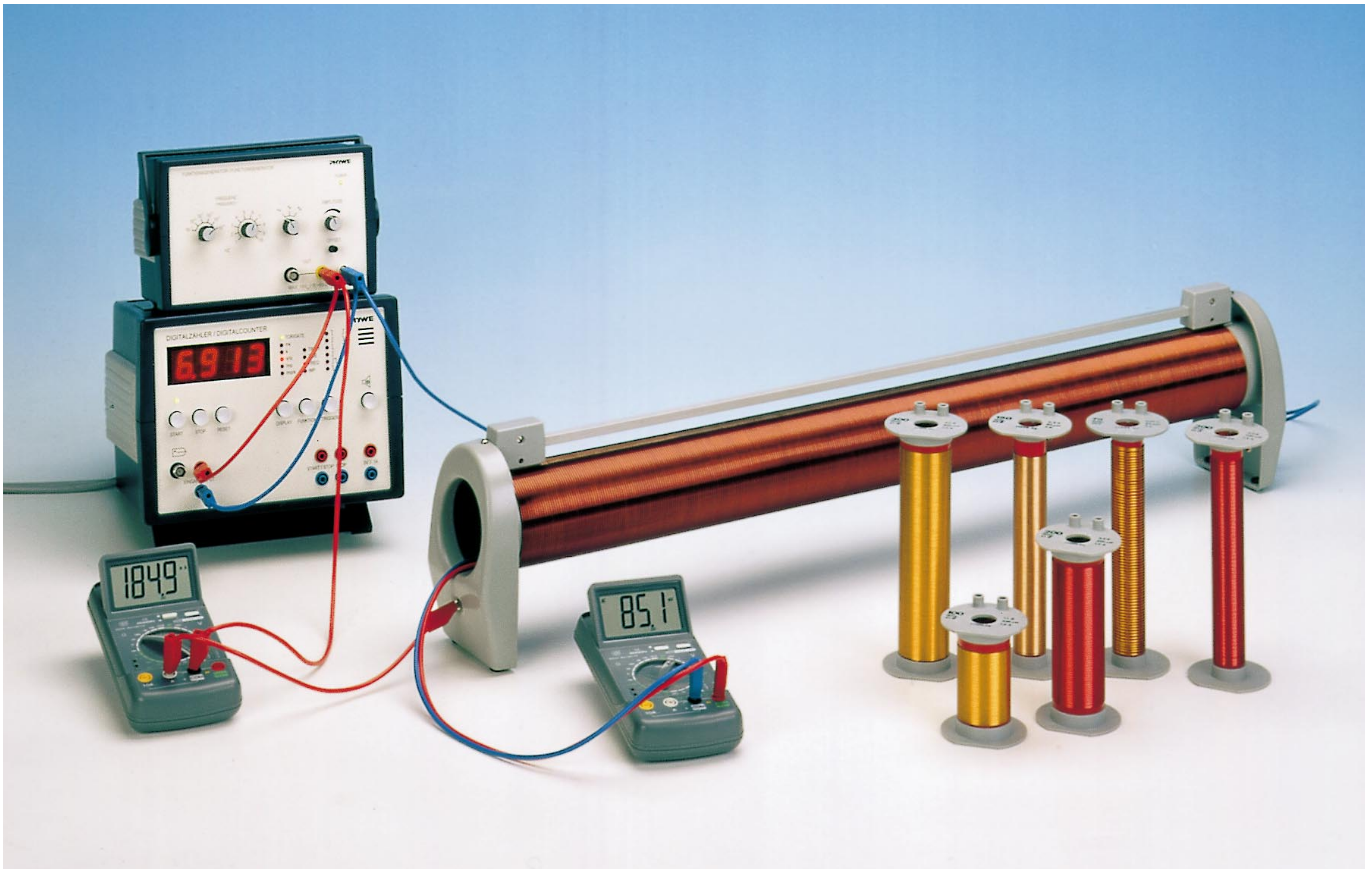
The variation with time of the magnetic flux ϕ, where:

$$\phi = \int_A \vec{B} \cdot d\vec{a}$$

produces an electical voltage U

$$U = \oint_C \vec{E} \cdot d\vec{s} \,.$$

Fig. 1: Experimental set-up for magnetic induction.



Where $\vec{E}$ is the electrical field strength, $\vec{B}$ is the magnetic flux density, A is the area enclosed by the conductor loop and C is its boundary.

The relationship between ϕ and U is given by Maxwell's 2nd equation and is

$$U = -\frac{d\phi}{dt} \qquad (1)$$

for one conductor loop.

For n parallel conductor loops through which the same flux ϕ passes,

$$U = n \oint \vec{E} \cdot \vec{ds} \qquad (2)$$

In the present case, the magnetic field is produced by a long coil ("primary coil"). Since $\vec{B}$ is constant inside long coils,

$$\phi = \vec{B} \cdot \vec{A}. \qquad (3)$$

Maxwell's 1st equation

$$\int_{C'} \vec{B} \cdot \vec{ds} = \mu_o \int_{A'} \vec{j} \cdot \vec{da},$$

together with Maxwell's 4th equation

$$\int_{A''} \vec{B} \cdot \vec{da} \cdot o,$$

gives the relationship between the steady current I flowing the area A'

$$I = \int_{A'} \vec{j} \cdot \vec{da}$$

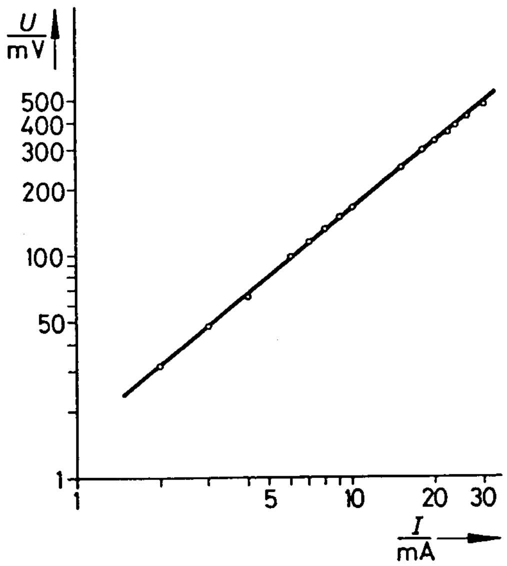
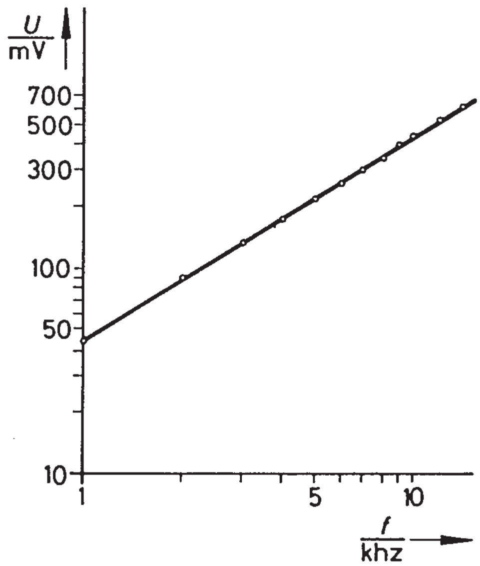


Fig. 2: Induced voltage as a function of the current in the primary coil at f = 10.7 kHz, diameter of the induction coil d = 41 mm.

Fig. 3: Induced voltage as a function of the frequency in the primary coil with a primary current of 30 mA and an induction coil diameter of 41 mm.



and the magnetic field $\vec{B}$ produced thereby. C is the boundary of A, A" is any desired enclosed area, $\vec{j}$ the electrical current density and μ_o the magnetic field constant:

$$\mu_o = 1.26 \cdot 10^{-6} \frac{Vs}{Am}.$$

For a long coil with n' turns, one obtains

$$|\vec{B}| = \mu_o n' \cdot I/l \qquad (3)$$

inside the coil.

If an alternating current I of frequency f or angular frequency f or angular frequency ω flows through the primary coil,

$$I = I_o \cdot \sin \omega t,$$

then, from (1), the voltage induced in a secondary coil (n turns, crosssectional area A) is obtained:

$$U = -\mu_o nA \cdot n'\omega I_o/l \cdot \cos \omega t \qquad (4)$$

The results of the different experiments are shown in Fig. 2–5 and listed in Table 1.

Table 1

Fig.	Exponent	Standard Error
2	0.995	±0.023
3	0.996	±0.005
4	1.033	±0.011
5	1.98	±0.023

Fig. 4: Induced voltage as a function of the diameter of the secondary coil with a primary current of 30 mA and a frequency of 10.7 kHz.

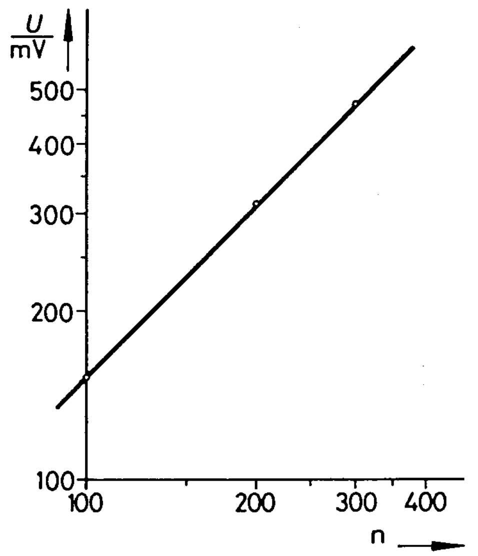


Fig. 5: Induced voltage as a function of the number of turns of the secondary coil with a primary current of 30 mA and a frequency of 10.7 kHz.