The Charge of an Electron

1   Introduction

A semiconductor such as silicon, when pure, has low conductivity, but if it is "doped" by adding a small proportion of an element, such as phosphorus, with one more outer electron than silicon, the extra electron is less tightly bound than the rest and permits much greater conductivity. This is an N-type material. Similarly, doping with an element that has one less outer electron creates gaps or "holes" that also enhance conductivity. This is a P-type material.

The invention of the transistor in 1947 by three researchers at Bell Laboratories was the spark that ignited the solid-state electronics revolution that has made modern computers possible and changed every aspect of human life. An NPN transistor is a three terminal, solid-state, electronic device constructed by sandwiching a piece of P-type semiconductor material between two pieces of N-type material. A schematic diagram of an NPN transistor is shown in Figure 1. The base terminal (B) is connected to the P-type material while the collector (C) and emitter (E) terminals are connected to the N-type material on either side of the P-type.
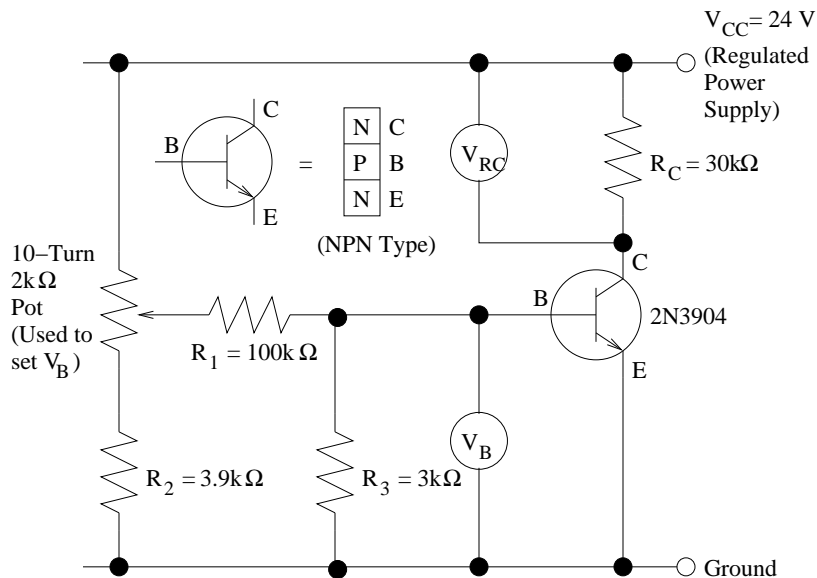

Figure 1: Circuit for measuring the current-voltage relationship for the NPN transistor.

The current-voltage relationship for this type of transistor has been shown both experimentally and theoretically to be

$$I_C = I_0 \left[e^{qV_B/kT} - 1 \right] \tag{1}$$

where I_C is the collector current, I_0 is a constant, q is the charge of the electron, V_B is the base voltage, k is Boltzmann's constant ($1.381 \times 10^{-23}\,\mathrm{J/K}$), and T is the temperature in Kelvin. Rather than measure the collector current I_C directly, it is convenient to measure the

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voltage V_{RC} across a collector resistor R_C and relate it to I_C by Ohm's law ($V_{RC} = I_C R_C$). Also, since at room temperature and with a base voltage of about 1 V $e^{qV_B/kT} \gg 1$, we can use the simpler equation

$$V_{RC} = I_0 R_C e^{qV_B/kT}. \tag{2}$$

Taking the natural log of both sides we have

$$\ln V_{RC} = \ln I_0 R_C + (q/kT) V_B. \tag{3}$$

Therefore, a plot of $\ln V_{RC}$ vs. V_B should be a straight line with a slope q/kT.

2   Procedure

Shown in Figure 1 is the circuit that has been set up to perform the experiment. The network of resistors is used to divide the voltage applied to the circuit by the power supply suitably between the different components. The voltages V_B and V_{RC} will be measured with two digital multimeters (DMMs).

1. Use one of the DMMs to measure the room temperature and record it in the data table below.

2. Convert the temperature to Kelvin ($T_K = T_C + 273$) and record this value in the data table.

3. Turn on the power supply.

4. Adjust the 10-turn potentiometer to set the base voltage V_B at about 0.420 V.

5. Measure V_B and V_{RC} with the DMMs and record the values in the data table below.

6. Repeat steps 4 and 5 increasing the base voltage in steps of about 0.020 V.

7. Enter the data into an Excel spreadsheet.

8. Use Excel to calculate the natural log of each of the V_{RC} values.

9. Create a graph of $\ln V_{RC}$ vs. V_B.

10. Fit the data with a line to obtain the slope.

11. Print a copy of the graph for each member of the group and insert a copy into your notebook.

12. Calculate the charge of the electron q from the value of the slope.

13. Compare your value for the charge of the electron with the accepted value of 1.602×10^{-19}C by calculating the % difference given by

$$\% \, difference = \frac{your\,value - accepted\,value}{accepted\,value} \times 100\%. \tag{4}$$

3   Data

T = _____°C   T = _____ K

V_B (V)	V_{RC} (V)

Slope = _____ C/J q = _____ C   % difference = _____