How does a transformer perform under load?

EEP 9.2 **S**

Task

To connect up a model of a transformer and use it to examine which conformity to law is given when the transformer is under load.

Equipment

Plug-in board	06033.00	1
On/off switch	39139.00	1
Resistor, 47 Ω	39104.62	1
Resistor, 100 Ω	39104.63	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
Connecting cable, 25 cm, red	07313.01	2
Connecting cable, 25 cm, blue	07313.04	2
Connecting cable, 50 cm, red	07314.01	2
Connecting cable, 50 cm, blue	07314.04	2
Multi-range meter	07028.01	2
Power supply, 0...12 V-,6 V~, 12 V~	13505.93	1

Set-Up and Procedure

— Connect up the circuit as shown in Fig. 1; first without the voltmeter; the switch is open, the yoke is placed, bare side down, on the U-core and firmly connected with the tightening screw; the 1600 turn coil is the primary coil of the model.

— Select the 30 mA~ measurement range, set the power supply to 12 V~ and switch it on.

— Insert the 100 Ω resistor in the secondary circuit, close the switch and measure the currents I_p (in the primary circuit) and I_s (in the secondary circuit). Note the measured values in Table 1.

— Carry out the same procedure with the 47 Ω resistor, again measuring I_p and I_s and noting the values.

— Change the measurement range to 300 mA~ and short circuit the secondary coil by replugging the connecting cable to the ammeter from 1 to 2 (see Fig. 1); again measure I_p and I_s and note the measured values.

— Open the switch and re-connect the measuring instrument for the primary current as voltmeter parallel to the secondary coil (shown as broken line in Fig. 1); select the 10 V~ measurement range.

— Close the switch, measure the short-circuited U_s and note the value in Table 1.

— Re-connect the connecting cable to the ammeter from 2 to 1; successively insert the components in the secondary circuit as above, and in each case measure U_s and note the value.

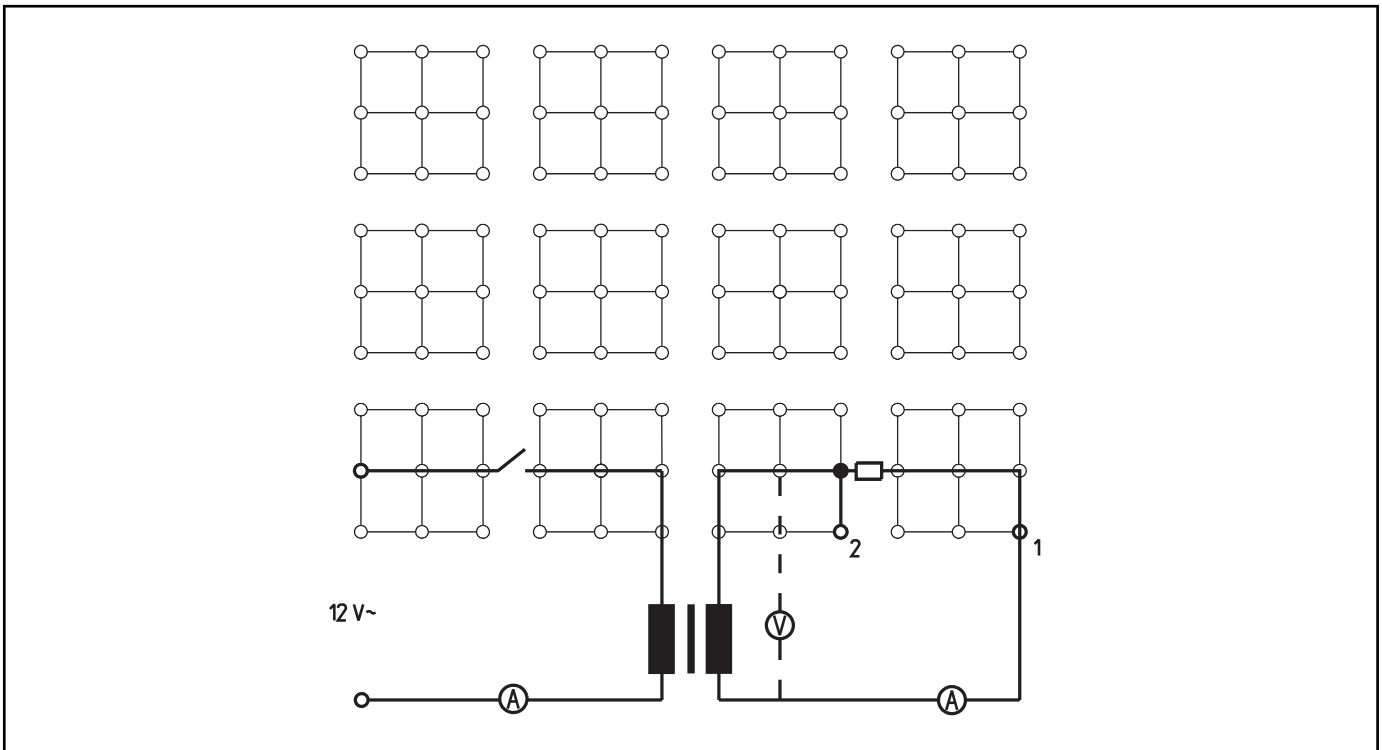
— Switch off the power supply.

Measurement Results

Table 1: N_p = 1600; N_s = 400; U_p = 12 V~)

Component in the secondary circuit	$\frac{I_p}{mA}$	$\frac{I_s}{mA}$	$\frac{U_s}{V}$	$\frac{I_s}{I_p}$
100 Ω resistor				
47 Ω resistor				
Short circuit				

Fig. 1



Evaluation

1. How does the secondary voltage U_s react when the strength of the secondary current I_s, the load on the transformer, increases?

2. For a transformer without load we found: $U_p:U_s \approx N_p:N_s$,, i.e. that the voltages behave roughly the same as the numbers of turns.
   a) How large is the ratio $N_p:N_s$ for the transformer you have experimented with?

   b) Calculate the quotients $I_s:I_p$ and enter their values in the Table
   c) Which value do the quotients $I_s:I_p$ appear to approach?

   d) Which law must accordingly be valid for a transformer under heavy load? (Express the relationship between the strengths of the currents and the numbers of turns mathematically and in words.)

Transforming current

(How does a transformer perform under load?)

When very high current strengths are required on a technical scale, e.g. for welding equipment or electric smelting furnaces, then so-called heavy current transformers are used. Their secondary coils have only a few turns of large diameter wire.

In the case of an ideal transformer under load, the primary and secondary performances are equal, so that $I_s:I_p = N_p:N_s$ is valid.

The students should recognize from this experiment that the ratio Is:Ip increases with increasing load, so that, for the transformer under load:

$I_s:I_p \approx N_p:N_s$.

Notes on Set-Up and Procedure

Should three multi-range meters be available for each working group, then I_p, I_s and U_s can be determined with the other values to save time.

Measurement Results

Table 1: N_p = 1600; N_s = 400; U_p = 12 V~)

Component in the secondary circuit	$\frac{I_p}{mA}$	$\frac{I_s}{mA}$	$\frac{U_s}{V}$	$\frac{I_s}{I_p}$
100 Ω resistor	11.5	18	2.8	1.6
47 Ω resistor	13.3	28	2.7	2.1
Short circuit	50	185	1.2	3.7

Evaluation

1. The secondary voltage decreases when the strength of the secondary current increases, i.e. on increasing the load on the transformer.
2. a) $U_p:U_s$ = 4:1 = 4.
   b) Refer to the 5th column of Table 1.
   c) The quotients Is:Ip appear to approach the number 4 = 4:1.
   d) The following must be valid for a transformer under heavy load:
   $I_s:I_p \approx N_p:N_s$; the behaviour of the strengths of the currents is roughly the same as that of the inverse of the numbers of turns

Remarks

For an ideal transformer, the following relationship is valid:$U_p:U_s = N_p:N_s$ and $U_p \cdot I_p = U_s \cdot I_s$. From this we have: $U_p:U_s = N_p:N_s = I_s:I_p$ or $I_s:I_p = N_p:N_s$.

It is more reasonable, that the students work with the relationship which applies in practice: $I_s:I_p \approx N_p:N_s$

They should also understand that the values of the quotients approach each other more closely, the greater the load which is on the transformer.

The transformer model with which the students experiment is not a heavy current transformer, as the secondary coil consists of 400 turns of thin wire. It would therefore be absurd to want to work towards the equalness of the quotients $I_s:I_p$ and N_p/N_s. The behaviour of a transformer under heavy load can, however, can be derived from the results.

Transforming current

(How does a transformer perform under load?)

Room for notes

PHYWE	**What effect does a coil have in a direct current circuit when the circuit is switched on?**	EEP 10.1	S

Problem

Investigate the effect of a coil installed in one of the branches in a parallel circuit of two filament lamps

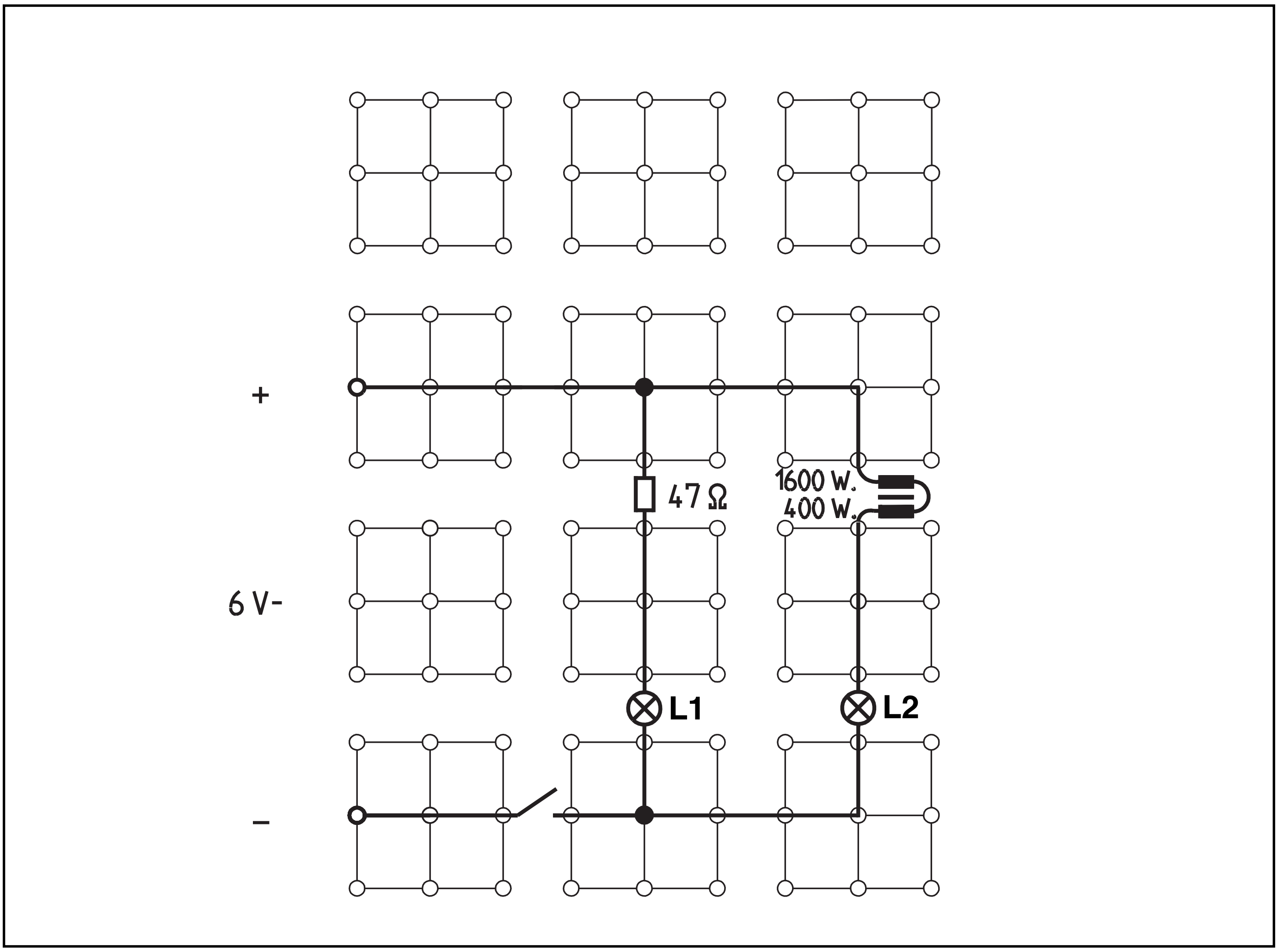
Equipment

Plug-in board	06033.00	1
On/off switch	39139.00	1
Lamp holder E10	17049.00	2
Filament lamp, 4 V/0.04 A, E10, 2 pcs.	06154.03	(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	1
Connecting cables, 50 cm, blue	07361.04	1
Power supply, 0...12 V-, 6 V~, 12 V~	13505.93	1

Set-Up and Procedure

- 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 6 V.
- Toggle on/off switch back and forth repeatedly. While doing this, observe both filament lamps L1 and L2 **simultaneously**. Note observations under (1).
- Loosen tightening screw and remove iron core from coil.
- Toggle on/off switch back and forth repeatedly. Again, observe both filament lamps simultaneously. Note observations under (2).
- Switch power supply unit off.

Fig. 1



S	EEP 10.1	What effect does a coil have in a direct current circuit when the circuit is switched on?	PHYWE

Observations

(1) Circuit is switched on:

Circuit is still switched on:

Circuit is switched off:

(2)

Evaluation

1. How can you explain the behavior of the coil described under (1) when switched on?
   Note: Use your knowledge of electromagnets and electromagnetic induction in your explanation.

2. What role does the 47 Ω resistor play?

3. Why do both filament lamps go off at the same time when switched off?

4. Why does the phenomenon observed when switching the circuit on not occur when the iron cores are removed from the coils?

(What effect does a coil have in a DC circuit when the circuit is switched on?)

The students know that voltage is induced in a coil as long as the magnetic field inside the coil varies. They are familiar with electromagnets and, therefore, know that a coil with a current flowing through it produces a magnetic field and they know the factors responsible for the strength of the magnetic field.
This magnetic field takes time to form when the circuit is switched on and takes time to fade away when the circuit is switched off. This causes self-induced voltage to be formed each time.
In this experiment, the student should see that the self-induced voltage formed when switching on the circuit counteracts the increase in current.

Notes on Set-Up and Procedure
Since the inductance is relatively small, it may be difficult for the students to see that there is a delay between the lighting of filament lamp L1 and filament lamp L2. Encourage them to keep trying until they perceive the delay. In the end, they may find it easier to see this by carrying out the experiment once at a low operating voltage.

Observations
(1) Circuit is switched on: Filament lamp L2 lights up after L1.
Circuit is still switched on: Both filament lamps shine with the same intensity.
Circuit is switched off: Both filament lamps go out at the same time.
(2) Both filament lamps go on and off at the same time.

Evaluation
1. After the circuit is switched on, current begins to flow and forms a variable magnetic field (one with increasing intensity). This variable magnetic field inside the coils produces an induced voltage which counteracts the connected operating voltage and delays the increase in current until it reaches its maximum value.
2. The lamps should apparently shine with the same intensity. Because the two coils have a combined resistance of 48 Ω, the 47 Ω resistor must be connected in series with filament lamp L1.
3. After the connection to the power supply unit is interrupted, both filament lamps are in a series connection. The induction current produced by the fading magnetic field must flow through both filament lamps. That is why both lamps must go out at the same time.
4. The change in the magnetic field (from zero to its maximum value) is so minimal that the induction produced when switching the circuit on can no longer be observed.

Notes
The coil functions both as a field coil and an induction coil. The voltage produced by the variation in the coil current and the resulting variation in the strength of the magnetic field in the coil is called self-induced voltage.
According to Lenz's Law, this voltage always counteracts its cause.
The following equation applies:

$$U_i = -L\ (dI/dt).$$

L is the self-induction coefficient or inductance. It is measured in Henry (H). The coils used in this experiment without the iron core have an inductance of 50 mH and 3 mH respectively. With a closed core, the coil with 400 turns has an inductance of 100 mH, and the coil with 1600 turns has an inductance of 700 mH.

T

EEP 10.1

Self-Induction When Switching on a Circuit

(What effect does a coil have in a DC circuit when the circuit is switched on?)

Room for notes

What effect does a coil have when the circuit is switched off?

Problem
Investigate the direction of the self-induced voltage produced when a direct current circuit is switched off.

Equipment

Plug-in board	06033.00	1
On/off switch	39139.00	1
Changeover switch	39169.00	1
Lamp holder E10	17049.00	1
Neon lamp, 110 V, E10	07506.90	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	1
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 coil on U-core.
- Use the tightening screw to press U-core and yoke together firmly.
- Set up experiment as shown in Fig. 1. Changeover switch should be set to position 1 initially.
- Select measurement range of 30 mA- and shift the pointer on the current meter out of the zero position to the right by turning the adjusting screw on the back panel.
  Important! Since you do not know which direction the self-induced current is going to flow before the experiment, you must allow for the pointer to deflect to the left without damaging the meter!
- Switch on the power supply unit and set direct voltage to 10 V.
- Put switch changeover switch to position 2, thereby turning the left circuit on and the right circuit off. Observe deflection of pointer on current meter.
- Switch changeover switch back again and note reaction of current meter under (1).
- Switch power supply unit off.

Second Experiment
- Set up experiment as shown in Fig. 2.
- Switch on power supply unit and set direct voltage to 10 V again.
- Turn switch on.
- Turn switch off and observe the neon lamp.
- Toggle switch back and forth repeatedly, observe neon lamp, and note observation under (2).
- Switch power supply unit off.

Fig. 1

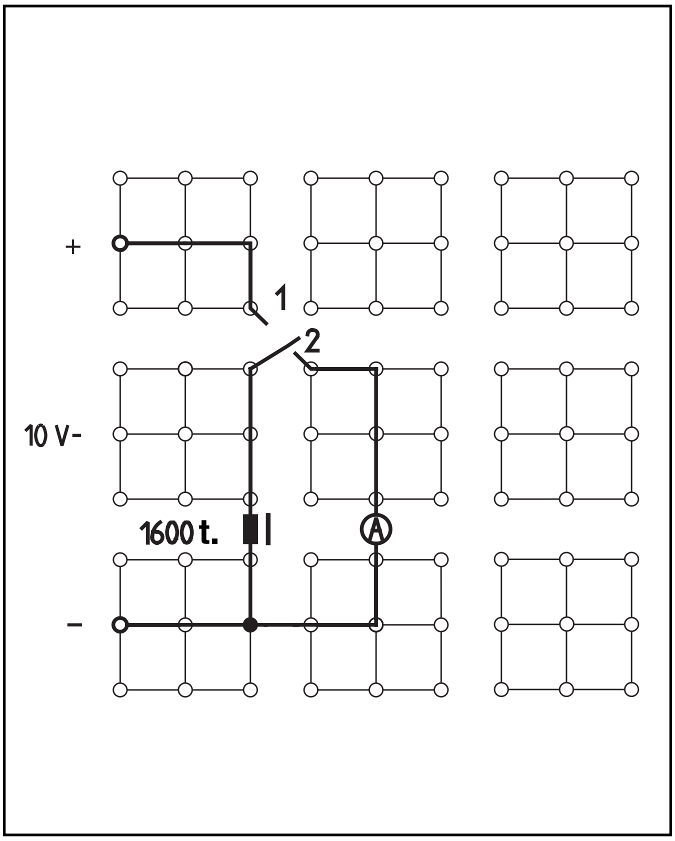
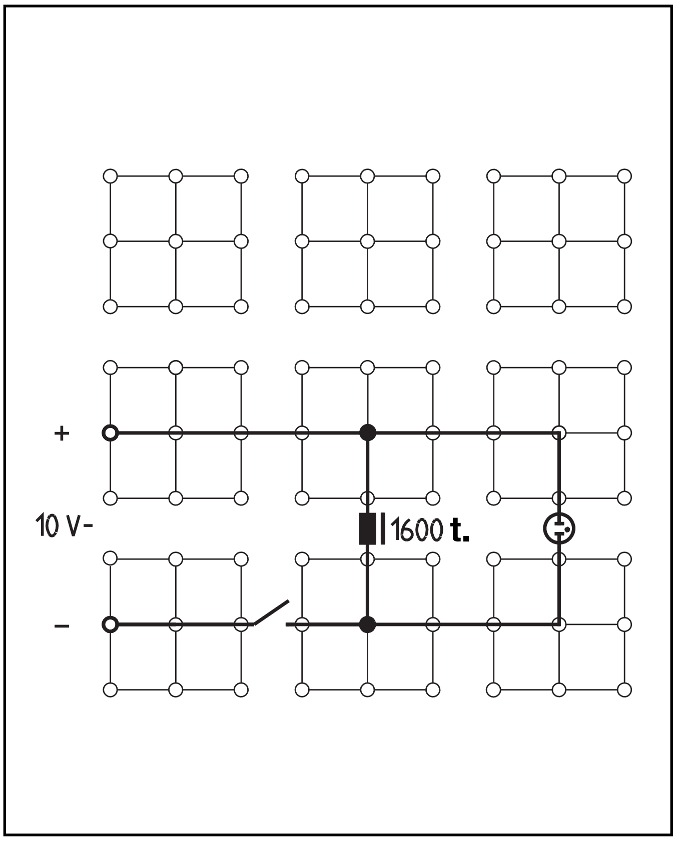


Fig. 2



S	EEP 10.2	What effect does a coil have when the circuit is switched off?

Observations

(1)

(2)

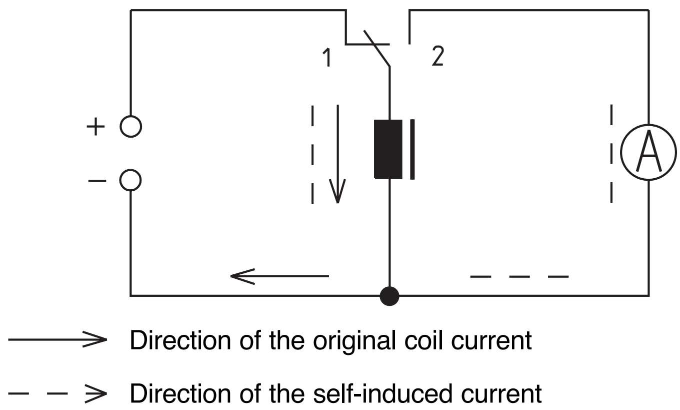


Fig. 3

Evaluation

1. The observations you made in the first experiment should indicate to you the direction of the self-induced current and, consequently, that of the self-induced voltage when the circuit is switched off. Expound upon your observations and explain.

2. Draw in the direction of the self-induced current when the circuit is switched off in Fig. 3 (use the dotted lines).

3. What conclusion can you draw about the level of the self-induced voltage based on your observation in the second experiment?
(Note: Compare the connected voltage with the trigger voltage of the neon lamp.)

(What effect does a coil have when the circuit is switched off?)

In the last experiment, the students learned that self-induced voltage is formed in a coil when a direct current circuit is switched on, and that this self-induced voltage counteracts the connected voltage. Now, they should learn that self-induced voltage formed when a circuit is switched off has the same direction as the original (i.e.ÿconnected) voltage.
If the students can already predict the results of the first experiment based on their knowledge of the laws of induction and Lenz's Law, then they should carry out the experiment to confirm their prediction nevertheless.
Furthermore, the second experiment should demonstrate that self-induced voltage can attain values that greatly exceed the original voltage.

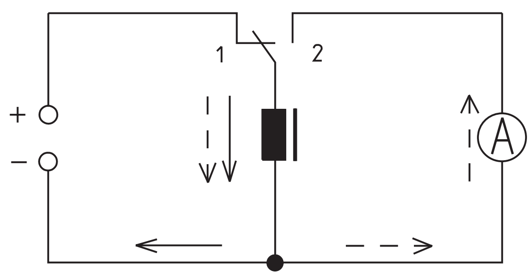
Notes on Set-Up and Procedure
In the first experiment, the instructor may need to advise the students not to wait too long to flip the switch to position 2. Taking too long to switch over may cause the magnetic field to collapse due to the spark at breaking before the self-induced current can flow through the current meter.
To save time, it is recommended that the pointers on the current meter be shifted before starting the first experiment and then set back to zero. A student can take care of this before class.

Observations
(1) The pointer on the current meter deflects to the left when the original circuit is interrupted.
(2) The neon lamp shines briefly each time the circuit is interrupted.

Evaluation
1. A self-induced current is formed when the circuit is switched off. It flows in the same direction as the original current. Therefore, the self-induced voltage also has the same direction as the original voltage.
2. See Fig. 3.
3. Self-induced voltage is many times greater than the connected voltage of 10 V since the trigger voltage of the neon lamp is about 70 V (operating voltage = 110 V).

Notes
Before starting the second experiment, the instructor should expound upon the trigger and operating voltages of the neon lamp used in the experiment and, if necessary, demonstrate the trigger voltage in a preliminary experiment. To do this, connect the neon lamp in series with a 100 kΩ resistor and then connect a direct voltage source. Starting at 0 V, slowly increase the voltage until the neon lamp lights up. For power supply, you can use the power supply unit 0600 (order no. 13672.93).
High self-induced voltages when switching off a circuits can damage technical combination circuits and electronic components. Make sure that the necessary measures are taken to prevent this from happening, e.g. that the capacitors are connected in parallel.

Fig. 3



⟶ Direction of the original coil current
– – > Direction of the self-induced current

Self-Induction when Switching off a Circuit

(What effect does a coil have when the circuit is switched off?)

Room of notes

How does a coil act in an alternating current circuit?

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.

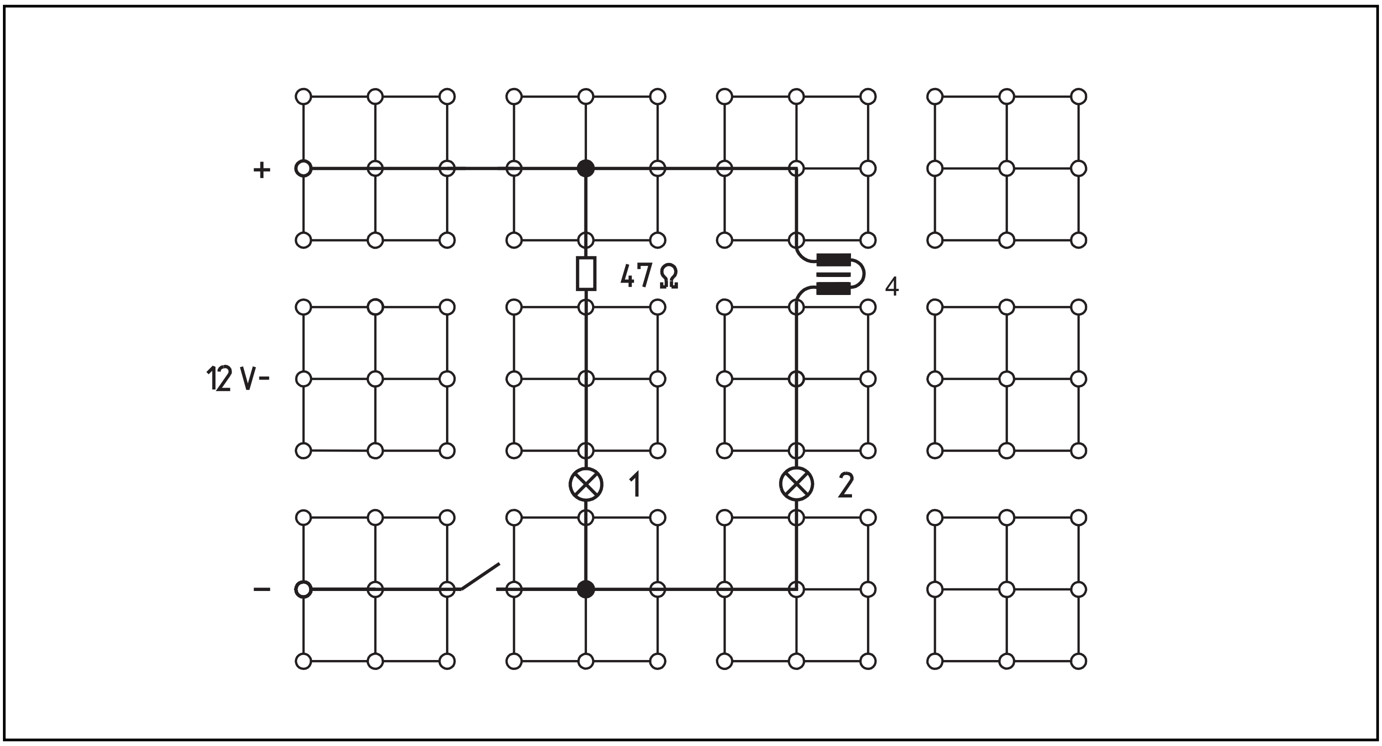
Equipment

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



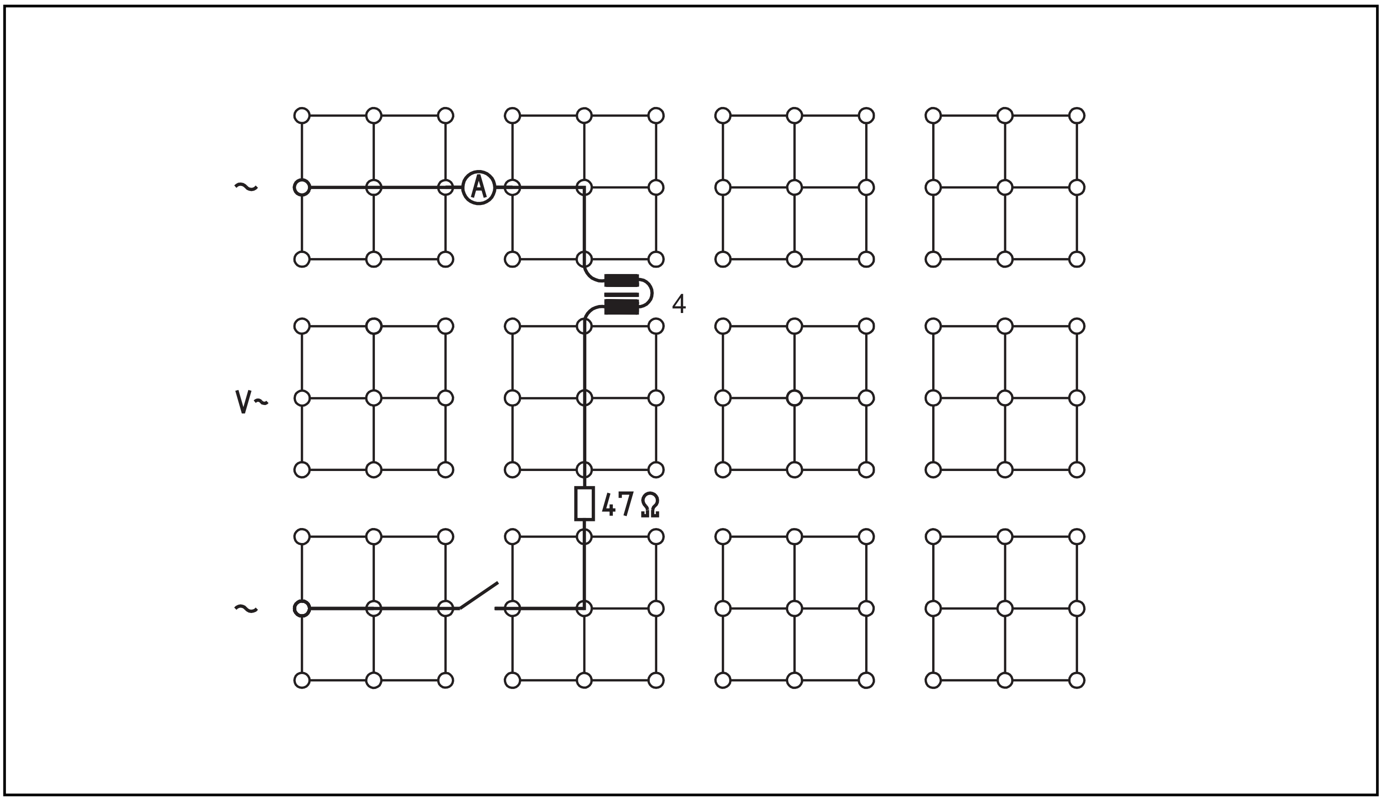
S	EEP 10.3	How does a coil act in an alternating current circuit?	PHYWE

Observations and Measurement Results

(1)

(2)

Fig. 2



(3) Table 1

Coil with	U /V	I /mA	$R_{\sim}/\Omega$	R_{-}/Ω
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.

(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

Coils in Alternating Current Circuits

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

Room for notes

Does the resistance of certain components decrease with an increase in temperature?

Problem

Determine whether and how the resistance varies depending on temperature using an NTC resistor.

Equipment

Plug-in board	06033.00	1
Lamp holder E10	17049.00	1
Filament lamp, 4 V/0.04 A, E10, 1 pc.	06154.03	(1)
NTC resistor, 1.3 Ω	39110.03	1
Wire building block	39120.00	1
Connecting cables, 25 cm, red	07360.01	1
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	2
Power supply, 0...12 V-, 6 V~, 12 V~	13505.93	1
Matches		

Set-Up and Procedure

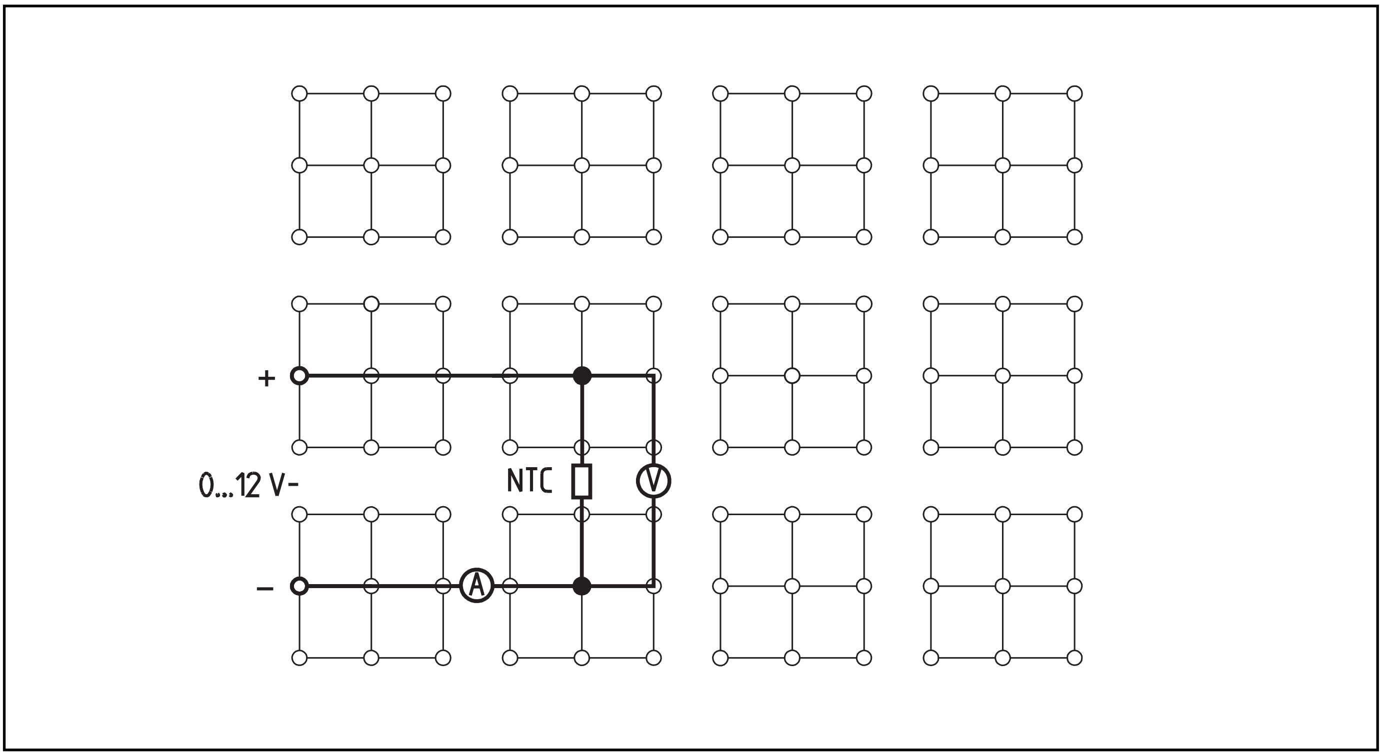
First Experiment

— Set up experiment as shown in Fig. 1. Select measurement ranges of 10 V- and 30 mA-.
— Switch on power supply unit and set voltage to 3 V- initially. Measure current and note under (1).
— Set voltage on power supply unit to the maximum value and observe the current meter closely (2). As soon as the indicator approaches 30 mA, turn voltage down a bit until the current is constant at I = 30 mA. Now, measure the necessary voltage U and note (3).
Important! The current must not exceed 30 mA, since this could destroy the NTC resistor.
— Switch power supply unit off.
— Touch the NTC resistor and note its temperature. Enter observation under (4).

Second Experiment

— Remove the wire building block from the circuit and put the filament lamp in its place.
— Switch on power supply unit and set direct voltage to maximum value.
— Observe filament lamp and current meter. Measure the maximum value for current I_{max} and the voltage necessary for this U_{max} at the NTC resistor.
— Note measurements and observations under (5).
— Warm NTC resistor with a lighted match.
Important! You should hold the lighted match with the flame next to the resistor at least 5 mm away. Too much heat will destroy the resistor. Also, make sure the current does not exceed 30 mA!
— Keep observing the current meter after removing the flame from the resistor. Touch the NTC resistor again to cool it off more quickly.
— Note observations under (6).
— Switch power supply unit off.

Fig. 1



S	EEP 11.1	Does the resistance of certain components decrease with an increase in temperature?	PHYWE

Observations and Measurement Results

(1) At U = 3 V-: I = ...
(2) Observation:

(3) With I = 30 mA the necessary voltage is: U = ...
(4) Observation:

(5) For I_{max} = ... necessary voltage: U_{max} = ...
Observation:

(6) Observations:

Evaluation

1. Why does the current continue to rise in the first experiment when the voltage at the NTC resistor reaches a certain value?

2. How large are the resistance values for the components at the start (U = 3 V) and at the end of the first experiment?

3. In the second experiment, at what point does the current stop increasing after attaining a certain value after the heat source is removed from the NTC resistor?

Does the resistance of certain components decrease with an increase in temperature?

Room for notes

(Does the resistance of certain components decrease with an increase in temperature?)

In connection with Ohm's Law, the students have already learned that metallic conductors generally have a resistance which increases with increasing temperature.
Now, they should discover that the opposite is true for NTC resistors (**N**egative **T**emperature **C**oefficient). The first experiment does not just serve as an introduction to this topic. It is also useful in demonstrating the terms self-heating (in the first experiment) and external heating (in the second experiment). The second experiment should be used to confirm these concepts.

Notes on Set-Up and Procedure

The experiment set-ups should not present a problem to the students if they are already relatively familiar with connecting and operating the multi-range meters.
When heating externally with the lighted match, they should be extra careful not to destroy the NTC resistor.

Observations and Measurement Results

(1) For U = 3 V: I = 3 mA.
(2) At maximum voltage, I increases very rapidly at first, then more and more slowly and would exceed 30 mA.
(3) For I = 30 mA, the necessary voltage is: U = 9.6 V.
(4) Observation: The NTC resistor feels warm. It is clearly warmer than room temperature.
(5) For I_{max}= 26 mA, the necessary voltage is: U_{max} = 8.9 V.
Observation: The current increases rapidly to about 10 mA, then more and more slowly until attaining its maximum value.
At about 15 mA, the filament lamp begins to shine weakly. It shines more and more brightly until the current remains constant. It does not, however, attain its maximum brightness (because its nominal current is 40 mA).
(6) Observations: Current increases rapidly to the maximum allowable value of 30 mA as soon as a lighted match is held to the NTC resistor.
The current drops as soon as the match goes out. If the NTC resistor is touched, thereby cooling it more quickly, then the current drops even faster. The current returns to its original value of approx. 26 mA when the experiment set-up is left alone.

Evaluation

1. The resistance value for the NTC resistor decreases as its temperature increases. This occurs when the current exceeds a certain value, thus warming the component even more.
2. U = 3 V; I = 3 mA; from this, we get R = 1000 Ω = 1 kΩ (initially);
U = 9 V; I = 30 mA; from this, we get R = 300 Ω (in the end).
3. The resistance value of the filament lamp increases as the temperature of the filament increases. This counteracts the effect of the NTC resistor, and the current stops increasing at a certain value.

Notes

NTC resistors are also referred to as NTC thermistors. They are widely used in circuits for measuring technique, control technique, and automatic control.
Their behavior is due to an increase in the concentration of floating charge carriers as the temperature increases. This effect is predominant over the increase of conductive resistance when there is an increase in temperature which is caused by the more intense interaction of the floating charge carriers with the unit cubes.
Question number 3 under Evaluation offers an opportunity to expand upon the laws of series connections. Rephrase the answer in the following way: In a series connection of a filament lamp and an NTC resistor, the partial voltage at the NTC resistor decreases while the partial voltage at the filament lamp increases until

NTC Resistors

(Does the resistance of certain components decrease with an increase in temperature?)

Room for notes