4. Experimental Objectives

1) Understand the basic characteristics of the photosensitive resistance and measure its V-I characteristic curve and illumination characteristic curve.
2) Understand the basic characteristics of silicon photocell and measure its V-I characteristic curve and illumination characteristic curve.
3) Understand the basic characteristics of photodiode, and measure its V-I characteristics and illumination characteristic curves.
4) Understand the basic characteristics of phototransistor, and measure its V-I characteristics and illumination characteristic curve.

5. Precautions

1) The intensity of the light source used in the measurement of the characteristics of all photosensitive sensors in this apparatus is relative light intensity. The sensor to be tested and the calibration sensor (Cali photocell) are installed on the same plane, and the same illuminance can be obtained at the same time. Use the characteristic of light intensity and short circuit current are in linear relationship of the calibration photocell to compare and measure the characteristics of the measured sensor. The light intensity in the experiment is a relative value. If a standard illuminance is expected, a calibrated light meter is needed to use. (The maximum illuminance can be obtained by this apparatus is 1500 Lx.)
2) This apparatus cannot be operated for a long time under the maximum illumination. After completing the large illumination experiment, the illumination must be adjusted to the minimum to avoid the measurement error and damage the sensor caused by the light heat.
3) Since the cold resistance of the filament of the incandescent lamp is very small, it is equivalent to an instantaneous short circuit for the power supply, so the power supply short circuit protection circuit may be triggered. The filament resistance is greatly affected by temperature. The higher the temperature, the greater the filament resistance, and the lower the illuminance. Therefore, during the experiment, as the experiment time increases, the filament temperature increases and the illuminance decreases. This is normal phenomenon.
4) The shape of the light characteristic curve of some photosensitive elements may be different from that shown in some textbooks. This is due to the difference in key materials and manufacturing processes.

6. Experimental Procedures

A. Measure characteristics of photoresistor

(1) Measure V-I characteristic of photoresistor

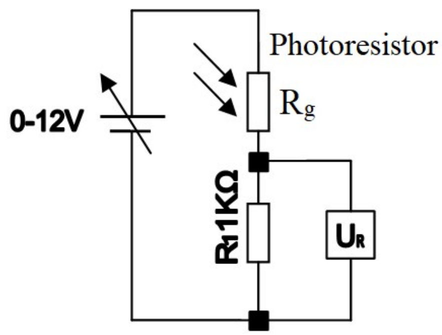

Figure 5. Schematic circuit for measuring characteristics of a photoresistor

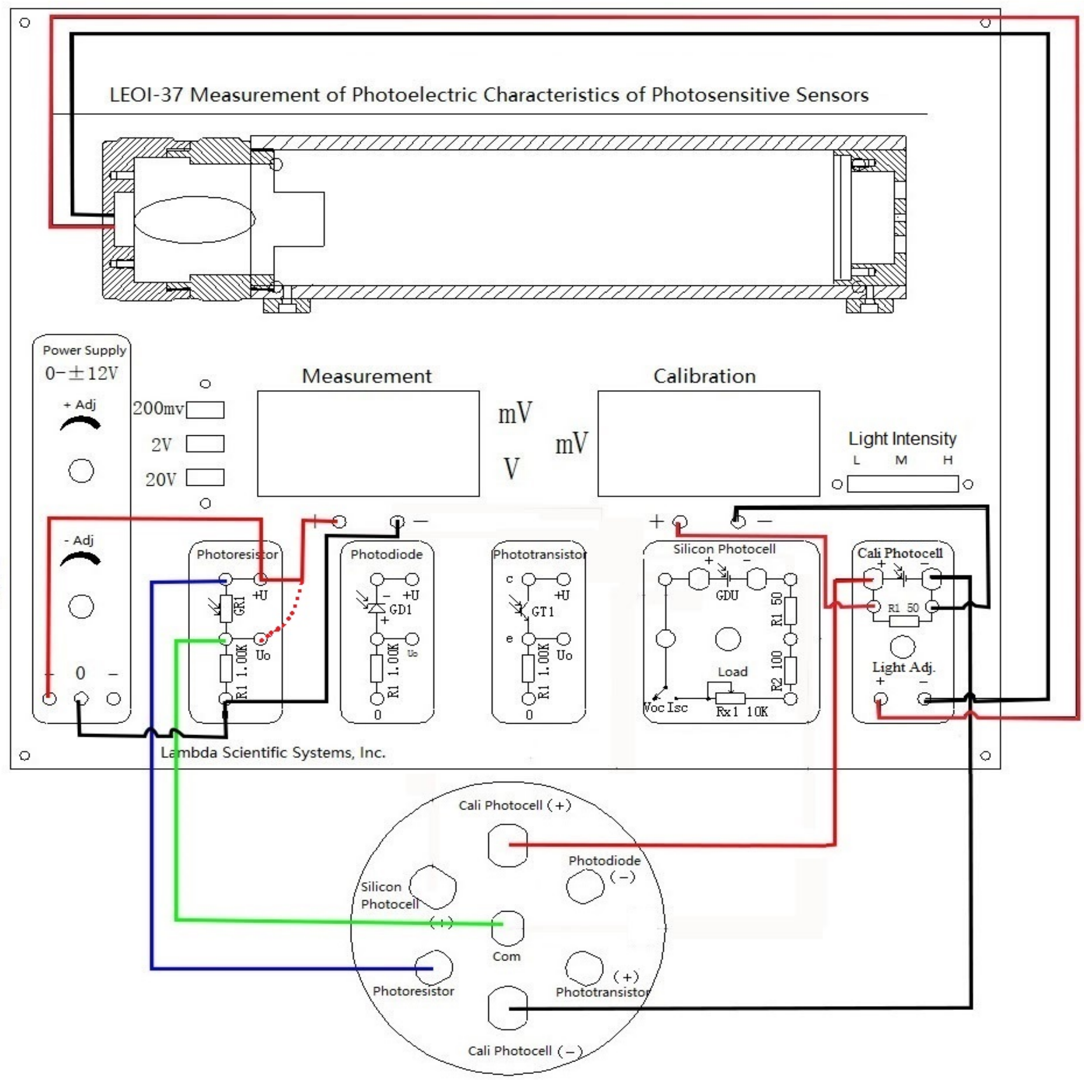

Figure 6 Wiring schematic of measuring characteristics of a photoresistor

a) Figure 5 is the circuit schematic for measuring characteristics of the photoresistor. According to Figure 3, wire the experiment setup as shown in Figure 6.

For the circuit of calibration photocell: Connect the calibration silicon photocell to the “Cali Photocell” terminals. Connect its output to the calibration voltmeter. The light source is an ordinary tungsten filament lamp with an adjustable power supply of 0- 24 V. The light intensity is adjusted by the “Light Adj.” potentiometer. Note: the wiring for the calibration system is same for measuring all other sensors below.

b) Per Figure 6, connect the tested photoresistor to the panel. Connect the 0 - +12 V power supply. Use the "Light Adj.” knob to adjust the relative light intensity U_1 (displayed on the Calibration voltmeter) to a certain value (for example, 5 mV). Under this lighting condition, adjust the total voltage U of the "Photoresistor" measurement circuit (i.e. the voltage between "+ U" and "0", which is adjusted using the "+Adj.” knob) to 2 V (displayed on the Measurement voltmeter). Then measure the voltage U_R on the series resistance R_1 = 1kΩ (that is, the voltage between "U_0" and "0". Note: <u>need to switch the wiring from the previous measurement point "+U" to measurement point "U_0").</u> Repeat this measurement for total voltage U at 4V, 6V, 8V and 10V respectively.
The voltage across the photoresistor is $U_C = U - U_R$. Calculate the current flowing through R_1 (also the photoresistor) using formula $I = \frac{U_R}{1k\Omega}$ voltage. Then calculate the resistance of the photoresistor $R_g = \frac{U_C}{I}$.

c) Adjust the light intensity to different values (such as the voltage U_1 at 5 mV, 10 mV, 15 mV, 20 mV, 25 mV, 30 mV). Repeat step b) to obtain Rg, I and U_C of the photoresistor under different light intensities.

d) Record these measurement results into Table 1.

e) According to the data in Table 1, plot a set of V-I characteristic curves (U_C-I) of the photoresistor.

Table 1 Measurement data of current *I* of different applied voltages at different light intensities

Light Intensity U_1 (mV)	5.0				10.0				15.0			
U (V)	U_R(V)	U_C(V)	I(mA)	R_g(Ω)	U_R(V)	U_C(V)	I(mA)	R_g(Ω)	U_R(V)	U_C(V)	I(mA)	R_g(Ω)
2.0												
4.0												
6.0												
8.0												
10.0												
Light Intensity U_1 (mV)	20.0				25.0				30.0			
U/V	U_R(V)	U_C(V)	I(mA)	R_g(Ω)	U_R(V)	U_C(V)	I(mA)	R_g(Ω)	U_R(V)	U_C(V)	I(mA)	R_g(Ω)
2.0												
4.0												
6.0												
8.0												
10.0												

(2) Measure illumination characteristic of photoresistor

a) The experimental circuit is basically the same as (1).

b) Use the "+Adj." knob to adjust the voltage U_C across the photoresistor (i.e. the voltage between "+ U" and "U_0") to a certain value (e.g. 0.5 V). Adjust the "Light Adj." Knob to change illumination, and measure the corresponding voltage U_R (that is, the voltage between "U_0" and "0" across the series resistance R_1 = 1 kΩ under different relative light intensity U_1). Calculate current $I = \frac{U_R}{1k\Omega}$ and calculate the resistance of the photoresistor $R_g = \frac{U_C}{I}$.

c) Change the voltage U_C across the photoresistor. Repeat step b), adjust the relative light intensity U_1, measure U_R, and calculate I and *Rg*.

d) Record the measured data in Table 2.

e) According to the data in Table 2, plot a set of illumination characteristic curves (U_1-I) of the photoresistor

Table 2 Measurement data of photoresistor at different voltages with different illuminations

Light Intensity U_1 (mV)	U_C=0.5V			U_C=1.0V			U_C=1.5V		
	U_R(V)	I(mA)	R_g(Ω)	U_R(V)	I(mA)	R_g(Ω)	U_R(V)	I(mA)	R_g(Ω)
3.0									
6.0									
9.0									
12.0									
15.0									
18.0									
21.0									
24.0									
27.0									

Light Intensity U_1 (mV)	U_C=2.0V			U_C=2.5V					
	U_R(V)	I(mA)	R_g(Ω)	U_R(V)	I(mA)	R_g(Ω)			
3.0									
6.0									
9.0									
12.0									
15.0									
18.0									
21.0									
24.0									
27.0									

B. Measure characteristics of silicon photocell

(1) Measure V-I characteristic of silicon photocell

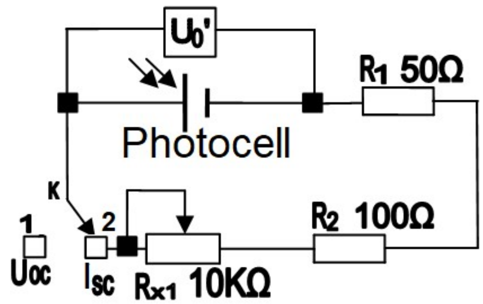

Figure 7. Schematic circuit for measuring characteristics of a photocell

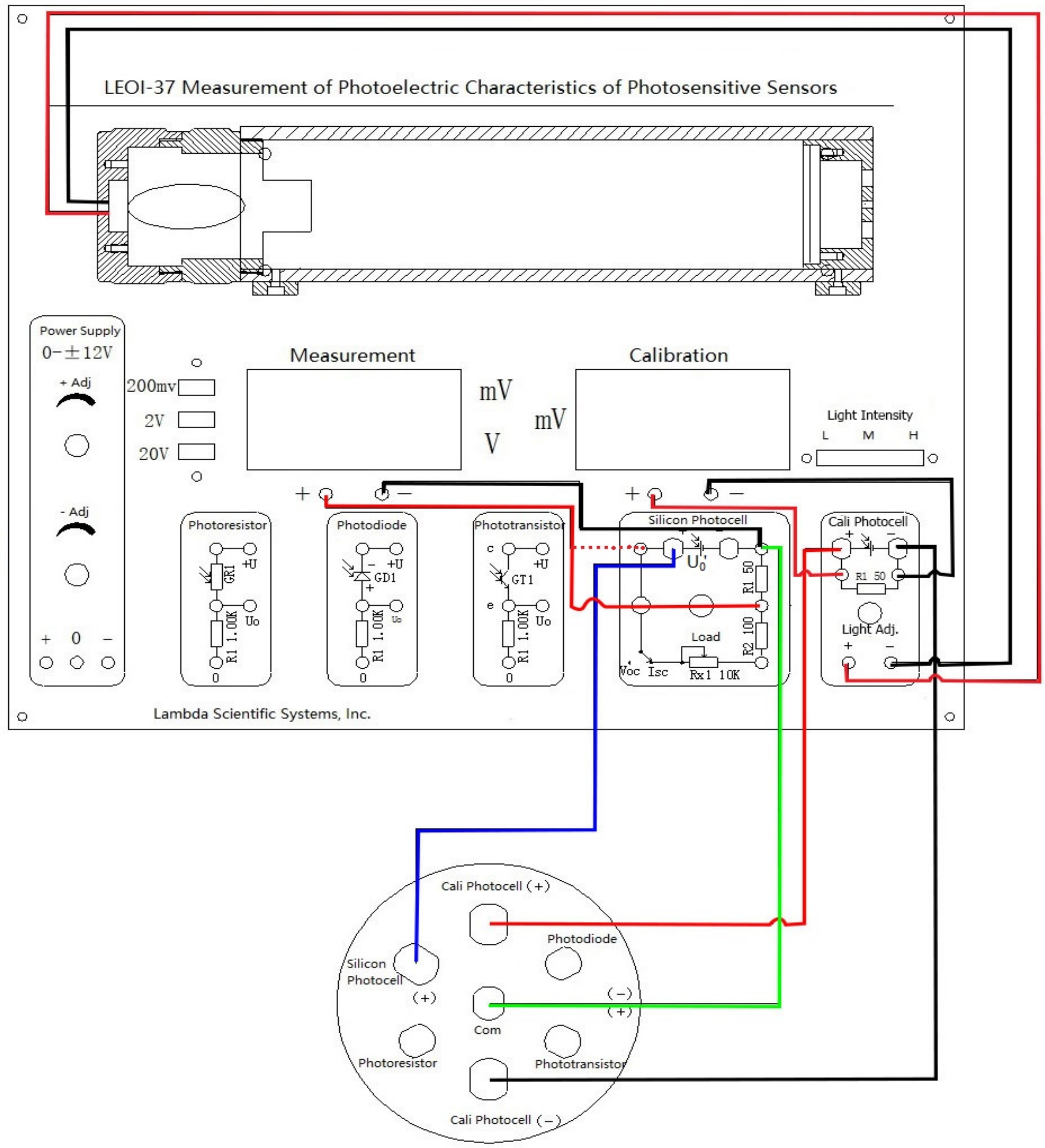

Figure 8 Wiring schematic of measuring characteristics of a photocell

a) Connect the experimental circuit according to the Figure 7 and Figure 8.

b) When measuring the V-I characteristic, adjust the variable resistor Rx1 (10 KΩ) and indirectly measuring the load current by measuring the voltage on the known resistor R_1 (50 Ω).

c) Adjust light intensity (voltage U_1) using "Light Adj." knob. For U_1 from 0 to 30.0 mV, measure photocurrent I and photo voltage U_0' (the voltage across the silicon photovoltaic cell) under different load conditions (150 Ω-10 KΩ). The value of the photocurrent I is calculated by measuring the voltage U_R across the sampling resistor R_1 (50 Ω) on the series circuit, $I = \frac{U_R}{50\Omega}$. The total load is calculated $R_L = U_0'/I$.

d) Record the measured data in Table 3.

e) According to the data in Table 3, plot a set of V-I characteristic curves (U_0'-I) of the photocell.

Table 3 Measurement data of the relationship between photocurrent and photovoltage at different load resistances for silicon photocells at different illuminances

Relative light intensity U_1 (mV)											
5.0				10.0				15.0			
U_0'(V)	U_R(mV)	I(mA)	R_L/Ω	U_0'(V)	U_R(mV)	I(mA)	R_L/Ω	U_0'(V)	U_R(mV)	I(mA)	R_L/Ω
Relative light intensity U_1 (mV)											
20.0				25.0							
U_0'(V)	U_R(mV)	I(mA)	R_L/Ω	U_0'(V)	U_R(mV)	I(mA)	R_L/Ω				

(2) Measure illumination characteristic of silicon photocell

a) The experimental circuit is same as (1). Adjust the variable resistor Rx1 (i.e. the "Load" knob) to zero, and short R_2 using a wire, i.e. the total load is R_1 (50Ω).

b) Adjust light intensity U_1, from 0 to 30.0 mV, at each light intensity, measure the open circuit voltage Uoc and short circuit current Isc of the photocell. For measuring Uoc, the toggle switch is turned to the left and the circuit is disconnected. The open circuit voltage Uoc is the voltage across the silicon photovoltaic cell. For measuring Isc, the toggle switch is turned to the right, by measuring the voltage U_R across the sampling circuit R_1 (50Ω), Isc is calculated by $I_{sc} = \frac{U_R}{50\Omega}$.

c) Record the measured data in Table 4.

d) According to the data in Table 4, plot a set of illumination characteristic curves (U_1-U_{OC}) and (U_1-I_{SC}) of the photocell.

Table 4 Measurement data of the relationship between open circuit voltage, short circuit current and illuminance of the silicon photocell

Light intensity U_1 (mV)	U_{oc}(V)	U_R(mV)	I_{sc}(mA)	Light intensity U_1 (mV)	U_{oc}(V)	U_R(mV)	I_{sc}(mA)
0				15.0			
3.0				18.0			
6.0				21.0			
9.0				24.0			
12.0				27.0			

(3) Measure negative bias characteristic of silicon photocell

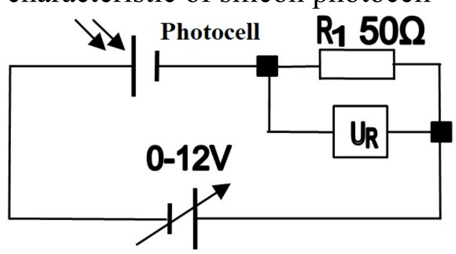

Figure 9 Schematic circuit for measuring negative bias characteristics of a photocell

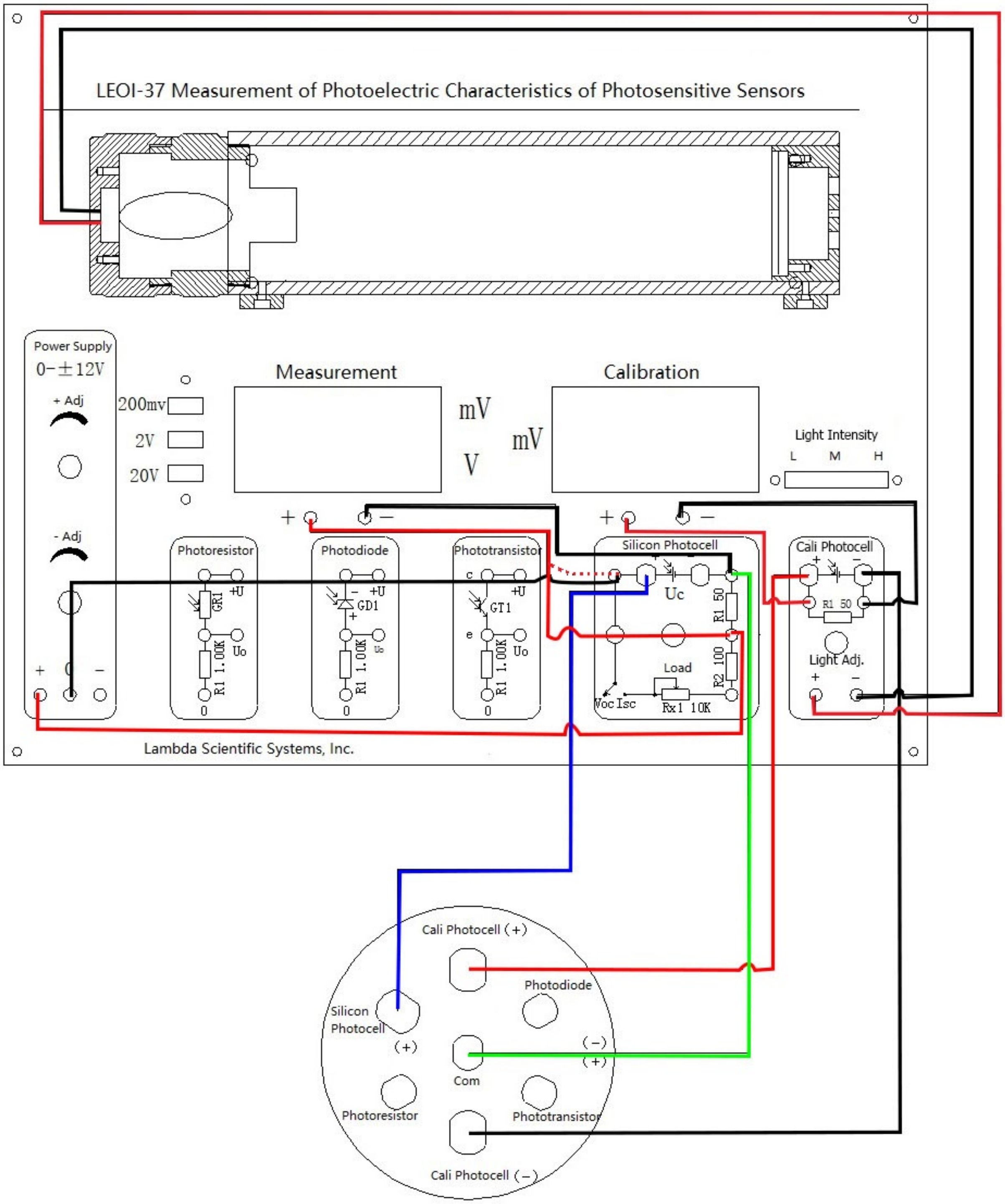

Figure 10 Wiring schematic of measuring negative bias characteristics of a photocell

a) Wiring the experimental circuit according to the Figure 9 and Figure 10. Place the toggle switch to the left (*Voc*).

b) Use “+Adj” potentiometer to adjust the voltage U_C applied to the two ends of the photocell. Adjust the light intensity U_l using “Light Adj.” Measure the voltage U_R on the series resistance R1 = 50Ω at different relative light intensities. Calculate current $I = \frac{U_R}{50\Omega}$.

c) Change the voltage U_C across the silicon photocell, adjust the relative light intensity U_l in the same manner as above, measure U_R, and calculate I.

d) Record the measured data in Table 5.

e) According to the data in Table 5, plot a set of negative bias characteristic curves (U_c-I) of the photocell.

Table 5 Measurement data of current I and light intensity U_l at different bias voltage U_c of the silicon photocell

Light intensity U_l (mV)	U_C=0V		U_C=-2V		U_C=-4V	
	U_R(mV)	I(mA)	U_R(mV)	I(mA	U_R(mV)	I(mA
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						
24.0						
27.0						
Light intensity U_l (mV)	U_C=-6V		U_C=-8V		U_C=-10V	
	U_R(mV)	I(mA	U_R(mV)	I(mA	U_R(mV)	I(mA
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						
24.0						
27.0						

C. Measure characteristics of silicon photodiode

(1) Measure V-I characteristic of photodiode

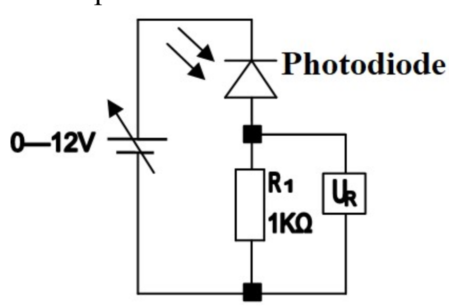

Figure 11. Schematic circuit for measuring characteristics of a photodiode

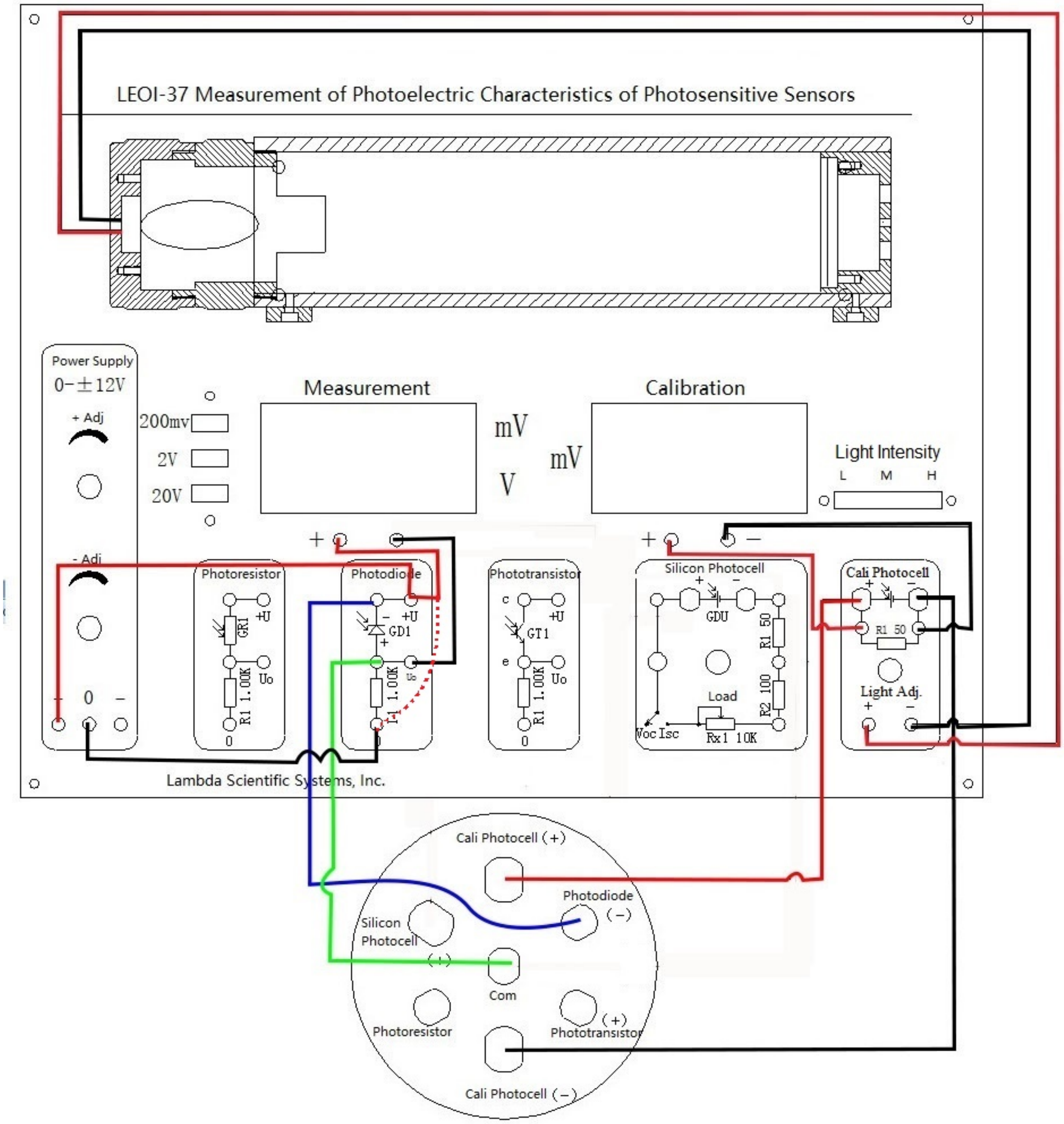

Figure 12 Wiring schematic of measuring characteristics of a photodiode

a) Connect the experimental circuit according to Figure 11 and Figure 12.

b) Adjust the relative light intensity U_1. Under this lighting condition, adjust the +12 V power supply using "+Adj" knob, and measure the bias voltage Uc on the photodiode (i.e. the voltage between "+U" and "U_0") to be 0, 2 V, 4 V, 6 V, 8 V and 10 V respectively, at the same time, for every Uc value, measure the corresponding voltage U_R on the series resistance $R_1 = 1k\Omega$ (i.e. the voltage between "U_0" and "0"). Calculate current $I = \frac{U_R}{1k\Omega}$.

* Note that the photodiode in the experimental circuit actually works under reverse bias (i.e. negative bias).

c) Change the relative light intensity U_1 (such as 3 mV, 6 mV, 9 mV, 12 mV, 15 mV, 18 mV, 21 mV, 24 mV, 27 mV), repeat the step 2). Obtain multiple sets of data U_c, U_R, and I.

d) Record the measured data into Table 6.

e) According to the data in Table 6, plot a set of V-I characteristic curves (U_c-I) of the photodiode.

Table 6 Measurement data of the relationship between bias voltage U_c and photocurrent I of photodiode under different illuminations.

Bias U_C(V)	Relative light intensity U_1(mV)									
	3.0		6.0		9.0		12.0		15.0	
	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)
0										
2.00										
4.00										
6.00										
8.00										
10.00										
Bias U_C(V)	Relative light intensity U_1(mV)									
	18.0		21.0		24.0		27.0			
	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)		
0										
2.00										
4.00										
6.00										
8.00										
10.00										

(2) Measure illumination characteristic of silicon photodiode

a) The experimental circuit is the same as (1).

b) Use the "+Adj" knob to get a certain bias voltage Uc on the photodiode (e.g. 2V). Adjust light intensity U_1 to different illumination intensities, under each illumination intensity, measure the corresponding voltage U_R across the series resistance $R_1 = 1k\Omega$ and calculate current $I = \frac{U_R}{1k\Omega}$.

c) Change the bias voltage Uc on the photodiode, repeat step b). Obtain a multiple sets of data Uc, U_R and I.

d) Record the measured data in Table 7.

e) According to the data in Table 7, plot a set of illumination characteristic curves (U_1-I) of the photodiode.

Table 7 Measurement data of the relationship between light intensity and photocurrent at different bias voltages of the photodiode

Light Intensity	U_C=0V		U_C=2V		U_C=4V	
U_1(mV)	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						
24.0						
27.0						
Light Intensity U_1(mV)	U_C=6V		U_C=8V		U_C=10V	
	U_R(mV)	I(mA)	U_R(mV)	I(mA)	U_R(mV)	I(mA)
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						
24.0						
27.0						

D. Measure characteristics of silicon phototransistor

(1) Measure V-I characteristic of phototransistor

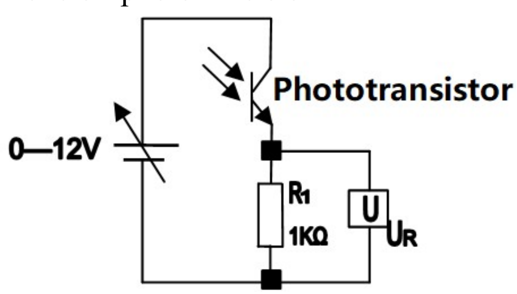

Figure 13. Schematic circuit for measuring characteristics of a phototransistor

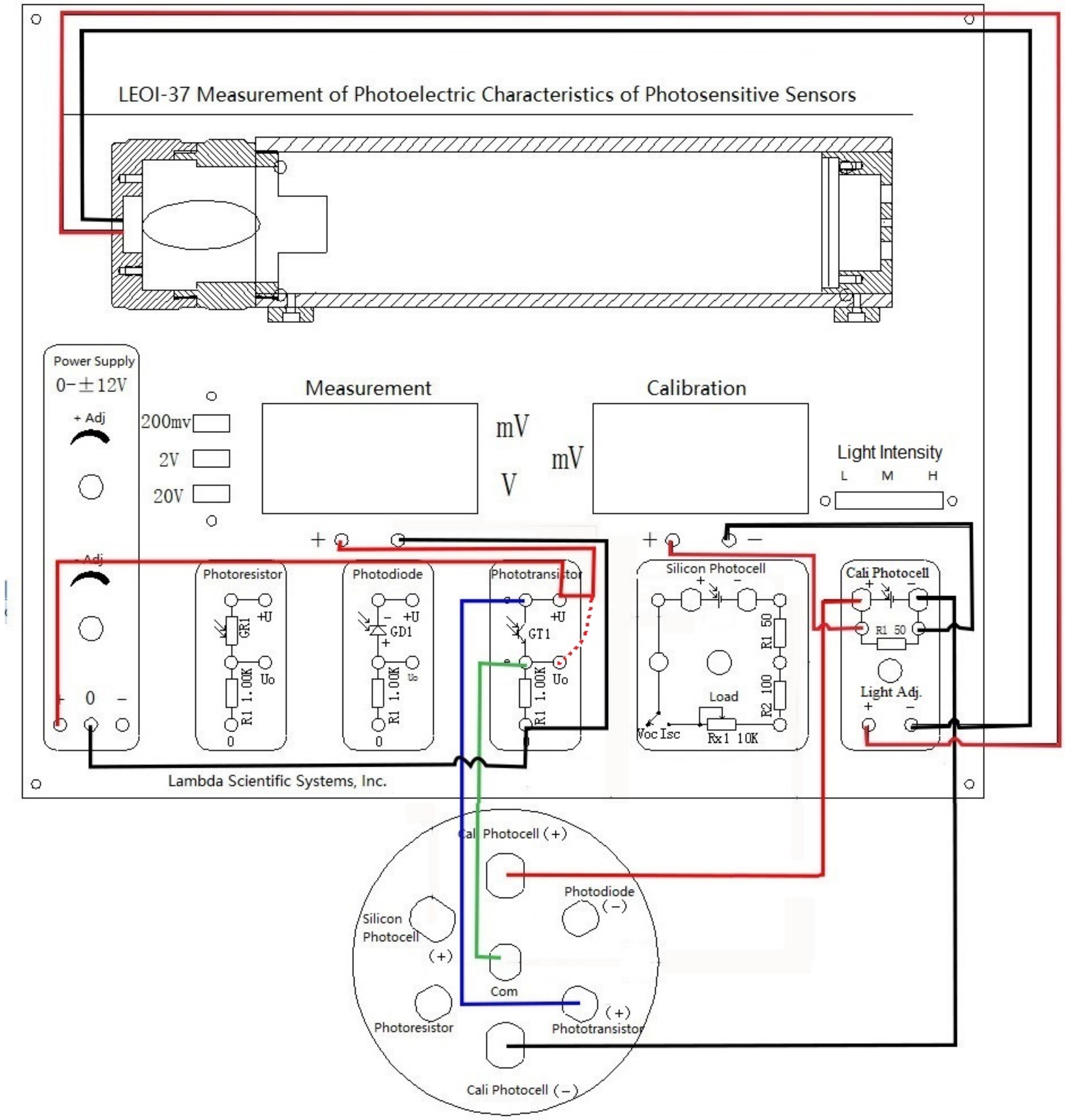

Figure 14 Wiring schematic of measuring characteristics of a phototransistor

a) Connect the experimental circuit according to Figure 13 and Figure 14.

b) Adjust the relative light intensity U_1 to a certain value (e.g. 5 mV). Under this lighting condition, adjust the +12 V power supply using “+Adj” knob, and measure the total voltage U on the circuit (i.e. the voltage between "+U" and "0") to be 0, 2 V, 4 V, 6 V, 8 V and 10 V respectively, at the same time, for every U_0 value, measure the corresponding voltage U_R on the series resistance $R_1 = 1k\Omega$ (i.e. the voltage between "U_0" and "0"). Calculate the bias voltage $U_C = U - U_R$ and current $I = \frac{U_R}{1k\Omega}$ of the phototransistor.

c) Change the relative light intensity (such as 5 mV, 10 mV, 15 mV, 20 mV, 25 mV), repeat step b), obtain multiple sets of U_R, U_C and I.

d) Record the measured data in Table 8.

e) According to the data in Table 8, plot a set of V-I characteristic curves (Uc-I) of the phototransistor.

Table 8 Measurement data of the relationship between the bias voltage and the photocurrent of the phototransistor under different illuminations.

Light intensity U_1(mV)	5.0		10.0		15.0		20.0		25.0	
U(V)	U_C(V)	I(mA)	U_C(V)	I(mA)	U_C(V)	I(mA)	U_C(V)	I(mA)	U_C(V)	I(mA)
0										
2.00										
4.00										
6.00										
8.00										
10.00										

(2) Measure illumination characteristic of phototransistor

a) The experimental circuit is the same as (1).

b) Use the "+Adj." knob to adjust the total voltage U of the circuit (i.e. the voltage between "+ U" and "0") to a certain value (e.g. 0.5 V). Adjust the "Light Adj." Knob to change illumination, and measure the corresponding voltage U_R (i.e. the voltage between "U_0" and "0" across the series resistance R_1 = 1 kΩ under different relative light intensity U_1). Calculate the bias voltage $U_C = U - U_R$ and the current $I = \frac{U_R}{1k\Omega}$ on the phototransistor.

c) Change the bias voltage Uc on the phototransistor, repeat step b) to obtain multiple sets of U_1, U_R, Uc and I.

d) Record the measured data in Table 9.

e) According to the data in Table 9, plot a set of illumination characteristic curves (U_1-I) of the phototransistor.

Table 9 Measurement data of the relationship between light intensity and photocurrent at different bias voltages of the phototransistor

Light Intensity U_1(mV)	U_C=0.5V		U_C=1.0V		U_C=1.5V	
	U_R(V)	I(mA)	U_R(V)	I(mA)	U_R(V)	I(mA)
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						
Light Intensity U_1(mV)	U_C=2.0V		U_C=2.5V			
	U_R(V)	I(mA)	U_R(V)	I(mA)		
3.0						
6.0						
9.0						
12.0						
15.0						
18.0						
21.0						