ECEN204	**Lab 1**

Instrumentation – DC Measurements: Report

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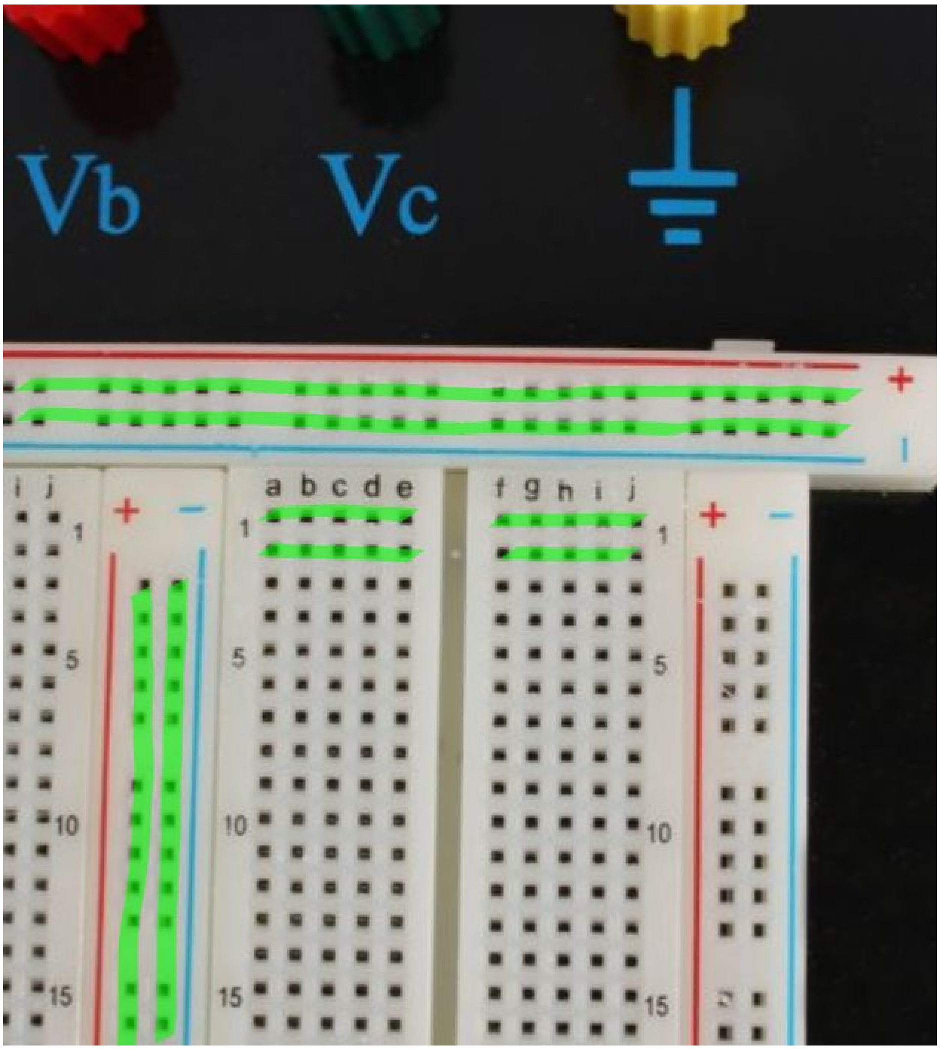
Complete a report on Lab 1 by providing the following results from your measurements and adding your conclusions where requested. Also insert graphs and tables as appropropriate.

This should be handed in at the start of Lab 2.

1. Continuity with DMM (Section 3.1)

Show a basic sketch of your breadboard and indicate the internally electrically connected pattern on the board.



2. Current and voltage measurements (Section 2.1 and Section 3.2)

(a) Show your calculated currents and voltages from Section 2.1 for the circuit in Figure 8.

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)
16.25	6.025	10.22	1.625	3.375	3.375	26.4	20.3	34.5

(b) Now show your measured values from Section 3.2 for the actual circuit:

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)
16.17	6	10.16	1.62	3.337	3.337	26.14	19.88	33.7

(c) How does the calculated and measured values of current, voltage and power compare? List the % difference between these two sets of values in the table below:

% Difference between calculated and measured:

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)
0.5	0.4	0.58	0.3	1.12	1.12	0.98	2	2.3

(d) Can you explain why the observed values would differ from the calculated values ?

The meter itself, while in an ideal case has zero or infinite resistance for ammeter, and voltmeter respectively, is not ideal. So when measuring amps, the ammeter does in fact alter the total circuit resistance ie decreasing the current, and for volts it does in fact draw some current through its branch thus decreasing the voltage drop across the measured branch.

3. Internal resistance of ammeter and voltmeter (Section 2.3)

(a) Show the expected voltages calculated across R_A and R_B in Figure 10 for the different values of R_A and R_B.

R_A	R_B	V_{RA}	V_{RB}
1 kΩ	10 kΩ	0.27	2.72
100 kΩ	1 MΩ	0.27	2.72

(b) Now assume that these voltages are measured with voltmeters with resistances (i) R_M = 10 kΩ, (ii) R_M = 1 MΩ, and (iii) RM = 10 MΩ. Use a table to show your expected voltages across R_A and R_B for the different resistances as dependant on the different values of R_M.

R_M	R_A	R_B	V_{RA}	V_{RB}
10 kΩ	1 kΩ	10 kΩ	*250mV*	*2.5V*
10 kΩ	100 kΩ	1 MΩ	*27mV*	*250V*
1 MΩ	1 kΩ	10 kΩ	*272mV*	*2.72V*
1 MΩ	100 kΩ	1 MΩ	*250mV*	*2.5V*
10 MΩ	1 kΩ	10 kΩ	*273mv*	*2.73V*
10 MΩ	100 kΩ	1 MΩ	*270mV*	*2.7V*

(c) How does the accuracy of the measurements depend upon the relationship between R_M and R_A and R_B? What value of R_M is necessary for the measured voltage to be accurate? Explain the influence of R_M in obtaining accurate measurements.

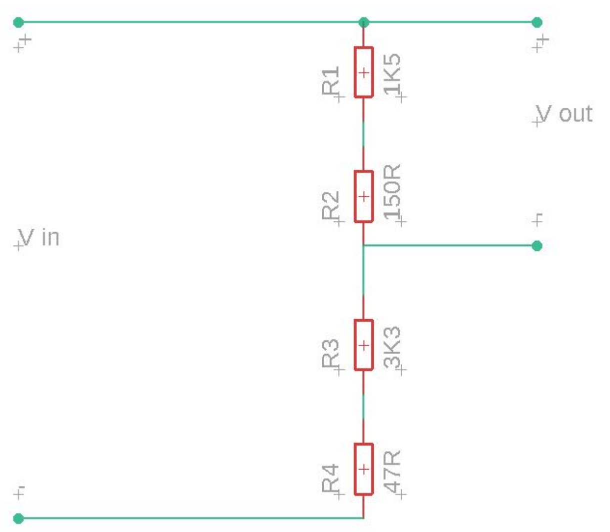
R_M must be significantly larger than that component across which it is taking measurement of. As there should ideally be no current draw through the meter. This is seen with R_m = 10k and $R_{a,b}$ = 100K, 1M; a clear outlier.

5. Voltage divider circuits (Section 3.3)

(a) Write an expression for the voltage V_{out} observed in Figure 9 in terms of R_1, R_2 and the supply voltage V_{in}.

$$V_{out} = V_{in}\frac{IR_2}{I(R_1+R_2)} = \frac{V_{in}R_2}{R_1+R_2}$$

(b) Sketch the circuit for the voltage divider design in Section 2.2 (b). Indicate the values of all resistors in your design.



(c) Show the results of the test of your voltage divider (Section 3.3) as a function of different values of input voltage V_{in}.

V_{in} (V)	1	2	3	4	5
V_{out} (V)	0.303	0.615	0.902	1.193	1.51
V_{in}/V_{out} %					

(d) Show the results of the test of your voltage divider (Section 3.3) for an input voltage V_{in} = 3 V and different values of the load resistance R_L.

R_L	100 Ω	500 Ω	1 kΩ	5 kΩ	10 kΩ	50 kΩ	100 kΩ
V_{out} (V)	0.08	0.312	0.4	0.82	0.901	0.979	0.99

(e) Explain your observations in (d) above and how this may limit the use of such a voltage divider circuit as a stable voltage source in a circuit.

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4. Resistance measurement with a DMM (Section 3.4)

(a) Show your resistance measurements of different resistors and also the % difference from the indicated value.

Stated resistor value	1 Ω	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ
Measured resistor value	1.1	10	100.7	0.999k	10.11k	98.7k	0.99M
% Difference	10	0	0.7	0.1	1.01	1.3	1

(b) Comment on the observed difference vs. the expected tolerance from the resistor.

All these resistors were at most had a 10% tolerance, most 5%. All were well within these tolerances and the 1R was just on the edge, but it should be considered it's a lower resistance value and was measured on a 2 probe meter.

5. Measuring low resistances (Section 3.5)

(a) Compare the resistance value obtained by using the Fluke DMM to that obtained from the four wire measurement with the benchtop instrument.

2 Wire Fluke Measurement	
4 Wire Measurement	*0.185, 0.186, 0.183, 0.185, 0.184* ***0.1846 0.185 (3sf)***

(b) Explain how a 4 wire measurement produces a much more accurate value for low resistances.

Basically this method remove the resistances and electrical contributions of the meter/probes/contacts themselves from the measurement. As with simple 2 probe meter the leads and contacts are essentially in series with the measured resistor. The 4 wire isolate the resistor and evaluates the resistance according to ohm's law.

(c) It is given that the copper wire used as the low resistance sample is 1.34 meter long and has a diameter of 0.4 mm. Use your four wire resistance measurement to calculate the conductivity of the copper wire. How does your calculated value compare to the conductivity values for Cu that are quoted in the literature ? [Reference the values for σ_{Cu} that you can find in the literature].

σ = L/RA

= 134cm / ***0.185 ohm * 1.26e-3cm²***

= 574860.5749 (Ωcm)$^{-1}$

=5.74x10^{-5} /Ωcm

These are close in comparison to value more accurately measured;
Pure copper at 5.96×10^{7} 1/Ωm [1] and annealed copper (of which I assume more closely represents the wire measured) at 5.80×10^{7} 1/Ωm [2]

[1] Douglas Giancoli (2009) [1984]. "25. Electric Currents and Resistance". In Jocelyn Phillips (ed.). Physics for Scientists and Engineers with Modern Physics (4th ed.

[2] Copper wire tables : United States. National Bureau of Standards

(c) Calculate what the resistance will be for a Si wire of the same dimensions as the copper (assuming we could draw Si into a wire !) if it is given that undoped (intrinsic) Si will have a carrier density of 1 x 10^{10} cm^{-3} and electron and hole mobilities μ_e = 1350 cm^2.V^{-1}.s^{-1} and μ_h = 450 cm^2.V^{-1}.s^{-1} at room temperature.

$\sigma = N_e e \mu_e + N_h e \mu_h$

$\sigma = 10^{10}cm^{-3} \times e \times 1350\ cm^2V^{-1}s^{-1} + 10^{10}cm^{-3} \times e \times 450\ cm^2.V^{-1}.s^{-1}$

$\sigma = 10^{10}cm^{-3} \times e \times (1350\ cm^2V^{-1}s^{-1} + 450\ cm^2.V^{-1}.s^{-1})$

$\sigma = 2.88 \times 10^{-6}\ 1/\Omega cm$

resistivity = $3.47 \times 10^{5}\ \Omega cm$

$R = 3.47 \times 10^{5}\ \Omega cm * 134cm / 1.26 \times 10^{-3}\ .cm^2$

$R = 3.69 \times 10^{10} \Omega$

6. Additional Questions

6.1 Calculation of conductivity from an I-V graph

The "lead" in an old fashioned pencil is of course not lead, but manufactured from a composite that is a mixture of clay/polymer and graphite. The more graphite the composite contains the darker the writing will be and the "softer" the pencil is. Figure 1 below gives an indication of this softness/hardness scale and how this will influence the colour of the writing from the pencil.

Hardness	9H	8H	7H	6H	5H	4H	3H	2H	H	F	HB	B	2B	3B	4B	5B	6B	7B	8B	9B
Carbon (%)	41	44	47	50	52	55	58	60	63	66	68	71	74	76	79	82	84	87	90	93
Clay (%)	53	50	47	45	42	39	36	34	31	28	26	23	20	18	15	12	10	7	5	2

Figue 1: The influence of the % of graphite loading in pencil lead on the softness of the lead.

However, graphite (a form of carbon) is an electrical conductor and adding this material to the clay will also make the pencil lead electrically conductive. We can thus view the pencil lead as a resistor with the value of resistance dependant on the % graphite content.

In an industrial control process in a pencil factory a four wire resistance measurement is used to measure the resistance of pencil lead and from these measurements calculate the approximate graphite content. The circuit for the measurement is shown in Figure 2, and the voltage drop over the pencil lead is measured for different values of the current through the pencil lead.

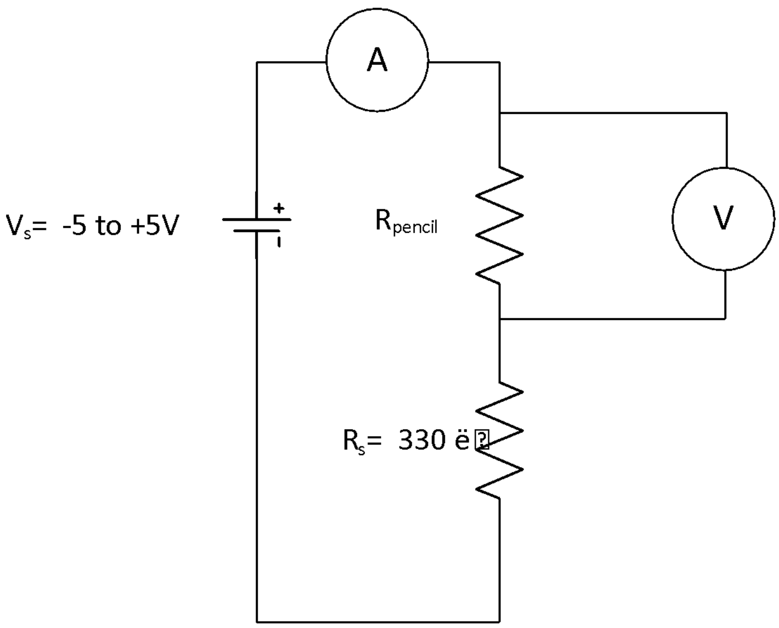


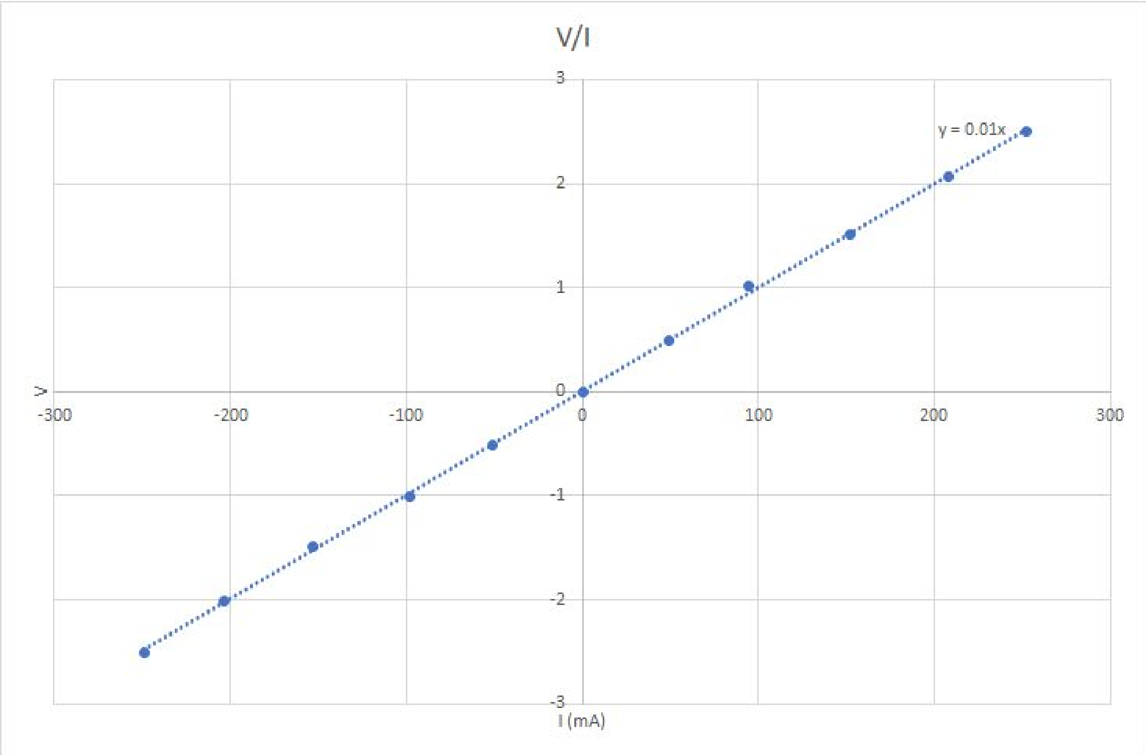
Figure 2: Circuit for measurement of pencil lead resistance by measuring the I-V curve.

The results from this current – voltage measurement is shown below.

Current (mA)	Voltage (V)
-51	-0.511
-98	-1.005
-153	-1.49
-204	-2.001
-249	-2.51
0	0
49	0.497
94	1.015
152	1.509
208	2.07
252	2.508

The pencil lead under measurement is 13.5 cm in length and have a circular cross section with a diameter of 1.8 mm. We must now use this data to calculate the electrical conductivity of the pencil lead in order to use it as a quality control measure in the manufacturing process.

(a) Use the measured data and plot a graph of voltage vs current. Insert your graph below.



(b) Use this graph to calculate the electrical resistance of the pencil lead. Clearly show your method.

Using the linear trendline fit to get an average gradient (V/I), I got a resistance of **0.1×10^3 Ohms ⇒ 10 Ohms**

(c) Use this resistance value as well as the geometry of the pencil lead (length, cross sectional area) to calculate resistivity and conductivity of this material.

p = RA/L
p = 10 Ω *(pi*0.09^2)cm^2/13.5cm
p = 0.018 Ω

(d) Discuss at least two reasons why a series of I-V measurements and a calculation of the resistance from these measurements may be better than a single measurement as performed by a DMM.

A series of measurements will result in a more accurate/reliable final figure due to

a) outliers can be excluded
b) resistance can be calculated from averaged gradient

(e) What do you think is the purpose of the 330 Ω resistor in the measurement circuit as shown in Figure 2.

To prevent a large current draw from the supply through the pencil, which would have heated very quickly.

6.2 Design of a __bipolar voltage signal:__ You must design a circuit that will supply a variable -5V to +5V output that can be used for a reference signal. To do this you are given two 9V batteries, a 10 kΩ potentiometer and you have access to a full range of resistors. Sketch your circuit design.

A potentiometer is a variable resistor, typically with three contacts as in the sketch below. The third contact, called the wiper, can be manually moved to make contact at any point with the fixed resistive strip. As the point of contact changes, the resistances R_{13} and R_{23} will also change. If the wiper moves closer to contact 2, R_{13} will increase while R_{23} will decrease. The opposite will happen when the wiper moves closer to contact 1. The resistance R_{12} will always be constant.

By turning the potentiometer knob you should now create an output voltage that will vary between – 5V (potentiometer in the one extreme position) to + 5V (potentiometer in the opposite extreme position).

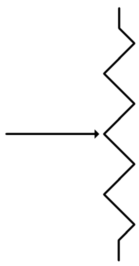


Figure 3: A potentiometer

(a) Sketch the circuit you will construct and clearly show the position of the output voltage. Also show the values of all resistors that you will use in the construction of your circuit.

(b) Calculate the power consumption of your circuit assuming that no load is connected to it.