Wrocaw University of Science and Technology

GENERAL PHYSICS
LABORATORY REPORT

Chair of Electronic and Photonic Metrology
ELECTRIONIC MEASUREMENTS LABORATORY

Theme of class: DETERMINATION OF SOLID STATE DENSITY

Group no: 1

Students:
1. Ivan Melnyk 275510
2.
3.

Date of class: 2023-03-14

Submission Date: 2023-03-07

Lab assistant: mgr in. Krzysztof Adamczyk

Contents

1 Introduction

1.1 Theory

Density can be measure using weight and volume. To calculate errors we can use two methods: direct and indirect.

Direct

For direct measurements we can calculate both: A and B uncertainties.

Indirect

Resistance is measured indirectly using the ammeter-voltmeter method. Figures **??**, **??** show different ways of implementing said method. In both instances, the resistance is calculated using the Ohm's law: $R = \frac{U}{I}$.

The method error is calculated using the following formulas:

- CVM: $\Delta_m R = \frac{-R_m^2}{R_V - R_m}$, $\delta_m R = \frac{-R_m}{R_V}$;
- CCM: $\Delta_m R = R_A$, $\delta_m R = \frac{R_A}{R_m - R_A}$;

The CVM circuit should be used for small resistances and the CCM circuit should be used for big resistances. The following equation describes the threshold resistance for which the choice of the circuit doesn't matter: $R_{thr} = \sqrt{R_V \cdot R_A}$.

1.2 Equipment

The following devices were used during the laboratory:

- Micrometer screw
- Calliper
- Lab Balances
- Measurement element

2 Experiment

2.1 Measuring the parameters of the object with Calliper

For the first measurement we were using Calliper and Lab Balances. First of all we measured all parameters of the given metal object. To be more precise we repeated the measurement 5 times. Then we read from the instrument documentation its uncertainties and wrote it to our table to perform calculations.

No	ϕ_{in}	$\Delta\phi_{in}$	ϕ_{out}	$\Delta\phi_{out}$
1	11.95	0.05	15.9	0.05
2	11.9	0.05	15.9	0.05
3	11.9	0.05	15.85	0.05
4	11.95	0.05	15.95	0.05
5	11.9	0.05	15.9	0.05
	h	Δh	m	Δm
1	32.8	0.05	7.92	0.01
2	32.75	0.05	7.93	0.01
3	32.75	0.05	7.93	0.01
4	32.8	0.05	7.93	0.01
5	32.85	0.05	7.95	0.01
No	ϕ_{in}	ϕ_{out}	h	m
mean	11.92	15.9	32.79	7.932
u_A	0.00075	0.00125	0.00175	0.00012
u_B	0.3441007604	0.458993464	0.9465657663	0.04579542335
u_{A+B}	0.3441015778	0.4589951661	0.946567384	0.04579558057
$\bar{V}$	2851.487655			
ρ	2.781705888			
c $(\bar{V})$	431.2854846			

Table 1: Dimensions measurements, uncertainties

Example calculations for ϕ_{in} are shown in the equations below.

$$u_B(\phi_{in}) = \sqrt{\frac{(\Delta\bar{\phi}_{in})^2}{3}} = \sqrt{\frac{(0.05 \cdot 11.92)}{3}} = 0.3441007604 \tag{1}$$

$$u(\phi_{in}) = \sqrt{u_A^2(\bar{\phi}_{in}) + u_B^2(\bar{\phi}_o)} = \sqrt{0.00075^2 + 0.3441007604^2} = 0.3441015778 \tag{2}$$

Formulas used in the calculations

- $\frac{\delta V}{\delta h} = \pi \frac{d^2}{4}$

- $\frac{\delta V}{\delta d} = 2\pi \frac{h}{4}$
- $(\frac{\delta \rho}{\delta M})^2 = (\frac{1}{V_t})^2$
- $(\frac{\delta \rho}{\delta v_t})^2 = (-\frac{M}{V_t^2})^2$
- $dx = \frac{0.05_{mm}}{2} = 0.025_{mm}$
- $\mu_a(h) = \sqrt{\frac{(h_{tot}-h_1)^2+(h_{tot}-h_2)^2+(h_{tot}-h_3)^2+(h_{tot}-h_4)^2+(h_{tot}-h_5)^2}{5(5-1)}}$
- $\mu_b(h) = \frac{dx}{2\sqrt{3}}$
- $\mu_c(h) = \sqrt{\mu_a^2(h) + \mu_b^2(h)}$
- $\mu(V_n) = \sqrt{(\frac{\delta V}{\delta h})^2 \cdot \mu^2(h) + (\frac{\delta V}{\delta d})^2 \cdot \mu^2(d)}$
- $\mu(V_{total}) = \sqrt{\mu^2(V_1) + \mu^2(V_2) + \mu^2(V_3) + \mu^2(V_4) + \mu^2(V_5) - \mu^2(V_6)}$
- $\mu_a(d)\sqrt{\frac{(d_{tot}-d_1)^2+(d_{tot}-d_2)^2+(d_{tot}-d_3)^2+(d_{tot}-d_4)^2+(d_{tot}-d_5)^2}{5(5-1)}}$
- $\mu_b(d) = \frac{0{,}05_{mm}}{2\sqrt{3}}$
- $\mu_c(d) = \sqrt{\mu_a^2(d) + \mu_b^2(d)}$
- $\mu_a(M) = \sqrt{\frac{(m_{tot}-m_1)^2+(m_{tot}-m_2)^2+(m_{tot}-m_3)^2+(m_{tot}-m_4)^2}{4(4-1)}}$
- $\mu_b(M) = 0.1_g$
- $\mu_c(M) = \sqrt{\mu_a^2(M) + \mu_b^2(M)}$
- $\mu(\rho) = \sqrt{(\frac{\delta \rho}{\delta M})^2 \cdot \mu^2(M) + (\frac{\delta \rho}{\delta V_t})^2 \cdot \mu^2(v_t)}$

2.2 Measuring the parameters of the object with Micrometer screw

In this experiment using micrometer screw instead of calliper

R_x	$R_m[]$	$R_r[]$	Accuracy	$\Delta_{res}[]$	$\Delta R[]$	$\delta R[]$	$R \pm \Delta R[]$
Positive polarity							
R_2	424.4	600	$0.8+3$	0.1	3.6952	0.870688	424.4 ± 3.7
R_4	OL	600	$0.8+3$	0.1			
D	OL	600	$0.8+3$	0.1			
R_2	420	60000	$0.5+2$	10	22.1	5.261905	420 ± 23
R_4	2650	60000	$0.5+2$	10	33.25	1.254717	2650 ± 34
D	OL	60000	$0.5+2$	10			
R_2	400	600000	$0.5+2$	100	202	50.5	400 ± 202
R_4	2600	600000	$0.5+2$	100	213	8.192308	2600 ± 213
D	OL	600000	$0.5+2$	100			
Negative polarity							
R_2	424.4	600	$0.8+3$	0.1	3.6952	0.870688	424.4 ± 3.7
R_4	OL	600	$0.8+3$	0.1			
D	OL	600	$0.8+3$	0.1			
R_2	420	60000	$0.5+2$	10	22.1	5.261905	420 ± 23
R_4	2650	60000	$0.5+2$	10	33.25	1.254717	2650 ± 34
D	42.69	60000	$0.5+2$	10	20.21345	47.349379	42.69 ± 20.22
R_2	400	600000	$0.5+2$	100	202	50.5	400 ± 202
R_4	2600	600000	$0.5+2$	100	213	8.192308	2600 ± 213
D	178400	600000	$0.5+2$	100	1092	0.612108	178400 ± 1092

Table 2: Direct resistance measurements (for: R_m – measured resistance, R_r – range, Accuracy: ± (a of reading + n – number of uncertain digits), Δ_{res} – resolution, $\Delta R, \delta R$ – limiting error)

Example calculations for $R_r = 600\,\Omega$ (R_2, positive polarity) are shown in the equations below.

$$\Delta R = \frac{a}{100} \cdot R_m + n \cdot \Delta_{res} = \frac{0.8}{100} \cdot 424.4\,\Omega + 3 \cdot 0.1\,\Omega = 3.6952\,\Omega \tag{3}$$

$$\delta R = \frac{\Delta R}{R_m} \cdot 100 = \frac{3.6952\,\Omega}{424.4\,\Omega} \cdot 100 \approx 0.870688 \tag{4}$$

2.3 Uncertainties

2.3.1 Calliper

2.3.2 Micrometer screw

For indirect measurements, we used two digital meters and resistor standard. Measurements were taken for 8 different ranges using CVM and CCM methods

Rx	V	V_r	Acc	ΔV	δV
30	4.892	6	0.3%+2	0.01668	0.3408830744
100	4.896	6	0.3%+2	0.01669	0.3408496732
300	4.897	6	0.3%+2	0.01669	0.3408413314
1000	4.898	6	0.3%+2	0.01669	0.3408329931
3000	4.899	6	0.3%+2	0.01670	0.3408246581
10000	4.899	6	0.3%+2	0.01670	0.3408246581
30000	4.899	6	0.3%+2	0.01670	0.3408246581
100000	4.899	6	0.3%+2	0.01670	0.3408246581

Table 3: Indirect resistance measurements for $E \sim 4.8\,\mathrm{V}$ (R_x – true value for resistance, V – measured voltage,V_r – range, ΔV – absolute error, δV – relative error)

I	Ir	Acc	ΔI	δI	R_m
136.909	1000	0.1+0.01	0.236909	0.1730412172	35.73176343
42.7542	100	0.05+0.005	0.0527542	0.1233895149	114.5150652
15.7777	100	0.05+0.005	0.0257777	0.1633805941	310.3747695
4.42445	10	0.05+0.02	0.00542445	0.1226016793	1107.030252
1.55186	10	0.05+0.02	0.00255186	0.1644388025	3156.856933
0.48787	10	0.05+0.02	0.00148787	0.3049726362	10041.60945
0.16289	10	0.05+0.02	0.00116289	0.7139112284	30075.51108
0.04875	10	0.05+0.02	0.00104875	2.151282051	100492.3077

Table 4: (I – circuit current, Ir – range, ΔI – absolute error, δI – relative error, R_m – measured value)

ΔR	δR	R_m +- ΔR	R_V	R_A
0.6952729034	0.5139242916	35.732+-0.696	10	0.0001
2.466725518	0.4642391882	114.6+-2.5	10	0.001
6.155519102	0.5042219256	310.4+-6.2	10	0.001
23.88751465	0.4634346724	1107+-24	10	0.01
62.4794227	0.5052634606	3157+-63	10	0.01
155.4916618	0.6457972942	10042+-160	10	0.01
285.1473195	1.054735887	30076+-290	10	0.01
403.2423945	2.492106709	100492+-410	10	0.01

Table 5: (ΔR – absolute error, δR – relative error, R_V – internal voltmeter resistance, R_A – internal ammeter resistance)

ΔmR	δmR	c	R_c	$R_c + -\Delta R$
0.0001	0.000002798638249	-0.0001	35.73166343	35.7+-0.7
0.001	0.000008732551747	-0.001	114.5140652	114.5+-2.5
0.001	0.000003221921755	-0.001	310.3737695	310.4+-6.2
0.01	0.000009033258406	-0.01	1107.020252	1107.0+-23.9
0.01	0.00000316771773	-0.01	3156.846933	3156.8+-62.5
0.01	0.0000009958572889	-0.01	10041.59945	10042+-160
0.01	0.0000003324965384	-0.01	30075.50108	30076+-300
0.01	0.00000009951011401	-0.01	100492.2977	100492+-410

Table 6: (ΔmR – systematic error, δmR – relative error c - correction factor R_c – calculated resistance)

Example calculations

$$V = \frac{\alpha \cdot V_r}{\alpha_{max}} = \frac{39.5 \cdot 7.5\,\mathrm{V}}{75} = 3.95\,\mathrm{V} \tag{5}$$

$$\Delta V = \frac{0.3}{100} \cdot V + 2 \cdot 0.001 = \frac{0.3}{100} \cdot 4.896 + 2 \cdot 0.001 = 0.016\,69\,\mathrm{V} \tag{6}$$

$$\delta V = \frac{\Delta V}{V} \cdot 100 = \frac{0.01669}{4.892} \cdot 100 \approx 0.3408830744 \tag{7}$$

$$R_m = \frac{U_r}{I_r} = \frac{4.896\,\mathrm{V}}{42.7542\,\mathrm{mA}} = 114.515\,065\,2\,\Omega \tag{8}$$

$$\delta_m R = \delta I + \delta V = -0.340\,849\,673\,2\,\% + 0.123\,389\,514\,9\,\% = -0.464\,239\,188\,2\,\% \tag{9}$$

$$\delta_m R = -\frac{R_A}{R_m - R_A} = -\frac{0.001\,\Omega}{114.515\,065\,2\,\Omega + 0.001\,\Omega} \approx 0.000008732551747 \tag{10}$$

$$c = -\Delta_m R = -(0.001\,\Omega) = -0.001\,\Omega \tag{11}$$

$$R_c = R_m + c = 114.515\,065\,2\,\Omega + 0.001\,\Omega = 114.514\,065\,2\,\Omega \tag{12}$$

CVM

Rx	V	V_r	Acc	ΔV	δV
30	4.813	6	0.3%+2	0.01668	0.346478288
100	4.814	6	0.3%+2	0.01669	0.3466555879
300	4.814	6	0.3%+2	0.01669	0.3467179061
1000	4.814	6	0.3%+2	0.01669	0.3467802243
3000	4.814	6	0.3%+2	0.01670	0.3468425426
10000	4.814	6	0.3%+2	0.01670	0.3468425426
30000	4.814	6	0.3%+2	0.01670	0.3468425426
100000	4.814	6	0.3%+2	0.01670	0.3468425426

Table 7: Indirect resistance measurements for $E \sim 4.8\,\mathrm{V}$ (R_x – true value for resistance, V – measured voltage,V_r – range, ΔV – absolute error, δV – relative error)

I	Ir	Acc	ΔI	δI	R_m
158.929	1000	0.1+0.01	0.258929	0.1629211786	30.28396328
46.1189	100	0.05+0.005	0.0561189	0.1216830844	104.3823682
15.9575	100	0.05+0.005	0.0259575	0.1626664578	301.6763277
4.85882	10	0.05+0.02	0.00585882	0.1205811288	990.7755381
1.62778	10	0.05+0.02	0.00262778	0.1614333632	2957.402106
0.48942	10	0.05+0.02	0.00148942	0.3043234849	9836.132565
0.1634	10	0.05+0.02	0.0011634	0.711995104	29461.44431
0.04927	10	0.05+0.02	0.00104927	2.129632636	97706.51512

Table 8: (I – circuit current, Ir – range, ΔI – absolute error, δI – relative error, R_m – measured value)

ΔR	δR	R_m +- ΔR	R_V	R_A
0.5945032389	0.5093994666	30.3+-0.6	10	0.0001
2.228779607	0.4683386722	104.4+-2.3	10	0.001
5.922371182	0.5093843639	301+-6	10	0.001
21.19934675	0.4673613531	991+-22	10	0.01
58.18497537	0.5082759058	2957+-60	10	0.01
151.0541421	0.6511660275	9836+-160	10	0.01
278.2432642	1.058837647	29461+-280	10	0.01
394.5386408	2.476475179	97707+-395	10	0.01

Table 9: (ΔR – absolute error, δR – relative error, R_V – internal voltmeter resistance, R_A – internal ammeter resistance)

ΔmR	δmR	c	R_c	$R_c + -\Delta R$
30.28406328	0.00000330208861	-3.028396328	27.25556695	27.3+-0.6
104.3833682	0.000009580253808	-10.43823682	93.94413136	94.0+-2.3
301.6773277	0.000003314821956	-30.16763277	271.508695	272+-6
990.7855382	0.00001009320532	-99.07755381	891.6979843	892+-22
2957.412106	0.000003381357507	-295.7402106	2661.661895	2662+-60
9836.142565	0.000001016660776	-983.6132565	8852.519309	8853+-160
29461.45431	0.0000003394267874	-2946.144431	26515.29988	26515+-280
97706.52512	0.0000001023473308	-9770.651512	87935.86361	87936+-400

Table 10: (ΔmR – systematic error, δmR – relative error c - correction factor R_c – calculated resistance)

3 Conclusion

3.1 Direct measurement

Linear resistor behave similarly for both polarities and the meter only displayed an "OL" error message when the chosen range was too small.

A diode is constructed to only allow current to flow in one direction and, ideally, has infinite resistance in the other direction. We believe that is the reason why the meter displayed an "OL" message for the positive polarity and numerical values for the negative polarity. It remains unclear to us why the numerical values of the same diode differed for different ranges, with one "OL" message within them. The most likely explanations are either human error or the meter influencing the component.

3.2 Indirect measurement

Digital measurements showed the expected circuit behavior - once the threshold resistance had been reached, the results became unreliable for incorrectly chosen circuits. Analog measurements didn't seem to be influenced by an incorrect choice of circuit and returned correct values regardless of the resistance threshold; we do not yet know why.