Measuring the Charge of Electron (Remake of Keithley Procedure)

Materials Needed:
- 2 kΩ 10-turn Variable Resistor
- 3.9 kΩ Resistor
- 30 kΩ Resistor
- 100 kΩ Resistor
- 3 kΩ Resistor
- NPN 2N3904 Transistor
- 2 Multimeters or Voltmeters
- Power Supply (24V)
- Knowledge of room temperature

Background:

Measurement of the electronic charge can be very challenging using the tradition approach, i.e., the Milliken Oil Drop Experiment. In the current version of this classic experiment latex spheres are suspended in solution. The spheres are naturally charged and are of an assortment of sizes. They are accelerated in an electric field which is reversible to eliminate factors such as the viscous forces caused by the solution. The spheres are illuminated and viewed through a microscope or microscope configured with a camera. The fundamental notion about which the experiment is designed is that each sphere will have a charge of a few to several fundamental electronic charges and that the minimum difference in charge is 1 *e*. The best spheres to select, and there are many of all sizes, for the best results are the smallest spheres. These are difficult to see and you must trace the motion of many spheres to collect data leading to a measurement of the *e*.

Years ago, Keithley Instruments released a few procedures to measure various fundamental constants. The procedure outlined here is taken from their originally released procedure and provides a method to measure *e* without the difficulties associated with Milliken's experiment.

In this experiment, an NPN transistor is used. In short, charge (electrons) is (are) excited by thermal activation over a barrier and the barrier is adjusted by using a potential difference. The emitter and collector currents are approximately equal in magnitude and opposite in direction summing to the very low current in the base of the transistor. The current from the collector will be measured across a 30kΩ resistor. The barrier is "distorted" by the potential which changes the probability of excitation of the charge into the conduction process. The expected collector current should have the form

$$I_c = A\left[e^{\frac{qV_b}{kT}} - 1\right]$$

where *q* is the charge on the charge carriers, *k* is the Boltzmann's constant ($1.38\text{x}10^{-23}$J/K) and *T* is the temperature of the transistor (room temperature). This current is measured as a voltage,

V_{RC}, as shown in the circuit below across the 30kΩ resistor. Since kT at room temperature is about 1/40th of a volt, for potentials, V_B, significantly larger than that, the first term in the I_c expression above dominates and the V_{RC} is expected to have the form

$$V_{RC} = B\left[e^{\frac{qV_B}{kT}}\right]$$

where B is R_cA.

Activity:

Setup the circuit as shown in figure 1. Measure V_{RC} at approximately 20 different values of V_b. The range of V_B should be something like 0.5V to 0.8V. The strong exponential dependence makes the collector current change rapidly over this range.

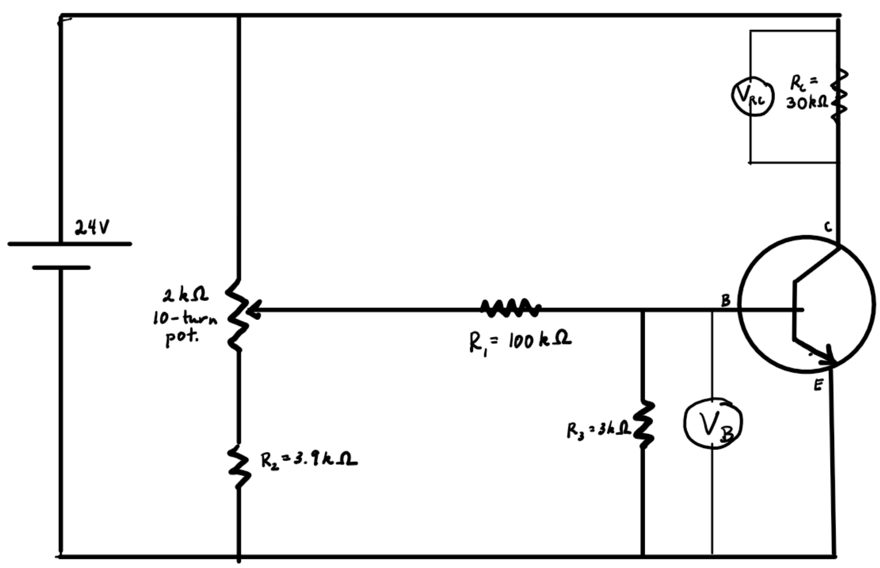

Fig. 1. Schematic of the circuit needed to measure the value of the charge on the charge on the charger carriers in an NPN transistor.

1. After collecting the data, develop a way to plot the data which will allow the slope of the line formed by the plotted data to be q/kT.
2. Convert this slope to find q.
3. Compare this value to that known for the charge on an electron.
4. Include this comparison as part of a short summary that discusses possible sources of error.
5. Using the expression for V_{RC} above, discuss another variable you could change to extract the electronic charge from the data.