Experiment Name: Electric_Current_and_Ohms_Law

Overview

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Fundamental Concepts in Electrical Engineering Lab1 - Electric Current and Ohms Law

Objectives

- Learn the fundamental physical mechanisms of current flow in electric circuits
- Learn the difference between conventional current and microscopic flow of charged particles
- Learn Ohm's Law
- Learn how to build a simple electric circuit
- Learn how to use a power supply and oscilloscope to perform electrical measurements
- Learn how to process the measurement results to prove Ohm's Law

Components

- Resistors: 1Ohm (1%, 0.25W), and 100Ohms (10%, 0.5W)
- Circuit prototyping breadboard
- Electric wires

Equipment

- Adjustable power supply (at least 0 - 5V voltage range, and 0.5A maximum current)
- Tektronix TBS 1202B-EDU Oscilloscope

Theory

1. Electric Current

Let's first clarify what electric current is. In order to have electric current we need a closed-loop circuit made at least by a voltage source, a conductive path, and a load. But what is a voltage source? A very common voltage source is a battery, so let's look at how batteries generate electricity.

The question we try to answer is how does a battery create a positive charge at one terminal and a negative charge at the other terminal? This happens through chemical reactions, which can be of many types so instead of going in more details on the chemistry part I propose to use a modeling approach. We can imagine these chemical reactions like some kind of "motor" or "pump" that pulls electrons from one of the two metallic terminals of the battery and pushes them towards the other terminal. This mechanism stabilizes when the voltage between the two terminals reaches a predefined value, for example 1.5V in most common batteries. This model can be visualized in the figure below:
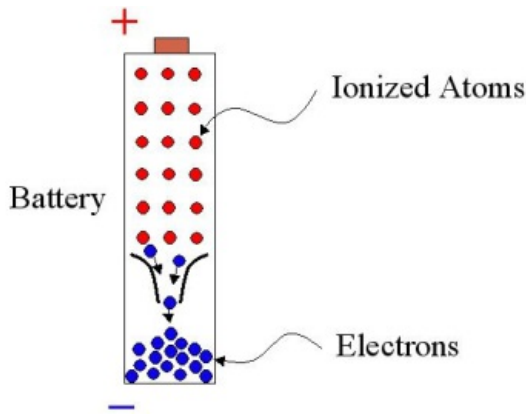
At 1.5V the "electrons" pump stops. The battery region near the negative terminal has an excess of mobile electrons while the region near the positive terminal has an excess of positively charged ionized atoms, which have been depleted of part of their the electrons.

If the battery is not connected in a circuit there is no electric current flowing inside, and the battery can be imagined like an electrostatic charged "device". Let's take a look next at a conductive path and load made of a metallic wire and a resistor, as shown in the figure below:
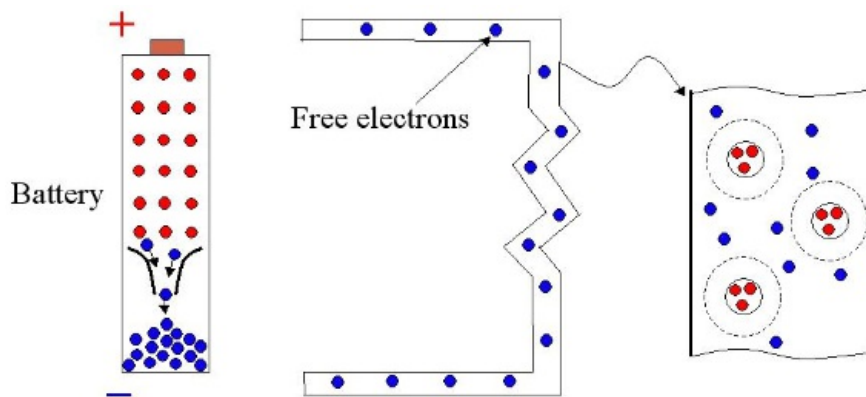
A simple way to imagine this is to visualize a metal as made of many atoms which each is neutrally charged: the negative charge of the electrons is equal to the positive charge of the nuclei. This is exemplified in the magnified view of the metallic wire on the right side of the figure.

What is special about metals is that many of the electrons do not stay attached to their atom, they just float around within the metal. This happens mainly due to a thermal agitation force that is higher than the force that attracts these electrons to their atom's nucleus. So millions of atoms have these loose electrons floating around, but still the total number of electrons is equal to the total number of positive charges in the atoms, so the metallic wire is neutrally charged. Let's connect now the metallic wire to the battery, as I am showing in the following figure.
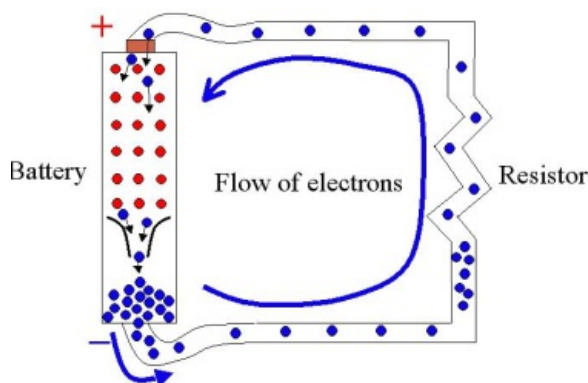
From electrostatics we know that particles charged with opposite polarity attract each other and particles charged with the same polarity repel each other.

Based on this, electrons on the negatively charged side of the battery, which tend to repel each other since they are charged with the same polarity, find a way to flow out of the battery through the metallic wire, so they start "pushing" each other through that "exit" path. As they enter the metallic wire they push the mobile floating electrons inside the metal. This pushing propagates from electron to electron through the entire metallic wire and resistor towards the positive terminal of the battery, where the electrons are attracted inside by the positive charge of the ionized atoms. Since this flow would eventually neutralize the negative

and positive charges of the battery, thus lowering the 1.5V, the "motor" or "pump" inside the battery turns on and pushes more electrons towards the negative terminal trying to maintain the 1.5V potential difference. This mechanism maintains the flow of electrons through the circuit.

So we learned that at a microscopic level of analysis, electric current in metals consists of negative charged electrons that flow in a circuit starting from the negative terminal of a source/battery, passing through the circuit elements, and entering back into the source/battery through the positive terminal.

How shall we define the direction the electric current in a general circuit made out of a voltage source, conductive path, and one or multiple loads? Shall we pick the direction of electrons flow and say that this is the direction of electric current?

To answer these questions let's notice that electric current made out of positive charges exists and flows from the positive terminal into the negative terminal of a voltage source. An example would be the positive ions flow in electrolysis; they are positively charged particles and travel from the positive terminal to the negative terminal of the electrolysis electrodes. Other examples may be related to electric discharges though various gases where ions form. When positive charged ions form they travel towards the negative terminal, and when negative ions form they travel towards the positive terminal of the voltage source, so this direction is opposite to the electrons flow direction in the example above.

So in some circuits positive charges flow in one direction and negative charges in the opposite direction. Then, how shall we consider the direction of electric current when we write analytic equations like Ohm's law, Kirchhoff's voltage and current laws?

To answer this question let's notice that what we talked about so far was the physical mechanism of charge flow inside conductors and the important part is that flowing particles can be both positively or negatively charged. Positive charges flow in one direction while negative charges flow in opposite direction.

To avoid any confusion, in analytic equations and mathematical analysis instead of considering the electric current as a microscopic structure of charged particles flow we use instead an abstract model of electric current. This abstract model defines electric current direction as flowing from the positive terminal of the power supply through an external circuit and back into the negative terminal of the power supplies. This is only a convention or a model and does not represent a physical phenomenon occurring inside the circuits' wires. We use this model only to be consistent across various equations and formulae in circuit analysis. The following figure illustrates this concept:
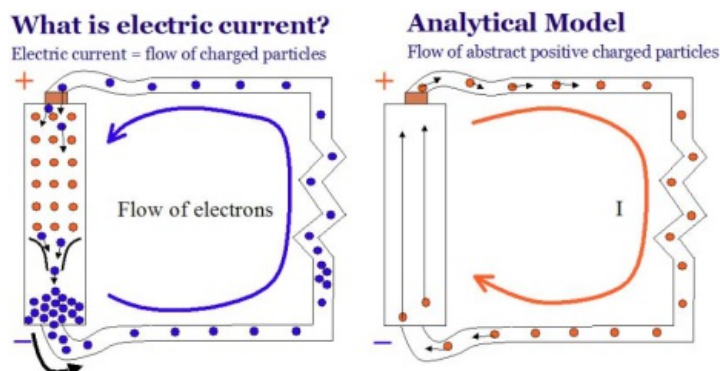

So in conclusion we know that microscopically the electric current in metallic wires is made out of negatively charged particles - electrons flowing from "-" to "+" terminals of the power supply, but we do not use this knowledge in circuit analysis. Instead when analyzing circuits we use an abstract model which describes the electric current as a flow of positive charge from the "+" to the "-" terminals of the power supply.

2. Ohm's Law

Ohm's Law is used to calculate the voltage drop on a resistor when knowing the current and resistor value. To illustrate this let's look at the figure below:
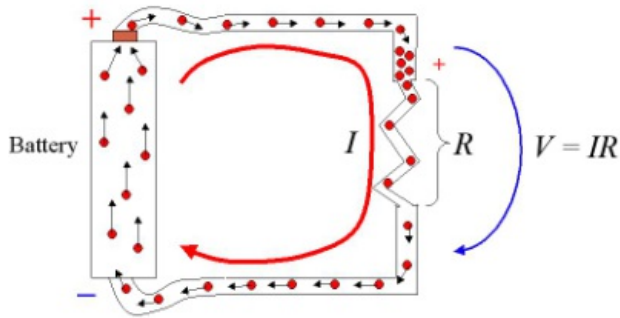
We know use the analytical model of electric current as consisting of positively charged particles flowing from the positive terminal of the voltage source, through the circuit and back into the negative terminal of the voltage source. This circuit has a resistor in the path, which we can view as a section of the path that partially blocks the flow of electric current. This is analogous to traffic on a highway that at some point has a lane closed and cars slow down and accumulates at the beginning of the narrow section. This is illustrated in the figure above by a larger number of charged particles accumulated at the entrance into the resistor. Since these particles are positively charged, if we take a voltmeter and measure the voltage between the entrance into the resistor section and the exit from the resistor section we will notice a difference in electric potential due to higher density of positive particles at the entrance. This difference of potential is called voltage drop on the resistor. Ohm's law quantifies this voltage drop as being equal to the intensity of the electric current multiplied by the resistance of the resistor: V=IR.

Experimental Setup

Construct the circuit shown in the diagram below and continue with the steps listed in the "Procedure" section.
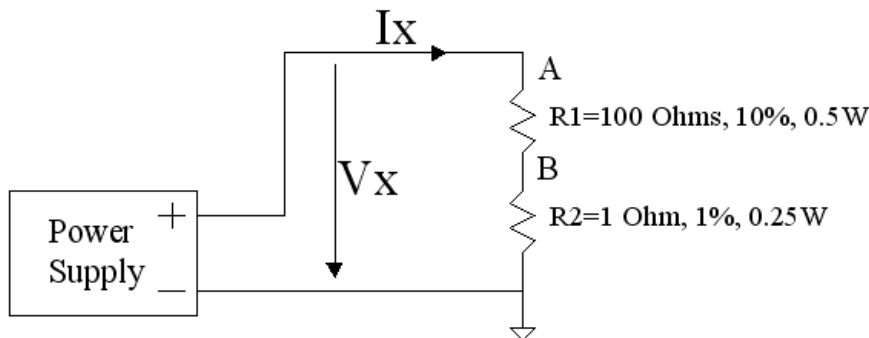

In this circuit the 1Ohm 1% resistor is used as a current to voltage converter with the transfer function: 1A -> 1V, 100mA -> 100mV, 10mA -> 10mV,... This way we can use one channel of the oscilloscope to probe the current through the circuit.

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Procedure

Step 1

Construct the circuit in the diagram below, and connect channel 1 of the TBS1000B-EDU oscilloscope to node A and channel 2 to node B.
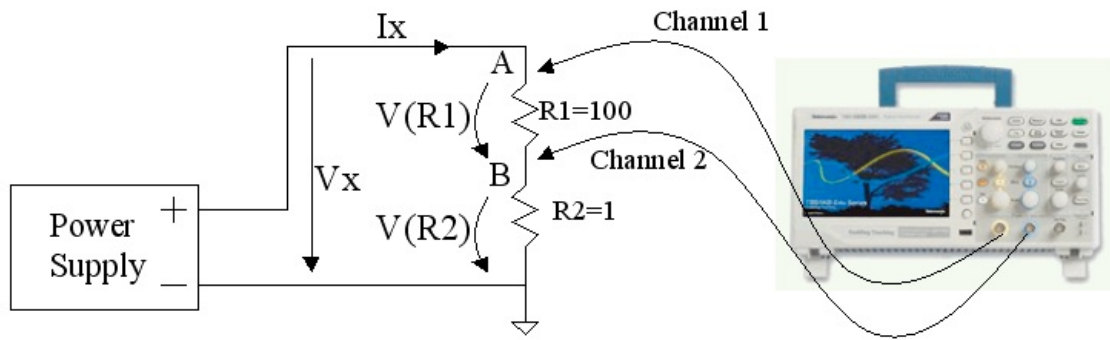
Channel 1 will measure the voltage *Vx* and channel 2 will measure the voltage drop on R2, which has the resistance equal to 1 Ohm. As we discussed in the theory section, we will use the voltage drop on R2 to give us the information of the current through the circuit, *Ix*, with a 1:1 conversion rate. For example if we measure 100mV, this represents *Ix*=100mA.

Here is an example of testbench setup:
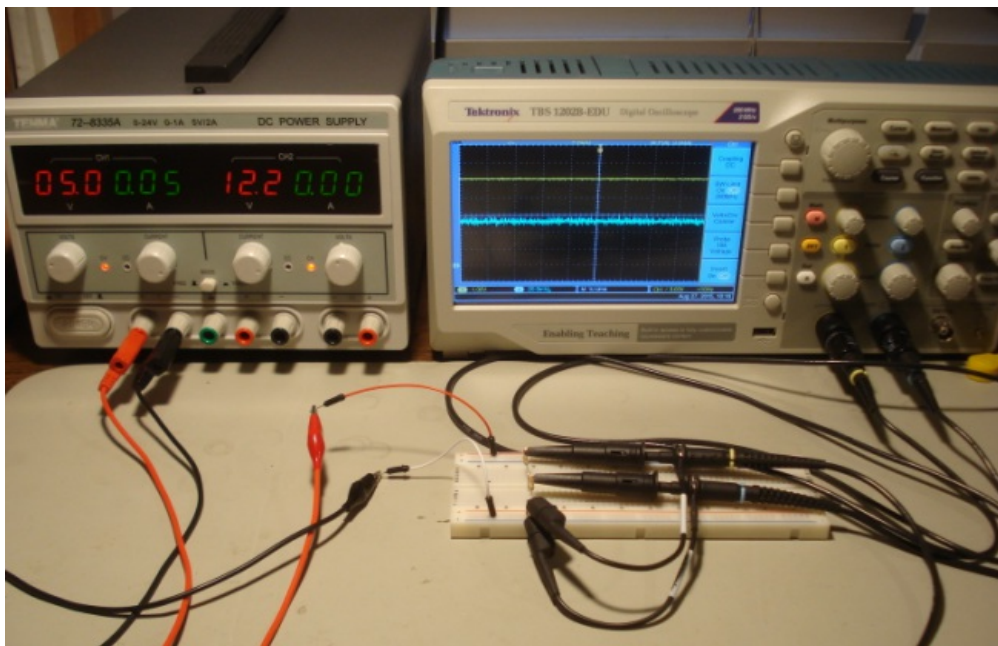
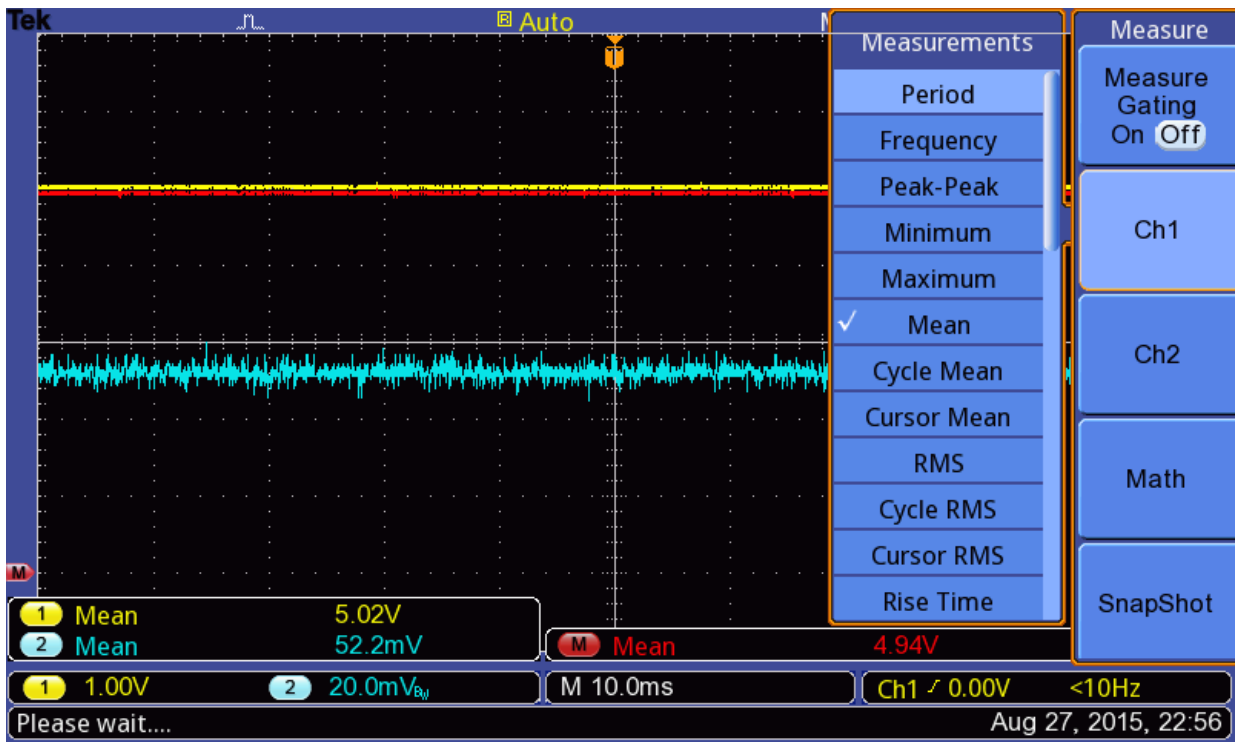and here is a detailed picture of the schematic implementation:

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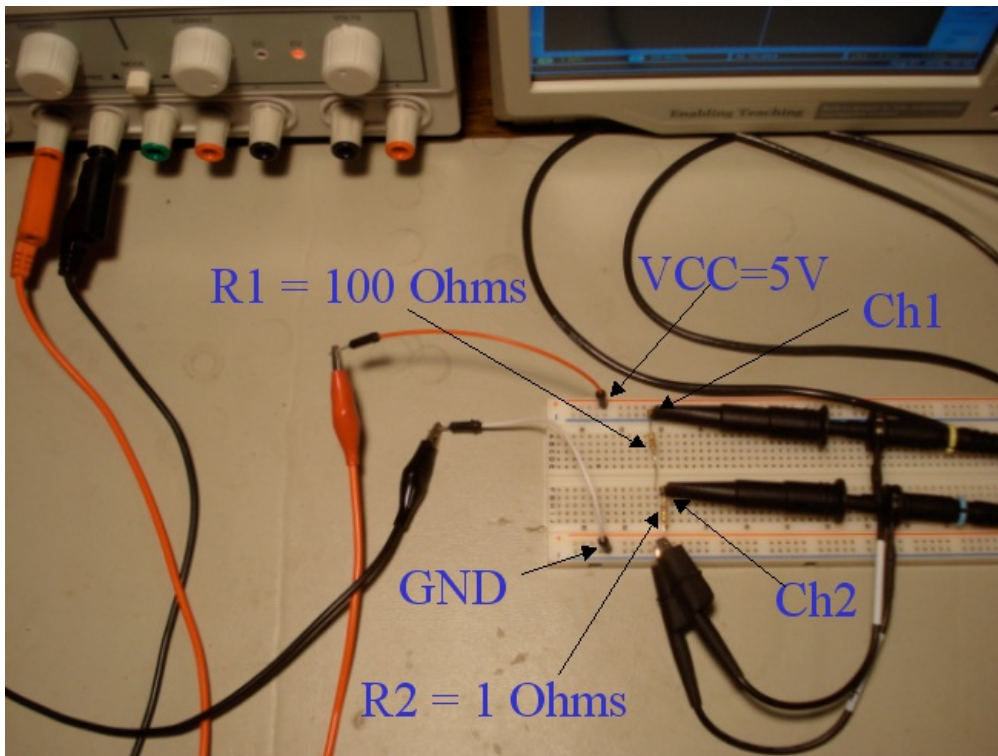
Step 2

- Setup the power supply voltage to 5V.
- Setup the Oscilloscope Channel 1 Input to DC mode, Vertical scale =1V/div, and Channel 2 input to DC mode, Vertical scale = 20mV/div.
- Setup the Oscilloscope time base to 500ns/div (this is not important here since we measure DC voltages that do not change in time and are represented as horizontal lines on the display)
- Setup the Oscilloscope Trigger to Auto mode.
- Alternately press the "Autoset" button and make the adjustments to settings after the oscilloscope displays the waveforms.
- With this setup the oscilloscope screen should display two horizontal lines representing the voltages at nodes A and B of the circuit, as shown in the picture below:
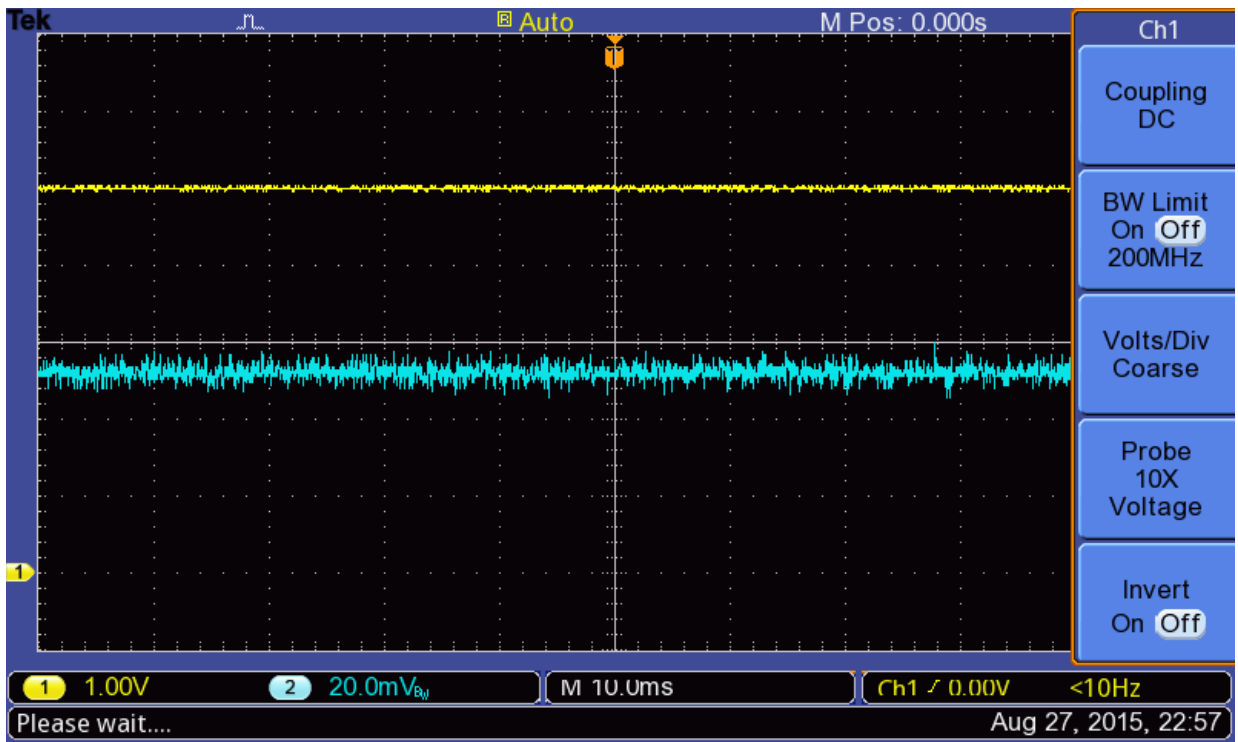
- Press the "Math" button on the oscilloscope front panel and select "Ch1-Ch2". This signal will represent the voltage drop on R1 resistor, V(R1). Here is a picture showing Ch1(yellow), Ch2(blue), and Math(red) traces:
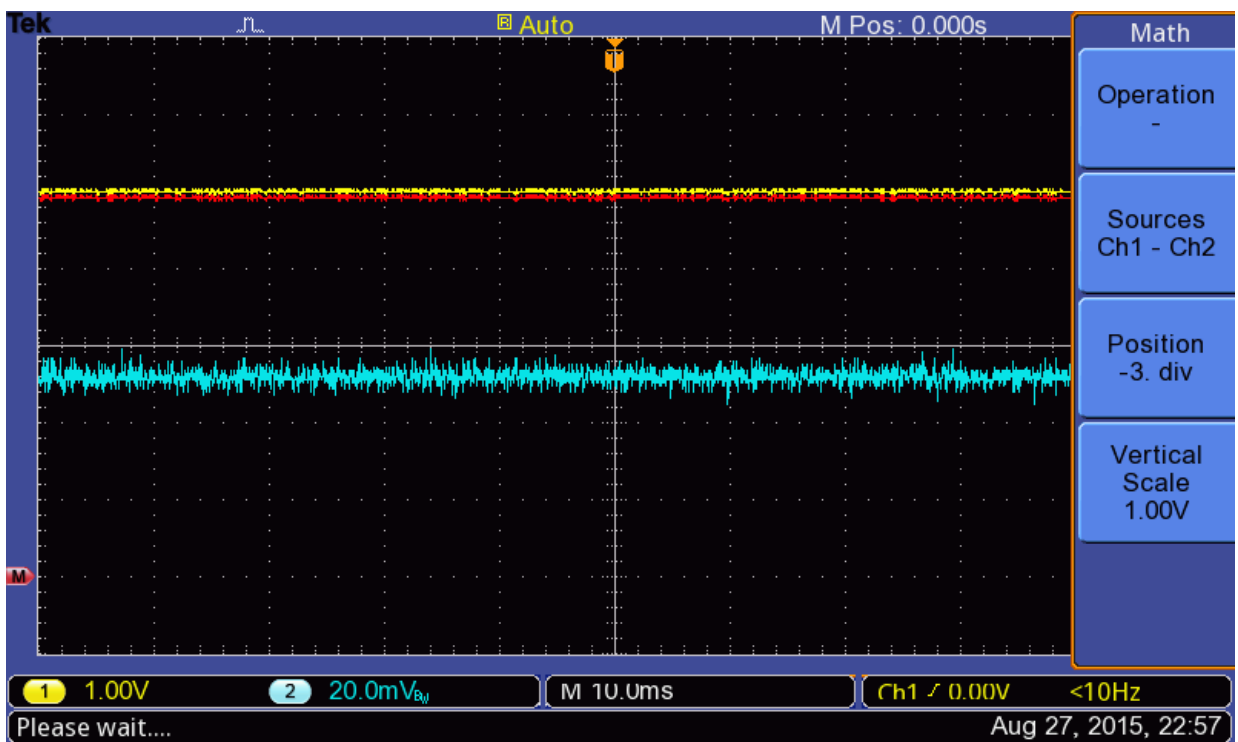
- Use the built-in "Measure" function of the oscilloscope to measure the voltage levels of the channel 1, channel 2, and "Math" traces. Select "Mean" from the measure menu, like it is shown in the picture below:

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- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.
- Determine *Ix* from the voltage measured at node B of the circuit (Channel 2). In the waveforms example shown above Ix = 52.2mA, which is determined by translating 52.2mV measured on Ch2 to 52.2mA as described in the theory section of this lab.
- Divide *V(R1)/Ix* and explain what this quantity represents.

Step 3

- Setup the power supply voltage to 4V.
- Repeat the procedure at step 2 and record the V(R1)/Ix calculated value
- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.

Step 4

- Setup the power supply voltage to 3V.
- Repeat the procedure at step 2 and record the V(R1)/Ix calculated value
- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.

Step 5

- Setup the power supply voltage to 2V.
- Repeat the procedure at step 2 and record the V(R1)/Ix calculated value
- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.

Step 6

- Setup the power supply voltage to 1V.
- Repeat the procedure at step 2 and record the V(R1)/Ix calculated value
- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.

Step 7

- Setup the power supply voltage to 0V.
- Repeat the procedure at step 2 and record the V(R1)/Ix calculated value

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- Insert a screenshot of the oscilloscope display showing channel 1, channel 2, Math signals, and the measured values.
- Comment on any issues you have encountered or any difference between this step and previous steps.

Step 8

- Insert the *V(R1)/Ix* calculated values at Steps 2-7 in the table below:

	Vx=5V	Vx=4V	Vx=3V	Vx=2V	Vx=1V	Vx=0V
Ix						
V(R1)/Ix						

- Comment on the variation of the *V(R1)/Ix* values as function of the power supply voltage.
- Did we prove Ohm's law? Explain your answer.