1.3.3

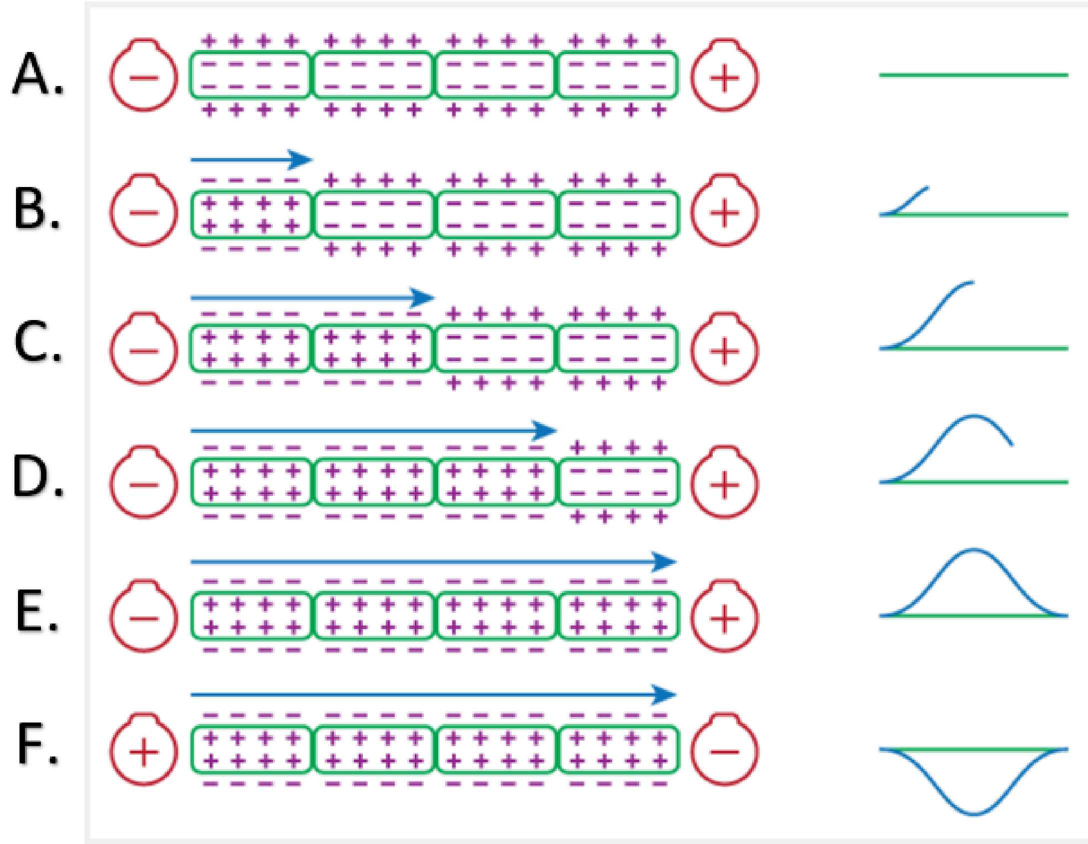
Electrocardiogram (EKG)

We have been discussing action potentials and how they are generated and conducted through the heart muscle. We have also described their role in triggering contraction of the cardiac muscle. An important technique for diagnosis of problems in the heart is to measure its electrical activity. This is accomplished using an electrocardiograph, which creates a record of the electrical activity of the heart, the **electrocardiogram** or **EKG.**

The EKG does not measure individual action potentials but instead represents currents flowing through the extracellular fluids as the charges associated with the heart change. Think what happens when you connect a wire between the opposite poles of a battery, current flows through the wire. A similar event is taking place in the extracellular fluids of the body when some of the heart cells are at rest (negative inside and positive outside) while others are depolarized (positive inside and negative outside). When this happens the extracellular fluid acts just like the wire between the two poles of a battery, that is, it conducts an electrical current. Sensors placed on the surface of the body can detect the electrical flow. If those sensors are connected to a recording device that interprets the direction and magnitude of the current, a tracing can be made of the events taking place during one complete cycle of the heart.

To help you understand how the EKG is generated, let’s examine a hypothetical situation in which we have four cells connected end to end. We will explore what happens as an action potential is generated in one cell and then propagates to the other three cells.

Refer to the next figure as we explain the process.

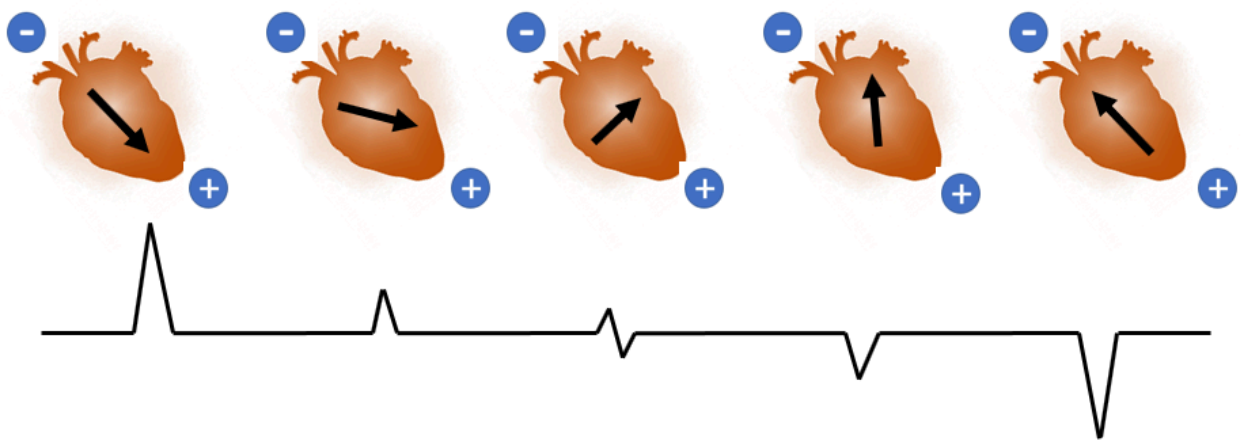


Deflection wave on EKG created as the wave of depolarization moves toward or away from the positive electrode.
Drawn by BYU-Idaho student Nathan Shoemaker Fall 2016

In the figure, A-E represents the progression of an action potential beginning with the first cell of the group and then spreading to the next cells. In this example, the positive sensor is placed to the right of the cells and the negative sensor is placed to the left of the cells.

- In "A", all of the cells are at rest. Since all of the cells have the same charge (+) on the outside of the cells no current is flowing and the tracing would be flat as shown on the graph to the right of the cells. If there is no deflection (no current), we say that we are at the **isoelectric point.**
- As the first cell depolarizes (B), there now exists a charge difference on the outside of the cells and a current will begin to flow. Since the current is flowing from the negative to the positive areas we will see an upward deflection on our recording device. The rule of thumb is that if there is a charge difference (hence current flow) a positive (upward) deflection will be recorded if the charge in the extracellular fluid around the positive electrode is positive.
- In C, the action potential has reached the midpoint, at this point we will get the maximum deflection on the EKG.
- In D, only one cell remains at rest and the tracing is returning toward the isoelectric point.
- In E, all of the cells are depolarized, all negative on the outside and the EKG has returned to the isoelectric point.
- In F, we show how the EKG tracing would look if we repeated the process but this time reversed the position of the electrodes, the positive electrode on the left and the negative on the right.

It should be apparent that where one places the electrodes affects the appearance of the EKG tracings. If a wave of depolarization is moving toward a positive electrode there should be a positive deflection. If it is moving away from a positive electrode toward a negative electrode there would be a negative deflection. If the wave is moving perpendicular to an electrode axis then there will be a biphasic deflection equally positive and negative. How large the deflection is depends both on how closely the wave is oriented to the axis of the electrodes as well as how much of the heart muscle is involved in the depolarization or repolarization. As you will learn in lab, in a typical EKG the electrodes are placed at different positions to give different “looks” of what is happening in the heart.



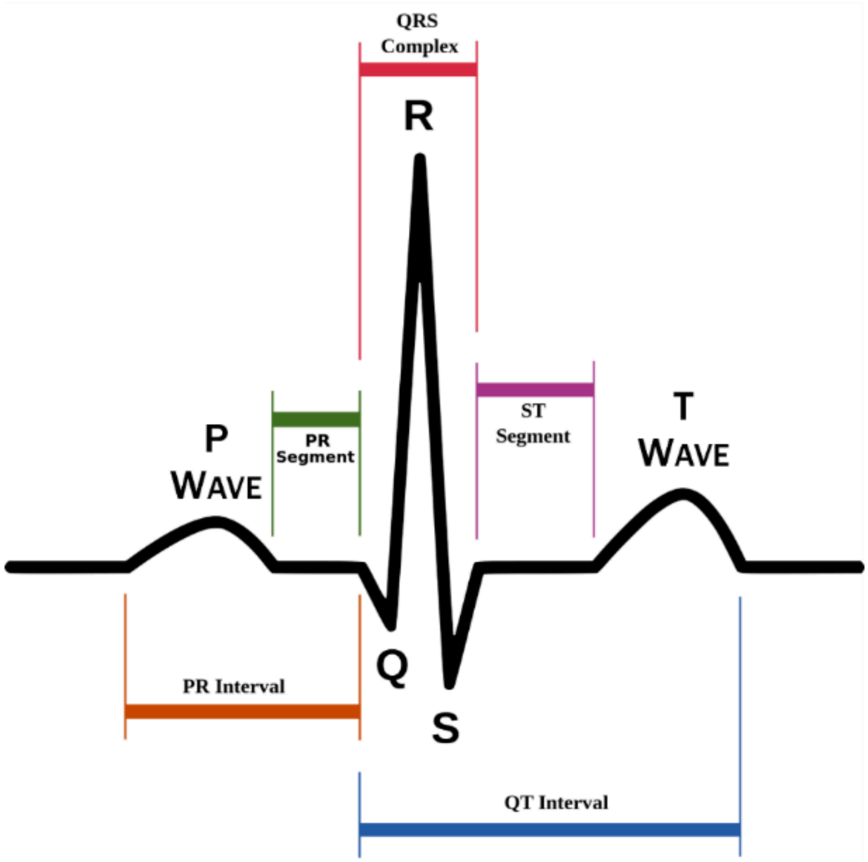
The difference in deflection on ECG determined by if the wave of depolarization/repolarization is traveling toward or away from the positive electrode.
Created by BYU-Idaho instructor T. Orton Fall 2017

Each different positioning of the electrodes is referred to as a different **lead** and there are 12 leads in a typical EKG.

To view this process in action, see this resource:

- Electrocardiography Basics by Osmosis Video: https://books.byui.edu/-xrUJ

When all of the electrical events for one cycle are put together we get an EKG tracing.



EKG Tracing.
Author: Agateller (Anthony Atkielski).Site: https://books.byui.edu/-LRXs License: Creative Commons 3.0

The image above shows a typical EKG. Notice that there are several deflections from the isoelectric point that occur during the cycle. Each deflection is referred to as a wave and each wave is labeled with a letter. A typical EKG has five waves, P, Q, R, S and T. The **P wave** is generated during depolarization of the atria which causes the atria to contract pushing the blood to the ventricles below. The next three waves (Q, R, S) are generated during depolarization of the ventricles which causes the ventricles to contract forcing the blood out of the heart to the lungs and the rest of the body. Since all are generated during ventricular depolarization we typically refer to these three waves collectively as the **QRS complex.** The Q wave is the first downward deflection and then back to isoelectric, the R is the large upward deflection and then back to isoelectric, and the S is the second downward deflection and back to isoelectric. The final wave, the **T wave,** is generated during repolarization of the ventricles. You may be asking yourself where the wave representing repolarization of the atria is. We typically do not observe a repolarization wave for the atria because it is occurring at the same time the ventricles are depolarizing. Since the muscle mass of the ventricles is so much larger than that of the atria, ventricular depolarization probably masks any waves associated with atrial repolarization. Now let's see if you are getting it. What would the tracing shown in the EKG figure look like if the positive and negative leads were switched?

Hopefully, it is becoming apparent that any change in the heart that affects how the action potential's spread through the tissues can be detected on the EKG. For example, if a section of heart muscle were damaged by a heart attack the tracing would be altered, usually in a predictable manner. With practice, the physician can diagnose many abnormalities based on the shape and timing of the various waves. It is important to note that the EKG measures one main thing – the electrical signal as it travels through the heart. It can show if the signal is getting through the conduction fibers as it should or how quickly the heart is beating. In order to measure the strength of the heart you would have to look at several other factors such as: the pressure inside the ventricles at each beat, the resistance of the vessels and/or the volume of blood being ejected with each beat. We will discuss these measures of heart function later in this module as we look at heart regulation. In lab you will learn more about analyzing EKG’s and what types of problems can be detected by this tool.