

How Do We Sense, Think, and Move? -- Lab #11

Bioelectronics – Measuring Electrical Properties of the Body

Experiment #1 – Your Body's Resistance

Equipment: Digital multimeter, Banana leads

Important Equipment Warnings for Today's Lesson



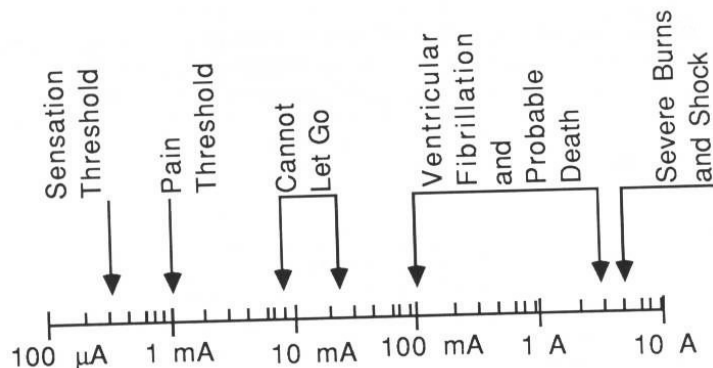
- *In general you should never place your body into a circuit!*
- *Make certain that the multimeter is not connected to anything before you try this experiment.*

Using the digital multimeter and two banana leads, measure the resistance of your body by holding a lead in each of your hands. Record the values for each member of your group.

1. Based on Ohm's law and the resistance of your body, what would you predict to be the current that would go through your body if you held one terminal of a 1.5 V battery in one of your hands and the other terminal in the other hand? What if you held one terminal of a 110 V power source in one of your hands and the other terminal in the other hand?
2. Why do you think different people give different resistance values? What variables could influence the measurement? Explain why you think they would make a difference.

The salty fluids within the human body are electrical conductors (they are not as conductive as metal, but they are much better than insulating materials such as plastics or glass). The interior resistance of an arm (from hand to shoulder) can be estimated to be less than 100 Ω . Any voltage applied across this internal resistance will cause currents to flow and heat to be generated. If currents are large or the connection time is long, then this heat will be sufficient to cause burns that destroy tissue.

Fortunately for us, the resistance of dry skin is a very important protection at low voltages. Typically, over an ordinary contact area, the skin inserts 10 - 100 k Ω between an outside conductor (like the end of a banana lead) and the internal body fluids. Therefore, at voltages below about 50 V, the skin provides safe current limiting protection - if it is dry! Be extremely careful not to have electrical contact with a voltage supply if you have wet or sweaty skin.



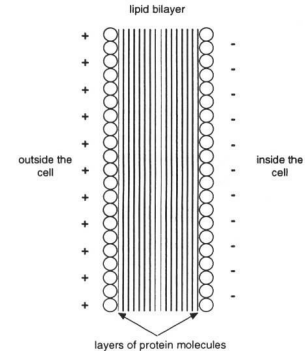
The severity of shock depends on the amount of current flowing through the body

Electrical Potential of Your Heart

Equipment: EKG MBL sensor, Electrode patches

Background Information

Heart muscle cells are polarized when at rest. This means that the cells have slightly unequal concentrations of ions across their cell membranes. An excess of positive sodium ions on the outside of the membrane causes the outside of the membrane to have a positive charge relative to the inside of the membrane. The inside of the cell is at a potential that is about 90 mV less than the outside of the cell membrane. The 90 mV difference is called the resting potential.



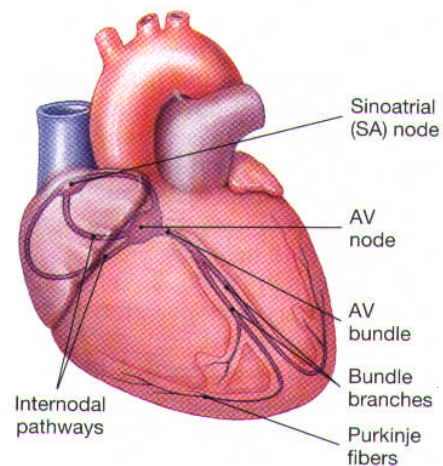
The typical cell membrane is relatively impermeable to the entry of sodium, but the stimulation of a muscle cell causes an increase in its permeability to sodium. Some sodium ions migrate into the cell. This causes a change (*depolarization*) in the electrical field around the cell. The change in cell potential from negative to positive and back to negative is a voltage pulse called the *action potential*. In muscle cells, the action potential causes a muscle contraction.

The effect of this depolarization and repolarization for the entire heart can be measured on the skin surface. Making such a measurement is called an electrocardiogram (EKG or ECG). The depolarization of the heart also leads to the contraction of the heart muscles and therefore the EKG is an indirect indicator of heart muscle contraction.

Cardiac muscle tissue (muscle tissue of the heart) differs from skeletal muscles because it is able to contract on its own. This property of cardiac muscle tissue is called *automaticity*, or *autorhythmicity*. The cells responsible for initiating and distributing the signal to contract are part of the conducting system of the heart. The conducting system of the heart is a network of specialized cardiac muscle cells that initiate and distribute electrical impulses.

The heart's conducting system includes:

- The *sinoatrial* (SA) node in the wall of the right atrium.
 - The *atrioventricular* (AV) node at the junction between the atria and ventricles.
 - *Internodal pathways* that link the SA node to the AV node and conducting cells that connect the AV node to the ventricular muscle cells. The conducting cells include those in the AV bundle, the bundle branches, and the Purkinje fibers.
3. Why is a closed circuit necessary in order for an electrical signal to be transmitted to different areas of the heart?



Conducting System of the Heart

The group of cells that depolarize the fastest is called the sinoatrial (SA) node. These cells are located in the right atrium of the heart. The cells of the atria are all physically connected and therefore the depolarization of the cells of the SA node cause all the cells of both atria to depolarize and contract almost simultaneously.

The atria and ventricles are electrically isolated from each other by connective tissue that acts like the insulation on an electric wire. Therefore, the depolarization of the atria does not directly affect the ventricles. However, there is another group of cells in the right atria called the AV node that will conduct the depolarization of the atria down a special bundle of conducting fibers (called the AV bundle) to the ventricles.

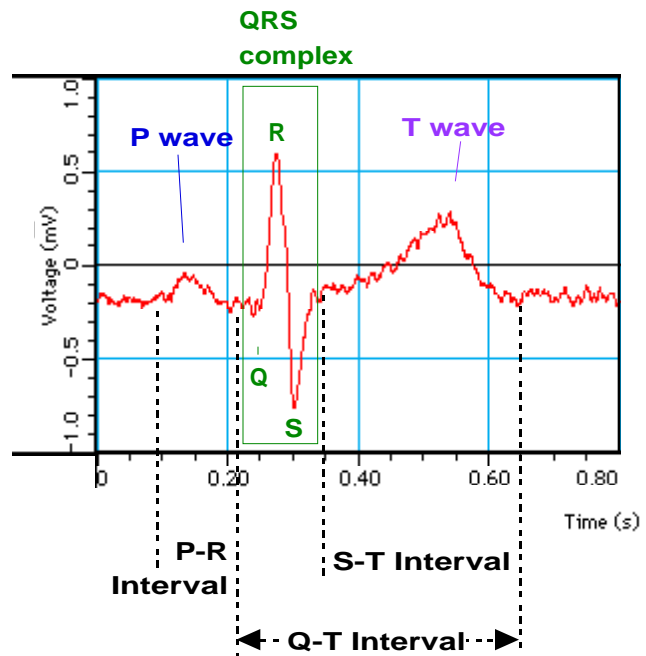
In the muscle wall of the ventricles at the Purkinje fibers, which comprise a special system of muscle fibers that bring depolarization to all parts of the ventricles almost simultaneously. This signal then causes the ventricular contraction.

There is a time delay inherent in this conduction process starting with the AV node and atria contraction and ending with ventricular contraction. This time delay is extremely important because the atria must contract before the ventricles. If all the chambers contracted at the same time, then blood could not flow through the heart because the AV valves would prevent blood flow between the atria and ventricles.

When a portion of the heart is polarized and the adjacent portion is depolarized, this creates an electrical current that moves through the body. This current is greatest when one half of the connected portion of the heart is polarized and the adjacent half is not polarized. The current decreases when the ratio of polarized tissues to non-polarized tissues is less than one to one. The changes in these currents can be measured, amplified, and plotted over time. The EKG represents the summation of all the action potentials from the heart as detected on the surface of the body. It does not measure the mechanical contractions of the heart directly.

This sample plot of voltage vs. time shows the important features of a sample EKG plot.

- The small P wave accompanies the depolarization of the atria. The atria begin contracting around 100 ms after the start of the P wave.
- The QRS complex appears as the ventricles depolarize. This is a relatively strong electrical signal because the mass of the ventricular muscle is much larger than that of the atria. The ventricles begin contracting shortly after the R wave.
- The smaller T wave indicates ventricular repolarization. The atria repolarize during the QRS complex and therefore this repolarization is not separately measurable.



Sample EKG plot

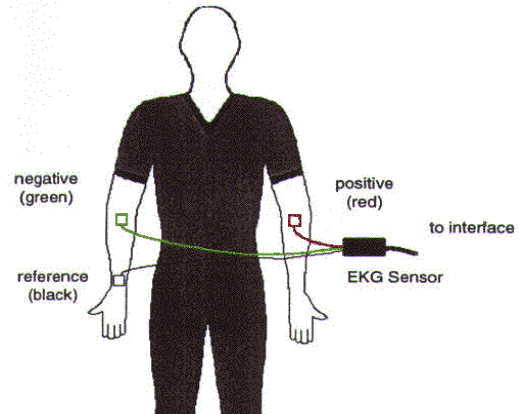


Introduction to A New Tool: Using An EKG Sensor

Today you will each use an EKG sensor to measure the potential of your own heart. If you follow the directions carefully, you will end up with a printout of your own EKG. However, be sure to keep in mind that this experiment does not represent a true medical study and that reading an EKG effectively takes considerable medical training and skill. Therefore, do not be alarmed if your data or graphs seem “different” from those of your partners.

Pick one person to be the first subject in your group. Use the following guidelines to prepare to take an EKG measurement from the first subject.

- Obtain a damp paper towel from the hallway. Using this paper towel, wipe off the area inside each elbow and the inside of the right wrist.
- Obtain three electrodes from your lab instructor. Be sure to leave them in place until you have completed all of today’s activities.
- Firmly place the electrodes on your skin - one on your right wrist, one on the inside of the right elbow, and one on the inside left elbow (as pictured).
- Connect the sensor to the electrodes. The reference (black) lead should be connected to your wrist. This lead will be the “flat line” potential on your EKG. The positive (red) lead should be connected to the electrode on your left elbow. Finally the negative (green) lead should be connected to the electrode on your right elbow. Try to adjust the wires so that they are not twisting or pulling on the electrodes.



- In general you should never place your body into a circuit! This is especially true since these electrodes have been designed specifically to reduce the resistance of your skin.*
- Fortunately, the EKG sensor’s circuitry isolates the subject from the possibility of electrical shock in two ways: 1) the sensor signal is transmitted through an opto-isolation circuit (that is, light is transmitted at one point in the circuit) and 2) the power for the sensor is transferred through a transformer.



- A very small fraction of students may react to the electrodes. For example, you may have an allergy to the substance on the electrodes. If you feel a burning sensation or are extremely uncomfortable, then remove the electrodes immediately and rinse the area. You can finish the lab by using a partner's data to answer all questions.

Experiment #2 – Effect of the Sampling Rate

Once you are safely and securely connected to the EKG sensor, remain fairly still and breathe normally. Someone else should operate the computer while data is collected for your heart. Setup the *ScienceWorkshop* software to collect and graphically display data from the EKG sensor (file *Lab #11 MBL – EKG Sensor*). Click on the Sampling Options button and record the current sampling rate in your logbook.

Sampling Options...

Record a set of data and sketch it in your logbook (you do not need to print this data).

4. Does this seem to be an appropriate sampling rate for the system that you are trying to measure? Explain why or why not?
5. Change the sampling rate by an order of magnitude (that is, multiply or divide by about ten) and collect a new set of data. Is this rate more or less appropriate? Explain.
6. Change the sampling rate by another order of magnitude and collect a new set of data. Is this rate more or less appropriate? Explain.
7. Decide what rate is best for this system and record the value in your logbook along with a brief explanation of why this value is best.
8. What are the drawbacks of a sampling rate being set too low? Too high?

Experiment #3 – Electrical Potential of Your Heart

Once your sampling rate is set, you should collect your EKG data. Once you have collected a “good” set of data, then print one copy for your logbook. In addition, save the file with your data for further analysis. Some of the data values you may be able to read directly off your printout, but some you may need to use the analysis tools in the software (such as the cursor button).

Disconnect the EKG sensor from the electrodes, **but leave the electrodes attached to your arms**. The next person in the group should become the subject and repeat the experiment. Do not start task #3 until all members of your group have saved and printed their data.

Analyzing Your Data

Using your data, answer the following questions for your heart. Explain how you make any measurements or any calculations that you do. You must justify all answers.

9. Identify and estimate the following quantities:
 - Peak-to-peak value of the voltage between the R wave and the S wave.
 - The P-R time interval.
 - The Q-R-S time interval.
 - The Q-T time interval.
10. What was the frequency of your heart during the testing (in *beats/min* and in *Hz*)?
11. What would happen if you switched the red and green leads? Try it out experimentally and make a sketch of your results in your log book (do not bother printing this graph). Explain any differences that may occur due to this change.

Experiment #4 – EKG After Mild Exercise

Once each member of your group has completed their own EKG and printed their graph, you are ready to study the effect of mild amounts of exercise on your EKG. Each member of your group should complete this experiment.

One at a time, you should stand up and exercise for three minutes (jog in place, “step in time”, walk up and down the stair case, walk briskly around the hallway, ...). After the three minutes are up, then sit back down and get reconnected to the EKG sensor as quickly as possible. Collect a new set of data.



- If you have a medical reason why you should not perform some mild exercise, then feel free to use one of your partner’s data to answer the questions.

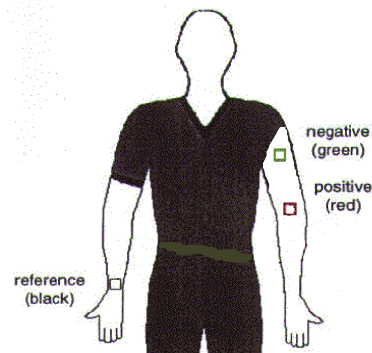
Each member of your group should complete this experiment and analyze their own data.

12. Answer questions 9 - 10 for this new data set.
13. Briefly describe the exercise that you completed. What effect did the exercise have on your EKG? What things seemed unaffected?

Experiment #5 – Electrical Potential of a Bicep Muscle

Pick one person to be the subject for this experiment. Try to pick someone who is wearing short sleeves.

- a. Use a damp paper towel to wipe off the area above and below the bicep muscle on the arm without an electrode on the wrist.
- b. Firmly place electrodes on your skin so that you have 1 on your right wrist, 1 on the upper portion of the left bicep, and 1 on the lower portion of the left bicep (as pictured).
- c. Connect the sensor to the electrodes. The reference (black) lead should be connected to your wrist. The red and green leads should be connected to the bicep muscle area. Try to adjust the wires so that they are not twisting or pulling on the electrodes.



You will now prepare to collect data when the subject is relaxing his/her bicep muscle and when he/she is flexing the muscle. A good technique for flexing the muscle is to lift up on the table. Whether flexing or relaxing the muscle, try to stay as stationary as possible.

14. Describe and sketch the behavior of the data for this muscle. Are you convinced that this muscle generates a voltage when it is flexed? Explain.
15. How is the signal from the bicep muscle similar to and different from the signal from the heart muscle?
16. Estimate a repolarization time for the bicep muscle. Explain on what information you based your estimate.

Concluding Questions

17. In your own words, explain the purpose of the “goop” that is on the electrodes. Why do medical technicians and patients need to be extremely careful about the equipment that is connected to patients?
18. Based on the data collected in your lab group and at least one other, what is an “average” amount of time between the start of depolarization of the atria and the start of the depolarization of the ventricles for a human heart?
19. Based on the data collected in your lab group and at least one other, what is an “average” amount of time required for the depolarization of the ventricles and the subsequent ventricular repolarization for a human heart?

End of Lab Cleanup

- Turn off the multimeter.
- Throw away all used electrodes and paper towels into the trashcan (and not the recycle bin).

Reference Sources

- *EKG Sensor*, Pasco Scientific, © 1996.
- *Fundamentals of Anatomy and Physiology*, Third Ed., F.H. Martini, Prentice Hall, © 1995.
- *ZAP!* J. Pine et al., Jones and Bartlett Publishers, 1996, pg. 35.
- *Introductory Physics Experiments*, Physics Dept., Michigan State University, 1990.