E&M Lab
Introduction to Multimeter Measurements and Uncertainties

1. Objectives

- The general aim of this lab is to introduce you to the proper use of a digital multimeter with its associated uncertainties and to show how to propagate those uncertainties. While this lab gives instructions specific to the METEX M-3800 multimeter, the principles of use and the rules for determining and propagating uncertainties apply to all multimeters regardless of manufacturer or model.

2. Material

- Parallel circuit board (3 resistors); multimeters (2); regulated power supply; wires.

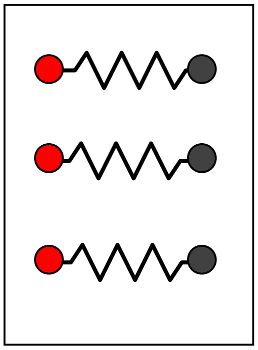

Figure 1: Parallel circuit board

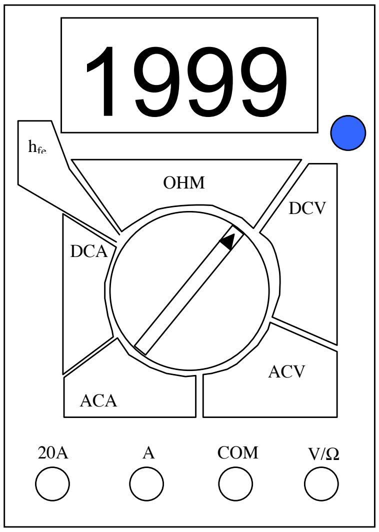

Figure 2: METEX M-3800 Multimeter

3. The Multimeter

The METEX M-3800 multimeter can measure resistance (any setting in the OHM range except for the setting with a musical note), direct current voltage (DCV), alternating current voltage (ACV), alternating current (ACA), and direct current (DCA). The transistor mode (blue circle and hfe setting) is not used in this course. The main display is referred to as a 3 1/2 digit display. This means that only the last three digits can take-on any value; the leading (most significant) digit can only be a blank, a ‘0’, or a ‘1’. A floating decimal point can appear before any of the digits; its position depends on the chosen setting. If the multimeter reads only a single digit ‘1’ in the leftmost position with no digits following, then the setting is too low (the value being measured is beyond the maximum value at the current setting). For example, at the 200 Ω setting, the maximum value the multimeter can read is 199.9 Ω. To read values of 200 Ω or higher, one must set the dial to a higher range.

The multimeter also has four ports. The ‘COM’ port is always connected whether the multimeter is used as an ohmmeter (OHM), as a voltmeter (DCV or ACV), or as an ammeter (DCA or ACA).

4. Using the Multimeter as an Ohmmeter:

To use the multimeter as an ohmmeter, it must be connected only to a single resistor or set of resistors (there can be no circuit elements other than resistors and wires). The ‘V/Ω’ and ‘COM’ ports must be connected across (in parallel to) the resistance one wants to measure, as shown in Figure 3 below.

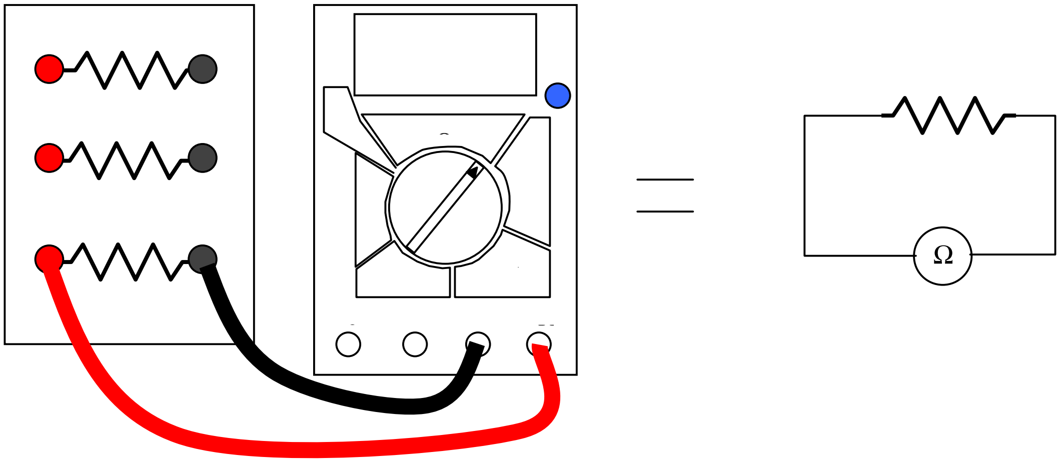

Figure 3: Measuring the resistance of a single resistor.

Measure the resistance of each of the three resistors in turn and take note of the measurement in your log-book.

For example, if the ohmmeter is set to the 2 kΩ setting and the display reads ‘ 0.122’, then the best estimate of the measurement from the multimeter is 0.122 kΩ or 122 Ω.

5. Uncertainties on Measurements:

Now that you have measured the resistances of all three resistors, it is important to note that the measurements are incomplete. All you have is the best estimate that the multimeter can give but this estimate has a range of possible values due to random and systematic factors. Consider the table on the very last page. It states that for a range setting of 2 kΩ, the uncertainty in the measurement is ± 0.5% ± 1.

The ± 0.5% is a relative or percent uncertainty. It effectively states that on the 2 kΩ setting, there is an uncertainty of at least ± 0.5% of the reading. This uncertainty must be converted into an absolute uncertainty in order to properly quote the measurement. On a reading of 0.122 kΩ, 0.5% is 0.00061 kΩ which must be rounded to as many decimals as the reading. Therefore, the reading is actually—so far—just simply 0.122 ± 0.001 kΩ = 122 ± 1 Ω.

The last part of the '± 0.5% ± 1', that is the ± 1, represents the absolute uncertainty in the last digit. The last column of the table on the last page indicates that at the 2kΩ setting, the last digit has a size of 1 Ω. Therefore, the ± 1 represents an absolute uncertainty of ± 1 Ω (at the 20 kΩ setting the ± 1 represents an absolute uncertainty of ± 10 Ω, and so on) and the reading finally becomes 122 ± 1 ± 1 Ω.

6. Adding Uncertainties:

Absolute uncertainties usually add numerically just like regular numbers do. So a measurement like 122 ± 1 ± 1 Ω becomes 122 ± 2 Ω (the ± 1 ± 1 were simply added together). The final, proper quote, of the measurement is therefore 122 ± 2 Ω.

Do this in your log-book now for all three resistors you measured.

This process of adding uncertainties also works when you add or even subtract measurements. Whether measurements are added or subtracted, the absolute uncertainties add. For example, consider the circuit in Figure 4 below.

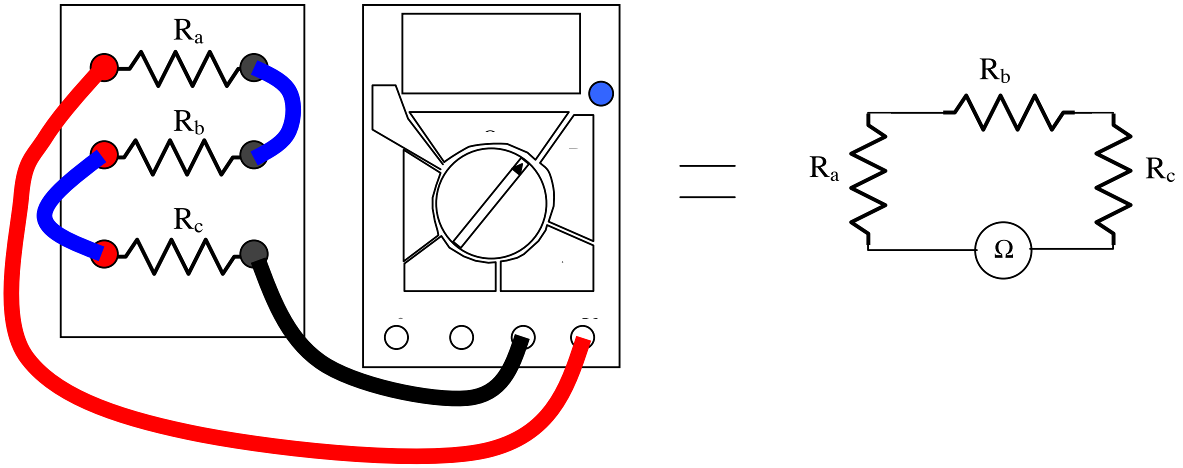

Figure 4: Three resistors in series.

In this example we shall use $R_a = 122 \pm 2\ \Omega$, $R_b = 218 \pm 2\ \Omega$, and $R_c = 485 \pm 3\ \Omega$ (all measurements with their uncertainties obtained as explained above). Resistors in series add their resistances so the theoretical sum of the three resistances should be 122 Ω + 218 Ω + 485 Ω = 825 Ω with an uncertainty of ± 2 Ω ± 2 Ω ± 3 Ω = ± 7 Ω; in other words, 825 ± 7 Ω.

But what if the direct measurement with the ohmmeter, in this example, gives 831 ± 5 Ω (again obtaining the uncertainties according to the table on the last page)?

7. Comparing Results:

In the example above we have two experimental results for the equivalent resistance of three resistors in series: 825 ± 7 Ω, by applying theory to three resistances that were measured independently, and 831 ± 5 Ω, by directly measuring the equivalent resistance of the three resistors in series.

You can easily conclude whether or not there is agreement between the two values. All you have to do is compare the range of possible values for the two results (825 ± 7 Ω means 818 Ω to 832 Ω and 831 ± 5 Ω, means 826 Ω to 836 Ω). If there are values in both ranges that overlap, then you can say that the two results are in agreement and discuss the relevance of that agreement in your lab report's conclusion; otherwise you must acknowledge the disagreement and explain in the conclusion what might logically account for—with well reasoned arguments—the disagreement.

For this log-book lab activity: measure your equivalent resistance for the three resistors (uncertainties and all); compare it with the theoretical sum of the three individual resistances (uncertainties and all); and make a statement, with an explanation, about agreement or disagreement.

Henceforth, the term ***measure*** will invariably mean: OBTAIN THE BEST ESTIMATE AND ITS UNCERTAINTY; NO MEASUREMENT IS COMPLETE WITHOUT ITS UNCERTAINTY!

8. Using the Multimeter as a Voltmeter:

To use the multimeter as a voltmeter, the 'V/Ω' and 'COM' ports must be connected across (in parallel to) the part of the circuit for which one wants to measure the voltage. If the multimeter reads a positive value, then the point in the circuit to which the 'COM' port is connected is at a lower voltage than the point to which the 'V/Ω' port is connected; for negative readings, the 'COM' port is at a higher voltage. Figure 5 below shows the next circuit you must wire.

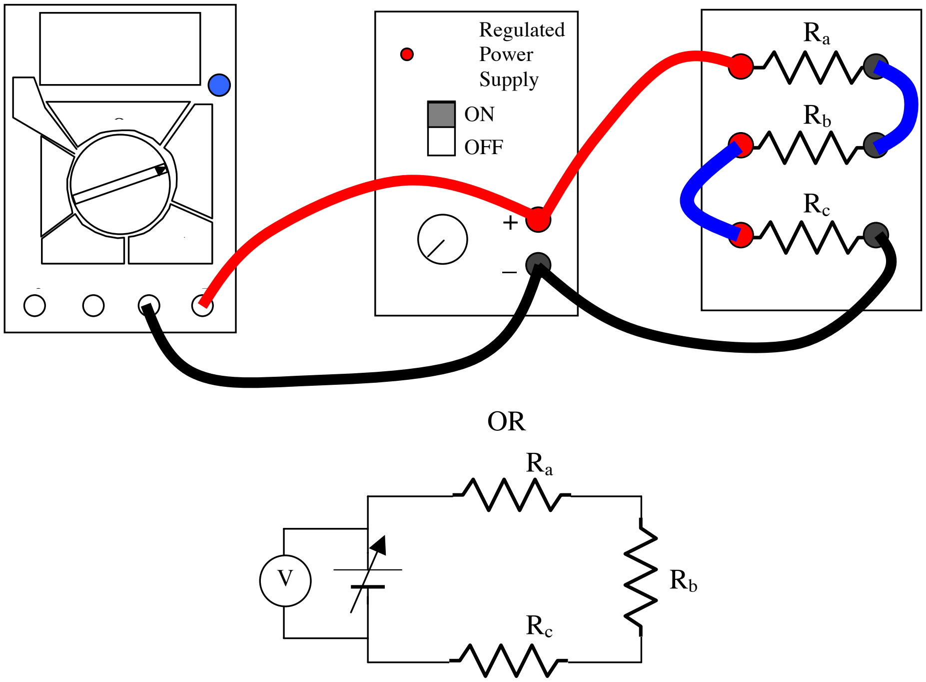

Figure 5: Circuit for voltage measurement.

In the circuit from Figure 5, the multimeter is connected as a voltmeter. As wired, it can measure the voltage across the terminals of the variable power supply (also known as a regulated power supply); this would also correspond to the total of the voltages across each resistor (the voltage across the entire resistance of the three).

For this log-book lab activity:

- ***set the voltage of the power supply as close to 10.00 V as you can with the multimeter at the 20 V DCV setting;***
- ***measure the actual value you obtain (always with uncertainties and all);***
- ***remove the voltmeter from the power supply without disturbing the rest of the circuit and connect it across just one of the resistors;***
- ***measure the voltage across that resistor;***
- ***repeat the measurement for the two other resistors; and***
- ***verify the claim that the voltage across the power supply (approximately 10.00 V) is also the sum of the voltages across each resistor.***

9. Using the Multimeter as an Ammeter:

To use the multimeter as an ammeter, the ‘A’ and ‘COM’ ports must connected into (in series within) the branch of the circuit for which one wants to measure the current through. If the multimeter reads a positive value, then positive current is flowing into the ‘A’ port of the multimeter and leaving from the ‘COM’ port (notice the difference: it isn’t the same principle as for a voltmeter); for negative readings, positive current is flowing into the ‘COM’ port and leaving from the ‘A’ port.

This wiring of an ammeter is a bit more challenging than connecting an ohmmeter or voltmeter and requires that a single wire in the existing circuit be replaced by the ammeter and two wires. Figure 6 below shows the circuit of Figure 5 with the ammeter placed between resistors R_a and R_b.

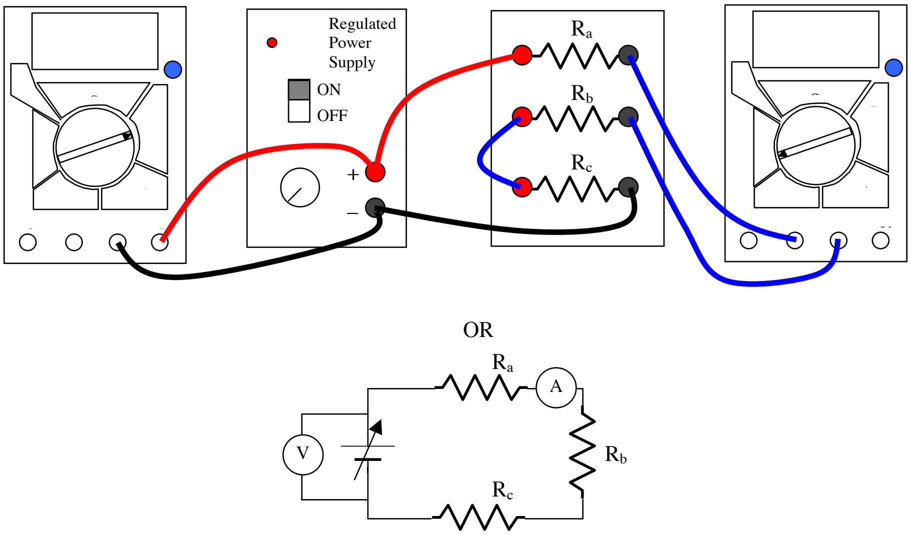

Figure 6: Circuit for voltage and current measurement

Theory predicts that the current should be the same no matter where the ammeter is placed (whether it is between R_a and R_b, between R_b and R_c, between R_c and the negative terminal of the power supply, or between the positive terminal of the power supply and R_a.

For this log-book lab activity:

- ***wire the circuit as shown in Figure 6 and turn on the ammeter with the dial set to the 20 mA DCA setting or 200 mA DCA setting (you will have to find out which one is better for you);***
- ***set the voltage of the power supply as close to 10.00 V as you can with the voltmeter dial set to the 20 V DCV setting and measure that voltage;***
- ***measure the current between resistors R_a and R_b;***
- ***move the ammeter so it is between R_b and R_c and re-measure the current;***
- ***move the ammeter so it is between R_c and the power supply and re-measure the current;***
- ***move the ammeter so it is between the power supply and Ra and re-measure the current; and***
- ***verify the claim that all the currents are the same.***

10. Finding the Average of a Set of Measurements:

You should now have four current values that are supposed to be all the same. When a set of measurements is expected to be a single value, it is convenient to take the average of the set. For example, consider the following four currents: 12.09 ± 0.07 mA, 12.11 ± 0.07 mA, 12.04 ± 0.07 mA, and 12.13 ± 0.07 mA. To properly calculate the average with uncertainties, you would first calculate the average normally (which works out to 12.09 mA in this example). The uncertainty on this average would then simply be the highest measurement minus the lowest measurement and that result divided by the number of measurements:

$$\frac{12.13-12.04}{4}=0.02$$

Therefore, the average of the above example would be 12.09 ± 0.02 mA.

Find your own average for the four currents you obtained previously.

11. Multiplying and Dividing Uncertainties:

A resistance, R, that satisfies Ohm's Law can also be obtained through the relation $\Delta V/I = R$, where ΔV is the voltage across the resistance and I is the current through the resistance. For the example given above with Figure 6, suppose that the average current I = 12.09 ± 0.02 mA was obtained with a constant voltage measured by the voltmeter of 9.98 ± 0.06 V. The equivalent resistance of the three resistors is then

$$\frac{\Delta V}{I}=\frac{9.98\pm 0.06\text{ V}}{(12.09\pm 0.02)\times 10^{-3}\text{ A}}=\frac{9.98\text{ V}\pm 0.61\%}{0.01209\text{ A}\pm 0.17\%}=825\,\Omega\pm 0.78\%=825\pm 6\,\Omega\,.$$

The process is very simple although perhaps a tiny bit tedious: when multiplying or dividing, it is the relative (percentage) uncertainties that add. So, the first step is to convert the absolute uncertainties into percentages (0.06 V of 9.98 V is 0.61%, and so on). The next step is to perform the actual operation normally (9.98 V divided by 0.01209 A is 825 Ω). Then, the relative uncertainties add whether you multiply or divide (0.17% and 0.61% add to 0.78%). Finally, the resultant relative uncertainty is converted into an absolute uncertainty (0.78% of 825 Ω is 6 Ω).

To finish this log-book lab activity:

- ***perform the above calculations with your own measurements;***
- ***compare the newly obtained resistance with the other two values from the first comparison; and***
- ***make a statement, with an explanation, about agreement or disagreement of all three values of the equivalent resistance.***

Table for determining uncertainties on multimeter readings (METEX M-3800)
(excludes natural fluctuations during measurement)

FUNCTION	RANGE	Accuracy (second number refers to uncertainty in last digit)	Resolution (last digit)
DC VOLTAGE	200 mV	± 0.5% ± 1	100 µV
	2 V		1 mV
	20 V		10 mV
	200 V		100 mV
	1000 V		1 V
AC RMS VOLTAGE	200 mV	± 1.2% ± 3	100 µV
	2 V	± 0.8% ± 3	1 mV
	20 V		10 mV
	200 V		100 mV
	700 V	± 1.2% ± 3	1 V
DC CURRENT	200 µA	± 0.5% ± 1	0.1 µA
	2 mA		1 µA
	20 mA		10 µA
	200 mA	± 1.2% ± 1	100 µA
	2 A		1 mA
	20 A	± 2.0% ± 5	10 mA
	20 µA		10 nA
AC RMS CURRENT	200 µA	± 1.0% ± 3	0.1 µA
	2 mA		1 µA
	20 mA		10 µA
	200 mA	± 1.8% ± 3	100 µA
	2 A		1 mA
	20 A	± 5.0% ± 7	10 mA
	20 µA		10 nA
RESISTANCE	200 Ω	± 0.5% ± 3	0.1 Ω
	2 kΩ	± 0.5% ± 1	1 Ω
	20 kΩ		10 Ω
	200 kΩ		100 Ω
	2 MΩ		1 kΩ
	20 MΩ	± 1.0% ± 2	10 kΩ