

# Experiment 1: Measuring the Current-Voltage Characteristics of Electric Elements

## 1. Purpose

- Master the method to measure the current-voltage characteristics of linear resistors, non-linear resistors, and current sources.
- Know how to use DC electrical instruments and equipment.

## 2. Principal and Illustration

### A. Current-voltage characteristics of resistors

In electronics, the relationship between the direct current (DC), denoted by  $I$ , through an electronic element and the DC voltage across its terminals, denoted by  $V$ , is called a current–voltage characteristic of the element. It is also known as I-V curve (or current-voltage curve) when we plot the relationship on I-V plane.

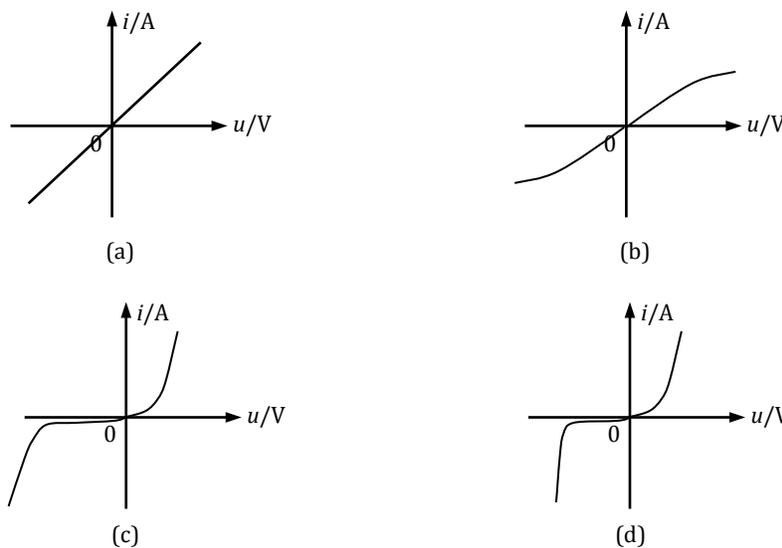


Figure 1. The current-voltage characteristics of resistors.

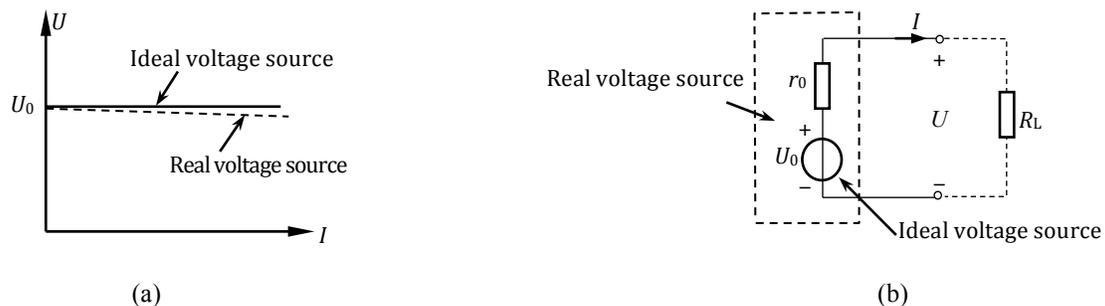
According to Ohm's Law, The I-V curve of a linear resistor is a line pass through the origin of coordinate, as shown in Figure 1 (a). The reciprocal of the slope of the line is equal to the resistance  $R$  of the resistor. The I-V curve in Figure 1 is symmetric about the origin, which is known as bidirectional conductivity. Almost all kinds of resistors have this property. In reality, environmental factors such as temperature or material characteristics of the resistor can produce a non-linear I-V curve. For example, the

temperature of a lamp could be extremely high when it works. The resistor of the lamp increases as its temperature increases. Therefore, the stronger current flowing through the lamp results in its higher temperature, which further leads to the larger resistance of it. Generally, the *cold resistance* and the *hot resistance* of the same lamp might be quite different, the later could be more than ten times of the former. The I-V curve of a bulb is shown in Figure 1 (b).

Normal semiconductor diodes are a kind of non-linear resistors. The resistance of a diode changes with the current flowing through it. The I-V curve of a diode is shown in Figure 1 (c), where we can see that diodes have unidirectional conductivity. The forward voltage of a diode is always very small (about 0.2 to 0.3 V for Germanium diode and 0.5 to 0.7 V for Silicon diode), and the forward current increase rapidly as the forward voltage increases; while the backward current increases quite slightly as the backward voltage increases, even when the later increases to tens of Volts, in this case, the backward current is always close to zero. However, it should be noted that the diode will be broken if the backward voltage exceeds its limiting value. Zener diodes are a particular kind of semiconductor diodes. They have very similar forward, but quite different backward characteristics, as shown in Figure 1 (d). At the beginning, as the backward voltage increases from zero, the backward current almost keeps the same and is close to zero; however, when the backward voltage exceed some threshold (known as Zener voltage), the current rises suddenly, then the voltage between its two terminals will keep the same and will not increases any more as the backward voltage increases.

### B. Current-voltage characteristics of voltage and current sources

The voltage across the terminals of an *ideal voltage source* doesn't change with the current flowing through it, and thus its I-V curve is a horizontal line that is parallel with the I-axis, as shown in Figure 2 (a) (solid line).



**Figure 2. (a) The current-voltage characteristics of voltage source. (b) The circuit model for the real voltage source.**

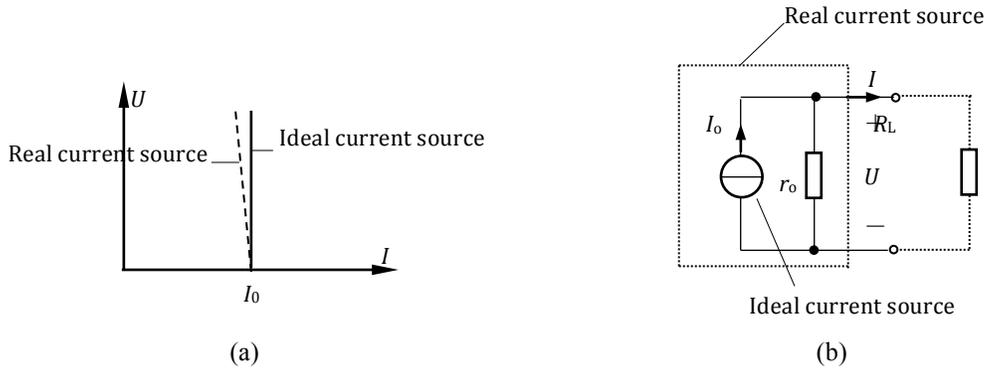
However, most voltage sources in reality, such as batteries and generators, have finite internal resistances. As a result, the voltage across the terminals of a *real voltage source* with load will be slightly smaller than that without load ( $I = 0$ ), since nonzero current will cause the voltage drop across its internal resistance. The I-V curve of a real voltage

source is also a line but with a small negative slope, as shown in Figure 2 (a) (dashed line). The circuit model of a real voltage source is shown in Figure 2 (b) and its internal resistance can be estimated by

$$r_0 = (U_0 - U)/I \quad (1)$$

where  $U$  and  $I$  are the voltage and current across the terminals of the source when they are connected to a load, while  $U_0$  is the open circuit voltage of the source. Equation (1) indicates that the smaller the internal resistance is, the closer the real voltage source is to the ideal one.

Nowadays, we can produce voltage sources of quite high performance, i.e., they are very close to ideal ones, such as various types of voltage-stabilized sources. Their I-V curve is very close to a horizontal line. The DC voltage-stabilized source that we will use in the experiment has very small internal resistance and thus can be considered as ideal voltage source if the current flowing through is within a certain given range.



**Figure 3. (a) The current-voltage characteristics of current source. (b) The circuit model for the real current source.**

Similarly, an ideal DC current source maintains a fixed value of current regardless of the voltage across its two terminals. Its I-V curve thus is a vertical line that is parallel with the  $U$ -axis, as shown in Figure 3 (a) (solid line). The DC current-stabilized source that we use in the experiment has very similar I-V curve. However, for a normal DC current source, the current drops slightly as the increase of the voltage across its two terminals. Its I-V curve is shown in Figure 3 (a) (dashed line). The circuit model of such a current source is shown in Figure 3 (b) and its internal resistance can be estimated by

$$r_0 = U/(I_0 - I) \quad (1)$$

where  $U$  and  $I$  are the voltage and current across the terminals of the source when they are connected to a load, while  $I_0$  is the short circuit current of the source.

### 3. Contents and Steps

#### A. Measure the current-voltage characteristics of linear resistor

Connect the electric elements as shown in Figure 4. Note that the voltmeter is connected in parallel, while the ammeter is connected in series, with the resistor  $R_L$ . Both voltmeter and ammeter are numerical ones. Change the output voltage of the voltage-stabilized source to make the voltage across the resistor arise from 0 V to 10 V steadily, and record the corresponding voltages and currents into the Table 1.

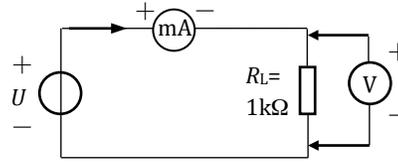


Figure 4. The electric circuit to measure the current-voltage characteristics of linear resistor.

Table 1. The measured data for the current-voltage characteristics of linear resistor.

$U$ (V)						
$I$ (mA)						

#### B. Measure the current-voltage characteristics of nonlinear lamp

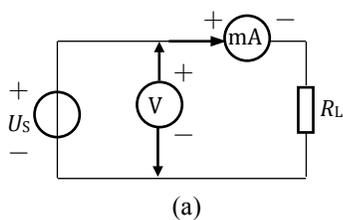
Replace the resistor in Figure 4 by a lamp (12 V), repeat the above experiment, and record the corresponding voltages and currents into the Table 2. Note that the voltage across the lamp must smaller than 12 V.

Table 2. The measured data for the current-voltage characteristics of lamp.

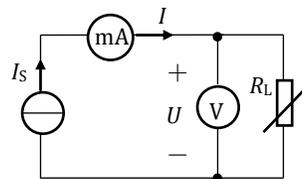
$U$ (V)						
$I$ (mA)						

#### C. Measure the current-voltage characteristics of voltage-stabilized source

Connect the electric elements as shown in Figure 5 (a). Note that the voltmeter is connected in parallel, while the ammeter is connected in series, with the voltage-stabilized source. Both voltmeter and ammeter are numerical ones. The output voltage of the voltage source is 6 V. Change the values of the resistor  $R_L$ , as shown in Table 3, and record the corresponding voltages and currents into the Table 3.



(a)



(b)

Figure 5. The electric circuits to measure the current-voltage characteristics of (a) voltage-stabilized source, and (b) current-stabilized source.

**Table 3. The measured data for the current-voltage characteristics of voltage-stabilized source.**

$R_L (\Omega)$	$\infty$	1000	900	800	700	500	300	200
$I$ (mA)								
$U$ (V)								

**D. Measure the current-voltage characteristics of current-stabilized source**

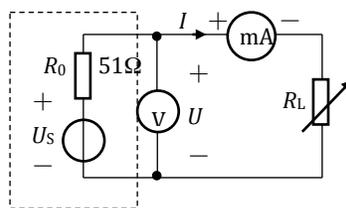
Connect the electric elements as shown in Figure 5 (b). The output current of the current source  $I_S$  is 5 mA. Change the values of the resistor  $R_L$ , as shown in Table 4, and record the corresponding voltages and currents into the Table 4.

**Table 4. The measured data for the current-voltage characteristics of current-stabilized source.**

$R_L(\Omega)$	0	200	600	800	1k	2k	5k
$I$ (mA)							
$U$ (V)							

**E. Measure the current-voltage characteristics of real voltage source**

Connect the electric elements as shown in Figure 6. The output voltage of the voltage source  $U_S$  is 6 V. The voltage source  $U_S$  and the resistor  $R_0$  is connected in series to simulate a real voltage source (the circuit in the dashed box). Change the values of the resistor  $R_L$ , as shown in Table 5, and record the corresponding voltages and currents into the Table 5.



**Figure 6. The electric circuits to measure the current-voltage characteristics of real voltage source.**

**Table 5. The measured data for the current-voltage characteristics of real voltage source.**

$R_L(\Omega)$	$\infty$	2k	1.5k	1k	800	500	300	200
$U$ (V)								
$I$ (mA)								

## 4. Questions

- (1) What are the linear and nonlinear resistors?
- (2) When the current is extremely small, the resistance of a lamp is only several Ohms, then which circuit (shown in Figure 7) is better to measure its current-voltage characteristics, and why?

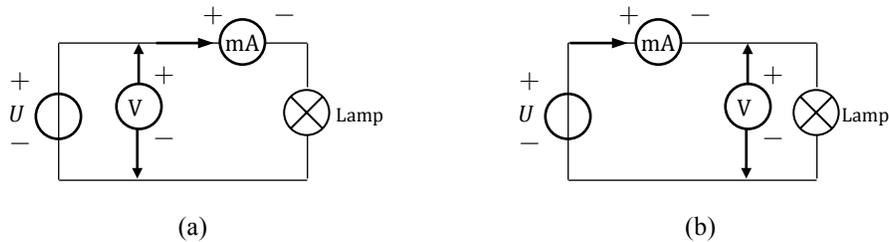


Figure 7. Two different electric circuits to measure the current-voltage characteristics of lamp.

## 5. Writing Your Report

- (1) Based on the data you recorded, plot the curves of the current-voltage characteristics of resistor, lamp, voltage-stabilized source, current-stabilized source, and real voltage source.
- (2) Based on the results, summarize and describe the current-voltage characteristics of these elements.
- (3) Answer the questions in section 4.