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Resistance of a digital voltmeter: teaching creative thinking through an inquiry-based lab

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Abstract

We propose an inquiry-based electronics experiment in which students can practice being creative. Through this activity students can learn under what conditions the use of a voltmeter will have measurable effects on the electric circuit and how to design the circuit to measure the internal resistance of the voltmeter.

Introduction

It is usually assumed that a voltage measurement does not affect the electrical current in a circuit. Although the effect of using a voltmeter on the electrical current is often insignificant due to the voltmeter's large internal resistance (typically about 10 MΩ), in a circuit with resistance of tens of kΩ or higher the effect can be observed.

There are many ways to find the internal resistance of a digital voltmeter (DVM), and one of the main goals of this activity is to stimulate students' creative thinking [1], by having them first figure out how to observe the effect of the DVM on the electric current and then how to accurately measure its internal resistance. Another goal is to have students 'discover' under what conditions a given DVM will significantly affect the current flow.

This activity is suitable for an undergraduate General Physics laboratory, but can also be used in the high school physics lab. Students have to design a circuit, without the help of the instructor, using a breadboard, voltage source, resistors and a digital multimeter (DMM) in order to measure the unknown resistance of a DVM. This inquiry-based activity sparks discussion and exchange of ideas between students, and students find these activities more interesting than the traditional 'cookbook' type of labs because they give them an opportunity to exercise their creativity.

In order to have a significant amount of current flowing through the DVM, students must first guess its internal resistance value and then select the appropriate resistor or resistors to build the circuit. Students can be challenged to come up with different methods for measuring the internal resistance of the DVM and then to compare the results. Two very simple and accurate methods will be presented in this article.

Two simple and accurate methods

Method 1

The simplest and the fastest method is to use another DMM, set for resistance measurement, and insert its power leads directly into the DVM whose internal resistance we wish to determine. One lead should be inserted into the COM and the other one into the

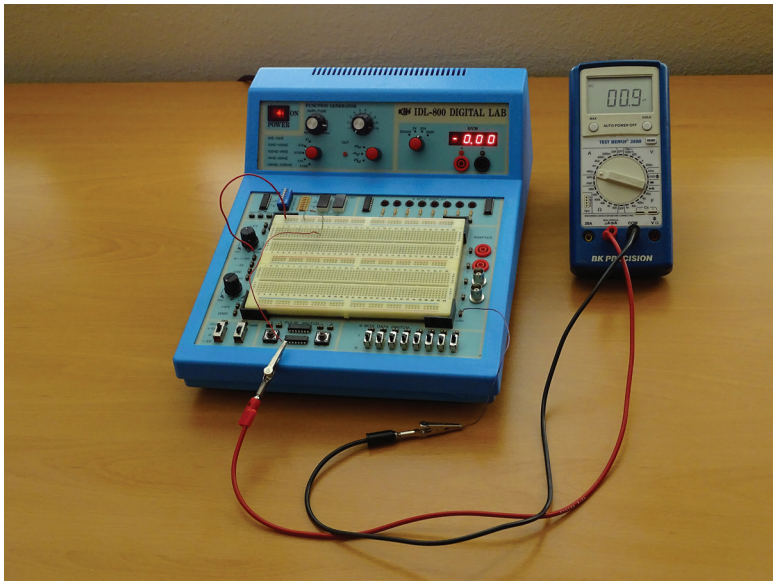

Figure 1. A simple circuit design with a voltage source, a resistor and a digital ammeter connected in series, using a breadboard. Without measuring the voltage, the current is 0.9 μA.

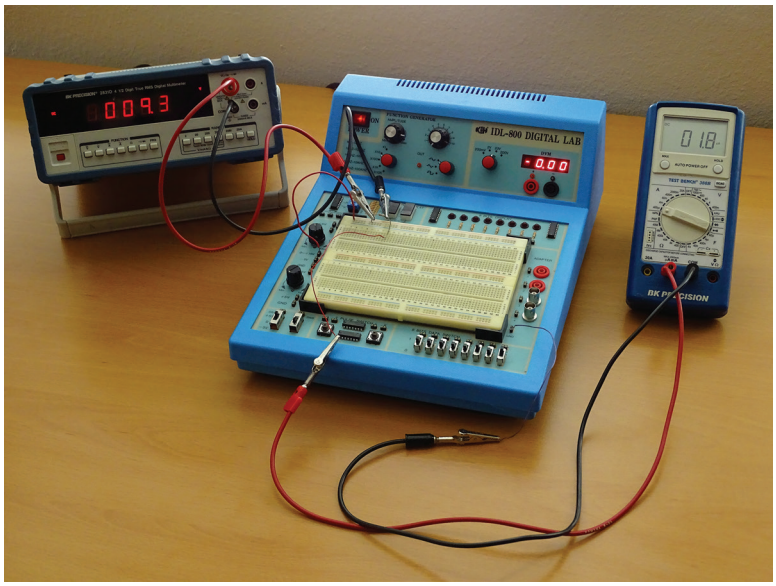

Figure 2. The circuit from figure 1 with a DVM measuring the voltage. During this voltage measurement the current is 1.8 μm. The current increases because the color code resistor and the internal resistor of the DVM are connected in parallel.

V, Ω hole. This method gives the resistance reading within seconds. In this case two DMMs can measure each other's internal resistance. Students, however, generally do not see this solution. This direct measurement of the internal resistance of both of our DVMs gave the value $R_{\mathrm{DVM}} = 10.0\,\mathrm{M}\Omega$.

Method 2

The second method uses the circuit shown in figure 1. It contains a voltage source, a colour coded resistor and a digital ammeter connected in series. The resistance of the colour coded resistor was measured as $R = 10.6$ MΩ

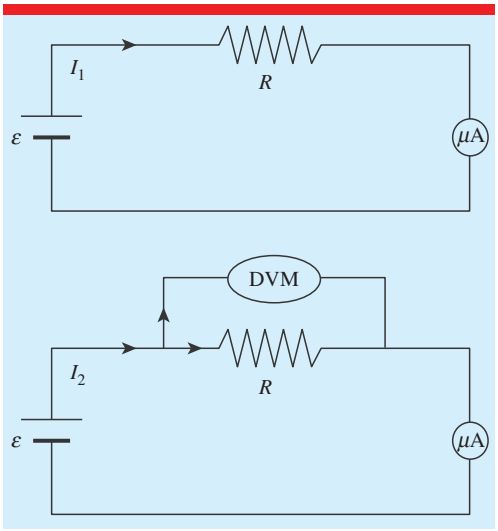

Figure 3. Circuit diagrams corresponding to figure 1 (upper circuit) and figure 2 (lower circuit).

whereas the current in this circuit was measured as $I_1 = 0.9\ \mu$A. The idea is to observe how the measurement of the voltage affects the current in the circuit. Then from this change in current the internal resistance of the DVM can be determined.

Figure 2 shows the same circuit with a DVM measuring the voltage ($\varepsilon = 9.3$ V in this experiment). The color code resistor and the internal resistor of the DVM are connected in parallel and as a result the current increases to $I_2 = 1.8\ \mu$A. Figure 3 displays circuit diagrams corresponding to the experiments shown in figure 1 (upper diagram) and figure 2 (lower diagram).

The equivalent resistance in the second circuit, R_{eq}, can be found using $R_{\text{eq}} = \frac{\varepsilon}{I_2} = 5.2\,\text{M}\Omega$, whereas the internal resistance of the DVM can be calculated from $\frac{1}{R_{\text{eq}}} = \frac{1}{R} + \frac{1}{R_{\text{DVM}}}$ as $R_{\text{DVM}} = \frac{RR_{\text{eq}}}{R-R_{\text{eq}}}$ which in this case gives $R_{\text{DVM}} = 10.1\,\text{M}\Omega$. Comparison of the two methods presented here reveals almost identical values.

Suggestions to instructors

- Ask students to measure the internal resistance of the DVM by building an electric circuit
- Ask students to be creative and come up with different methods or to measure the internal resistance of two DVMs at the same time in the same circuit
- Observe students' experiments and tell them whether or not they are using the DMMs properly
- Remind students that in order to measure the current, if that is what they want to measure, they have to break the circuit and insert an ammeter to close it
- Give students access to various resistors, from Ω, through kΩ to MΩ, and have them realize that unless they use resistors whose values are close to or higher than the value of the internal resistance of the DVM, the effect of using the DVM may not be observed
- The use of a breadboard makes the task a bit more challenging and much more interesting.

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