The Charge of an Electron

I. Objective

The objective of this experiment is to measure electronic charge.

II. Background and Theory

The classical method for measuring the charge on an electron is known as the Millikan Oil Drop Experiment, which was first performed by R. A. Millikan in 1909. Patience and skill are necessary to perform the Millikan experiment. By contrast, the method for measuring electronic charge in this experiment is quite simple and gives results that are accurate to within a few percent.

This experiment makes use of a transistor, which is in the circuit of **Figure 1**. It can be shown[1] that the collector current of a transistor is, to a good approximation, an exponential function of base voltage. Thus, from the theory of the junction transistor[2], we can express:

$$I_C = A\left[e^{\frac{q V_b}{kT}} - 1\right] \qquad (1)$$

where I_C is the collector current, A is a constant, e is the base of the natural logarithms, q is the electronic charge, V_b is the base-to-emitter voltage, k is Boltzmann's constant, and T is absolute temperature.

Rather than measure I_C, we measure the voltage V_{RC} across the collector resistor, R_C, and relate it to I_C by Ohm's Law. Also, since kT at room temperature corresponds to about 1/40 of a volt, for voltages significantly larger than this the expotential term is much greater than unity, and so we can write, to a good approximation:

$$V_{RC} = B\, e^{\frac{q V_b}{kT}} \qquad (2)$$

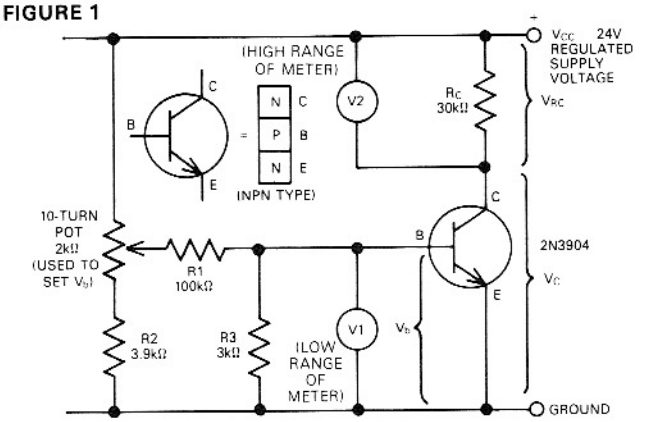
where B is another constant. This is our working equation.

III. Equipment

NPN transistor 2N3904
10-Turn Potentiometer, 2kΩ
Resistors: 3.9kΩ, 3kΩ, 30kΩ
24V regulated power supply
2 Keithley DMMs (Keithley Model 177)
Thermometer (DTh) (Keithley Model 871)
Semi-log graph paper, 3 cycles

voltages V_{RC} and V_b, and turn on the voltage supply to 24V. Adjust V_b by adjusting the 10-turn potentiometer. At the lowest value of V_b, the transistor is "off" and V_{RC} is close to zero. At the highest value of V_b, the transistor is "on" and V_{RC} has its largest value. At intermediate values of V_b, V_{RC} is governed by the exponential function, equation (2). Record several values of V_b at evenly spaced intervals, and the corresponding values of V_{RC}. Record the temperature and convert to degrees Kelvin.

FIGURE 1



V. DATA

V_b	V_{RC}

T = ______________

k=1.3806×10^{-23}Joules/°K

VI. Analysis

Plot a graph of V_{RC} as a function of V_b on 3-cycle semilog graph paper. Plot V_b on the linear axis and V_{RC} on the logarithmic axis. Fit a straight line to the data. Deviations from a straight line may occur at the extreme ends of the graph. The straight line is indicative of the expotential relationship between V_{RC} and V_b. **Figure 2** shows the results obtained by a student.

To obtain a value for q, determine the "slope" of the line from the formula:

$$\text{slope} = \frac{\ln V_{RC2} - \ln V_{RC1}}{V_{b2} - V_{b1}} \qquad (3)$$

where (V_{RC2}, V_{b2}) and (V_{RC1}, V_{b1}) are two points on the straight-line graph, and ln means "take natural logarithm." The electronic charge is found by equating the slope to q/kT:

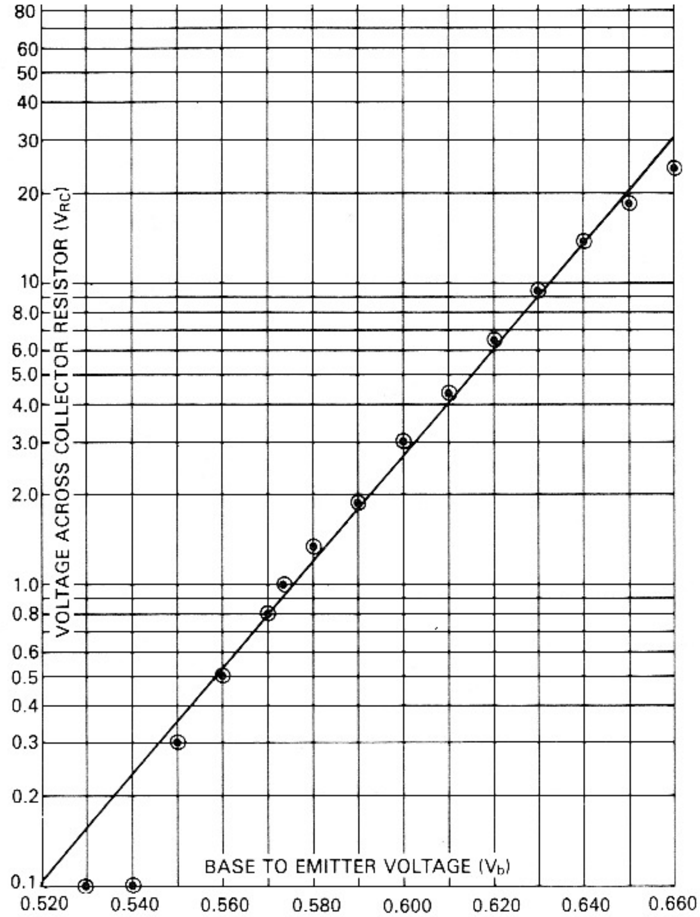
$$\text{slope} = q/kT \qquad (4)$$

and solving for q.

Compare your value for electronic charge to the accepted value and determine your error.

VII. References

[1] See Appendix.
[2] *An Introduction to Semiconductor Electronics,* Nanaviti, R.P., McGraw-Hill, New York, 1963.



a junction diode. The answer is that for a diode, the charge carriers behave as if they are approximately doubly charged.

Appendix

In Reference 2, p. 136, the following relationships are given:

$$I_E = a_{11}\,(e^{q\,V_E/kT} - 1) - a_{12}\,(e^{q\,V_c/kT} - 1),$$

$$I_c = a_{21}\,(e^{q\,V_E/kT} - 1) - a_{22}\,(e^{q\,V_c/kT} - 1),$$

where V_E is the emitter-to-base voltage, which is the same as V_b in our notation, V_c is the collector-to-base voltage, I_E is the emitter current, I_c is the collector current, and a_{11}, a_{12}, a_{21} and a_{22} are constants. $a_{12} = a_{21}$ and $a_{11} \cong a_{22}$. We can eliminate the term in V_c and obtain:

$$a_{11}I_E - a_{12}I_c = (a_{11}{}^2 - a_{12}{}^2)(e^{q\,V_E/kT} - 1)$$

Since the base current is much less than I_E or I_c, $I_E = I_c$ and we have:

$$I_c \cong (a_{11} + a_{12})(e^{q\,V_E/kT} - 1)$$

which is our equation (1).

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