Theory

Heart muscle cells are polarized at rest. This means the cells have slightly unequal concentrations of ions across their cell membranes. See Figure 1. 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 millivolts (mV) less than the outside of the cell membrane. The 90 mV difference is called the **resting potential.** See Figure 1.

The typical cell membrane is relatively impermeable to the entry of sodium. However, 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. This change in cell potential from negative to positive and back is a voltage pulse called the **action potential.** In muscle cells the action potential causes a muscle contraction. Other ions and charged molecules are involved in the depolarization and the recovery back to the polarized state. These include potassium, calcium, chlorine and charged protein molecules. The effect of this depolarization and repolarization for the entire heart can be measured on the skin surface. This is an electrocardiogram (EKG). The depolarization of the heart also leads to the contraction of the heart muscles and therefore the EKG is also an indicator of heart muscle contraction (although this is an indirect measurement).

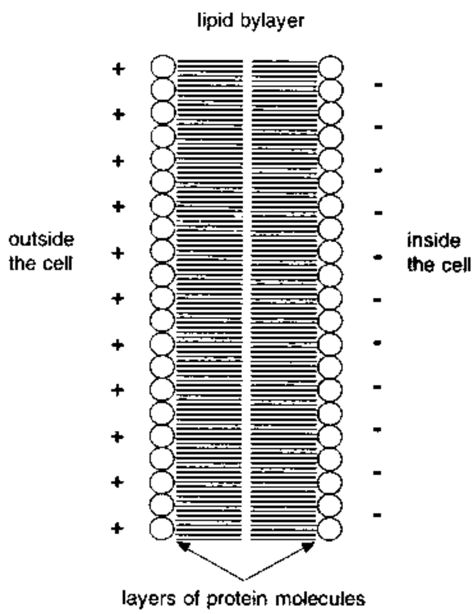

Figure 1
Animal Cell Membrane (sectional view)

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

The atria and the ventricles are isolated from each other electrically by connective tissue that acts like the insulation on an electric wire. The depolarization of the atria does not directly affect the ventricles. There is another group of cells in the right atria, called the *atrioventricular* or **AV node,** that will conduct the depolarization of the atria down a special bundle of conducting fibers (called the **Bundle of His**) to the ventricles. In the muscle wall of the ventricles are the **Purkinje fibers,** which are a special system of muscle fibers that bring depolarization to all parts of the ventricles 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 Figure 2.

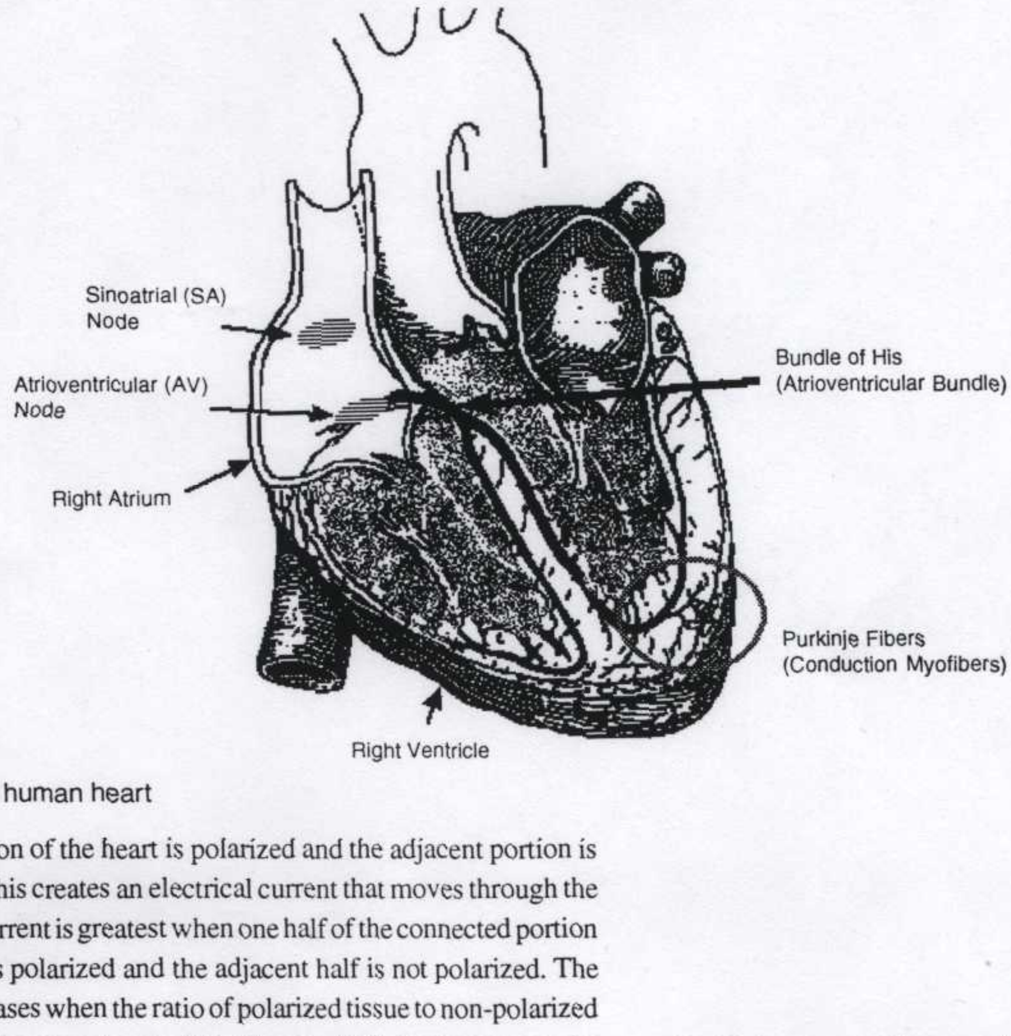

Figure 2
Cross section of human heart

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.

➤ **Note:** An excellent text about the electrocardiogram and other phenomena of bioelectricity is *Physics with Health Science Applications* by Paul Peter Urone, ©1986, John Wiley & Sons, Inc., New York.

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 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.

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 0.04 seconds. 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 heart's **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 <u>during</u> 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 Figure 3.

P-R interval ....120-200 milliseconds

QRS interval ....under 100 milliseconds

Q-T interval .....under 380 milliseconds

➤ **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 considerable training and skill. This sensor is NOT intended for medical diagnoses.*

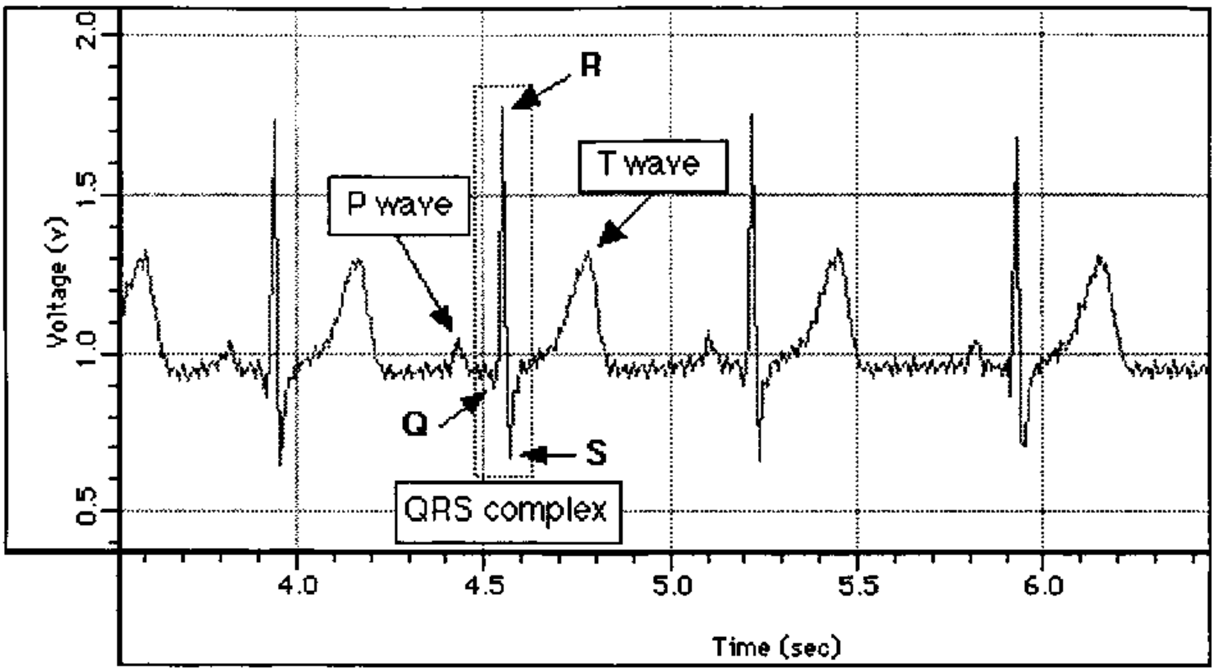

Figure 3
Sample EKG Graph

*Suggested Reading

The following are authoritative sources of information concerning the use of EKG machines and electocardiographs in medical practice.

Carr, Joseph J. and John M. Brown. *Introduction to Biomedical Equipment Technology*. New York: John Wiley & Sons, 1981.

Conover, Mary Boudreau. *Understanding Electrocardiography, Seventh Edition.* St. Louis: Mosby, 1996.

Wagner, Galen S. *Mariott's Practical Electrocardiography, Ninth Edition.* Baltimore: Williams and Wilkens, 1994.