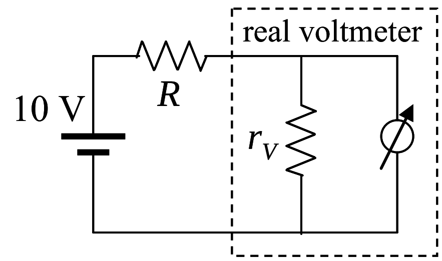
Lab #1: Electrical Measurements I

Goal: Learn to measure electrical quantities; investigate the properties of electrical meters, batteries and power supplies.
Equipment: Batteries (dry cells), digital multi-meters (DMM), assorted resistors and variable resistor bank, regulated DC power supplies.

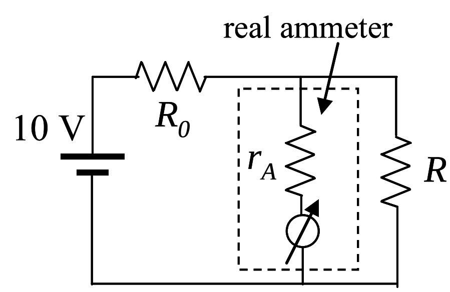
1 Voltmeter



When we want to know the voltage between two points, we connect a voltmeter (DMM) and read off the result. We like to think that this has no effect on the circuit we are studying, but this is not strictly true. A 'real' voltmeter always draws *some* current and thus represents a (small) load on the circuit. Instead of having infinite internal resistance, the instrument acts as if there is some finite resistance r_V in parallel, as shown in the figure on the right.
In order to measure the internal resistance r_V of your voltmeter, set up a circuit as shown in the figure. The voltage U is provided by a DC power supply. The voltmeter is connected in series with a resistor box that provides the variable R. As R is increased, the reading of the instrument decreases. When $R = r_V$, the reading is exactly half of what it was with $R = 0$, since the voltage drop across both resistors is now the same (hint: r_V is large, some where between 2 and 20 MΩ). Estimate the uncertainty of your result.
For future reference, record the make and the serial number of your DMM and list its the internal resistance r_V .

2 Ampère meter

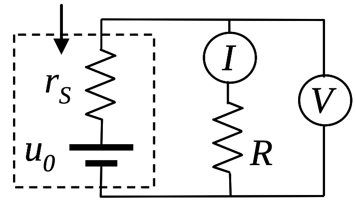
When you want to know the current that flows through a wire, you interrupt the wire and insert an Ampère meter (short, 'ammeter'). The current now flows through the instrument. The circuit is unaffected by this only if the resistance of the ammeter is zero. This is never strictly true, as a real ammeter has a (small) internal resistance r_A, as shown in the figure on the right.
In order to determine r_A, set up a circuit as shown in the figure. The purpose of the resistor R_0 is to limit the current in the circuit (say, to 50 mA). A resistor box provides the variable resistor R. Start out with a large R and decrease its value. Some of the current then flows through R and the value indicated by the meter decreases. When $R = r_A$, the reading is exactly half of what it was with $R = \infty$. Determine rA and estimate the uncertainty of your result.



For future reference, record the make and the serial number of your DMM and list its the internal resistance r_A when it is used as an ammeter.

3 Voltage source (battery)

A battery is a device that produces a voltage difference between its poles. When a 'load' resistor R is connected between these poles, a current I flows. As we make R smaller, the current cannot grow indefinitely, and the voltage V across the battery drops. That is, the battery behaves as if there is an 'output resistance' r_S inside the battery that limits the current flow.



In order to measure r_S, connect a variable load R (resistor box) and a voltmeter across the battery as shown in the figure on the right. In addition, insert a second DMM as a current meter in the circuit to measure the current I through the load resistor. If R is very large, I = 0 and $V=u_0$.

Start at a large load R (kΩ) and work your way down until I has become a few mA. Continue till you draw about 50 mA. Be aware that a small R means a large current, which alters the battery irreversibly. Be reluctant to apply small loads and if you do, only for the duration of the reading.

Assuming that the ammeter has no internal resistance and the internal resistance of the voltmeter is infinite, show that

$$\frac{1}{V} = \frac{1}{u_0}\left(\frac{r_S}{R} + 1\right) \tag{1}$$

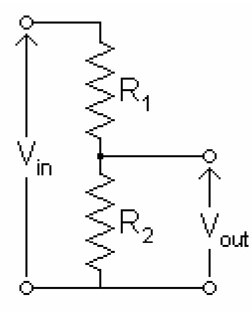
Plot $1/V$ versus $1/R$, and determine r_S from a straight-line fit to your data. Estimate the error.

Discuss if and how the internal resistances r_V and r_A of the voltmeter and the ammeter affect your measurement.

4 Voltage source (regulated power supply)

A regulated power supply is constructed to keep the voltage constant. In other words, its internal resistance is much smaller than that of a battery. Thus, as we lower the load resistance R, the voltage V changes only very little. Lowering R too much blows the fuse of the supply.

To measure a small *change* of a voltage, it is better to measure not relative to ground, but relative to a fixed 'reference' voltage that is of the size of u_0. One then can use the DMM on a more sensitive scale, to observe small changes of V.



A useful method to generate a reference voltage is to use any DC power supply followed by a 'voltage divider'. A voltage divider (see figure on the right) consists of two (or more) resistors in series. The input voltage, V_{in}, is applied across the complete resistor chain. A tap between the resistors in the chain provides an output voltage V_{out} that is a fixed fraction of the input voltage.

Construct such a voltage divider by connecting R_1 = 10 kΩ and R_2 = 4.7 kΩ in series across the +15V power supply of your workstation. The voltage V_{out} across R_2 now represents a (divided) 'power supply' and can be used as a reference.

5 Output Resistance of a Voltage Divider (optional)

The voltage V_{out} across R_2 of the voltage divider you have constructed in sect.4 represents a (divided) 'power supply'. Find the output resistance r_S of this 'power supply'. Connect a load resistor R across R_2. Measure the voltages across resistor R (or R_2) and the current through the load resistor for R = 3.3, 6.8, 10, 33, 100 kΩ, and ∞. Show analytically that r_S equal the resistance of R_1 and R_2 in parallel. Compare the result to the measurements of the +5V power supply of your workstation, and discuss the result.

6 Summary

List the values for the internal resistances that you have measured in a summary table. These are typical values that represent the departure of real from ideal devices that you may memorize for future reference.