The ammeter as an ohmic resistor in a circuit

Experiment Objectives

- Determination of the internal resistance of an ammeter
- Extension of the ammeter's measuring range by connecting a shunt in parallel

Principles

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

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. Ammeters are connected in series so the current to be measured flows through them. An ammeter thus increases an electric circuit's total resistance with its own internal resistance. Therefore – compared to the circuit without the measuring instrument – a smaller current flows.

The experiment initially determines the ammeter's internal resistance by measuring the voltage that drops at the ammeter during the current measurement. Ohm's law applies:

$$R_i = \frac{U}{I_{Ri}} \qquad (1)$$

where I_{Ri}: current through the measuring instrument

The second part of the experiment detects the ammeter's influence on an electric circuit. This involves measuring the current I in a simple circuit with resistance R and an ammeter. This circuit's total resistance consists of the resistance R and the measuring instrument's internal resistance $R_{i,1}$:

$$R_G = R + R_{i,1} \qquad (2)$$

Then switch a (second) ammeter on. The circuit's total resistance R_G^* increases by this ammeter's internal resistance:

$$R_G^* = R_G + R_{i,2} \qquad (3)$$

The ratio of the currents results in:

$$\frac{I}{I_{Ri}} = \frac{R_G^*}{R_G} \qquad (4)$$

If currents should be measured that exceed the measuring range, then a resistance (shunt) R_p must be connected in parallel, diverting part of the current to the ammeter. The factor by which the current's measured value I_{Ri} must be multiplied to get the actual current I comes from Kirchhoff's laws and Ohm's law:

$$I = I_{Ri} + I_{Rp} \qquad (5)$$

where I: total current

I_{Rp}: current through the shunt

The voltage drop is the same at the ammeter as at the shunt, i.e.:

$$I_{Rp} \cdot R_p = I_{Ri} \cdot R_i \qquad (6)$$

or

$$I_{Rp} = I_{Ri} \cdot \frac{R_i}{R_p} \qquad (7)$$

(7) inserted into (5) gives:

$$I = I_{Ri} \cdot \left(1 + \frac{R_i}{R_p}\right) \qquad (8)$$

The expression in brackets is the factor sought. The smaller the shunt 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, STE 576 74
3 Resistor 82 Ohm, STE 2/19 .... 577 33
1 Resistor 4.7 kOhm, STE 2/19 .... 577 52
1 Bridging plugs STE 2/19, set of 10 .... 501 48

1 DC power supply 0...±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

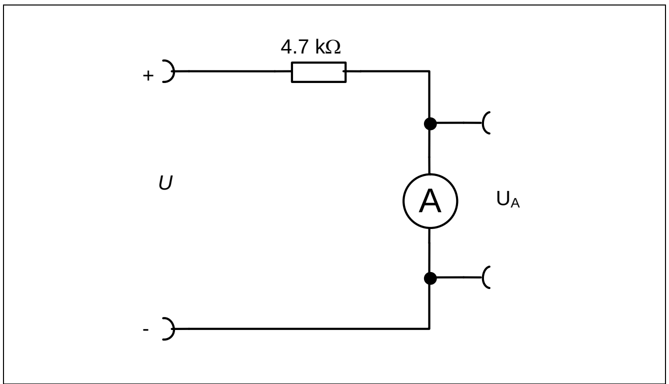

Fig. 1

- Experiment setup according to fig. 1.
- Pay attention to the measured quantities and polarities on both measuring instruments.
- Set a measuring range on the ammeter of 1 mA.
- Turn on the power supply and carefully increase the voltage until the ammeter measures a current I_{Ri} = 1 mA.
- Measure the voltage drop U_A with the voltmeter and note it in Table 1.
- Set the power supply back to 0 V.

Remark: Set the voltage back to 0 V after every experiment to avoid overloading the ammeter A with a new wiring.

b) Impact of the ammeter on the current

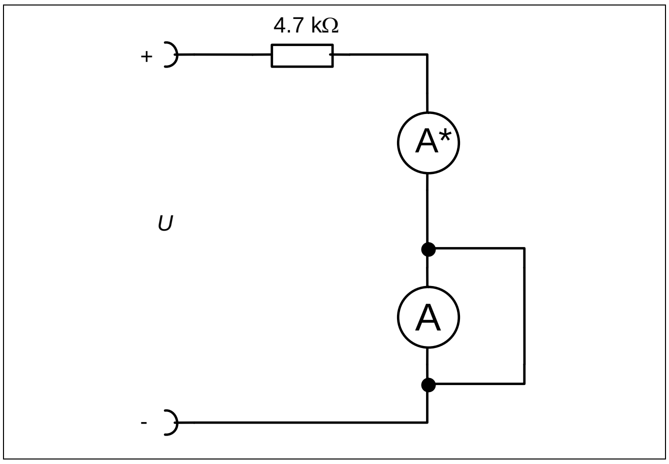

Fig. 2

- Connect an additional ammeter A* according to fig. 2.
- First, short-circuit ammeter A with a bridging plug.
- Set a measuring range on the ammeter A* of 1 mA.
- Carefully increase the voltage until the ammeter A* measures a current of I = 1 mA.
- Remove the bridging plug so both ammeters now measure the current.
- Measure and make a note of the current.
- Set the power supply back to 0 V.

c) Extension of the measuring range

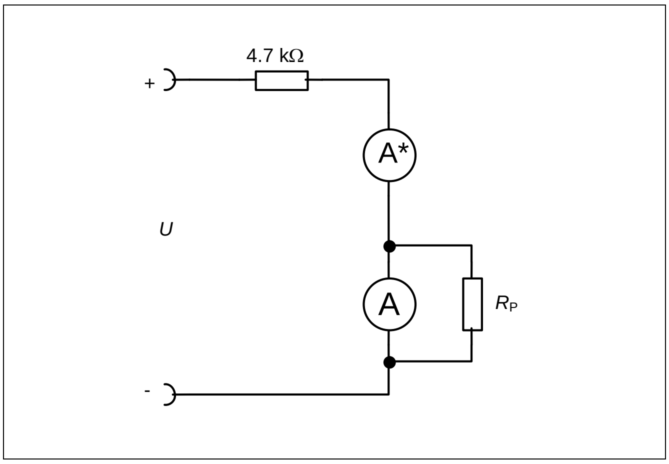

Fig. 3

- Set a measuring range on the ammeter A* of 10 mA.
- Then connect a shunt in parallel to the ammeter A according to fig. 3. Initially, implement a resistance R_p = 246 Ω by connecting 3 resistors 82 Ω in series.
- Carefully increase the voltage until the ammeter A* measures a current of I = 2 mA.
- Read and make a note of the currents I on the ammeter A* and I_{Ri} on the ammeter A.
- Set the power supply back to 0 V.
- Repeat the experiment with the other shunts according to Table 2, implementing the different resistances by connecting the available resistors in series and in parallel. Set the voltage back to 0 V after each scenario!

Measurement Examples

a) Determination of the internal resistance

Table 1:

$\frac{I_{Ri}}{\text{mA}}$	$\frac{U_A}{\text{V}}$	$\frac{R_i}{\Omega}$
1.0	0.48	480

b) Impact of the ammeter on the current

- Result: I = 0.92 mA

c) Extension of the measuring range

Table 2:

$\frac{R_P}{\Omega}$	$\frac{I}{\text{mA}}$	$\frac{I_{Ri}}{\text{mA}}$	$\frac{I}{I_{Ri}}$	$\left(1+\frac{R_i}{R_p}\right)$
246	2.0	0.73	2.7	3.0
164	2.0	0.53	3.8	3.9
82	2.0	0.29	6.9	6.9
41	2.0	0.16	12.5	12.7

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 ammeter 531 110 in the 1 mA measuring range amounts to about 480 Ω .

Remark: This value corresponds to the information on the 500 mV voltage drop in this measuring instrument's 1 mA range within the measuring accuracy.

b) Impact of the ammeter on the current

- From (4) we get: $I_{Ri} = I \cdot \frac{R_G}{R_G^*}$

  where $R_G = 4.7\,k\Omega + 480\,\Omega \approx 5.2\,k\Omega$

  and $R_G^* = 5.2\,k\Omega + 480\,\Omega \approx 5.7\,k\Omega$

  hence: $I_{Ri} = 1\,mA \cdot \frac{5.2\,k\Omega}{5.7\,k\Omega} = 0.91\,mA$

  which is in line with the measured value.
- Using the ammeter decreased the current by a factor of $\frac{R_G}{R_G^*} = 0.91$.

Remark: An ammeter's internal resistance should be small, compared to a circuit's total resistance, so the measurement's impact remains insignificant.

c) Extension of the measuring range

- Calculate the ratio of the current I to the measured current I_{Ri} and the factor for extending the measuring range according to (8), and enter them in Table 2.
- Connecting a resistor R_p in parallel increases the measuring range by a factor of $\left(1+\frac{R_i}{R_p}\right)$.
- Greater currents can now be measured in the 1 mA measuring range.

Remark: Shunts are often used for very high currents. They consist of thick copper bars with a small resistance, configured on the corresponding measuring instrument so the measuring range increases by a factor of 10 or 100.