Experiment 3. Time-varying voltages: The Electrocardiogram and Fluorescent lights.

In this experiment, you will use an oscilloscope to measure the time-varying voltages from two quite different sources: 1) your heart, and 2) a photo-detector aimed at the fluorescent lights overhead.

An oscilloscope is a device which displays a graph of voltage vs. time (voltage on the vertical axis, time on the horizontal axis). If the input voltage is DC, that is, constant in time, then the oscilloscope displays a horizontal line, whose vertical position indicates the voltage. Your TA will introduce you to the use of the oscilloscope. The oscilloscope screen has 1 cm divisions on both axes. There are two separate input connectors to the oscilloscope labeled channel 1 and channel 2. Each input channel has a volts per division (volts/div) knob which sets the vertical (volts) scale. A single seconds per division (sec/div) knob sets the horizontal (time) scale. There are also position knobs for adjusting the vertical and horizontal position of the display.

Under the volts/div knob is a 3-position switch which reads "AC - ground - DC". In the ground position, the input to the oscilloscope is grounded (set to 0 volts), and the display becomes a horizontal line whose position is the zero volts position and which can be adjusted with the vertical position knob. For instance, one could set the middle line of the screen to be 0 volts. Then positions above the middle line would be positive voltages, and positions below the middle would be negative voltages. When the switch is in the DC position, the signal is input to the oscilloscope unaltered. The DC position is the one you will use to make all measurements in this lab. There is a small knob in the center of both the volts/div and time/div knobs, called the CAL or calibration knob. This should always be in the fully CW (clockwise) position in order for the volt/div and sec/div scale settings to be correct.

Oscilloscope Front Panel

Electrical connections to the oscilloscope are made through a special kind of connector called a BNC connector. The BNC connector is used with coaxial cables (coax, for short). Coax cables have a central wire carrying the signal voltage and an outer cylindrical conductor which is usually grounded (0 volts). The outer conductor on the
BNC connector on an oscilloscope is always grounded, and it is important to remember that the outer wire of a coax cable is always at zero volts when it is connected to an oscilloscope.

Part I. The EKG

Your heart is a complicated electrochemical machine which produces time-varying voltages as it beats (some details are in your textbook, section 17-11). These heart voltages produce small voltage differences between points on your skin which can be measured and used to diagnose the condition of your heart. Usually, nine electrodes, positioned at various points of the patient’s body, are used when recording a full electrocardiogram (EKG). However, in this lab, we will only use two electrodes to measure the voltage between your right and left hands.

A typical plot of voltage difference between two points on the human body vs. time is shown below. The P deflection corresponds to the contraction of the atria at the start of the heart beat. The QRS group corresponds to the contraction of the ventricles. The T deflections correspond to a repolarization or recovery of the heart cells in preparation for the next beat. Every heart pattern is slightly different, and the interpretation of an EKG requires experience with many patients.

The EKG apparatus that you will use consists of two electrodes, an amplifier, and a storage oscilloscope. Signals travel from the hands, one placed on each electrode, to the EKG amplifier, and then on to the oscilloscope. The voltage that is measured is the potential difference between the two electrodes:

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\[ V = V_1 - V_2. \]  

Thus if you place your left hand on electrode 1 and your right hand on electrode 2, then the voltage measured will be the difference

\[ V_{\text{input}} = V_{\text{LH}} - V_{\text{RH}} \]  

The voltage difference between your hands are inconveniently small to measure directly. Therefore the signal from the electrodes is fed into an amplifier, which amplifies the signal. (The amplifier also filters the signal and contains an isolator to protect you from electric shocks.) Thus the voltage \( V_{\text{scope}} \) registered on the oscilloscope is larger than the input voltage at the electrodes by an amplification factor \( A \):

\[ V_{\text{scope}} = A V_{\text{input}} \]  

In most of this experiment you can ignore this amplification since your main concern is with the time variation of the voltage. Nevertheless, when you want to know the actual voltage between your hands, you need to know the amplification factor \( A \) which you will determine by using a known calibration signal, \( V_{\text{input}} = 1 \text{ mv} \).

**EKG Procedure**

1) Electrode assembly
   a) Check that the cables from the electrode handles are plugged into the proper connections on the amplifier input - marked "left" and "right" on the amplifier.
   b) Run a cable from the amplifier out jack to the Channel 1 input on the oscilloscope.
   c) Plug the EKG amplifier power cord in to the power junction box.
   d) Turn on the EKG amplifier on and switch its mode switch to "operate".
Next turn on the oscilloscope and make sure the switches are all set as shown on the handout taped to the scope. Be careful that the inner knobs marked "cal" on the CH1 VOLTS/DIV and the SEC/DIV controls are turned fully clockwise until a "click" is felt. You should now see a dot, or a short vertical line moving slowly across the screen of the oscilloscope. If it is not visible, ask your instructor for help.

2) Baseline Setting
Begin by sliding the input switch below the Channel 1 VOLTS/DIV knob from DC to ground. Then adjust the vertical position until the trace is on some horizontal reference line at or below the center of the screen. By setting the grounded signal to a known reference line on the display, subsequent measurements of voltage amplitude can be easily determined using the grid marks on the scope. Now, slide the input switch back to D.C. to continue with experiment.

3) EKG Trace
One person should sit down in front of the electrode assembly with their hands wrapped gently around the electrodes, palms down. It is important to have good skin contact and at the same time have relaxed muscles in the hands, arms, and shoulders. Muscle tension will cause voltage noise in the oscilloscope traces. With the hands in place on the electrodes, the EKG patterns will appear on the screen.

You will need a partner to operate the oscilloscope controls. To store a trace, push in the "store" button on the upper right corner of the oscilloscope. This will display a repeating EKG pattern across the screen. To stop the display after one sweep, slide the trigger "mode" switch from "P-P auto" to "single sweep". Now press the "reset" button to run a sweep across the screen. Note that pressing the reset button causes the green "ready" lamp to light. An EKG pattern should begin appearing immediately and move left to right across the screen. If not, set the trigger level (- or +) to its midposition, or a setting which causes repeatable sweeping of the trace. Your goal here is to be able to produce a good stored EKG pattern. Try adjusting the VOLTS/DIV and TIME/DIV controls to other settings from those recommended and note the effect. Experiment until a good signal is obtained.

4) Amplification Factor
The voltage displayed on the oscilloscope differs from the input voltage of your hands by the amplification factor $A$ in Eq. (3). To find $A$, switch the amplifier mode switch to "calibrate"; then press the red button while the oscilloscope makes a single sweep in storage mode. This produces an input voltage whose peak (positive) value is $1 \text{ mV} = 10^{-3}$ volts. By measuring the height of the peak voltage on the oscilloscope, you can calculate the amplification factor $A$ of your amplifier. Include a careful picture of the trace, and be sure to indicate the horizontal and vertical scales (in SEC/DIV and VOLTS/DIV respectively).

5) Voltage between the hands
Switch the amplifier back to "operate" and choose one member of your group to make an EKG trace with the left hand on electrode 1 and the right hand on 2. Once you have
stored a good trace with at least two R peaks, make a careful drawing of the plot. Measure the time between successive R peaks and then find your subject's pulse rate, which is simply the frequency f of the heart expressed in beats/min. (Remember that frequency = 1/ period: f = 1/T.) Measure the peak voltage (that is, the voltage at the R peak) on the screen and, using the known amplification factor A, calculate the actual peak value of $V_{LH} - V_{RH}$ for your subject.

Repeat the preceding paragraph with a second member of your group and comment on the similarities and differences between the two traces.

6) Hands reversed
Have one of the subjects already used in part 5) above reverse his or her hands on the electrodes (RH on 1, LH on 2) and again make a careful drawing of the resulting EKG trace in such a way as to facilitate comparison with the previous plot.

Questions:
How should your plots in 5) and 6) differ? In what aspects should they be the same? How well do your plots fit these expectations?

**Part II. The Photodetector**

In the US, the standard electrical outlet produces an AC voltage with a frequency of 60 Hz and an amplitude of about 170 V; the "rms-value" or average magnitude of the voltage is about 120 V. This powerline voltage, when applied to an overhead fluorescent lamp, causes mercury vapor in the tube to become excited. When the mercury gas atoms jump down to their normal energy levels they emit UV (ultraviolet) photons which strike the fluorescent coating on the tube's inner wall, thus producing visible light. Because the line voltage is oscillating, the intensity of the light produced by the lamp oscillates or "flickers". The eye does not detect this flickering intensity because the frequency of the flicker is too high, but a suitable photodetector connected to the oscilloscope will reveal the periodic variation in the intensity of the light.

**PROCEDURE:**
Disconnect the output cable from the EKG amplifier to the oscilloscope. Connect the short photo detector cable directly to the oscilloscope's Ch.1 input terminal. CAUTION: Hold the cable by the connector end, not by the fragile diode. Now bend the cable gently into a curve (near its center) so the detector points upward at the overhead lights. Set up the oscilloscope to display the signal from the detector. Increase the sweep rate and adjust the voltage scale until the periodic nature of the signal is evident.

When the scope is ready, store one sweep of the detector output and make a drawing of the sweep in your notebook, properly labeled. Measure the period and amplitude of the signal. From the period, compute the frequency. Is the measured frequency what you expect?
If you cover the detector with your hand, what happens to the signal Amplitude? What about its frequency?

**Prelab Questions** (due at the beginning of your lab session).

The graph below shows a sinusoidal voltage displayed on an oscilloscope screen. The volts/div setting is 50 V/div and the time/div setting is 5 msec/div \( (5 \times 10^{-3} \text{ sec/div}) \). The vertical position knob on the oscilloscope has been adjusted so that the middle (dark) horizontal line is at zero volts.

1. What is the period \( T \) of this signal?

2. What is the frequency \( f \) of this signal?

3. Could this signal be the AC voltage from a standard wall socket (in the USA)?

4. What is the amplitude of this signal?

5. How many times a second does this signal equal zero volts? That is, what is the frequency (in hertz) of the zero-crossings of this signal.

6. Dry lab