Spring 2020

CSEN 1099 – Introduction to Biomedical Engineering

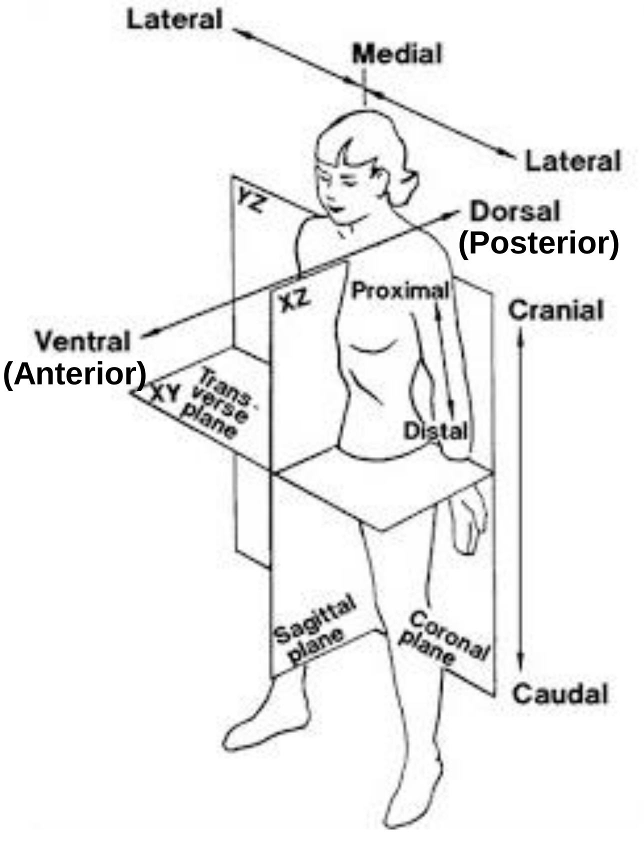
Anatomy and Physiology Background (1)

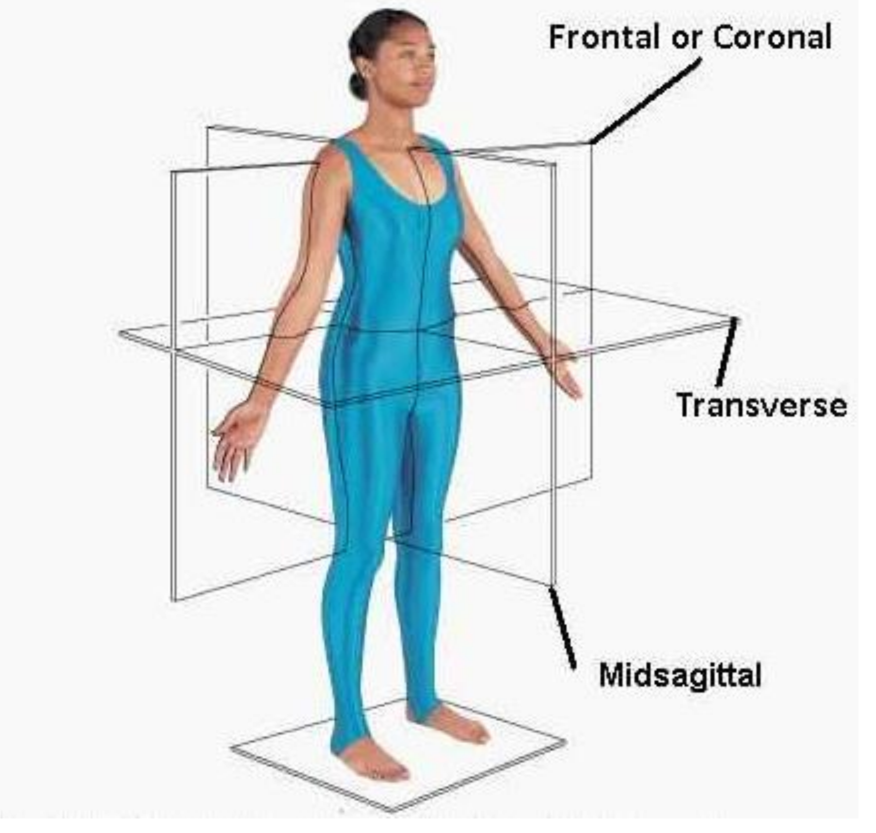
Seif Eldawlaty

Anatomy and Physiology Background

- It is important for biomedical engineers to have knowledge about life sciences

- Anatomical Positions and Planes





Anatomy and Physiology Background

- We will cover three topics in this biological background:
  - The Cell Organization
  - The Heart
  - The Brain

Cellular Organization

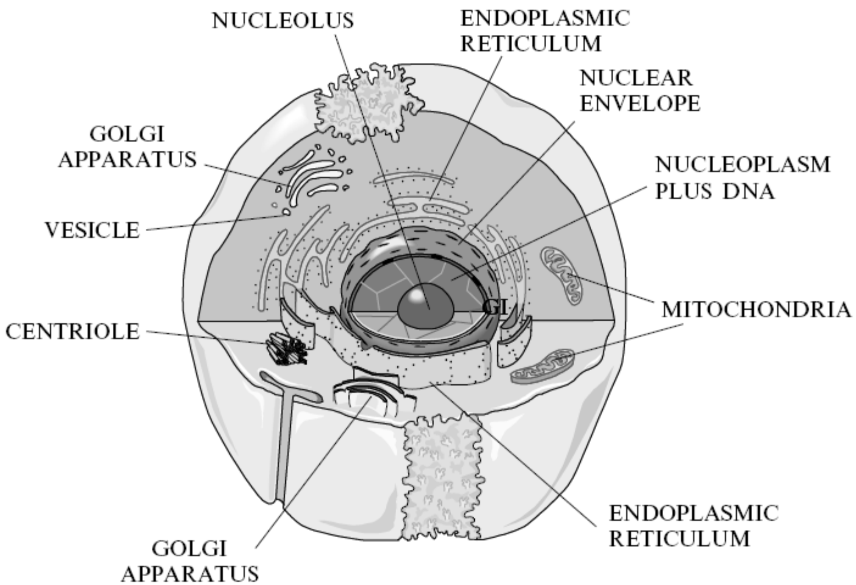
- The smallest anatomical and physiological unit in the human body that can, under appropriate conditions, live and reproduce on its own is the cell

- The cell theory states that:

  (1) All organisms are composed of one or more cells

  (2) The cell is the smallest unit of life

  (3) All cells come from previously existing cells



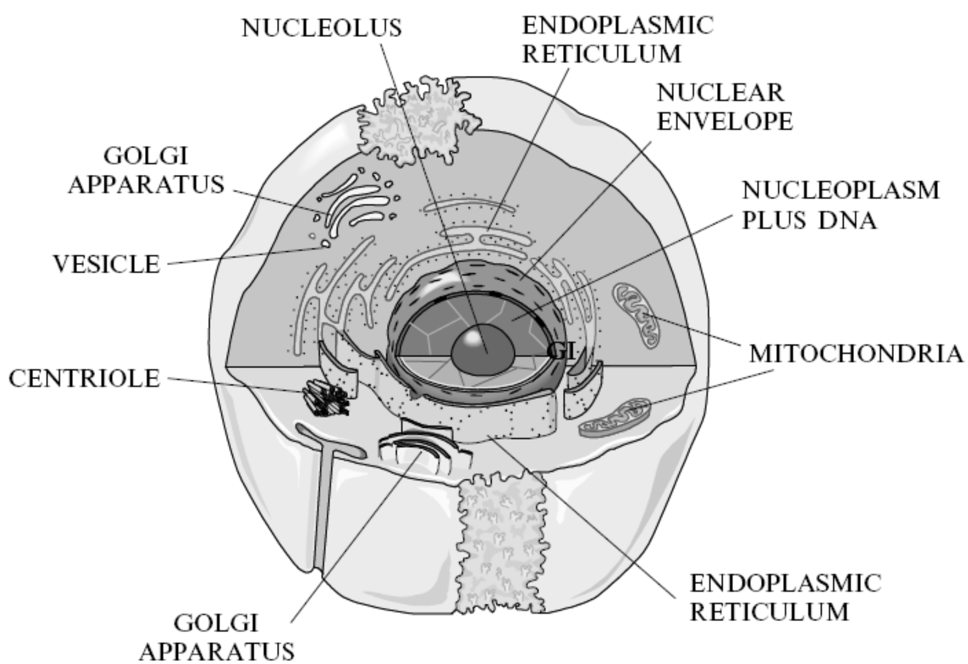
Cellular Organization

- All cells are surrounded by a plasma membrane that separates, but does not isolate, the cell’s interior from its environment

- In addition to a plasma membrane, all cells have a region that contains

  1- DNA which carries the hereditary instructions for the cell

  2- Cytoplasm which is a semifluid substance that includes everything inside the plasma membrane except for the DNA



Cellular Organization

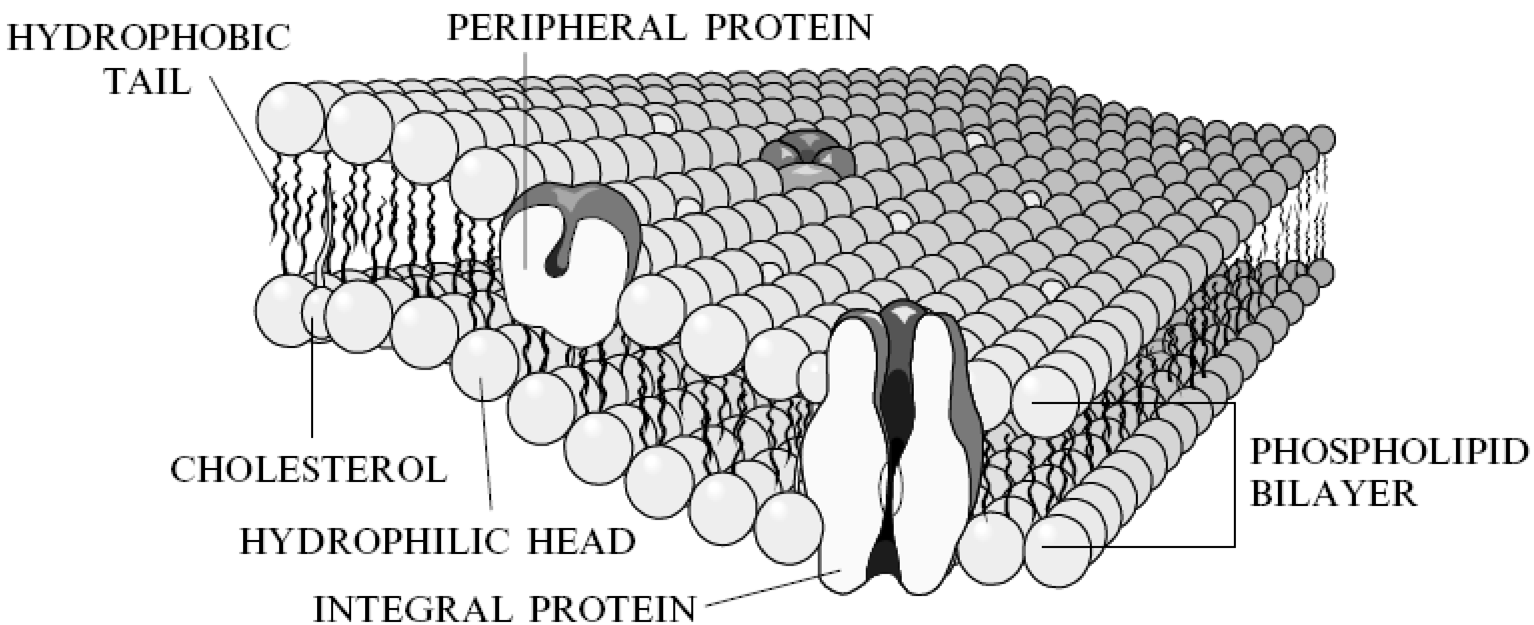
- The plasma membrane performs several functions for the cell:

  1- It gives mechanical strength

  2- Provides structure

  3- Helps with movement

  4- Controls the cell's volume and its activities by regulating the movement of chemicals in and out of the cell



Cellular Organization

- Some molecules (e.g., oxygen, carbon dioxide, and water) can easily cross the plasma membrane
- Other substances (e.g., large molecules and ions) must move through the protein channels
- An ion is an atom or molecule in which the total number of electrons is not equal to the total number of protons, giving the atom a net positive or negative electrical charge
- Osmosis is the process by which substances move across a selectively permeable membrane such as a cell's plasma membrane
- Diffusion refers to the movement of molecules from an area of relatively high concentration to an area of relatively low concentration

Cellular Organization

- Intracellular: Inside the cell. Extracellular: Outside the cell

- A typical mammalian cell has:

  - Intracellular sodium ion (Na^+) concentrations of 12mM (12 moles of Na^+ per 1000 liters of solution) and extracellular Na^+ concentrations of 120mM

  - Intracellular potassium ion (K^+) concentrations of 125mM and extracellular K^+ concentrations of 5mM

  - Intracellular chloride ion (Cl^-) concentrations of 5mM and extracellular Cl^- concentrations of 125mM

  - Intracellular anion (e.g., proteins, charged amino acids, sulfate ions, and phosphate ions) concentrations of 108mM

Cellular Organization

- Example:

  How many molecules of sodium and potassium ions would a cell that has a volume of 2 nl contain?

  Solution:

  Given that Avogadro's number states that there exists 6.023 x 10^{23} molecules/mole

  Given that intracellular concentrations of Na^+ and K^+ are 12mM and 125mM, respectively

$$Na^+\text{:}\ \ 12\,\frac{\text{moles}}{1000\ \text{liters}} \times 6.023 \times 10^{23}\,\frac{\text{molecules}}{\text{mole}} \times 2 \times 10^{-9}\ \text{liters} = 1.45 \times 10^{13}\ \text{molecules}$$

$$K^+\text{:}\ \ 125\,\frac{\text{moles}}{1000\ \text{liters}} \times 6.023 \times 10^{23}\,\frac{\text{molecules}}{\text{mole}} \times 2 \times 10^{-9}\ \text{liters} = 1.51 \times 10^{14}\ \text{molecules}$$

Cellular Organization

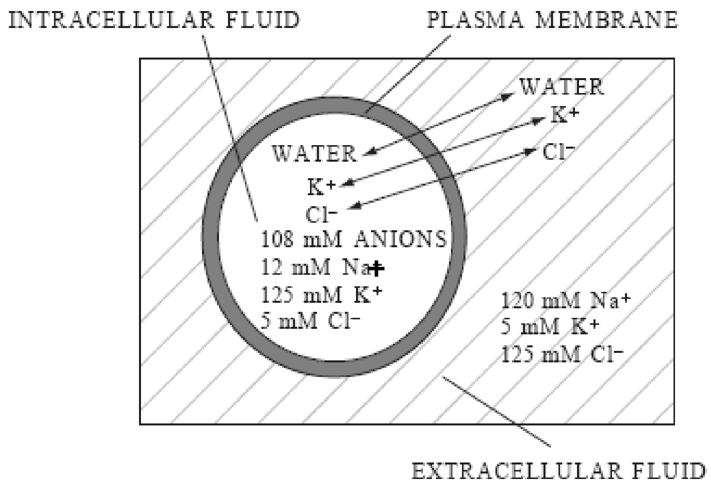
- Substances that can easily cross the plasma membrane achieve **diffusion equilibrium** when the concentration of the substance inside the cell equals the concentration of the substance outside of the cell

- Active transport, which requires an input of energy, can be used to move them from areas of low concentration to areas of high concentration

- Cells must also achieve **electrical equilibrium** where the overall concentration of cations in a cell must equal the overall concentration of anions in that cell

Cellular Organization

- Example: Consider the cell given below. Is this cell at electrical equilibrium? Assume the average negative charge/molecule of anions is -1.2



Solution:

Total +ve charges inside the cell = 12 (Na^+) + 125 (K^+) = 137

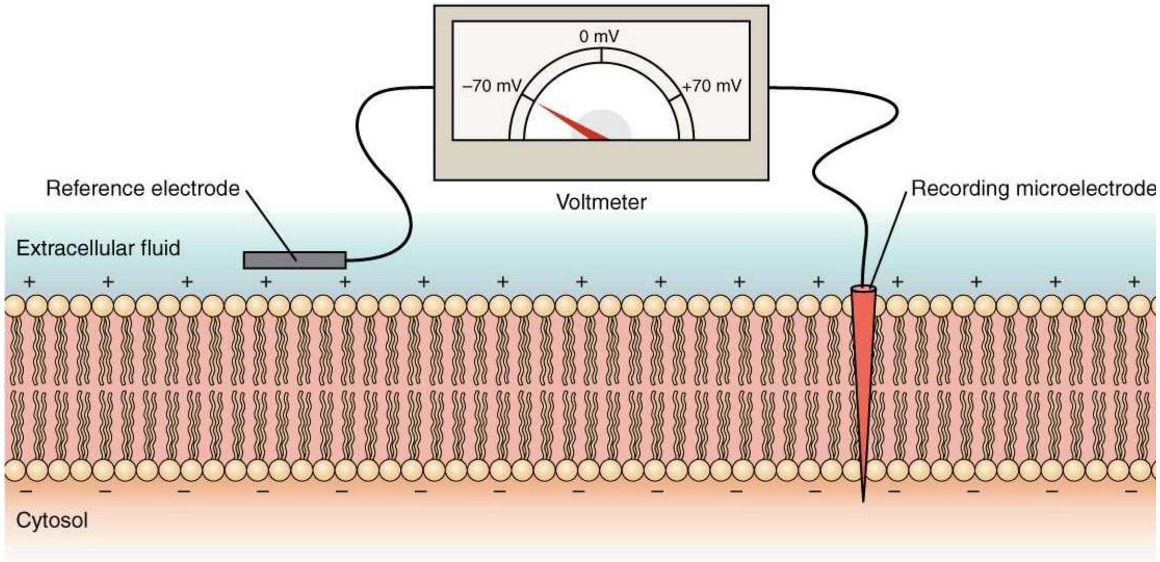
Total –ve charges inside the cell = 5 (Cl^-) + 1.2*108 (Anions) = 135

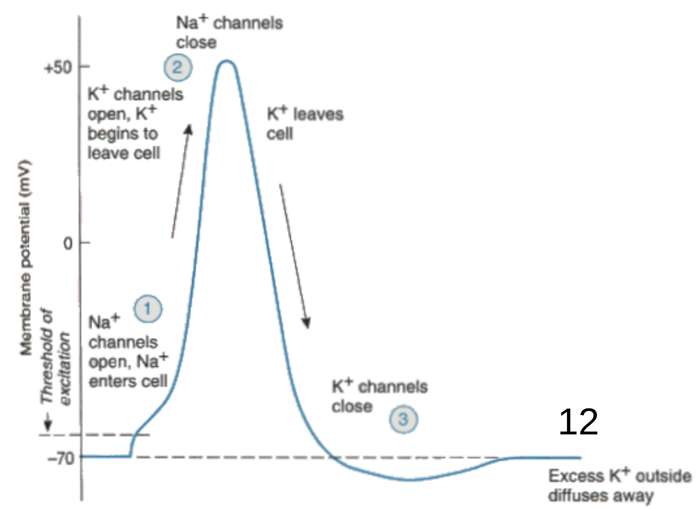
So the cell is approximately in electrical equilibrium

- Real cells, however, cannot maintain this equilibrium without expending energy, since real cells are slightly permeable to Na^+

Cellular Organization

- In order to maintain equilibrium and keep Na^+ from accumulating intracellularly, mammalian cells must actively pump Na^+ out of the cell against its diffusion and electrical gradients
- Real cells exist in a steady state, rather than at equilibrium
- One of the consequences of the distribution of charged particles in the intracellular and extracellular fluids is that an electrical potential exists across the plasma membrane (**membrane potential**)

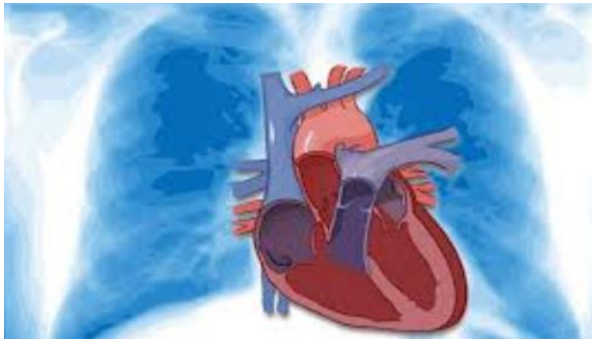


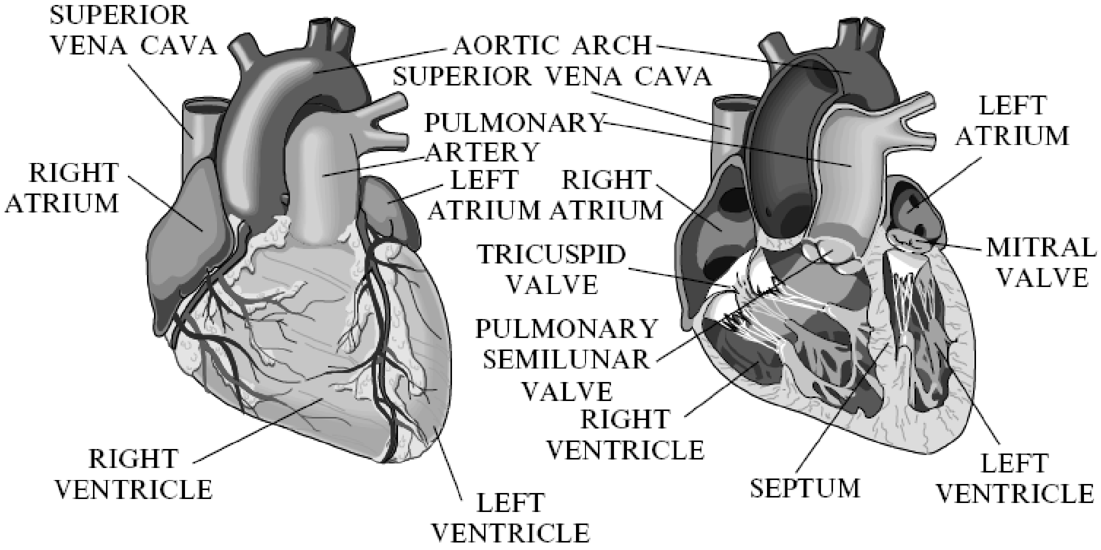


The Heart

- The heart is the pumping station that moves blood through the blood vessels

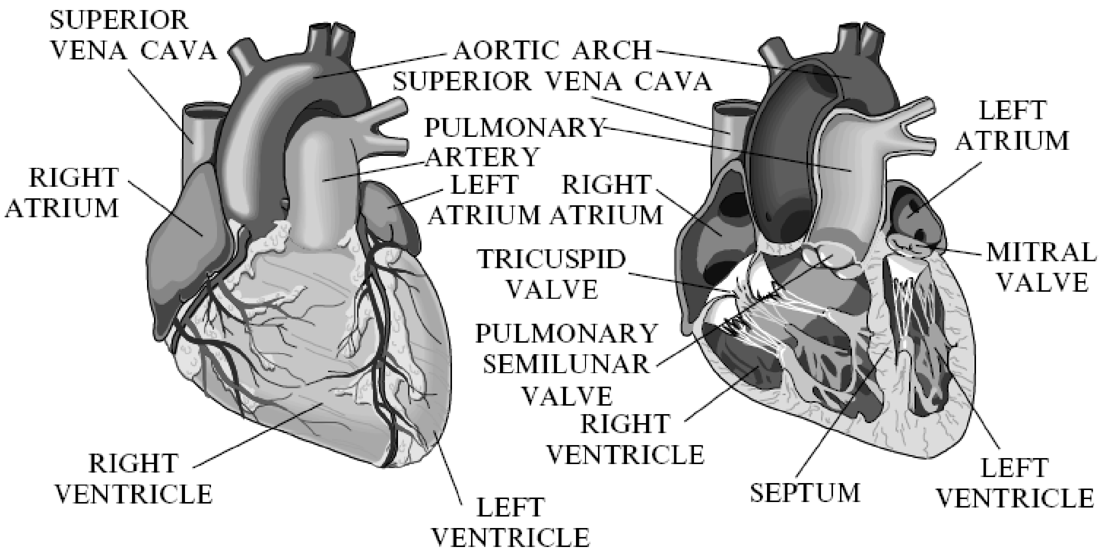
- Blood carries necessary substances such as nutrients and oxygen to body cells and transports waste away from cells





The Heart

- It consists of two pumps: the right side and the left side
- The right side moves deoxygenated blood that is loaded with carbon dioxide **from** the body **to** the lungs
- The left side receives oxygenated blood that has had most of its carbon dioxide removed **from** the lungs and pumps it **to** the body
- Each side has one chamber (**the atrium**) that receives blood and another chamber (**the ventricle**) that pumps the blood away from the heart

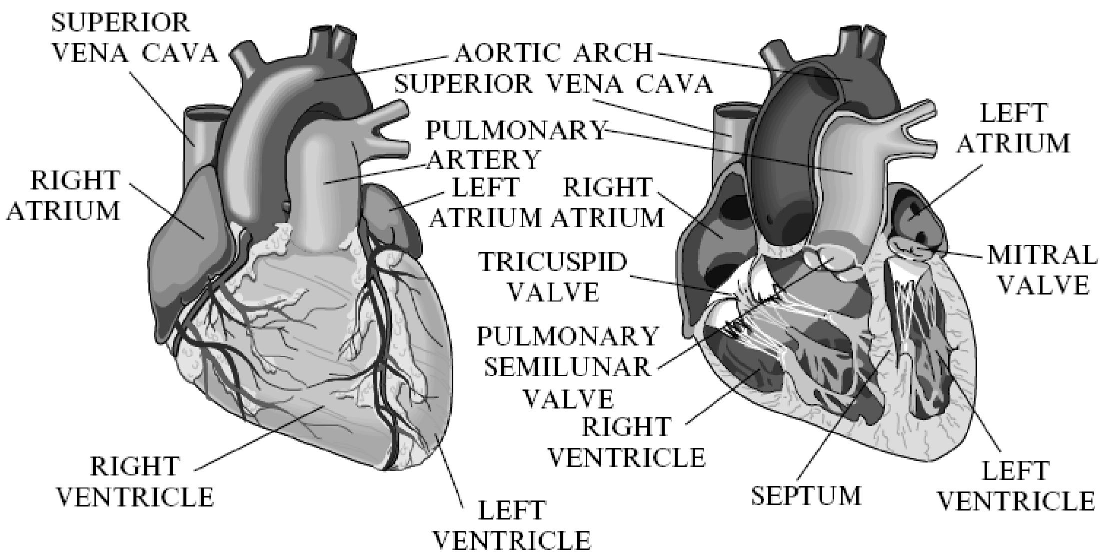


- How the heart works? http://www.youtube.com/watch?v=oZ1_TAwCUWw

The Heart

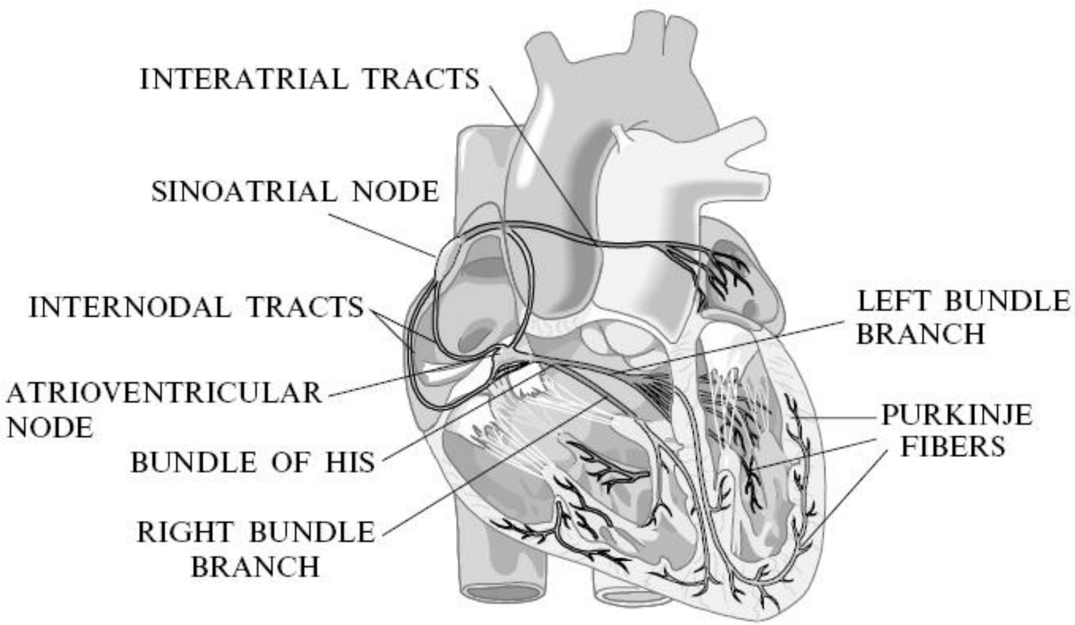
- Blood vessels that carry blood away from the heart are called **arteries** and those that carry blood toward the heart are called **veins**

- The average adult has about 5 L of blood with 75% of the blood is in the systemic circulation in the veins, 20% in the arteries, and 5% in the capillaries



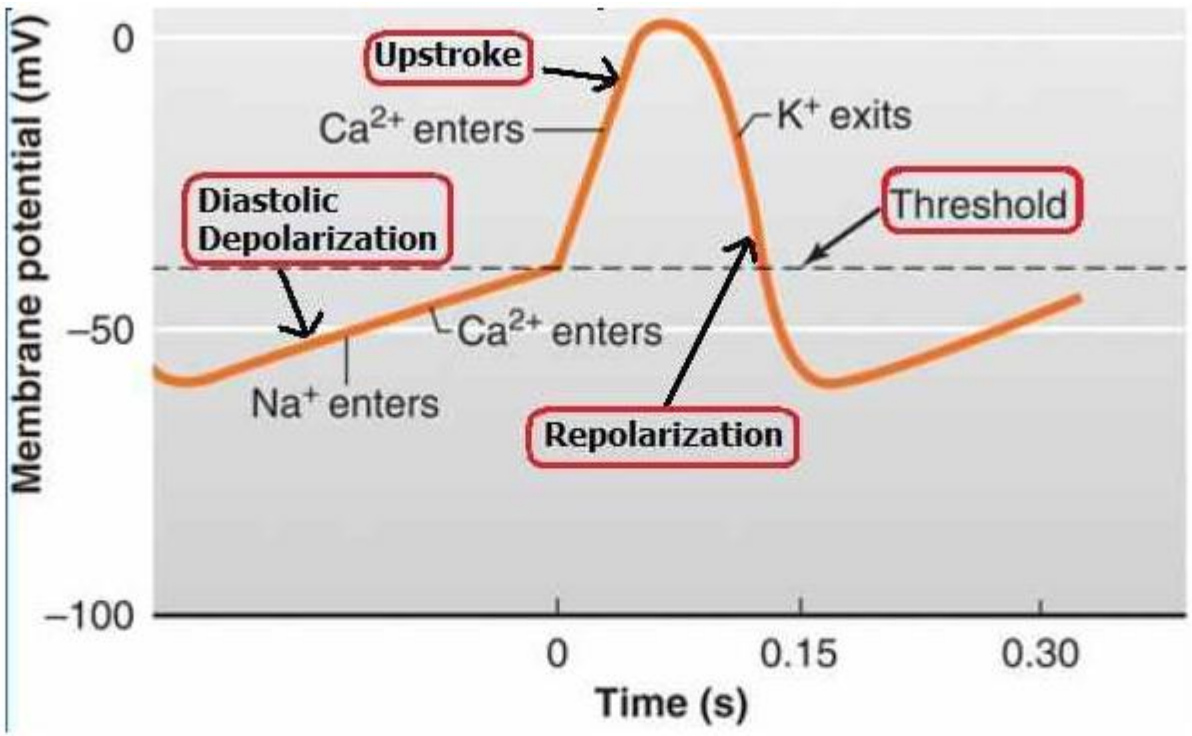
Cardiac Cycle

- Cardiac output is the product of the heart rate and the volume of blood pumped from the heart with each beat (i.e., the stroke volume)
- Each time the heart beats, about 80 ml of blood leave the heart
- The cardiac cycle refers to the repeating pattern of contraction (**systole**) and relaxation (**diastole**) of the chambers of the heart
- The cardiac cycle begins with a self-generating electrical pulse in the pacemaker cells of the sinoatrial (SA) node



Cardiac Cycle

- Pacemaker Cells Action Potential Phases

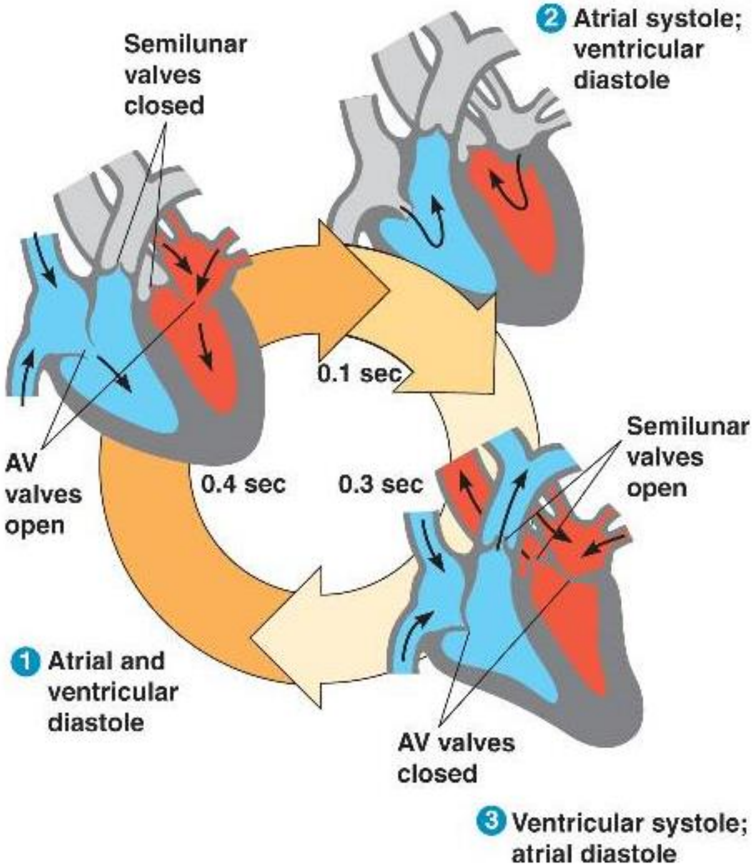


- The cells in the sinoatrial node depolarize on the average of every 0.83 sec in a typical adult at rest
- This gives a resting heart rate of 72 beats per minute: 5/8 of each beat is spent in diastole and 3/8 in systole

Cardiac Cycle

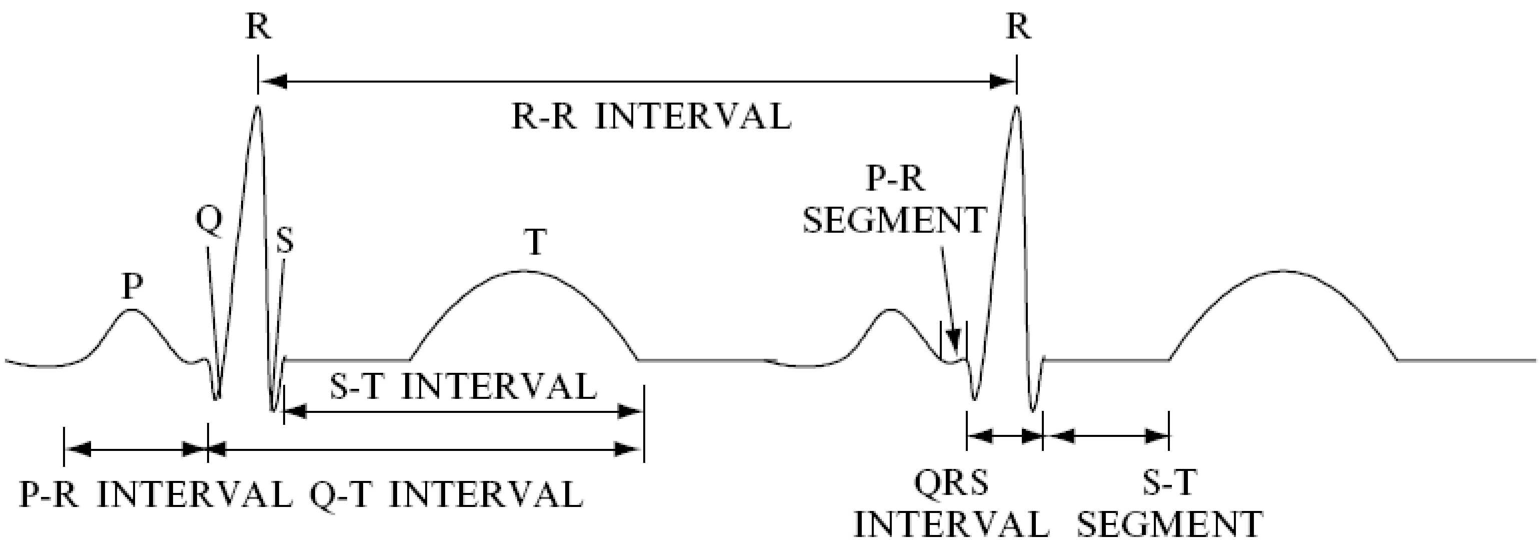
- Cardiac cells are linked and tightly coupled so that action potentials spread from one cell to the next

- When cardiac cells depolarize, they also contract



Electrocardiogram (ECG)

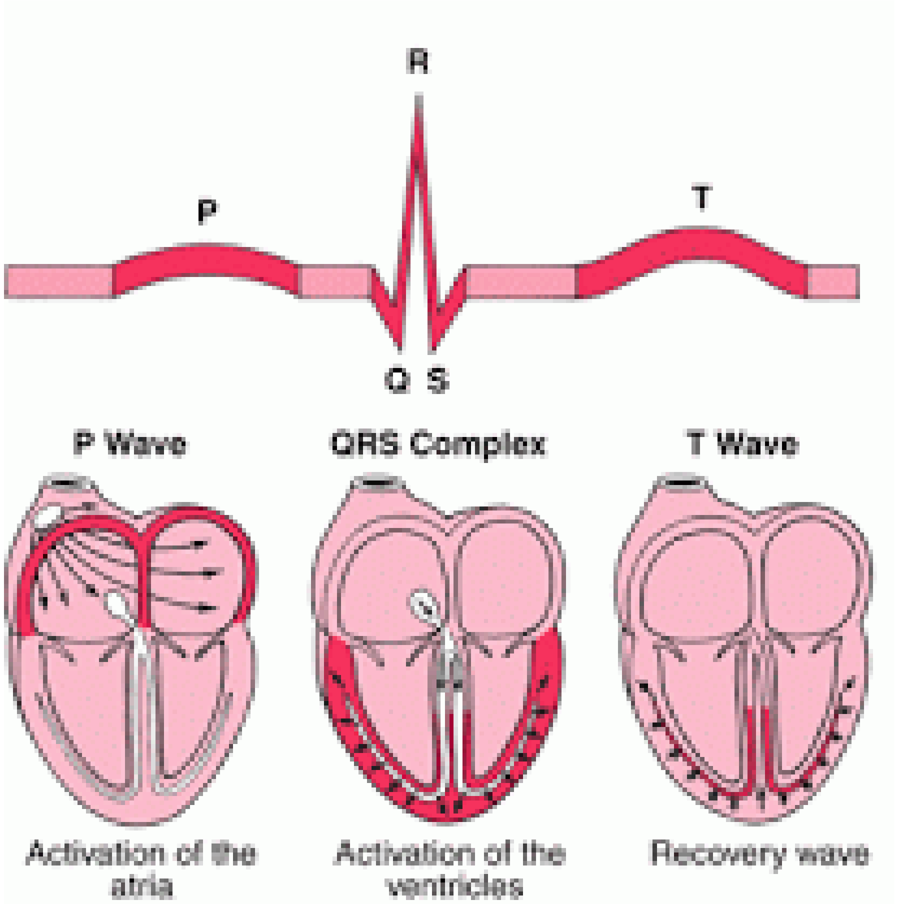
- ECG is an electrical measure of the sum of these ionic changes within the heart



- The P wave represents the depolarization of the atria
- The QRS represents the depolarization of the ventricles
- Ventricular repolarization shows up as the T wave

Electrocardiogram (ECG)

- The P wave represents the depolarization of the atria
- The QRS represents the depolarization of the ventricles
- Ventricular repolarization shows up as the T wave



Electrocardiogram (ECG)

- Example:

  What would be the heart rate given by an ECG in which 10 R-waves occurred in 6.4 s?

  What would be the cardiac output of the heart if the stroke volume is 75 ml?

  Solution:

  A sequence of 10 R-waves represents 9 R–R intervals or beats of the heart

$$\left(\frac{9\ \text{beats}}{6.4\ \text{s}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right) = 84\ \text{bpm}$$

  The cardiac output (given in liters per minute) is the product of the heart rate and the stroke volume

$$\text{CO} = 84\,\frac{\text{beats}}{\text{min}} \times 75\,\frac{\text{ml}}{\text{beat}} = 6300\,\frac{\text{ml}}{\text{min}} = 6.3\,\frac{\text{liters}}{\text{min}}$$

Measuring Blood Pressure

- Blood pressure can be measured directly or indirectly (noninvasively)
- First invasive blood pressure measurement was done by Stephen Hales in 1727 when he measured the blood pressure of a horse by inserting a pipe into an opening of an artery and measured the height of the blood in the pipe

- Invasive: A needle that is coupled to a pressure transducer into a vein or artery

Non-invasive Blood Pressure Measurement

- Sphygmomanometer:
  - A cuff is used to apply sufficient pressure to an artery to prevent the flow of blood through the artery

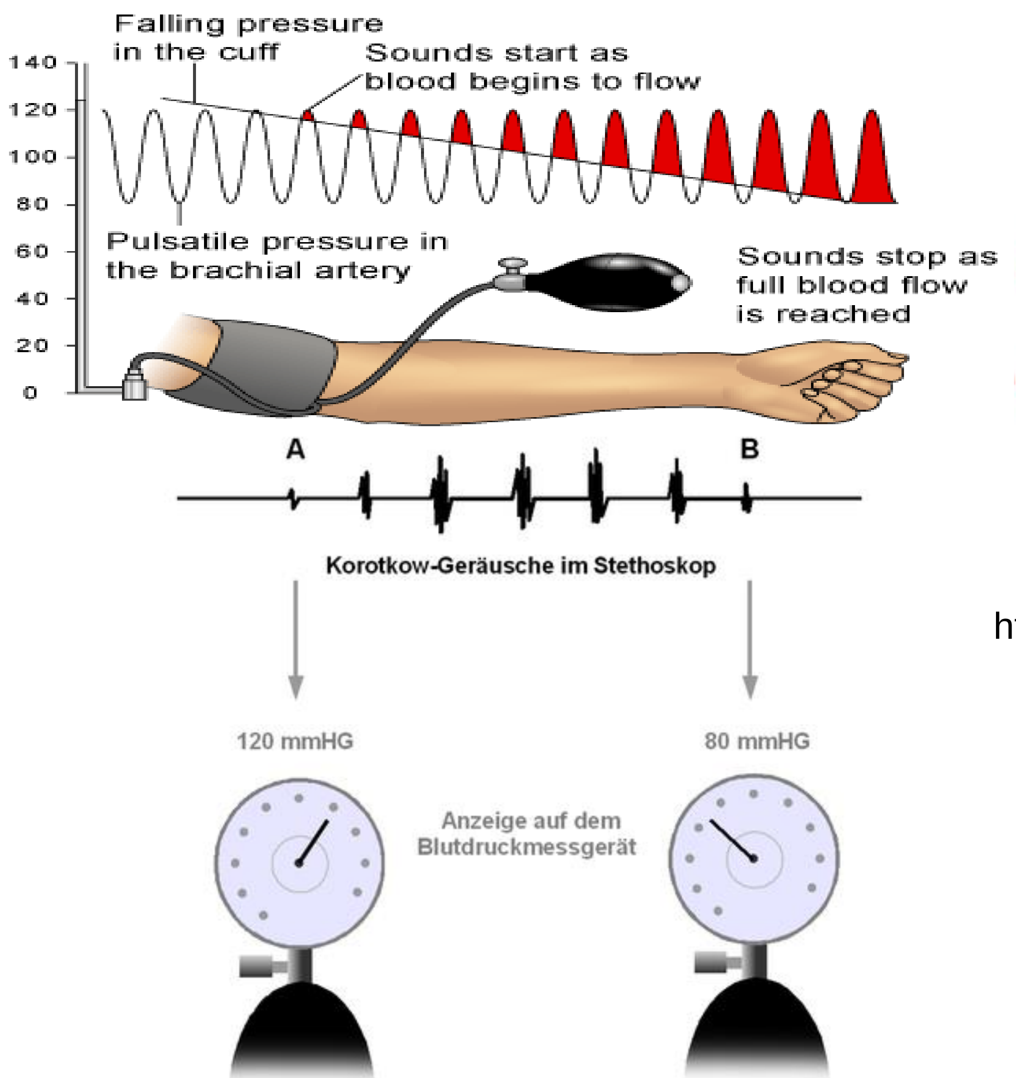
  - A stethoscope is used to listen to the change in sounds as the cuff is slowly deflated

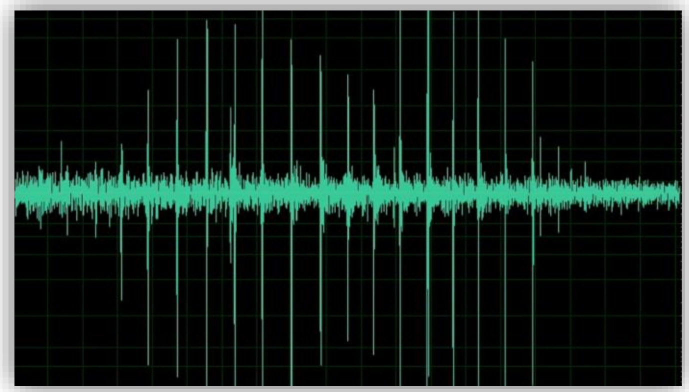
  - The first Korotkoff sounds occur when the systolic pressure first exceeds the pressure in the cuff so that blood once again flows through the artery beneath the stethoscope (the maximum pressure)

  - The Korotkoff sounds disappear when the pressure in the cuff drops below the diastolic pressure (the minimum pressure)

Non-invasive Blood Pressure Measurement

- Sphygmomanometer:



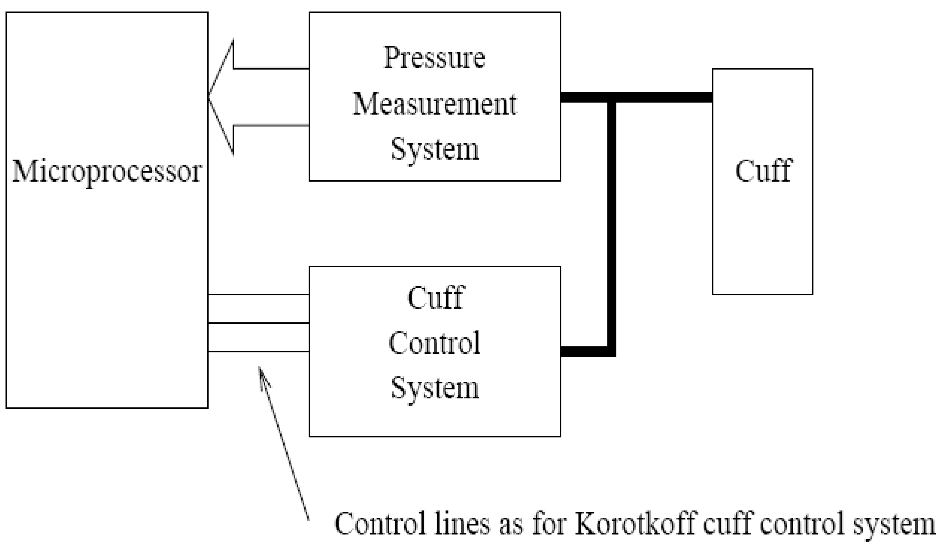


https://www.youtube.com/watch?v=5gn8cbY9rkc

Non-invasive Blood Pressure Measurement

- Oscillometer:
  - In 1885, the French physiologist Marey observed that if he placed a patient's arm in a pressure chamber then the pressure of the chamber would fluctuate with the pulse and the magnitude of the fluctuation would vary with the pressure of the chamber

  - Modern version of the system uses a microprocessor to periodically inflate and slowly deflate a cuff



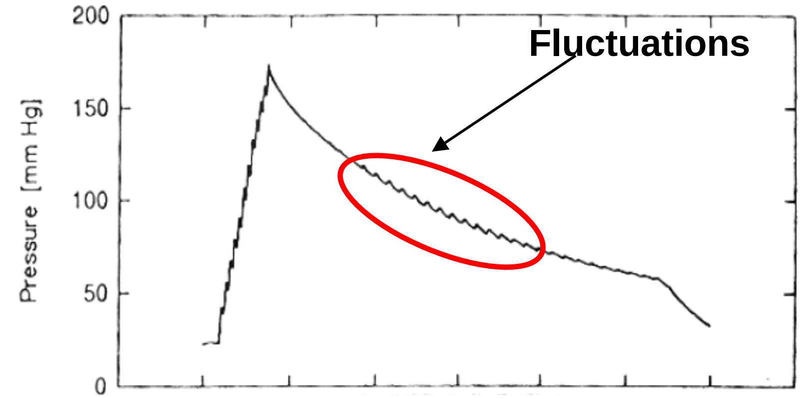
Non-invasive Blood Pressure Measurement

- Oscillometer:

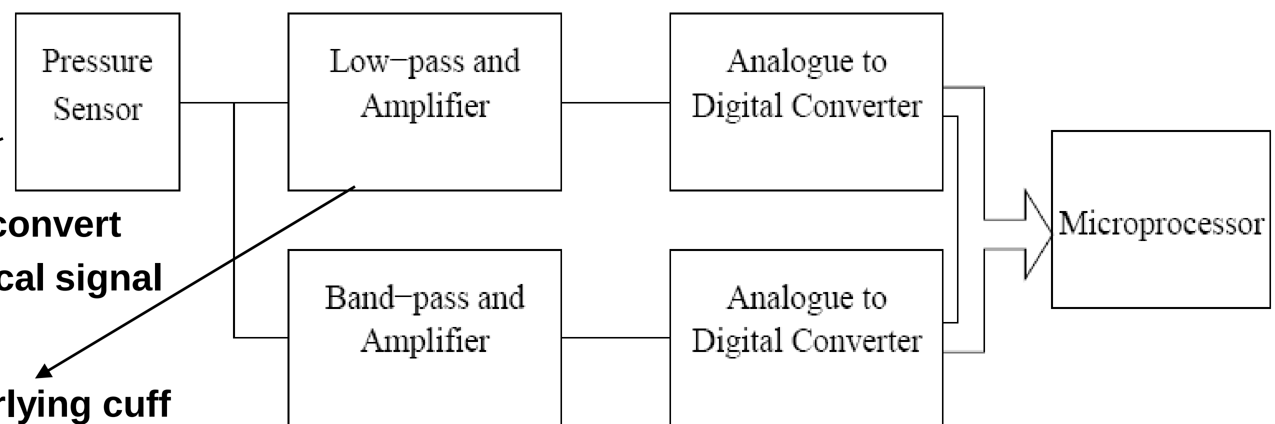
  The pressure of the cuff has 2 components:

  1- The cuff pressure

  2- The fluctuations



- Pressure Measurement System Block Diagram:



Piezo-resistive to convert pressure to electrical signal

To find the underlying cuff pressure

To find the fluctuations