Lab #1 – Introduction to Electricity And Magnetism Laboratory

Purpose of today's lab:

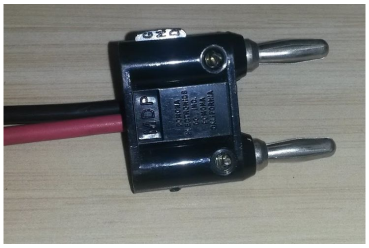
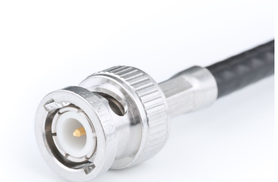
- To get familiar with electrical connectors, multimeter and power supplies.
- To learn/review analysis of uncertainties (errors) in measurements.
- To learn/review how to perform a linear curve fit.
- To learn/review how to report and compare data.
- To learn/review how to write a lab report.

Required equipment and parts:

- Multimeter
- Two power supplies
- PC with Python data analysis software
- Resistor box

1. Introduction to lab equipment:

- A banana connector (commonly banana plug for the male, banana socket or banana jack for the female) is a single-wire (one conductor) electrical connector used for joining wires to equipment.
- Note the "Ground" (GND) notch on the "banana-to-2-wire" adaptor!
- Red color is typically used for 'Hot' signal (signal that goes from the power source to the device), while black color is typically used for the 'Ground' signal (signal that goes from the device back to the ground terminal of the power source).
- The BNC (Bayonet Neill–Concelman) connector is a miniature quick connect/disconnect connector used for coaxial cable.

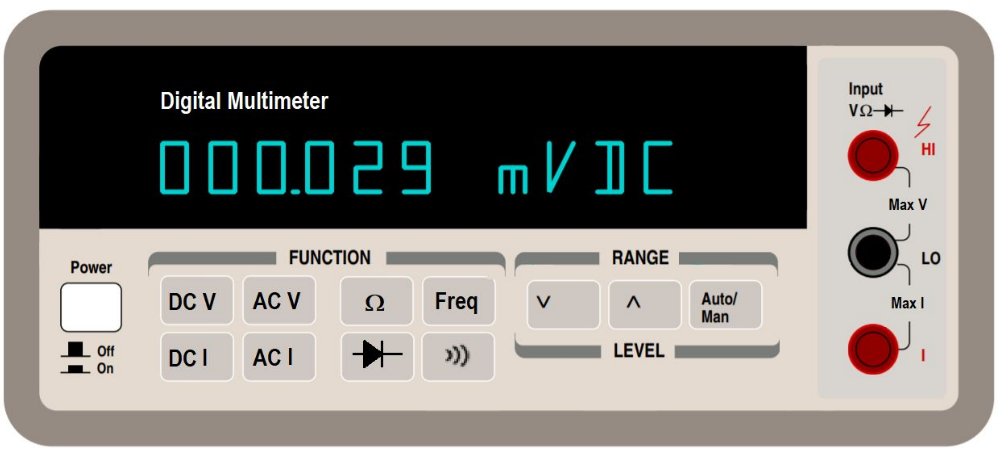





banana test connector banana-to-2-wire adaptor BNC test connector alligator test connector

<u>In today's lab, you will use only the banana connectors !!!</u>

Digital Multimeter:

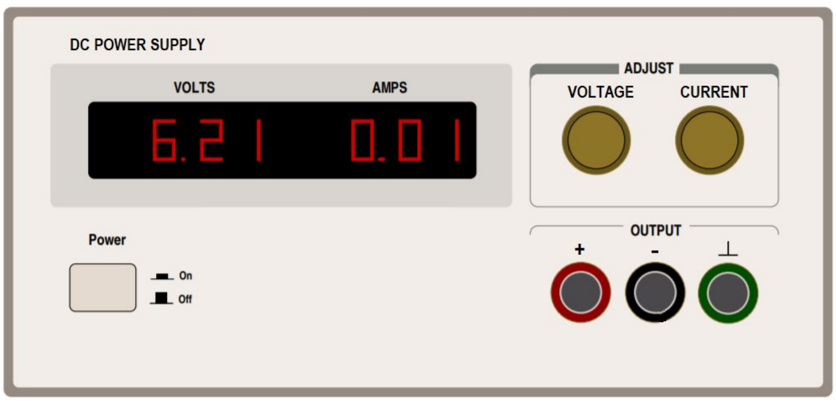
- Multimeter is used to measure DC (direct) or AC (alternating) voltage, current, resistance, frequency in Hertz (Hz), and several other parameters - see figure below.
    - "DC V": measurement of DC voltage in Volts (V). We will use this function most of the time in this lab. This function of the multimeter is called 'Voltmeter'.
    - "DC I": measurement of DC current in Volts (V). This function of the multimeter is called 'Ammeter'.
    - "Ω": measurement of resistance in Ohms (Ω). This function of the multimeter is called 'Ohmmeter'.
- Most multimeters will have three input terminals - HI, LO, I. For most measurements we use HI and LO terminals, while for current measurements, we use I and LO terminals. Some multimeters can have more than these three terminals for additional measurements.
- When connecting the banana connectors to the multimeter, make sure that the ground (minus) lead is connected to the LO terminal of the multimeter! (See the 'ground notch' on the banana-to-2-wire adaptor on the previous page.)
- Multimeter precision and measurement range can be adjusted by either manually changing the Range or choosing the Auto range option.
- **Locate the digital multimeter on your workbench and identify the buttons and terminals shown in the figure below.**



Digital Multimeter

<u>Power supply:</u>

- Power supply is used to deliver voltage (VOLTS) or current (AMPS) to the circuit.
- Typical power supply will have three output terminals: + (red), - (black), ⏚ (green), which stand for Hi, Low, and ground. We use the + and - terminals to output voltage (or current), and if the application calls for it, one can also use the ground terminal (not used in this exercise).
- Based on the resistance of the load/circuit to which power supply is connected, the power supply can be in CC (constant current) or in CV (constant voltage) mode.
- The Voltage and Current adjustment knobs are used to set the voltage and current limits (compliance) to protect the circuit.
- **Locate the power supply/supplies on your workbench and identify the buttons and terminals shown in the figure below.**
- **Before connecting the power supply to any circuit, make sure that Voltage and Current knobs are turned down (to the minimum). Afterwards, you should adjust these knobs to appropriate values.**



Power Supply

2. Measurement of resistance:

Choose a resistance between 20 Ω and 2000 Ω on the resistor box. Measure the resistance using the multimeter. Choose 'Ω 2W' option on the multimeter. Report your result in the lab report.

Note that the error of a digital instrument (such as this multimeter) is given by the last digit it can measure (provided that the readout is stable and not fluctuating). For example, if the multimeter reads 8.54 Ω, then the error is 0.01 Ω.

However, some digital instruments might display more digits than warranted by their precision, which is then generally indicated by the manufacturer, so care must be taken when estimating the readout error.

'Part 7' of this manual explains how to report data and error with proper significant figures and decimal places.

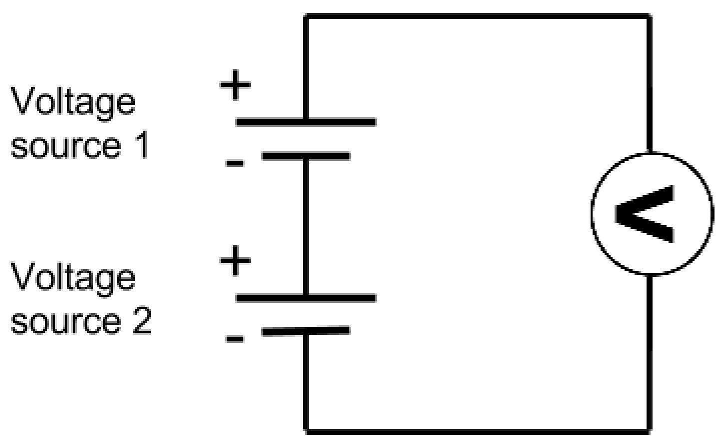
3. Measurement of voltage:

Choose a voltage between 5.0 V and 10.0 V on one of the two power supplies and measure it with the multimeter. Choose 'DC V' option on the multimeter. Report the voltage with associated error (in proper form) in your lab report, and indicate which power supply you used.

4. Series connection of voltage sources:

In this activity, you will connect two voltage sources (the two power supplies) in series, and measure the resulting voltage. In Part 8 you will then analyse if the series voltages are additive.

Connect the two DC voltage sources (power supplies) and the voltmeter (multimeter) as shown in the circuit diagram below. Pay attention which terminals are HI (+) and which ones are LO (-). Have your lab instructor check your connections before you turn on the power supplies.

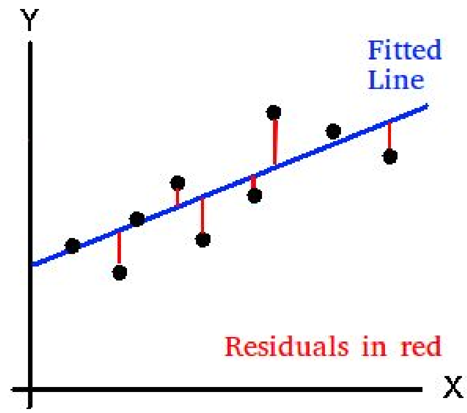


Choose which power supply is 'voltage source 1' (V_1) and which one is 'voltage source 2' (V_2). Set V_1 to 5.0 V, and do not change it. Vary the voltage V_2 from V_2 = 0.0 V to 10.0 V in 2.0 V increments, and record the total voltage reading (V_T) on your multimeter. In your lab report, make a the table like the one below.

V_1 (Volts)	V_2 (Volts)	V_T (Volts)
5.0	0.0	
5.0	2.0	
5.0	4.0	
5.0	6.0	
5.0	8.0	
5.0	10.0	

5. Linear Regression (Linear Fit)

Before you analyze the data for series addition of voltage source, you need to get familiar with linear regression. Linear regression is the most widely used statistical analysis technique for modeling the relationship between a dependent variable y and an independent variable x. It fits a straight line through the set of n points in such a way that makes the sum of squared residuals of the model (that is, vertical distances between the points of the data set and the fitted line) as small as possible. As a result, it determines the slope and the intercept of the fitted line (Y = intercept + slope * X).



6. Linear Regression using Python

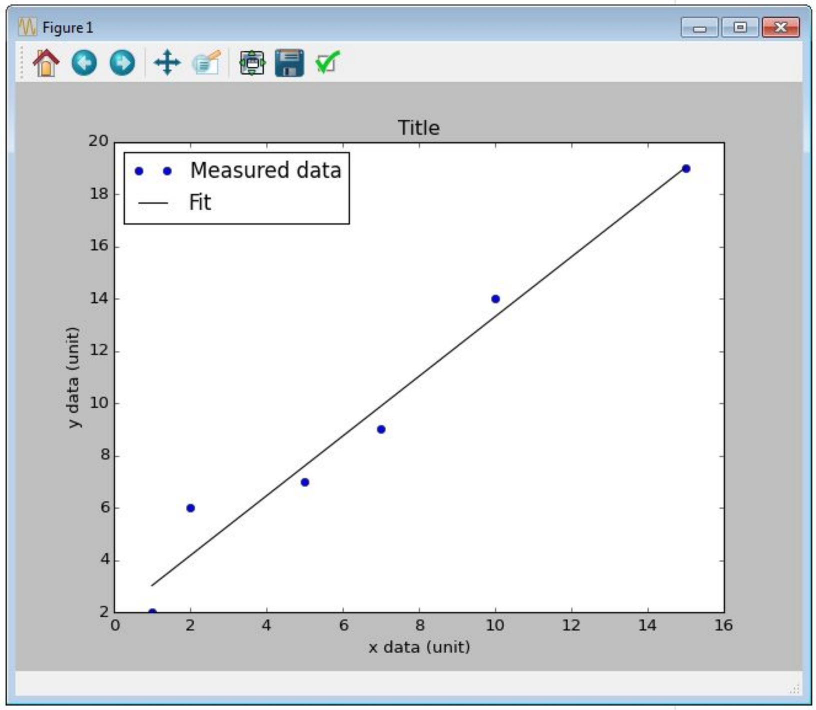
Python is a widely used general-purpose, high-level programming language. Using NumPy, SciPy and Matplotlib libraries allows the effective use of Python in scientific/engineering computing. PyCharm (by JetBrains) is an integrated development environment (IDE), a platform that allows one to write, debug and execute the software code. Shown below is the main screen of PyCharm, together with the result window showing a plot.

Now, you will graph V_T (y-axis) against V_2 (x-axis). Start PyCharm by double clicking the icon on the Desktop. Type in the code shown below. In the section 'Experimental Data', input **your** results for V_2 and V_T (which one is x and which one is y?) Change the labels and title of the plot appropriately and include the correct units.

Execute the code by pressing the green run button. The results of your linear regression analysis will be displayed at the bottom part of the screen. Another window should open with your graph.

Linear fit template.py | Linear fit template - multiple plots.py | Non-linear fit template.py

```python
# Calculates the linear regression model y = a + bx
# Returns the y-axis intercept (a) and the slope (b)
# Plots the data and the calculated fit

# Import Scipy packages

from scipy import stats
import numpy as np
import matplotlib.pyplot as plt

# Input x and y data

x = np.array([1, 2, 5, 7, 10, 15])
y = np.array([2, 6, 7, 9, 14, 19])

# Perform linear regression of the xy data
# Print results

slope = stats.linregress(x, y)[0]
std_err = stats.linregress(x, y)[4]
intercept = stats.linregress(x, y)[1]

print ("slope = "), slope
print ("standard error of the slope = "), std_err
print ("intercept = "), intercept

# Calculate the linear fit data
# with the calculated fit and intercept
# from linear regression

fit = intercept + slope * x

# Plot the xy data and the calculated fit
# on the same graph
# Annotate the plot

plt.plot(x, y, 'o')         # Markers: o:circle
plt.plot(x, fit, 'k-')      # Markers: k: black color, -: line
#Common matplotlib markers and colors are listed in the appendix of the lab manual.

plt.title('Title')
plt.legend(['Measured data','Fit'],loc=0, prop={'size':15})  #'loc=0: 'best location'
plt.xlabel('x data (unit)')
plt.ylabel('y data (unit)')

plt.show()
```



Run: Linear fit template

```
slope =  1.1432038835
standard error of the slope =  0.104657818749
intercept =  1.8786407767
```

4: Run | Python Console

- Plot the graph and submit it with your lab report!

7. Data reporting:

You can see that the results of the linear regression (for slope and slope error) are not rounded to proper significant figures. You will now perform this task and report this result correctly in your lab report (see also the “Tutorial For Writing Lab Reports” for more details). Use the following two rules:

- First, round the error (slope error) to <u>one</u> significant figure (this is done in most cases)
- Second, round the result (slope) to the same number of decimal places as its error.

For example: 1.6402 ± 0.02789 → round error to 0.03 → round number to 1.64 → report result as 1.64 ± 0.03.

Exercise: round the numbers and the associated errors to correct number of significant figures

994.6402334 ± 1.2304044
0.00046 ± 0.00023

8. Analysis of the results:

In these laboratories, you will often be asked to compare a measured parameter (or a parameter computed from your measured values) to an expected parameter (from an equation or from other experiments).

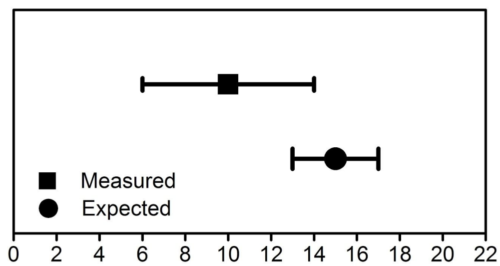
Your measured/computed value should always be reported in this form: **$x_{measured}$ ± □$x_{measured}$ (unit)**
where □$x_{measured}$ is the error (or uncertainty) of the measured value $x_{measured}$. Your expected value (which might be given to you or which you might also need to measure or calculate) should (most of the time) also contain error **$x_{expected}$ ± □$x_{expected}$ (unit)**

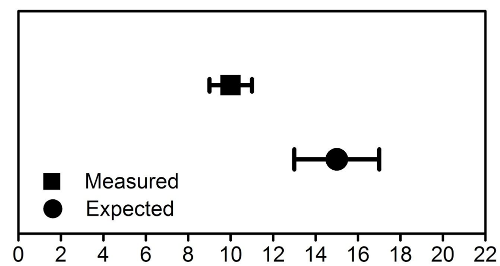
Next, you will compare your measured value with the expected value by finding the **discrepancy** between the two values: $|x_{measured} - x_{expected}|$. The discrepancy might be **significant** or **insignificant**, depending on the size of the errors associated with the values.

- If the measured and expected values $x_{measured}$ ± □$x_{measured}$ and $x_{expected}$ ± □$x_{expected}$ overlap (left figure below), then the discrepancy is insignificant and you can say that the two values (measured and expected) are in agreement.
- If the two values <u>do not overlap</u> (right figure below), then the discrepancy is significant, and you cannot say that the two values are in agreement. In this case, you can calculate and report the percent difference between the measured and the expected values as

$$Percent\ difference = \frac{|Measured - Expected|}{Expected} \cdot 100\%$$

Measurements and their errors (uncertainties): In these two examples, we compare measured and expected values of some quantity x. In the first example, $x_{measured}$ = 10 ± 4, while the expected value is $x_{expected}$ = 15 ± 2. Error bars for $x_{measured}$ and $x_{expected}$ are shown. In the second example, the measured value is $x_{measured}$ = 10 ± 1. What can you conclude about the two different results?





If you expect the values to be the same, then you would need to figure out the cause of the discrepancy. It could be many reasons, such as:

- user error: incorrect measurements, underestimation of errors, mistakes in data calculation, mistakes in calculations of data error propagation, etc.
- instrumentation: bad apparatus, wrong calibration of instruments, drift in instrument readings, etc.

If you overestimate your errors, you might get an agreement between your measured and expected values, but your measurements will be imprecise, and your conclusion might be wrong. If you underestimate your errors, you might also arrive to erroneous conclusion about the results of your experiment, claiming that your measurements were more precise than they were.

Now, you will determine the validity of the equation $\mathbf{V_T = V_1 + V_2}$ by comparing the measured result for slope (from Python) with the expected result (from equation Y = intercept + slope * X).

- Determine the expected value for the slope if the two voltage sources are additive?
  You should figure out the expected slope without calculation - by analyzing the equation
  $V_T = V_1 + V_2$.
- Determine the measured value (with error) of the slope of the linear fit of V_T vs V_2.
- Determine the discrepancy of the measured and expected values.
- Determine if the discrepancy is significant of insignificant.
- Write a conclusion of the results of your analysis. Are the series voltages additive?

Lab Station Shutdown

Your Labstation should have been neat and clean when you came in. Let your instructor know if it was not.
You are responsible for the following items before leaving:

- Turn off all the equipment, and please report any defective equipment.
- Delete any data in the Work-Folder after you are finished & empty the Trash Folder.
- Return all cables to where they belong.
- Clean your area of trash and push your chairs under the bench.
- Have your instructor inspect your Lab Station.