Measurements in electric circuits and Ohms Law

Objective

Learn to use voltmeter and amperemeter to perform measurement of voltage and current in simple electric circuits, learn and examine Ohm's law in simple electric circuits.

Theory

Electric circuits form the foundation for all electric and electronic devices in use today. Simple electric circuits are composed from the basic electric elements such as resistors, capacitors and inductances and can be understood in terms of electric current flow through and changes of electric potential, or voltage, in such elements.

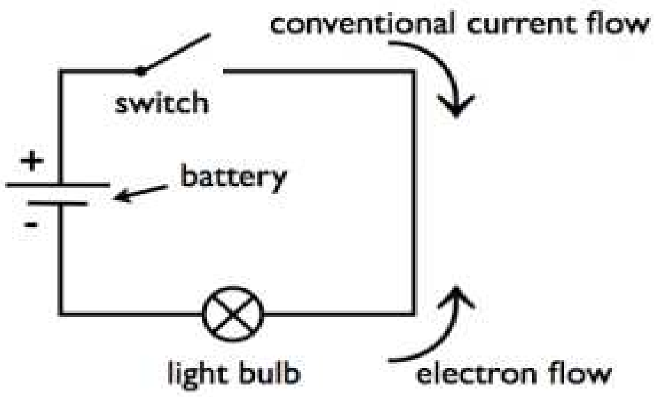


Figure 1 A simple electric circuit diagram.

A useful analogy for the movement of the electric current in such circuit is that of water flowing in a system of pipes. In this analogy, electric current can be thought of as water flow and electric potential can be thought of as the water's pressure. As water flows from high pressure towards low pressure in regular pipes, the electric current flows from the regions with high electric potential towards the regions with low potential. Just like greater pressure causes water to flow faster, greater voltage causes electric current to be stronger. And just like flowing water can make mechanisms to work, so does electric current makes numerous electric and electronic devices function.

Note that due to historical reasons, the current in the circuit diagrams is usually shown as flowing from positive (high) electric potential to negative (low). In reality, the current flow is caused (in most cases) by the movement of negatively charged electrons, which move from negative battery poles to positive poles, in exactly opposite direction (Figure above)!

The basis to good understanding of behavior of electric current in different electric circuits lies in the ability to measure electric voltage and current in different parts of such circuits. Such measurements are performed using the instruments known as voltmeters and amperemeters.

Voltmeter is the device used to measure the difference in the electric potential, or voltage, between different parts of electric circuits. The electric potential is analogous to the pressure in water pipes, and is measured in the units of Volts, which is why the name “voltmeter”. In circuit diagrams, voltmeters are usually indicated with the letter V enclosed in a circle.

Figure 2 Voltmeter is a device used to measure the difference in electric potential, or voltage, between different points in a circuit.

The voltmeter can only measure the difference in the electric potential, or voltage, between two points in an electric circuit; it is not possible to measure the “absolute voltage”, only voltage difference. In the end, the voltage difference is what is important for moving electric currents. In order to measure voltage, the voltmeter should be connected *in parallel* to the points between which the voltage is to be measured, as shown below. The reading on the voltmeter, then, shows the electric potential difference between these two points. Electrically, voltmeter can be thought of as a resistor with very high resistance – no current flows through voltmeter when it is connected to an electric circuit.

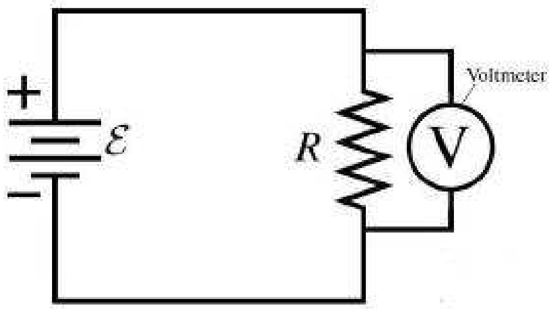


Figure 3 Voltmeter is connected in parallel to the two points in the circuit between which the voltage is to be measured.

Amperemeter is an instrument for measuring the strength of electric currents. Electric current is the flow of electric charge through a point, and is measured in the units of Ampere, which is why the name amperemeter. One Ampere corresponds to the electric current for which one Coulomb of charge passes through some point in one second. In circuit diagrams, amperemeters are denoted with the letter A enclosed in a circle. Amperemeters are also sometimes called galvanometers.

Figure 4 Amperemeter is a device used to measure the strength of electric current flowing through different parts of a circuit.

As amperemeter measures the flow of the electric current, as could be expected, it should be connected *in series* to the point through which the current is to be measured, as shown below. Electrically, amperemeter can be thought of as a resistor with very small, nearly zero resistance – there is no voltage difference over an amperemeter when current flows through it.

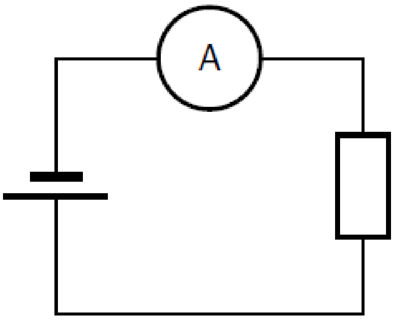


Figure 5 Amperemeter is connected in series to the point for which the electric current is to be measured.

In many modern applications both amperemeter and voltmeter instruments are combined into single electromechanical or electronic *multimeter* devices. Such devices can be used as either amperemeters or voltmeters depending on the position of an adjustable switch.

Figure 6 Modern l multi-meters combine the functions of both voltmeter and amperemeter instruments.

If both voltage and current measurements are to be performed at the same time, the amperemeter is usually connected in series and the voltemeter is connected in parallel to the element of the circuit where the measurement is to be performed, as shown below.

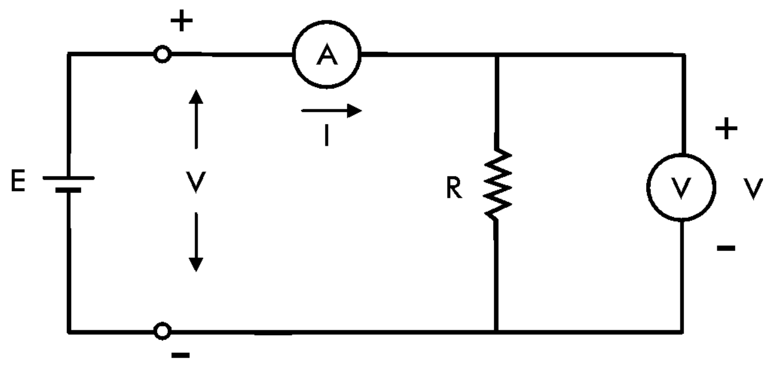


Figure 7 If both voltage and current are to be measured together, the amperemeter is connected in series and the voltemeter is connected in parallel.

Ohm's Law

The voltage and current in simple electric circuits are related via the basic Ohm's law. Ohm's law was discovered by Georg Ohm when he was investigating the basic properties of electric currents in 1781. According to Ohm's law, for an element of an electric circuit, the current in that element is directly proportional to the voltage change over that element. The constant relating the voltage and the current is called resistance, and is usually denoted with letter *R*. Therefore, if a current flowing through a circuit element is I, and the voltage change over such element is *V*, then Ohm's law states that

$$V = I \cdot R$$

In terms of our water analogy, the more pressure (*V*) is applied, the more current flows through a circuit element. The constant *R* describes how hard it is to make the current flow through the element. If current is measured in Amperes and voltage is measured in Volts, resistance is measured in Ohms, often denoted with the Greek symbol Ω (read as "Omega"). Thus, 1 Volt = 1 Ampere · 1 Ω.

Ohm's law is an approximate law. Although all circuit elements have some resistance, resistance may depend on the current itself (Ohm's law implies that resistance is independent of the applied current or voltage). The electrical devices for which Ohm's law is true and the resistance is constant are called linear electrical devices. Such devices are resistors, capacitors, and conductors. The devices for which Ohm's law is not satisfied are called nonlinear electrical devices. Among many important such devices are diodes, vacuum lamps, and transistors.

Ohm further established that the resistance in many cases can be calculated using following simple formula

$$R = \rho \frac{l}{A}$$

where Greek letter ρ (read as "rho") describes the property of the material known as electrical resistance, ℓ is the length of the resistor and A is the area of the resistor. In terms of our water analogy, that is, the bigger the resistor is, the easier the current (I) can move through it, and the longer the resistor it, the more pressure (V) is required to move the same current through it.

It is easy then to understand that, if two similar resistors are put next to each other, this is equivalent to having a resistor of twice bigger area (A), so that twice as much current can go through. Thus, the resistance of such two side-by-side resistors has to be two times smaller. Similarly, one resistor is put right after another, this is equivalent to having a resistor that is two times longer (ℓ), thus requiring twice as much voltage to move the same current through. Thus, the resistance of such two one-after-another resistors has to be two times bigger.

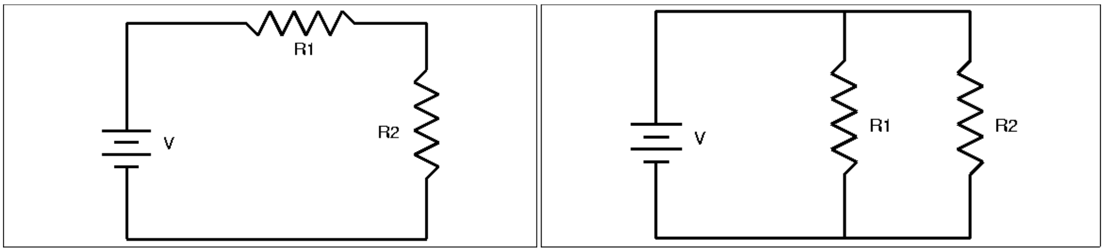


Figure 8 Two resistors connected in series require more voltage to move the same current, while two resistors connected in parallel allow more current to pass for the same voltage.

In more general form, the equivalent resistance of two resistors connected in series would be given by

$$R = R_1 + R_2$$

and that connected in parallel would be

$$1/R = 1/R_1 + 1/R_2.$$

Equipment

- Electric circuit experiment set;
- Mounted lamp element;
- Two mounted resistor elements;
- Cables.

Procedures

1. Familiarize yourself with the electric circuit experiment set.
   The electric circuit experiment set contains a circuit board with a number of ports with which you can implement various electric circuits using special provided electric elements and cables, a DC power source of 5V and 12V (upper left), an AC power source of 12V (upper right), a two way switch (lower left), a battery pack (lower right), and a voltmeter and an amperemeter (the upper part). Note that the units of measurement on the voltmeter are Volts and on the amperemeter are Amperes.
2. Be sure that you understand the DC power, the circuit board, and the voltmeter/amperemeter parts of the electric circuit experiment set before your proceed further.

3. Use provided mounted lamp element and red and black cables to implement the *circuit A* below connected to the 5V DC power source. As a rule, use red cables to connect positive and black cables to connect negative-labeled contacts. Once complete, be sure to verify your circuit with the instructor and obtain his/her permission to proceed further. DO NOT TURN THE POWER ON before talking with your instructor.
4. Turn the power on and obtain the measurement of the voltage and the current going through the lamp with the built-in voltmeter and amperemeter instruments.
5. Turn the power off and re-connect your circuit to the 12V DC power source.
6. Turn the power on and re-obtain the measurement of the voltage and the current for the lamp using the built-in voltmeter and amperemeter instruments.
7. Repeat steps 3-6 using the *green resistor* instead of the lamp. Note: because of the high current the resistor may burn when connected to 12V if left on too long – *do not keep the power on any longer than is necessary to take your measurements.*
8. Turn the power off and implement the *circuit B* below connected to the 5V DC power source.
9. Use this new circuit to obtain a series of three measurement – (i) the voltage and the current for each of the resistors R1 and R2 separately, and (ii) the total voltage drop and the total current through both resistors R1 and R2 together. Consult the extra diagrams in circuit B for the proper ways to connect the voltmeter and the amperemeter, if necessary.
10. Turn the power off and implement the *circuit C* below connected to 5V DC power source.
11. Use this new circuit to obtain a series of three measurement of (i) the voltage on and the current for each of the resistors R1 and R2, and (ii) the total voltage drop and the total current through both resistors R1 and R2 together. Consult the extra diagrams in circuit C for the proper ways to connect the voltmeter and the amperemeter, if necessary.

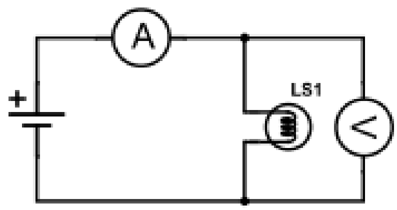
ANALYSIS (TO BE PERFORMED IN THE REPORT)

12. Calculate the resistance of the lamp element using your measurements in (4) and (6) and Ohm's law, V=IR, when the lamp was connected to the 5V and 12V DC power source. Does the lamp satisfy Ohm's law? Why do you think that is?
13. Calculate the resistance of the green resistor using your measurements in (7) and Ohm's law, V=IR, for 5V and 12V. Does resistor satisfy Ohm's law?
14. Calculate the resistance R1 and R2 using Ohm's law, V=IR, and your measurements of V and R for each resistor in (9i).
15. Use your measurements of the total voltage drop and the total current through R1 and R2 in (9ii) to calculate the total resistance of two resistors in series, and verify that Rtot=R1+R2, that is, Vtot=Itot (R1+R2).
16. Calculate the resistance R1 and R2 using Ohm's law, V=IR, and your measurements of V and R for each resistor in (11i).
17. Use your measurements of the total voltage drop and the total current through R1 and R2 in (11ii) to calculate the total resistance of two resistors in parallel, and verify that 1/Rtot=1/R1+1/R2, that is Itot=Vtot/R1+V tot/R2.

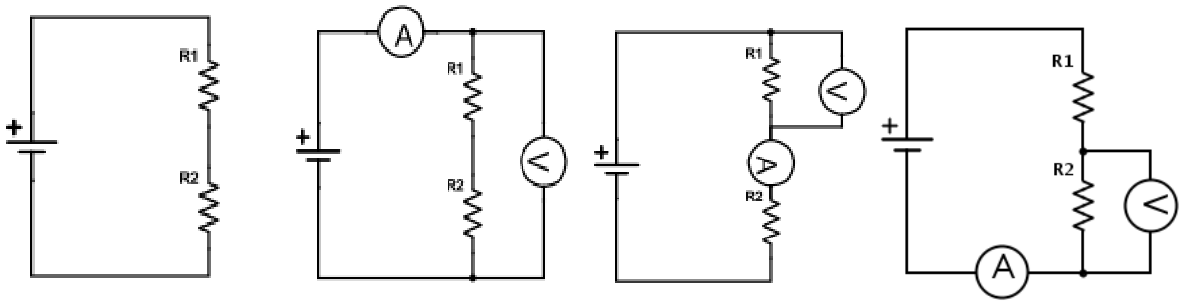
(Sample report and other information can be found at http://scinetcentral.com/~mishchenko/PHY102.html)

ELECTRIC CIRCUIT DIAGRAMS

Circuit A;



Circuit B;



Circuit C;