

VORLESUNG 2

Vorlesung
Humboldt-Universität zu Berlin
Institut für Physik

Biologische Physik

Die Dynamik biologischer Prozesse im menschlichen Körper

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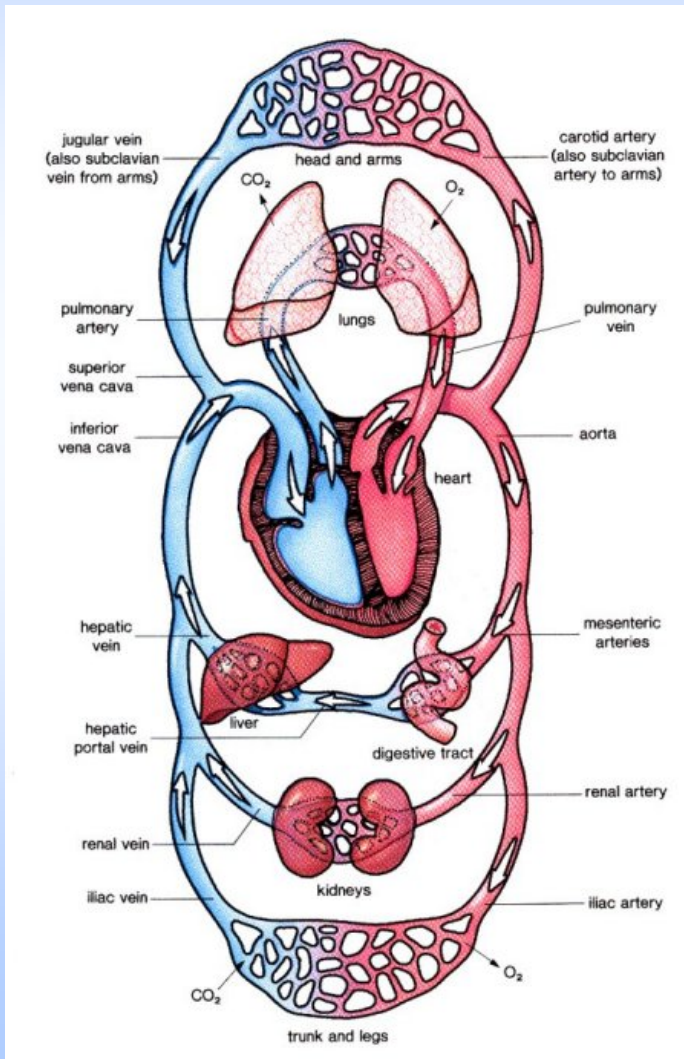


**Max Planck Institute
of Colloids and Interfaces**



1. The Cardiovascular System

closed loop: oxygen from the lungs to the tissues and carbon dioxide from the tissues back to the lungs



pump 1 - left heart
systemic arteries
gas exchange 1 - capillaries
systemic veins
pump 2 - right heart
pulmonary arteries
gas exchange 2 - capillaries





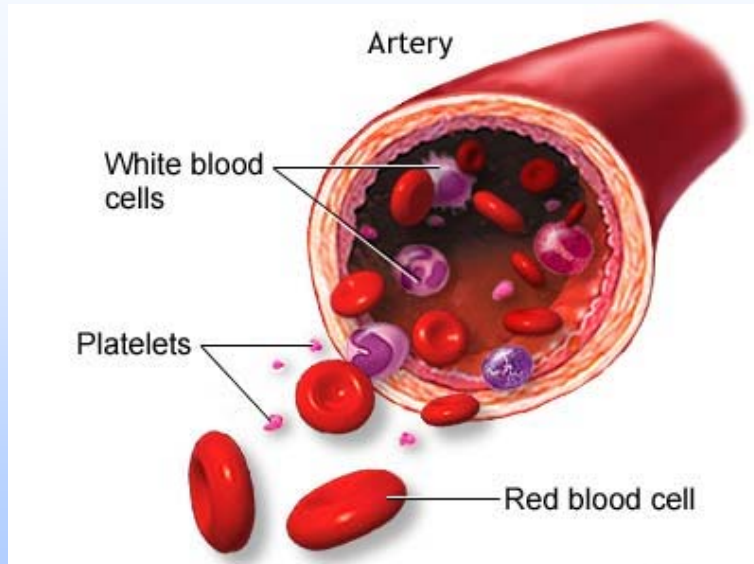
1. The Cardiovascular System

3 COMPONENTS: CIRCULATORY SYSTEM

BLOOD

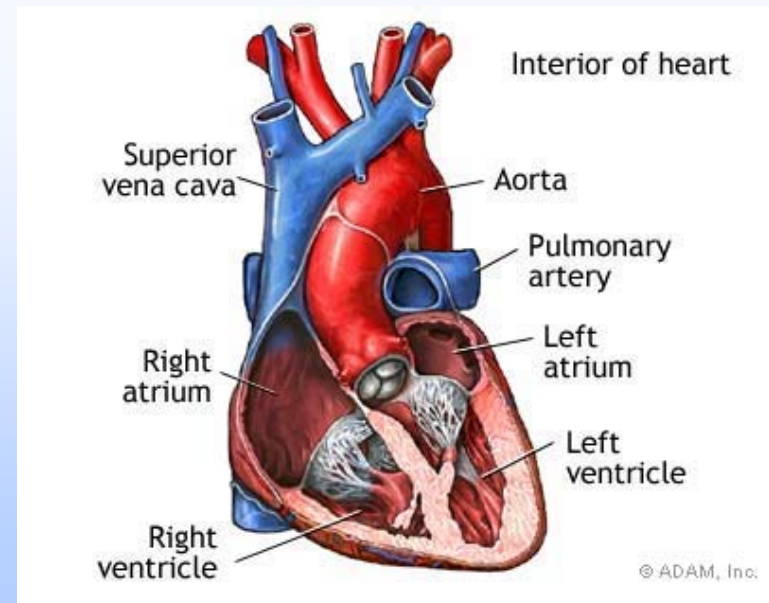
vehicle for transport
(oxygen, fuel,
carbon dioxide, waste)

complex fluid



HEART

four-chambered pump
composed mostly
of cardiac muscle

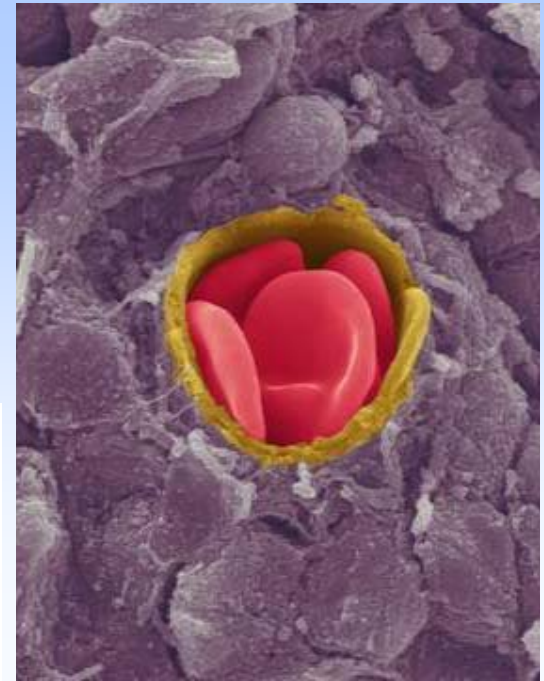




blood

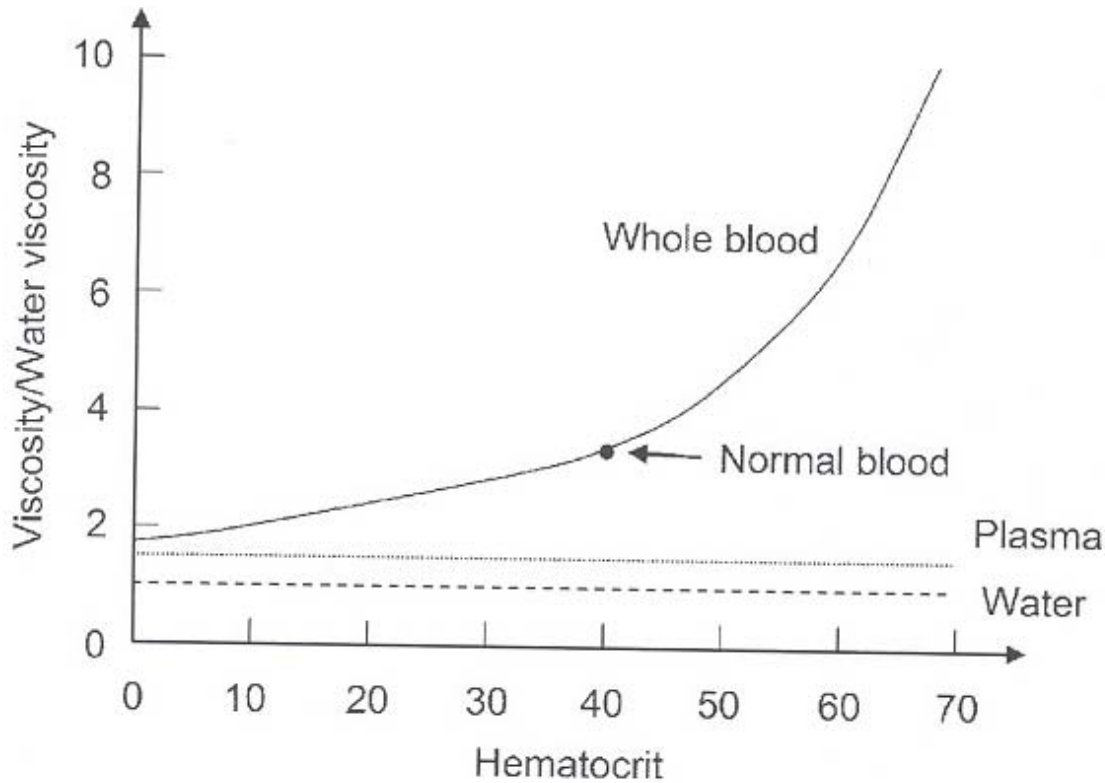
non-Newtonian fluid

- plasma
- red blood cells
- white blood cells
- platelets



human red blood cells
in a capillary

but assumed to be
Newtonian fluid



$$\tau = \mu \frac{du}{dx}$$





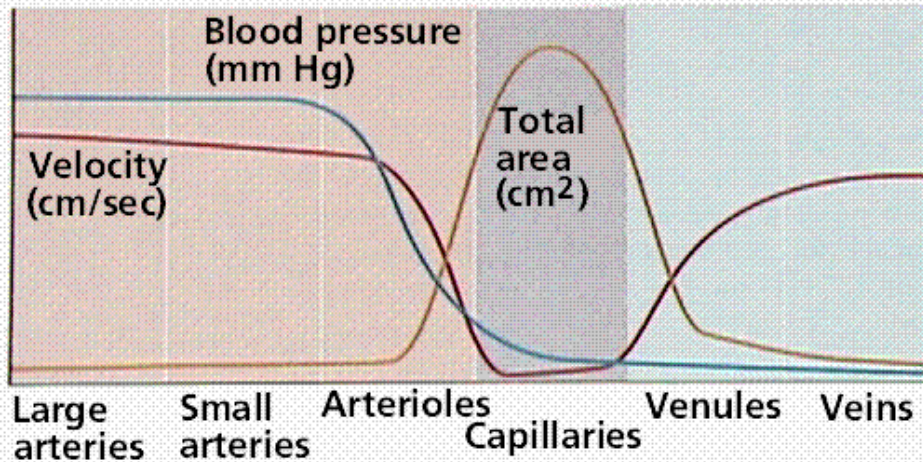
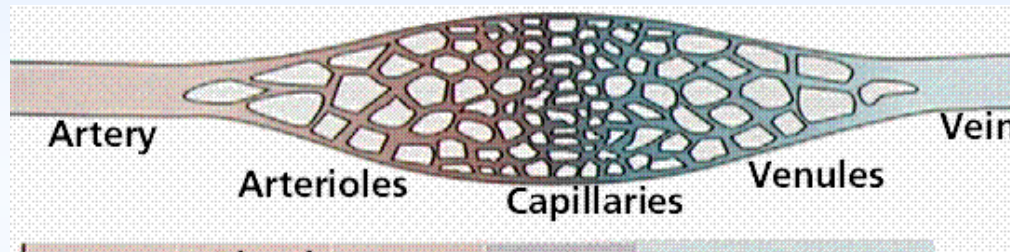
CIRCULATORY SYSTEM:

1.1 Blood Flow

blood pressure: force per unit area that the blood exerts on the walls of blood vessels

systolic pressure: 120 mm Hg

diastolic pressure: 80 mm Hg



Vessel	D (cm)	A (cm ²)	P (mm Hg)	v (cm/s)
Aorta	2.5	2.5	100	33
Small arteries	0.5	20	100	30
Arterioles	3×10^{-3}	40	85	15
Capillaries	6×10^{-4}	2500	30	0.03
Venules	2×10^{-3}	250	10	0.5
Small veins	0.5	80		2
Venae cavae	3.0	8	2	20





1.1 Blood Flow

incompressible, Newtonian fluid, steady and lamellar flow:

Stokes equation:
$$\mu \nabla^2 \mathbf{u} = \nabla P$$

flow through a cylinder, only axial flow:

Hagen-Poiseuille equation:
$$Q = -\frac{\pi P_x}{8\mu} r_0^4 = -\frac{P_x}{8\pi\mu} A_0^2$$

N vessels with total cross-sectional area $A = N A_0$:

$$Q = -\frac{P_x}{8\pi\mu} A_0 A \quad \text{and} \quad V = \frac{Q}{A}$$

vasodilators, vasoconstrictors

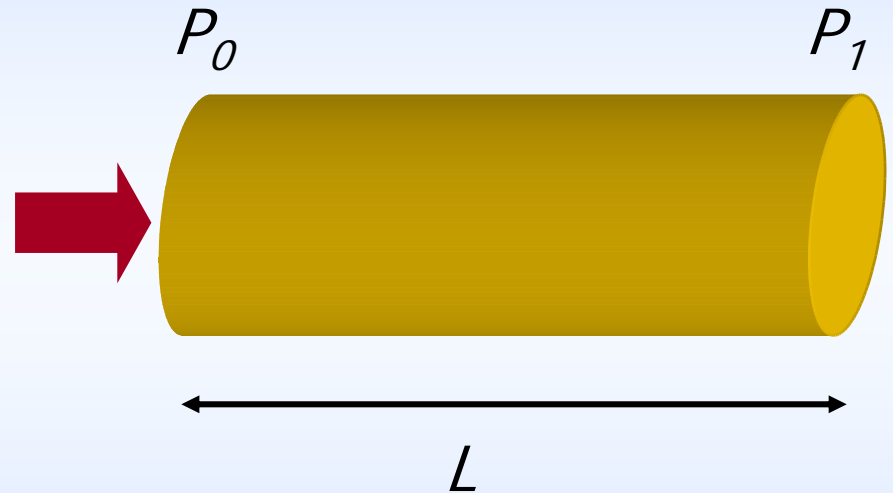
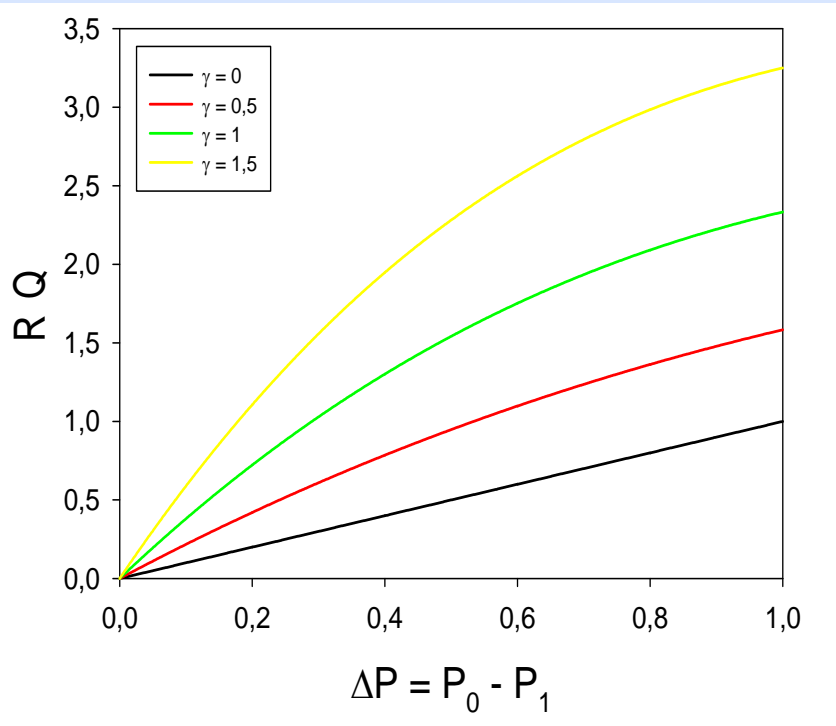




1.2 Compliant Vessel

assumption about compliance:

$$A = A_0 + cP$$



scaled
flow

$$RQ = (P_0 - P_1) \left(1 + \gamma(P_0 + P_1) + \frac{\gamma^2}{3} (P_0^2 + P_0P_1 + P_1^2) \right)$$

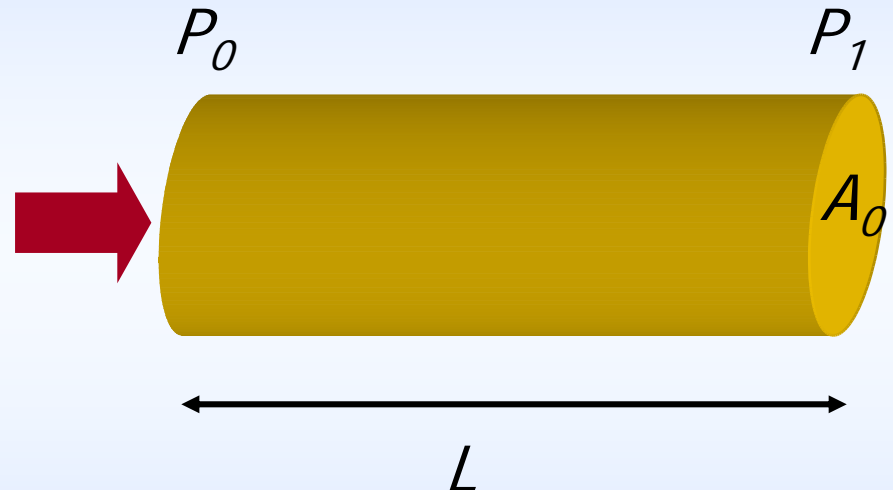
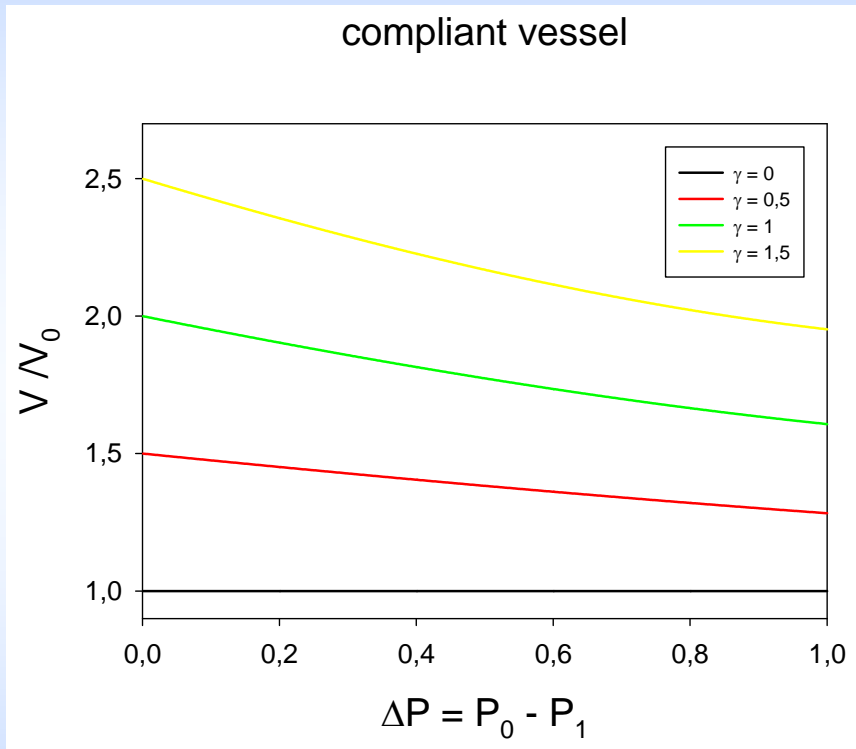




1.2 Compliant Vessel

assumption about compliance:

$$A = A_0 + cP$$



$$V_0 = A_0 L$$

volume

$$\frac{V}{V_0} = \frac{3 (1 + \gamma P_0)^4 - (1 + \gamma P_1)^4}{4 (1 + \gamma P_0)^3 - (1 + \gamma P_1)^3}$$

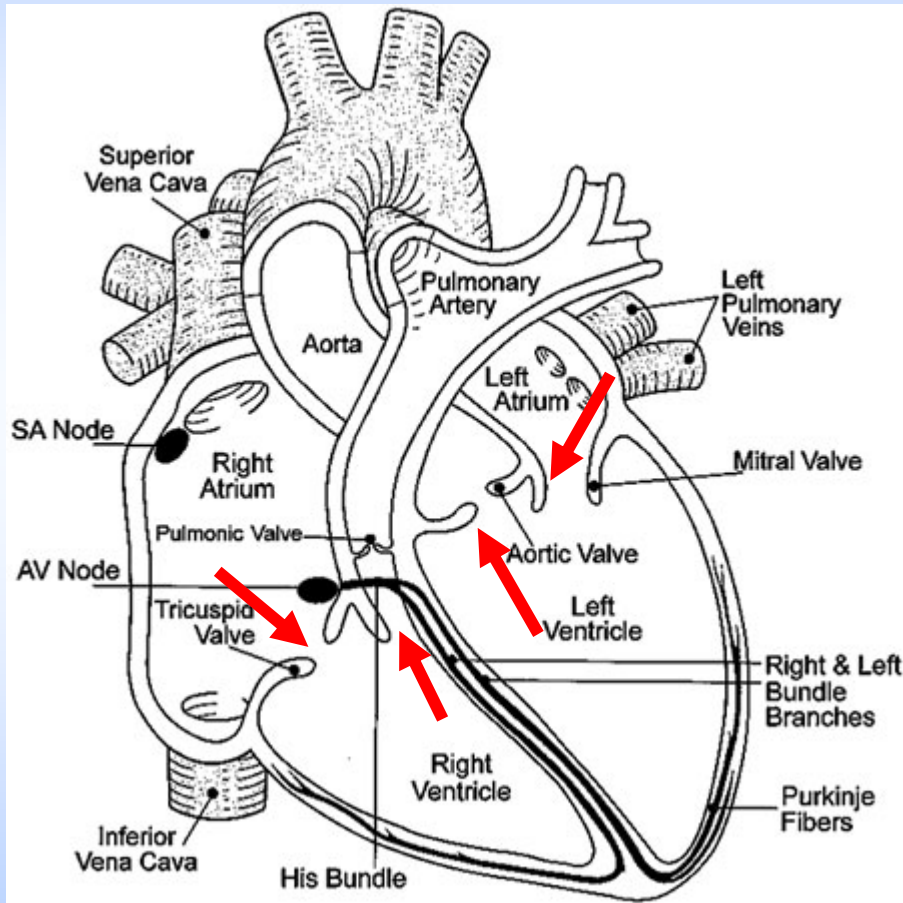




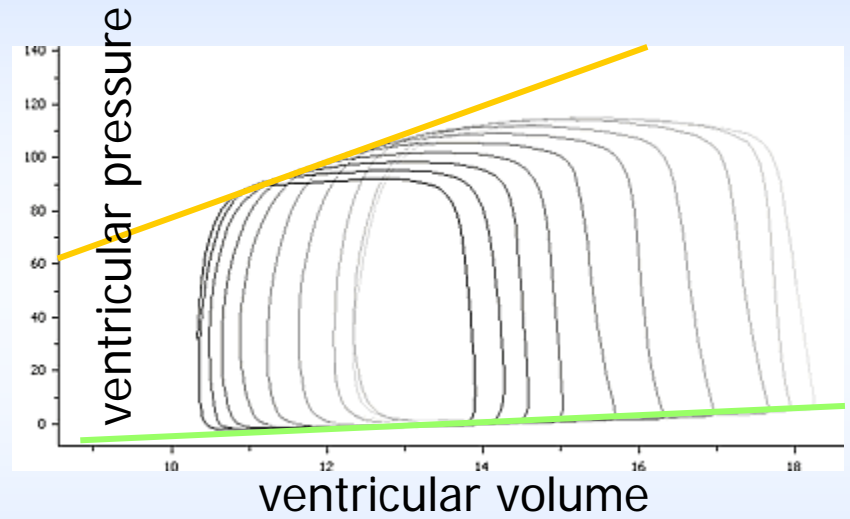
HEART

1.3 Cardiac Output

4 chambers – 2 pumps



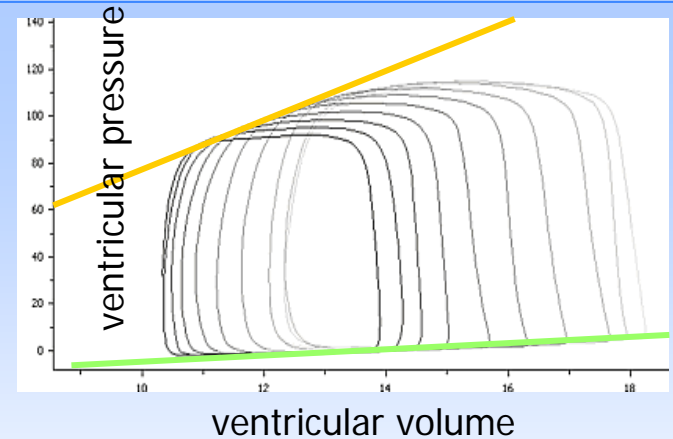
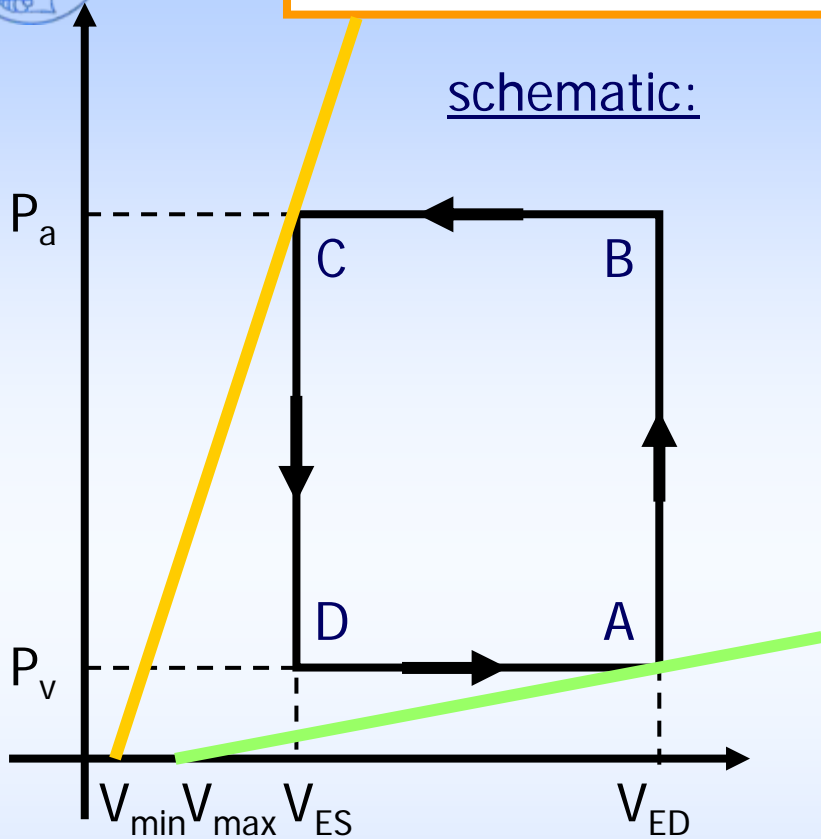
experimental data:





1.3 Cardiac Output

schematic:



- A: inflow valve closes
- B: outflow valve opens
- C: outflow valve closes
- D: inflow valve opens

total cardiac output:

$$V_h = V_{max} - V_{min} \quad \text{and} \quad C_d > C_s$$

$$Q = FV_{stroke} = F(V_{ED} - V_{ES}) = F(V_h + C_d P_v - C_s P_a)$$

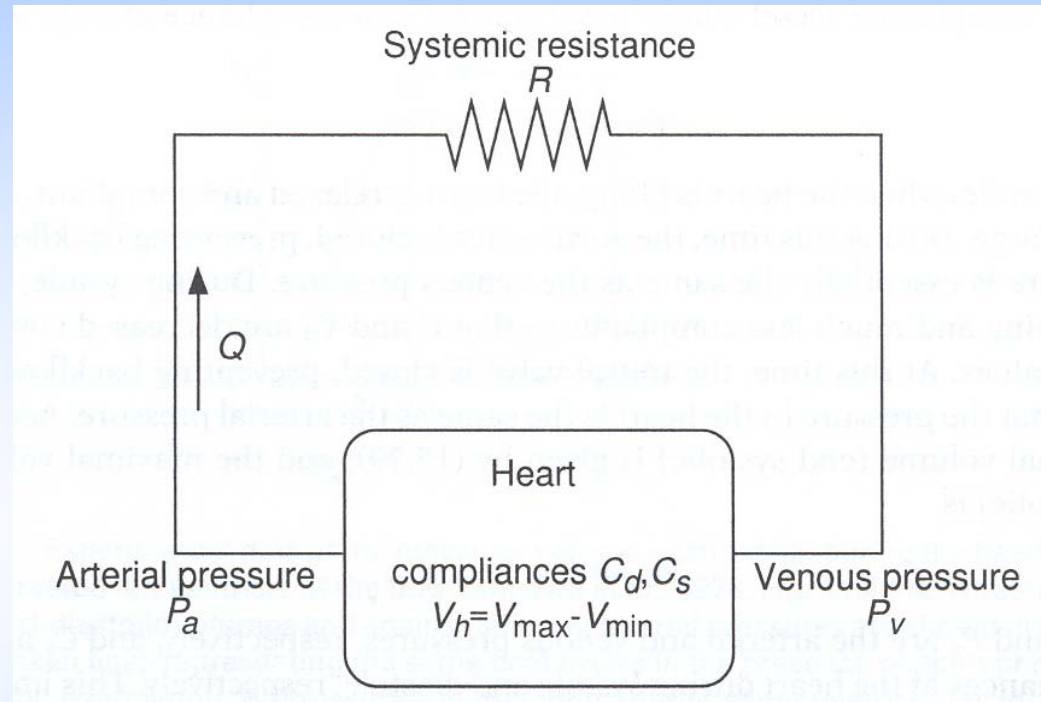
Frank-Starling-Mechanismus: "Das Herz pumpt, was es bekommt"





1.4 Simple Circulatory System

schematic:



$$Q = F(V_h + C_d P_v - C_s P_a)$$

$$Q = \frac{1}{3R\gamma} \left((1 + \gamma P_a)^3 - (1 + \gamma P_v)^3 \right)$$

$$\frac{V}{V_0} = \frac{3(1 + \gamma P_a)^4 - (1 + \gamma P_v)^4}{4(1 + \gamma P_a)^3 - (1 + \gamma P_v)^3} = \text{const}$$

"material parameters" known

3 unknowns:

Q, P_a, P_v

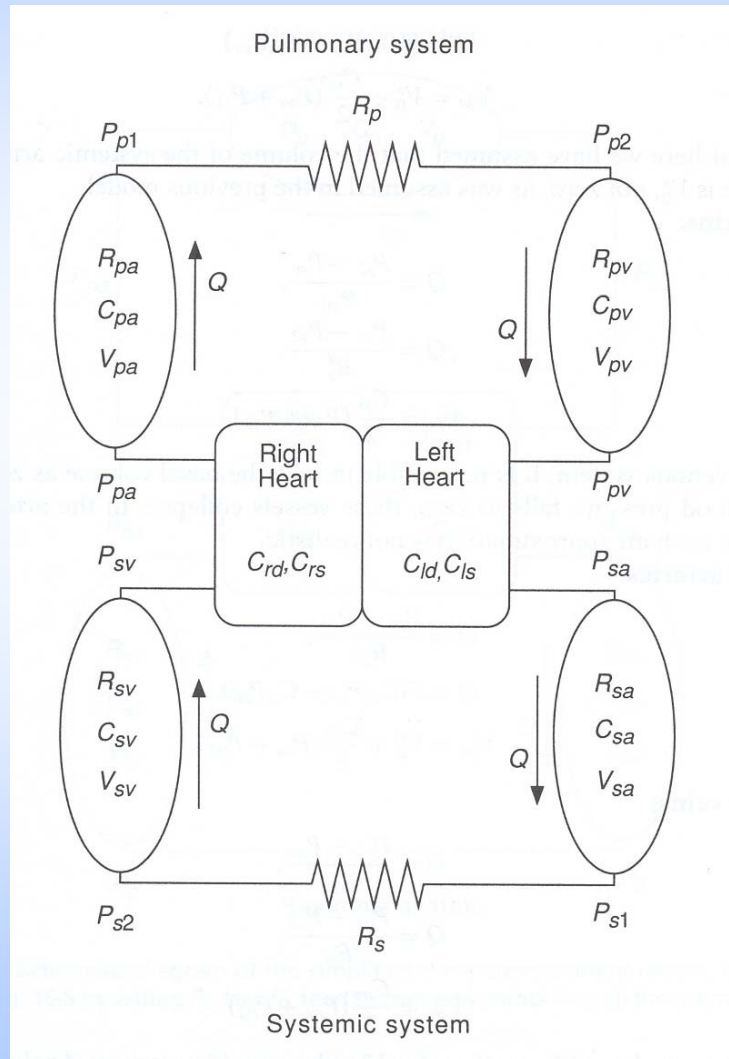
NUMERICAL !!





1.6 Extensions

multicompartment model:



fetal circulation:

