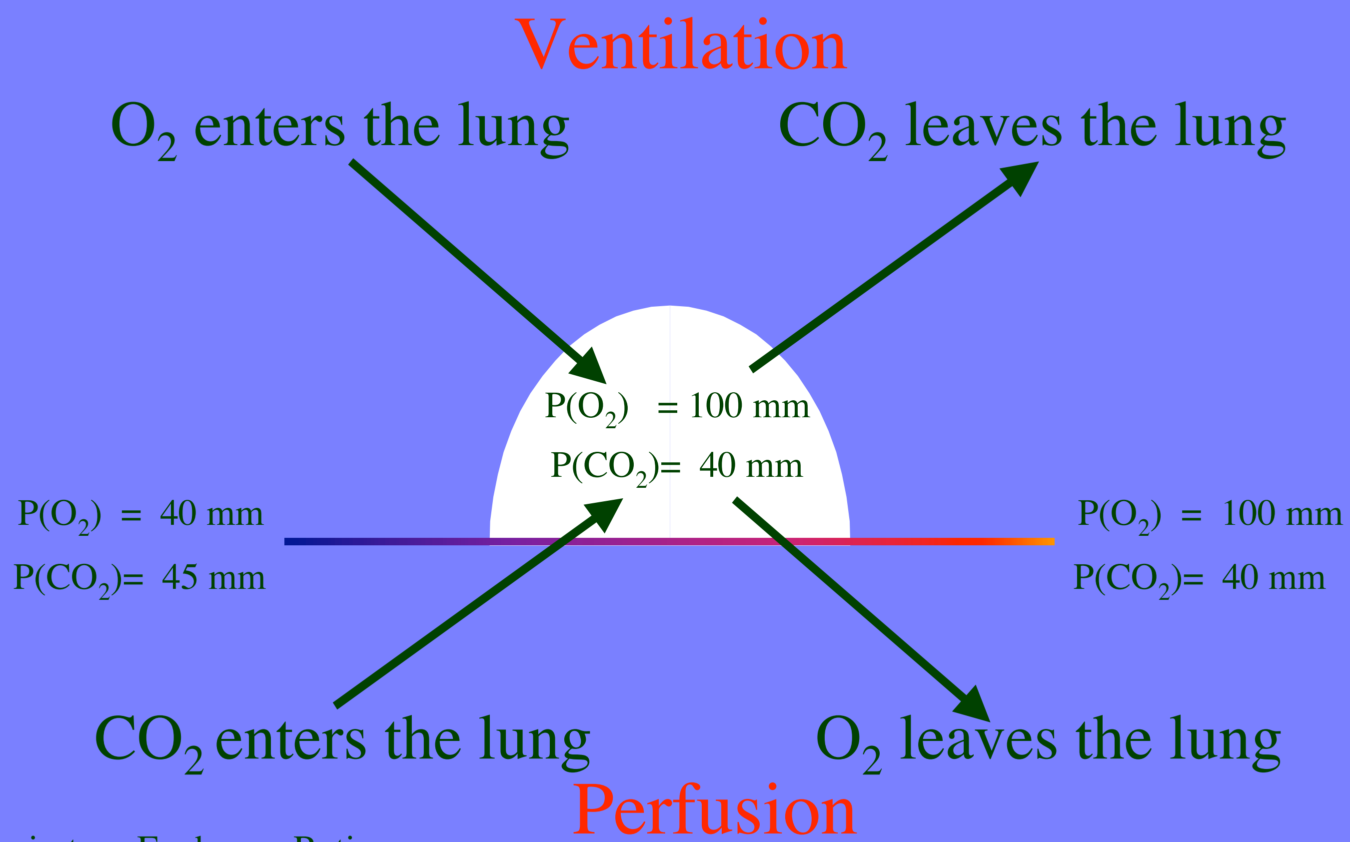
Lecture 13: The Cardiovascular System

ref: Cardiovascular Physiology, D. Mohrman and L. Heller, 4th ed. McGraw-Hill (1997)

- Blood
- Heart
- Blood Vessels   Arteries - capillaries - Veins

Ventilation-Perfusion Relationships



Respiratory Exchange Ratio

$$8.63\ R^*[C_A(O_2) - C_V(O_2)]Q = V\ P(CO_2)$$

Increase V/Q (Shunt) : Increase $P(O_2)$ / Decrease $P(CO_2)$ (hypocapnia)

Decrease V/Q (Ventilation Defect) : Decrease $P(O_2)$ / Increase $P(CO_2)$ (hypercapnia)

Blood (5 liters or 11 pints)

- plasma + RBC + WBC + platelets

  RBC (erythrocytes) $5x10^6/mm^3$; WBC (leukocytes) $7000/mm^3$; platelets (clotting) $2x10^5/mm^3$

- Plasma: H_2O + electrolytes (ions/Ca) + proteins

- RBC: hematocrit = V_{RBC}/V_{total}

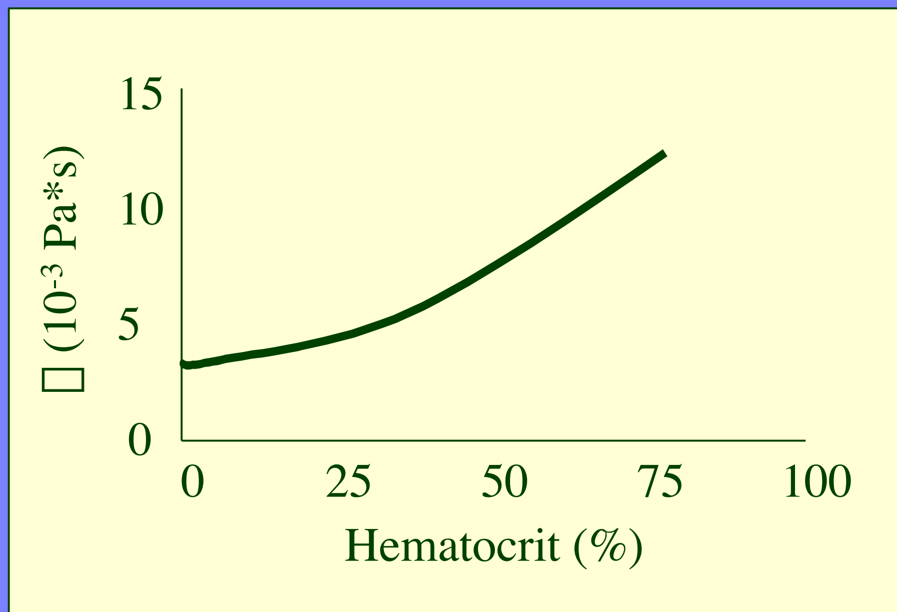
- WBC: 50-70% Phagocytes — neutrophils (gobblers); 20-40% Lymphocytes — produce antibodies

  1-4% eosinophils (eat paracites; allergy complex) <1% Basophils (histamines) 2-4% Monocyte (macrophages - BIG)

Blood

- Density: $\rho_{blood} = 1.04 \text{ gm/cm}^3 = 1.04\text{x}10^3 \text{ kg/m}^3$

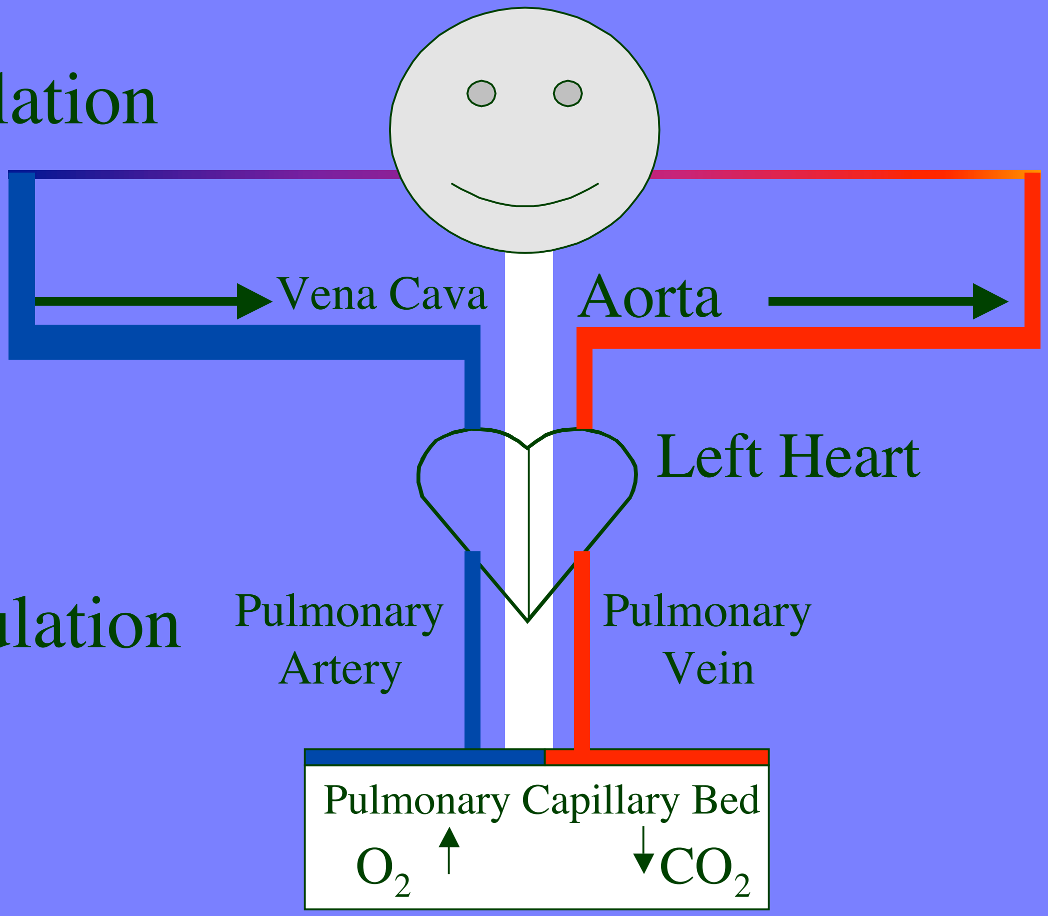
- Viscosity:



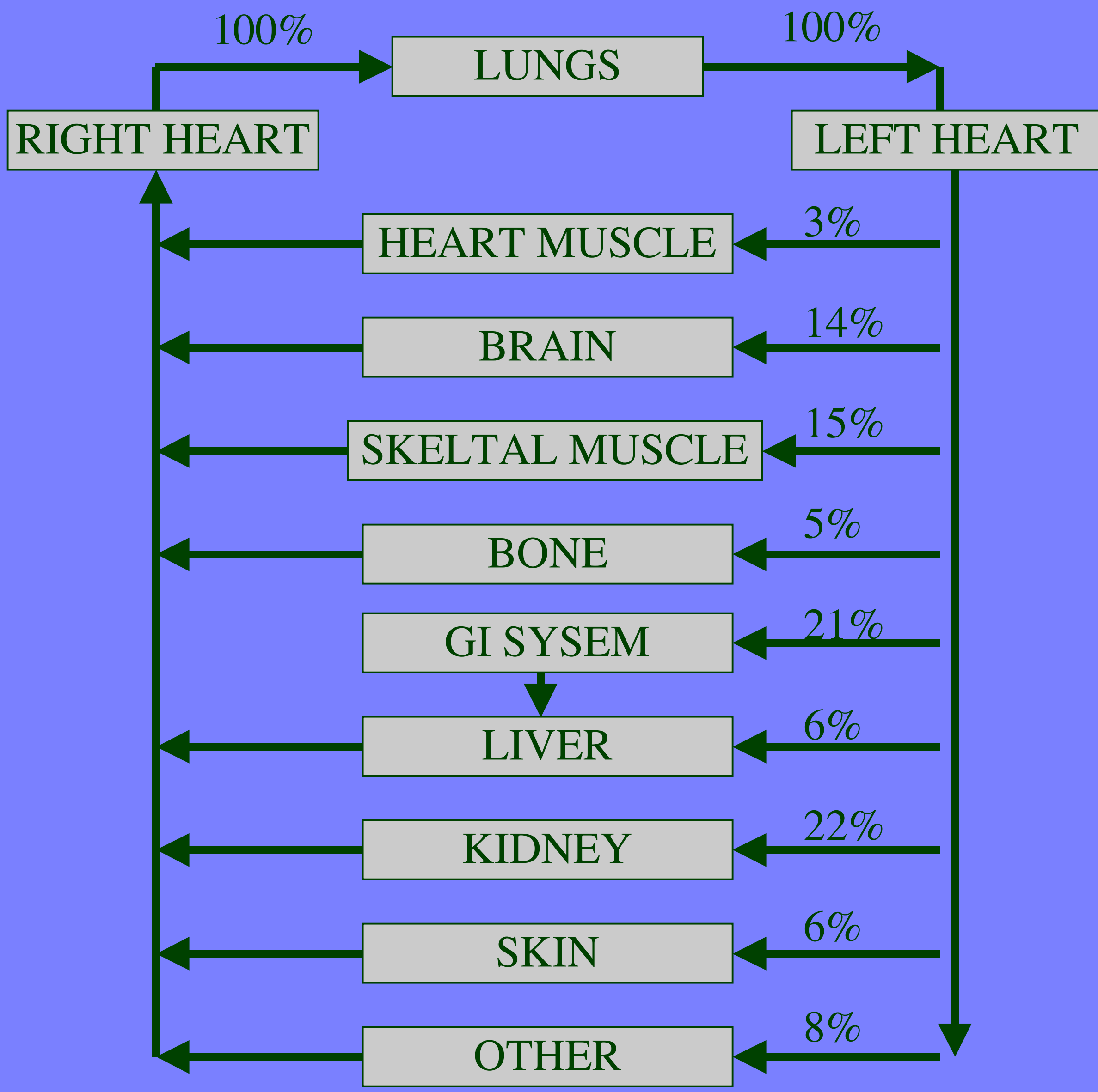
$$\Delta P = R * (\Delta V/\Delta t)$$
$$R = 8\pi\eta L/A^2 \text{ (tube)}$$

Blood

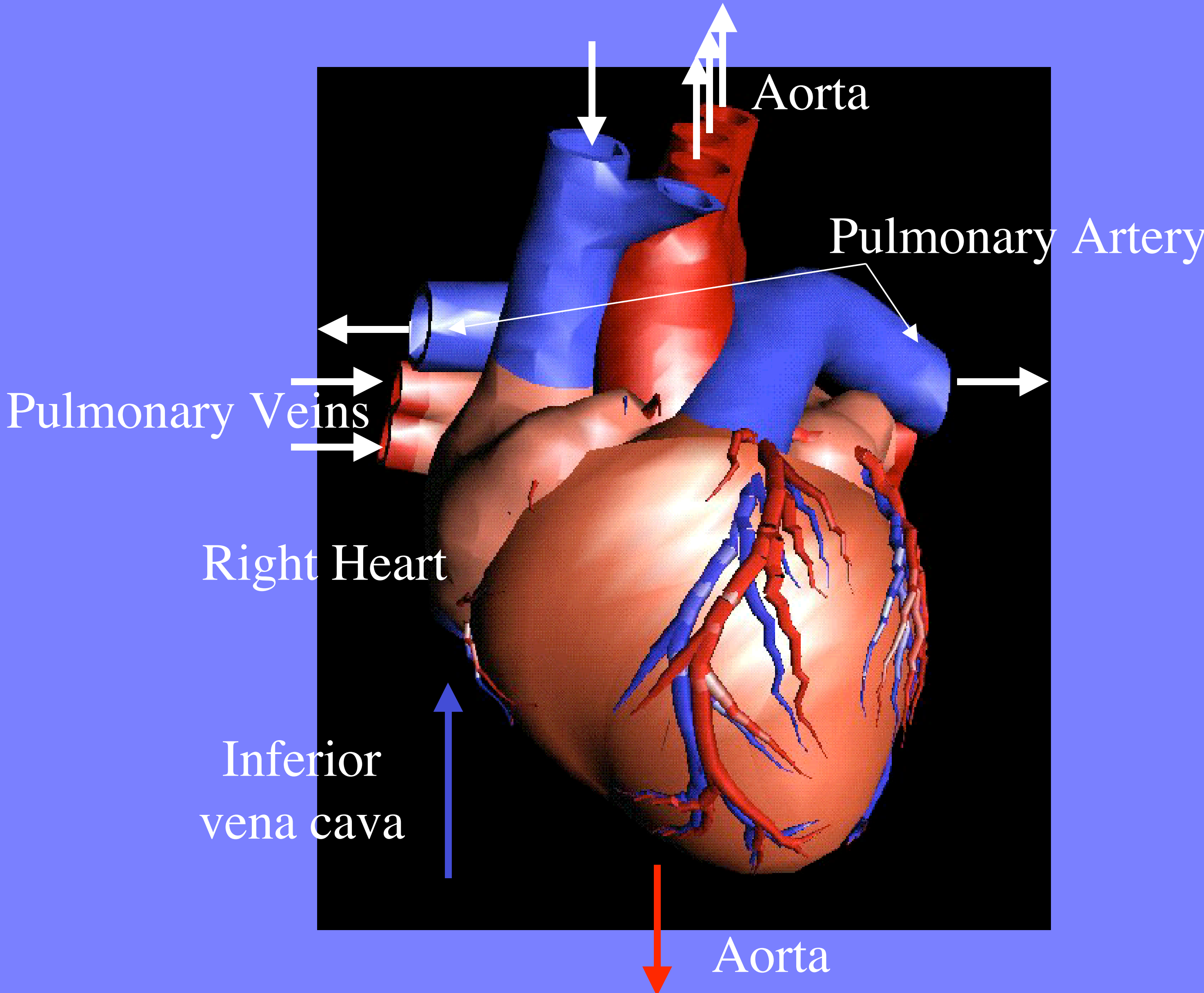
- 80 % systemic circulation
  - 15% arterial
  - 10% capillaries
  - 75% venous
- 20% pulmonary circulation
  - 46% arterial
  - 7% capillary
  - 46% venous



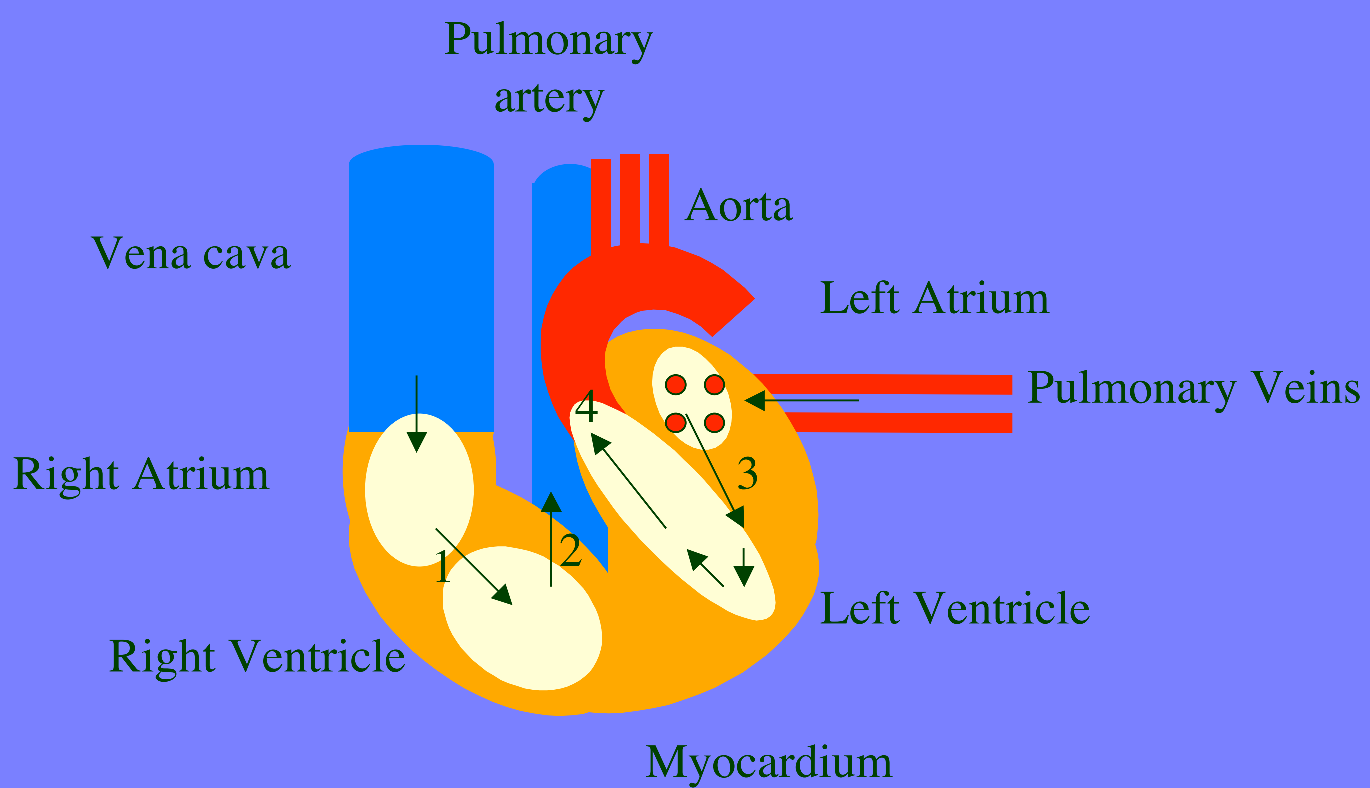
Blood Flow


100%
LUNGS
100%
RIGHT HEART
LEFT HEART
HEART MUSCLE
3%
BRAIN
14%
SKELTAL MUSCLE
15%
BONE
5%
GI SYSEM
21%
LIVER
6%
KIDNEY
22%
SKIN
6%
OTHER
8%

The Heart


Aorta
Pulmonary Artery
Pulmonary Veins
Right Heart
Inferior
vena cava
Aorta

Heart Chambers and Valves



Valves
1. Tricuspid valve
2. Pulmonic valve
3. Mitral valve
4. Aortic valve

Cardiac Output

- Cardiac Output = Heart Rate x Stroke Volume

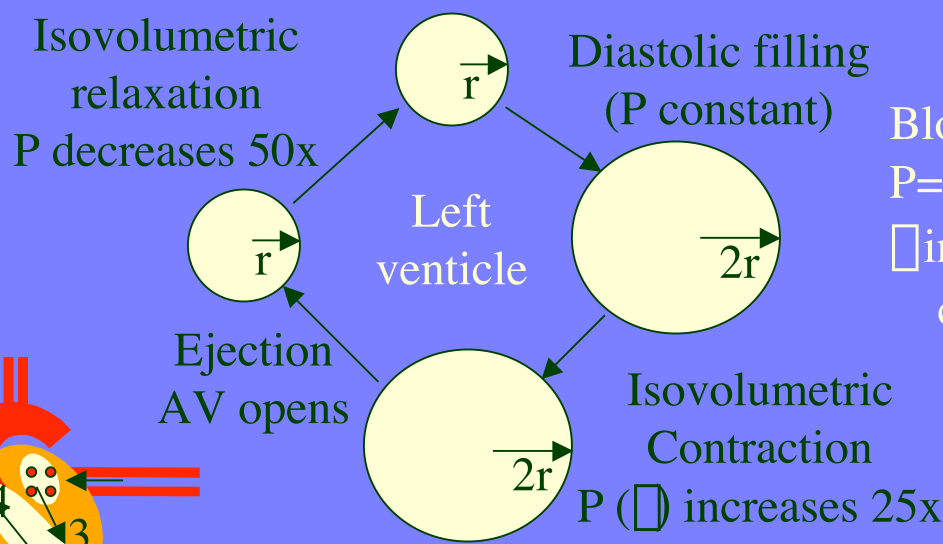
liters/min		beats/min	x	liters/beat
5.8 l/m	=	72 b/m	x	80 ml/b

- Stroke Volume Control
  - Ventricular Pressure = Force/Area

Muscles provide SURFACE TENSION
(T = Force per unit length)

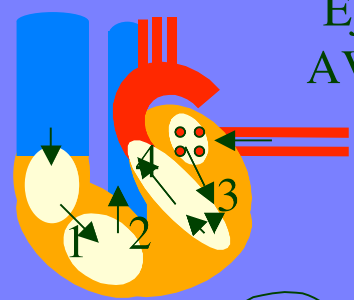
P=T/r (cylinder)
P=T/2r (sphere)

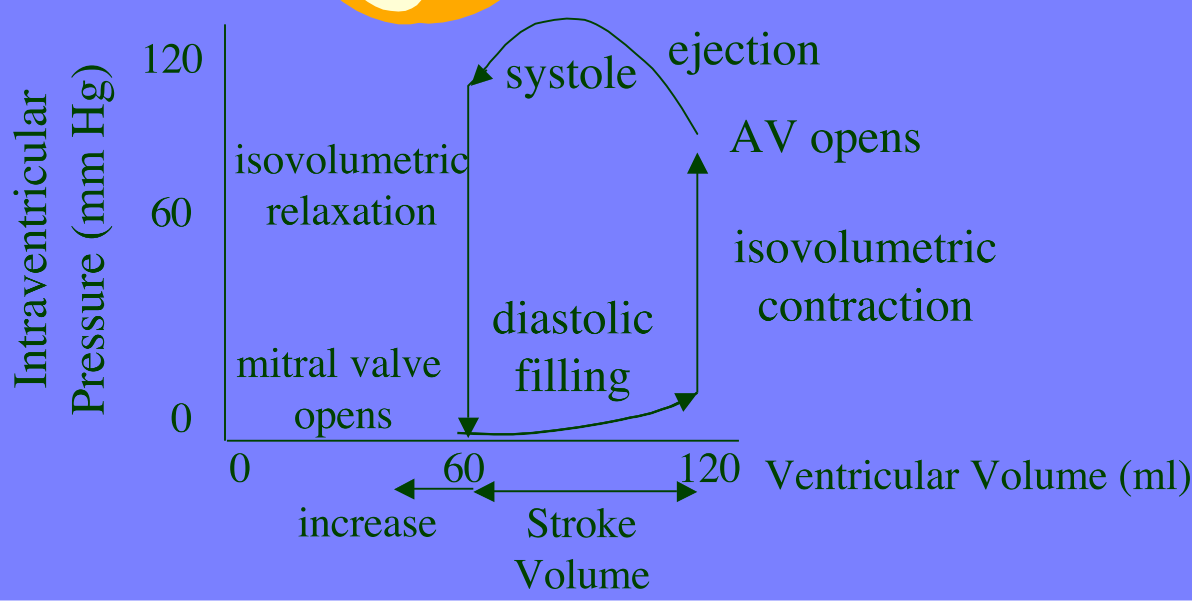
Cardiac Output



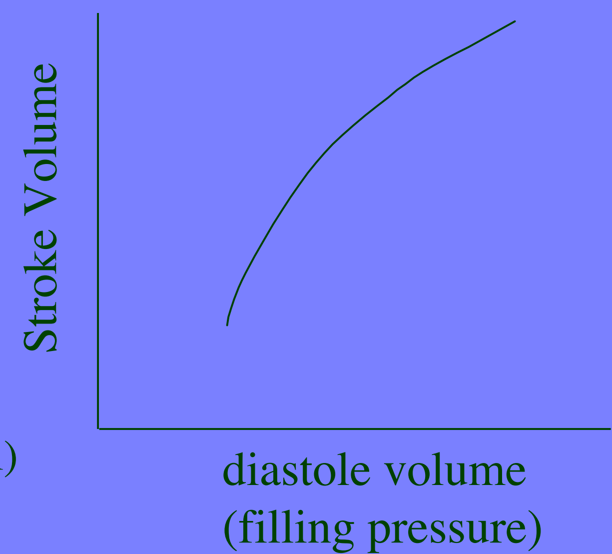
Blood is " incompressible"
P=□/4r
□increases when
cardiac muscles contract

1. Tricuspid valve
2. Pulmonic valve
3. Mitral valve
4. Aortic valve





Frank-Starling Law



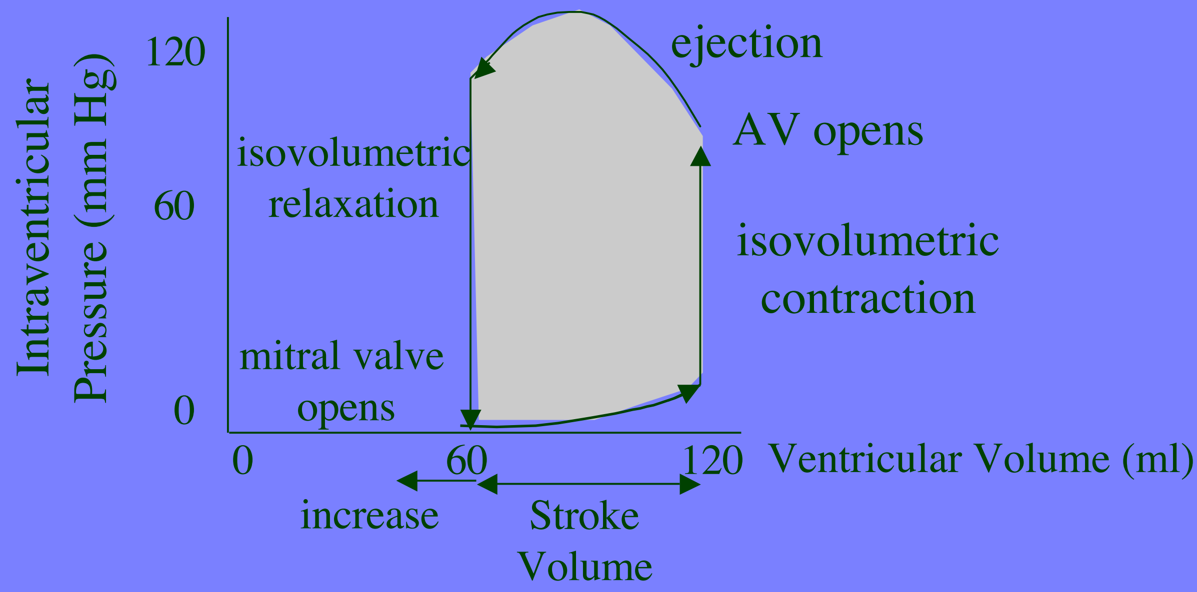
Cardiac Output Control

• Cardiac Parasympathetic Nerve Activity:	HR (-)
• Cardiac Sympathetic Nerve Activity:	HR (+)/SV (+)
• Arterial Pressure:	SV (-)
• Filling Pressure (Frank-Starling Law):	SV (+)

Cardiac Output: Work and Energy

Area =$\int$ P dV = W = 1.2 J/Beat

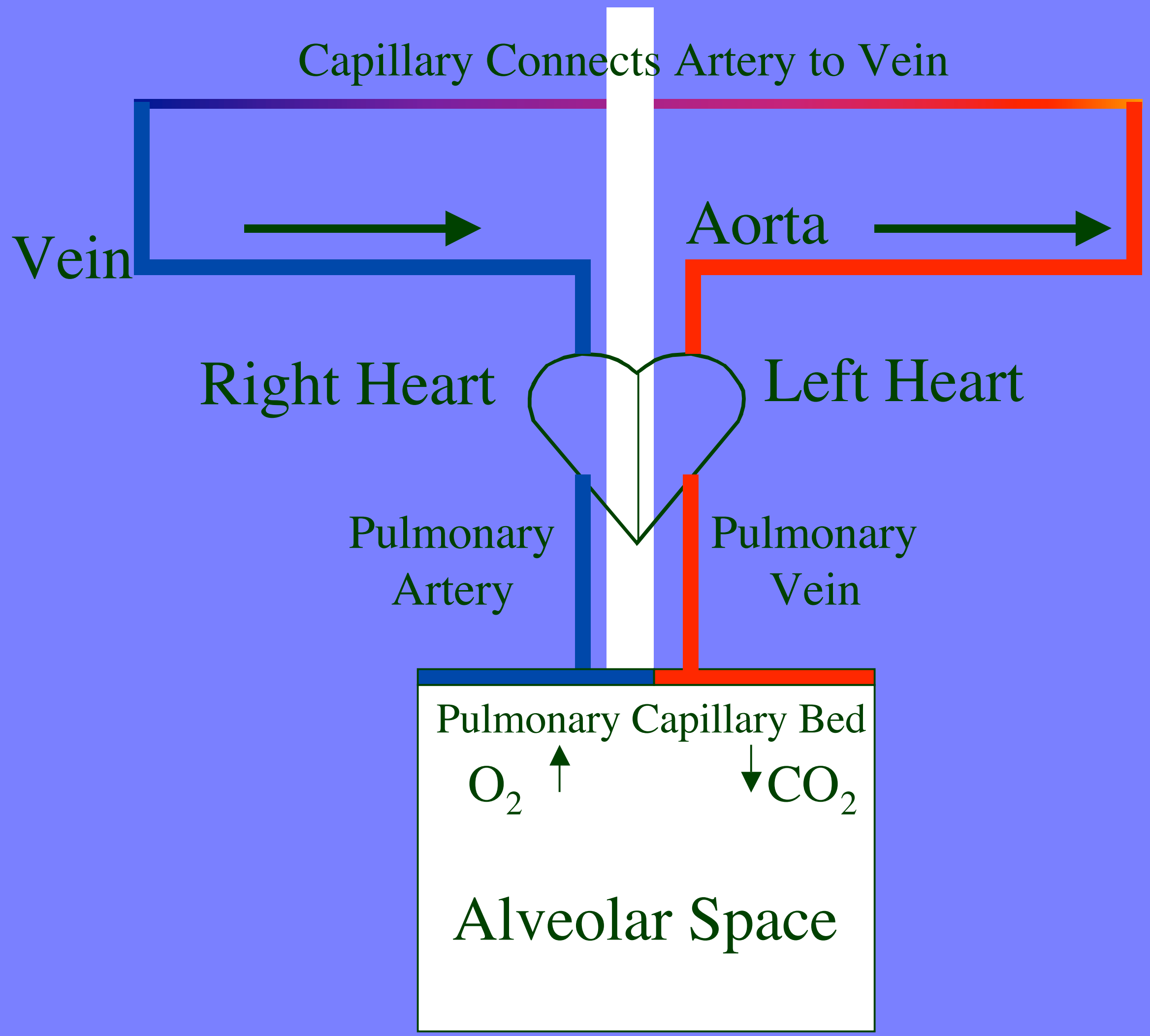
Power = W x HR ~ 1 watt = 20 kcal/day



Heart Muscle and Control

- Striated (like skeltal muscle)
- "Autorhythmic" (spontaneously contract)
  - Individual cells of cardiac muscle isolated in a saline solution beat spontaneously at random rates.
  - Sinoatrial node "pacemaker" beats faster to control heart rhythm.
- The primary cardiovascular control center is located in the medulla oblongata of the brain
  - The heart is innervated by sympathetic and parasympathetic nerve fibers.
- Temperature, ion concentration, and hormones affect heart rate.

Vascular System



Pressure Drops

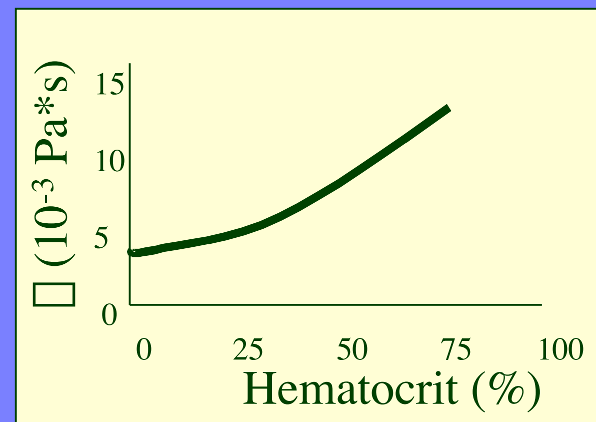
$\square P = R * Q$

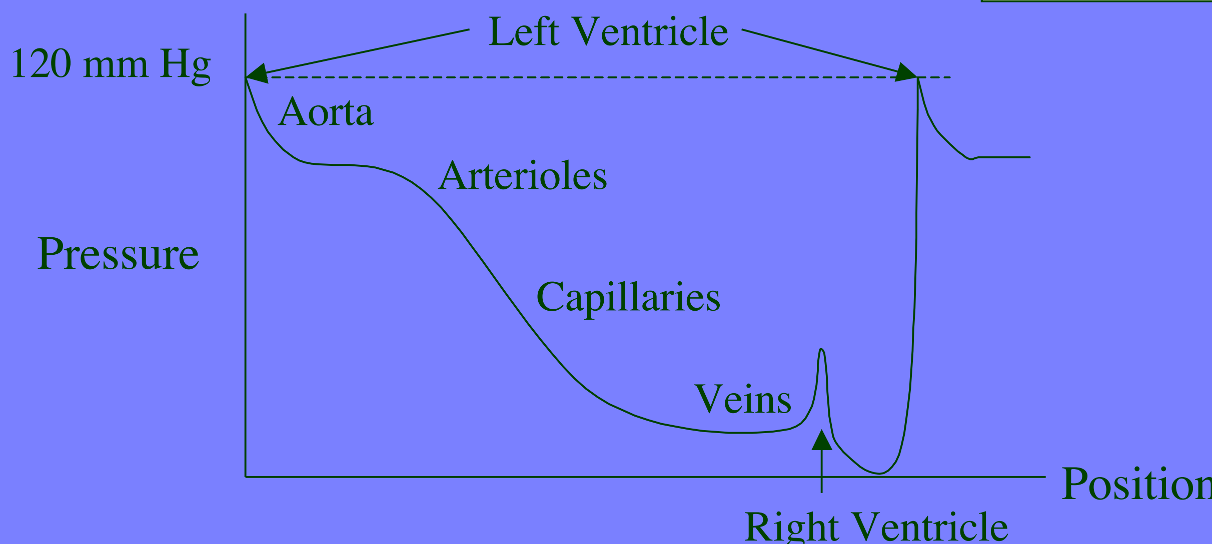
$R = 8\square\square L/A^2$ (tube)

$Q = \square PA^2/8\square\square L$

(Poiseuille equation)

Capillaries: Q= 50 pl/s





Blood Velocity

$Q\ (m^3/s) = v\ (m/s) * A\ (m^2)$

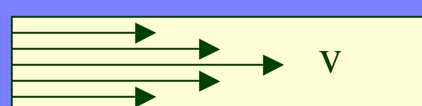
□P=8□□Lv/A

Capillary Blood Flow: v =Q/A ~1 mm/s

Laminar vs Turbulent Flow

Reynolds Number: R = □vr/□ (for tube radius r)

Laminar Flow:



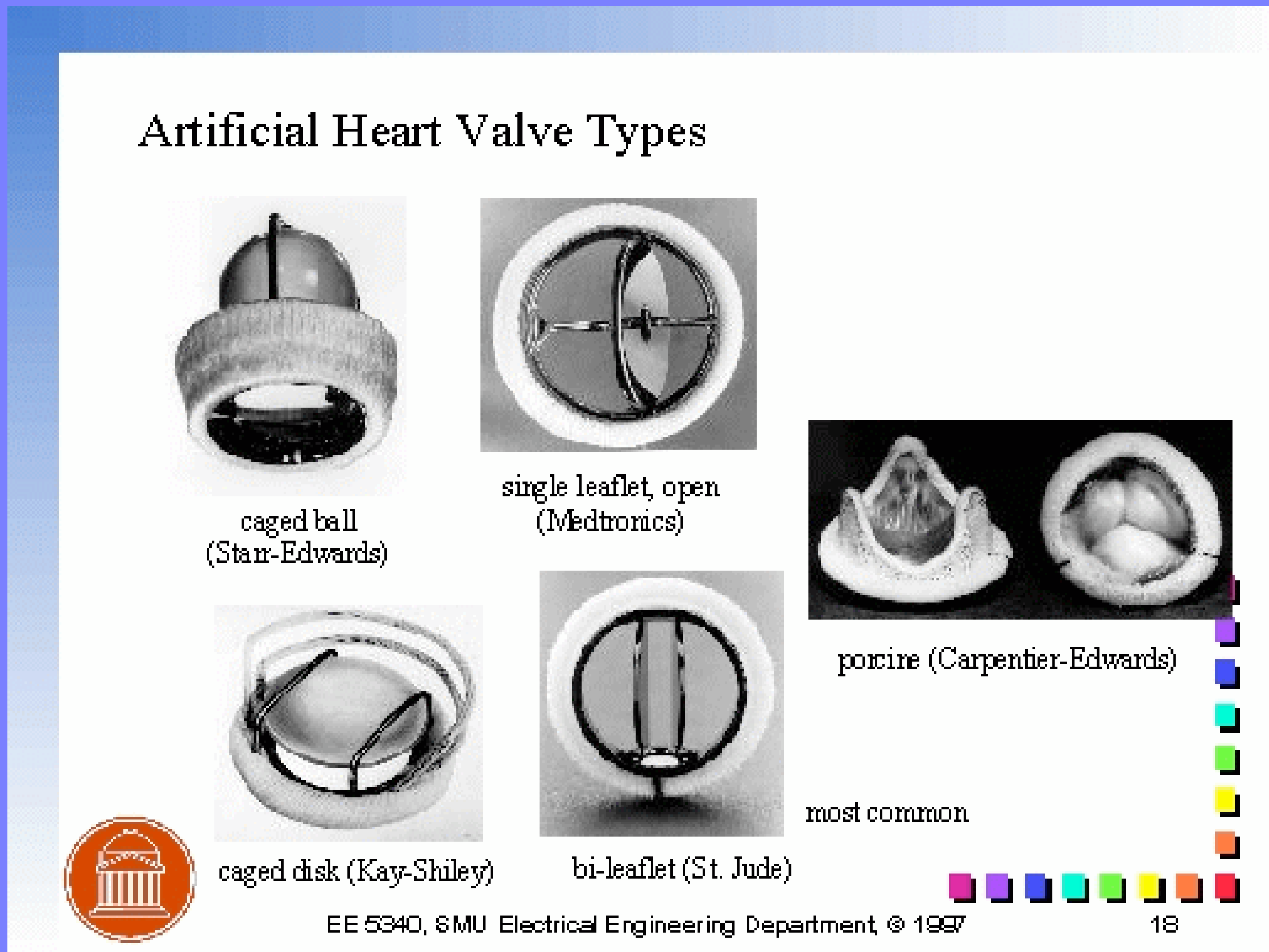
Turbulent Flow: R > 1000 for blood: Aorta during systole

Cardiac Cycle

- Left Heart
  - Diastole (lowest aortic presure): ventricle contracts

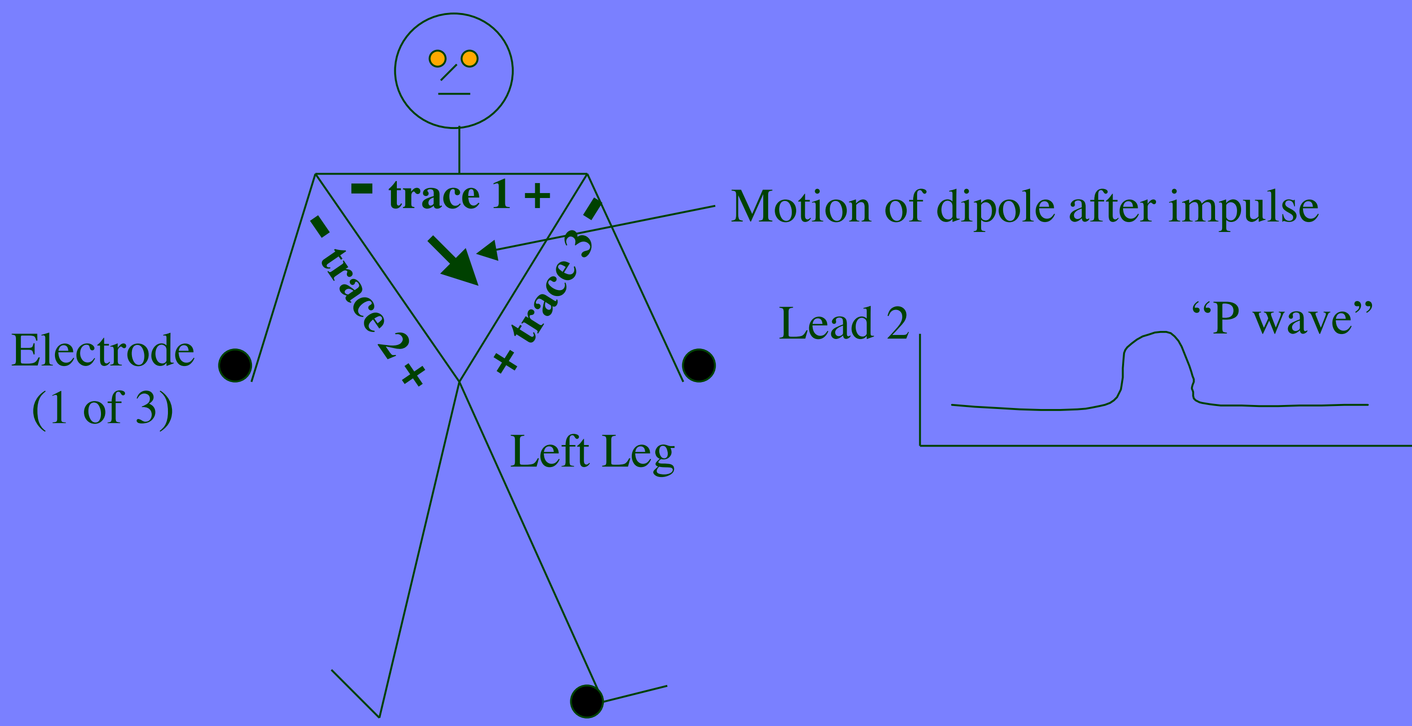
0-0.02 s	aortic valve opens - HEART SOUND
0- 0.1 s	aortic pressure increases to Systole
0.1-0.25 s	aortic valve closes as blood leaves ventricle
...	

Heart Valves



An estimated 78,000 people get replacement heart valves in the United States each year, according to the American Heart Association.

Electrocardiology



A wave of - and + charge moves across the heart muscle and is measurable on the skin

Potential changes of 0.001 Volt arise