ENGR 206

Experiment 2
Power Supply and Digital Multimeter

Objective

To become familiar with the use of the Agilent E3631A Triple Output Power Supply (PS) and the Agilent 34401A Multimeter (DMM) and use these instruments to make measurements of current, voltage and resistance.

Introduction to the Agilent E3631A Triple Output Power Supply

The Agilent E3631A Triple Output Power Supply can provide three DC voltages that can be set independently to desired values over these specified ranges: 0 to +6 volts, 0 to +25 volts, and 0 to -25 volts. The following sections will guide you through the set-up and use of these three configurations. The detailed user's guide for this device is found here.
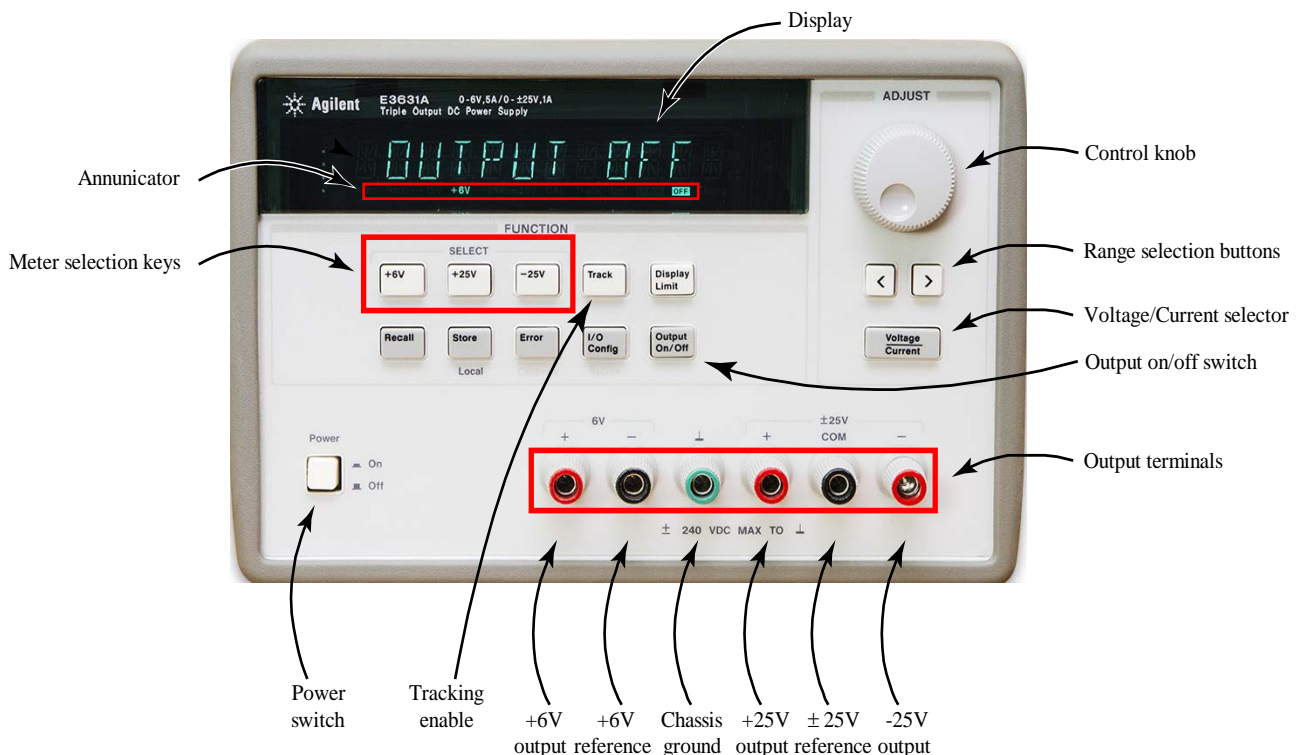

Figure 1: Agilent E3631A power supply controls

The basic layout of the power supply and the identity of its important controls are shown in Figure 1.

- Power Switch. Its function should be obvious.
- Display. The display shows both the voltage across and current through the terminal that is selected by the meter selection keys.
- Meter selection keys. The meter selection keys, $\boxed{+6V}$, $\boxed{+25V}$, and $\boxed{-25V}$, select the output voltage and current of any one supply (+6V, +25V, or -25V output) is being monitored on the display and allows the adjustment of that supply by the control knob.
- Control knob. The control knob adjusts the voltage or current selected by the meter selection keys. Usually, only one digit of the display will be blinking. Turning the control knob clockwise or counter clockwise increases or decreases the value of the blinking digit.
- Range selection buttons. These buttons, $\boxed{<}$ $\boxed{>}$, move the blinking digit in the display to the left or right, allowing the control knob to select different digits.
- Tracking enable. Pressing this key enables or disables the track mode of ±25V supplies.

- Voltage/current adjust selection key. This key selects whether the displayed supply output is active as a constant voltage (CV) source or a constant current (CI) source. Note that each of the three outputs can be configured as either a CV or CI source. The control knob functions to voltage control or current respectively.
- Output On/Off key. This key enables or disables all three power supply outputs.
- Output terminals. The power supply has the following terminals
    - **Chassis ground**. The chassis ground terminal (green) is a "true earth" ground. It is connected to the main ground of the science building via the ground pin of the instrument's power cord. This is true earth ground in the sense that it is close to the electric potential of the earth.
    - **+6V output and +6V reference.** This pair of terminals, the +6V output (red terminal) and its associated reference (black terminal, labeled '-') provide the output of the adjustable +6V voltage supply. The reference is said to be "floating" (i.e. disconnected) from the chassis ground. So, when the output of the +6V supply is set to a particular value, say +3V, that says only that there is a potential difference of 3V between the '-' and '+' terminals of the +6V supply.
    - +**25V output, -25V output and ±25V reference.** The +25V and -25V terminals (red) provide the outputs of the adjustable +25V and -25V supplies with respect to a common reference terminal (black), labeled 'COM'. This reference terminal is also floating, and is tied neither to the chassis ground, nor to the reference of the +6V supply.
- Annunciator is part of the display that comprises a number of small indicators that illuminate to give the status of the supply. When lit, these indicators have the following meaning:
    - +**6V** The display is currently showing the output voltage and current for +6V supply. Activating the control knob now will change the value of the +6V supply.
    - +**25V** The display is showing the output voltage and current for +25V supply. Control knob changes the +25V supply.
    - -**25V** The display is showing the output voltage and current for -25V supply. Control knob changes the -25V supply.
    - **CAL** The power supply is in calibration mode.
    - **Track** The outputs of +25V and -25V supplies are in track mode.
    - **Limit** The display shows the voltage and current limit value of a selected supply.
    - **OFF** The three outputs of the power supply are disabled.
    - **CV** The displayed output is in constant-voltage mode.
    - **CC** The displayed output is in constant-current mode.
    - **Unreg** The displayed output is unregulated (output is neither CV nor CC).

Using the 0 to +6 volt adjustable single supply

Figure 2 shows the procedure for using the power supply to provide a single voltage adjustable between 0 and +6 volts.
1) Plug the probes into the +6V terminal (the red terminal) and +6V reference (the black terminal). Conventionally, we use a red lead for the +6V and a black lead for the reference. The equivalent circuit for this is shown in the figure to the right. The power supply is modeled as an ideal voltage source; the +6V output of the power supply the '+' terminal of the ideal voltage source and the +6V reference terminal of the power supply is the '-' terminal of the ideal voltage source. It's important to note that the black terminal is NOT the same as the chassis ground (the green terminal). See the note below.
2) Turn the power supply on by pressing the power button. The power supply will go into its power-on / reset state; all outputs are disabled (the **OFF** annunciator in the display lights up and the main display says, "OUTPUT OFF"); the display is selected for the +6V supply (the **+6V** annunciator in the display should be lit); and the control knob is selected for voltage control.
3) Enable the outputs by pressing the (Output On/Off) button. The **OFF** annunciator on the display will turn off and the **+6V** and **CV** (constant voltage) annunciators should be lit.
4) Push the (+6V) meter select button if necessary. This assures that the display is reading the value of the +6V output. Push the (+25V) or (-25V) buttons to read the outputs of the other sources.
5) Once the output is on, the voltage or current is selected, and the meter is set to read the appropriate output, turn the control knob to get the desired voltage or current while watching the display. One digit on the display will be flashing. That's the digit that the control knob will adjust. To select another digit, use the (<) (>) buttons.
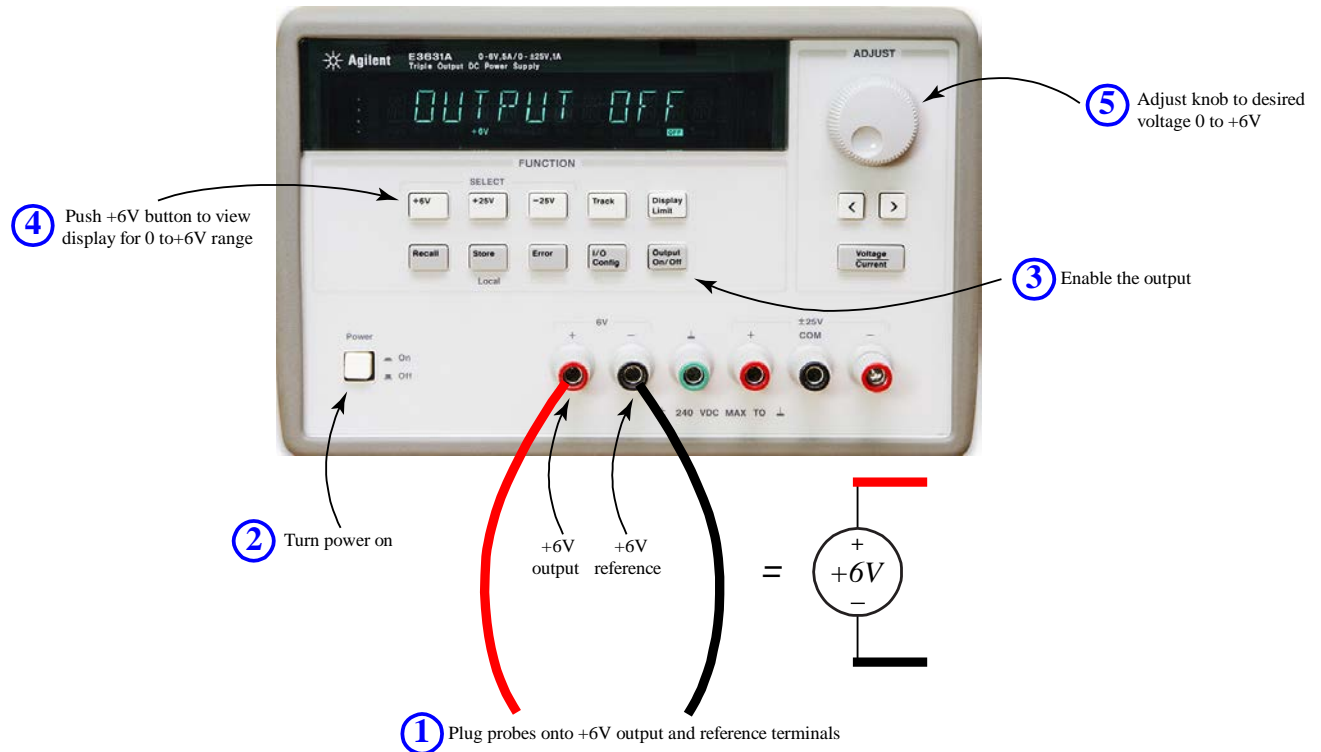
Figure 2: Using the 0 to +6 volt adjustable single supply

Using the 0 to ±25V volt adjustable supply

Figure 3 shows the procedure for using the power supply to provide a single voltage adjustable between 0 and +25V, or between 0 and -25V, or both!
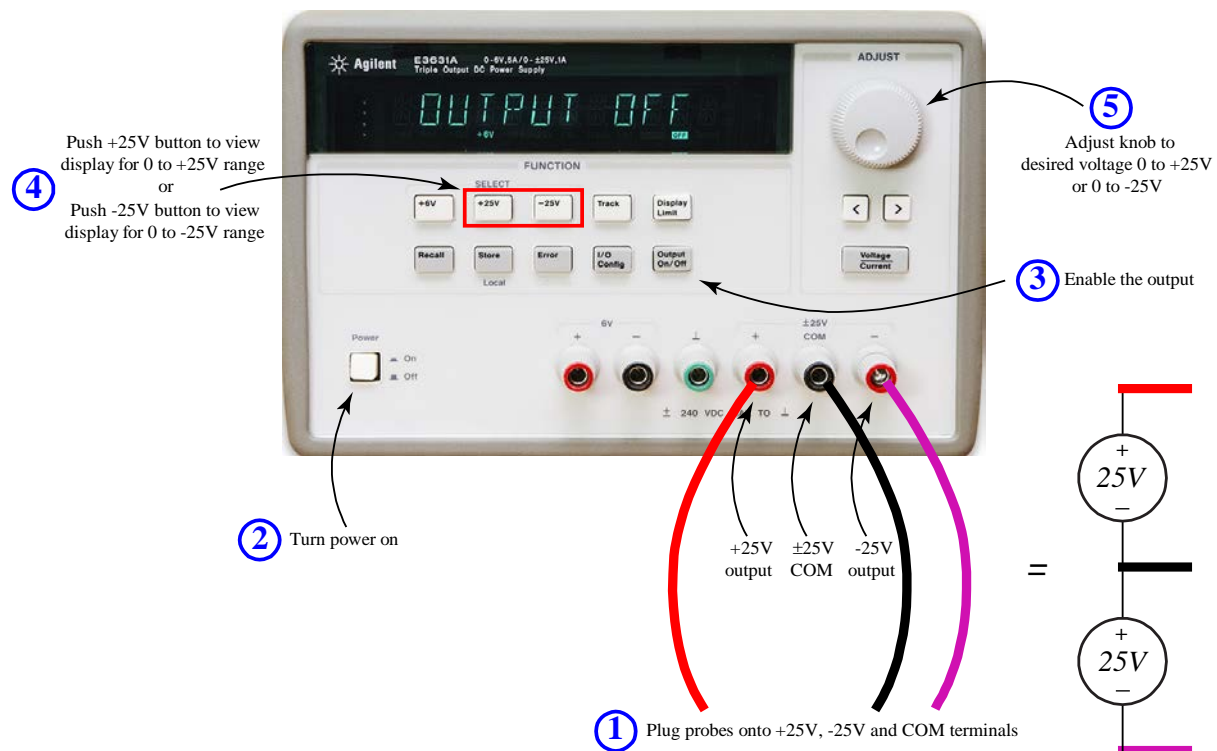

Figure 3: Using the 0 to +20 volt adjustable single supply

1. For positive voltages from 0 to +25V, plug probes into the +25V terminal and the COM terminal. For negative voltages from 0 to -25V, plug probes into the -25V terminal and the COM terminal. You can have both +25V and -25V outputs active simultaneously, each set to a different voltage. This trio of terminals is modeled as two ideal voltage sources in series attached together at the COM terminal, as depicted in the figure. The +25V output of the power supply is equivalent to the '+' terminal of the upper voltage source and the -25V output of the power supply is equivalent to the '-' terminal of the lower voltage source. If this equivalent circuit isn't crystal-clear to you, please review your basic circuits material *now*!
2. Turn the power supply on by pressing the power button.
3. Enable the outputs by pressing the `Output On/Off` button.
4. Push the `+25V` or `-25V` meter select buttons to make the display read the appropriate output.
5. Adjust the control knob to adjust the flashing digit in the display. Use the `<` `>` buttons to select another digit.

Tracking enable button

By default, you can separately adjust the outputs of the +25V and -25V. However, pushing the tracking enable button, `Track`, puts the supply in track mode. In track mode, the **Track** light in the annunciator turns on, and the -25V output is set to exactly the negative of the +25V supply value. When you turn the output knob, the output of both sources change symmetrically. Track mode is useful in certain cases, for example, to supply ±15V to power an op amp, something we will do in later experiments.

Using the constant voltage supply as a constant current supply

In several of our experiments, we will need to have a current source. The Agilent E3631A Triple Output Power Supply has a constant current (**CI**) mode, however it's a bit of a pain in the neck to get it to work. Not to worry, though. We can easily get the constant voltage supply to provide a constant current without going into its special CI mode. Notice that the display of the supply shows both the voltage being selected by the voltage adjustment knobs (on the left side of the display) and the current being provided by the supply (on the right side). To emulate a current source, simply hook up the voltage supply to the load, and then adjust the voltage until the current reads the desired value.

> Important note
> Make sure that you never connect either of the reference (black) terminals to any of the voltage (red) terminals (+6V or ±25 V) together, for example by miss-wiring your circuits or by accidentally allowing the probes to touch.

Introduction to the Agilent 34401A Multimeter

The Agilent 34401A Multimeter (DMM) can be used to measure five electric circuit variables: resistance, DC voltage, DC current, AC voltage, and AC current. This section will show you how to make three of the basic measurements: DC voltage, DC current and resistance. The 34401A can also measure other things, such as temperature and the frequency or period of periodic signals. The detailed user's guide for this device is found here. Parts of the following description are exerpted from "An Introduction to Using the Agilent 54622D Digital Oscilloscope, E3631A DC Power Supply, 34401A Digital Multimeter, and 33220A Arbitrary Waveform Generator" by Walter Banzhaf, University of Hartford, Ward College of Technology, USA.
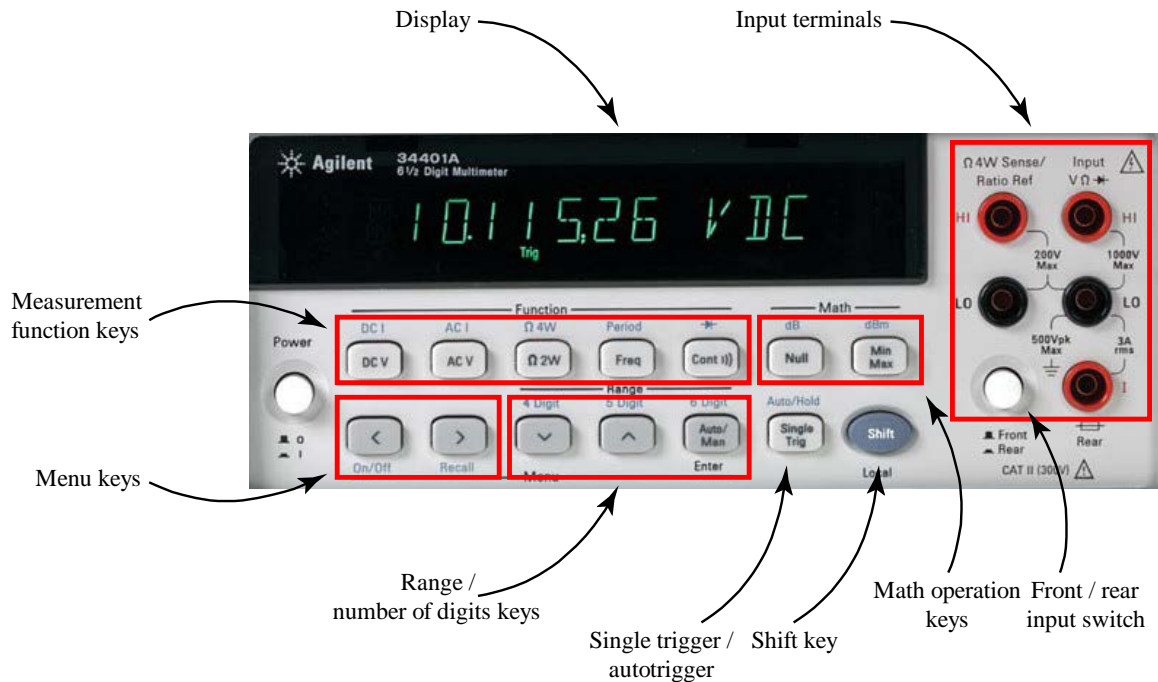
The basic configuration of the DMM is shown in Figure 4.

Figure 4: Agilent 34401A Multimeter

The key controls of the meter for this laboratory are:
- The Measurement function keys in conjunction with the Shift key are used to select whether the meter is being used to measure and display resistance, DC voltage, DC current, AC voltage, and AC current.
- The Range keys select the range of the measurement and number of digits that the meter will display.
- The Input terminals are where the probes are attached. The Fornt/Rear switch should be set on 'Front'.

Measuring DC voltage

The configuration of the meter to measure DC voltage is shown in Figure 5

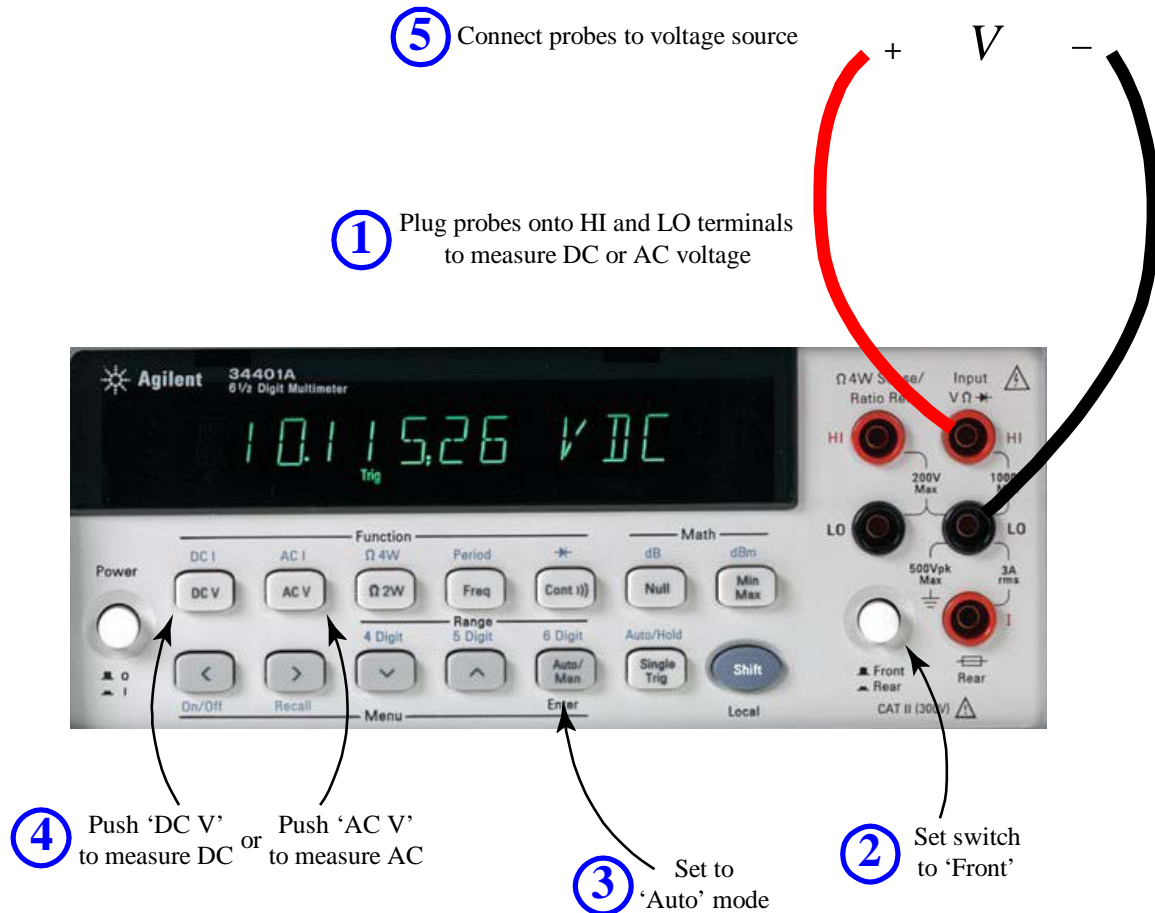**Figure 5: Using the DMM to measure DC voltage**

1. Plug the red probe into the red terminal VΩ labeled HI and the black probe into the black terminal labeled LO. Using this convention, when a positive voltage is applied across the terminals (i.e. the potential of the HI terminal is greater than that of the LO terminal), the meter reads a positive number.
2. Make sure Front/Rear input switch is set to the 'Front' position for front connecting terminals.
3. Press Auto / Man button so that the "Man" disappears from the display. The automatic ranging mode is now in effect. This allows the meter to find the optimum range to display the voltage. The meter can measure voltages in ranges 100 mV, 1V, 10V, 100V, 1000V. The maximum resolution is 100 nV on the 100mV scale.
4. Press DC V button to measure DC voltage (or press AC V button to measure AC voltage).
5. Connect the probes to the voltage source and verify that the voltage measurement on the display screen is comparable to that on the display of the voltage source. Comment on the discrepancy, if any.

Measuring DC current

The configuration of the DMM to measure DC current is shown in Figure 6.

① Plug probes onto HI and LO terminals to measure DC or AC voltage

③ Push 'Shift'+'DC V' to measure DC current or **Push 'Shift' + 'AC V' to measure AC current**

② Set to 'Auto' mode

③ Push 'Shift' to enable current measurement

④ Connect probes in series with circuit

V_S

R

Positive current is defined to flow into the 'I' terminal
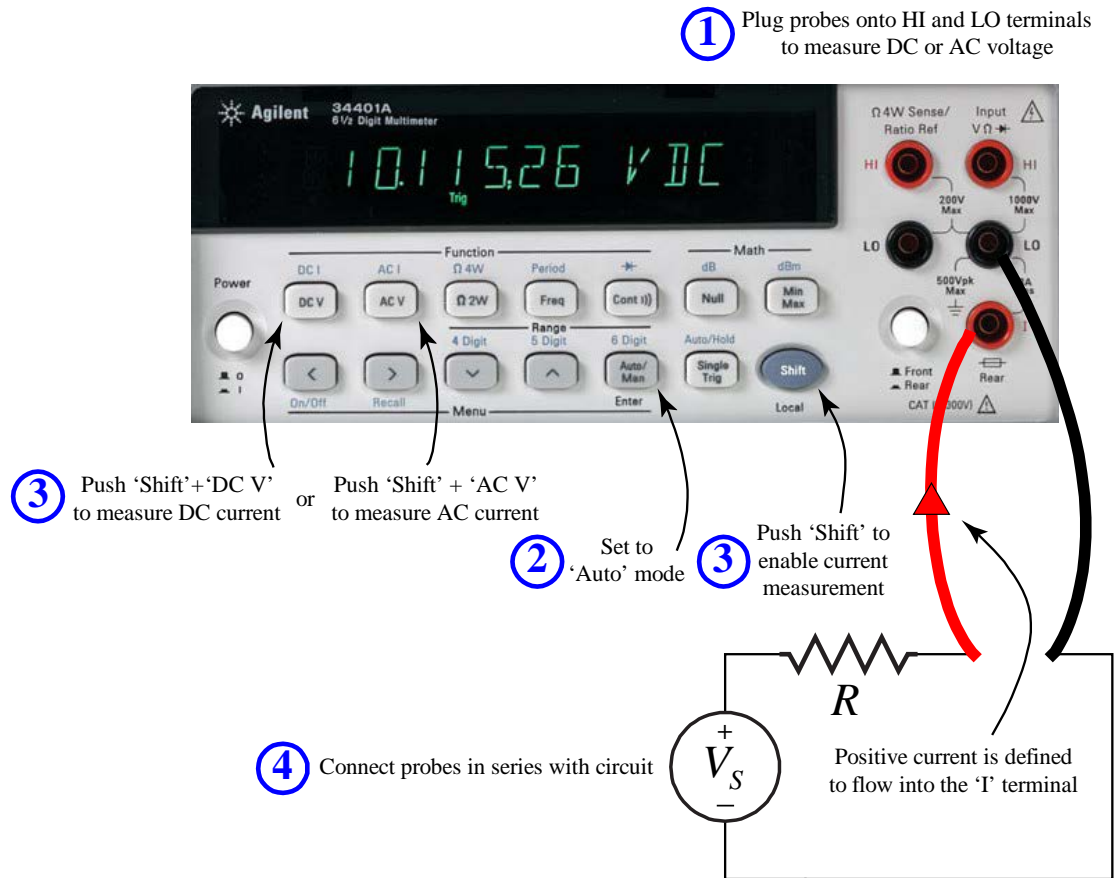
Figure 6: Using the DMM to measure DC current

1. Insert the black probe into the black terminal labeled 'LO'; then insert the red probe into the red terminal labeled 'I' (at the bottom of the right-hand corner) for current measurements. Make sure Terminals button is set to the "Out" position for front connecting terminals. Notice that positive current flow is defined to flow into the 'I' terminal. Thus, if the meter reads +1.00…, it means that +1 amp is flowing into the 'I' terminal. If the meter reads -1.00…, it means that -1 amp is flowing *into* the 'I' terminal, or equivalently that +1 amp is flowing *out of* the 'I' terminal.
2. Press Auto / Man button so that the "Man" disappears from the display. The automatic mode is now in effect.
3. Press the Shift button and the DC V button to measure DC current or press the Shift button and the AC V button to measure AC current.
4. Measure the current with probes in series with the load; then view the current measurement on the display screen.

CAUTION: For current measurements, the probes must be in series with the load only and current limited to less than 3 amps. If the circuit draws 3 amps or more, a fuse will blow and disable the instrument.

Measuring resistance

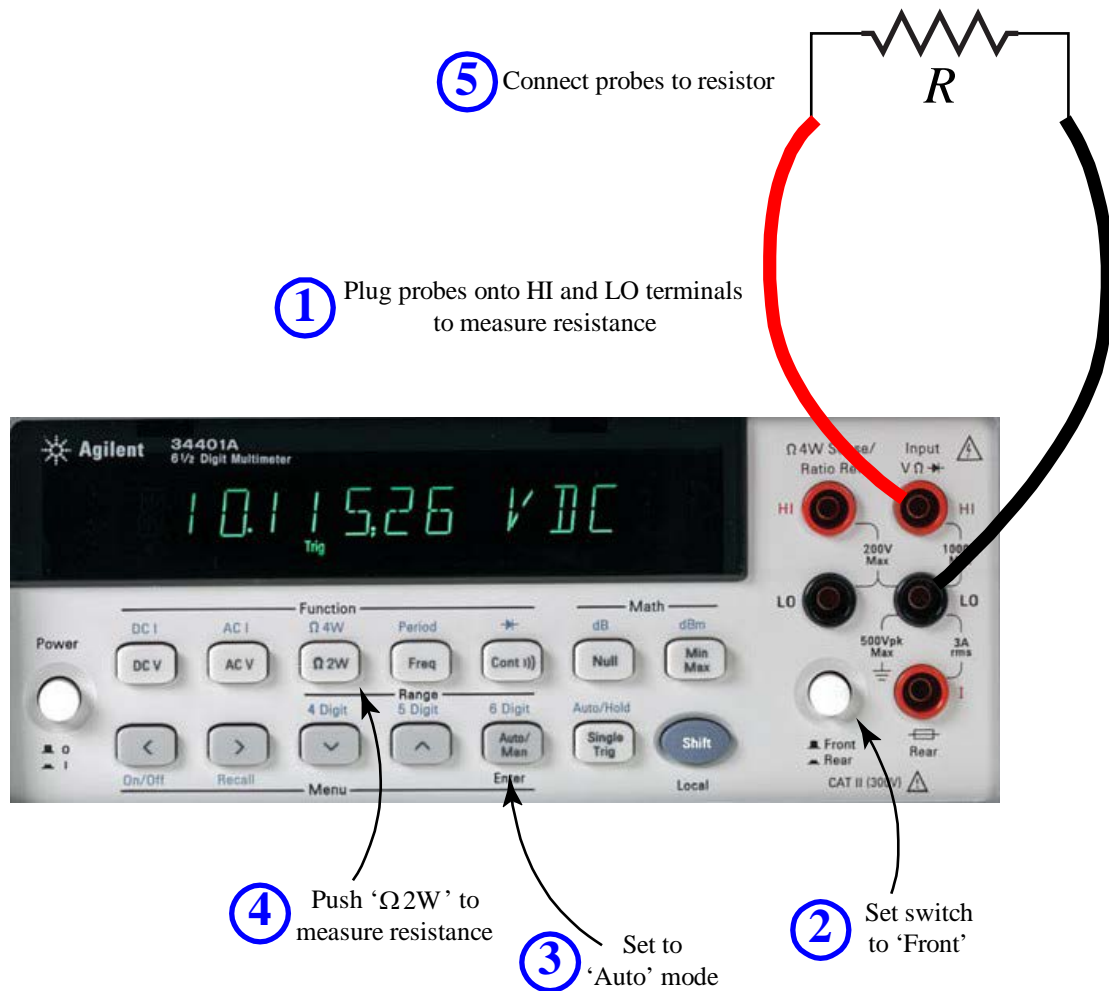The configuration of the DMM to measure resistance is shown in Figure 7.

Figure 7: Using the DMM to measure resistance

1. Plug the red probe into the red terminal VΩ labeled HI and the black probe into the black terminal labeled LO.
2. Make sure Terminals button is set to the "Out" position for front connecting terminals.
3. Press Auto / Man button so that the "Man" disappears from the display; the automatic mode is now in effect.
4. Press Ω 2W button to measure resistance.
5. Place probes across resistor, then view the resistance value on the display screen

Note:

- NEVER measure resistance in a "live" circuit. Turn off all power to the circuit. If an ohmmeter is used in a "live" circuit, at best you will get incorrect readings; at worst you can seriously damage the DMM.
- You must insert the ohmmeter leads across the two points in a circuit for which you want to measure the resistance, as shown in Figure 7.
- The DMM will Autorange unless you override it by selecting a range using the buttons on the 'Range' panel You can choose the number of digits displayed, using the ('Shift') DIGITS buttons.
- Make sure your hands don't contact both test leads while making a measurement, otherwise, you'll be measuring the device under test in parallel with you.

Laboratory work

1. <u>Resistance measurements</u>. The purpose of this section is to learn to read the resistor code and verify resistance values in series and parallel with the DMM.
   a. Set up the DMM to measure resistance.
   b. Without connecting the test leads to anything, what does the display read? Why?
   c. Connect the two test lead together, what is the reading now? Why?
   d. The color codes of four resistors are given below. See Appendix A for a list of the resistor codes.

      brown, black, yellow, xxx
      green, brown, orange, xxx
      yellow, violet, red, xxx
      blue, gray, brown, xxx

      where xxx represents either gold, silver, or no band. Pick out these four resistors from your bag of components, record the fourth band of the actual resistors used, and determine their nominal values and tolerance. Order these resistors according to increasing value of resistance, R_1 for the smallest and R_4 for the largest.
   e. Measure each of the four resistors. Are the resistor values within tolerance?
   f. Verify that two resistors connected in series exhibit an overall resistance equal to the sum of the two individual resistances. Do this for the pairs $R_1 - R_2$, $R_2 - R_3$, $R_3 - R_4$, and $R_1 - R_4$. Comment on the result in each case. Specifically, is the value of the series combination within the uncertainty expected given the tolerance of the resistors?
   g. Verify that two resistors connected in parallel exhibit an overall resistance equal to the product over the sum of the two resistances. Do this for the pair $R_1 - R_2$, $R_2 - R_3$, $R_3 - R_4$, and $R_1 - R_4$. Comment on the result in each case.

2. <u>V-I characteristic of a resistor</u>. The purpose of this section is to learn to measure current and to verify Ohm's Law experimentally.
   a. Set up the circuit shown in Figure 6 using resistor R_1 and the voltage source in its 0 to +25V configuration as the voltage source, V_S.
   b. Select 11 evenly spaced points of voltage, v_i, between 0 and +10V (i.e. 0V, +1V, …, +10V). The values of voltage don't have to be exact. Using the DMM, measure the current flowing through the resistor at each voltage. Also record the value of v_i as measured by the display in the power supply.
   c. Plot the voltage (ordinate) vs. current (abscissa) and fit a straight line to your data using linear least-squares regression (see Appendix B). Report the slope and intercept of the line, and the correlation coefficient. What is the relation between the slope of the line and the resistance, R_1?
   d. Repeat this experiment with R_2. (Extra: also do R_3 and R_4.)

3. <u>DC current measurement</u>. The purpose of this section is understand the convention of measuring voltage and current.
   a. Set up the power supply and DMM to measure the current, *I*, in each of the circuits shown in Figure 8. Choose $R = 1k\Omega$. Pay attention to the convention of voltage and current, as discussed in conjunction with Figure 2, Figure 3 and Figure 6; namely, the COM terminal of the voltage supply is equivalent to the '-' terminal of the circuit and the arrow on the head of the resistor indicates the direction in which current flow is taken to be positive
   b. Report values of I_1, I_2, I_3, I_4, I_5, I_6, I_7 and I_8
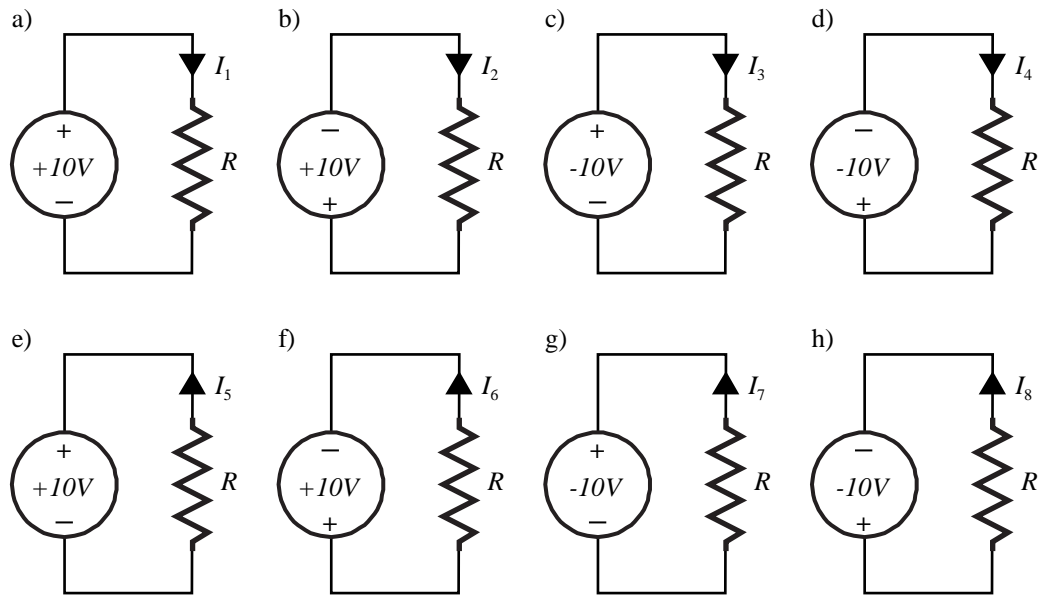
Figure 8: Circuit for part 3

4. <u>DC voltage and current measurements of series circuit</u>. The purpose of this section is to verify KVL and KCL for a circuit with elements connected in series.

   a. Set up the DMM to measure DC voltage. Without connecting the test leads to anything, what is displayed on the DMM? Why? Connect the two test leads together, what is the reading? Why?

   b. Connect R_1, R_2, R_3 and R_4 in series as shown in Figure 9a.

   c. Connect the voltmeter as shown in the figure and measure the voltage drop, V_1, across R_1 with the red probe on the +5V side and the black probe between R_1 and R_2. What is the voltage? Measure the voltage drops V_2, V_3 and V_4 across the remaining resistors, R_2, R_3 and R_4. What is the sum of the voltage drops? Comment. (Extra: Using the voltage divider relation, calculate what you expect to find for the voltage drops, V_1, V_2, V_3 and V_4. Comment.)

   d. Set up the DMM to measure current as shown in Figure 9b. Measure the current I_1. Repeat for currents I_2, I_3 and I_4. Since you have measured the voltage drop across each resistor above, use Ohm's Law to calculate the current you expect to be flowing through each resistor. Is the result what you expect? Comment.

   e. Using the sum of the voltage drops across the resistors and the sum of the resistors, use Ohm's Law to calculate the current. Comment.
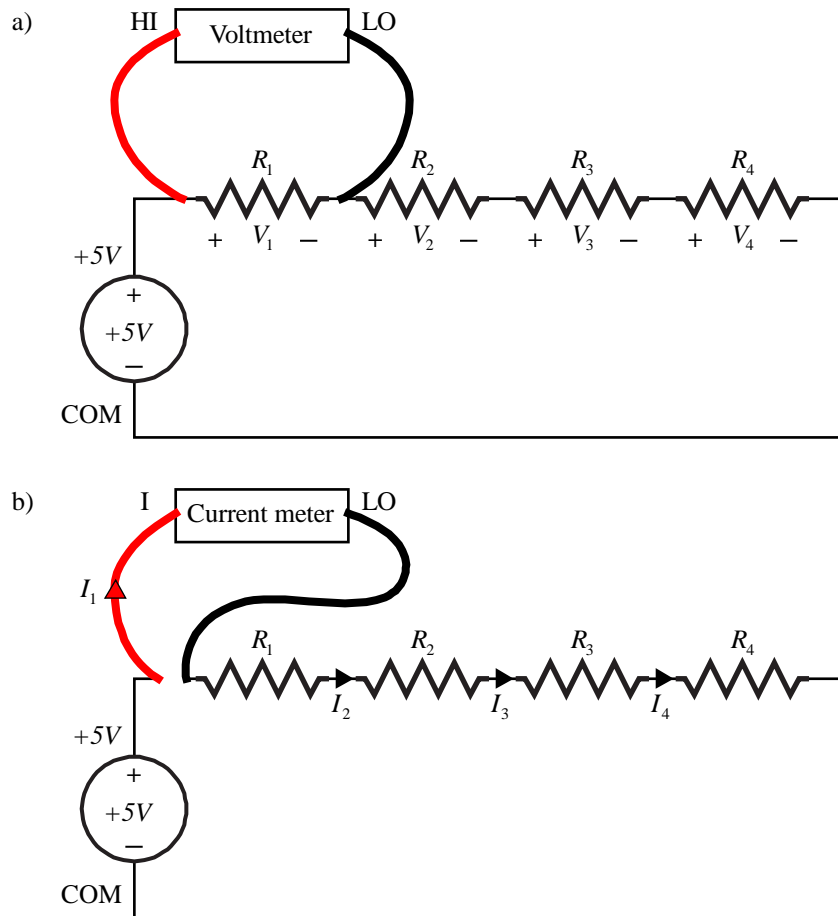
Figure 9: Circuit for part 4

5. <u>DC Voltage and Current Measurements of parallel circuit</u>
   The purpose of this section is to verify KVL and KCL for a circuit with elements connected in parallel.
   a. Set up the DMM to measure DC voltage.
   b. Connect R_1, R_2, R_3 and R_4 in parallel as shown in Figure 10a.
   c. Connect the voltmeter as shown in the figure and measure the voltage drop, V_1, across R_1 with the red probe on the +5V side and the black probe between R_1 and R_2. Measure the voltage drops V_2, V_3 and V_4 across the remaining resistors, R_2, R_3 and R_4. Comment.
   d. Set up the DMM to measure current as shown in Figure 10b. Measure the current I_1. Repeat for currents I_2, I_3 and I_4. Since you have measured the voltage drop across each resistor above, use Ohm's Law to calculate the current you expect to be flowing through each resistor. Comment.
   e. Measure the current, I_s, flowing out of the voltage source. Using the sum of the currents through the resistors and the sum of the resistors, use Ohm's Law to calculate the current. Comment. (Extra: Using the current divider relation, calculate what you expect to find for the voltage drops, I_1, I_2, I_3 and I_4. Comment.)
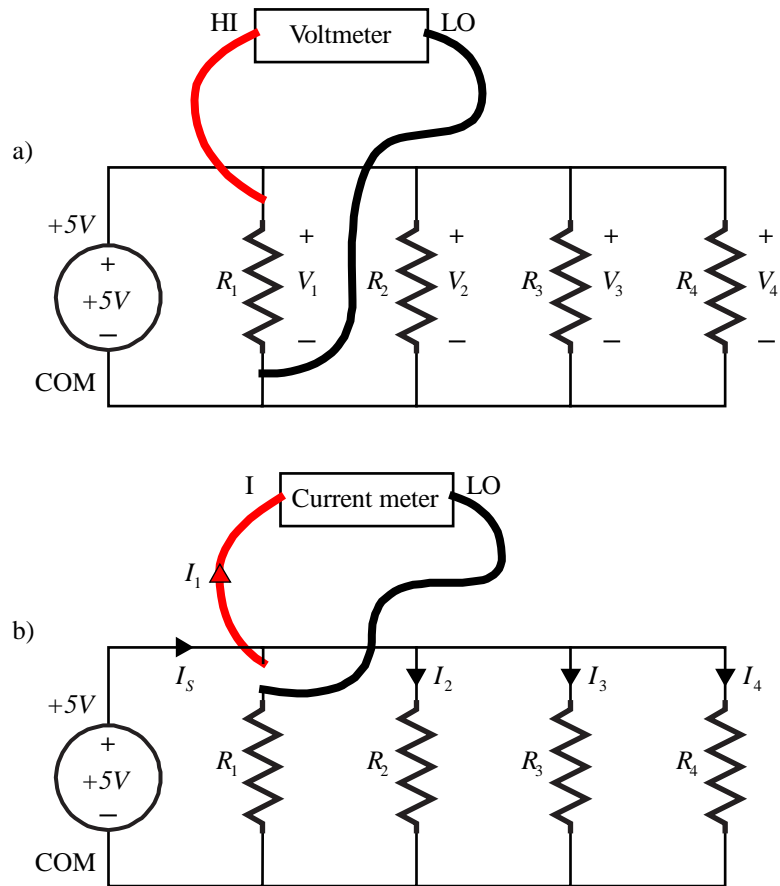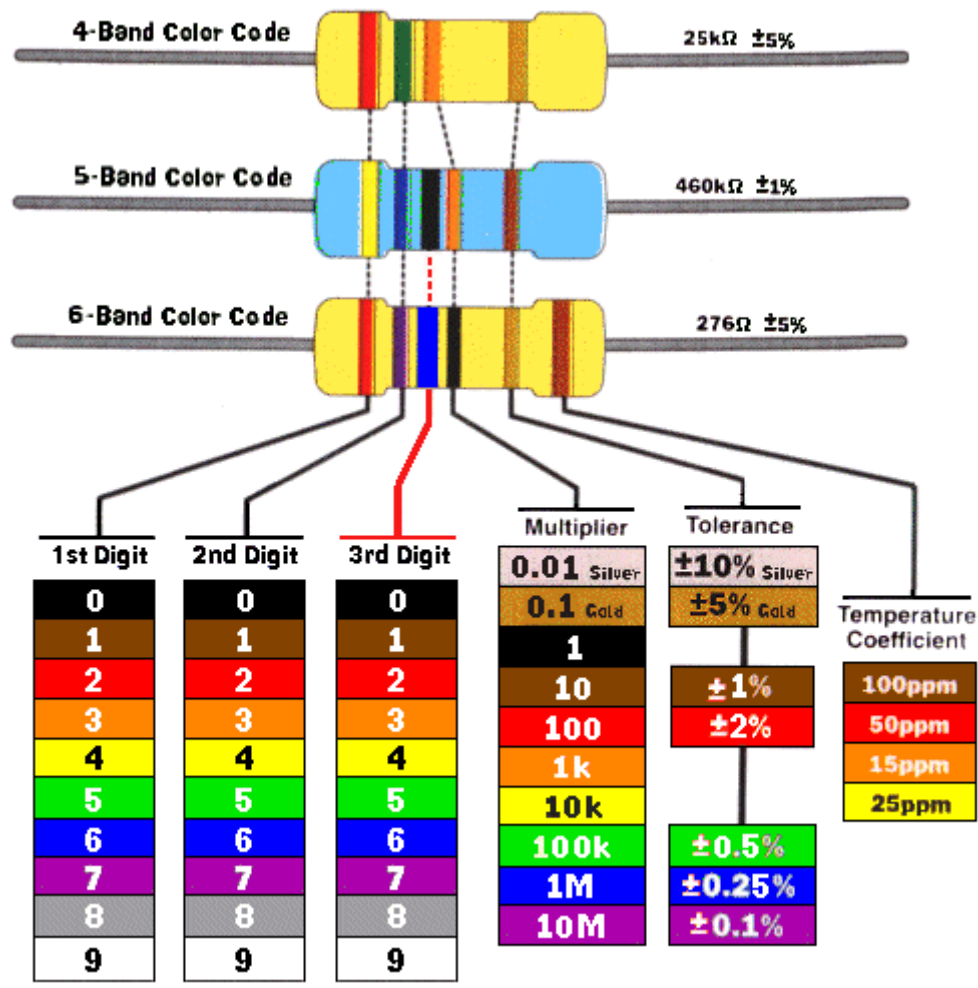
Figure 10: Circuit for part 5

Appendix A: Resistor codes

Appendix B: Least-squares linear interpolation

You can use Matlab or Excel to calculate the least-squares linear regression line for a series of data points. The following brief description can help you calculate the slope, intercept and correlation coefficient of the line.

Given N measured points with abscissa values, x_i and ordinate values, y_i, we wish to fit the straight-line with equation, $y = ax + b$, where a is the slope and b is the intercept, that will minimize the sum of the square error between measured points and the line.

Define:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

$$s_{xx} = \sum_{i=1}^{N} (x_i - \bar{x})^2 = \sum_{i=1}^{N} x_i^2 - N\bar{x}^2$$

$$s_{yy} = \sum_{i=1}^{N} (y_i - \bar{y})^2 = \sum_{i=1}^{N} y_i^2 - N\bar{y}^2$$

$$s_{xy} = \sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y}) = \sum_{i=1}^{N} x_i y_i - N\bar{x}\bar{y}$$

Then,

$$b = \frac{s_{xy}}{s_{xx}}$$

$$a = \bar{y} - a\bar{x}$$

and the correlation coefficient is defined as

$$r = \frac{s_{xy}}{\sqrt{s_{xx}s_{yy}}}.$$