Final (EN)

29.03.2025

Instructions:

- Write your full name and school on each sheet.
- Clearly indicate which sub-/question you are answering.
- Explain your reasoning and indicate intermediary calculations.
- Number your pages.

Formulae

Kinematics (UAM)

$x = \frac{1}{2}at^2 + v_0 t + x_0$

$v = at + v_0$

$v^2 - v_0^2 = 2a(x - x_0)$

Forces

$F = ma$

$F_f \leq \mu N$

Work, Energy, Power

$W = Fd \cos\theta$

$E_{cin} = \frac{1}{2}mv^2$

$E_{pes} = mgh$

$E_{el} = \frac{1}{2}kx^2$

$P = \frac{W}{t} = Fv$

Momentum

$p = mv$

$F = \frac{\Delta p}{\Delta t}$

Thermal concepts

$Q = mc\Delta\theta$

$Q = mL$

Ideal gas laws

$p = \frac{F}{A}$

$pV = nRT = Nk_B T$

$E_K = \frac{3}{2}k_B T$

Oscillations and waves

$T = \frac{1}{f}$

$c = f\lambda$

$T = 2\pi\sqrt{\frac{l}{g}}$

$T = 2\pi\sqrt{\frac{m}{k}}$

Electricity

$I = \frac{Q}{t}$

$F = k \cdot \frac{|q_1 q_2|}{r^2}$

$V = \frac{W}{q}$

$E = \frac{F}{q}$

$V = RI$

$P = VI = RI^2 = \frac{V^2}{R}$

$R = R_1 + R_2 + \cdots + R_n$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$

$\rho = \frac{RA}{L}$

Electro-magnetism

$F = qvB \sin\theta$

$F = BIL \sin\theta$

Circular motion

$v = \omega r$

$a = \frac{v^2}{r}$

Gravitation

$F = G\frac{mM}{r^2}$

$g = \frac{F}{m}$

Quantum physics

$E = hf$

$\lambda = \frac{hc}{E}$

Optics

$n_1 \sin\alpha_1 = n_2 \sin\alpha_2$

$\frac{1}{q} + \frac{1}{p} = \frac{1}{f}$

A magnet falling through a coil

The aim of this practical work is to study electromagnetic induction braking experimentally. A neodymium magnet falls through a coil in a closed circuit. Figures 1 and 2 show the experimental set-up and the electrical circuit to be created.

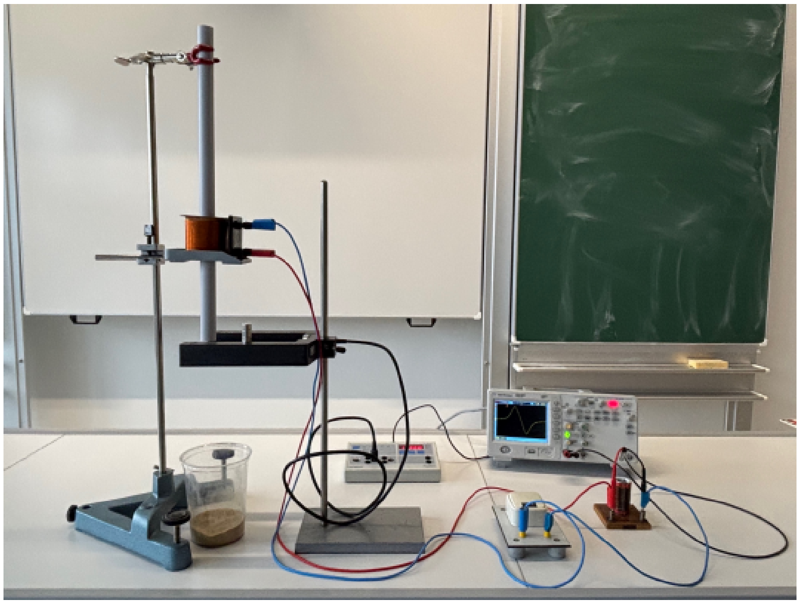

Figure 1

Equipment:

- Tripod
- Tube length 50 cm
- Tube clamp
- Coil with 600 turns and an internal resistance of $r = 2.5\,\Omega$
- Photogate-controlled electronic chronometer
- Magnet of length $L = 30\,\text{mm}$ and mass $m = 42.5\,\text{g}$
- Value resistor from $R = 1\,\Omega$ to $R = 5\,\Omega$
- Channel 1 of an oscilloscope
- Pot filled with sand to cushion the fall of the magnet
- Teslameter

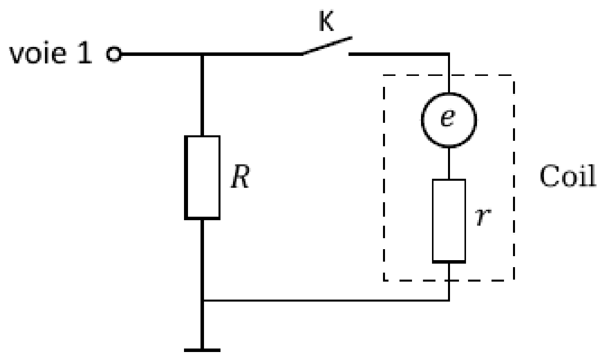

Figure 2

The questionnaire consists of three parts: in the first part, you will use a teslameter to determine the magnetic moment of the magnet used in the following. For parts 2 and 3, you will set up the experimental apparatus shown in figures 1 and 2. The experiment involves releasing the magnet from the top of the tube without any initial velocity. The magnet slides down the tube through

the coil and creates an electromotive force e.
In Part 2, you determine the kinetic energy of the magnet by measuring its speed at the bottom of the tube using the cell's shutter time. and you compare this kinetic energy with the case when the magnet falls in free fall.
In parts 2 and 3, you study the voltage induced by the passage of the magnet through the coil. The voltage induced in the circuit as a function of time is displayed using the oscilloscope.

1. Determining the magnet's magnetic moment **10 p.**

The magnetic field of a magnetic dipole along the axis O_z perpendicular to its surface (see figure 3), can be described by

$$B_z = \frac{\mu_0 m}{2\pi z^3} \quad ,$$

where z is the distance along axis O_z from the centre of the dipole (in m), and m its magnetic moment in Nm/T.

a) Using the teslameter, measure B_z on the O_z axis at distances of between 3 and 10 cm. Record your results in a table. 3 p.

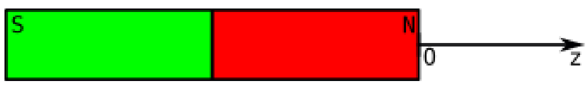

Figure 3

b) Plot B_z as a function of $\frac{1}{z^3}$. 4 p.

c) Add a suitable regression curve (fit) and deduce the value of the magnetic moment in SI units. 3 p.

2. Loss of energy from the magnet falling through the coil **22 p.**

a) Using a diagram, show that when the magnet passes through the coil, a magnetic force $\vec{F}_m$ is exerted on the magnet in the opposite direction to the direction of movement. To simplify the diagram, the coil can be represented by a single turn. 3 p.

b) Let v_0 and v be the speeds of the magnet at the bottom of the tube in the case where the switch is respectively open and closed. Let ΔE_c be the difference between the corresponding kinetic energies:

$$\Delta E_c = \frac{1}{2}mv_0^2 - \frac{1}{2}mv^2$$

Assuming a resultant resistive force (frictional force between the tube and the magnet, air resistance), show that :

$$\Delta E_c = -W(\vec{F}_m)$$

The central hypothesis to be tested in this experiment is that the work of the magnetic force is equal to the heat Q dissipated by the Joule effect in the electric circuit:

$$W(\vec{F}_m) = -Q = -\int_0^t P\ dt \quad ,$$

where P is the power dissipated by the Joule effect. Show that the heat Q can be written as :

$$Q = \frac{R+r}{R^2} \int_0^t u^2 \, dt \quad ,$$

where u is the voltage across resistor R measured on channel 1 of the oscilloscope. 5 p.

c) Measure the shutter time when switch K is open. Repeat at least twice this measurement and deduce the speed v_0. 2 p.

d) The following measurements should be repeated for six vertical coil positions.

Measure the shutter time when switch K is closed. Repeat at least twice this measurement and deduce the speed v.

On the oscilloscope, select a time scale of 100 ms/div and a voltage scale of of 200 mV/div. Press the STOP/HOLD button on the oscilloscope immediately after the passage of the magnet through the coil. Refocus the oscillogram and reduce the time scale to 10 ms/div.

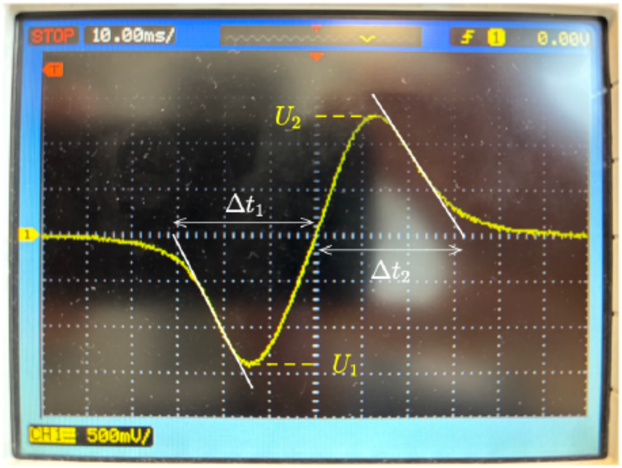

Figure 4

On the oscilloscope screen, measure the quantities Δt_1, Δt_2, U_1 et U_2 as defined in figure 4. 6 p.

e) The integral $\int_0^t u^2 dt$ is equal to the area under the blue curve representing $u^2 = f(t)$ It will be approximated by the sum of the areas of the triangles A_1 and A_2 defined in figure 5.
Use the measurements taken in the previous question to determine the area of the triangles. It is not necessary to display the blue curve on your oscilloscope.

Calculate the values of ΔE_c and Q for each of the measurements.

Plot Q as a function of ΔE_c.

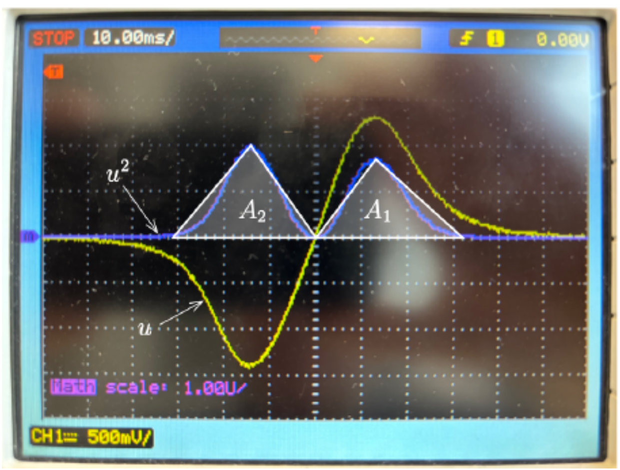

Figure 5

Show that these two quantities are proportional and interpret the proportionality coefficient k. 6 p.

3. Determining the peak induced voltage for a real coil **8 p.**

An ideal flat coil is considered to be one in which the turns are infinitely compressed. However, the spatial extension of a real coil, i.e. the fact that the turns are wound over a certain length, can have repercussions on the electromotive force (EMF) e induced by the passage of the magnet. The passage of the magnet causes a variation in the magnetic flux, which in turn creates a voltage in the circuit.
By treating the falling magnet as a magnetic dipole of magnetic moment m, it can be shown that the induced EMF of the coil of length L and radius a and comprising N turns can be described as a function of the position z of the magnet and its speed v by

$$e = -\frac{\mu_0\, m\, N\, v}{2L}\left(\frac{(z-L/2)^2}{(a^2+(z-L/2)^2)^{\frac{3}{2}}} - \frac{1}{(a^2+(z-L/2)^2)^{\frac{1}{2}}} - \frac{(z+L/2)^2}{(a^2+(z+L/2)^2)^{\frac{3}{2}}} + \frac{1}{(a^2+(z+L/2)^2)^{\frac{1}{2}}}\right)$$

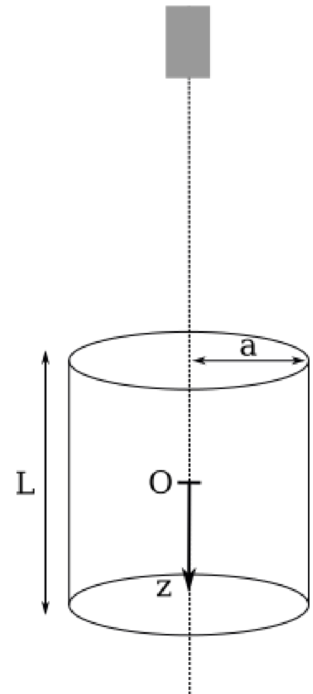

Figure 6

The graph in figure 7 shows the EMF induced by the fall of the magnet through coils of different lengths. The initial position of the magnet is fixed at 40 cm above the centre of the coil. The radius of the coil is $a = 2.6\,\text{cm}$.

a) Measure the voltage U across the resistor R using the oscilloscope and determine the height of the voltage peaks (one negative, the other positive). 2 p.

b) Plot the peaks of the different coils of figure 7 as a function of their size. Connect the points with a suitable regression curve. In order to add your measurement to the graph, you must determine the EMF : $e = (R+r)/R \cdot U$. Add your measurement to the graph so that it can be distinguished from the other points, and conclude. 4 p.

c) Why is the first (negative) peak (in absolute terms) slightly lower than the second (positive) peak? 2 p.

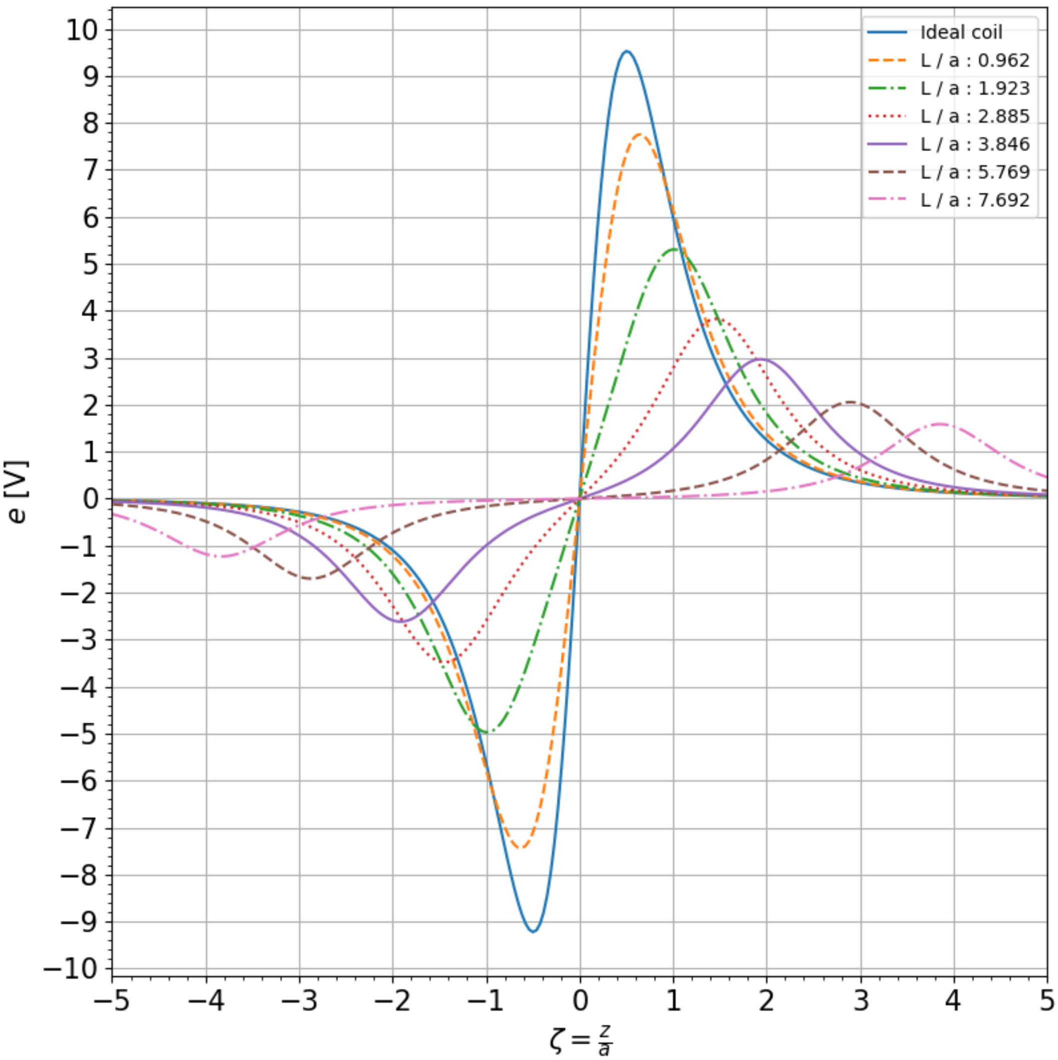
Ideal coil
L / a : 0.962
L / a : 1.923
L / a : 2.885
L / a : 3.846
L / a : 5.769
L / a : 7.692
e [V]
$\zeta = \frac{z}{a}$

Figure 7