Introductory Laboratory Course

E2: Internal Resistance of Measuring Instruments

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1 Physical background and assignments

The experiment E2: Internal Resistance of Measuring Instruments allows the determination of key characteristics of ammeters and voltmeters.

Unlike electrostatic measuring devices which have an infinite internal resistance but do not significantly influence the currents of those circuits they are used on, the instruments examined here have a non-negligible internal resistance that does change the flow of currents. Depending on the concrete electrical schematic, the measuring device can thus systematically modify the values it records. It is therefore of interest to know the exact internal resistance of every instrument in order to allow for corrections: either through a specific circuit design minimizing the influence of the device's internal resistance, or by mathematically accounting for the influence it exerts.

The importance of internal resistances becomes apparent, for example, if an instrument's effective operational range must be extended. If a voltmeter is to be used to measure a voltage U that is significantly higher than the maximal value the device can handle, an additional resistance that is connected in series with the voltmeter reduces the effective voltage measured since the total voltage is split over the two resistances. If both resistances are known the voltmeter can hence be used to measure higher values of U without interfering with the original circuit. Similarly, the ammeter's effective range can be increased with additional resistors that are connected in parallel: the current that flows from the original circuit towards the ammeter is separated and a lower current flows through the instrument, while the current in the original circuit stays the same. It follows that an instrument's internal resistance can play a major role in its application to a particular circuit, since the exact resistances needed in order to increase its range inter alia depend on the instruments internal resistance.

A full description of the experimenters' assignments, the physical background of the experiment, its overall design and all schematics can be found in [Green Book, pp. 6-8]. The experiment was carried out as described in that manual except where noted otherwise. All data used in the calculations and regressions can be found in the appendix.

2 Data and data analysis

2.1 Internal resistance of the voltmeter

In order to measure the internal resistance R_V of the voltmeter at desk 4, two series of measurements were taken. The first series used a generator voltage of $U_B^{(1)} = (15 \pm 0.2)\ V$, while during the second, the voltage was increased to $U_B^{(2)} = (19.8 \pm 0.2)\ V$. Both values were taken from the generator's digital display in a resolution of $0.1\ V$ and include an approximate uncertainty of two digits.

For both series, the precision resistance R_x was changed in varying increments, reflecting the expected value of $R_V \approx 25\ k\Omega$ and aiming at 20 data points per series:

starting at 500 Ω, R_x was increased rapidly in steps of 5 $k\Omega$ up to 20 $k\Omega$. The range between 20 and 30 $k\Omega$ was measured using smaller increments of 1 $k\Omega$ in order to allow for more data points in the vicinity of R_x's expected value. The remaining measurements between 30 $k\Omega$ and 50 $k\Omega$ were again taken in increments of 5 $k\Omega$, with a final measurement at $R_x = 111\ k\Omega$.

The sources of uncertainty in this experiment were the precision resistance, the voltmeter, and the generator: the precision resistance's uncertainty $u_{R_x} = (R_{x_i} \cdot 0.1\%)\ \Omega$ is the x-axis error in the following regressions, and in itself small enough to ignore. The voltmeter has a systematic error of $u_{U_V}^{syst} = 0.63\ V$ and a reading error, i.e. a statistical uncertainty, of $u_{U_V}^{stat} = 0.5\ V$, for a total uncertainty of $u_{U_V} = \sqrt{(0.63^2 + 0.5^2)}\ V = 0.8\ V$. The generator, as indicated above, has a systematic uncertainty of two digits, or $u_{U_B} = 0.2\ V$. All subsequently mentioned errors were, when applicable, calculated from these sources according to the laws of error propagation as detailed in formulas (29) to (32) in [Blue Book, pp. 36-37].

In order to determine R_V, a linear regression was carried out with the help of *OriginPro 8.6*, using the linear fitting function $y = a \cdot x + b$ (cf. Figure 1). Given formula (2.3) in [Green Book, p. 7], the coefficients and parameters were as follows:

$$a = \frac{1}{U_B^{(i)} \cdot R_V} \qquad b = \frac{1}{U_B^{(i)}} \tag{1}$$

$$y = \frac{1}{U_V} \qquad x = R_x \tag{2}$$

Note that the interception parameter b was fixed for both series of measurements.

In order to determine the total uncertainty of R_V, systematic and statistical errors were treated separately. First, the individual data points were weighed according to the statistical y-error using OriginPro's "instrumental" method:

$$u_y = \frac{1}{U_V^2} \cdot u_{U_V}^{stat} \tag{3}$$

As a result, the uncertainty of the slope u_a reflects the statistical fluctuations during the experiment, and the statistical error of R_V can be found through the law of error propagation as:

$$u_{R_V}^{stat} = \sqrt{\left(\frac{1}{U_B^2 \cdot a} \cdot u_{U_B}\right)^2 + \left(\frac{1}{U_B \cdot a^2} \cdot u_a\right)^2} \tag{4}$$

Second, the regression was repeated twice to create a "tunnel" reflecting R_V's systematic uncertainty. Once, the systematic error was added to the data points U_{V_i}, while for the second regression they were subtracted (cf. Figure 2):

$$u_{R_V}^{syst} = \frac{1}{2} \cdot (R_V^{max} - R_V^{min}) \tag{5}$$

$$U_{V_i}^{+} = U_{V_i} + u_{U_V}^{syst} \tag{6}$$

$$U_{V_i}^{-} = U_{V_i} - u_{U_V}^{syst} \tag{7}$$

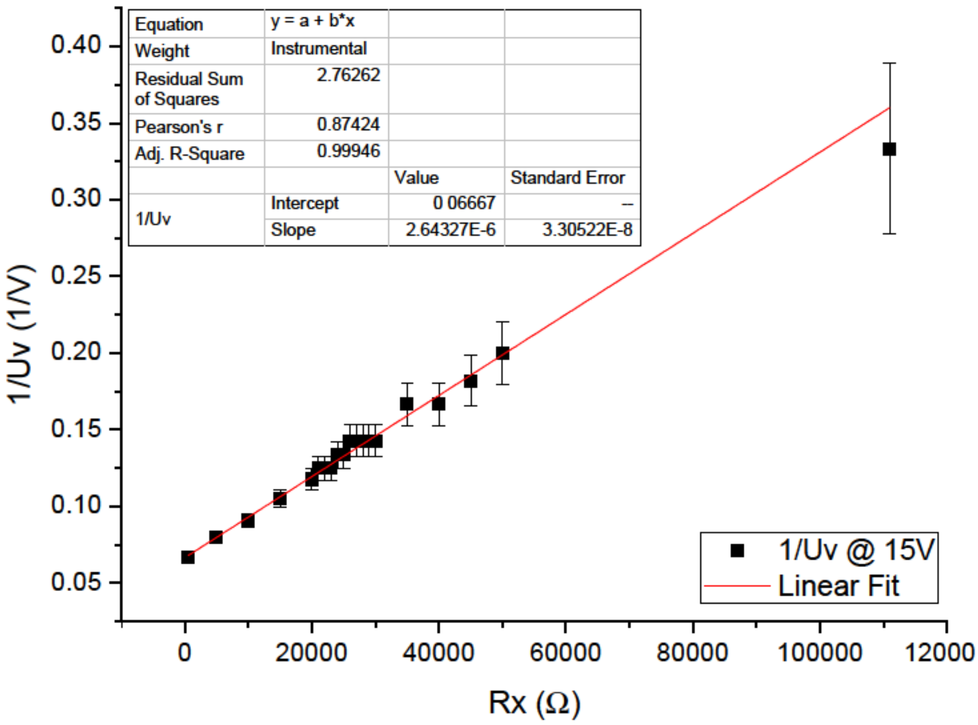

Figure 1: Linear regression to calculate R_V from the slope a

The three regressions resulted in different values for a and, thus, R_V: in addition to the middle value - representing an average - this method gives the maximal and minimal values of a: they would occur if the systematic error was fully skewing the results of the experiment in one direction or the other.

The resulting total uncertainty for R_V follows as:

$$u_{R_V} = \sqrt{(u_{R_V}^{syst})^2 + (u_{R_V}^{stat})^2} \tag{8}$$

Finally, the results from the two series of measurements $R_V^{(i)}$ can be combined into a weighed average according to formulas (55) through (57) in [Blue Book, p. 47]:

$$R_V^{(1)} = (25221 \pm 4562)\ \Omega \tag{9}$$
$$R_V^{(2)} = (24990 \pm 3423)\ \Omega \tag{10}$$
$$R_V = (25122 \pm 2738)\ \Omega \tag{11}$$

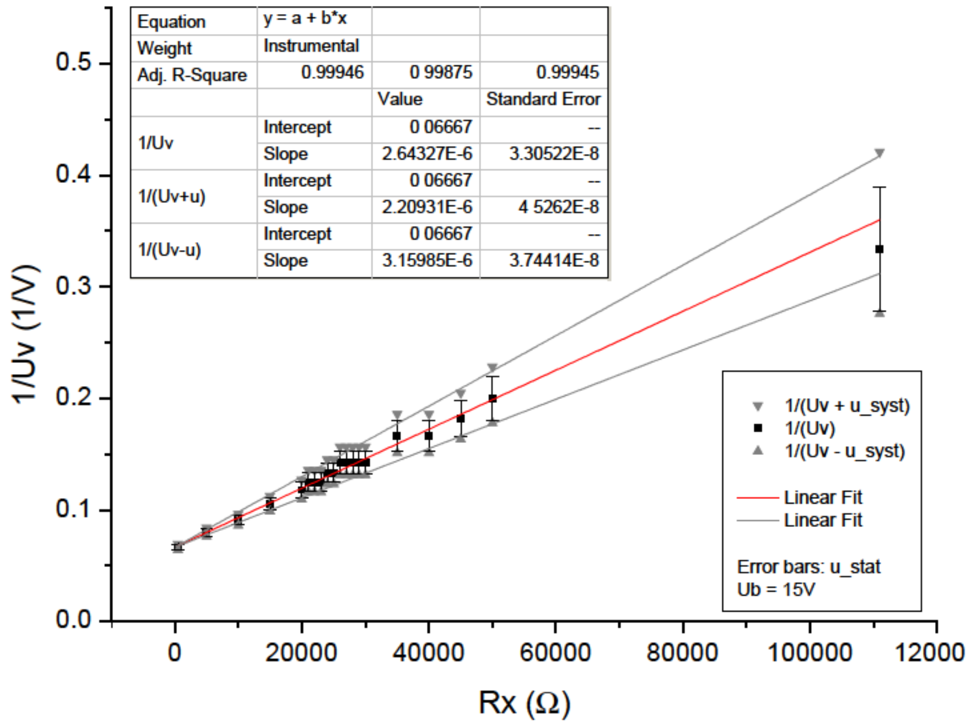

Figure 2: Illustration of the "tunnel" method used to determine the statistical and systematic errors of U_V

2.2 Internal resistance of the ammeter

The overall strategy to measure the internal resistance of the ammeter at desk 4 closely resembles the one outlined above. Again, there were two series of measurements at $U_B^{(1)} = (15 \pm 0,2)\ V$ and $U_B^{(2)} = (19,8 \pm 0,2)\ V$.

The error sources in this circuit were as described above, the only exception being the ammeter contributing instead of the voltmeter. Its uncertainty consisted of a systematic error $u_{I_A}^{syst} = 1.5\ \mu A$ and a reading error $u_{I_A}^{stat} = 2.5\ \mu A$ for a total of $u_{I_A} = \sqrt{1.5^2 + 2.5^2}\ \mu A = 2.9\ \mu A$. The precision resistance's error was ignored.

A potential further source of errors is the current I_0: the linear regressions used here require a constant I_0. In reality, however, the current varies with the circuit's total resistance, and thus with every change of R_x. A large R_0 minimizes the absolute variation of R in the circuit and thus stabilizes I_0. In this case, the variation of I_0 can be considered very small due to the very large $R_0 \approx 200\ k\Omega$ and is thus ignored. It should be noted, however, that a very large R_0 reduces the absolute value of I_0 according to Ohm's law and is therefore problematic in its own way: in order to minimize the ammeter's uncertainty, it should be operated near its maximum operating value. If I_0 is reduced too far, the ammeters relative uncertainty thus greatly increases, thereby significantly increasing the final result's uncertainty.

The regressions were carried out with the following parameters and coefficients:

$$a = \frac{R_A}{I_0} \qquad b = \frac{1}{I_0} \tag{12}$$

$$y = \frac{1}{I_A} \qquad x = \frac{1}{R_x} \tag{13}$$

where b was fixed. As described above, in order to create the "tunnel", I_A was varied with its systematic error to $I_{A_i}^{\pm} = I_{A_i} \pm u_{I_A}^{syst}$.

The current I_0 was first measured directly as I_0^{mes} by removing the resistor R_x from the circuit, effectively reducing formula (2.4) in [Green Book, p. 8] to $I_A = I_0^{mes}$. In this configuration, the uncertainty of I_0^{mes} is thus equal to the uncertainty of the ammeter.

Alternatively, instead of using a fixed value for b, the regressions described below can also be carried out with a variable b, allowing for an alternative method of determining I_0. The resulting u_b reflects the statistical error for I_0^{reg}, and the three values obtained from the "tunnel" give an interval for its systematic error.

At a generator current of $U_B = 15\ V$, the following results can be reported:

$$I_0^{mes} = (75 \pm 3)\ \mu A \tag{14}$$

$$I_0^{reg} = (77 \pm 1)\ \mu A \tag{15}$$

And, likewise, for $U_B = 19.8\ V$:

$$I_0^{mes} = (100 \pm 3)\ \mu A \tag{16}$$

$$I_0^{reg} = (98 \pm 1)\ \mu A \tag{17}$$

Note that for the determination of R_A only I_0^{mes} was used.

The regressions necessary to determine R_A could then be carried out following the same steps that are explained in detail above.

With an expected internal resistance of $R_A \approx 1\ k\Omega$, the increments of R_x were chosen as follows: starting at $0.5\ k\Omega$, R_x went up in $0.1\ k\Omega$ steps to $1.5\ k\Omega$. Then, the step size was increased to $5\ k\Omega$ up to $50\ k\Omega$. A final measurement was taken with the maximum possible value of $R_x = 111\ k\Omega$.

The statistical error used in the weighing process was

$$u_y = \frac{1}{I_A^2} \cdot u_{I_A}^{stat} \tag{18}$$

and led to a value of u_a reflecting the statistical uncertainties of the experiment:

$$u_{R_A}^{stat} = \sqrt{(I_0 \cdot u_a)^2 + (a \cdot u_{I_0})^2} \tag{19}$$

The systematic error of R_A was then determined using a similar "tunnel" to that described in formulas (5) through (8).

Using this strategy, the two series of measurements yielded the following results $R_A^{(i)}$ for the ammeter's resistance. Both values were finally combined into a weighed average R_A:

$$R_A^{(1)} = (1667 \pm 346)\ \Omega \tag{20}$$
$$R_A^{(2)} = (1657 \pm 255)\ \Omega \tag{21}$$
$$R_A = (1662 \pm 205)\ \Omega \tag{22}$$

3 Error analysis and results

The value of R_V experimentally found was very close to the initial expectation of 25 $k\Omega$. The large uncertainty around the final value of R_V is largely due to the systematic error of U_V and, hence, the voltmeter's systematic error: a systematic error always skews the results into a particular direction. Thus, especially in regression analysis and in experiments where the systematic error scales with the observed value, the systematic error makes the determination of the slope a significantly less reliable, a problem that cannot be countered by weighing the individual data points. For comparison, the statistical uncertainty of the weighed average R_V was only 308 Ω, while the systematic error was 2720 Ω. A simple solution to drastically reduce the uncertainty of R_V would thus be any step that can minimize systematic errors of U_V: using better equipment or measuring the same value with different instruments.

The same basic observations hold true for R_A, where the purely statistical uncertainty was only 46 Ω and the systematic error a full 200 Ω: the foremost contributor to the results' uncertainty is the systematic error of the ammeter, and every attempt to minimize its error can greatly reduce the experiment's uncertainty. It should be noted that R_A was found to be around 60 % higher than initially expected: 1.6 $k\Omega$ instead of 1 $k\Omega$. Since all results remain consistent with each other, including both series of measurements resulting in similar values for R_A, grave errors on the part of the experimenters seem unlikely. Most probably, the internal resistance of the ammeter at desk 4 is simply higher than expected.

References

[Blue Book] Müller, U. *Einführung in die Messung, Auswertung und Darstellung experimenteller Ergebnisse in der Physik.* 2007.

[Green Book] Müller, U. *Physikalisches Grundpraktikum. Elektrodynamik und Optik.* 2010.

A Appendix

Table 1: Data used in the regressions for $R_V^{(1)}$ at $U_B = 15V$

R_x [Ω]	u_{R_x}	U_V [V]	$1/U_V$	u_{1/U_V}	$1/U_V^+$	u_{1/U_V^+}	$1/U_V^-$	u_{1/U_V^-}
5,0E+02	5,0E-01	1,5E+01	6,7E-02	2,2E-03	6,4E-02	2,0E-03	7,0E-02	2,4E-03
5,0E+03	5,0E+00	1,3E+01	8,0E-02	3,2E-03	7,6E-02	2,9E-03	8,4E-02	3,5E-03
1,0E+04	1,0E+01	1,1E+01	9,1E-02	4,1E-03	8,6E-02	3,7E-03	9,6E-02	4,6E-03
1,5E+04	1,5E+01	9,5E+00	1,1E-01	5,5E-03	9,9E-02	4,9E-03	1,1E-01	6,3E-03
2,0E+04	2,0E+01	8,5E+00	1,2E-01	6,9E-03	1,1E-01	6,0E-03	1,3E-01	8,1E-03
2,1E+04	2,1E+01	8,0E+00	1,3E-01	7,8E-03	1,2E-01	6,7E-03	1,4E-01	9,2E-03
2,2E+04	2,2E+01	8,0E+00	1,3E-01	7,8E-03	1,2E-01	6,7E-03	1,4E-01	9,2E-03
2,3E+04	2,3E+01	8,0E+00	1,3E-01	7,8E-03	1,2E-01	6,7E-03	1,4E-01	9,2E-03
2,4E+04	2,4E+01	7,5E+00	1,3E-01	8,9E-03	1,2E-01	7,6E-03	1,5E-01	1,1E-02
2,5E+04	2,5E+01	7,5E+00	1,3E-01	8,9E-03	1,2E-01	7,6E-03	1,5E-01	1,1E-02
2,6E+04	2,6E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
2,7E+04	2,7E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
2,8E+04	2,8E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
2,9E+04	2,9E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
3,0E+04	3,0E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
3,5E+04	3,5E+01	6,0E+00	1,7E-01	1,4E-02	1,5E-01	1,1E-02	1,9E-01	1,7E-02
4,0E+04	4,0E+01	6,0E+00	1,7E-01	1,4E-02	1,5E-01	1,1E-02	1,9E-01	1,7E-02
4,5E+04	4,5E+01	5,5E+00	1,8E-01	1,7E-02	1,6E-01	1,3E-02	2,1E-01	2,1E-02
5,0E+04	5,0E+01	5,0E+00	2,0E-01	2,0E-02	1,8E-01	1,6E-02	2,3E-01	2,6E-02
1,1E+05	1,1E+02	3,0E+00	3,3E-01	5,6E-02	2,8E-01	3,8E-02	4,2E-01	8,9E-02

Table 2: Data used in the regressions for $R_V^{(2)}$ at $U_B = 19.8V$

R_x [Ω]	u_{R_x}	U_V [V]	$1/U_V$	u_{1/U_V}	$1/U_V^+$	u_{1/U_V^+}	$1/U_V^-$	u_{1/U_V^-}
5,0E+02	5,0E-01	2,0E+01	5,0E-02	1,3E-03	4,8E-02	1,2E-03	5,2E-02	1,3E-03
5,0E+03	5,0E+00	1,7E+01	5,9E-02	1,7E-03	5,7E-02	1,6E-03	6,1E-02	1,9E-03
1,0E+04	1,0E+01	1,4E+01	7,1E-02	2,6E-03	6,8E-02	2,3E-03	7,5E-02	2,8E-03
1,5E+04	1,5E+01	1,3E+01	8,0E-02	3,2E-03	7,6E-02	2,9E-03	8,4E-02	3,5E-03
2,0E+04	2,0E+01	1,1E+01	9,1E-02	4,1E-03	8,6E-02	3,7E-03	9,6E-02	4,6E-03
2,1E+04	2,1E+01	1,1E+01	9,1E-02	4,1E-03	8,6E-02	3,7E-03	9,6E-02	4,6E-03
2,2E+04	2,2E+01	1,1E+01	9,5E-02	4,5E-03	9,0E-02	4,0E-03	1,0E-01	5,1E-03
2,3E+04	2,3E+01	1,0E+01	1,0E-01	5,0E-03	9,4E-02	4,4E-03	1,1E-01	5,7E-03
2,4E+04	2,4E+01	1,0E+01	1,0E-01	5,0E-03	9,4E-02	4,4E-03	1,1E-01	5,7E-03
2,5E+04	2,5E+01	1,0E+01	1,0E-01	5,0E-03	9,4E-02	4,4E-03	1,1E-01	5,7E-03
2,6E+04	2,6E+01	1,0E+01	1,0E-01	5,0E-03	9,4E-02	4,4E-03	1,1E-01	5,7E-03
2,7E+04	2,7E+01	9,5E+00	1,1E-01	5,5E-03	9,9E-02	4,9E-03	1,1E-01	6,3E-03
2,8E+04	2,8E+01	9,0E+00	1,1E-01	6,2E-03	1,0E-01	5,4E-03	1,2E-01	7,1E-03
2,9E+04	2,9E+01	9,0E+00	1,1E-01	6,2E-03	1,0E-01	5,4E-03	1,2E-01	7,1E-03
3,0E+04	3,0E+01	9,0E+00	1,1E-01	6,2E-03	1,0E-01	5,4E-03	1,2E-01	7,1E-03
3,5E+04	3,5E+01	8,0E+00	1,3E-01	7,8E-03	1,2E-01	6,7E-03	1,4E-01	9,2E-03
4,0E+04	4,0E+01	7,5E+00	1,3E-01	8,9E-03	1,2E-01	7,6E-03	1,5E-01	1,1E-02
4,5E+04	4,5E+01	7,0E+00	1,4E-01	1,0E-02	1,3E-01	8,6E-03	1,6E-01	1,2E-02
5,0E+04	5,0E+01	6,5E+00	1,5E-01	1,2E-02	1,4E-01	9,8E-03	1,7E-01	1,4E-02
1,1E+05	1,1E+02	4,0E+00	2,5E-01	3,1E-02	2,2E-01	2,3E-02	3,0E-01	4,4E-02

Table 3: Data used in the regressions for $R_A^{(1)}$ at $U_B = 15V$

$1/R_x$ [1/Ω]	u_{1/R_x}	I_A [A]	$1/I_A$	u_{1/I_A}	$1/I_A^+$	u_{1/I_A^+}	$1/I_A^-$	u_{1/I_A^-}
2,0E-03	2,0E-06	1,8E-05	5,7E+04	8,2E+03	5,3E+04	6,9E+03	6,3E+04	9,8E+03
1,7E-03	1,7E-06	2,0E-05	5,0E+04	6,3E+03	4,7E+04	5,4E+03	5,4E+04	7,3E+03
1,4E-03	1,4E-06	2,3E-05	4,4E+04	4,9E+03	4,2E+04	4,3E+03	4,8E+04	5,7E+03
1,3E-03	1,3E-06	2,5E-05	4,0E+04	4,0E+03	3,8E+04	3,6E+03	4,3E+04	4,5E+03
1,1E-03	1,1E-06	2,5E-05	4,0E+04	4,0E+03	3,8E+04	3,6E+03	4,3E+04	4,5E+03
1,0E-03	1,0E-06	2,8E-05	3,6E+04	3,3E+03	3,4E+04	3,0E+03	3,8E+04	3,7E+03
9,1E-04	9,1E-07	3,0E-05	3,3E+04	2,8E+03	3,2E+04	2,5E+03	3,5E+04	3,1E+03
8,3E-04	8,3E-07	3,0E-05	3,3E+04	2,8E+03	3,2E+04	2,5E+03	3,5E+04	3,1E+03
7,7E-04	7,7E-07	3,3E-05	3,1E+04	2,4E+03	2,9E+04	2,2E+03	3,2E+04	2,6E+03
7,1E-04	7,1E-07	3,5E-05	2,9E+04	2,0E+03	2,7E+04	1,9E+03	3,0E+04	2,2E+03
6,7E-04	6,7E-07	3,5E-05	2,9E+04	2,0E+03	2,7E+04	1,9E+03	3,0E+04	2,2E+03
2,0E-04	2,0E-07	5,5E-05	1,8E+04	8,3E+02	1,8E+04	7,8E+02	1,9E+04	8,7E+02
1,0E-04	1,0E-07	6,5E-05	1,5E+04	5,9E+02	1,5E+04	5,7E+02	1,6E+04	6,2E+02
6,7E-05	6,7E-08	6,8E-05	1,5E+04	5,5E+02	1,4E+04	5,3E+02	1,5E+04	5,7E+02
5,0E-05	5,0E-08	7,0E-05	1,4E+04	5,1E+02	1,4E+04	4,9E+02	1,5E+04	5,3E+02
4,0E-05	4,0E-08	7,0E-05	1,4E+04	5,1E+02	1,4E+04	4,9E+02	1,5E+04	5,3E+02
3,3E-05	3,3E-08	7,3E-05	1,4E+04	4,8E+02	1,4E+04	4,6E+02	1,4E+04	5,0E+02
2,9E-05	2,9E-08	7,3E-05	1,4E+04	4,8E+02	1,4E+04	4,6E+02	1,4E+04	5,0E+02
2,5E-05	2,5E-08	7,5E-05	1,3E+04	4,4E+02	1,3E+04	4,3E+02	1,4E+04	4,6E+02
2,2E-05	2,2E-08	7,5E-05	1,3E+04	4,4E+02	1,3E+04	4,3E+02	1,4E+04	4,6E+02
2,0E-05	2,0E-08	7,5E-05	1,3E+04	4,4E+02	1,3E+04	4,3E+02	1,4E+04	4,6E+02
9,0E-06	9,0E-09	7,5E-05	1,3E+04	4,4E+02	1,3E+04	4,3E+02	1,4E+04	4,6E+02

Table 4: Data used in the regressions for $R_A^{(2)}$ at $U_B = 19.8V$

$1/R_x$ [1/Ω]	u_{1/R_x}	I_A [A]	$1/I_A$	u_{1/I_A}	$1/I_A^+$	u_{1/I_A^+}	$1/I_A^-$	u_{1/I_A^-}
2,0E-03	2,0E-06	2,3E-05	4,4E+04	4,9E+03	4,2E+04	4,3E+03	4,8E+04	5,7E+03
1,7E-03	1,7E-06	2,8E-05	3,6E+04	3,3E+03	3,4E+04	3,0E+03	3,8E+04	3,7E+03
1,4E-03	1,4E-06	3,0E-05	3,3E+04	2,8E+03	3,2E+04	2,5E+03	3,5E+04	3,1E+03
1,3E-03	1,3E-06	3,3E-05	3,1E+04	2,4E+03	2,9E+04	2,2E+03	3,2E+04	2,6E+03
1,1E-03	1,1E-06	3,5E-05	2,9E+04	2,0E+03	2,7E+04	1,9E+03	3,0E+04	2,2E+03
1,0E-03	1,0E-06	4,0E-05	2,5E+04	1,6E+03	2,4E+04	1,5E+03	2,6E+04	1,7E+03
9,1E-04	9,1E-07	4,0E-05	2,5E+04	1,6E+03	2,4E+04	1,5E+03	2,6E+04	1,7E+03
8,3E-04	8,3E-07	4,3E-05	2,4E+04	1,4E+03	2,3E+04	1,3E+03	2,4E+04	1,5E+03
7,7E-04	7,7E-07	4,5E-05	2,2E+04	1,2E+03	2,2E+04	1,2E+03	2,3E+04	1,3E+03
7,1E-04	7,1E-07	4,5E-05	2,2E+04	1,2E+03	2,2E+04	1,2E+03	2,3E+04	1,3E+03
6,7E-04	6,7E-07	4,8E-05	2,1E+04	1,1E+03	2,0E+04	1,0E+03	2,2E+04	1,2E+03
2,0E-04	2,0E-07	7,5E-05	1,3E+04	4,4E+02	1,3E+04	4,3E+02	1,4E+04	4,6E+02
1,0E-04	1,0E-07	8,5E-05	1,2E+04	3,5E+02	1,2E+04	3,3E+02	1,2E+04	3,6E+02
6,7E-05	6,7E-08	8,8E-05	1,1E+04	3,3E+02	1,1E+04	3,2E+02	1,2E+04	3,4E+02
5,0E-05	5,0E-08	9,0E-05	1,1E+04	3,1E+02	1,1E+04	3,0E+02	1,1E+04	3,2E+02
4,0E-05	4,0E-08	9,0E-05	1,1E+04	3,1E+02	1,1E+04	3,0E+02	1,1E+04	3,2E+02
3,3E-05	3,3E-08	9,3E-05	1,1E+04	2,9E+02	1,1E+04	2,8E+02	1,1E+04	3,0E+02
2,9E-05	2,9E-08	9,5E-05	1,1E+04	2,8E+02	1,0E+04	2,7E+02	1,1E+04	2,9E+02
2,5E-05	2,5E-08	9,5E-05	1,1E+04	2,8E+02	1,0E+04	2,7E+02	1,1E+04	2,9E+02
2,2E-05	2,2E-08	9,5E-05	1,1E+04	2,8E+02	1,0E+04	2,7E+02	1,1E+04	2,9E+02
2,0E-05	2,0E-08	9,5E-05	1,1E+04	2,8E+02	1,0E+04	2,7E+02	1,1E+04	2,9E+02
9,0E-06	9,0E-09	9,5E-05	1,1E+04	2,8E+02	1,0E+04	2,7E+02	1,1E+04	2,9E+02