

## UNIVERSITY PHYSICS LAB II

## Experiment 7

The Charge of an Electron

Equipment: Power Supply, Digital Multimeter

Supplies: Three resistors (100 k $\Omega$ , 10 k $\Omega$ , and 33 k $\Omega$ ), a 20 or 5 k $\Omega$  10-turn potentiometer and two **npn** transistors (2N2222 and 2N3766)

A. Objective

The objective of this experiment is to measure the charge of an electron.

B. 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 (see Appendix 1). 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 (see Appendix 2), which is shown in the circuit in the procedure.

It can be shown 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, we can express:

$$I_c = A[e^{(qV_B/kT)} - 1] \quad (1)$$

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.

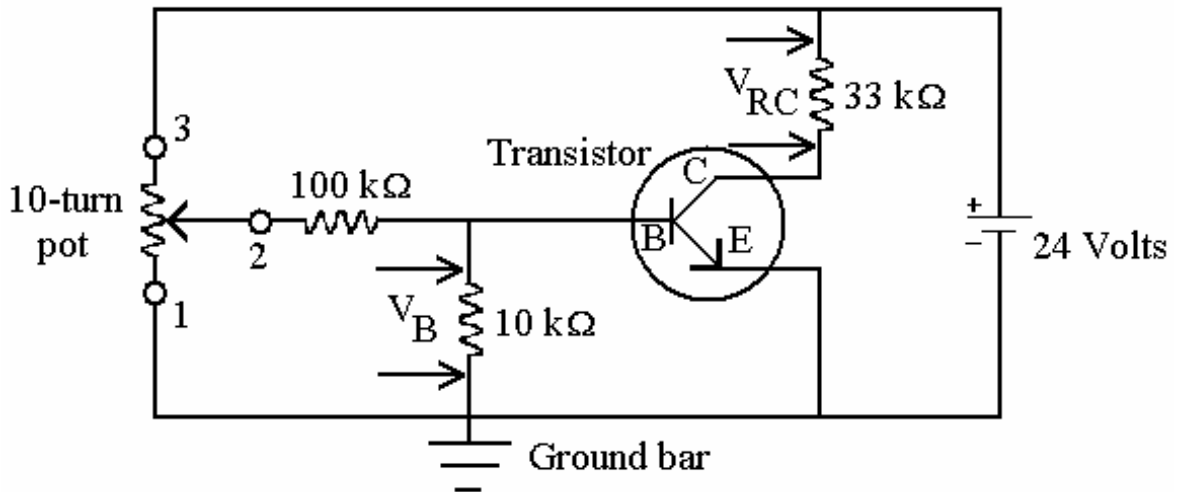
Rather than measure  $I_c$ , we measure the voltage  $V_{RC}$  across the collector resistor,  $R_C$ , and relate it to  $I_c$  by Ohm's Law. Also, at room temperature the exponential term is much greater than unity, and so we can write, to a good approximation:

$$V_{RC} = D e^{(qV_B/kT)} \quad (2)$$

where  $D$  is another constant. This is our working equation.

Procedure -- Experiment 7

1. Set the DC power supply to 24 volts.
2. Construct the circuit shown below using the 2N2222 transistor.



Use the digital multimeter to measure  $V_B$  and  $V_{RC}$ .

3.  $V_B$  can be changed by adjusting the 10-turn pot. 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:

$$V_{RC} = D e^{(qV_B/kT)} \quad (3)$$

$k$  = Boltzmann's constant =  $1.38 \times 10^{-23}$  J/K

4. By changing the pot, set values of  $V_B$  suggested in the data sheets and record the corresponding values of  $V_{RC}$ . When doing this please follow these steps:
  - a) Use the pot to set  $V_B$  to 0.40 volts.
  - b) Read  $V_{RC}$ .
  - c) Check  $V_B$  to make sure that there has been no change. If it has changed, adjust the pot as necessary and read  $V_{RC}$ .
  - d) Repeat this process increasing  $V_B$  by 0.01 volts each time until a value of 0.60 volts is reached.
5. Repeat this process using the 2N3766 transistor.

6. Record the room temperature and convert to Kelvin.
7. For the first set of data plot a graph of  $V_{RC}$  as a function of  $V_B$  on 4-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 straightline may occur at the extreme ends of the graph. Use only the linear region to draw your straight line.

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

$$Slope = \frac{\ln(V_{RC_2}) - \ln(V_{RC_1})}{V_{B_2} - V_{B_1}} \quad (4)$$

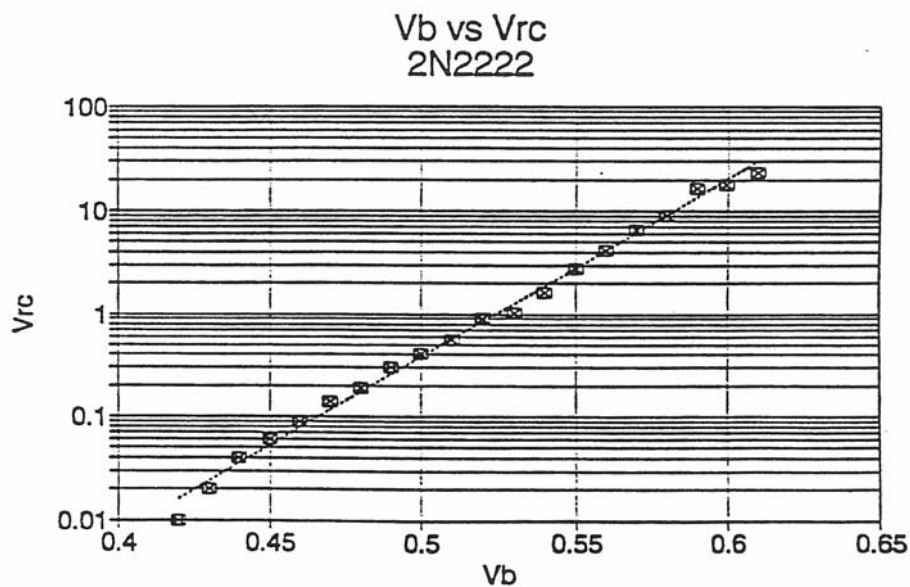
Where  $(V_{B_2}, V_{RC_2})$  and  $(V_{B_1}, V_{RC_1})$  represent two points on the line (do not pick the data points), and **ln** means "take the natural logarithm". The electron charge is found by equating the slope to  $q/KT$ :

$$Slope = q/kT \quad (5)$$

and solving for  $q$ .

Compare your value for electronic charge to the accepted value ( $1.602 \times 10^{-19}$  Coul.) and determine the percentage difference.

8. Repeat part 7 using the data from the second transistor. Use the same sheet of graph paper. A sample graph using the data from just one transistor is shown below.



Room Temperature = \_\_\_\_\_ °F = \_\_\_\_\_ Kelvin

Section #

Results using the 2N2222 transistor		Results using the 2N3766 transistor	
$V_B$ (Volts)	$v_{RC}$ (Volts)	$v_B$ (Volts)	$v_{RC}$ (Volts)
0.40		0.40	
0.41		0.41	
0.42		0.42	
0.43		0.43	
0.44		0.44	
0.45		0.45	
0.46		0.46	
0.47		0.47	
0.48		0.48	
0.49		0.49	
0.50		0.50	
0.51		0.51	
0.52		0.52	
0.53		0.53	
0.54		0.54	
0.55		0.55	
0.56		0.56	
0.57		0.57	
0.58		0.58	
0.59		0.59	
0.60		0.60	

$q =$  \_\_\_\_\_ Coulombs

$q =$  \_\_\_\_\_ Coulombs

Difference from accepted

value = \_\_\_\_\_ %

Difference from accepted

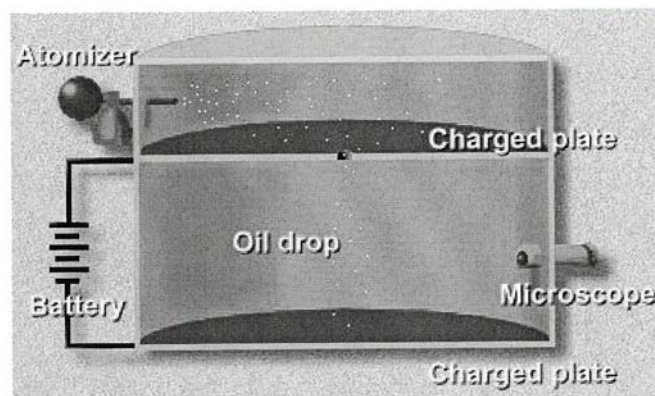
value = \_\_\_\_\_ %

## Millikan's Oil Drop Experiment

*An experiment performed by Robert Millikan in 1909 determined the size of the charge on an electron. He also determined that there was a smallest 'unit' charge, or that charge is 'quantized'. He received the Nobel Prize for his work. We're going to explain that experiment here, and show how Millikan was able to determine the size of a charge on a single electron.*

What Millikan did was to put a charge on a tiny drop of oil, and measure how strong an applied electric field had to be in order to stop the oil drop from falling. Since he was able to work out the mass of the oil drop, and he could calculate the force of gravity on one drop, he could then determine the electric charge that the drop must have. By varying the charge on different drops, he noticed that the charge was always a multiple of  $-1.6 \times 10^{-19}$  C, the charge on a single electron. This meant that it was electrons carrying this unit charge.

Here's how it worked. Have a look at the apparatus he used:



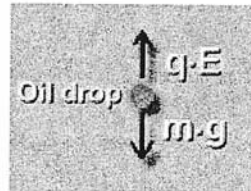
An atomizer sprayed a fine mist of oil droplets into the chamber. Some of these tiny droplets fell through a hole in the upper floor. Millikan first let them fall until they reached terminal velocity. Using the microscope, he measured their terminal velocity, and by use of a formula calculated the mass of each oil drop.

Next, Millikan applied a charge to the falling drops by illuminating the bottom chamber with x-rays. This caused the air to become ionized, and electrons to attach themselves to the oil drops.

By attaching a battery to the plates above and below this bottom chamber, he was able to apply an electric voltage. The electric field produced in the bottom chamber by this voltage would act on the charged oil drops; if the voltage was just right, the electromagnetic force would just balance the force of gravity on a drop, and the drop would hang suspended in mid-air.

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When a drop is suspended, its weight  $m \cdot g$  is exactly equal to the electric force applied  $q \cdot E$



The values of  $E$ , the applied electric field,  $m$  the mass of a drop, and  $g$ , the acceleration due to gravity, are all known values. So you can solve for  $q$ , the charge on the drop:

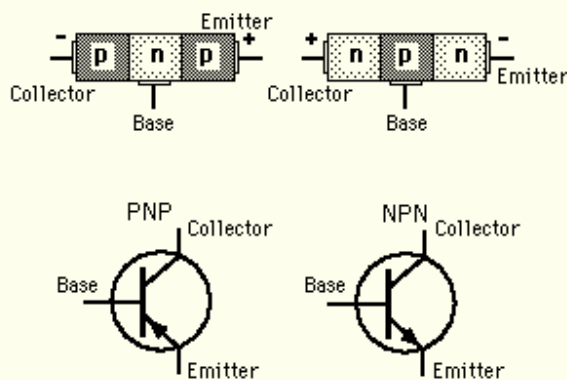
$$q \cdot E = m \cdot g$$
$$q = \frac{m \cdot g}{E}$$

Millikan determined the charge on a drop. Then he redid the experiment numerous times, each time varying the strength of the x-rays ionizing the air, so that differing numbers of electrons would jump onto the oil molecules each time. He obtained various values for  $q$ .

The charge  $q$  on a drop was always a multiple of  $-1.6 \times 10^{-19} \text{ C}$ , the charge on a single electron.

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## The Junction Transistor



A bipolar junction transistor consists of three regions of [doped](#) semiconductors. A small current in the center or base region can be used to control a [larger current](#) flowing between the end regions (emitter and collector). The device can be characterized as a [current amplifier](#), having many applications for [amplification](#) and [switching](#).

## Transistor Structure

