Electric Current and the Cathode Ray Oscilloscope

Experiment #1

In this experiment, you will investigate the role that current plays in electrical circuits, and will also familiarize yourself with the operation of a cathode ray oscilloscope (CRO). You will accomplish this by assembling a simple circuit and measuring a few basic properties of current-carrying wires, followed by a few simple experiments with the CRO.

PART 1: Electric Current

In an electrically conducting material, such as the copper in some wires, some of the electrons are not tightly bound to the nucleus of the atoms. Rather, they are free to move through the material nudging their way past the atoms to create a flow of charge. This flow of charge is called electrical current. How many electrons are free to move, rather than being bound to the nucleus, depends on the type of atoms that make up the conductor. Copper has 1 free conduction electron per atom, the remaining 28 electrons being bound to the nucleus. The conduction electron density of copper is $n = 8.43 \times 10^{28} \text{ electrons/m}^3$.

Procedure

You are provided with a 6 V battery charger (this acts like a 6 V battery, basically), a digital multimeter to measure current (this is an ammeter), a wooden square with two binding posts, a rheostat, a number of connecting wires and, at the front of the lab, a spool of thin “fuse” wire. Assemble the circuit as shown in diagram 1, making sure that you keep the battery switched to “off” while making any connections. The digital multimeter should be connected according to diagram 2, the cables should be connected where the + symbols are shown, as connecting it incorrectly can damage the multimeter! At the setting shown, the multimeter reading will be in amperes. A rheostat is a variable resistor and is used to control the amount of current that flows in a circuit. For the moment, set it to offer the maximum resistance (minimum current). To do this, connect one of the leads to the centre jack of the rheostat, and the other lead to one of the other two jacks. Look at the back of the rheostat. There is a large wire coil that connects the centre jack to the rotating wire bridge. Turn the bridge away from the jack your lead is connected to in order to maximize the wire length that the current flows through. Then the resistance, being proportional to that length, attains its greatest value. Make sure that the fuse wire is bound tightly by the binding posts, DO NOT wrap the wire around the binding post, instead, insert the fuse wire through the hole in the binding post and clamp down on it firmly as shown in diagram 3. Also make sure that the fuse wire is not slack between both posts, a slack wire may not melt under the maximum current.
Switch the battery charger to “on”. If the ammeter reads a negative value, then reverse the wires on the ammeter. You can now increase and decrease the current flowing through the circuit by adjusting the rheostat setting. At a high enough current setting, the fuse wire will start to glow red-hot. Note this current in your lab report and then cool the wire by gently blowing on it. **Record any observed change in current while blowing on the wire.**

Now slowly increase the current until the fuse wire melts. This will create an open circuit, so that no more current will flow. The same principle is used in electrical fuses to prevent current overloads (if for whatever reason, too much current begins to flow through a wire, the fuse will break and stop the current before the wire heats up too much). At what current, \( I_{\text{critical}} \), did the fuse wire melt?

**Analysis**

You can think of current in a wire as a measure of the amount of charge that passes a cross-section of the wire each second, \( I = \frac{\Delta q}{\Delta t} \). Since the electrons travel with a drift velocity \( v \) in a wire of cross-section \( A \), then in a time, \( \Delta t \), electrons will travel a distance \( s = v \Delta t \). If the electron density is \( n \), then the number of electrons that go through the cross-section \( A \) is \( nA \). The total charge of these electrons is \( neA \), where \( e \) is the electronic charge \( 1.6 \times 10^{-19} \) C. The current is thus \( neA \frac{v \Delta t}{\Delta t} = neA v \).

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I = neA v
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Use the value of \( n \) derived above to calculate the drift velocity of the electrons flowing through the fuse wire as it melted (the diameter of the wire is 0.202 mm).

**Discussion**

**Question 1:**

Why did the current in the wire change when you cooled it? Is the relationship between current and wire temperature a direct relationship or an inverse one? How about the relationship between resistance and temperature?

**Question 2:**

You measured the current in the thick connecting wires (red or black wires) that led to the fuse wire. Is the current in the fuse wire the same as in these thicker wires? Why is this so? Using the current equation above, is the electron drift velocity the same in the thicker wires as in the fuse wire? If not, why not?

**PART 2: The Cathode Ray Oscilloscope**

The CRO is a valuable tool often used in many areas of science and industry. Its most important function is the ability to measure voltages that vary in time. To fully characterize a voltage that varies in time using a hand-held voltmeter, you would have to plot how the readings change with time on a graph. This is not only time consuming, but impossible to do if the voltage changes too rapidly (for example, the voltage from a wall socket changes sinusoidally from +115 V to –115 V and back to +115 V in 1/60th of a second). The CRO plots the voltage on a screen and can track changes in a fraction of a microsecond.

**Procedure**

The front panel of the CRO is pictured below. Note that there are more than 2 different models of oscilloscopes used in the lab. At first glance the model you are using may look different than the one presented below, however the operation is identical for all model. To use the instrument to its full
potential, you must become familiar with all of its functions and controls. Take a few moments to familiarize yourself with the many switches and knobs on the front panel.

Starting up: The first step in operating the CRO is to plug it in and turn it on. Press the POWER SWITCH (3) and note that the POWER INDICATOR (2) turns green. Next, rotate the INTENSITY, FOCUS and ILLUMINATION knobs (4), (6), and (8) to their middle settings. These control the spot intensity, spot focus and grid illumination respectively. Set the SLOPE switch (24) to “+”, the COUPLING switch (25) to “AC”, and the TRIGGER SOURCE switch (26) to “CH 1”. (Triggering: in order to properly display the signal on the screen, the trace must be properly “triggered”. That is, the horizontal sweep must start at the same voltage level each time or the trace will appear to “move” across the screen making measurements impossible. The signal used to properly trigger the CRO is usually the voltage input itself i.e. from channel 1 or channel 2). Set the TIME/DIVISION knob (30) in the microsecond (μs) range and make sure the TIME VARIABLE knob (31) is in the calibrated position (turned fully clockwise until it clicks – otherwise the time scale will not be correct!). Now set the CHANNEL 1 COUPLING (10) to “GND” (ground). This should give you a horizontal line across the OSCILLOSCOPE SCREEN (36). Adjust the CHANNEL 1 VERTICAL POSITION (9) knob so that the line appears over the middle line of the screen. You should repeat these steps each time you turn on the CRO during the course.

Motion of the electron beam: The line you see on the screen is actually made up of many closely spaced dots produced when electrons strike the fluorescent dye on the screen. The vertical position of each dot is determined by the input voltage to the oscilloscope. The horizontal motion on the screen is determined by the TIME/DIVISION knob. Set this to 0.5 secs/div and observe that a spot now moves slowly across the screen, reaches the end, then starts over. Use the stopwatch to time the spot and compare the time it takes to cross each division (one of the large squares) with the TIME/DIVISION setting. How long would the spot take to cross the screen with the TIME/DIVISION knob set to 0.2 μs/div?

Alternating (A.C.) voltage from a transformer: You are provided with a step-down transformer that converts the power outlet’s 120 Volts to 6.3 Volts. The alternating current (A.C.) from the power outlet cycles between its maximum value in one direction to the same value in the other direction then back again. In North America, this happens 60 times each second (has a frequency of 60 Hertz). Plug the transformer into the wall socket and connect the two leads from the transformer to THE CHANNEL 1 INPUT (11). Turn the CHANNEL 1 SENSITIVITY (12) knob to 5 volts/div, the CHANNEL 1 COUPLING to “AC” and turn THE CHANNEL 1 SENSITIVITY CALIBRATION (13) knob fully clockwise until it clicks (be sure that this knob is set properly, otherwise the voltage scale will not be correct!). Note: make sure that the CHANNEL 1 is not set to “ground”. If the channel is set to ground, irrespective of the input voltage, the
signal seen on the screen will always correspond to zero voltage. Adjust the TIME/DIVISION setting until you see at least one full A.C. cycle on the screen. The trace on the screen represents the variation of voltage with time. What mathematical function best describes this trace? Determine the period of the trace and calculate the frequency of the transformer output. Does the transformer change the frequency of the power outlet? (Allow for a 5% error in the frequency). Notice that the maximum voltage is in fact greater than 6.3 Volts. This is actually the root mean squared (rms) value of the A.C. signal, and its significance will be covered in class. Since the A.C. signal changes constantly over its cycle, we can say it “behaves” like a D.C. signal of 6.3 Volts. What is the actual maximum value of the A.C. signal (that is, what is its amplitude)?

**Direct (D.C.) voltage from a battery:** Set the CHANNEL 1 COUPLING switch to “DC” and connect the leads to the 1.5 Volt battery. Turn the CHANNEL 1 SENSITIVITY knob to 0.5 volts/div and record the voltage of the battery. What happens when you reverse the leads to the battery?

**Sound vibrations:** Acoustic vibrations (sounds) are traveling waves with oscillating pressure; they are not directly measurable using the CRO. Instead, we can use a microphone to convert the pressure variations in sound waves to corresponding variations in voltage. Connect the microphone outputs to the CRO and set the CHANNEL 1 SENSITIVITY knob to 20 mV/div. Human speech consists of many hundreds of different frequencies, which you can now observe by talking into the microphone. A tuning fork, on the other hand, resonates with only a single frequency. Strike the tuning fork on something soft (the sole of your shoe, for example) then hold it close to the microphone. Set the TIME/DIVISION knob to a setting where you can see a few periods of the tuning fork signal and determine the frequency of the tuning fork. Determine the % error between this frequency and the nominal value printed on the tuning fork itself.

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\text{% error} = 100 \times \frac{|\text{measured} - \text{nominal}|}{|\text{nominal}|}
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