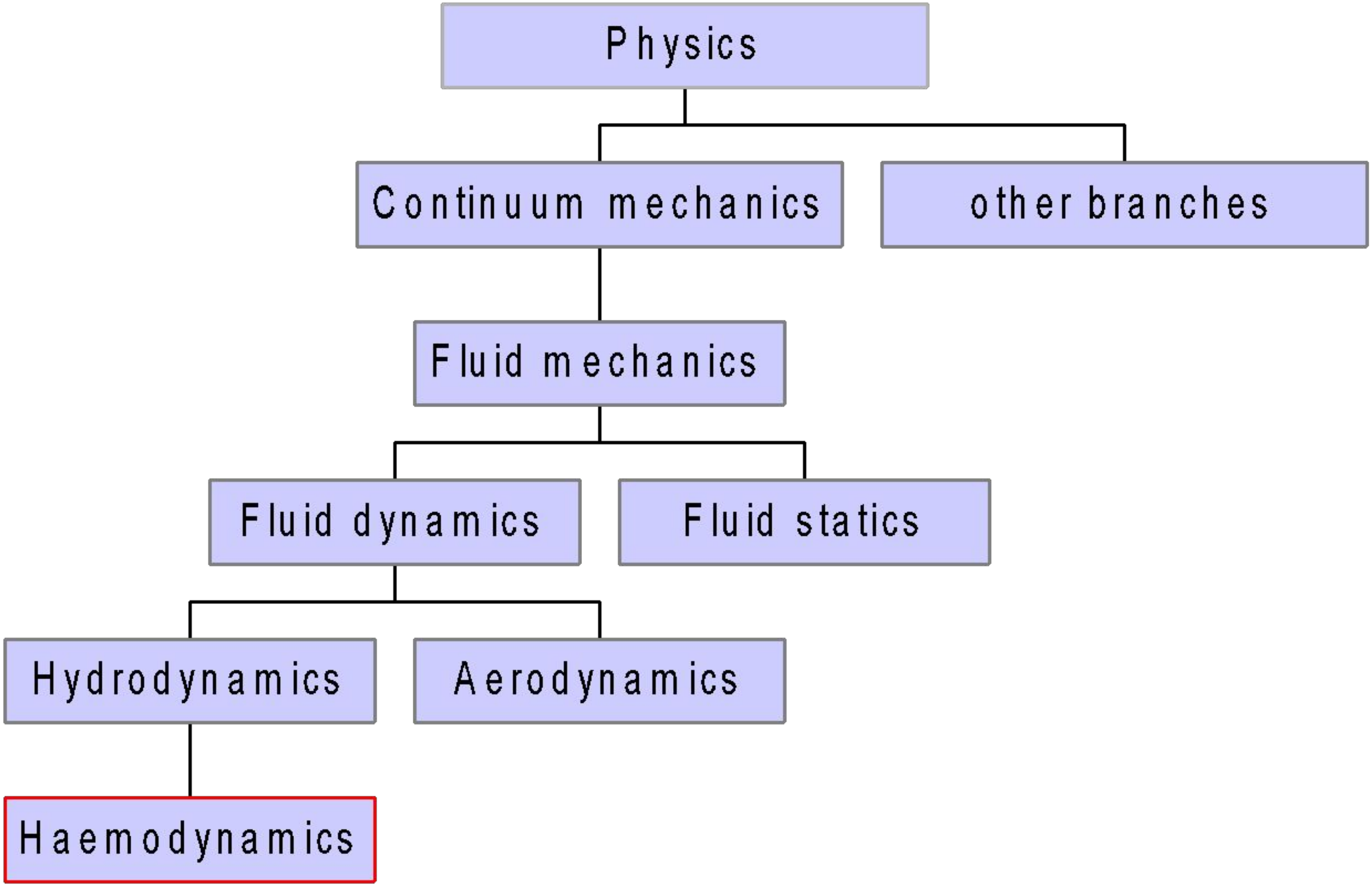
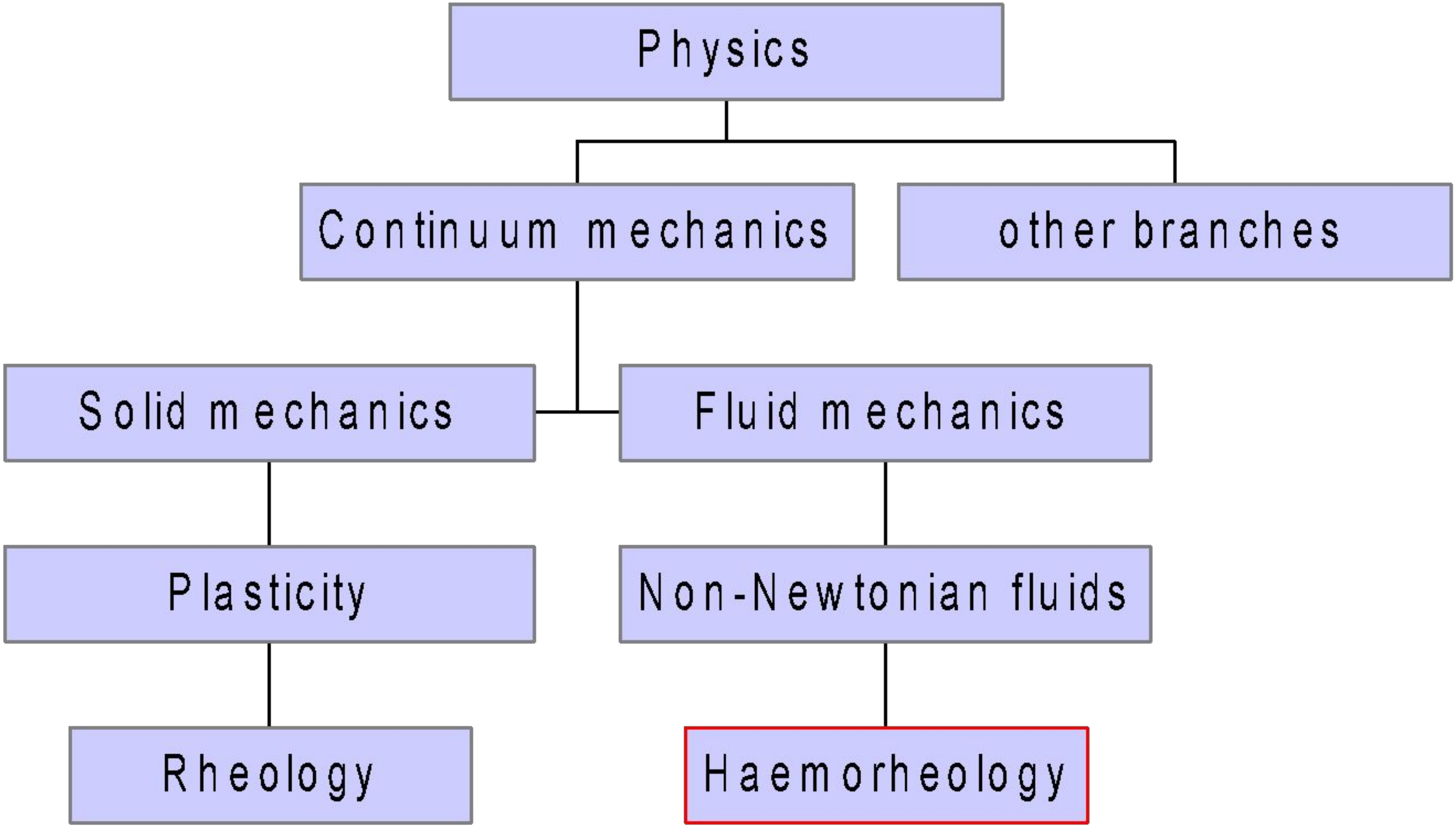
Haemodynamics
Haemorheology

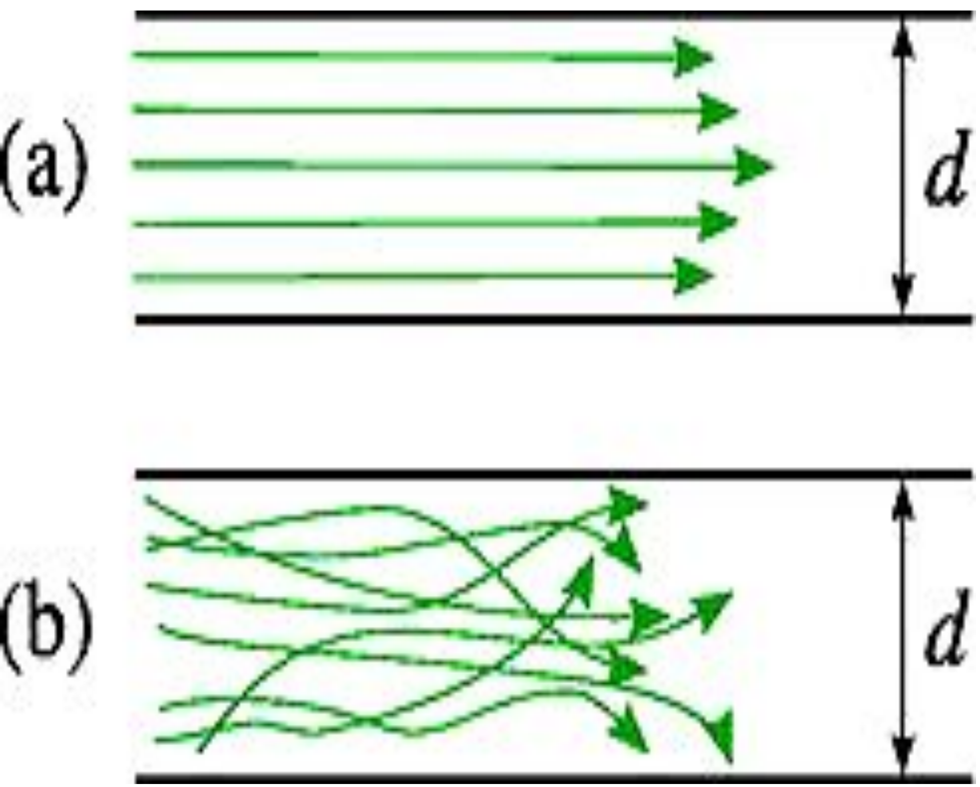
Branches of physics



Branches of physics



Laminar and turbulent flow



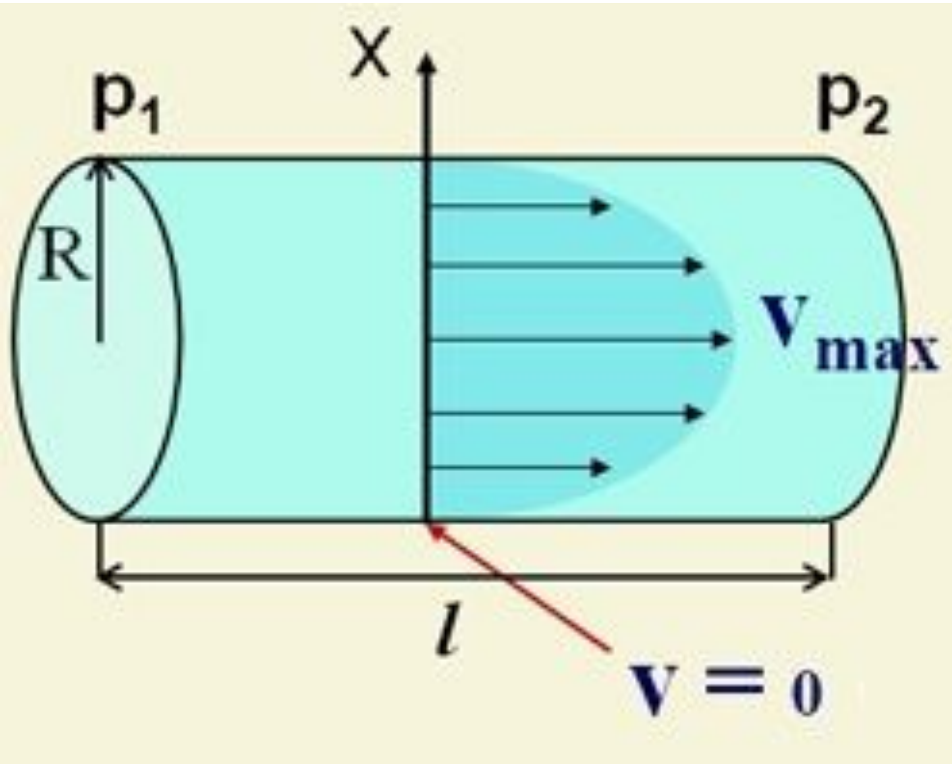
(a) occurs when a fluid flows in parallel layers, with no disruption between the layers

(b) is a flow regime that demonstrates chaotic changes in pressure and flow velocity

Viscosity

- The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress

Viscosity



Viscosity is a property of the fluid which opposes the relative motion between the two surfaces of the fluid that are moving at different velocities. When the fluid is forced through a tube, the particles which compose the fluid generally move more quickly near the tube's axis and more slowly near its walls; therefore some stress is needed to overcome the friction between particle layers to keep the fluid moving.

Newton's Law of Viscosity

$$F = -\eta \frac{dV}{dZ} S$$

- **F** is the shear stress in the fluid
- **η** is a scalar constant of proportionality, the shear viscosity of the fluid
- **dV/dZ** is the derivative of the velocity component that is parallel to the direction of shear, relative to displacement in the perpendicular direction.
- **S** is the surface (area) between fluid and the tube.

- **Newtonian fluid**

  fluid in which the viscous stresses arising from its flow, at every point, are linearly proportional to the local strain rate (the rate of change of its deformation over time).

- **Non-Newtonian fluid**

  viscosity is dependent on shear rate or shear rate history.

  Shear thickening (dilatant) - apparent viscosity increases with increased stress.

  Shear thinning (pseudoplastic) - apparent viscosity decreases with increased stress

Reynolds number

Is the important dimensionless quantity refers to ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities, in which is known as a boundary layer in the case of a bounding surface such as the interior of a pipe.

Reynolds number

Used to help predict flow patterns in different fluid flow situations.

At low Reynolds numbers viscous forces are dominant, and is characterized by smooth, constant fluid motion (laminar flow).

At high Reynolds numbers flow is dominated by inertial forces, which tend to produce chaotic eddies, vortices and other flow instabilities (turbulent flow).

Reynolds number

$$Re = \frac{\rho v_s^2 / L}{\mu v_s / L^2} = \frac{\rho v_s L}{\mu} = \frac{v_s L}{\nu} = \frac{\text{Inertial forces}}{\text{Viscous forces}}$$

wherein:
v_s - mean fluid velocity, [m/s]
L - characteristic length, [m]
μ - (absolute) dynamic fluid viscosity, [Pa*s]
ν - kinematic fluid viscosity: $\nu = \mu / \rho$, [m^2/s]
ρ - fluid density, [$kg*m^{-3}$]

Pascal's law

- Pascal's law is a principle in fluid mechanics that states that a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere

Bernoulli's principle

$$\rho v^2/2 + \rho g h + p = \text{const}$$

- $\rho v^2/2$ is dynamic pressure,
- $\rho g h$ is hydraulic head
- p = static pressure

Hagen–Poiseuille law

$$\mathbf{Q = \Delta P\, \pi r^4/8\eta L}$$

flow of liquid depends on following factors: like the pressure gradient (ΔP), the length of the narrow tube (L) of radius (r) and the viscosity of the fluid (η) along with relationship among them.

Assumptions:

- The tube is stiff, straight, and uniform
- Liquid is Newtonian , i.e., viscosity is constant
- The flow is laminar and steady, not pulsatile, and the velocity at the wall is zero (no slip at the wall)

Hagen–Poiseuille law

$$Q = \Delta P \pi r^4 / 8\eta L$$

The Pressure Gradient (ΔP) : Shows the difference in the pressure between the two ends of the tube, determined by the fact that any fluid will always flow from high pressure to low pressure region and the flow rate is determined by the pressure gradient ($\Delta P = P_1 - P_2$)

Radius of tube: The liquid flow varies directly with the radius to the power 4.

Viscosity (η): The flow of the fluid varies inversely with the viscosity of the fluid and as the viscosity of the fluid increases, the flow decreases vice versa.

Length of the Tube (L): The liquid flow is inversely proportional to the length of the tube, therefore longer the tube, greater is the resistance to the flow.

Resistance(R): The resistance is described by $8\eta L/\pi r4$ and therefore the Poiseuille's law becomes

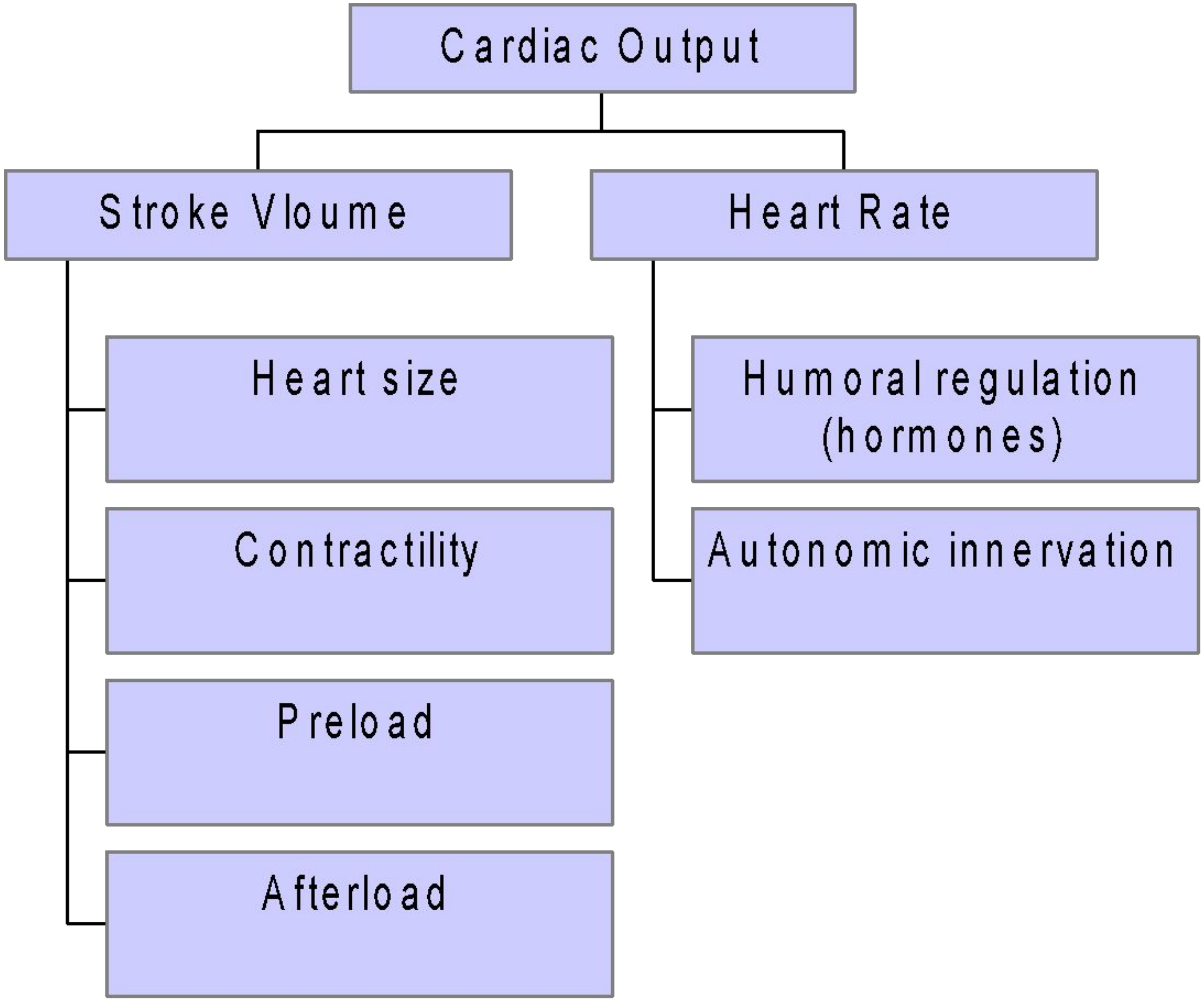
$$Q = (\Delta P)/R$$

Cardiac output

$$CO = HR \times SV$$

Is the volume of blood being pumped by the heart, in particular by the left or right ventricle, per unit time.

Major factors influencing cardiac output



Frank–Starling law

- The Frank–Starling law of the heart represents the relationship between stroke volume and end diastolic volume. The law states that the stroke volume of the heart increases in response to an increase in the volume of blood in the ventricles, before contraction (the end diastolic volume), when all other factors remain constant. As a larger volume of blood flows into the ventricle, the blood stretches the cardiac muscle fibers, leading to an increase in the force of contraction.

Myocardial contractility

Myocardial contractility (cardiac inotropy) represents the innate ability of the heart muscle to contract. Changes in the ability to produce force during contraction result from incremental degrees of binding between thick and thin filaments.

This results in better ejection of the blood in the ventricles.

Controlled by extrinsic factors

- sympathetic stimulation of the heart
- hormones
- K+ and Ca++ channel blockers

Preload

Preload is the end diastolic volume that stretches the right or left ventricle of the heart to its greatest dimensions under variable physiologic demand. It is the initial stretching of the cardiomyocytes prior to contraction; therefore, it is related to the sarcomere length at the end of diastole.

Afterload

- Afterload is the stress in the wall of the left ventricle during ejection. It is the end load against which the heart contracts to eject blood. Afterload is readily broken into components: one factor is the aortic pressure/ pulmonary pressure the left/right ventricular muscle must overcome to eject blood.

Vascular resistance

Vascular resistance is the resistance that must be overcome to push blood through the circulatory system and create flow.

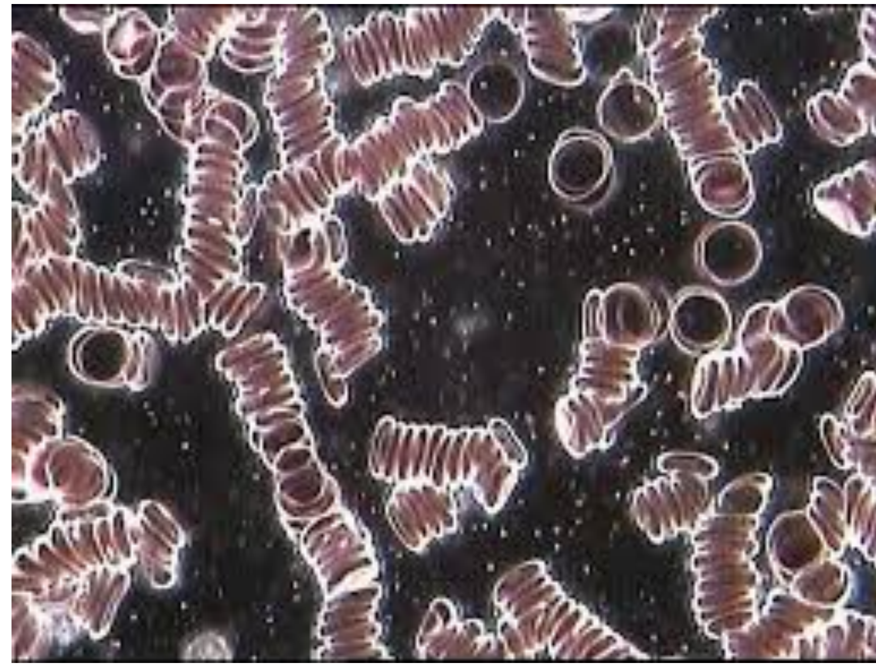
Resistance is a factor of:

- Blood viscosity
- Total blood vessel length
- Vessel diameter

Rouleaux

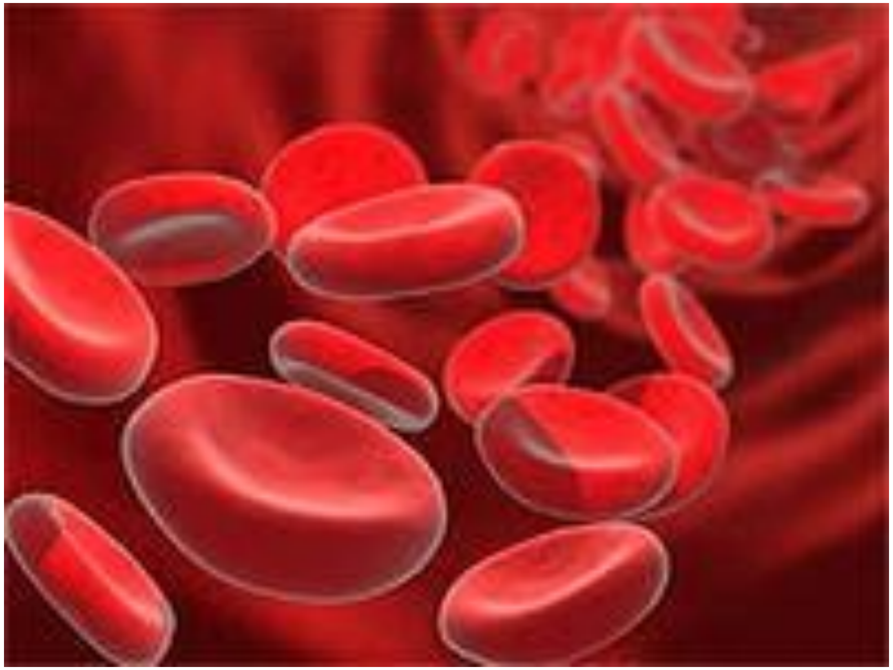
Rouleaux are stacks or aggregations of red blood cells which form because of the unique discoid shape of the cells in vertebrates. The flat surface of the discoid RBCs gives them a large surface area to make contact with and stick to each other; thus forming a rouleau.

Rouleaux



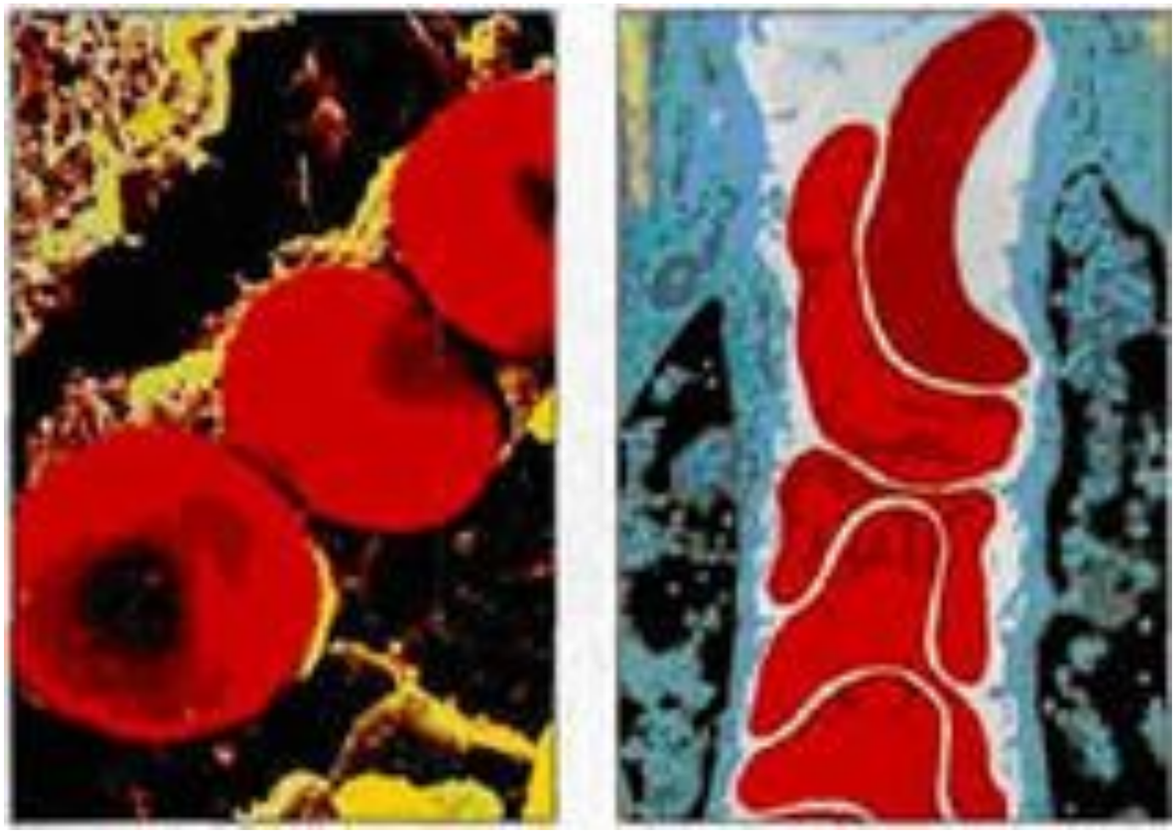
Diameter of blood vessel is more than diameter of rouleaux

Rouleaux



Diameter of blood vessel is nearly equal to diameter of rouleaux

Rouleaux



Diameter of blood vessel is less than diameter of RBC

$$\eta' = \eta(1 + KC) \qquad K = 2,5 \cdot \left(\frac{4}{3}\pi R^3\right)$$

Hagen–Poiseuille law

$$\mathbf{Q = \Delta P \pi r^4 / 8 \eta L}$$

$$\mathbf{Q = (\Delta P)/R}$$

Pressure gradient: created by the heart.

Resistance

- **Radius of tube:** diameter of blood vessels.
- **Viscosity :** property of blood.

Length of the tube

Now summarize three major concepts presented in this lecture

- 1.
- 2.
- 3.