How does a coil act in an alternating current circuit?

EEP 10.3

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Problem

Prove that a coil in an alternating current circuit possesses a resistance in addition to the ohmic resistance from its wound wire and investigate the factors responsible for this additional resistance.

Equipment

Plug-in board	06033.00	1
On/off switch	39139.00	1
Lamp holder E10	17049.00	2
Filament lamp, 6 V/0.5 A, E10, 2 pcs.	35673.03	(1)
Resistor, 47 Ω	39104.62	1
Coil, 400 turns	07829.01	1
Coil, 1600 turns	07830.01	1
U-core	07832.00	1
Yoke	07833.00	1
Tightening screw	07834.00	1
Wire building block	39120.00	3
Connecting cables, 25 cm, red	07360.01	2
Connecting cables, 25 cm, blue	07360.04	1
Connecting cables, 50 cm, red	07361.01	2
Connecting cables, 50 cm, blue	07361.04	2
Multi-range meter	07028.01	1
Power supply, 0...12 V-, 6 V~, 12 V~	13505.93	1

Set-Up and Procedure

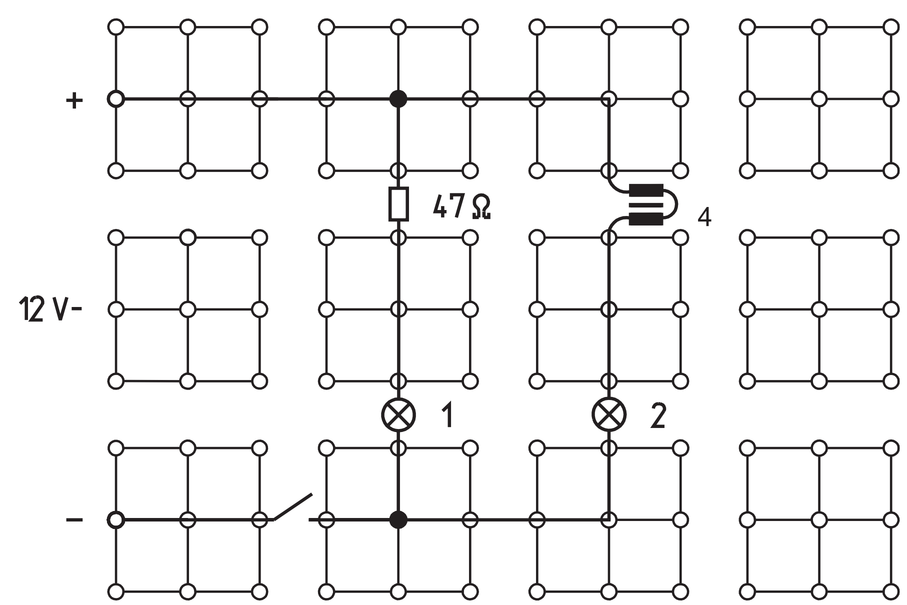
First Experiment

— Place coils on U-core.
— Use the tightening screw to press U-core and yoke together firmly.
— Set up experiment as shown in Fig. 1. Switch should be in off position initially.
— Switch on power supply unit and set direct voltage to 12 V.
— Switch on circuit, observe brightness of filament lamps, and compare. Note results under (1).
— Toggle on/off switch back and forth slowly at first, and then more and more quickly. Observe the filament lamps while doing this. Note observations under (2).
— Switch power supply unit off.

Second Experiment

— Set up experiment as shown in Fig. 2. Select measurement range of 30 mA-. Circuit should be switched off initially. The coils should be connected in series as in the first experiment initially.
— Set alternating voltage to 6 V and switch on power supply unit.
— Switch on circuit, measure current, and enter in Table 1 under (3).
— Remove the coil with 400 turns from the circuit (thereby reducing the total number of turns in the series connection from 2000 to 1600). Measure current and note.
— Change measurement range to 300 mA-. Remove the coil with 1600 turns and replace with coil with 400 turns and proceed as above.
— Leave the coil with 400 turns in circuit. Remove yoke (I-core) of the iron core from the circuit. Measure current and note.
— Finally, remove the U-core from the circuit. Measure current and note.
— Switch power supply unit off.

Fig. 1



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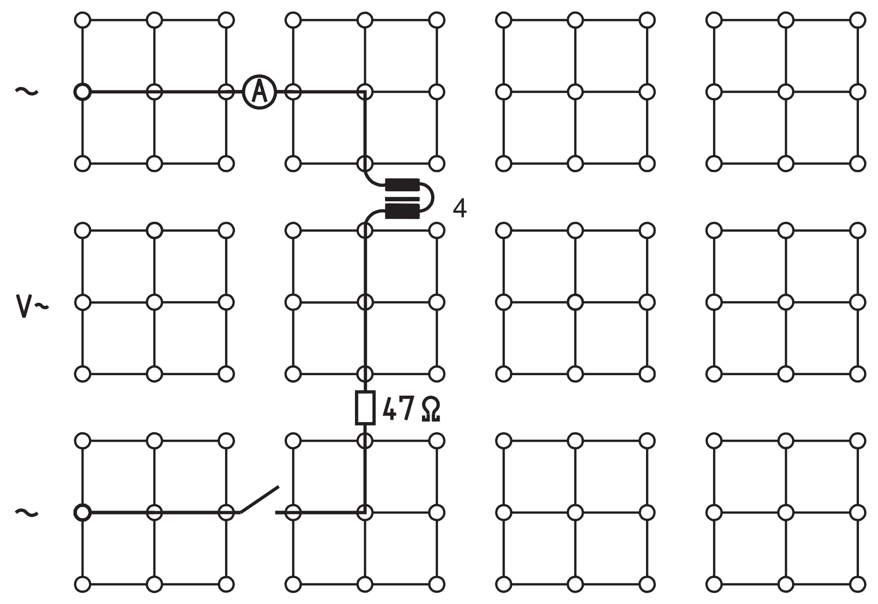
Observations and Measurement Results

(1)

(2)

Fig. 2



(3) Table 1

Coil with	U /V	I /mA	$R_{\sim}/\Omega$	$R_{\_}/\Omega$
2000 turns, U- and I-core				
1600 turns, U- and I-core				
400 turns, U- and I-core				
400 turns and U-core				
400 turns				

Evaluation

1. What conclusion can you draw from the observations you made under (2) regarding the values for current and resistance in both branches?

2. Calculate the values for impedance $R_{\sim}$ resulting from the measurements entered in Table 1 and enter the results in the next to last column of Table 1.
3. Enter the value for combined resistance $R_{\_}$ represented by the coil and resistor in the last column of Table 1 (add the values for resistance printed on the components).
4. Compare line for line the resistance values in Table 1 for the series connection of coil and resistor for both the direct current and alternating current circuits respectively.
   The discrepancies can only be the result of the behavior of a coil in the alternating current circuit. Explain the difference between the values for resistance for a coil in direct current and alternating current circuits.

5. The differences between $R_{\sim}$ and R_{-} are caused by the inductive resistance of every coil in the alternating current circuit. Based on the results of both experiments, explain the factors responsible for inductive resistance.

Coils in Alternating Current Circuits

(How does a coil act in an alternating current circuit?)

The students know that self-induced voltage is generated in a coil in a direct current circuit when the circuit is switched on or off. They also know which direction the self-induced current has.
Based on this knowledge, they can probably predict what happens when alternating current flows through a coil.
The first experiment demonstrates that the additional resistance, which coils possess in an alternating current circuit as opposed to their resistance in a direct current circuit, is dependent on frequency. Of course, there is no alternating voltage source used to provide a variable frequency in this experiment, but a similar effect can be achieved by switching the switch for direct voltage on and off at different rates.
The second experiment is used to provide a semi-quantitative analysis of the dependency of inductive resistance on the number of turns and the coil core.

Notes on Set-Up and Procedure

In the series connection of the coils with the core, make sure the students do not cross polarity since this would cause the magnetic fields of the coils to cancel each other out partially.
The students must change the measurement range in the second experiment because there should be a large discrepancy in the values for inductive resistance in the series of measurements.

Observations and Measurement Results

(1) Both filament lamps shine with the same intensity.
(2) While the filament lamp L1 keeps shining with the same intensity, filament lamp L2 gets dimmer and dimmer the greater the switching frequency.
(3) See Table 1.

Evaluation

1. The current in the branch with the coil decreases as the switching frequency increases. The resistance in this branch increases as the switching frequency increases. In the other branch, the resistance remains constant.
2. See Table 1, next to last column.
3. See Table 1, last column.
4. The resistance values for R are greater than those for R_ in every case. The difference is greatest when the number of turns is at its greatest and the iron core is closed.
   A magnetic field is formed and fades periodically in the alternating current circuit. The self-induced voltage resulting from this counteracts the connected alternating voltage and reduces the current.
   There is no additional resistance in the direct current circuit.
5. The inductive resistance depends on the number of turns on the coil and on the core in the coil.
   The greater the number of turns on the coil, the greater the inductive resistance. Inductive resistance is also greater when the coil has a closed iron core.

Notes

Make sure the students do not equate the difference between $R_\sim$ and R_ with inductive resistance which is represented by the following equation

$$X_L = \omega \cdot L = 2\,\pi \cdot f \cdot L$$

$R_\sim$ is the impedance Z, and with R_ = R, the following relationship applies:

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (\omega \cdot L)^2}\,.$$

L is inductivity, which is measured in Henry (H).

(3) Table 1

Coil with	U /V	I /mA	$R_\sim/\Omega$	R_/Ω
2000 turns, U- and I-core	6	4.2	1429	95
1600 turns, U- and I-core	6	6.0	1000	92
400 turns, U- and I-core	6	48	125	50
400 turns and U-core	6	110	55	50
400 turns	6	112	54	50

(How does a coil act in an alternating current circuit?)

Room for notes