Bioelectric Measurements

7.1 Objectives

- Determine the amplitude of some electrical signals in the body.

- Observe and measure the characteristics and amplitudes of muscle potentials due to the heart muscles (EKG).

7.2 Introduction

Many biological systems, ranging from the single cell to the human body produce electrical signals that can be detected and recorded by sensitive electronic equipment. In recent years, the study of these signals has played an increasingly important role in the biological sciences, particularly in human medicine. Recently, there has been much interest in the electrical characteristics of plants. Even though research in this area is still in its infancy, there seems to be some evidence that plants change their electrical characteristics in response to changes in the environment.

While a complete explanation of the origins of electric phenomena in biological systems is not possible here, we will introduce the very basic concept of electricity produced by ionic diffusion. The weak electrical signals measured in this experiment are typical of those encountered in animal and plant cells. Through this experiment you will gain basic knowledge of bioelectric measurements and the precautions necessary for obtaining meaningful data from biological systems.

7.3 Key Concepts

As always, you can find a summary on-line at HyperPhysics[1]. Look for keywords: bioelectricity, electrocardiogram, electric shock

7.4 Theory

When the heart is at rest, the inside of the heart muscle cells are negatively charged and the exterior of the cells are positively charged. The cells are said to be polarized. Depolarization and repolarization of the heart muscle cells causes the heart to contract and blood to be pumped throughout your system. Depolarization is accomplished when some of the positively charged ions move through the cell membrane, resulting in a lower potential difference between the exterior and interior of the heart muscle cells. Shortly after depolarization, positive ions move back to their original location and the heart cells are repolarized. Fig. 7.1 is an electrocardiogram (EKG) of two successive heartbeats.

The P-wave represents the depolarization of the two atrium chambers of the heart. The Q, R and S waves represent the depolarization of the two ventricle chambers of the heart. The T wave represents the repolarization of the two ventricle chambers. The atria are repolarized at the same time as the ventricles are depolarizing and are therefore obscured by the much larger ventricle depolarization.

The EKG can be measured by placing electrodes on the surface of your body. However, the resistance of dry skin is fairly high and it is necessary to reduce this resistance in order to obtain any measurements. This can be done by applying a conducting paste or gel to the skin. In this lab you will use disposable adhesive foam EKG electrodes which contain a hydrogel to reduce the resistance of your skin.

In addition to measuring cardiac signals in this experiment, you will observe AC noise, which your body picks up because it acts as an antenna.

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[1]http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html
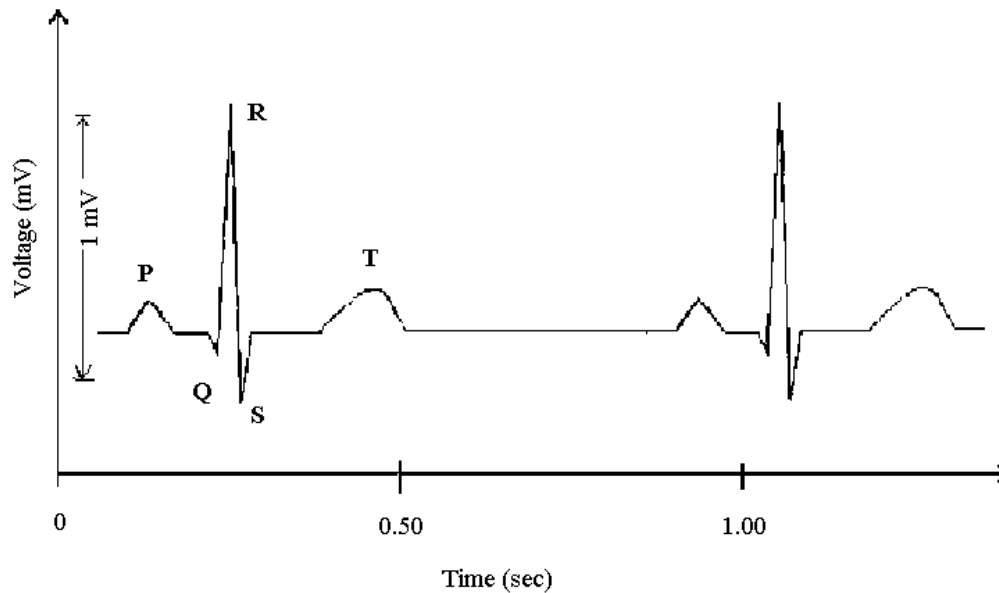
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Figure 7.1: Electrocardiogram (EKG) of two successive heartbeats with different waves labeled.

7.5   In today's lab

In this experiment we will look at a specific biological measurement, the electric potential produced by the human cardiac muscles. The heart puts out a signal varying from about -1 mV to $+1$ mV at a frequency of about $\frac{72 \text{ beats}}{60 \text{ s}} = 1.2$ Hz, corresponding to the contractions of the cardiac muscles. Customarily, placing an electrode on the skin of each arm makes this measurement. There is an arm-to-arm DC potential of about 20 mV due to the biceps and shoulder muscles. In addition, the whole body acts as an antenna picking up electromagnetic waves from the surrounding space. These signals are mostly 60 Hz from the 60 Hz power lines in the building. In a typical situation this may produce a potential between any two points on the body of 50–60 mV with a dominant frequency of 60 Hz. Thus, the cardiac signals are completely lost in the noise. Fortunately, we can use an amplifier to boost the signal from the cardiac muscle.

If a differential amplifier is connected to a subject as shown in Fig. 7.2, with an electrode on each arm and one on a leg as the common reference
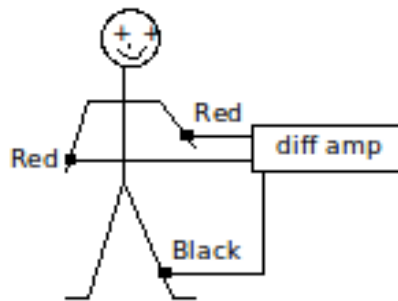
Figure 7.2: How we connect the amplifier to a person.

point, the cardiac muscle signals can be monitored. The AC coupling feature of the differential amp will remove the DC signal coming from the large muscles in the body. The inputs to the amplifier are the AC potential differences between the right arm and right leg, and between the left arm and right leg. The difference will be the AC potential difference between the right arm and the left arm. The noise induced by EM waves passing through the body is common to both arm-leg inputs and thus is removed by the common mode rejection feature, with the leg input as the reference. The output is the amplified cardiac signal alone. (See the previous lab on differential amplifiers for more information on how the common mode rejection and AC coupling features work.)

7.6   Equipment

- Differential amplifier

- Oscilloscope

- Disposable electrodes

Safety Precautions

Any time electronic equipment is connected to a human or animal subject, the matter of electrical shock must be considered. The severity of shock depends on the amount of current flowing through the body and the frequency of that current. See Figs. 7.3 and 7.4. The amount of current that
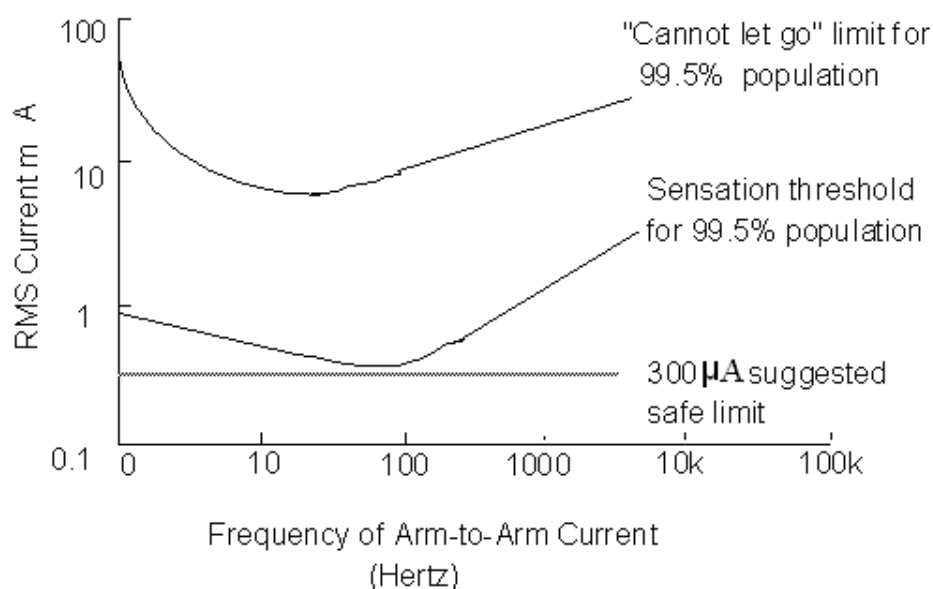
Figure 7.3: Thresholds for effects of current at different frequencies.

will flow through your body is determined by Ohm's Law, $I = V/R$, where the voltage is fixed, and the current is determined by your body's resistance. The arm-to-arm resistance with contacts on dry skin is on the order of 10^5 Ω. Sticking your fingers in a 120 V wall outlet would let a current of 1–2 mA flow through your body — definitely painful. With dry skin, the maximum voltage you should even consider touching is 30 V. Using the disposable electrodes can reduce your skin resistance to as low as 5×10^{-3} Ω. Such a reduction in body resistance significantly raises the possibility of severe injury from an electric shock.

Electronic instruments used to amplify and measure voltages have no potential difference across their inputs, and therefore present no risk of shock. However, if some malfunction of the equipment were to transpire and allow a high voltage to be present at the inputs, a severe shock to the subject could result. Although the probability of such a malfunction is very small, even one incident of shock in thousands of subjects would be unfortunate. Therefore, the system you will use completely precludes the possibility of large voltages being present at the inputs of the differential amplifier.
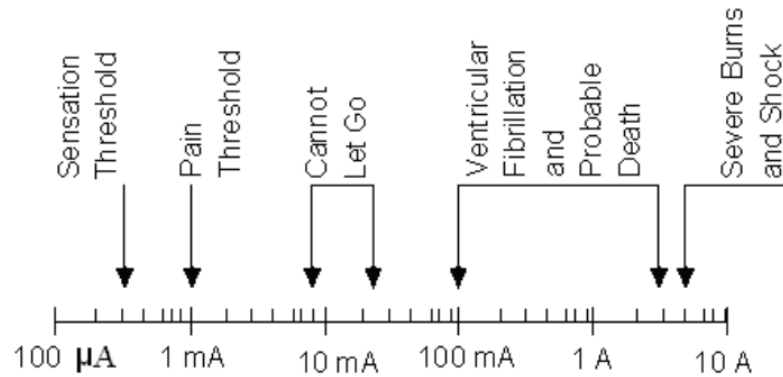
Figure 7.4: Effects of current that is oscillating at 60 Hz.

The safety device used is known as an **optical coupler**. (You already used an optical coupler in the previous lab.) An optical coupler converts the output of the differential amplifier to an optical signal; this optical signal is then detected and converted back to an electrical signal which can be displayed on the oscilloscope. Therefore, **no electrical path exists between the differential amplifier and the measuring device.**

7.7   Procedure

AC noise signal

First, we will view AC noise voltages, which the body picks up from the surrounding power lines and cables. This forms a large portion of the signal which you would detect if you were to connect a set of electrodes directly from your body to the oscilloscope.

1. To observe the AC noise signal, touch the red end of the cable connected to the oscilloscope with your finger (as indicated in Fig. 7.5).

2. Adjust the voltage sensitivity and the time base on the scope to get a reasonable view of the signal.

3. Sketch the noise signal that you see on the scope (Question 1). You may want to press the "lock" button on the oscilloscope to freeze the
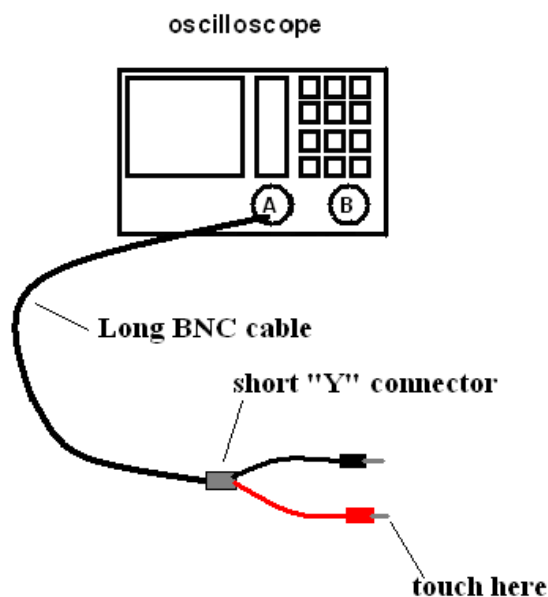
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Figure 7.5: Setup to detect AC noise.

scope's display (don't forget to push the lock button again to unlock the display afterwards).

4. Measure the peak-to-peak voltage and the frequency of the noise signal. Record this in Question 2 and answer Question 3.

AC cardiac signal

Finally, we wish to observe and measure your cardiac signal (EKG). The connections to be made for this section are shown in Fig. 7.6.

1. Attach one electrode to each arm (to get a better signal place them on your upper arm, not your wrist) and attach one electrode to the ankle. Make sure the part of the electrode where the snap goes is making good contact with your bare skin. Clip the red leads to the arm electrodes, and the black lead to the ankle electrode. (In order to reduce electrical cross-talk between the leads it helps to twist the 2 red lead wires around each other a few times before clipping them to the arm electrodes.)

oscilloscope

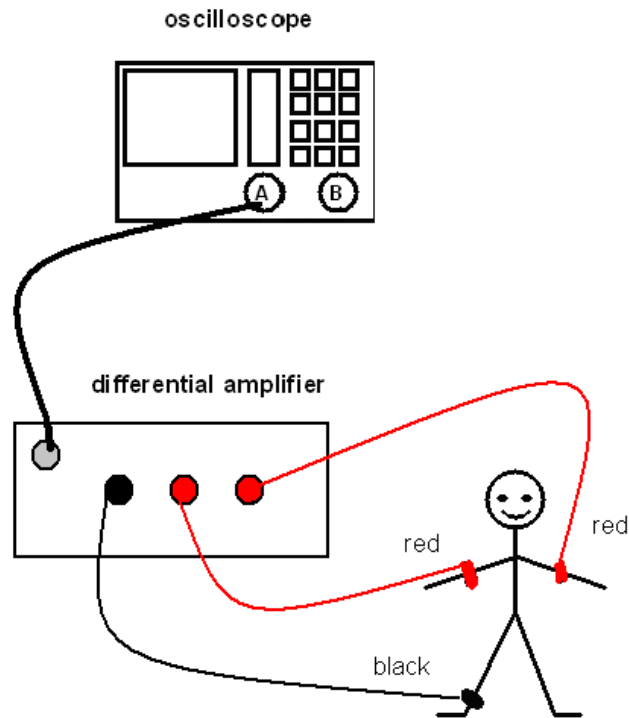differential amplifier

red

red

black

Figure 7.6: Setup to detect the AC cardiac signal.

2. Connect the AC output of the amplifier to channel A of the oscillo-
   scope. (You need to use the same amplifier as the previous lab so you
   know the value of the gain.) Because the heart muscle is constantly
   flexing and relaxing, the cardiac signal is a constantly changing volt-
   age. Hence, for this measurement the amplifier should be in AC cou-
   pling mode to eliminate offsets due to steady DC potentials. Set both
   the oscilloscope and the amp to AC coupling. (On the back of the
   amplifier make sure the switches are in "AC coupling" and "LOW"
   modes so that the gain will match what you measured last week.)

3. The amp is very sensitive to noise and for this experiment because
   the input signal (your EKG) is magnitudes smaller than the noise,
   just placing the amp too close to a power cord can destroy the signal.

Make sure to place the amplifier as far away as possible from all power cords and the oscilloscope. In addition, to help get a good EKG signal the student wearing the electrodes should sit motionless on a stool, not touch any metal, and be as relaxed as possible.

4. Adjust the voltage sensitivity and the time base on the scope to obtain a reasonable trace.

5. Sketch the cardiac signal (Question 4) that you see on the scope twice: once where you see several heartbeats and once where you can see the detail of a single heartbeat. (You may want to freeze the trace by pressing the LOCK button on the scope.)

6. Determine the peak-to-peak voltage and the frequency of the cardiac signal (Question 5) and answer Question 6.

7. Interchange the two red leads. Readjust the amplifier OFFSET knob and observe the heart signal. Sketch what you see on the scope when set up to look at the details of a single heartbeat (Question 7) and answer Question 8.

8. Measure the cardiac signal for the other member(s) in your lab group. Record your results in Question 9.

7.8 Questions

AC noise signal

1. Sketch the noise signal that you see on the scope. You may want to freeze the trace by pressing the LOCK button on the scope.

2. What is the peak-to-peak voltage, V_{pp}, and frequency of the noise signal? Don't forget the uncertainties and units.

   $V_{\text{pp}} =$

   Frequency $=$

3. Is the frequency of the noise signal consistent with 60 Hz (i.e. the frequency of electrical signal throughout the room)?

AC cardiac signal

4. Sketch the cardiac signal that you see on the scope twice: 1) where you see several heartbeats and 2) where you can see the detail of a single heartbeat. (You may want to freeze the trace by pressing the LOCK button on the scope.)

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5. What is the peak-to-peak voltage, V_{pp}, and frequency of the cardiac signal on the scope? Using the gain of your amp, calculate what is your actual V_{pp} The uncertainty of V_{pp} for your actual cardiac signal is given by

$$\delta V_{\text{pp (actual)}} = V_{\text{pp (actual)}} \left(\frac{\delta V_{\text{pp}}}{V_{\text{pp}}} + \frac{\delta(\text{gain})}{\text{gain}} \right) \tag{7.1}$$

V_{pp} read from the scope $=$

gain (from the amplifier lab, Exp. 6) $=$

actual $V_{\text{pp}} =$

frequency $=$

6. Predict what should happen to the output of a differential amplifier when its input leads are exchanged. (Recall that $C = k(A - B)$ from last week's lab.) Justify your prediction.

7. After interchanging the two red leads, sketch what you see on the scope when set up to look at the details of a single heartbeat:

8. Does this result agree with your prediction?

9. What is V_{pp} and frequency for the second group member?

V_{pp} read from the scope =

actual V_{pp} =

frequency =

Third team member (if present):
V_{pp} read from the scope =

actual V_{pp} =

frequency =