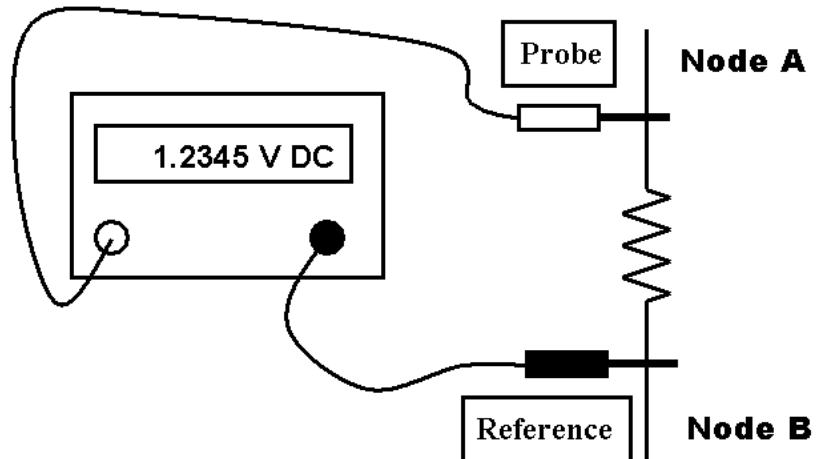


Basic Measurements with Electric Circuits

Voltage Measurements

Recall the basics of voltage and current measurements, which you learned in the pre-requisite courses.

- By definition, voltage is the difference of electric potentials between two nodes in a circuit, which we may denote **Node A** and **Node B**.
- Every voltmeter has two terminals for the two cables that ensure electrical connections to the two nodes.
- This sketch shows how to measure voltage across a resistor.
- If we swap the wires, as shown on the sketch below, the voltmeter will still measure



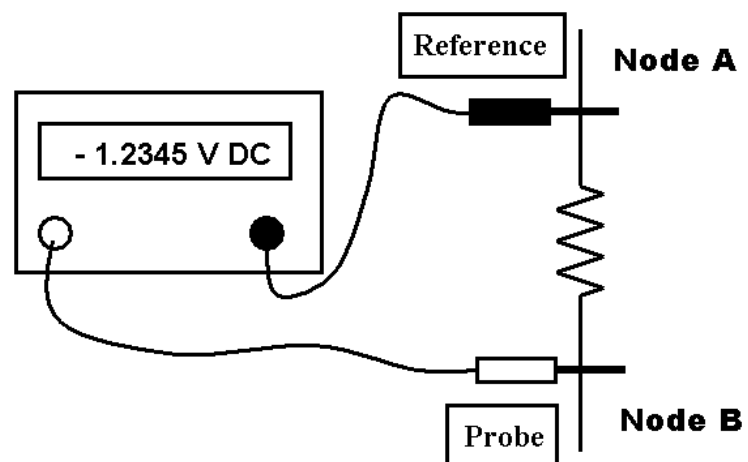
$$V_{\text{probe} - \text{reference}}$$

but, due to the reverse connections, the reading has the opposite sign. We will read:

$$V_{BA} = V_B (\text{the probe}) - V_A (\text{the reference})$$

Avoid the blunder made by students who neglected to build the right connections.

- Compare the two sketches. Notice the different connections and the opposite signs.
- When you do pre-lab calculations, keep 3 or 4 significant digits to match the accuracy of lab measurements.

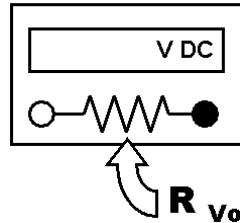


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- The voltmeter has its own internal (input) resistance, which is usually very high. For an ideal voltmeter the input resistance is infinitely large

$$R_{\text{Ideal voltmeter}} \rightarrow \infty$$

In real instruments, the voltmeter input resistance usually exceeds 1 M Ω (or $1 \times 10^6 \Omega$).



The internal (input) Resistance of a Voltmeter Is very high

$$R_{\text{Voltmeter}} > 1 \text{ MOhm}$$

- When we measure voltage V_{AB} , the voltmeter's internal resistance (between its two terminals) is connected in parallel with all circuit components that are also connected between these two terminals. In other words, the internal or input resistance of the voltmeter $R_{\text{Voltmeter}}$ is in parallel with the equivalent resistance R_{AB} . We expect that a good voltmeter, whose input resistance is very high, does not disturb the circuit: all voltages in the circuit remain unchanged after you connected the voltmeter between **Node A** and **Node B**.
- Note that you do not have to change anything in your circuit to measure voltages: just connect the voltmeter to the nodes of interest. Thus the voltage measurement is simple and noninvasive.

Current Measurements

□ To measure the current that flows through a branch of your circuit we should make this current flow through the ammeter. An ammeter has two terminals for two wires. Through one terminal labeled **Current In** on the diagrams below, the current from the circuit enters the ammeter; through the other terminal the current leaves the ammeter and flows back into the circuit. On the diagrams below this terminal is labeled **Current Out**.

□ Notice that in order to measure the current we have to interrupt the circuit: the diagrams show that instead of one **Node A** we work with **Node A1** and **Node A2**. These two nodes play distinct roles in our measurements: at **Node A1** the current leaves the circuit for the ammeter, and at **Node A2** the current is returned to the circuit.

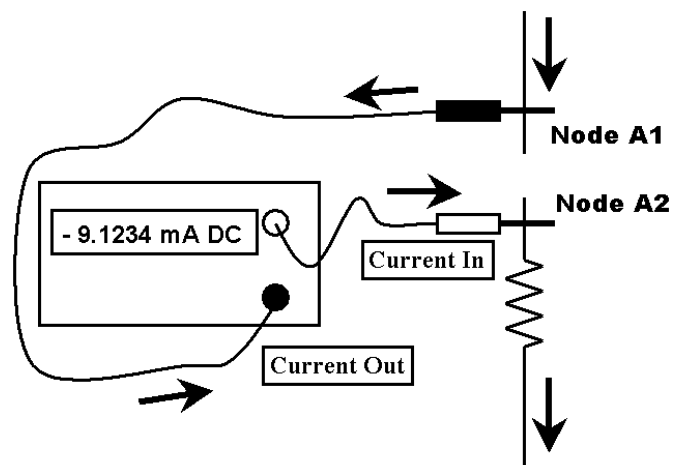
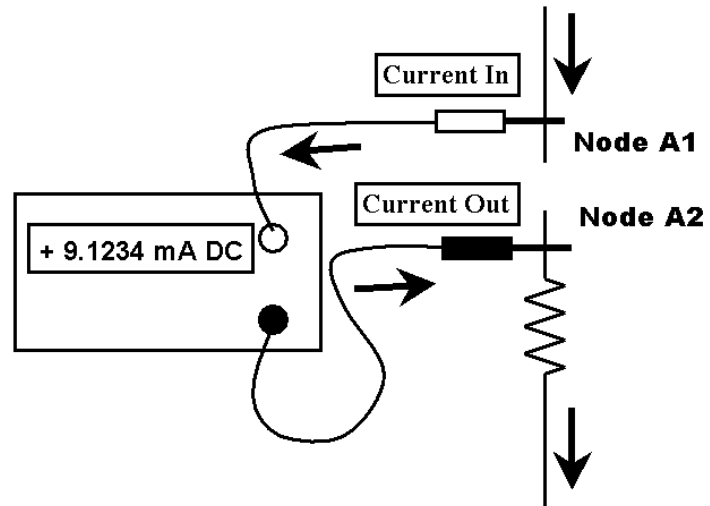
□ The current from the circuit enters the ammeter's **Current In** terminal as shown on this diagram (arrows indicate the current direction).

□ This diagram shows how to measure the current through a resistor. Notice that the circuit is broken at the point where we measure the current and the ammeter bridges the gap.

□ Notice that we make the current pass through the ammeter. Thus the ammeter is connected in series with the resistor in the circuit.

□ If we swap the wires as shown on this diagram, the current from the circuit will enter the **Current Out** terminal and the sign of the current measured by the ammeter will be reversed.

□ Take a close look at these two diagrams and make sure you understand the relationship between the connections of wires and the readings on the ammeter.



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- If we swap the wires, we will measure the current that enters the **Current Out** terminal of the ammeter and leaves from the **Current In** terminal: thus it has the same magnitude but the opposite sign compared with the current measured before the wires were swapped.
- Notice that you have to change your circuit in order to measure the current:
- Before each measurement, you have to create a new node (on the diagrams above, **Node A1** and **Node A2** were created from one **Node A**)
 - After the measurement, you have to restore the original circuit (connect the new **Node A1** and **Node A2** into the same **Node A** and disconnect the ammeter).

Thus a measurement of current is more complicated and more invasive than a voltage measurement.

The ammeter being used to measure the current through a circuit component is connected in series with that component. In other words, the internal or input resistance of the ammeter R_{Ammeter} is in series with the resistance of the component through which we measure the current.

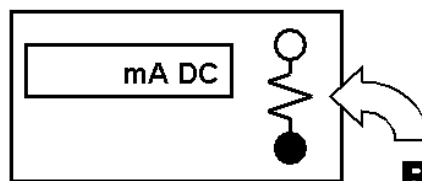
- We expect that a good ammeter, which does not disturb the circuit, should have a very low internal (or shunt) resistance.

Usually,

$$R_{\text{Ammeter}} \approx 1\Omega \text{ or less}$$

An ideal ammeter is expected to have zero internal resistance

$$R_{\text{Ideal ammeter}} = 0$$



**The internal (shunt)
Resistance
of an Ammeter
Is very low**

$$R_{\text{Ammeter}} < 1 \text{ Ohm}$$

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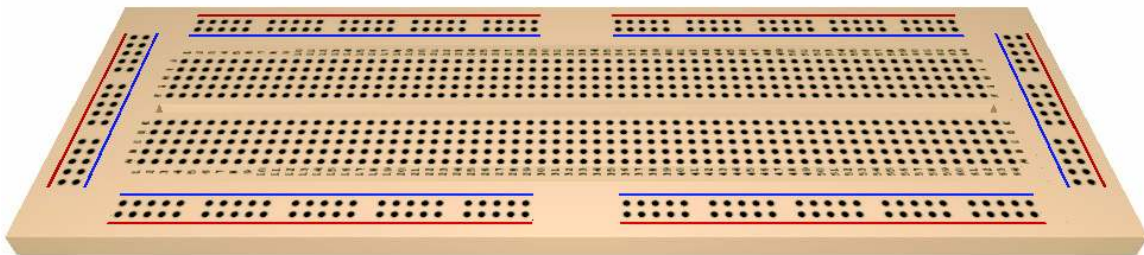
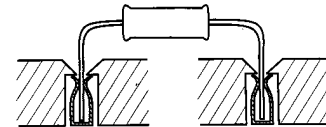
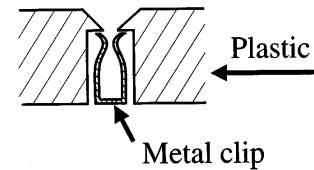
How to Build Circuits on the PB

In the lab, you will connect resistors, LEDs, and other components to each other on a PB, which allows you to build the circuit without soldering.

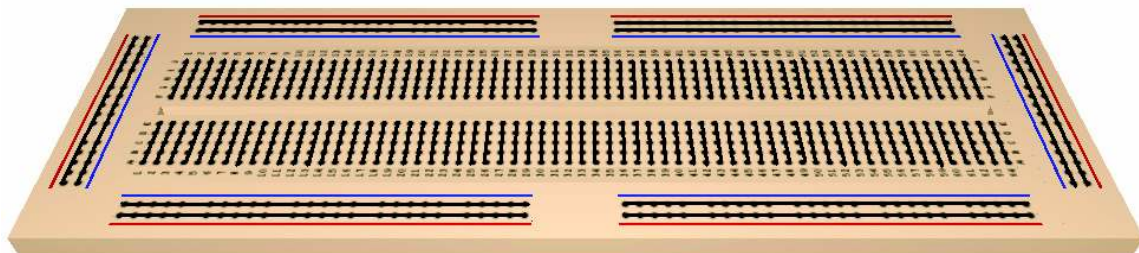
The PB used in the lab consists of several plastic blocks of various sizes, all about 0.4 inch (10 mm) thick. Each plastic block has many holes, into which you insert wires and plug in resistors and other circuit components.

Inside the plastic block, metal clips snugly hold your wires, etc., and ensure electric connections between circuit components.

Some of the holes on PB are connected to each other behind the plastic: they form nodes, to which you can connect several things such as a resistor and a wire that goes to the power supply.



The picture above shows a bare PB; the picture below also includes solid lines drawn across each group of connected holes.



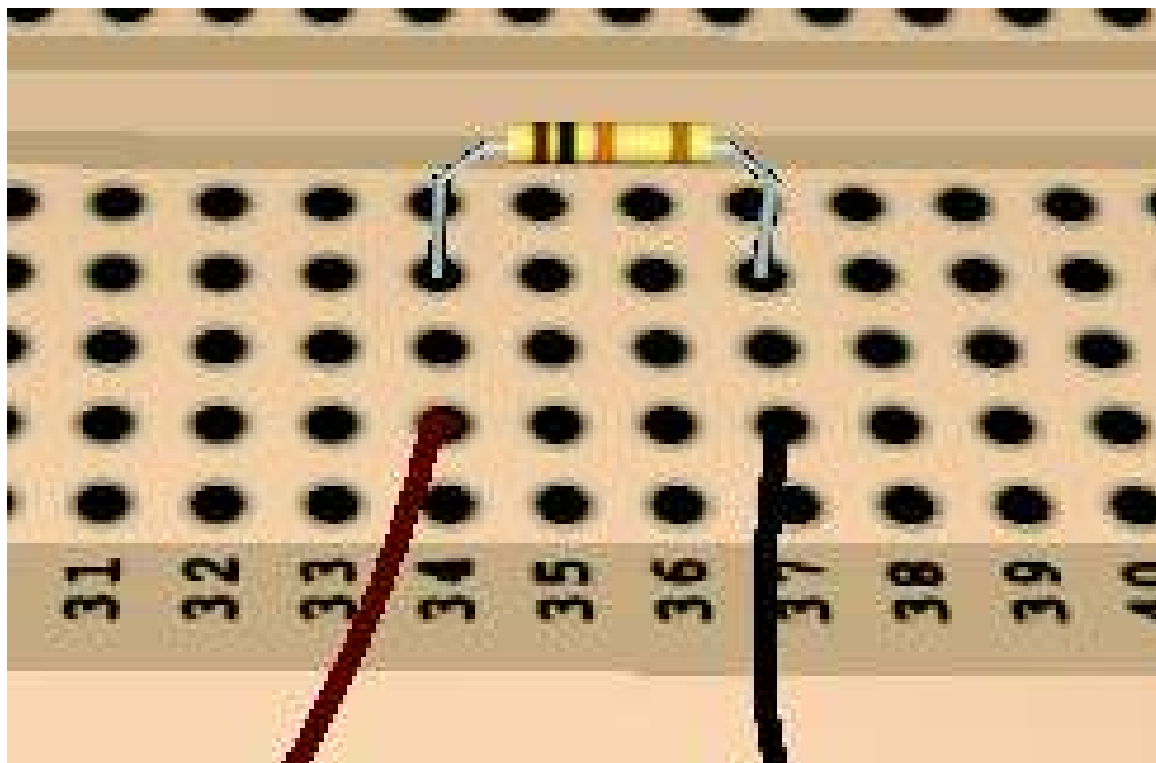
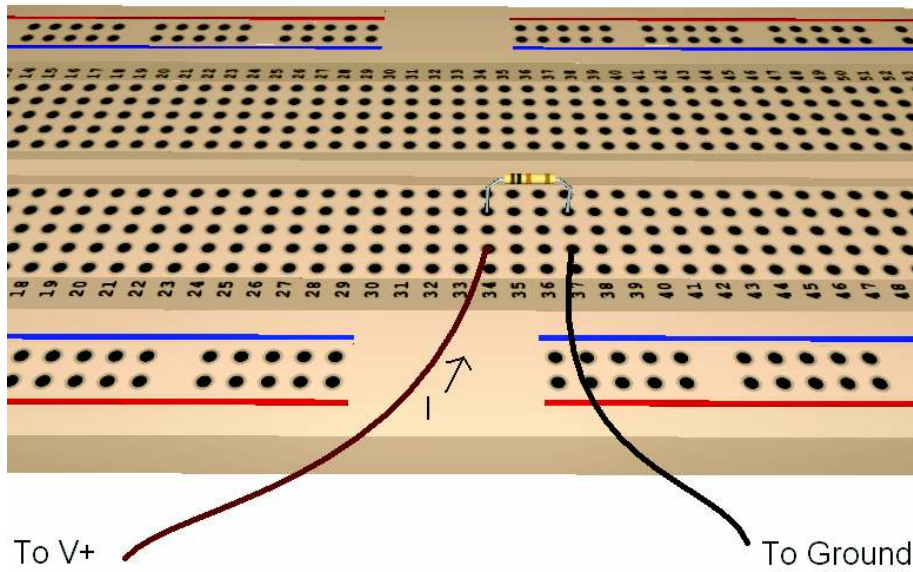
The long rows of connected holes are typically used as bus lines such as +5 V or the ground; in many experiments, they are connected to the power supply.

Note that the bus lines at the top and the bottom of the board are separated in the middle. If you wish to have a continuous bus line throughout the length of the board, add jumper wires.

Also, note that colored stripes along the bus lines serve for color-coding: for example, if you choose blue for ground, you will easily see all ground bus lines are on your board.

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Short rows of 5 holes each are used to build nodes in your circuit. For example, you can plug a resistor and a wire that goes to the power supply, as shown on the picture below.



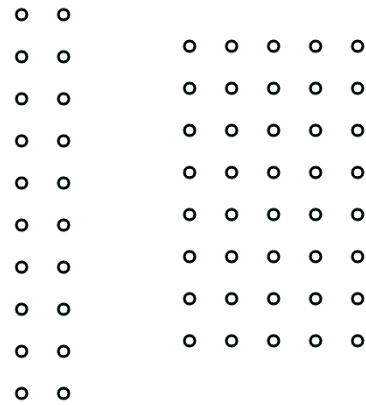
Zoomed-in view of the same picture clearly shows that the wires are inserted in the same rows of holes as the ends of the resistor.

How to Sketch Connections Before Building Your Circuit on a PB

The grid shown here can be used to sketch connections in your circuit: it is a clever way to plan the physical layout before building the real circuit on a PB.

The connections (nodes) between the holes are shown on the sketch below.

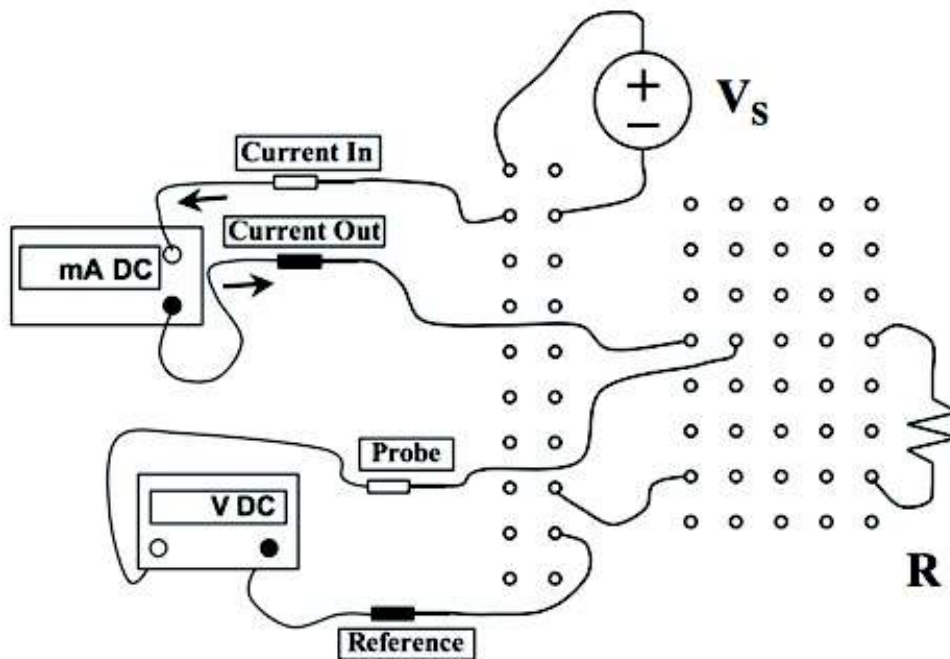
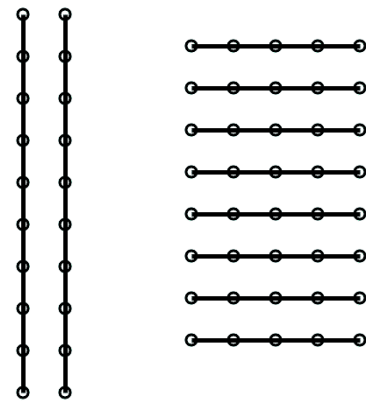
Note that the grid shows a small fraction of a PB used in the lab (see 3-D pictures on previous pages), but it is enough for simple circuits you will build in Lab 1.



The sketch at the bottom of this page shows connections for measurements of the current through and the voltage across a resistor.

Make sure you understand all connections on the sketch below (if needed, reread the previous sections).

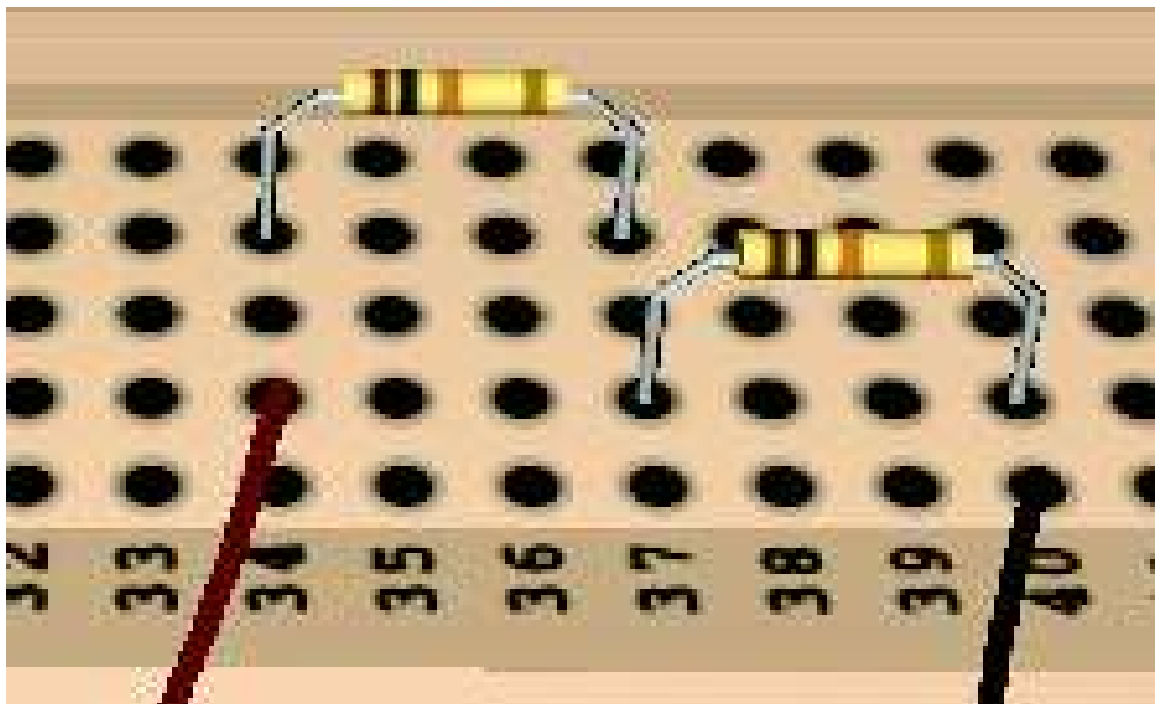
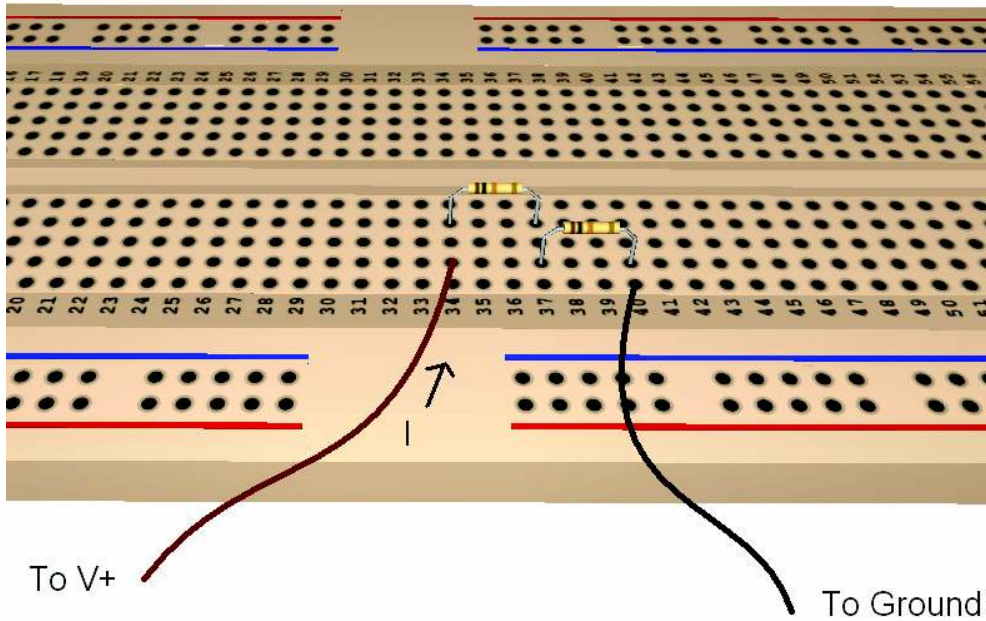
In the pre-lab, you will have to draw similar connections that will prepare you for effective circuit building on the NI ELVIS PB in the lab.



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Series Connections in Circuits on a PB and Circuit Diagrams

When two or more circuit components are connected in series, the same current flows through them all (there is no bypass for the current). The following picture shows an example of 2 resistors in series.

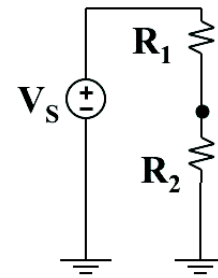


Zoomed-in view of the same picture clearly shows the rows where the wires and resistors are inserted to ensure the series connection.

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The circuit diagram for series connection of 2 resistors is shown here:

Note that the ground, to which the (-) terminal of the power supply and the “bottom” of resistor R_2 are connected on the diagram, are indeed connected to each other. Also, the ground serves as reference node, which has zero voltage.



The rule to remember:

All ground nodes are connected to each other, and they all have zero voltage.

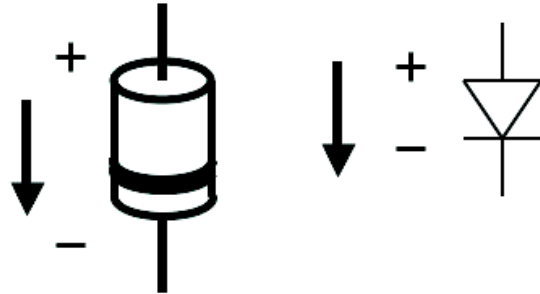
On the previous 3-D picture of the PB, resistor R_1 is connected to rows 34 and 37; resistor R_2 is connected to rows 37 and 40; row 37 corresponds to the fat dot on the circuit diagram, where R_1 and R_2 are connected to each other.

When you build circuits with resistors, it does not matter which end of a resistor connects to the ground and which one goes to the (+) terminal of the power supply. However, polarity is very important when you build circuits with semiconductor diodes.

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Circuits with Semiconductor Diodes

The circuit symbol for a semiconductor diode resembles an arrow or a triangle pointing a crossbar. The diode conducts large currents when it is forward-biased, in other words, when voltage is applied as shown on this diagram; then the current flows in the direction of the arrow.

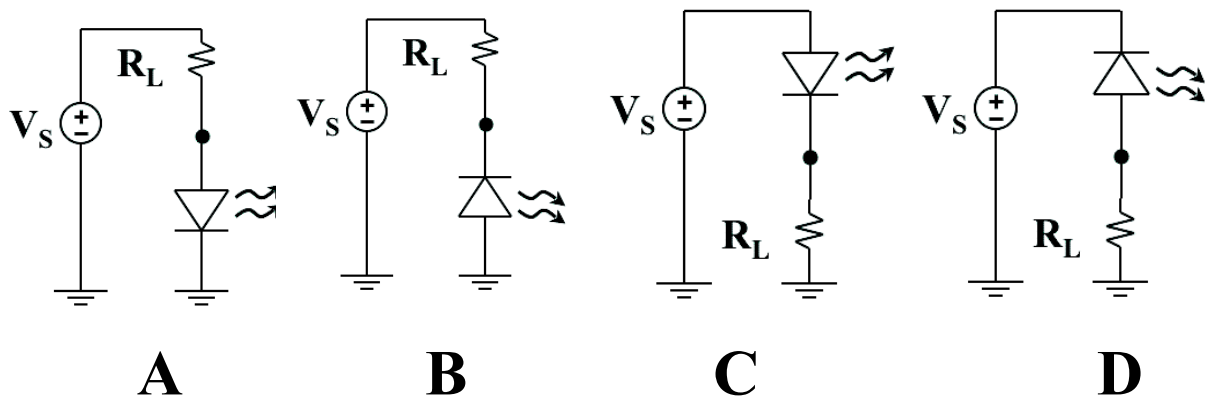
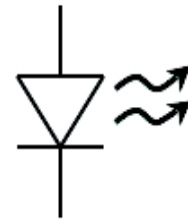


On the 3-D pictures on the next few pages, the diode is shown as a cylinder marked with a band, which corresponds to the crossbar on the circuit symbol.

In circuits, a diode must be connected in series with a load resistor; otherwise the current through it might get dangerously high.

In the lab, you will build circuits with an LED whose circuit symbol also includes wavy arrows; the polarity requirements are the same as for other diodes.

Thus, one can envision 4 various connections for the circuit with an LED, shown below and labeled A, B, C, D from left to right.

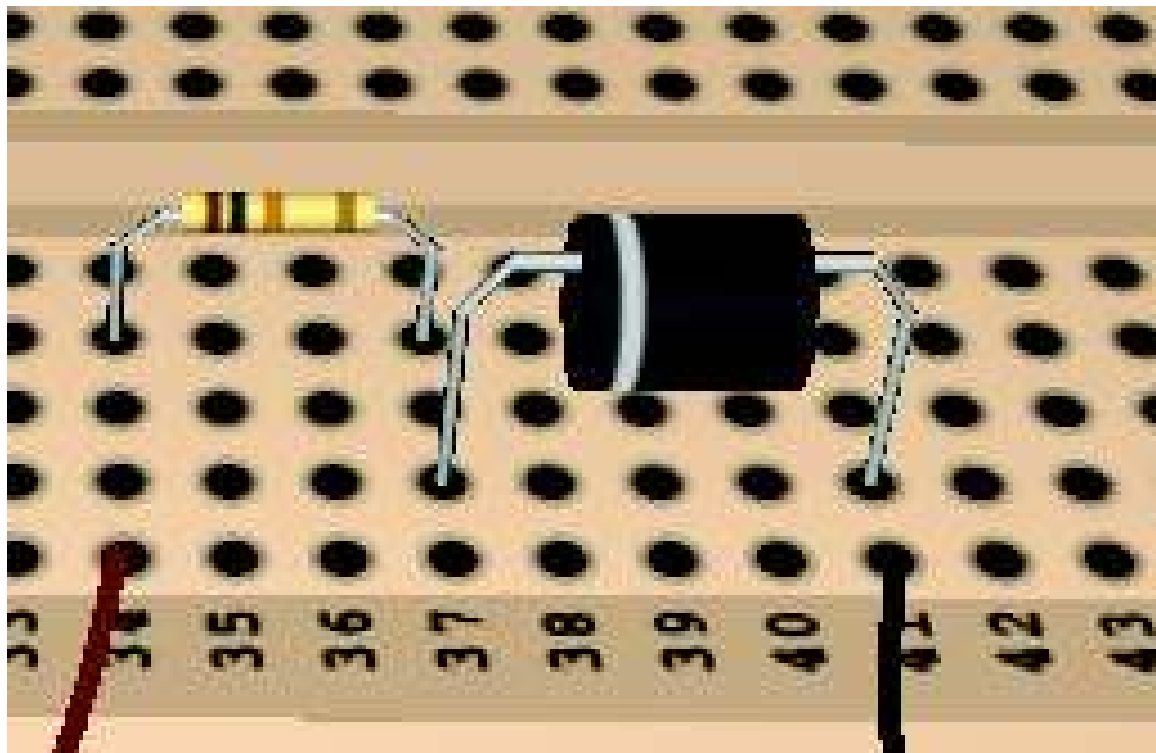
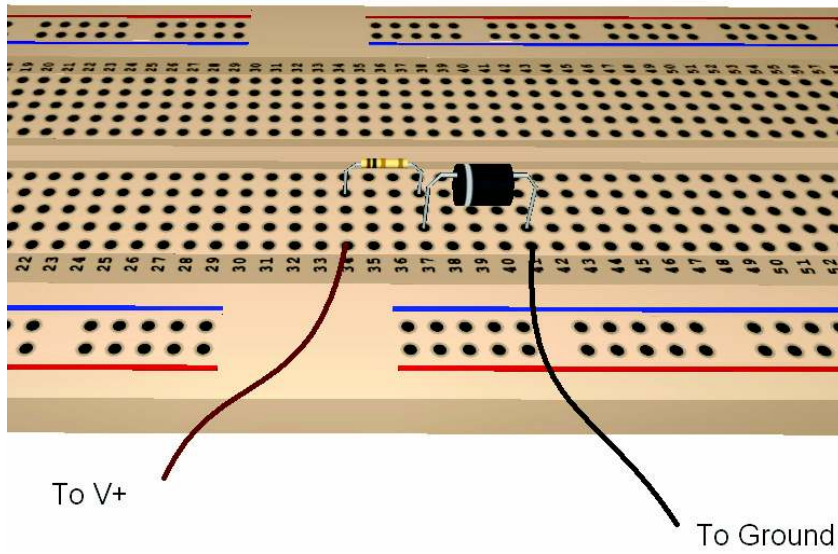


Of course, out of the 4 circuits, in only 2 the LED is forward-biased thus it will shine; in the other 2 circuits, the LED is reverse-biased and it will not shine.

The corresponding 3-D pictures of the circuit board are shown on the next pages.

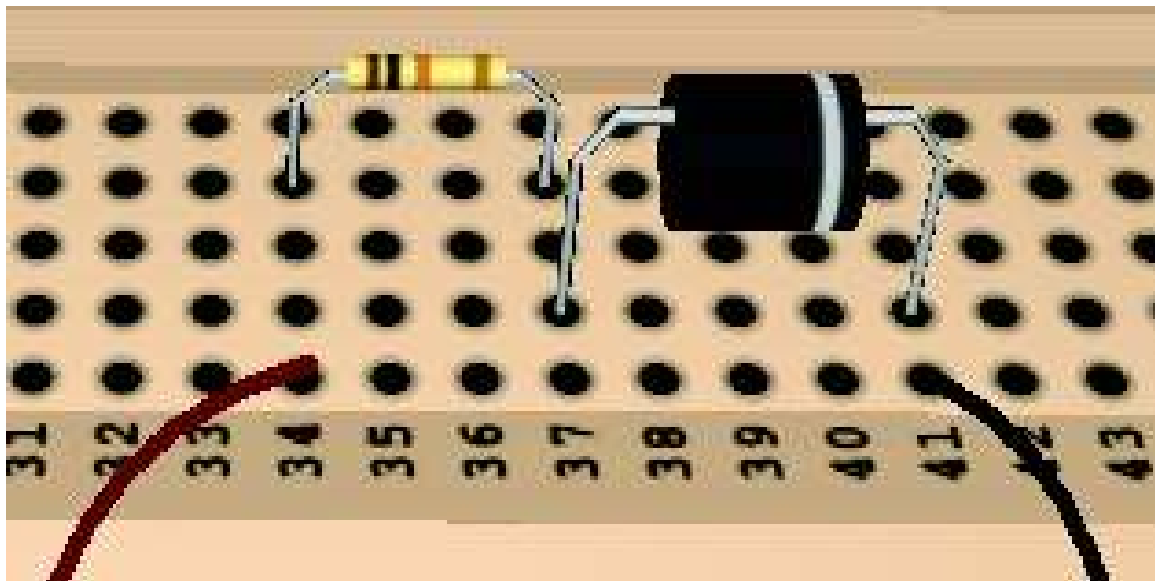
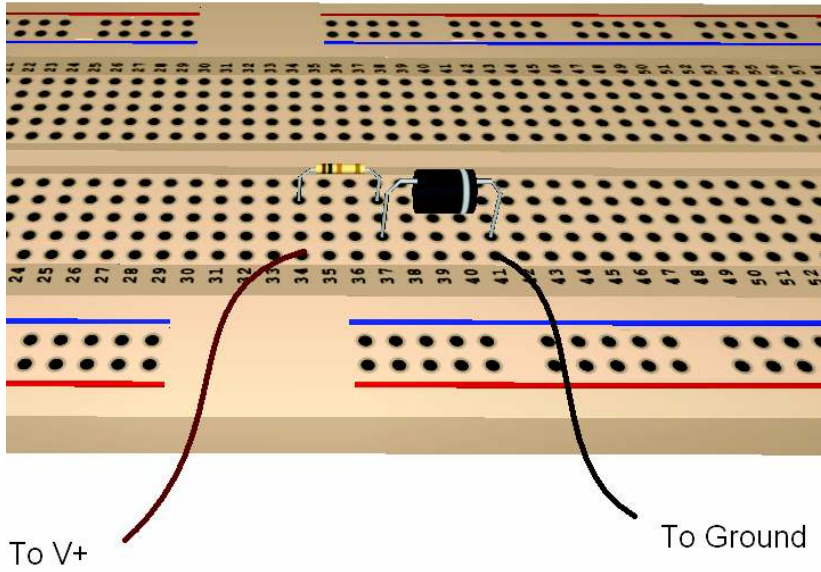
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One



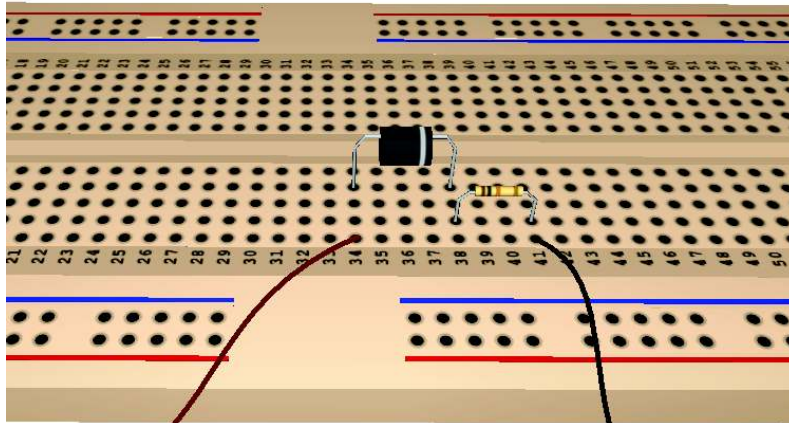
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Two



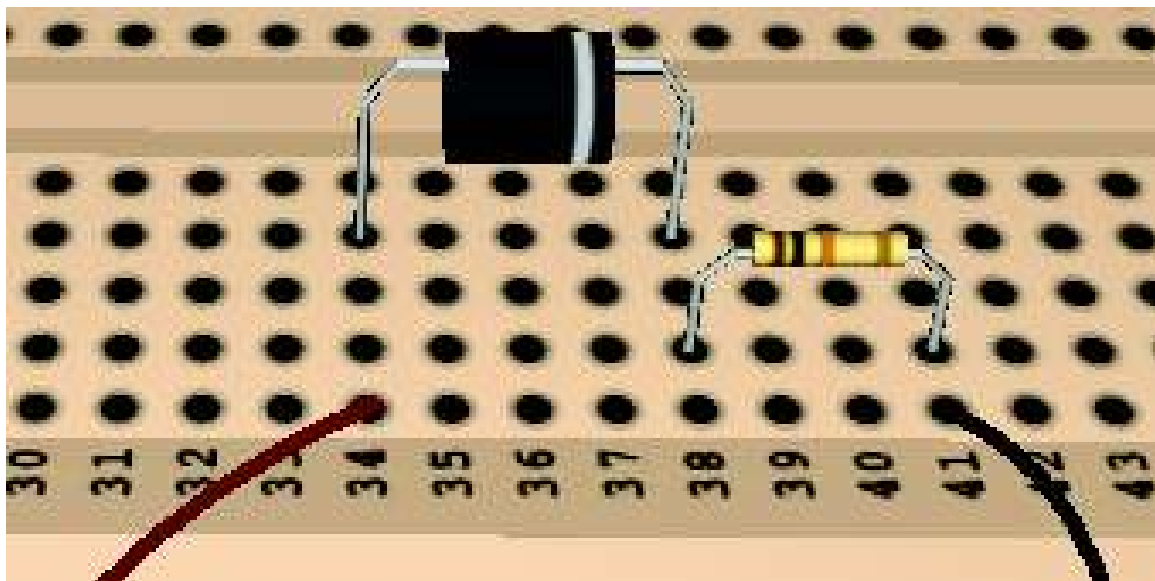
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Three



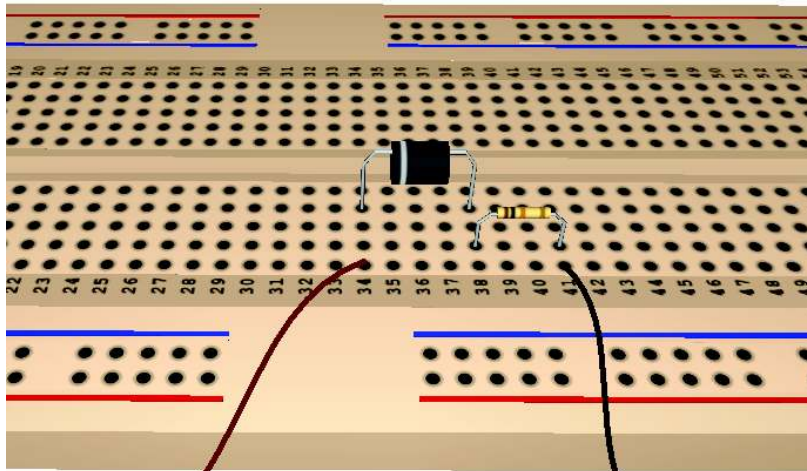
To V+

To Ground



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Four



To V+

To Ground

