

**The guide to experiments
at Basic Physics Laboratory
- electricity and magnetism.**

Tutors:

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General rules:

1. To get credit for laboratory classes in the 'Physics' module, the student must obtain passing grade for at least 9 out of 10 experiments.
2. An experiment that has been missed will be rated as zero added in the calculation of the grade average.
3. Performance of an experiment consists of:
Theoretical preparation to an experiment to be performed on a given day. (*'A Guide to Experiments at Basic Physics Laboratory'*)
 - a) ...' and a recommended handbook *Physics* by Douglas C. Giancoli) – **oral or written introductory test.**
 - b) Making measurements and writing the results in a protocol – admission to carry out experiments **depends on the assessment of theoretical preparation.**
 - c) Analysis of the measurement results in a paper protocol in accordance with '*A Guide...*' and lecturers recommendations.

The analysis should be handed over to the instructor during the same class.

It is necessary to obtain a positive grade for each of the aforementioned points to receive a credit for an experiment.

Students are obliged to come to classes on time. Those who will show up 15 minutes after the commencement of a class will not be allowed in the Laboratory.

Health and safety requirements in the Fundamentals of Experimental Physics Laboratory.

1. You may enter the Laboratory only together with the instructor / teacher/ and after collecting appropriate apparatus (as stated in '*A Guide ...*').
2. Electrical devices can be connected to the mains only in the presence of the instructor.
3. A person who damaged or destroyed the Laboratory equipment is financially responsible for it.
4. Disconnection of measurement system is carried out in the presence of the instructor .
5. After completion of measurements, the measurement station must be tidied up and the equipment must be returned to the lab assistants' room.
6. Eating and drinking is forbidden in the Laboratory.
7. All outerwear and luggage must be left in the cloakroom.

Schedule of Experiments for American Students

Group 1 Tuesday 11:45 - 14:45						Group 2 Tuesday 15:00 - 18:00					Group 3 Thursday 11:45 - 14:45				
	1. pair	2. pair	3. pair	4. pair	5. pair	1. pair	2. pair	3. pair	4. pair	5. pair	1. pair	2. pair	3. pair	4. pair	5. pair
Week 2															
Aug. 29 / 31	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2	Exp 2					
Week 3															
Sept. 5 / 7	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1	Exp 1					
Week 4															
Sept. 12 / 14	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5	Exp 5					
Week 5															
Sept. 19 / 21	Exp 6	Exp 7	Exp 8	Exp 9	Exp 6	Exp 7	Exp 8	Exp 9	Exp 6	Exp 7	Exp 8	Exp 9	Exp 6	Exp 7	Exp 8
Week 6															
Sept. 26 / 28	Exp 7	Exp 8	Exp 9	Exp 10	Exp 7	Exp 8	Exp 9	Exp 10	Exp 7	Exp 8	Exp 9	Exp 10	Exp 7	Exp 8	Exp 9
Week 8															
Oct. 3 / 5	Exp 8	Exp 9	Exp 10	Exp 6	Exp 8	Exp 9	Exp 10	Exp 6	Exp 8	Exp 9	Exp 10	Exp 6	Exp 8	Exp 9	Exp 8
Week 9															
Oct. 10 / 12	Exp 9	Exp 10	Exp 6	Exp 7	Exp 9	Exp 9	Exp 10	Exp 6	Exp 7	Exp 9	Exp 9	Exp 10	Exp 6	Exp 7	Exp 9
Week 10															
Oct. 17 / 19	Exp 10	Exp 6	Exp 7	Exp 8	Exp 10	Exp 6	Exp 7	Exp 8	Exp 10	Exp 6	Exp 7	Exp 8	Exp 10	Exp 6	Exp 7
Week 11															
Oct. 24 / 26	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4	Exp 4					
Oct. 31 / Nov 2	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3	Exp 3					

Exp 1	Determination of current-voltage characteristics	Exp 6	Characteristics of transformer
Exp 2	Direct current Kirchoff's laws	Exp 7	Capacitors
Exp 3	Lenses	Exp 8	The magnetic field of a long, straight wire
Exp 4	Measurements of refractive coefficient of transparent solids and liquids	Exp 9	Resonance in RLC circuit
Exp 5	Test of adjustment of resistors strength	Exp 10	Inductance of an inductor (a coil) in the alternate current circuit

List of experiences

Ex 1 Determination of current-voltage characteristics of a resistor, bulb and diode for direct current.

Ex 2 Direct current and Kirchhoff's laws.

Ex 3 Lenses.

Ex 4 Measurement of refractive coefficient of transparent solids and a liquid.

Ex 5 Test of adjustment of a resistor strength.

Ex 6 Characteristics of transformer.

Ex 7 Capacitors.

Ex 8 The magnetic field of a long straight wire.

Ex 9 Resonance in RLC circuit.

Ex 10 Inductance of an inductor (a coil) in the alternate current circuit.

Algorithm for evaluation of measurement uncertainties , the wps¹

principle

(after B. Piątek, Physics at school, 1/1976)

1. Find the formula relating the measured physical quantity with other physical quantities or with results of simple measurements of the same quantity:

$$y = f(a, b, c \dots).$$

2. Find out if the measurements of the quantities a, b, c, \dots are simple measurements or a sum or difference of a few simple measurements of the same quantity or a product or ratio of results of simple measurements by a dimensionless constant, or a combination of the above.

3. On the basis of the accuracies of the tools or instruments used for simple measurements of particular quantities and assuming the worst possible scenario¹ (wps principle) evaluate the absolute uncertainties $\Delta a, \Delta b, \Delta c, \dots$ of the quantities a, b, c, \dots .

4. Calculate the value of the measured quantity y , following the principles of approximations.

5. Find the highest possible values of a, b, c, \dots measured as

$$a + \Delta a; b + \Delta b; c + \Delta c \dots,$$

and the lowest possible values $a - \Delta a; b - \Delta b; c - \Delta c \dots$

6. On the basis of the worst possible scenario principle calculate the highest possible value of the quantity measures by a given method and with the use of given measuring instruments:

$$y_{\max} = f(a \pm \Delta a; b \pm \Delta b; c \pm \Delta c),$$

calculate the smallest possible value of a given quantity

$$y_{\min} = f(a \pm \Delta a; b \pm \Delta b; c \pm \Delta c).$$

Depending on the type of the formula, that is e.g. on whether a given quantity is in the numerator or denominator, in order to get the maximum value we add the uncertainties (when in the numerator) or subtract the uncertainties. If the formula is a combination of fractions and sums, one should analyze where the summation and where the subtraction should be made to get the maximum value.

7. Calculate $\Delta y_+ = |y_{\max} - y|$ and $\Delta y_- = |y - y_{\min}|$

8. If $\Delta y_+ \neq \Delta y_-$, then take the greater of these two differences as the maximum uncertainty Δy of the measured quantity y .

9. Write the final result of the measurement as

$$y \pm \Delta y$$

10. Express the measurement uncertainty in percentage ($\Delta y/y \times 100\%$)

¹ The worst possible scenario principle, wps: on evaluating the uncertainties of measurements, assume the worst possible scenario from the point of view of the measurement accuracy.

Ex1

Determination of current-voltage characteristics (or current-voltage curves) of a resistor, bulb and diode for direct current

EQUIPMENT :

Power supply, slide resistor, resistor, bulb, LED, amperemeter, multimeters, switch, wiring, mounting plate

Experiment A:

1. Connect the electric circuit according to the scheme (Fig. 1):

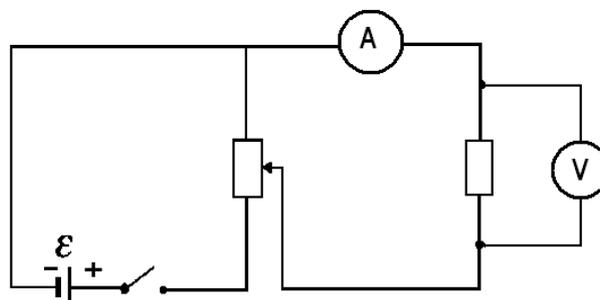


Fig.1

2. At the site of a resistor, place a resistor of 20Ω .

3. By changing the position of the slider on the slide resistor set subsequently 7 values of voltage supplying the receiver, from 0 to 3 V, e.g. at every 0.5 V. For each voltage value, read off the current intensity I .

4. Write the results in the table below.

Table 1

No of measurement	U (V)	I (mA)	ΔU (V)	ΔI (mA)
1	0			
2				
3				
4				
5				
6				
7				

5. The uncertainties of the simple measurements of current intensity and voltage, ΔI and ΔU , are the accuracies determined by the class of the measuring instrument (see Annex 1) and write the values to the table.

Ex1

6. Write the results of measurements to the Excel calculating sheet and draw the plot of $I(U)$.

Experiment B

7. Into the same circuit as in experiment A introduce a bulb instead of a resistor, (Fig. 2)

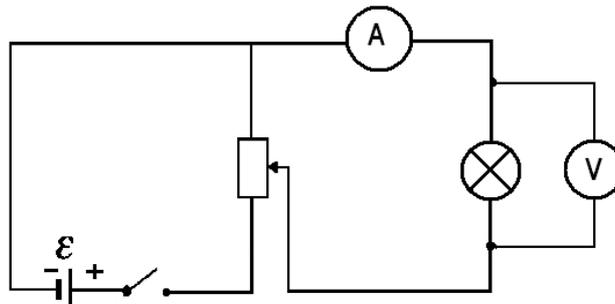


Fig. 2

8. Repeat procedures 3 - 6 described for experiment A for the circuit with the bulb.

Experiment C

9. In the same circuit replace the bulb with a light emitting diode LED, (Fig. 3)

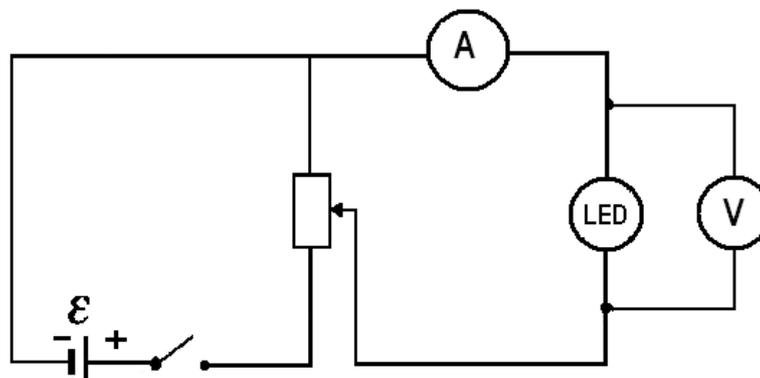


Fig. 3

10. By changing the position of the slider on the slide resistor set 14 values of voltage supplying the receiver, from 0 to 1.5 V, at every 0.5 V and then from 1.8 V to 3.6 V at every 0.2 V. For each voltage value read off the current intensity I .

11. Repeat the procedures 4 - 6 for the circuit with LED.

12. Compare the plots obtained and explain the differences between the current-voltage curves for the resistor, bulb and LED.

Ex 2

Direct current and Kirchhoff's laws

EQUIPMENT

Power supply, two resistors, two amperemeters and a multimeter, switch, wiring, mounting plate.

Experiment A:

1. Connect the electric circuit according to the scheme (Fig. 1):

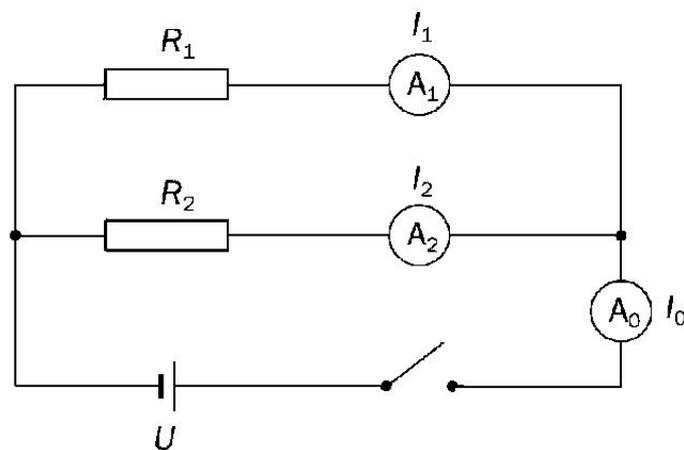


Fig.1

2. In the figure mark the direction of current in each section of the circuit.

Caution 1: Prior to making the experiment, set the voltage at a value from the range 3 - 6 V) which should be used to supply the circuit in order not to damage the amperemeter or burn the resistors.

3. After switching the power supply on, read off the current intensity values at the three sections I_1 , I_2 , I_0

Caution 2: If only one amperemeter (or multimeter) is available, insert it into the circuit subsequently at the three sites A_1 , A_2 , A_0 and read off the current intensities.

4. Write the results in the table given below.

Tabela1

	I (mA)	ΔI (mA)
I_0		
I_1		
I_2		

Ex 2

5. The uncertainty of the simple measurements of current intensity is the accuracy defined by the class of the measuring device ΔI (see Annex 1). Introduce it to the table.

6. Calculate the sum of intensities:

$$I = I_1 + I_2,$$

And compare the result with the value of I_0 .

The results are consistent if $|I - I_0| \leq I_0 + \Delta I_0$.

7. The results can be compared graphically. On the axis of current intensity mark the values of I and I_0 together with their uncertainties. If the ranges $(I_0 - \Delta I_0, I_0 + \Delta I_0)$ and $(I - \Delta I, I + \Delta I)$ have a common part, the results are consistent.

It means that the first Kirchhoff's law is satisfied.

Experiment B

Equipment

Power supply, three resistors, a multimeter with probing wires (red and black), switch, wiring, mounting plate

8. Connect the electric circuit according to the scheme below (Fig. 2)

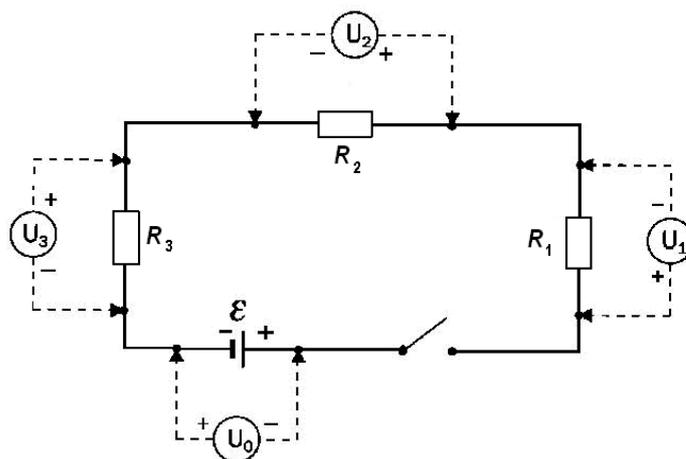


Fig. 2

9. After switching on the current in the circuit, introduce the multimeter into the subsequent elements of the circuit and read off the voltage U_0 , U_1 , U_2 and U_3 .

Caution 3: Make voltage measurements using one multimeter which you insert into particular sites, marked in Fig. 2.

Ex 2

Take care not to change the positions of the probing wires; the red wire (socket V) should be always connected from the plus side of the power supply, while the black wire (socket COM) should be always connected from the minus side of the power supply, Fig. 2.

10. Calculate the sum of voltage values:

$$U_S = U_0 + U_1 + U_2 + U_3$$

	U (V)	ΔU (V)
U_0		
U_1		
U_2		
U_3		

$$\Delta U_S = \Delta U_0 + \Delta U_1 + \Delta U_2 + \Delta U_3$$

11. Make a graphical comparison of results. On the axis of voltage mark the U_S value and its uncertainty.

If the range ($U_S - \Delta U_S$, $U_S + \Delta U_S$) includes zero, the results are consistent.

It means that the second Kirchhoff's law is satisfied.

Measurement of refractive coefficient of transparent solids and a liquid.

1. ...transparent solids (pin method)

Aim of experiment

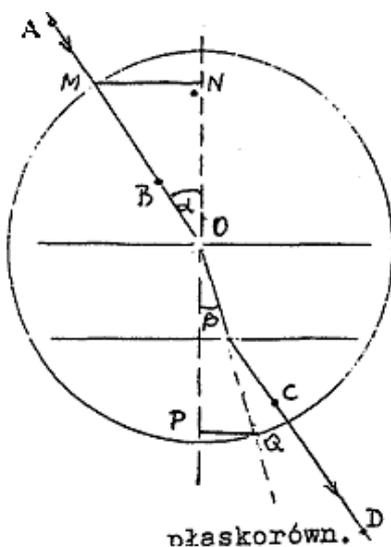
- Determination of refractive coefficient of transparent solid by the pin method.

Equipment

- Sheets of white paper
- Cork plate
- Optical parallel plate, prism
- compass (drawing tool), pencil
- 4 pins
- Protractor or triangle

Experiment

1. Place a sheet of white paper on the cork plate, then place an optical parallel plate (or a prism) on the paper and mark with a pencil the edges of the place through which light will pass.
2. Behind the optical parallel plate (or prism) stick in two pins, A and B, at the largest possible distance from each other, so that the line passing through the points A and B was not perpendicular to the edge of the plate or prism, and made an angle α with the normal to the edge, $\alpha \neq 0^\circ$.
3. In front of the optical parallel plate (prism) stick in two other pins C and D so that when looking along the line made by points C and D you would see pins A and B making one line., see Fig. 1.



rys.1. Optical parallel plate

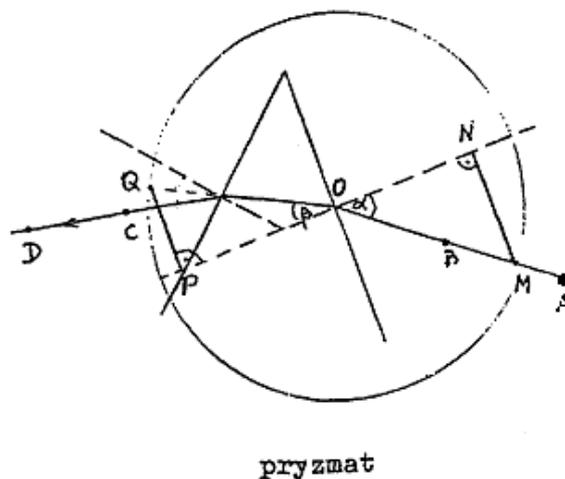


fig. 2. Prism

Ex 4

4. Remove the optical parallel plate (prism) and pins from the sheet of paper, draw a half-line passing through points A and B and ending at the edge of the plate (prism) and another half-line passing through points C and D and ending at the edge of the plate (prism), so the border between the solid and air.
5. From the point O draw a perpendicular to the edge and draw a circle of the radius r greater than 5 cm. Then, draw the sections MN and PQ perpendicular to the normal.
6. Measure the length of sections MN and PQ, and calculate the refractive coefficient of the material of which the plate (prism) is made, n , making use of the following equations:

$$\frac{MN}{r} = \sin \alpha,$$

$$\frac{PQ}{r} = \sin \beta, \text{ so the refractive coefficient is}$$

$$n = \frac{MN}{PQ}$$

7. Make 5 measurements for different angles and find the average value.
8. Repeat the experiment with the other object – a prism, see Fig. 2.
9. Compare the obtained value with the Table data and estimate the uncertainty of determination of the coefficient by the “wps” method.

2. ...a liquid

Aim of experiment

- Determination of light refractive coefficient of a liquid by a caliper

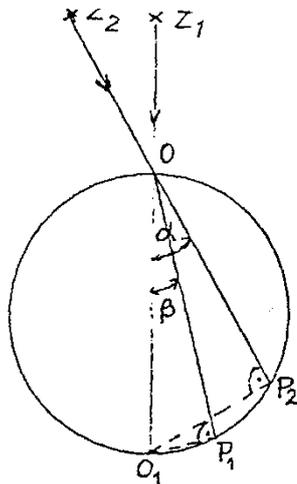
Equipment

- Glass beaker of thin walls, on one side covered with glued black paper with a vertical slit, while on the other side covered with tracing paper with millimeter scale
- a source of light (a bulb)
- power supply to the bulb
- electric wires
- caliper

Experiment

Ex 4

1. Fill the beaker with clean tap water so that the water level was at the middle of the slit height.
2. In front of the slit at a distance of 1 - 2 m put the source of light.
3. On the opposite side of the beaker there are two light bands – the lower corresponds to the beam that passed through the liquid and the upper to the beam that passed through the air above the liquid in the beaker.



$$\sin \alpha = \frac{O_1P_2}{OO_1}$$

$$\sin \beta = \frac{O_1P_1}{OO_1}$$

$$n = \frac{\sin \alpha}{\sin \beta}$$

Fig. 1 Passage of light beam through the liquid in the beaker

4. Move the source of light so that the upper and lower bands were on the same line. Read off their position on the scale (point O_1 in the figure).
5. Move the source of light to position Z_2 . Then on the scale two bands appear, the lower P_1 – that is closer to point O_1 and the upper P_2 – that is farther from O_1 .
6. Measure the lengths of the sections O_1P_1 and O_1P_2 using a caliper. The coefficient of refraction of the liquid relative to air n is :

$$n = \frac{O_1P_2}{O_1P_1}$$

7. Repeat the measurements a few times for different angles of incidence and find the average value.
8. Estimate the uncertainty of the coefficient determination; by the “wps” method estimate the uncertainty of the coefficient determination for one measurement (the one the closest to the average value) and this value is assumed to be the uncertainty of the average result for water.
9. Compare the result with the value given in the Tables.
10. Repeat the measurement for NaCl solution – add 3-4 spoonfuls of common salt to the water, or for a common cooking oil.

Test of adjustment of a resistor strength

Aims of the experiment

- Determination of the maximum power of electric current by measurements of voltage and intensity,
 - Testing the relation between the internal resistance of the current source and the resistance of a resistor (loading) on the maximum power consumption
-

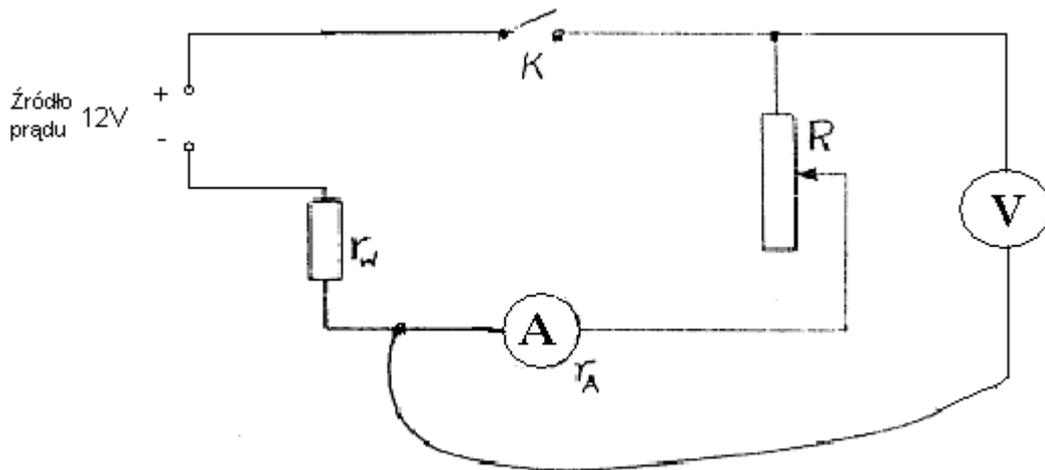
Equipment

Universal meter (ampere meter), voltmeter, slide resistor $20\ \Omega$, resistor $r_w \approx 12\ \Omega$, direct current supply (4V or 12V), circuit breaker, 7 wires.

Caution 1

As the internal resistance of a stabilized power supply is very small, it is necessary to use the resistor r_w , which acts as internal resistance of the source of current characterized by the electromotive force $E = 12\text{V}$.

Experiment



Rys. 1

1. Determine the value or resistance r_w with the use of an ohmmeter (electronic universal meter).

To do this

- a) Set the knob of the ohmmeter at the position of $200\ \Omega$,
- b) Connect one end of a wire to the radio socket in the stand of the resistor r_w , while the other end to the negative COM socket, the second wire connect to the socket marked with Ω ,
- c) Write down the result of measurement and the uncertainty of measurement ($\Delta r_w = 0.1\ \Omega$).

Ex 5

2. Make the connections as in the scheme shown in Fig. 1 (the voltmeter range 15 V), with the circuit breaker K open.
3. Set the resistance of the sliding resistor R (20 ohm) to a maximum value and set the knob of the miliampere meter to the range 1.5 A.
4. With the help of a piece of chalk mark on the sliding resistor 7 bars at more or less the same distance from one another, e.g. at every 2 cm or at distances equal to the width of the slider).
5. Changing the resistance R of the slide resistor by moving the slider from one mark to another, measure the current intensity and voltage, write down the results in a table, see below. While changing the slider position set the circuit breaker open.
6. You can write the result of measurement in the number of bars and on completion of the measurement you can convert the bars into volts and amperes taking into regard the preset range.

Table

Number of measurement	U [V]	I [A]	R [ohm]	P [W]	comment

7. On the calculation sheet or using a calculator find the values of $R=U/I$ and $P=U*I$ for each setting.
8. Draw the plot of $P = f(R)$.
9. Read from the table the value of resistance R_M at which the power is maximum.
10. From the table on the back wall of the universal meter read off the internal resistance of the miliampere meter in the range used (r_A).
11. Calculate the resistance $R = R_M - r_A$. at which the power consumption is maximum.
12. * Using the “WPS” algorithm (WSP stands for the wors possible scenario, see below, estimate the uncertainty of R_M determination and check if the following equation holds:

$$r_w = R_M \cdot$$

Algorithm for estimation of measuring uncertainties by the wps¹ method

Write the relation between the value of resistance to be determined R and the measured voltage U and current intensity I :

$$R = \frac{U}{I}$$

1. On the basis of the accuracies of the voltmeter and ampere meter (uncertainty of division and class of the instrument), evaluate the absolute uncertainties ΔU , ΔI .
2. Write the measured value of R_M rounded up to two decimal digits.
3. On the basis of the nkp principle calculate the highest possible value of the measured quantity that can be obtained by the method and instruments you use,

$$R_{M \max} = \frac{U + \Delta U}{I - \Delta I},$$

and the lowest possible value as

$$R_{M \min} = \frac{U - \Delta U}{I + \Delta I}.$$

4. Calculate $\Delta R_+ = |R_{M \max} - R_M|$ and $\Delta R_- = |R_M - R_{M \min}|$
5. If $\Delta R_+ \neq \Delta R_-$, the higher of these two values assume as the measure of the maximum uncertainty, ΔR_M .
6. Write the final result in the form

$$R_M \pm \Delta R_M$$

7. Calculate the uncertainty of the resistance determination in percentage ($\Delta R_M / R_M$)•100%.

¹ The worst possible scenario

Characteristics of Transformer

Problems

Alternative current, transformer structure and principles of operation, transformer voltage ratio, dependence of current intensity I_1 on the voltage U_1 in the primary circuit of transformer

Aim of experiment

The aim of the experiment is understanding of the transformer principles of operation and determination of the transformer voltage ratio. Students are asked to determine the characteristic of unloaded transformer $I_1 = f(U_1)$, transformer voltage ratio, characteristics of transformer loaded with an ohmic resistance $I_2 = f(U_2)$ at U_1 fixed for different resistance values R , and to calculate the transformer efficiency and phase shift.

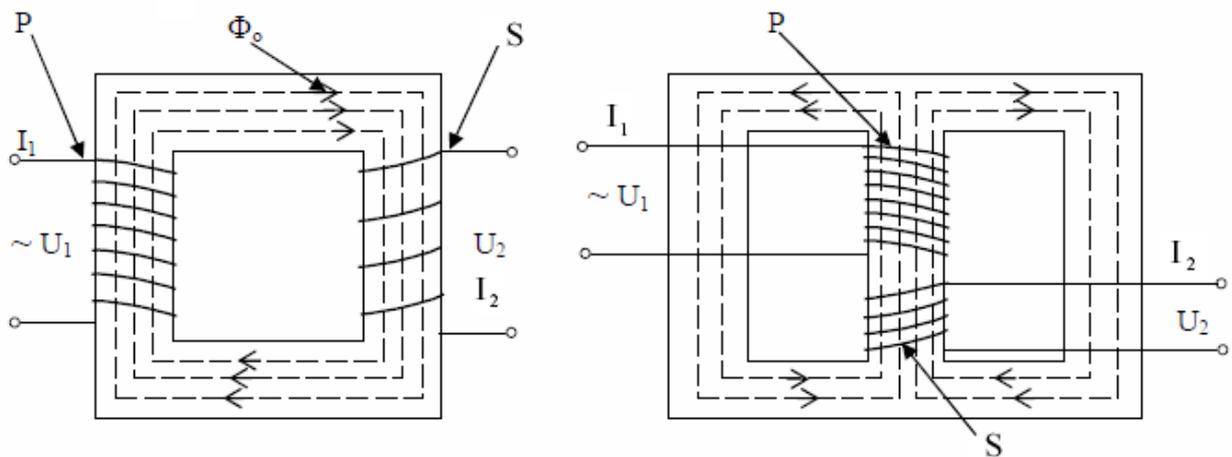


Fig. 1 Two schemes of transformer construction, where (U_1 and I_1) are the primary voltage and current intensity, (U_2 and I_2) are the secondary voltage and current intensity, (P) is the primary winding and (S) is the secondary winding.

Experiment

Part 1. Idle run

1. Assemble the circuit as shown in Fig. 2. It is a transformer supplied with alternative current from an autotransformer. Prior to switching on power supply the circuit must be checked by the teacher. .

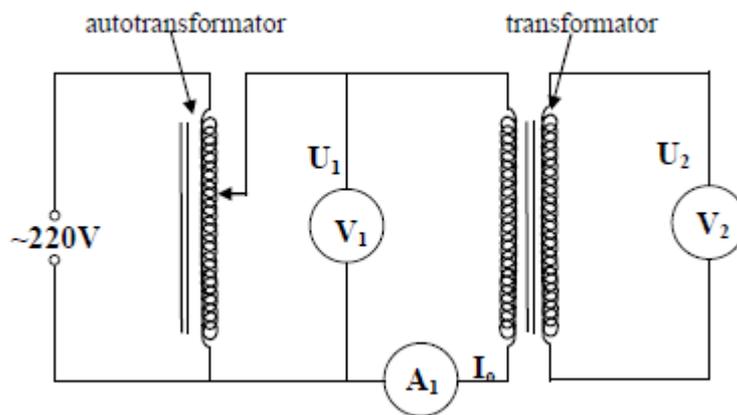


Fig.2. Scheme of the electric circuit for investigation of the transformer idle run.

2. The circuit is closed with the autotransformer knob at zero. Then, increase the voltage in the primary winding U_1 , and at every 20 V read off the current intensity I_1 in the primary circuit of the transformer and voltage U_2 in the secondary circuit. The upper limit of voltage in the primary circuit is set by the teacher (U_k).

Measurement uncertainties of U_1 , I_1 and U_2 are to be found from the following formulae:

$$\Delta I_{cat} = \Delta I_k + \Delta I_d \quad \text{_____ class of instrument} = \text{_____}, \text{ range} = \text{_____}, \Delta I_k = \text{_____}, \Delta I_d = \text{_____}$$

$$\Delta U_{1cat} = \Delta U_{1k} + \Delta U_{1d} \quad \text{_____ class of instrument} = \text{_____}, \text{ range} = \text{_____}, \Delta U_{1k} = \text{_____}, \Delta U_{1d} = \text{_____}$$

$$\Delta U_{2cat} = \Delta U_{2k} + \Delta U_{2d}, \quad \text{_____ class of instrument} = \text{_____}, \text{ range} = \text{_____}, \Delta U_{2k} = \text{_____}, \Delta U_{2d} = \text{_____}$$

Ex 6

Table 1. Results of measurements for characterization of the idle run of the transformer .

No.	I_1 [mA]	U_1 [V]	U_2 [V]	$N=U_1/U_2$	ΔN

where:

$$\Delta N = \frac{N_{\max} - N_{\min}}{2},$$

while N_{\max} and N_{\min} are defined as

$$N_{\max} = \frac{U_1 + \Delta U_1}{U_2 - \Delta U_2}, \quad N_{\min} = \frac{U_1 - \Delta U_1}{U_2 + \Delta U_2}.$$

The values of ΔN and N for each measurement should be rounded

3. Repeat the measurements described at 2 twice for the same voltages in the primary winding U_1 .
4. Calculate mean values of intensity I_1 , for the same U_1 voltages.
5. Plot the relations $I_1 = f_1(U_1)$ and $U_2 = f_2(U_1)$, marking the uncertainties following from the class of instrument and range. Use the program Simple-Stat available at the laboratory.
6. Calculate the transformer voltage ratio using the data provided by the producer and your own measurements

$$N_T = \frac{N_1}{N_2} \quad N = \frac{U_1}{U_2} = \frac{I_2}{I_1} \text{ (see Table 1)}$$

7. Then, apply simple linear regression in order to determine the slope Sa and standard deviation of the slope assumed as 3Sa. Compare the result N to the value provided by the producer, N_T .
8. For all measured N_i calculate the weighted mean N_w and the value of ΔN_w and check the agreement with the value N_T declared by the producer, according to the scheme:

$$\bar{N}_w = \left(\bar{N}_w \pm \Delta \bar{N}_w \right).$$

Part 2. Run on loading

9. Assembly the circuit as shown in Fig. 3. .

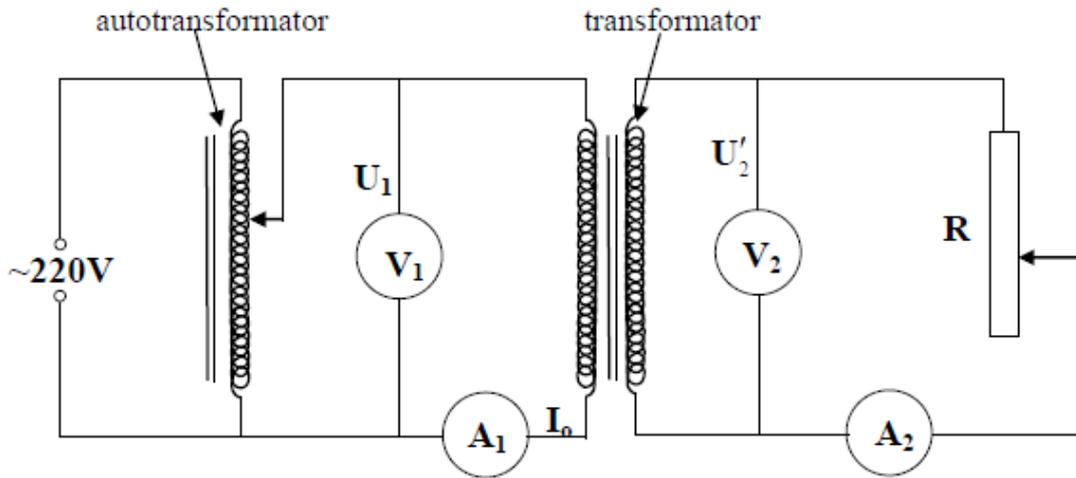


Fig. 3. Scheme of the electric circuit for investigation of the transformer run on loading

10. Set the resistor R at the maximum value. Set the voltage in the primary circuit to 100 V. Read off the indications of all measuring instruments.

11. Reduce resistance R and for 8-10 resistance values change the current intensity I_2 at every 0.05 A and at each set value read off the indications of the other measuring instruments.

Caution! The resistor should not be overheated.

12. Repeat measurements described at 10-11 for the voltage in the primary circuit of $U_1 = 120, 150, 170$ V.

Table 2. Results of measurements characterizing the transformer work under loading.

No.	I_1 [mA]	U_1 [V]	I_2 [mA]	U_2 [V]	$N=U_1/U_2$	ΔN

13. Plot the dependencies $U_2 = f_3(I_2)$, at $U_1 = \text{const}$, for each U_1 value separately, taking into account uncertainties of measurements.

14. Calculate the transformer voltage and from your own measurements:

$$N_T = \frac{N_1}{N_2} \quad N = \frac{U_1}{U_2} = \frac{I_2}{I_1} \text{ (see Table 1)}$$

15. For all values of voltage in primary and secondary circuits draw the relation U_2 vs U_1 using the Simple-Stat program available in the laboratory. Apply classical linear regression in order to determine the slope of the line and standard deviation, and standard deviation of the slope, S_a , which is used to estimate the uncertainty of final result $3S_a$. Compare the result to the value declared by the producer, N_T .

16. Taking into account all measurements N_i calculate the weighted mean N_w and the value of ΔN_w and compare the result with the value declared by the producer N_T ,

$$\bar{N}_w = (\bar{N}_w \pm \Delta \bar{N}_w).$$

17. On the basis of the data collected in Table 2 calculate for each measurement the transformer efficiency η . Applying the linear regression it is possible to estimate the transformer efficiency η according to the equation given below and compare it with the η_r value declared by the producer:

$$\eta = \frac{U_2 I_2}{U_1 I_1}.$$

18. Discuss the transformer efficiency and transformer voltage ratio values.

19. Sum up the results and their uncertainties and draw conclusions.

Direct current and Kirchhoff's laws

EQUIPMENT

Power supply, two resistors, two identical multimeters and one additional multimeter or amperemeter, switching device, wires and mounting plate.

Experiment A

1. Make the connections to get the following circuit (Fig. 1):

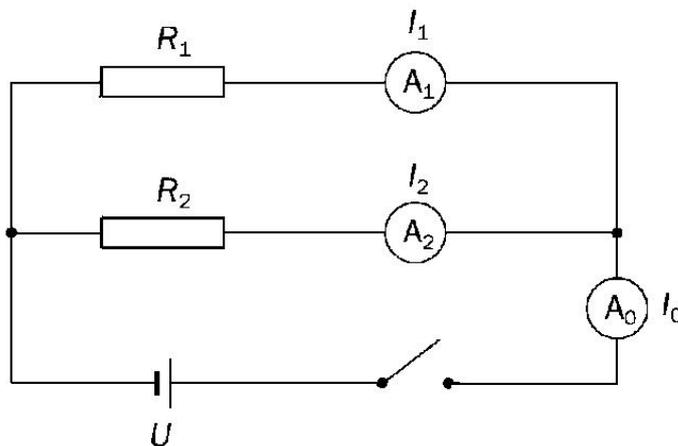


Fig.1

2. In Fig. 1 mark the direction of the current flow in each section of the circuit.

Caution 1: Prior to the experiment set the supplying voltage value to 5V, which should be applied to avoid damage to the amperemeter and resistors.

3. Switch on the power supply and read off the current intensities: I_1 , I_2 , I_0

Caution 2: Measurements of I_1 and I_2 should be performed with identical multimeters (of the same internal resistance), measurement of I_0 could be made by a multimeter of a different internal resistance.

4. Write the results of measurements in Table 1.

Table 1

	I (mA)	ΔI (mA)
I_0		
I_1		
I_2		

Ex 7

5. The uncertainties of current intensity measurements ΔI are assumed to be those following from the class of the measuring instruments, see Annex 1, write the relevant values in Table 1.

6. Calculate the sum of current intensities

$$I = I_1 + I_2,$$

and compare it with the value of I_0 .

The results are consistent if $|I - I_0| \leq I_0 + \Delta I_0$.

7. The results can be also compared graphically. On the axis representing the current intensity mark the values I and I_0 and the corresponding uncertainties ΔI . If the ranges $(I_0 - \Delta I_0, I_0 + \Delta I_0)$ and $(I - \Delta I, I + \Delta I)$ have a common part, the results are in agreement. It means that the first Kirchhoff's law is met.

Experiment B

Equipment

Power supply, three resistors, multimeter with probing wires red and black, switching device, wires and mounting plate.

8. Make the connections to obtain the following circuit (Fig. 2)

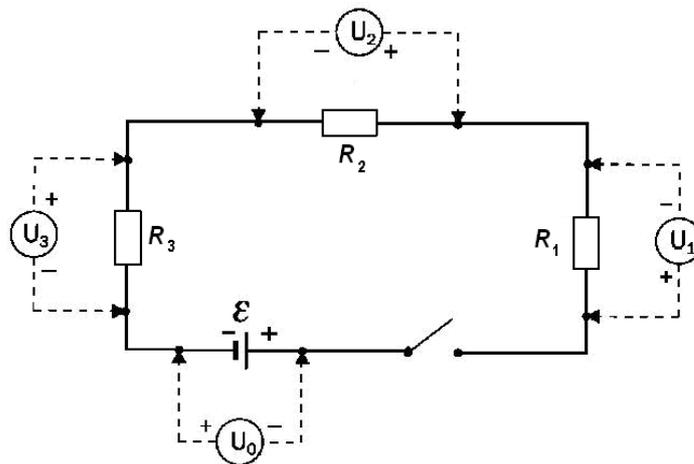


Fig. 2

9. Switch on power supply, connect the multimeter to subsequent elements of the circuit and read off the voltage values U_0 , U_1 , U_2 and U_3 .

Caution 2:

Use one and the same multimeter for measurement of the voltage values, connect it subsequently at appropriate sections of the circuit, as shown in Fig.2.

Ex 7

Take care to ensure the proper positions of the probing wires, the red one (socket V) should always be on the PLUS side, while the black one (socket COM) should be on the MINUS side, see Fig. 2.

10. Calculate the sum of voltages:

$$U_S = U_0 + U_1 + U_2 + U_3$$

	U (V)	ΔU (V)
U_0		
U_1		
U_2		
U_3		

$$\Delta U_S = \Delta U_0 + \Delta U_1 + \Delta U_2 + \Delta U_3$$

11. Make a graphic comparison of results. On the axis representing voltage mark U_S and its uncertainty. If the range ($U_S - \Delta U_S$, $U_S + \Delta U_S$) includes zero, the results are in agreement and the second Kirchhoff's law is met.

RELAXATION OSCILLATION IN AN RC SERIES CIRCUIT

INTRODUCTION, MAIN CONCEPTS

A capacitor is a set of two conductors (capacitor plates) separated from each other with a dielectric material. A capacitor is an electric element that accumulates charge and electric field. In the circuits with direct current no current flows through the capacitor, while in the circuits with alternative current it is possible. The parameter characterizing the capacitor is its capacity C ,

$$C = \frac{Q}{\Delta V} \quad [F] = \left[\frac{C}{V} \right]$$

Where Q is the electric charge accumulated on the capacitor plates and ΔV is the voltage across the capacitor plates. A capacitor connected in series with a resistor and a source of electromotive force emf make an RC circuit.

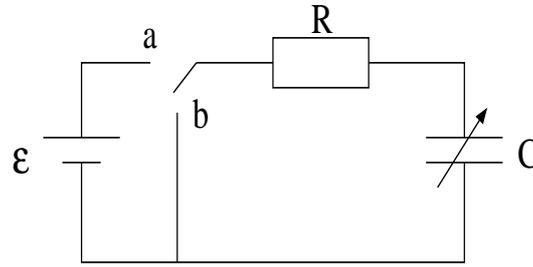


Figure 1: RC series circuit

If the switch is in position “a” (Fig. 1) the elements are connected with the emf source and the capacitor is charged until a final voltage is achieved across the capacitor plates. From the Kirchoff law for the circuit unit we can write:

$$\varepsilon = U_R + U_C \quad (1)$$

$$\varepsilon = IR + \frac{Q}{C} \quad (2)$$

$$\varepsilon = \frac{dQ}{dt}R + \frac{Q}{C} \quad (3)$$

The solution of eq. (3) is the relation:

$$Q(t) = \varepsilon C (1 - e^{-t/RC}) \quad (4)$$

and the voltage across the capacitor plate changes according to the equation:

$$U_C(t) = \varepsilon (1 - e^{-t/RC}) \quad (5)$$

The product $R \cdot C$ is called the time constant of the RC circuit

$$\tau_C = RC$$

After time τ_C the capacitor is charged to 63% of its final charge and target voltage.

If the switch is in position “b” (Fig.1), the capacitor is discharged through the resistor R. From the Kirchoff law we get:

$$U_R + U_C = 0 \quad (6)$$

which leads to the solution:

$$Q(t) = \varepsilon C e^{-t/RC} \quad (7)$$

and potential difference:

$$U_C(t) = \varepsilon e^{-t/RC} \quad (8)$$

RELAXATION OSCILLATION

In the experiment, the processes of charging and discharging of a capacitor in the RC series circuit is studied by observation of the relaxation oscillations of a neon lamp connected in parallel to the capacitor. The current flows through the neon lamp (it lights up) when the voltage applied to its electrodes exceeds the voltage of ignition. As the neon lamp and the capacitor are connected in parallel (have the same voltage) in order to light up the neon lamp upon the capacitor charging the capacitor must reach the voltage of the lamp ignition. When the lamp lights up the current flowing through the lamp caused the capacitor discharge. If the capacitor voltage drops below the voltage of lamp ignition, the capacitor's discharge stops and the process of its charging up starts again. This process will occur in cycles and you will observe lights up and going out of the neon lamp (relaxation oscillations) whose time depends on the capacitor's capacity.

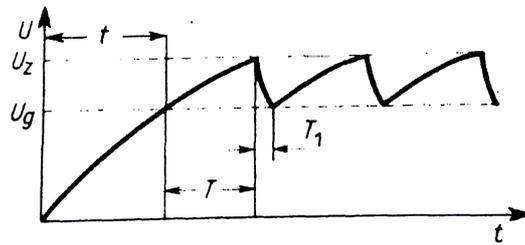


Figure 2: Changes in voltage upon the relaxation oscillations

Making use of eq. (5) we can describe the increase in voltage in the process of the capacitor charging as:

- Till the voltage of the lamp going out:

$$U_g = U_0 \left(1 - e^{-t/RC}\right)$$

- Till the voltage of the lamp ignition:

$$U_z = U_0 \left(1 - e^{-(t+T)/RC}\right)$$

where T is the period of the relaxation oscillations.

After transformations we get the expression describing the period of relaxation oscillations in the form:

$$T = RC \ln \underbrace{\frac{U_0 - U_g}{U_0 - U_z}}_{=K} \quad (9)$$

AIM OF THE EXPERIMENT

The aim of the experiment is to determine the value of the dimensionless coefficient K from equation (9) and the unknown capacity of the capacitor introduced into the circuit instead of the decade capacitor of variable capacity.

EQUIPMENT

A decade capacitor, capacitors of unknown capacity C_x , resistor R, power supply, neon lamp, stopper and wiring.

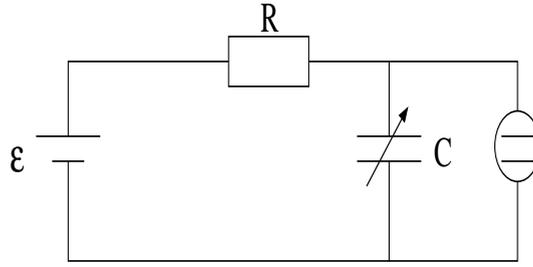


Figure 3: układ do badania drgań relaksacyjnych

1. Connect the circuit for investigation of relaxation oscillations as shown in the scheme given in Fig. 3.
2. For a fixed value of the decade capacitor capacity measure the duration of 11 lights up of the neon lamp, repeat each measurement three times.
3. Repeat the measurements for a few other capacities of the decade capacitor.
4. Note the measurement uncertainties ΔC , ΔR , Δt
5. Determine the mean value of the lamp light up duration \bar{t} and its standard deviation.
6. The period of the relaxation oscillations T is obtained from the relation:

$$T = \frac{\bar{t}}{10}$$

7. Determine the standard deviation of the period of oscillations:

$$S_T = \frac{1}{10} S_{\bar{t}}$$

8. Plot the relation $T(C)$, then find the slope value a from the plot, while the coefficient K and its uncertainty can be obtained from the relations

$$K = \frac{a}{R} \qquad \Delta K = K \left(\frac{\Delta a}{a} + \frac{\Delta R}{R} \right) \qquad (10)$$

9. Replace the decade capacitor by an additional capacitor of unknown capacity C_x or connect this additional capacitor in series with the decade capacitor, measure 3 times the duration of relaxation oscillations (11 lights up of the lamp).
10. Calculate the average duration \bar{t}_x , standard deviation $S_{\bar{t}_x}$, the period of relaxation oscillations T_x and S_{T_x}
11. Using the earlier obtained value of the coefficient K , calculate the unknown capacity of the additional capacitor from the relation:

$$C_x = \frac{T_x}{RK} \qquad \Delta C_x = C_x \left(\frac{\Delta T_x}{T_x} + \frac{\Delta R}{R} + \frac{\Delta K}{K} \right) \qquad (11)$$

Resonance in RLC circuits

Objective: studying the resonance in RLC (resistor, inductor, capacitor) circuits, finding the resonance curve and quality factor (Q).

Topics: alternating current, electric oscillations, electric effect in RLC circuit, quality factor.

1. INTRODUCTION

Alternating electric current (AC) is the flow of electric charge in which amplitudes of the current and voltage change periodically in time with frequency f . Values of the electric current and voltage at any given time (t) are determined by Esq. [1] and [2]:

$$U(t) = U_0 \sin \omega t \quad (1)$$

$$I(t) = I_0 \sin (\omega t + \varphi) \quad (2)$$

Where $U(t)$ and $I(t)$ are values of the voltage and current, respectively. Parameters U_0 and I_0 are peak values (amplitudes) of the voltage and current. $\omega = 2\pi f = 2\pi/T$ is the angular frequency, f is frequency, T is period and φ is phase difference between voltage and current.

Electric circuits can be described using Kirchhoff's rules (G. R. Kirchhoff 1824-1887). Let us consider series RLC circuit shown on **Fig. 1** and consisting of resistor R , inductor L and capacitor C .

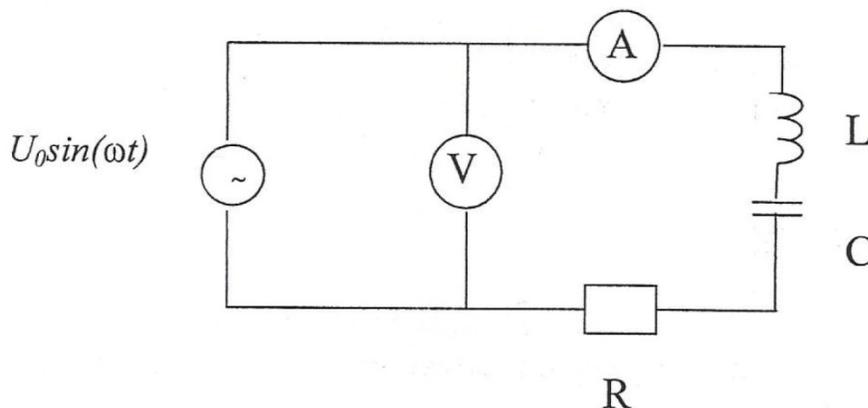


Figure 1. RLC circuit with the source of electromagnetic force

Voltage drop across individual elements R , L and C driven by alternating current are described by equations 3 through 5:

$$U_R(t) = RI(t) \quad (3)$$

Ex 9

$$U_L(t) = L \frac{dI(t)}{dt} \quad (4)$$

$$U_C(t) = \frac{q}{c} = \frac{1}{c} \int I(t) dt \quad (5)$$

Assume we connected the source of electromotive force (EMF) $U(t) = U_0 \sin(\omega t)$ to the circuit in Fig. 1. According to Kirchoff's second or loop rule the sum of all voltage drops around the circuit must be equal EMF.

$$U_R(t) + U_L(t) + U_C(t) = RI(t) + L \frac{dI(t)}{dt} + \frac{1}{c} \int I(t) dt = U_0 \sin(\omega t) \quad (6)$$

After division by L and calculating time derivative we obtain:

$$\frac{d^2 I(t)}{dt^2} + \frac{R}{L} \frac{dI(t)}{dt} + \frac{1}{LC} I(t) = \frac{U_0 \omega}{L} \cos(\omega t) \quad (7)$$

And after substitution in (7)

$$2\beta = \frac{R}{L}, \quad \omega_0^2 = \frac{1}{LC} \quad (8)$$

Where β is damping factor, and ω_0 is resonance angular (or circular) frequency. Therefore:

$$\frac{d^2 I(t)}{dt^2} + 2\beta \frac{dI(t)}{dt} + \omega_0^2 I(t) = \frac{U_0 \omega}{L} \cos(\omega t) \quad (9)$$

Equation (9) describes harmonic, damped driven oscillations. In this equation parameters of RLC circuit (resistance, inductance and capacitance) are substituted by universal parameters used in general theory of harmonic oscillations; i.e. by: natural frequency (resonant frequency in the presence of driving force) ω_0 and dumping coefficient β . Solution of equation (9) is the function:

$$I(t) = I_0 \sin(\omega t + \varphi) \quad (10)$$

After substitution of (10) to (9) we obtain equations that determine the amplitude of the current I_0 and the phase difference φ between the current and the voltage:

$$I_0 = \frac{U_0}{|Z|} = \frac{U_0}{\sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2}} = \frac{U_0}{\sqrt{R^2 + (X_L - X_C)^2}} \quad (11)$$

$$\operatorname{tg} \varphi = -\frac{\omega L - \frac{1}{\omega C}}{R} \quad (12)$$

Where parameters X_L and X_C are impedance of inductor (inductive reactance) and is impedance of capacitor (capacitive reactance), respectively.

The parameter Z in Eq. (11) is called the impedance of the electric circuit for alternating current.

Ex 9

Let us calculate the angular frequency $\omega = \omega_r$, called **resonance frequency** when inductive reactance is equal the capacitive reactance:

$$X_L = X_C \text{ or } \omega_r L = \frac{1}{\omega_r C} \quad (14)$$

After transformation of Eq. (14) we obtain formulas for angular resonant frequency ω_r and resonant frequency f_r :

$$\omega_r = \frac{1}{\sqrt{LC}} \text{ and } f_r = \frac{1}{2\pi\sqrt{LC}} \quad (15)$$

For series resonant circuit RLC, according to Eq. (13) the modulus of impedance $|Z|$ approaches minimum and the amplitude of the current I_0 is maximum and equal:

$$I_0 = I_{0max} = \frac{U_0}{R} \quad (16)$$

The phenomenon of sudden increase of amplitude of the current in the circuit when angular frequency ω approaches ω_r is called **resonance in the electric circuit**. In the Fig. 1 one can see the dependence of the current amplitude I_0 as the function of angular frequency ω in series resonant circuit RLC called **the resonance curve**.

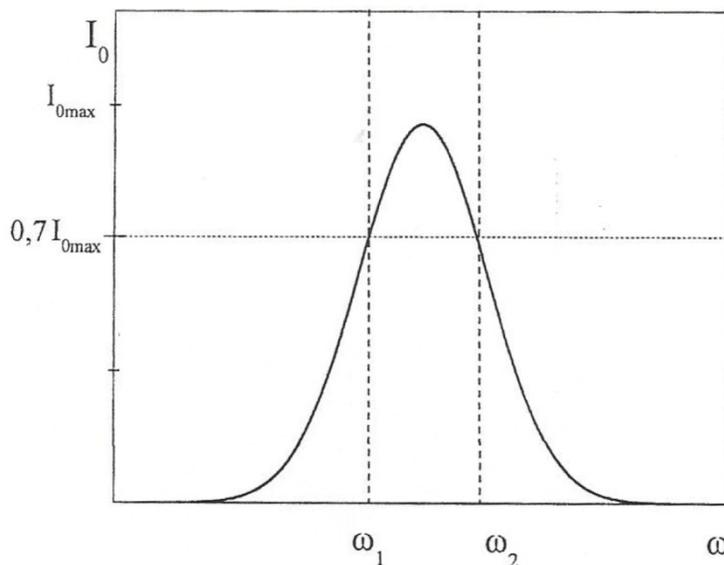


Figure 2. The dependence of current amplitude on angular frequency in series resonant circuit RLC.

Important parameter of the resonant circuit that is connected to energy losses in RLC circuit is dimensionless **quality factor Q**. It is defined as a ratio of energy stored E_z in the circuit to energy ΔE dissipated on resistor R as the heat per one full cycle of oscillations.

$$Q = 2\pi \frac{E_z}{\Delta E} \quad (17)$$

Ex 9

At resonance, quality factor of the ideal circuit, assuming solenoid L is characterized by inductance and its resistance is zero, indicates how many times voltage measured at inductance or capacitance exceeds the driving voltage:

$$Q = \frac{U_L}{U_0} = \frac{U_C}{U_0} = \frac{1}{R} \sqrt{\frac{L}{C}} \quad (18)$$

The quality factor of the electric circuit one can determine from the equation (19):

$$Q = \frac{\omega_r}{\Delta\omega} = \frac{\omega_r}{\omega_1 - \omega_2} = \frac{\omega_r}{2\Pi(f_1 - f_2)} = \frac{f_r}{f_1 - f_2} \quad (19)$$

-where f_r is the resonance frequency and f_1 and f_2 are frequencies at which the current amplitude reaches value described by Eq. (20):

$$I_0 = \frac{I_{0max}}{\sqrt{2}} \quad (20)$$

The parameter $\Delta\omega = 2\Pi(f_1 - f_2)$ is called the half-power bandwidth.

2. MEASUREMENTS

1. Connect elements into series RLC electric circuit to study resonances using alternating current according to Fig. 1.
2. Changing frequency f of the generator read values of current I_0 on the ammeter. Record data in the table:

	$f(kHz)$	$I(A)$

Table. 1.

3. CALCULATIONS

1. Enter data into Excel work sheet. Make the X-Y chart showing the dependence of current amplitude I_0 on frequency (resonance curve).
2. From the resonance curve estimate values f_r , f_1 and f_2 and calculate quality factor Q .

Ex 9

3. Knowing values of inductance L and capacitance C use Eq. (15) to calculate the resonance frequency of the circuit. Compare calculated value with the value estimated from the resonance curve.
4. Estimate measurement errors.
5. Assemble experimental results, computational data and conclusions from the experiments in the MS Word file and submit to your instructor.

4. SUGGESTED READING

1. Douglas Giancoli "Physics"; Pearson Education Limited 2014, 6th Edition.
2. Maria Kotłowska and Asja Kozak „On Physical Measurements”; Adam Mickiewicz University Scientific Publishing

Inductance of an inductor (a coil) in the alternate current circuit

The Kirchoff's laws are valid also for the alternate current but in the alternate current circuit the behavior of capacitors and inductors is different. In the circuit with direct current the capacitor is a break in the circuit so it is equivalent to a resistor of the infinitely large resistance. Alternate current flows through the capacitor which is charged alternatively in one and in the opposite direction. In the circuit with direct current the inductor's behavior is fully determined by the ohmic resistance of the wire it is made of, while in the circuit with alternate current the self-induction of the inductor plays a key role. The self-induction is related to the electromotive force:

$$E_L = -L \frac{dI}{dt} \quad (1)$$

where L is the inductance.

If the circuit with alternate current includes an ohmic resistor of resistance R and an inductor of the inductance L (Fig. 1), the role of resistance is played by the impedance Z defined as

$$Z = \sqrt{(R_L^2 + \omega^2 L^2)} \quad (2)$$

where R_L – is the total ohmic resistance of the inductor and resistor R ,
 $\omega = 2\pi f$ is the frequency of alternate current (in Poland $f = 50\text{Hz}$).

After transformation of eq. (2) we get

$$L = \frac{1}{2\pi f} \sqrt{(Z^2 - R_L^2)} \quad (3)$$

In order to find L you should determine the values of impedance and resistance R_L . The impedance can be calculated from the formula

$$Z = U/I. \quad (4)$$

After transformation

$$I = \frac{1}{Z} U. \quad (5)$$

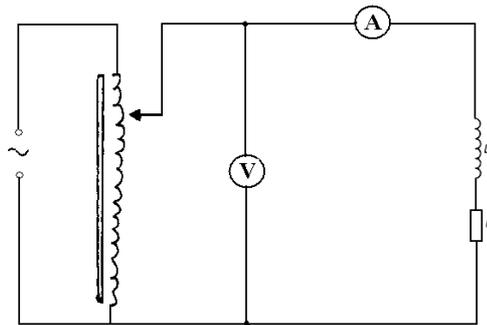
EQUIPMENT

Power supply providing alternate current (autotransformer), two inductors (coils)

of different inductances L , a resistor, amperemeter, voltmeter and wires.

Experiment A

1. Use a multimeter to determine the resistance R_L (total ohmic resistance of the inductor and the additional resistor R).
2. Connect the circuit according to scheme 303a.

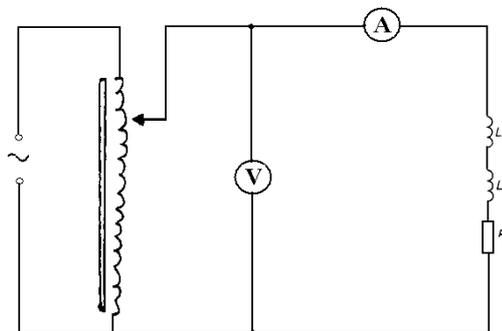


rys. 303a

3. Make about 10 measurements of the current intensity I and voltage U .
4. Draw the dependence $I(U)$ in the program SimStat, assuming that $a=1/Z$, so $Z=1/a$.
5. Calculate the inductance L using formula (3).
6. Estimate the uncertainty ΔL using the algorithm WPS.
7. Replace one inductor with another one and repeat the above procedure (1-6).

Experiment B

8. Connect in series both inductors with the resistor and determine the ohmic resistance of this circuit.
9. Connect the circuit according to scheme 303b.



rys. 303b

10. Repeat the procedure described above, from point 1 to 6.

Experiment C

11. Connect in parallel two inductors with the resistor and determine the ohmic resistance of this circuit.
12. Connect the circuit according to scheme 303c.

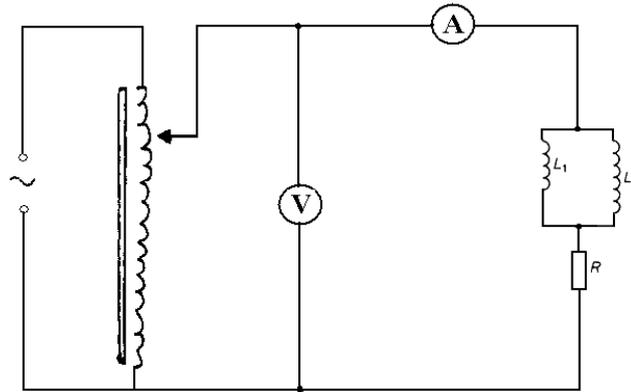


Fig. 303b

13. Repeat the above procedure described at points 1-6.
14. Formulate the laws describing inductance in the circuits from experiments B and C.