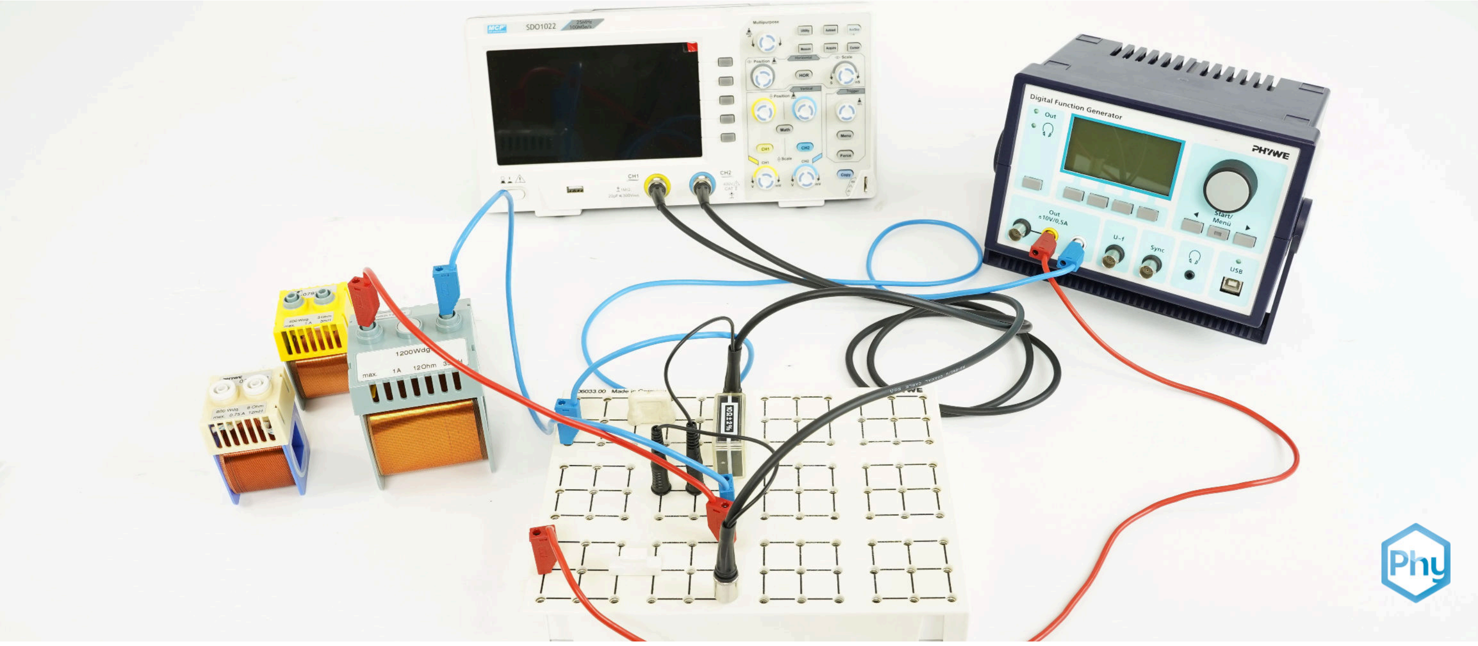
Coil in the AC circuit



Physics | Electricity & Magnetism | Electronics

Difficulty level	Group size	Preparation time	Execution time
hard	-	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/64ac07604c88d10002e3406f

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General information

Application

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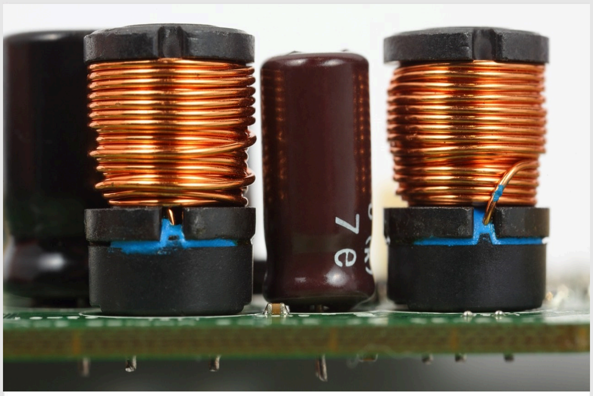

Electromagnetic coils on a board

Alternating current refers to electrical current that changes its direction (polarity) in regular repetition and in which positive and negative instantaneous values sum up, so that the net current is zero on average over time.

Alternating current always has a real and an imaginary component. There is single-phase or multi-phase alternating current, which can be differentiated depending on the phase shift φ. Since a coil's inductance depends on the current and since the inductance is subject to Lenz's rule, a change in voltage is retarded due to the inserted coil. This property makes a coil in a AC circuit a commonly used frequency filter component.

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Other information (1/2)

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Prior knowledge

Basic knowledge of physical quantities such as current, voltage and resistance should be available. Ideally, the process of electromagnetical induction should be known.

Scientific principle

The coil is connected in a circuit with a voltage source of variable frequency. Due to the inductance of the coil, a phase shift of the current occurs. The impedance and phase displacements are determined as functions of frequency. Parallel and series impedances are measured in comparison.

Other information (2/2)

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Learning objective

After the successful completion of this experiment you will be able to theoretically describe the phenomenon of inductance with respect to alternating currents. You will also be able to experimentally determine the frequency dependend impedances and the caused phase shifts.

Tasks

1. Determine the amplitude and phase of the inductive resistance as a function of the inductance.

2. Determine the amplitude and phase of an inductive resistance as a function of frequency.

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Safety instructions

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

Theory (1/4)

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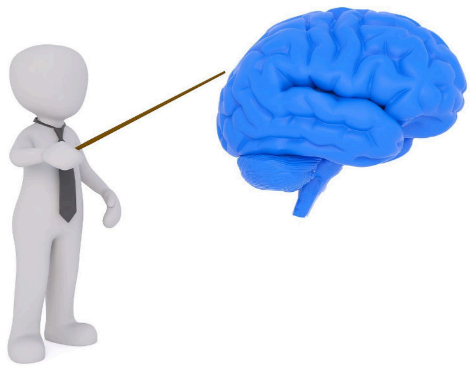
Any change in current through a coil induces a counter electromotive force that opposes the change in current. Therefore, in AC circuits, the voltage across the coil leads the current through the coil. Mathematically, this relationship is best described by using current, voltage, and resistance as complex quantities and considering their real components.

The current-voltage relationship for a coil is:

$$U = L \cdot \frac{dI}{dt} \qquad (1)$$

With I as current, U as voltage and L as inductance of the coil.



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Theory (2/4)

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If an alternating voltage

$$U = U_0 \cdot e^{i\omega t} \quad (2)$$

is now applied, the following applies to the current

$$I = \frac{1}{i\omega L} \cdot U_0 \cdot e^{i\omega t} \quad (3)$$

A coil therefore has the complex resistance

$$X_L = \frac{U}{I} = i\omega L = 2\pi i f L \quad (4)$$

If we now consider the real parts of equations (2), (3) and (4), we obtain the following relationships for voltage U, current I and resistance X_L:

$$U = U_0 cos(\omega t) \quad (5)$$

$$I = \frac{U_0}{\omega L} cos(\omega t - \frac{\pi}{2} = I_0 cos(\omega t - \frac{\pi}{2}) \quad (6)$$

$$X_L = \frac{U_0}{I_0} = \omega L = 2\pi f L \quad (7)$$

Theory (3/4)

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The total inductance of a series connection of coils is equal to the sum of the individual inductances:

$$L = L_1 + L_2 + \ldots + L_N = \sum_{i=1}^{n} L_i \quad (8)$$

The ohmic resistance of several coils connected in series is the sum of the individual resistances:

$$R_L = R_1 + R_2 + \ldots + R_N = \sum_{i=1}^{n} R_i \quad (9)$$

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Theory (4/4)

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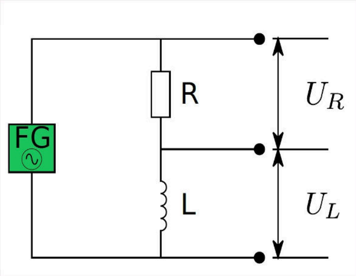

Dependence of inductive resistance on inductance and frequency

The amplitude of the current through the coil can be calculated as follows:

$$I_0 = \frac{U_{R0}}{R}$$

For the total resistance Z_L of the coil holds:

$$Z_L = \sqrt{R_L^2 + X_L^2} = \frac{U_{L0}}{I_0}$$

Finally, the inductive resistance can be calculated with this:

$$X_L = \sqrt{Z_L^2 - R_l^2}$$

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Equipment

Position	Material	Item No.	Quantity
1	Plug-in board, for 4 mm plugs	06033-00	1
2	Coil, 1200 turns	06515-01	1
3	Resistor 10 Ohm, 1W, G1	39104-01	1
4	PHYWE Digital Function Generator, USB	13654-99	1
5	Digital storage oscilloscope with USB, 100 MHz / 2CH, 1GS/s	EAK-P-1404	1
6	Connecting cord,19A,50cm, blue	07314-04	2
7	Connecting cord, 32 A, 500 mm, red	07361-01	2
8	Measuring cable BNC to 4 mm banana plug, length 1 m	EAK-MKS-1	2
9	brigde plug	06027-07	4
10	Coil, 400 turns	07829-01	1
11	Coil, 600 turns	06514-01	1

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Setup and procedure

Setup

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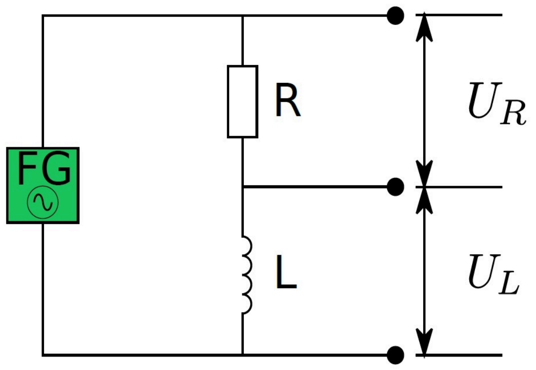

Experimental setup

- Set up the experiment according to the circuit diagram with
  - the resistor $(R = 10\Omega)$ and
  - the coil $(L = 35mH, R_L = 12\Omega, N = 1200)$.
- The voltage curve U_R of the measuring resistor is measured with $CH1$ and the voltage curve of the coil U_L with $CH2$ of the oscilloscope.
- Use the autoscaling of the oscilloscope.

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Procedure (1/3)

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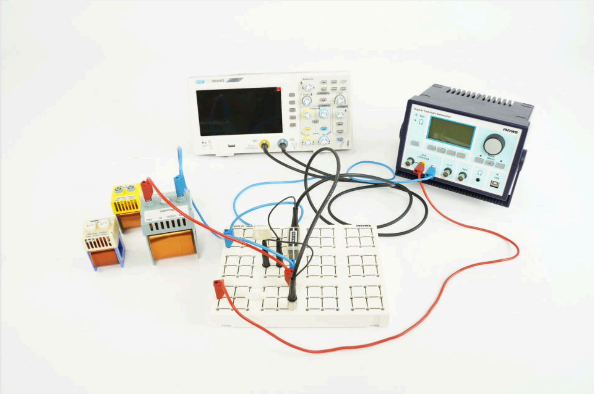
- Set a frequency of $f = 500Hz$ at the function generator.
- Select "Sine" as the waveform and set the amplitude of the input signal to $U_0 = 4V$.
- Note: The value of the measuring resistor R is negligible compared to the inductive resistance X_L at the frequencies considered, but the ohmic resistance R_L of the coil must be taken into account.

1. Phase shift between current and voltage

- observe the relative position of the voltage waveforms $U_L(t)$ and $U_R(t)$ and note your observations.



Experimental setup of a coil in a AC circuit

Procedure (2/3)

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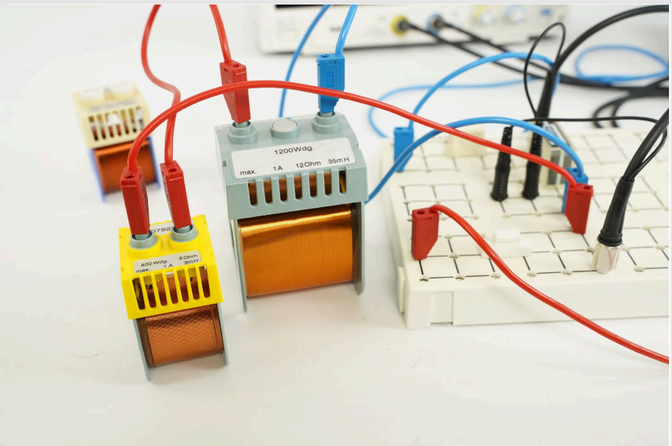
2. Dependence of inductive resistance on inductance

- Replace the coil $(N = 1200, R_L = 12\Omega, L = 35mH)$ with the other two coils with $(N = 600, R_L = 2.5\Omega, L = 9mH)$ and $(N = 400, R_L = 3\Omega, L = 3mH)$ and generate (if necessary by connecting the coils in series) the following numbers of turns: $N = 400, 800, 1200, 1600, 2000, 2400$
- Read the voltages U_{L0} and U_{R0} on the oscilloscope and write them down in a table.



Coils in series

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Procedure (3/3)

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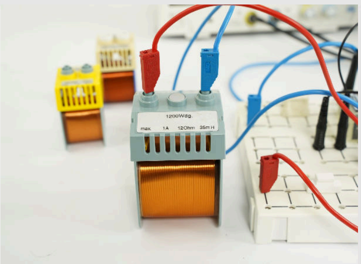

3. Dependence of the inductive resistance on the frequency

- Use the coil with $N = 1200$ and the resistor $R = 10\Omega$ as measuring resistor.
- Set the frequencies $f = 100Hz, 300Hz, 500Hz, 800Hz, 1200Hz, 2000Hz$ on the function generator one after the other.
- Read the amplitudes U_{L0} and U_{R0} on the oscilloscope and enter them into a table.

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Evaluation

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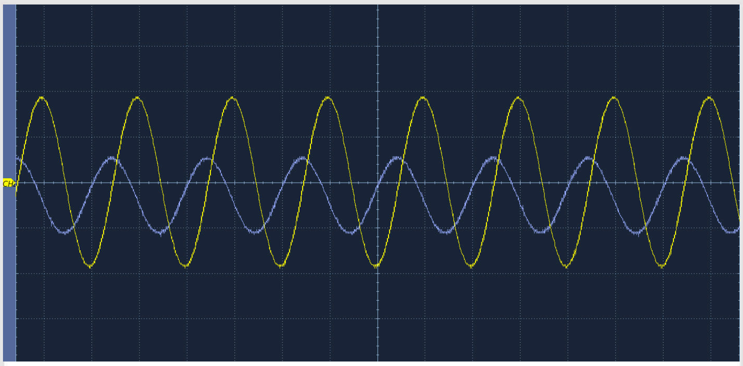
Evaluation (1/3)



Coil in the AC circuit (oscilloscope image)

voltage: yellow; current: blue

Phase shift between current and voltage

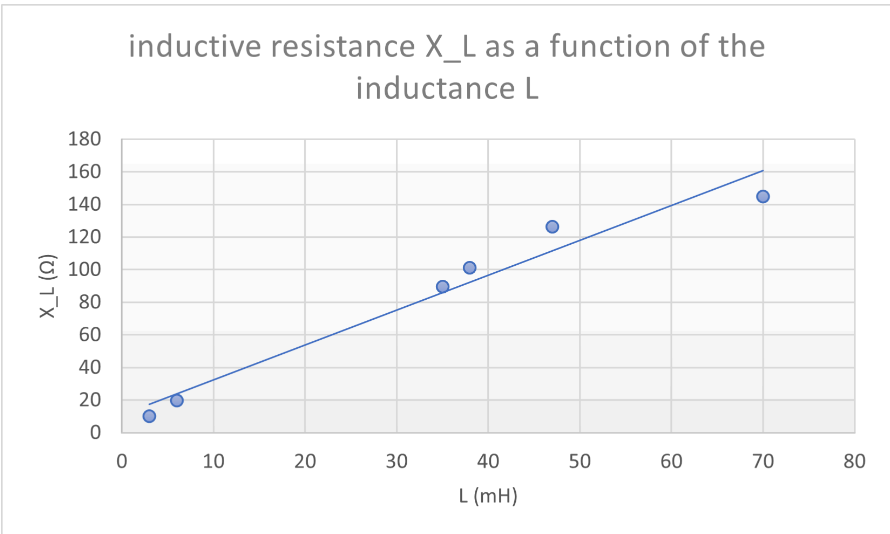
It can be seen that the current signal is shifted by a quarter of a period to the left compared to the voltage signal.

The current through the coil lags the voltage at the coil in phase by 90°.
The reason for this is that every change in current induces a reverse voltage.

Evaluation (2/3)

If the inductive resistances X_L are plotted against the inductances, the following relationship can be seen:

The inductive resistance X_L is proportional to the inductance L. This is confirmed by equation (4).



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Evaluation (3/3)

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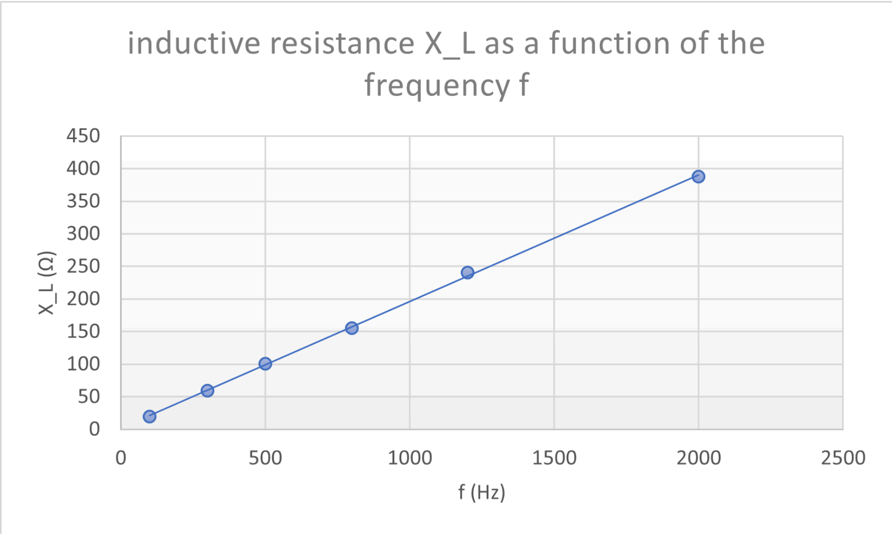

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