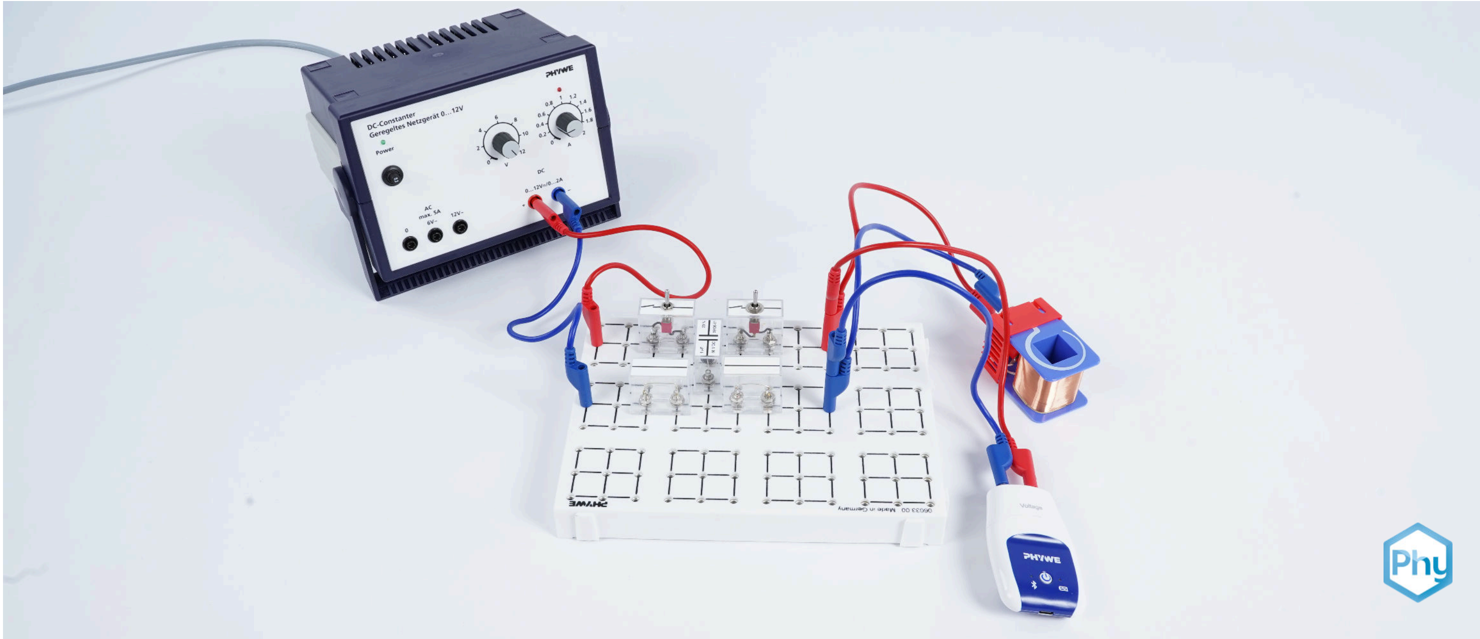
Damped electromagnetic oscillation



Physics | Electricity & Magnetism | Electromagnetic oscillations & waves

Difficulty level	Group size	Preparation time	Execution time
easy	-	10 minutes	20 minutes

This content can also be found online at:

https://www.curriculab.de/c/67ade1370fb2b7000296e856

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Teacher information

Application

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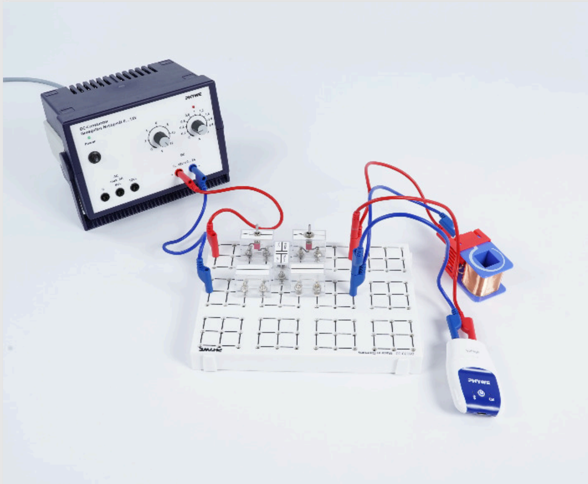

Experimental setup

Electromagnetic oscillating circuits are essential for numerous technical applications. They typically consist of an inductor and a capacitor, which together form an oscillating system. The frequency of this oscillation depends on the inductance and capacitance of these two components.

In real systems, energy is additionally lost due to the resistance of the components involved, causing the oscillation to decay. In this experiment, students will investigate how the properties of the components affect the oscillation period and how the damping of the oscillation can be characterized.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory I

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To understand why a capacitor and an inductor form an oscillating circuit, it is important to consider the properties of the two components. The voltage across a discharging capacitor with capacitance C is given by $U_C = Q/C$, where Q is the charge. If a current $I = \dot{Q}$ flows through a coil, it generates a self-induced voltage $U_L = L \cdot \dot{I}$. To describe the electromagnetic oscillating circuit, both equations must be correctly linked. The mesh rule is useful here: it states that the sum of all partial voltages in a mesh is equal to zero when the signs are taken into account. This leads to the following:

$$\frac{Q}{C} + LI' = \frac{Q}{C} + L\ddot{Q} = 0 \Leftrightarrow \ddot{Q} = -\frac{1}{LC}Q$$

This differential equation is solved by a sine or cosine function of the type $Q(t) = Q_0 \sin \omega_0 t$, with the natural frequency $\omega_0 = 1/\sqrt{LC}$

. The frequency is therefore inversely proportional to the inductance and capacitance. Since the period τ is also inversely proportional to the frequency, it follows that $\tau \propto \sqrt{LC}$.

Theory II

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Although this derivation shows the oscillation of the circuit, it does not take into account the resistance present in every realistic scenario. To include this, the equation for the voltage across a resistor, $U_R = RI$, is added to the mesh rule. The resistor is therefore connected in series with the other components. This results in the following equation:

$$\frac{Q}{C} + R\dot{Q} + L\ddot{Q} = 0$$

This equation has the solution (with a cosine function also satisfying the equation):

$$Q(t) = Q_0 e^{-\frac{R}{2L}t} \sin(\omega_0 t), \quad \omega_0 = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

The charge — and thus the current — oscillates, but decreases exponentially over time. The natural frequency has also changed. For damped oscillations to be visible, the square root must be positive, i.e., $R < 2\sqrt{LC}$.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Other teacher information (1/2)

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Prior

Students should be familiar with the concepts of self-inductance in coils and capacitance in capacitors. They should understand what a resistor is and know that a series connection of a capacitor and a coil forms an electromagnetic oscillating circuit. For the theoretical derivation, the mesh rule and a mathematical understanding of differential equations are required, though the derivation itself is optional for the experiment.

Principle

A capacitor is charged using a power supply unit. The connection to the power supply unit is then interrupted, and the capacitor is discharged through a coil. The voltage across the coil is measured and recorded using a Cobra SmartSENSE Voltage. This procedure is repeated for different capacitances and for a coil with and without an iron core in order to observe the effect of these changes on the period of the oscillation. The measurements can also be used to demonstrate that the oscillations are damped, due to the resistance of the components.

Other teacher information (2/2)

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Learning

The students should learn that a capacitor and an inductor connected in series form an oscillating circuit, which decays due to the resistance of the components. They should also understand that the period of the oscillation is proportional to both the inductance and the capacitance.

Tasks

1. Measuring the voltage as a function of time for $C = 1\mu F, 10\mu F$ and without an iron core in the coil. Note the respective period duration
2. Measuring the voltage as a function of time for $C = 1\mu F, 10\mu F$ and with an iron core in the coil. Note the respective period duration

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37079 Göttingen

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Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Safety instructions

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The general instructions for safe experimentation in science lessons apply to this experiment.

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Student information

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
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info@phywe.de
www.phywe.de

Motivation

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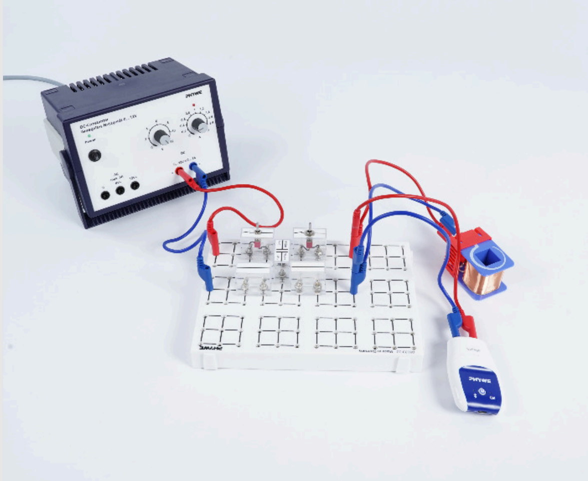

Fig. 1 Experimental setup

Whether in radios, smartphones, or wireless chargers, electromagnetic oscillating circuits form a central foundation of modern technology. They consist of a coil and a capacitor, which together generate an electrical oscillation, similar to a swing moving back and forth.

In these oscillating circuits, energy is exchanged between the electric and magnetic fields. In a simple experiment, it is possible to observe how these oscillations occur, which factors determine their frequency, and how they evolve over time.

Tasks

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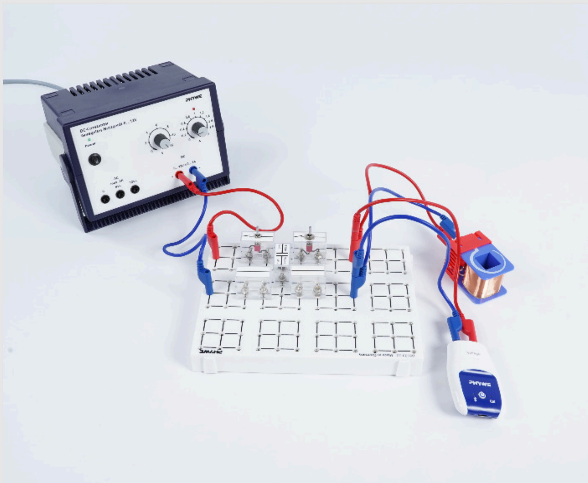

Experimental setup

1. Build the circuit
2. Measure the voltage across the coil while the capacitor is discharging for different capacitors. Note the period of the oscillation each time.
3. Repeat step 2, but use a coil with an iron core.

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
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info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Plug-in board, for 4 mm plugs	06033-00	1
2	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
3	Connecting cord,19 A,25cm, blue	07313-04	3
4	Connecting cord,19 A,25cm, red	07313-01	3
5	Cobra SMARTsense Voltage - Sensor for measuring electrical voltage ± 30 V (Bluetooth + USB)	12901-01	1
6	Coil, 1600 turns	07830-01	1
7	Iron core, U-shaped, laminated	07832-00	1
8	Wire building block, housing G1	39120-00	2
9	on-off switch, G1	39139-00	2
10	Capacitor 10 µF, G1	39105-52	1
11	measureAPP - the free measurement software for all devices and operating systems	14581-61	1
12	Capacitor 1nF/ 100V, G1	39105-10	1

Structure (1/2)

For measurements with the **Cobra SMARTsense** sensors, the **PHYWE measureAPP** is required. The app can be downloaded free of charge from the relevant app store (QR codes are provided below). Before starting the app, please check whether **Bluetooth** is **activated** on your device (smartphone, tablet, or desktop PC).

iOS

Android

Windows

Structure (2/2)

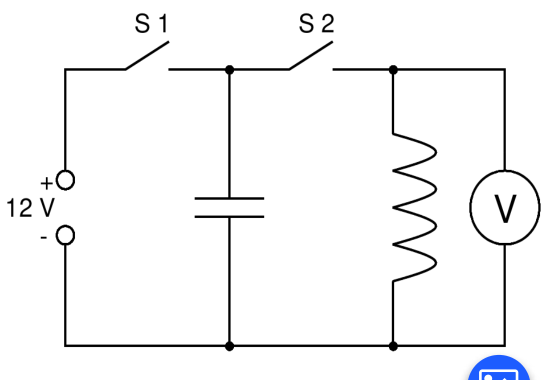

Fig. 2 Circuit diagram of the experiment

Set up the experiment according to the circuit diagram shown on the left. By clicking the button, you will also see the constructed experiment. Use the coil with 1200 windings, without an iron core, and a capacitor with a capacitance of $1 \mu F$.

Use the Cobra SmartSENSE Voltage as a voltmeter and turn it on by pressing the on/off button for three seconds.

Open the measure app and connect to the voltmeter. Set the measurement frequency to 10,000 Hz.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
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info@phywe.de
www.phywe.de

Procedure (1/3)

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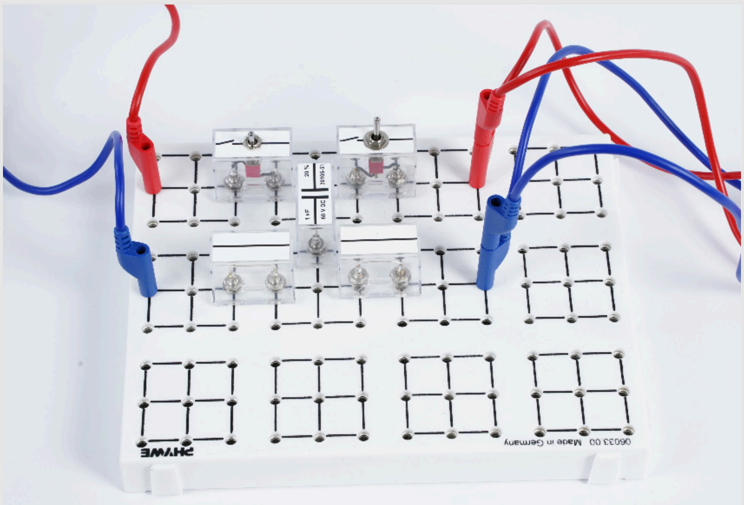

Charging the capacitor

Open switches S1 and S2 so that no current flows. Turn on the power supply unit and set it to a voltage of 12V and a current of 0.2A. Close switch S1 to charge the capacitor.

Start a measurement in the measure app. Now open switch S1 and then close switch S2 so that the capacitor discharges through the coil, ensuring that no current from the power supply unit flows. Stop and save the measurement.

Procedure (2/3)

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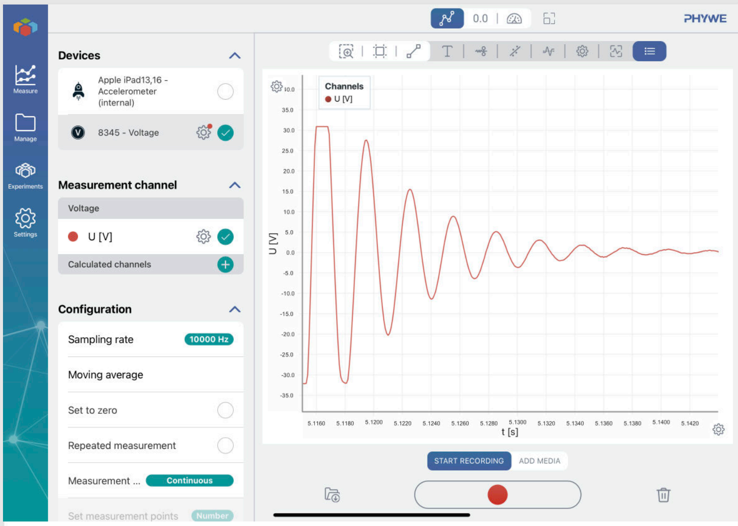

Example measurement

Use the zoom function to observe the discharging process more closely. An example measurement is shown on the left-hand side. It should represent an oscillation. You can determine the period of the oscillation by measuring the time interval between two maxima. The easiest way to read function values is by moving your finger along the bottom of the function. The corresponding function values will then be displayed.

Note the period, along with two pieces of information: the capacitance of the capacitor and the core of the coil — in this case, no core.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
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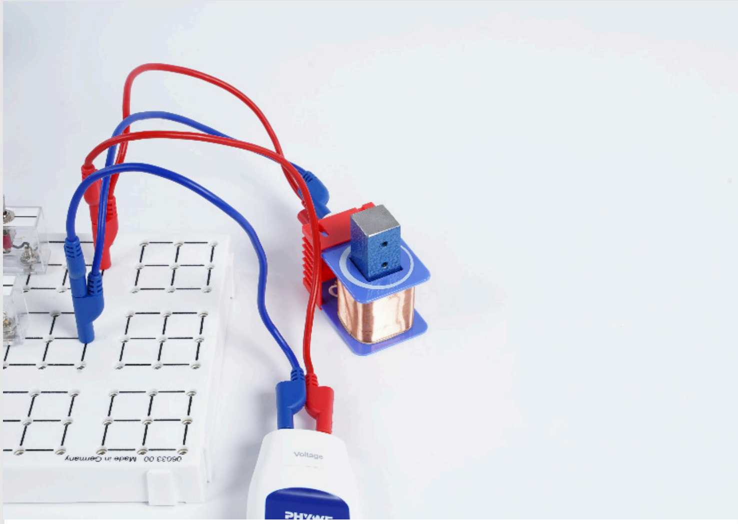
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure (3/3)



Experimental setup with a coil with an iron core

Switch off the power supply unit. Now, repeat the measurement for the same coil, but with a $10\mu F$-capacitor, and note the period again, along with the relevant information.

Finally, perform two more measurements: one with a $1\mu F$-capacitor and one with a $10\mu F$-capacitor. However, first insert the iron core into the coil. Be sure to note the respective period duration for both measurements.

Make sure to switch off the power supply unit before replacing any components!

Report

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Task 1

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How does the period duration relate to the inductance L of the coil and the capacitance C of the capacitor?

- ☐ The period duration does not depend on the capacitance
- ☐ The period duration is antiproportional to the inductance
- ☐ The period duration is proportional to the capacitance
- ☐ The period duration is antiproportional to the capacitance
- ☐ The period duration is proportional to the inductance

Check

Task 2

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How does vibration behave over time?

- ○ The oscillation decays exponentially.
- ○ The oscillation remains unchanged over time
- ○ The vibration gets bigger and bigger.
- ○ The oscillation decays linearly

Check

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
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info@phywe.de
www.phywe.de

Task 3

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Drag the words into the correct boxes!

As the capacitor discharges, current flows through the coil and a ________ builds up around it. This magnetic field, in turn, induces a voltage in the coil. The induced current flows back to the capacitor and recharges it. When the ________ is largely complete, the capacitor ________, and the cycle begins again. This is how the electromagnetic oscillation is created.

However, the measurements also show that the oscillation decreases ________. This is due to the fact that energy is lost as it is converted into ________ at the components. If ideal, resistance-free components were used, the oscillation would continue indefinitely.

- magnetic field
- exponentially
- discharges
- self-induction
- heat
- linearly

Slide	Score / Total
Slide 18: Untitled: Multiple Choice	**0/2**
Slide 19: Sed diam voluptua	**0/1**
Slide 20: Untitled: Drag the Words	**0/6**

Total amount 0 / 9

Solutions   Repeat

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

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www.phywe.de