



Lodz University of Technology
Institute of Physics

Laboratory of electronics

Exercise E02IFE

Diodes

Table of contents:

1. Purpose of the exercise	3
2. Hazards	3
3. Introduction	3
4. Available equipment.....	5
4.1. Experimental module	5
4.2. Multimeters	6
4.3. Power supply	6
5. Experimental procedure.....	6
6. Guidelines on writing reports	7
7. References	9
7.1. Basic reference materials.....	9
7.2. Other reference materials	9
8. Appendixes	10
A.1. Method for determining the Zener voltage.....	10
A.2. Least squares method	11

Before you start to perform an experiment you are obliged to learn the following theoretical subjects:

1. Intrinsic and doped semiconductors. [1], [2], [3].
2. p-n junction and metal-semiconductor (m-s) junction. [2], [3].
3. Zener breakdown. Avalanche breakdown. [1], [2], [3].

1. Purpose of the exercise

The purpose of experiment is to measure the current-voltage (I-V) characteristics of selected diodes. The silicon diode and the Zener diode are investigated.

2. Hazards

Type	Absence	Low	Medium	High
electrical shock hazards		+		
optical radiation hazards	+			
mechanical hazards (including acoustic hazards, noise)	+			
electromagnetic radiation hazards (invisible)	+			
biological hazards	+			
ionizing radiation hazards	+			
chemical hazards	+			
thermal hazards (including explosion and fire)	+			

The cables with banana plugs are designed exclusively for use in low-voltage circuits – do not connect them to the mains supply 230 V.

3. Introduction

Semiconductor diode is usually small semiconductor structure containing suitably housed p-n junction together with two leads. In the Schottky diodes, the metal-semiconductor junction (m-s) is used instead of the p-n junction. In practice, multiple variations of design and technology of diodes are used, sometimes with very different appearance and different electrical parameters. Current-voltage characteristics of each diode exhibits a partial similarity to the theoretical characteristics of ideal p-n or m-s junction, described by formula:

$$I = I_s \left[\exp\left(\frac{eU}{mkT}\right) - 1 \right], \quad (1)$$

where: I – current flowing through the junction, I_s – intensity of the reverse saturation current, U – voltage on the junction (positive values correspond to the direction of conduction i.e. to forward bias), T – junction temperature in kelvins, k – Boltzmann constant ($k = 1.38065 \times 10^{-23}$ J / K), e – electron charge ($e = 1.602176 \times 10^{-19}$ C), m – dimensionless parameter, which takes a value from 1 to 2.

Analysis of the actual diode junction should take into account such parameters and phenomena as series resistance of the junction, resistance of the leakage, processes of generation and recombination of charge carriers and breakdown of the junction. In the actual p-n junction, the voltage drops at the resistances of the p and n regions as well as on the connector contacts and on the resistances of the leads should be taken into account besides the voltage drop in the transition region. The sum of these resistances is called series resistance. The impact of series resistance is evident at high currents flowing through the diode, that is, for the direction of conduction and for breakdown of the junction.

The leakage resistance is the resistance parallel to the junction area. This resistance is a result of surface phenomena and the occurrence of defects in the regular structure of the connector. The current through the leakage resistance is added to the current flowing through an ideal p-n junction, increasing its value. Due to the usually very large leakage resistance, its influence on the characteristics of the diode is manifested at the polarization in the reverse direction. In the p-n junction, the phenomenon of generation and recombination of charge carriers may occur. Generation plays an important role during the reverse bias, and the recombination during the forward bias. The result of these two phenomena is flow of additional components of the current: generation current during reverse bias and recombination current during forward bias. The generation current is several orders higher than the reverse saturation current and in silicon diodes it determines the resultant reverse current diodes, whereas it is negligible in germanium diodes.

Beyond a certain reverse bias voltage, the reverse current begins to increase rapidly. This increase may be caused by electrostatic ionization (Zener breakdown), or by impact ionization (avalanche breakdown). The first of these effects occurs for strongly doped junctions and consequently for low voltages (in the case of silicon below 5 V). The second of these effects is typical for weakly doped junctions (for silicon junctions, the avalanche breakdown occurs for voltages greater than approx. 7 V). There is also possible simultaneous occurrence of both mechanisms, which in the case of silicon takes place if the breakdown occurs at a voltage close to 6 V.

The electrical properties of metal-semiconductor junction depend on the choice of materials forming the junction. In some cases, metal-semiconductor junction is well conducting in both directions at relatively low voltages. Such junction is called ohmic contact. In other cases, the metal-semiconductor junction conducts high currents in one direction at low voltages, whereas for reversed polarity the currents are vanishingly small. Such metal-semiconductor junction is called the rectifying junctions or the Schottky diode. The voltage drop across the Schottky diode in the conducting state is typically smaller than in the silicon diodes (for a silicon diode voltage drop takes values $\sim 0,7$ V) but larger than in the germanium diodes (Ge diodes voltage drop is $\sim 0,3$ V). A disadvantage of Schottky diode is the relatively low breakdown voltage in the reverse direction, which is typically 30 V \div 50 V (maximum values do not exceed 100 V).

Diode parameters change with temperature. The analysis of equation (1) for the conduction direction shows that the voltage drop across the diode junction decreases with increase of temperature. At service temperatures between 250 K \div 350 K (-20 °C \div 80 °C) the effect is as follows:

- voltage drop at the forward bias junction decreases by approx. 20 mV when temperature increases by 10 K
- intensity of the reverse saturation current increases nearly twice with increase of temperature by 10 K
- the Zener breakdown voltage decreases with increase of temperature depending on the breakdown voltage.

One should keep in mind that the increase in junction temperature is usually caused by the flow of excessive conduction current or breakdown current (Zener or avalanche). Therefore the measurements should be carried out as much as possible smoothly, not to allow excessive heating of the investigated diode.

4. Available equipment

4.1. Experimental module

The front panel of experimental module is shown in Fig. 1. The multimeters are connected to the system such that the values indicated for the forward direction are positive and for the reverse direction - negative.

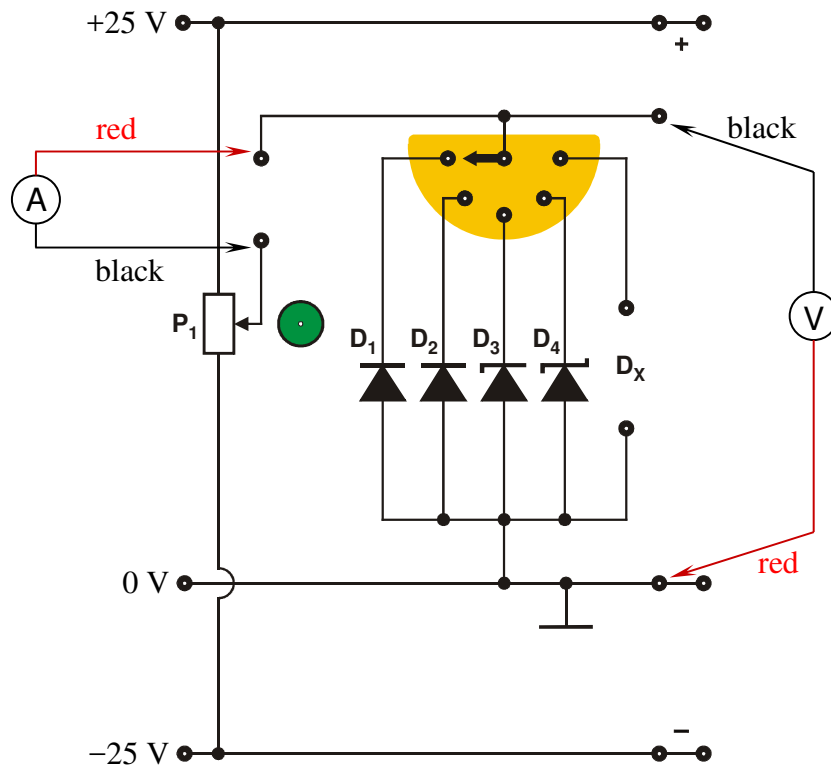


Fig. 1. The front panel of the module for measurement of current-voltage characteristics of four diodes

(D_1 – germanium diode; D_2 – silicon diode; D_3 – Zener diode; D_4 – Schottky diode).
The diagram shows the values of supply voltages and how to connect the multimeters.
The colours of leads are indicated.

4.2. Multimeters

Measurements of voltages and currents in the experimental module are made using digital multimeters AX-582B, KT890, M-3800, Protek 506 or UT804 (only selected models are available on a given measurement stand) [4]. Before measurements, check whether the correct measuring device are selected with the switches of each digital multimeters and whether the test probes are connected to the appropriate input terminals. One of the multimeter should be used as an ammeter and the other as voltmeter. You should also remember to choose the right range of the voltmeter (20 V DC or 40 V DC depending on the multimeter used) and of the ammeter for the forward direction (in the case of diodes D_1 , D_2 and D_4 please use the range 200 mA DC or 400 mA DC depending on the multimeter used). For the reverse direction, use the smallest available range, i.e. 20 μA or 400 μA DC depending on the multimeter used, with a reading resolution not lower than 0.01 μA . In the case of Zener diode D_3 the ranges 200 mA DC or 400 mA DC should be selected regardless of direction.

Attention: The multimeters KT890 and Protek 506 should not be used for reverse bias since their resolution 1 μA and 0.1 μA at the lowest available range can be insufficient during measurements of diode D_2 reverse current, which is of the order of tens of μA .

It results from Fig. 1 that the characteristics of each diode is measured in an accurate voltage measurement circuit. This is due to the properties of used laboratory instruments as well as due to the fact that in the method of accurate current measurement the internal resistance of ammeter would add to the diode series resistance making it difficult to perform accurate measurement.

4.3. Power supply

To supply power to the experimental module, the AC laboratory SIGLENT model SPD3303D was used [4]. Before the measurements, the stabilized power supply SPD3303D must be connected to the measuring circuit and the serial operation mode should be selected. After switching on the power, the symmetrical supply voltage at $\pm 25\text{ V}$ must be set.

5. Experimental procedure

The as reliable as possible measurements of the characteristics of individual diodes should be performed (tens of measurement points). During the exercise, the static current-voltage characteristics are measured with the “point by point” method. The required voltages are chosen (using a multi-turn potentiometer P_1) and the values of the applied voltage U and current I flowing through the diode are read. The density of measurement points should be selected according to the rate of change of the current passing through the diode.

1. Connect the circuit according to the diagram presented in Fig. 1. Use the clamp to select the second diode (D_2). Connect the power supply to the circuit using three wires of different colours (e.g. red: “plus”, black: “minus” and blue: “zero”).

WARNING: you have to set up the serial operating mode of the power supply and set up the output voltage initially to minimum/zero value.

2. Select the optimal ranges of DMMs (Digital MultiMeter).
3. **Before switching on the voltages at power supply connectors ask the supervisor to approve the circuit configuration.**
4. Adjust the symmetrical voltage to $\pm 25\text{ V}$. Notice the status of the power validity control LEDs (red: +25 V; green: -25 V).

5. Make the measurements of the current-voltage (I-V) characteristic of the investigated diode. Characteristic chart has to be composed of at least 40 measurement points (20 ÷ 25 for the forward direction and 15 ÷ 20 for the reverse direction). Fit the concentration of measurement points adequately to the rate of changes of the registered current through diode. Multitrotational potentiometer P₁ guarantee the fine tuning of diode bias voltage. The extremely left position of P₁ potentiometer is related to the maximum reverse bias voltage (about: -9 V). The extremely right position of P₁ potentiometer is related to the maximum forward bias voltage (value dependent on the selected diode). Start the measurements (both for reverse and forward directions) from 0 V bias voltage adjusted by P₁ potentiometer. Make the measurements efficiently to prevent the diode overheating (in particular for the forward direction).
NOTICE: voltage bias regulator with the build-in overload protection supports the current limit (75 mA) to protect the diodes.
6. **Don't forget to select the proper ammeter range when you pass from the reverse direction to the forward direction. Switch off DMM before you change the ammeter range.**
7. Write down the obtained results in the data table

Symbol of diode	№	reverse direction				forward direction			
		U [V]	ΔU [V]	I [μA]/[mA]	ΔI [μA]/[mA]	U [V]	ΔU [V]	I [mA]	ΔI [mA]
D ₂	1.								
	2.								

8. Repeat the measurement procedure listed above for Zener diode D₃.

6. Guidelines on writing reports

Report has to be composed of:

1. Front page (by using a pattern).
2. Description of experiment purposes.
3. Short introduction (basic definitions, formulas, description of used marks and symbols).
4. Schematic diagrams of tested circuits.

The report should contain only diagrams of the systems, which were actually compiled during the measurements. Each scheme must be accompanied by a sequence number and entitled. All the components shown in the diagram must be clearly described and identified using commonly used symbols.

5. List of used instruments and devices (id/stock number, type, setting and range values).
6. Measurement results.

The measured values should be presented in tables. Each table should have its number and title.

7. Plots.

Each plot showing the results of measurements should have its number and title containing information about what a given plot presents.

Use the obtained results to plot the current-voltage (I-U) characteristics of two investigated diodes. Show the characteristic of D₂ diode as two different graphs – for the forward and for the reverse direction, respectively. Draw the characteristic of the Zener diode D₃ as the separate chart with clearly marked Zener voltage (see Appendix A1).

Draw the additional characteristic in semi-logarithmic scale $\ln(I) \sim U$ for the forward direction of the D_2 diode (see Eq. 3 below and section IV.3.3 in [6]). Determine the range of the constant slope of this characteristic and show both the measurement points and the straight-line trend line.

8. Analysis of results.

Determine the value of the slope coefficient a of the line $\ln(I) = aU + b$ (use the least squares method – see Appendix A2) and the corresponding value of dimensionless parameter m of the D_2 diode for the range of constant slope of the $\ln(I) \sim U$ characteristic determined in point 7. Notice that in the case of analysis limited to the forward direction, equation (1) simplifies to the form:

$$I = I_s \exp\left(\frac{eU}{mkT}\right). \quad (2)$$

You can rewrite the Eq. (2) as

$$\ln(I) = \frac{eU}{mkT} + \ln(I_s) \quad (3)$$

to simplify the analysis of semi-logarithmic characteristic chart. If the investigated diode was not overheated the temperature T in Eq. (3) is equal to room temperature (about 300 K).

9. Determination of measurement uncertainties.

Determine the complex standard uncertainty of the m parameter calculated for the D_2 diode using the formula

$$u(m) = \sqrt{\left(\frac{\partial m}{\partial a}\right)^2 u^2(a) + \left(\frac{\partial m}{\partial T}\right)^2 u^2(T)} = m \sqrt{\left[\frac{u(a)}{a}\right]^2 + \left[\frac{u(T)}{T}\right]^2}, \quad (4)$$

where $u(a)$ is the standard uncertainty of type A of the slope coefficient a determined by the least squares method (see Appendix A2), and $u(T)$ is the standard uncertainty of the temperature T of the p-n junction. Since the measuring system does not allow temperature measurement, it should be assumed that the value of total standard uncertainty $u(T)$ results only from the standard uncertainty of type B, which can be estimated based on the uncertainty $\Delta_e T$ of temperature felt by experimenter, wherein

$$u(T) \approx u_B(T) \approx \frac{\Delta_e T}{\sqrt{3}}. \quad (5)$$

It can be assumed that under typical conditions $\Delta_e T = 10$ K, i.e. $T = (300 \pm 10)$ K, but in special situations the uncertainty value $\Delta_e T$ may be higher (e.g. just after turning on the air conditioning or opening the window in the laboratory).

Calculate the value of expanded uncertainty $U(m)$ of the m parameter for the D_2 diode, assuming the value of the expansion coefficient $k = 1.75$.

10. The final result.

Write the final result of the calculation of the m parameter for the D_2 diode with its expanded uncertainty $U(m)$, paying attention to the use of the appropriate format (see examples in Appendix A2).

11. Remarks and final conclusions.

The comments should contain assessment of the accuracy of measurements and own observations about the course of the exercise. The investigated diodes should be identified (i.e. their catalog symbols should be determined) by comparing the obtained results with the data sheets of selected diodes, which can be downloaded from the website of the Laboratory of Electronics. It is important to mention what actions and measurement procedures should be carried out differently (how?) if the exercise was to be repeated.

The report will be subject to the assessment of the presence and accuracy of all of the above components, clarity of presentation of the results (in the form of tables, graphs) and the quality of discussions and proposals formulated. Theoretical introduction is not required and in case of its inclusion in the report it will not affect the assessment.

7. References

7.1. Basic reference materials

- [1] F. Przewdziecki, A. Opolski, *Elektrotechnika i elektronika*, PWN, Warszawa, 1986.
- [2] A. Rusek, *Podstawy elektroniki*, the first part, WSiP, Warszawa, 1979.
- [3] K. Braclawski, A. Siennicki, *Elementy półprzewodnikowe*, WSiP, Warszawa, 1986.

7.2. Other reference materials

- [4] User manuals of the power supply and DMMs.
<https://fizyka.p.lodz.pl/pl/dla-studentow/information-technology/fundamentals-of-electronics/> .
- [5] Data sheets of tested diodes – at the web site of Electronics Lab.
<https://fizyka.p.lodz.pl/pl/dla-studentow/information-technology/fundamentals-of-electronics/> .
- [6] B. Żółtowski, *Wprowadzenie do zajęć laboratoryjnych z fizyki*, Skrypt PŁ, Łódź, 2002
(see also the webpage at:
<https://ftims.edu.p.lodz.pl/mod/resource/view.php?id=38541>).
- [7] M. Dems, *Experimental Methods in Science*, Skrypt PŁ, Łódź, 2008
(see also the webpage at:
<https://ftims.edu.p.lodz.pl/mod/resource/view.php?id=51212>).

8. Appendixes

A.1. Method for determining the Zener voltage

Zener voltage can be determined by several methods. One of the simplest method is to determine the Zener voltage based on the characteristics of the tested Zener diode. Example of a corresponding curve is shown in Fig. A1.1. I_{Zmax} means the maximum value of the current limit for the tested diodes (in the Laboratory of Electronics, the maximum current value is limited by the power system supplying the diodes). Assuming that $I_{Zmin} = 0.05 \times I_{Zmax}$, it is easy to find two suitable points on the curve, draw a straight line through them and find the point where it intersects the axis of voltage. The intersection point determines the sought Zener voltage U_z .

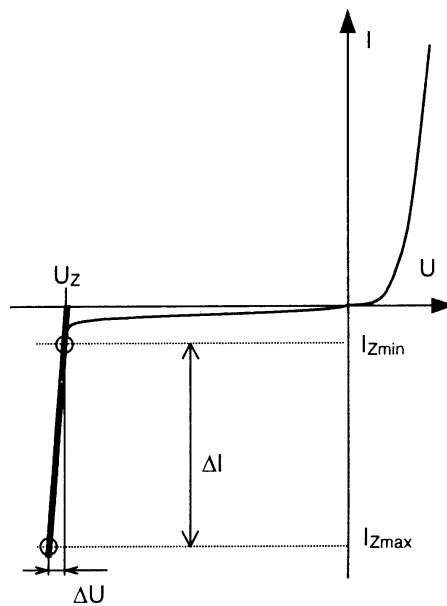


Fig. A1.1. The idea of the method of determining the Zener voltage

A.2. Least squares method

A complete description of the least squares method can be found in the script [7], which is available as a PDF file on the webpage with auxiliary materials for students taking classes in Laboratory of electronics. In this appendix, the scope of the presentation of the method corresponds to the scope of its use in Laboratory of electronics.

Experimentalists often need to find analytical form of the functional relation $y = f(x)$ based on n pairs of measurement results (x_i and y_i , where $i = 1, 2, \dots, n$), where the values of x and y change in some ranges. This process is called fitting, approximation or regression. In the case of experiments performed in Laboratory of electronics, the general form of the function results from known theoretical relationships or definitions of evaluated quantities and the purpose of regression is to determine the values of parameters in the assumed general form of the function. There are several methods used to solve this problem, among which the so-called **least squares method** is most often used. Assuming that each measurement result y_i is subject to Gaussian distribution with the same uncertainty and that the uncertainties of x_i are negligibly small, the method is based on minimizing the sum of squared differences between the actual values of the dependent variable $y_i(x_i)$ and the values predicted by the model function $f(x_i, a, b, c, \dots)$

$$S = \sum_{i=1}^n [y_i - f(x_i, a, b, c, \dots)]^2. \quad (\text{A2.1})$$

The sum S reaches the minimum with respect to all the parameters of the function f , i.e. a, b, c, \dots , when $\partial S/\partial a = 0$, $\partial S/\partial b = 0$, $\partial S/\partial c = 0$, \dots . An analytical solution of the system of equations obtained in this way is known only for some forms of the function f , however, minimization of the sum S for other functions can usually be done numerically. In the exercises available at Laboratory of electronics in Institute of Physics, only **linear regression** is used, where the goal is to adjust the coefficients of a linear function.

In the case of the linear function $\mathbf{f(x)} = \mathbf{a x + b}$ the solution of the system of equations $\partial S/\partial a = 0$ and $\partial S/\partial b = 0$ leads to finding the coefficients given by the formulas:

$$a = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \cdot \sum_{i=1}^n y_i}{D}, \quad (\text{A2.2})$$

$$b = \frac{\sum_{i=1}^n x_i^2 \cdot \sum_{i=1}^n y_i - \sum_{i=1}^n x_i \cdot \sum_{i=1}^n x_i y_i}{D}, \quad (\text{A2.3})$$

where

$$D = n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2. \quad (\text{A2.4})$$

The precision of the estimated coefficients a and b depends on their standard uncertainties of type A, i.e. the standard deviations, $u(a)$ and $u(b)$ given by the formulas:

$$u(a) = \sqrt{\frac{n \sum_{i=1}^n (y_i - ax_i - b)^2}{(n-2)D}}, \quad (\text{A2.5})$$

$$u(b) = \sqrt{\frac{\sum_{i=1}^n x_i^2 \cdot \sum_{i=1}^n (y_i - ax_i - b)^2}{(n-2)D}}, \quad (\text{A2.6})$$

where D is defined by equation (A2.4). In addition, a statistical relationship (correlation) between the values of two variables x_i and y_i may be assessed by calculating the linear correlation coefficient defined as:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \cdot \sum_{i=1}^n (y_i - \bar{y})^2}}. \quad (\text{A2.7})$$

The values of the r coefficient vary from -1 to $+1$. The limit values $r = \pm 1$ indicate an ideal linear correlation, while $r = 0$ means no correlation and an attempt to fit a linear function is unjustified in this case. A negative sign of the correlation coefficient means that an increase in the value of one variable is associated with a decrease in the value of other variable, while a positive sign means the same direction of changes of both variables.

If a theoretical relationship or a definition of estimated quantity corresponds to the linear function with zero y -intercept, $f(x) = a x$, the slope should be calculated from the formula:

$$a = \frac{\sum_{i=1}^n x_i y_i}{\sum_{i=1}^n x_i^2}, \quad (\text{A2.8})$$

and its standard deviation according to the formula

$$u(a) = \sqrt{\frac{\sum_{i=1}^n (y_i - ax_i)^2}{(n-1) \sum_{i=1}^n x_i^2}}. \quad (\text{A2.9})$$

The author of the report should always consider which of the two cases discussed above is appropriate in the context under consideration.

In practice, statistical functions available in Microsoft Excel and Open Office Calc programs are often used instead of performing successive stages of calculations according to the formulas (A2.2) – (A2.9). The function called REGLINP is particularly powerful, and its syntax is as follows:

=REGLINP(range_y; range_x; constant; stats)

where

- range_y – the range of cells containing y_i values,
- range_x – the range of cells containing x_i values,
- constant – the logical value PRAWDA which allows to calculate the y-intercept b, or the value FAŁSZ which means $b = 0$. All numeric values other than zero, e.g. 7, are interpreted as PRAWDA, and 0 corresponds to FAŁSZ,
- stats – a logical value specifying whether to calculate additional regression statistics; if stats is FAŁSZ only the coefficients a and b are returned.

As the REGLINP function returns a two-dimensional array of values, it should be entered as an array formula. To do this, you need to first highlight the range of cells for the function result, type your formula in the edit bar above the sheet, and then press the key combination Ctrl + Shift + Enter to enter the formula into the sheet.

Assume that cells A1:A5 contain known x_i values, cells B1:B5 contain known y_i values, and the area C1:D5 is selected as in example Table A2.1 below. When you type the following formula in the edit bar

=REGLINP(B1:B5; A1:A5; 1; 1)

and press the Ctrl + Shift + Enter combination, the calculation results will appear in the previously selected area. Starting from the upper-left corner of the area highlighted in light blue in Table A2.1, you will see the results returned in the following order:

- a – the value of the slope calculated according to the formula (A2.2),
 - b – the value of the y-intercept – the formula (A2.3),
 - u(a) – the value of standard deviation for the coefficient a – the formula (A2.5),
 - u(b) – the value of standard deviation for the coefficient b – the formula (A2.6),
 - r^2 – the square of the correlation coefficient r calculated according to the formula (A2.7),
- and further results F, d_f , SS_{reg} , SS_{resid} , which do not apply in Laboratory of electronics.

	A	B	C	C	D
1	1	110		a	b
2	2	131		u(a)	u(b)
3	3	192		r^2	se_y
4	4	317		F	d_f
5	5	489		SS_{reg}	SS_{resid}

Table A2.1. Sample data for calculations (x_i in column A and y_i in column B) and the order of regression results returned by the REGLINP function in the area highlighted in light blue.

If the constant argument has the value FAŁSZ, the results are returned in the order given above, except that the coefficient b is zeroed, and the result u(b) is absent.

If an array formula is difficult to understand, it can be replaced by a set of scalar formulas with the INDEKS function. Calling the function with the following arguments

=INDEKS(array; row_number; column_number)

returns the value of a single cell from the argument array at a position given by (row_num; column_num) coordinates, which are counted from (1;1) in the upper-left corner of the array. Thus, a number of scalar formulas must be used to obtain a set of results equivalent to calling REGLINP as a single array formula. Alternatively, some of the results returned in the table by the REGLINP function can also be obtained using specialized scalar functions NACHYLENIE, ODCIĘTA and R.KWADRAT.

a:	=INDEKS(REGLINP(B1:B5; A1:A5; 1; 1); 1; 1)	or	=NACHYLENIE(B1:B5; A1:A5)
b:	=INDEKS(REGLINP(B1:B5; A1:A5; 1; 1); 1; 2)	or	=ODCIĘTA(B1:B5; A1:A5)
u(a):	=INDEKS(REGLINP(B1:B5; A1:A5; 1; 1); 2; 1)		
u(b):	=INDEKS(REGLINP(B1:B5; A1:A5; 1; 1); 2; 2)		
r ² :	=INDEKS(REGLINP(B1:B5; A1:A5; 1; 1); 3; 1)	or	=R.KWADRAT(B1:B5; A1:A5)

Table A2.2. Scalar replacements for the REGLINP function entered as an array formula.

It should be remembered that the format of writing the result obtained together with its uncertainty informs about the type of this uncertainty. For example, the result $a = 136.173 \Omega$ together with its standard uncertainty $u(a) = 1.187 \Omega \approx 1.2 \Omega$ should be written as:

$$a = 136.2(1.2) \Omega \quad \text{the final result together with standard uncertainty}$$

If expanded uncertainty was calculated U – e.g. for the above result obtained for series of $n = 22$ pairs of measurements $U(a) = k(P, \nu) u(a) = 3.377 \Omega$, where $k(P, \nu) = 2.845$ is the coverage factor described by t-Student distribution for the assumed confidence level $P = 99 \%$ and the number of degrees of freedom $\nu = 20$ ($\nu = n - 2$, where 2 is the number of regression parameters) – please write:

$$a = (136.2 \pm 3.4) \Omega \quad \text{the final result together with expanded uncertainty}$$

WARNING! Depending on the character for the list separator selected in the regional settings of the operating system, **commas or semicolons should be used** in Microsoft Excel formulas. In the case of Open Office Calc, the list separator may be determined by the language version of the program.

The list separators and names of the functions and logical constants described above refer to Polish versions of programs. Users of other versions must use other language-specific list separators and names. In addition, the names have been translated only for selected languages. For all other languages, the English names are used. During the preparation of this appendix, this concerned, for example, the Ukrainian language.

Polish	English and Ukrainian
FAŁSZ	FALSE
INDEKS	INDEX
NACHYLENIE	SLOPE
ODCIĘTA	INTERCEPT
PRAWDA	TRUE
R.KWADRAT	RSQ
REGLINP	LINEST

Table A2.3. Names of selected functions and constants used in Polish, English and Ukrainian versions of spreadsheets.