Electrocardiography (EKG)

An Experiment For PHYS138

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Abstract

In this experiment, you will explore the connection between electric field lines and equipotential surfaces, and you will use a PASCO EKG sensor to measure the action potential of your heart.

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I. INTRODUCTION

A. The Physics

Objects with net electric charges attract or repel each other. If you want to change the position of a charged object relative other charged objects, you, in general, have to do (positive or negative) work. But sometimes it is possible to move a charged object relative to other charged objects along a surface without doing any work. The potential energy of the charged object does not change as you move it. If an electric charge can travel along a surface without the electric field or an external force doing any work, then the surface is an equipotential surface.

B. The Physiology

Heart muscle cells are polarized when at rest. This means that the net charge density of the fluid inside and outside of the cells is different, because of the difference in ion concentrations on either side of the muscle cell membranes. The potential inside of the cell membranes is approximately $-90\,mV$[1] with respect to the potential just outside the cell membranes. This potential difference is called the **resting potential**. At rest, we find an excess of positive sodium ions (Na^+) outside of the membranes.

A typical muscle cell membrane is relatively impermeable to sodium ions, but the stimulation of a muscle cell causes an increase in its permeability to Na^+. More sodium ions enter than leave the cell. This causes a change in the cell potential (depolarization). The potential inside of the cell becomes positive with respect to the potential outside of the cell membrane and then returns back to $-90mV$, as ions pumps re-establish the resting potential. The resulting voltage pulse is called the action potential (AP). In muscle cells, the action potential causes a muscle contraction. Depolarization and repolarization of the entire heart can be measured on the skin surface. Such a measurement is called an electrocardiogram (EKG or ECG). Depolarization of the heart leads to the contraction of the heart muscles and therefore an EKG is an indirect indicator of heart muscle contraction. *(See. Fig. 1)*

The cells of the heart will depolarize without an outside stimulus; that is, they will depo-

[1] I don't know the uncertainty for this measurement.

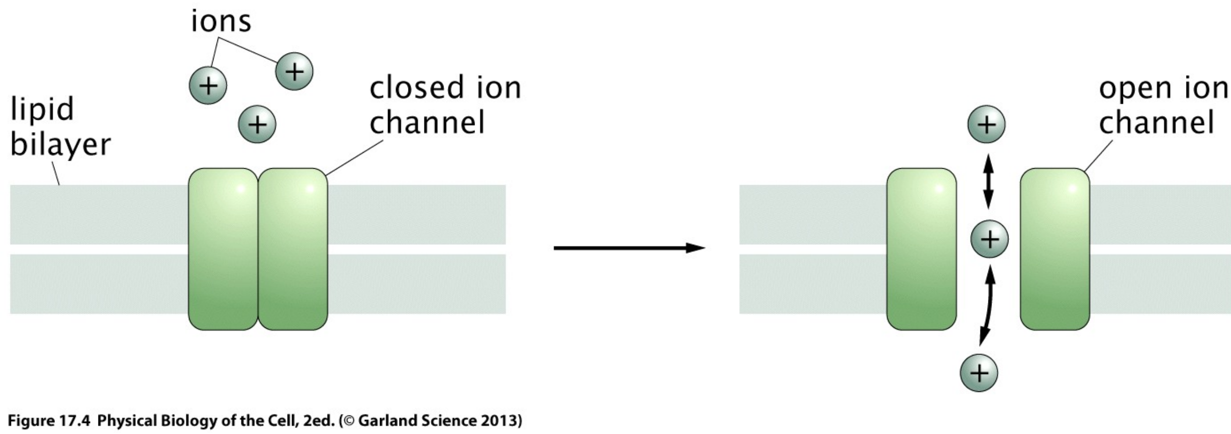

FIG. 1: Ion channels and transient membrane permeability.[a]

[a] When the muscle cell is at rest, the ion channel is closed, the concentration gradient is maintained across the cell membrane. Hence, the resting potential is maintained. When the muscle cell is stimulated, the ion channel opens, ions flow across the membrane until an equilibrium distribution of charges is established. Hence, the cell is depolarized,

larize spontaneously. The group of cells that depolarize the fastest is called the pacemaker (also known as the sinoatrial or SA node). These cell are located in the right atrium. The cells of the atria are all connected physically and thus the depolarization of the cells of the pacemaker cause all the cells of both atria to depolarize and contract almost simultaneously. This process causes a small time delay and so there is a short pause after the atria contract before the ventricles contract. Because the cells of the heart muscle are interconnected, this wave of depolarization, contraction and repolarization spreads across all the connected muscle of the heart. *(See. Fig. 2)*

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 tissue to non-polarized tissue 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 actions potentials from the heart as detected on the surface of the body and does not measure the mechanical contractions of the heart directly. The two atria contract due to the pacemaker and force blood into the two ventricles. Shortly after this contraction the two ventricles contract due to the signal

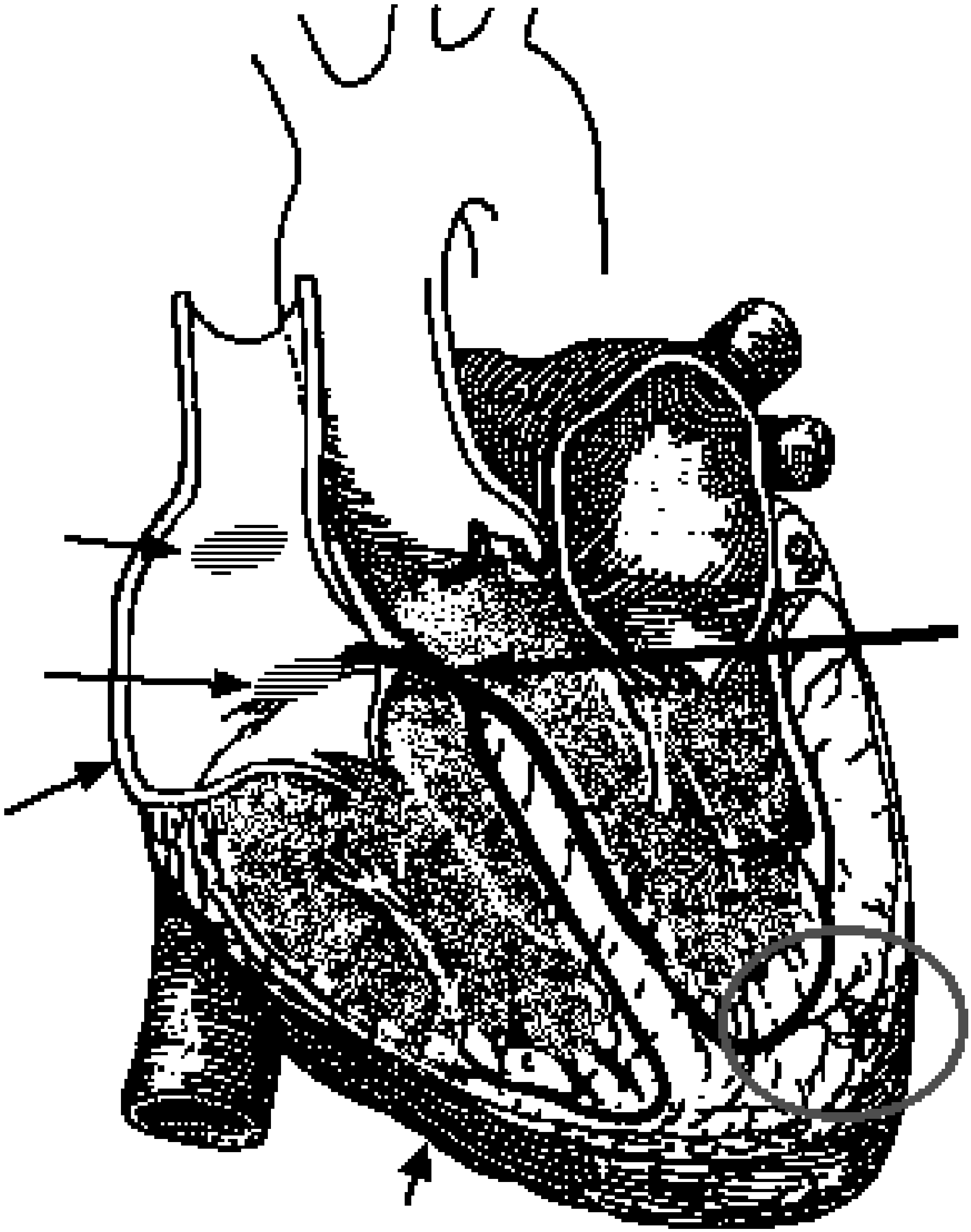

FIG. 2: Cross section of human heart

conducted to them from the atria. The blood leaves the two ventricles through pulmonary and aortic arteries. The heart muscle cells recover their polarity and in another second the cycle starts again.

C. The Electrocardiogram

One part of a typical EKG (electrocardiogram) is a flat line or trace indicating no detectable electrical activity. This line is called the **Isoelectric line**. Deviation from this line indicates electrical activity of the heart muscles.

The first deviation from the Isoelectric line in a typical EKG is an upward pulse followed by a return to the Isoelectric line. This is called the **P wave** and it lasts about $40\,ms$. This wave is caused by the depolarization of the atria and is associated with the contraction of the atria.

After a return to the Isoelectric line there is a short delay while the hearts **AV node** depolarizes and sends a signal along the atrioventricular bundle of conducting fibers (**Bundle of His**) to the **Purkinje fibers**, which bring depolarization to all parts of the ventricles almost simultaneously.

After the AV node depolarizes there is a downward pulse called the **Q wave**. Shortly after the Q wave there is a rapid upswing of the line called the **R wave** followed by a strong downswing of the line called the **S wave** and then a return to the Isoelectric line. These three waves together are called the QRS complex. This complex is caused by the depolarization of the ventricles and is associated the with the contraction of the ventricles.

After a short period of time the sodium and calcium ions that have been involved in the contraction migrate back to their original location in a process that involves potassium ions and the **sodium-potassium pump**. The movement of these ions generates an upward wave that then returns to the Isoelectric line. This upward pulse is called the T wave and indicates repolarization of the ventricles. The atria repolarize during the QRS complex and therefore this repolarization is not separately detectable.

The sequence from P wave to T wave represents one heart cycle. The number of such cycles in a minute is called the heart rate and is typically $70 - 80$ cycles (beats) per minute at rest.

Some typical times for portions of the EKG are given in Fig 3.

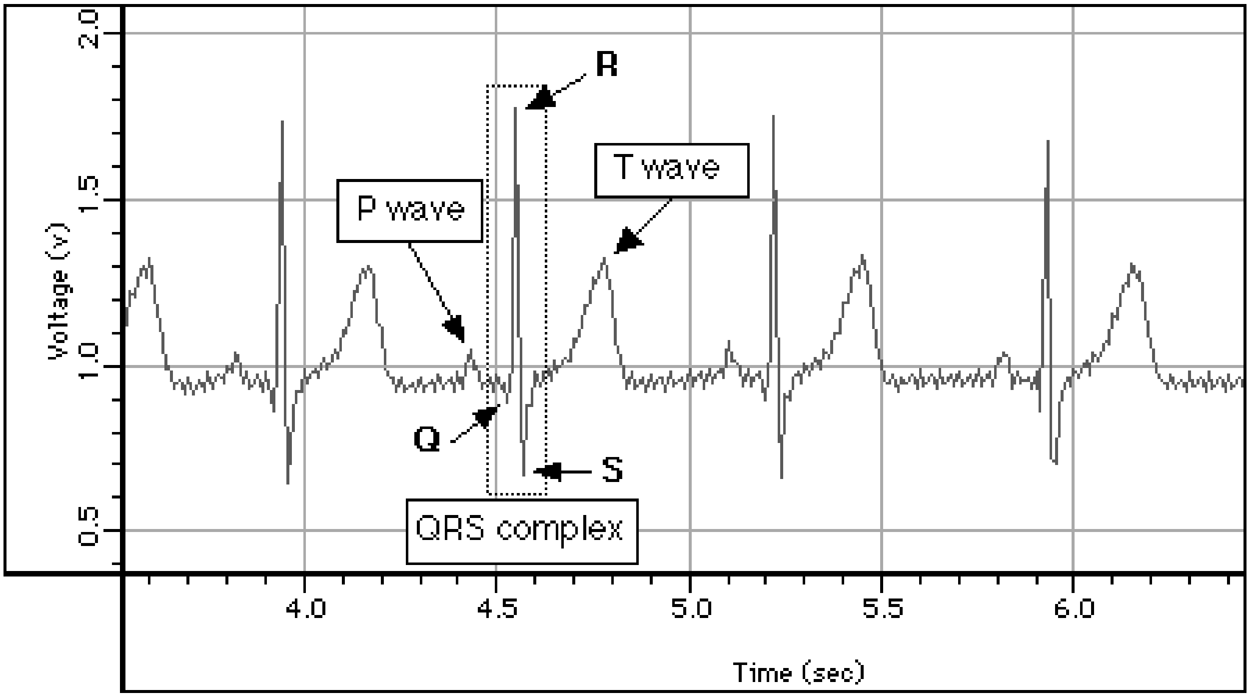

FIG. 3: Sample EKG Graph[a]

[a]

- $P - R$ interval .... $120 - 200\,ms$
- $Q\ R\ S$ interval .... under $100\,ms$
- $Q - T$ interval .... under $380\,ms$

NOTE:

- If your EKG does not correspond to the above numbers, DO NOT BE ALARMED! These numbers represent typical averages and many healthy hearts have data that fall outside of these parameters. To read a EKG effectively takes some further training and skill. The given sensor is NOT intended for medical diagnoses.
- The Graph the you will obtain may be inverted (up side down) than the given sample in Fig. 3. So, pay close when identifying components of the EKG.

II. APPARATUS AND PROCEDURES

The apparatus used in this lab consists of,

1. a PASCO Model CI-6539A EKG sensor;

2. EKG Electrode patches;

3. Rubbing alcohol.

A. Data Capture with PASCO Capstone

The EKG sensor measures cardiac electrical potential wave forms (voltages produced by the heart as its chambers contract). We use the software PASCO Capstone to record data sent from the EKG sensor.

1. Plug the EKG sensor into an Analog channel of the interface.

2. Open PASCO Capstone, wait until the Hardware Setup icon stops flashing.

3. Click Hardware Setup, then right click the Analog Channel port that you have the EKG sensor connected to and select **Heart Rate Sensor**.*(See. Fig. 4)*

4. Click on the properties of the sensor, and make sure that the Gain is set as 1×. *(See. Fig. 5)*

5. **Make sure your data is transfered to your excel file before you leave.**

B. Set-up the Test Subject

Pick one person to be the subject in your group and set-up the electrode onto his skin. *(See. Fig. 6 and Fig. 7)*

1. Obtain a paper towel and a little rubbing alcohol. With the dampened paper towel wipe off an area inside each elbow and inside of the right wrist.

2. Obtain three electrode patches from your instructor. The patches have been designed to reduce the resistance of your skin.

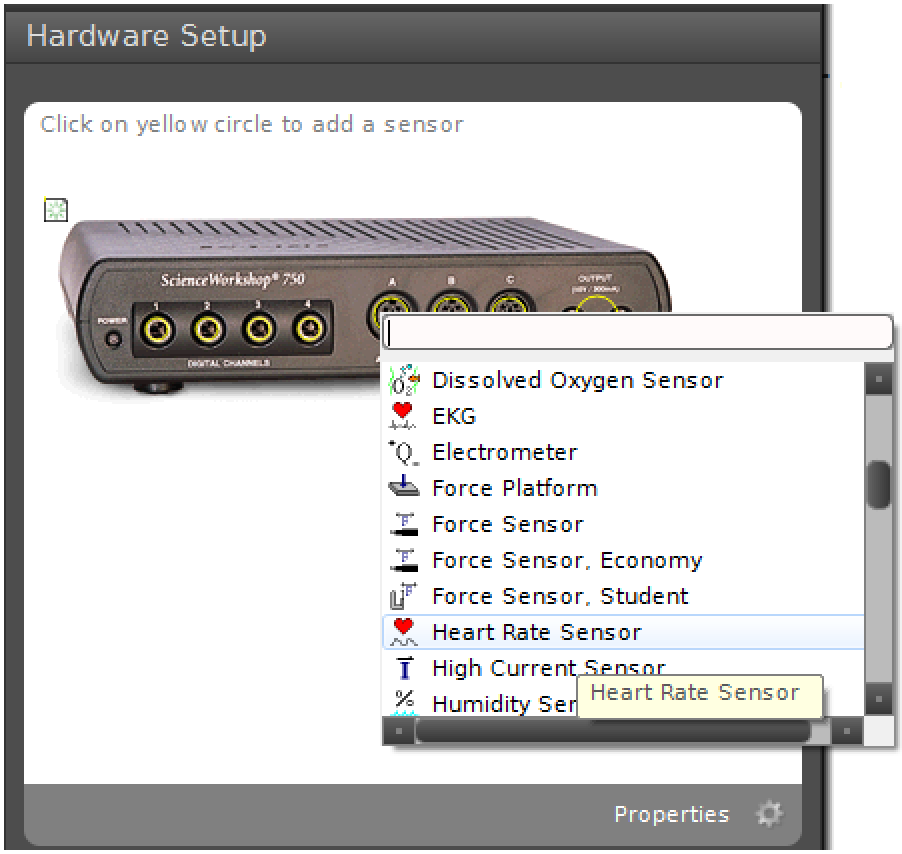

FIG. 4: Hardware Setup – EKG Sensor

3. Firmly place the electrode patches onto your skin - one on your right wrist, one on the inside of the right elbow, and one on the inside left elbow. Leave them in place until you have completed all EKG activities.

   Caution: A very small fraction of students may be allergic to the electrodes. If you feel a burning sensation or are extremely uncomfortable, then remove the electrodes immediately and rinse the area with plenty of water. Also, notify the instructor.

C. Measuring Heart Rate

1. Drag and drop a Graph from the right side of the window to the work space. For $x-$axis, *Select Measurement* as *Time.* For $y-$axis, *Select Measurement* as *Voltage. (See. Fig. 8)*

2. Drag and drop a Table from the right side of the window to the work space. For the first column, *Select Measurement* as *Time.* For the second column, *Select Measurement*

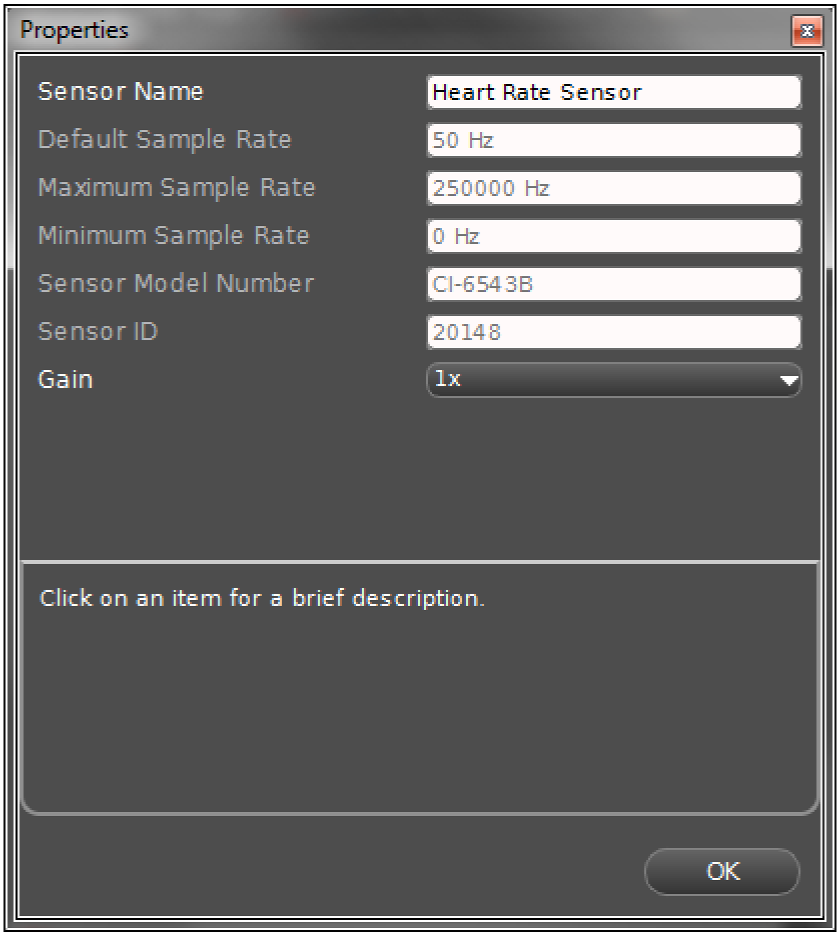

FIG. 5: Sensor Properties

as *Voltage*.

3. Set the Sampling Rate as 200 Hz.*(See. Fig. 9)*

4. Set recording conditions to start at time 0.000 s and stop at time 12.000 s. *(See. Fig. 10)*

5. Click the *Record* button without the knowledge of test subject. Transfer the data to Excel when the measurement is done.

D. Obtaining the Electrocardiography

This part is similar to Sec. II C. The difference is that this part is done with different *Sampling Rate* and *Recording Conditions*

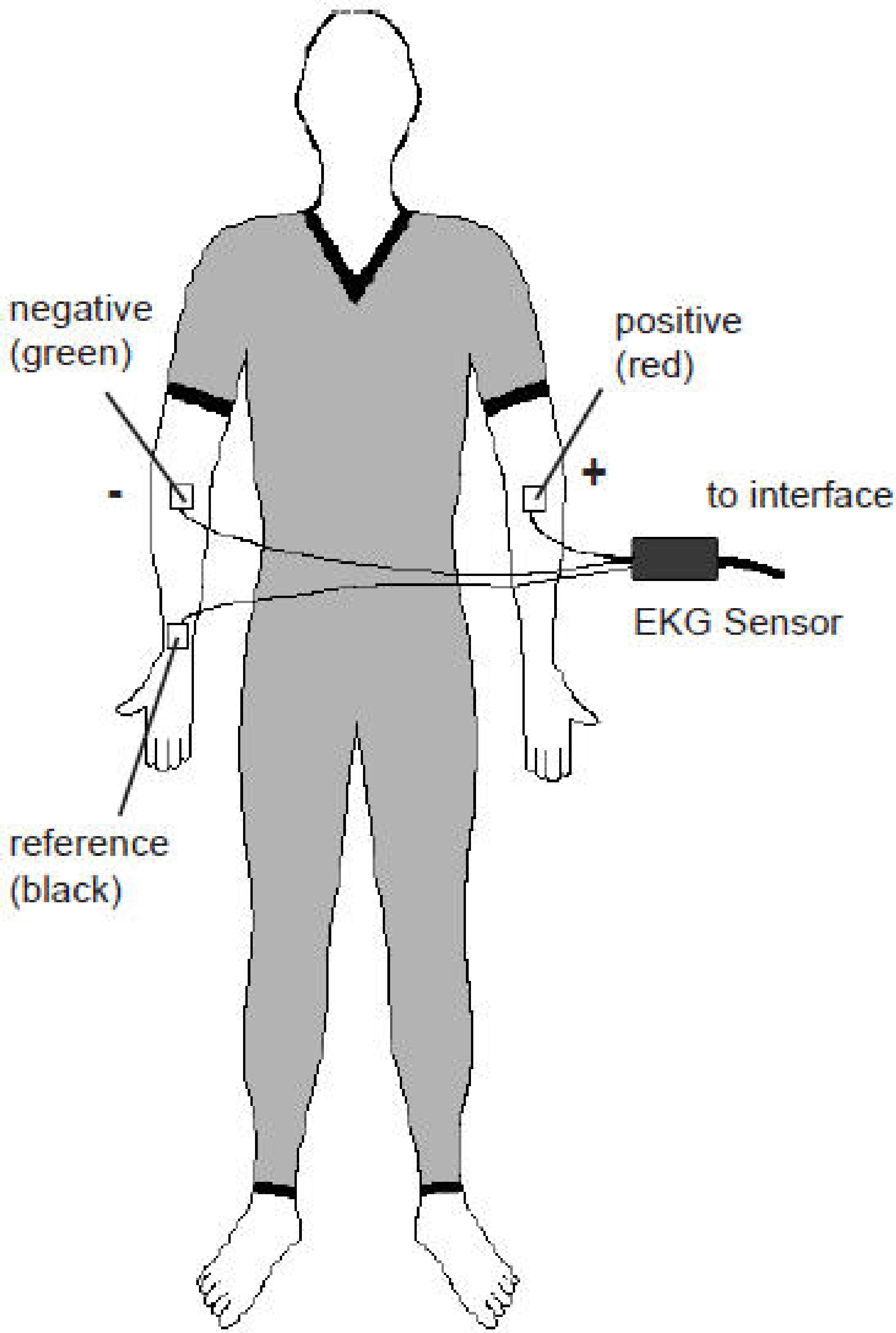

FIG. 6: Electrode Placement A.

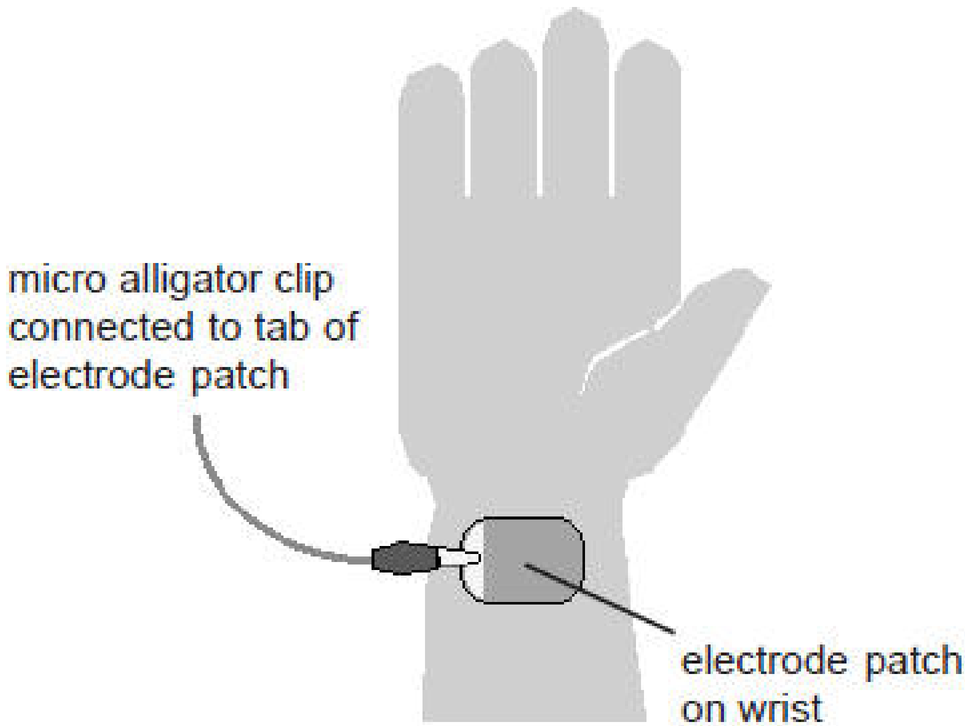

FIG. 7: Electrode Placement B.

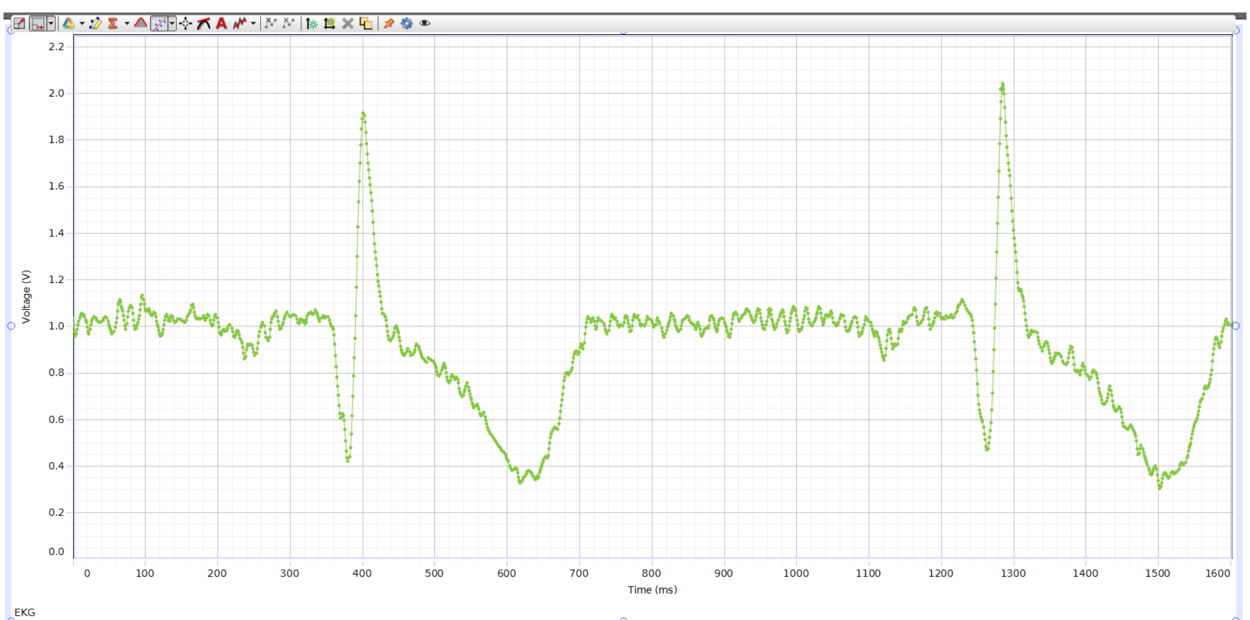

FIG. 8: Plot of an Electrocardiography

FIG. 9: Sampling Rate Set-up

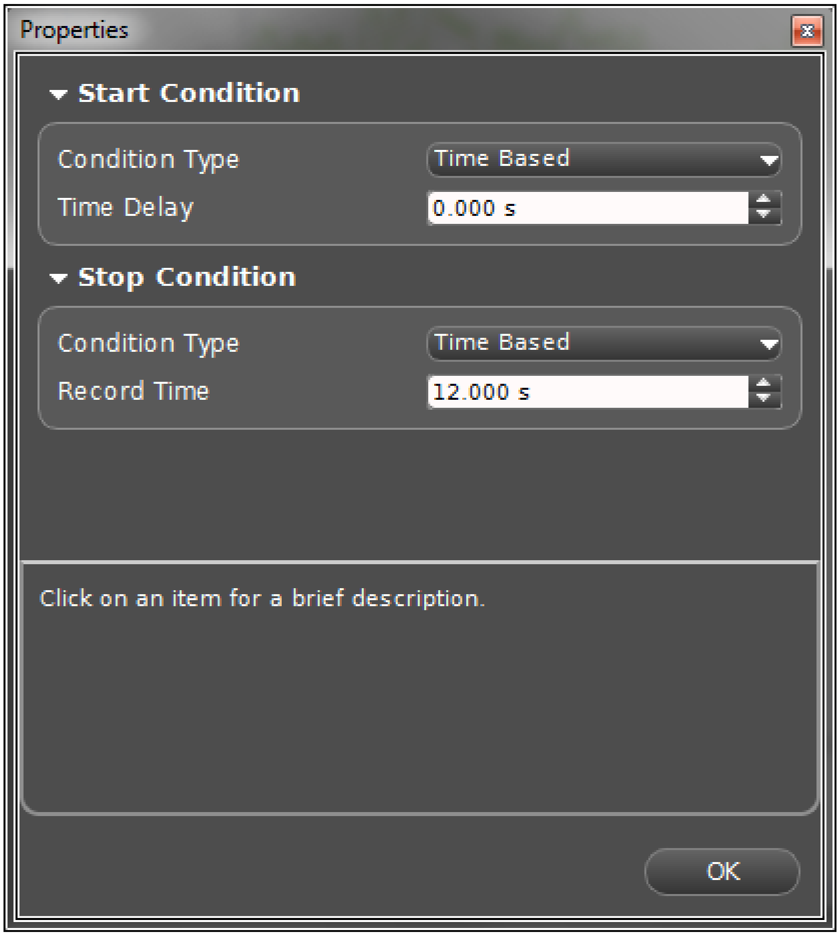

FIG. 10: Recording Conditions Set-up

1. Set recording conditions to start at time 0.000 s and stop at time 2.000 s.

2. Set the Sampling Rate as 1000 Hz.

3. Click the *Record* button without the knowledge of test subject. Transfer the data to Excel when the measurement is done.

E.

Repeat Sec. II C and Sec. II D, after 15 push-ups.

F.

Repeat Sec. II C, Sec. II D with the other partner of your group as the subject.

III. ANALYSIS

The data collected in this experiment is some-what sensitive. It is OK, should you choose not to share the data with anyone else, including the instructor. If you choose not to submit the data collected, please analysis the data set provided by the instructor.

A. Heart Rate

1. Identify the S wave peaks in your measurements.

2. By counting the amount of the peaks recorded, calculated your heart rate.

3. Justify the uncertainty in the heart rate measurement from the last step.

4. By measuring the time interval between each adjacent pair of S wave peaks in your measurement, calculate the average and standard deviation of the time taken between adjacent S wave peaks. Calculate your heart rate with uncertainty based on the measurement from the last step. Compare these two measurements of heart rates.

B. Electrocardiography

1. Isolate one full cycle of the Electrocardiography from your data. You may neglect the uncertainty for this section.

2. Notice the frequency of the noise in your Electrocardiography.

3. Measure the peak-to-peak value of the voltage between the R wave and S wave.

4. The P-R time interval. *i.e.*, the time taken from the start of the P wave to the end of the R wave.

5. The Q-R-S time interval.

6. The Q-T time interval.