The voltmeter as an ohmic resistor in a circuit

Experiment Objectives

- Determination of the internal resistance of a voltmeter
- Extension of the voltage meter's measuring range by connecting a dropping resistor in series

Principles

Measuring instruments are often used both to measure the current and to measure the voltage in electric circuits that have an ohmic resistance, also known as the internal resistance R_i, because of their technical design.

An important consequence of Kirchhoff's laws is that this internal resistance affects the current and the corresponding voltage drops in the electric circuit studied. Voltmeters are connected in parallel to the object of the measurement so a lower current flows through them. Hence a voltmeter reduces an electric circuit's total resistance. Therefore – compared to the circuit without the measuring instrument – a greater current flows, and the voltage changes correspondingly.

The experiment first determines the voltmeter's internal resistance by measuring the current through the voltmeter during the voltage measurement. Ohm's law applies:

$$R_i = \frac{U_{Ri}}{I_{Ri}} \quad (1)$$

where I_{Ri}: current through the measuring instrument

U_{Ri}: voltage drop at the measuring instrument

The second part of the experiment detects the voltmeter's impact on an electric circuit. This involves, in a simple circuit with two resistors R_1 and R_2, measuring the voltage drop U at resistor R_1. For the voltage drop (without measuring instrument):

$$U = U_G \cdot \frac{R_1}{R_1 + R_2} \quad (2)$$

where U_G: total voltage

If a voltmeter is connected in parallel to the resistor R_1, a voltage drop U_{Ri} occurs:

$$U_{Ri} = U_G \cdot \frac{R^*}{R^* + R_2} \quad (3)$$

where $R^* = \frac{R_1 \cdot R_i}{R_1 + R_i}$: resistance of the parallel connection

The ratio of voltages results in:

$$\frac{U}{U_{Ri}} = \frac{R_1 \cdot R_2}{(R_1 + R_2) \cdot R_i} + 1 \quad (4)$$

If voltages should be measured that exceed the instrument's measuring range, then a dropping resistor R_v should be turned on, generating a voltage drop. The factor by which the voltage's measured value U_{Ri} must be multiplied to get the actual voltage U comes from Kirchhoff's laws and Ohm's law:

For the voltage drops at the voltmeter and at the dropping resistor,

$$U = U_{Rv} + U_{Ri} \quad (5)$$

The current through the voltmeter is equal to the current through the dropping resistor, i.e.:

$$\frac{U_{Ri}}{R_i} = \frac{U_{Rv}}{R_v} \quad (6)$$

or

$$U_{Rv} = U_{Ri} \cdot \frac{R_v}{R_i} \quad (7)$$

(7) inserted into (5) gives:

$$U = U_{Ri} \cdot \left(1 + \frac{R_v}{R_i}\right) \quad (8)$$

The expression in brackets is the factor sought. The greater the dropping resistance chosen in relation to the internal resistance, the greater this factor, i.e. the extension of the measuring range, is.

Kem / JN 0608

Apparatus

2 Multimeter LDanalog 10 .... 531 110
1 Plug-in board DIN A4 .... 576 74
1 Resistor 680 kΩ, STE 577 75
1 Resistor 4.7 kΩ, STE 577 52
1 Resistor 220 kΩ, STE 577 71
1 Bridging plugs STE 2/19, set of 10 .... 501 48
1 DC power supply 0 to ±15 V 521 45
3 Connecting lead 19 A, 50 cm, red/blue, pair ... 501 45

Setup and carrying out the experiment

a) Determination of the internal resistance

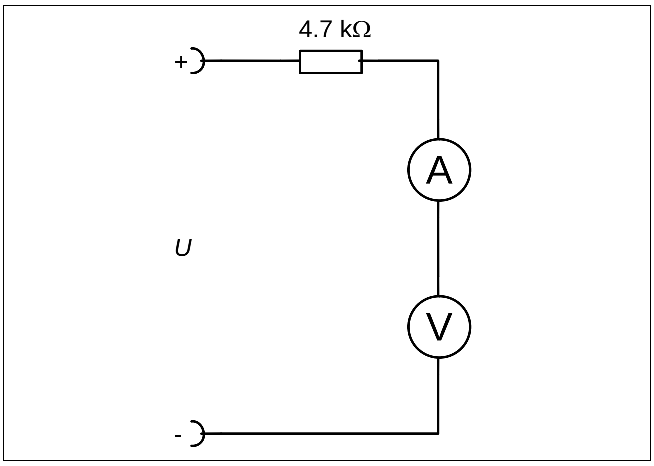

Fig. 1

- Experiment setup according to fig. 1. Pay attention to the measured quantities and polarities on the measuring instruments. Use the dropping resistor 4.7 kΩ to protect the ammeter also.
- Choose a measuring range on the ammeter of 50 μA and on the voltmeter of 1 V.
- Turn on the power supply and increase the voltage until the voltmeter has a voltage of U = 1 V.
- Measure the voltage and current and note them in Table 1.
- Set the voltage back to 0 V.

b) Impact of the voltmeter on the voltage

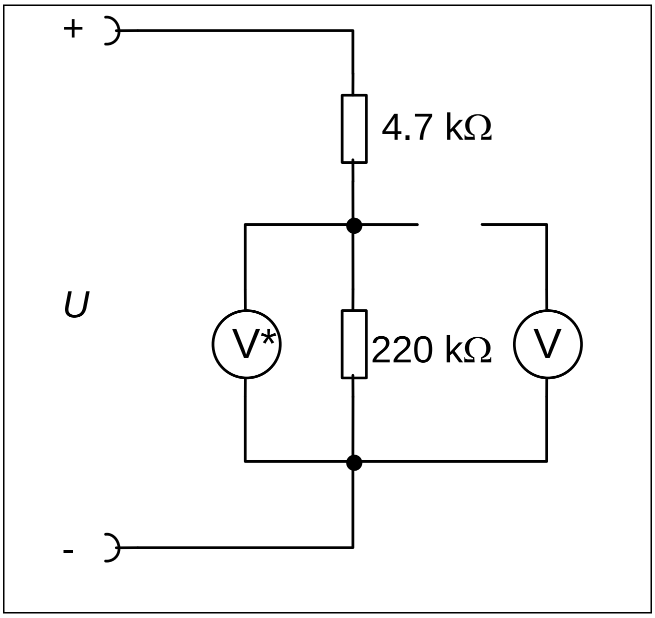

Fig. 2

- Experiment setup according to fig. 2. Choose a measuring range of 1 V on the voltmeter V*.
- Increase the voltage until the voltmeter V* has a voltage of U = 1 V.
- Connect the voltmeter V in parallel and make a note of the voltage.
- Set the voltage back to 0 V.

c) Extension of the measuring range

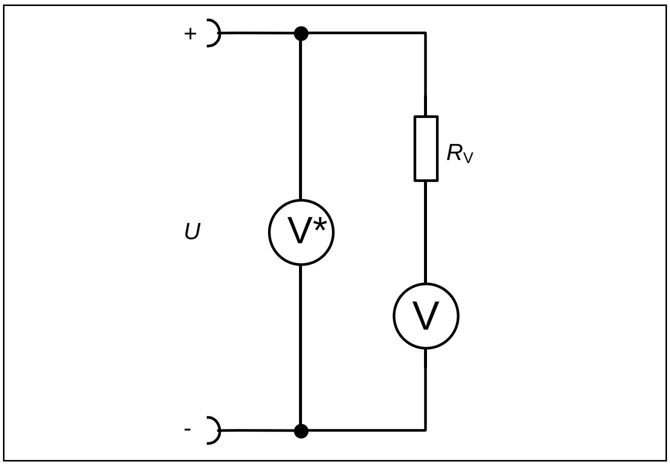

Fig. 3

- Experiment setup according to fig. 3. Pay attention to the measured quantities and polarities on the measuring instruments.
- Set a measuring range on the voltmeter V* of 10 V.
- Initially choose a dropping resistance R_V = 220 kΩ.
- Increase the voltage until the voltmeter V* has a voltage of U = 10 V.
- Read the voltage on the meter V and enter it into Table 2.
- Implement further resistances according to Table 2 and repeat the experiment.

Measurement Example

a) Determination of the internal resistance

Table 1:

$\frac{U}{\text{V}}$	$\frac{I}{\mu\text{A}}$	$\frac{R_i}{\text{k}\Omega}$
1.0	50	20

b) Impact of the voltmeter on the voltage

- Result: U = 0.84 V

c) Extension of the measuring range

$\frac{R_V}{\text{k}\Omega}$	$\frac{U}{\text{V}}$	$\frac{U_{Ri}}{\text{V}}$	$\frac{U}{U_{Ri}}$	$1+\frac{R_v}{R_i}$
220	10	0.83	12	12
680	10	0.29	34	35
900	10	0.22	45	46

Evaluation

a) Determination of the internal resistance

- Calculate the internal resistance R_i according to (1) and enter it into Table 1.
- The internal resistance of the voltmeter 531 110 in the 1 V measuring range amounts to about 20 kΩ .

Remark: Many voltmeters indicate the internal resistance value in kΩ /V. The internal resistance comes from the product of the measuring range (end value of the measuring range) with this value.
Example: 20 kΩ /V in the 1 V measuring range
$R_i = 20\ \text{k}\Omega/\text{V} \cdot 1\ \text{V} = 20\ \text{k}\Omega$

b) Impact of the voltmeter on the voltage

- The resistance subject to the measurement consists of the resistance R = 220 kΩ and the internal resistance of the voltmeter V*. This results in

$$R_1 = \frac{220\,\text{k}\Omega \cdot 20\,\text{k}\Omega}{220\,\text{k}\Omega + 20\,\text{k}\Omega} \approx 18.3\,\text{k}\Omega$$

and with Formula (4):

$$\frac{U}{U_{Ri}} = \frac{18.3\,\text{k}\Omega \cdot 4.7\,\text{k}\Omega}{(18.3\,\text{k}\Omega + 4.7\,\text{k}\Omega)\cdot 20\,\text{k}\Omega} + 1 = 1.19$$

i.e.

$$U_{Ri} = 0.84\,\text{V}$$

which is in line with the measured value.

- Using the voltmeter decreased the voltage drop by a factor of 0.84.

Remark: A voltmeter's internal resistance should thus be high compared to the resistance subject to measurement, so the measurement's impact remains insignificant.

c) Extension of the measuring range

- Calculate the ratio of the voltage U to the measured voltage U_{Ri} and the factor for extending the measuring range per (5), and enter them in Table 2.
- Connecting a resistor R_V in series increases the measuring range by a factor of $\left(1+\frac{R_v}{R_i}\right)$.
- Greater voltages can now be measured in the 1 V measuring range.

Remark: High-voltage probes use dropping resistances for high voltages. They are usually designed so the corresponding measuring range increases by a factor of 10 or 100.