5.3 The Characteristics of Voltage and Current of Nonlinear Resistance

Objectives

1. Understand the instruction of elementary electrical devices and the corresponding devices' error.
2. Learn the approach of electrical experiment and gain the principle for circuit connection.
3. Measure and plot the voltage-current curve of non-linear resistance

Theory

The investigation on voltage-current characteristic of electrical components via voltmeter-ammeter method is the elementary electrical experiment. From this experiment, the students will learn how to use properly the electrical equipment, connect circuit well, analysis of the circuit and the way to choose proper devices.

1. Measurement of Resistance via voltmeter-ammeter method

For a common resistor, if we can measure the voltage and current across it via voltmeter and ammeter, respectively, the resistance can be obtained using Ohm law

$$R = \frac{U}{I} \tag{5-3-1}$$

Figure 5-3-1 is the circuit of voltmeter-ammeter approach for the measurement of resistance of light bulb. As either voltmeter or ammeter has resistance, the influence on the accuracy of measurement of voltage-current (V-I) characteristic of light bulb can not be avoided. One thing to be noted is that any electrical instrument measure voltage or current will disturb the circuit under observation. Some devices, ammeter for instances, will indicate the flow of current by a meter movement. If the ammeter is connected directly to light bulb in serial (Fig. 5-3-1(a)), there will be some voltage drop due to the resistance of the flow of current through the ammeter due to its intrinsic resistance, hence, the voltage value read by the voltmeter will be higher than the actual one applied on the light bulb. From Eq. 5-3-1, we will see clearly the resistance measured using this way is larger than the actual one. Since the ammeter is a low resistance instrument, then the voltage drop across the ammeter ($V_a = I R_a$) is small compared to that across R. Then

$$R \cong V/I \qquad \text{if} \quad R_a << R \tag{5-3-2}$$

where R_a is the resistance of the ammeter.

If the resistance of the ammeter is taken into account, then

$$V = V_R + V_a = IR + IR_a = I(R + R_a) = I\ R' \tag{5-3-3}$$

where $R' = R + R_a$. Since $R' = V/I$, then

$$R = R' - R_a = V/I - R_a \tag{5-3-4}$$

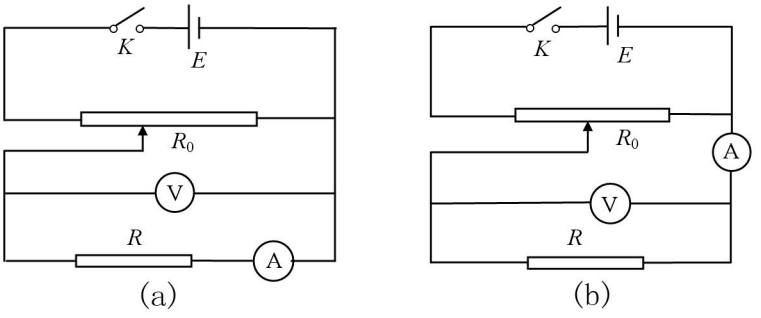

Figure 5-3-1 voltmeter-ammeter approach for the measurement of resistance of light bulb (a) the voltmeter is used for measuring both the voltage of R and ammeter, (b) the ammeter is used for measuring both the currents across of R and voltmeter.

On the contrary, if we connect the circuit as shown in Fig. 5-3-1(b), in this case, the current measured by the ammeter divides between the resistance R and the voltmeter in parallel. The voltmeter is a high resistance instrument and draws little current as long as the voltmeter resistance R_v is much greater than R. Thus,

$$R \cong V / I \qquad \text{if } R_v >> R \tag{5-3-5}$$

For a more accurate measurement, the resistance of the voltmeter must be taken into account. The current drawn by the voltmeter is $I_v = V/R_v$ and the total current measured by the ammeter is

$$I = I_R + I_v \tag{5-3-6}$$

The true current through the resistance is

$$I_R = I - I_v \tag{5-3-7}$$

and from Ohm's Law

$$R = \frac{V}{I_R} = \frac{V}{I - I_V} = \frac{V}{I - V/R_V} \tag{5-3-8}$$

Obviously, in this way, we will get a smaller value of resistance compared to the actual value of the light.

In short, due to the resistance of a meter (voltmeter or ammeter), a systematic error always exists. Thus, the voltmeter-ammeter approach is usually used for the measurement of resistance when the requirement of accuracy is not high, as well as $R_A << R$ ， $R_V >> R$.. Besides, the final approach for measurement depends on the resistance of R_A、R_V and R.

2. Volt-current characteristic (V-I) curve of resistance.

For an electrical resistor, the voltage and current relationship between the DC current through an electronic device and the DC voltage across its terminals is called a current–voltage characteristic of the device. If the resistor has a stable resistance, the voltage has a linear coefficient of current across the resistor. However, in some cases, the resistance of device is changes with some factor such as the thermal, it will exhibit a nonlinear V-I characteristics (light bulb, semiconductor diode)

In this experiment, we will employ the voltmeter-ammeter method to measure the V-I characteristic of a light bulb.

Figure 5-3-2 shows the V-I curve of a light bulb. It can be seen that the resistance varies with the voltage and current, i.e., lower resistance with small voltage and current and higher value with voltage and current.

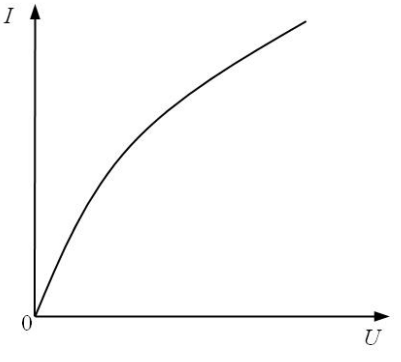

Figure 5-3-2 V-I curve for light bulb

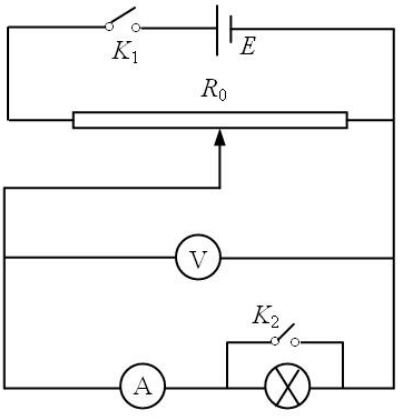

Figure 5-3-3 Circuit for the V-I characteristic of light bulb

As stated before, it is necessary to correct the systematic error using the circuit as shown in Fig. 5-3-3. As shown in Fig. 5-3-3. when the switch K_2 is open, the voltmeter will read the total voltage of light and ammeter, then we can get a V-I relationship of ammeter and light. However, it will record the voltage of ammeter when K_2 is closed. In this case, the V-I relationship of ammeter can be obtained.

Apparatus

DC power supply, Slide rheostat, voltmeter, ammeter, single pole single throw switch (SPST), light bulb

Procedure

1. Connect the circuit as shown in Fig. 5-3-3. Make sure the slide rheostat on the safety position. The output voltage of DC supply is around 10.0 V.
2. Open the switch K_2, select the proper range of ammeter (0~500 mA) and voltmeter (0~7.5 V). Increase the current by varying slide rheostat, record the successive voltage and currents from 0 mA to maximum range of voltmeter.
3. Then, close the switch K_2, this circuit is only used for ammeter characteristic measurement. The range of voltmeter can be tuned from 0 V to 3.0 V) while deflection of ammeter pointer keeps the same (0~500 mA). Increase the current by varying slide rheostat, record the successive voltage and currents from 0 mA to maximum range of voltmeter
4. Plot the V-I curves for ammeter and light bulb, and ammeter alone. Then get the data ΔU-I from the previous two curves and draw the curve for light bulb.

Data Record

Table 5-3-1 U-I data for ammeter and light bulb

	1	2	3	4	5	6	7	8
I（mA）								
U（V）								

Table 5-3-2 U-I data for ammeter alone

	1	2	3	4	5	6	7	8
I（mA）								
U_A（V）								

Questions

1. How to estimate the instrument error limitations of meters? How to determine the significant digits of indicating number?
2. Referring to figure 5-3-4, how to connect the wires to realize the switch between internal and external connecting method of an ammeter conveniently with single-pole double-throw switch if provided with another one? Please draw the circuit diagram.