VORLESUNG 3

Vorlesung
Humboldt-Universität zu Berlin
Institut für Physik

Biologische Physik

Die Dynamik biologischer Prozesse im menschlichen Körper

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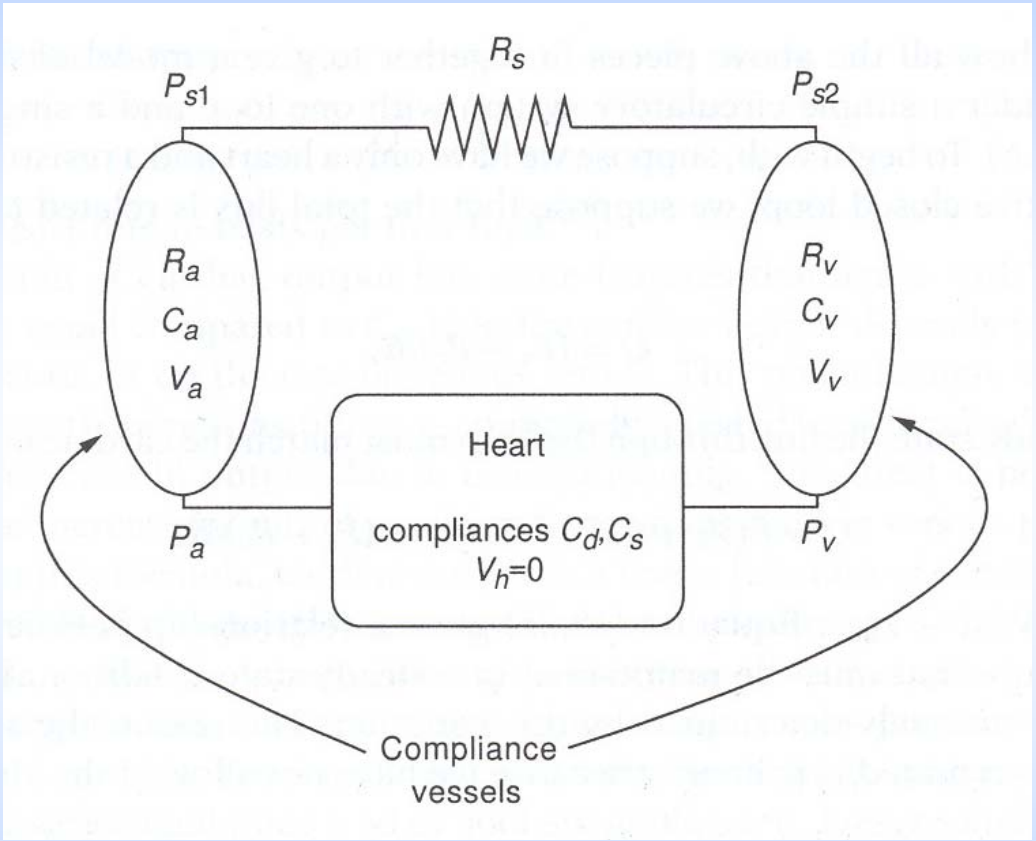
1.5 Simple Linear Circulatory System

schematic:



HEART

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

ARTERIAL SYSTEM

$$Q = \frac{P_a - P_{s1}}{R_a}$$

$$V_a = \frac{C_a}{2}(P_a + P_{s1})$$

CAPILLARIES

$$Q = \frac{P_{s1} - P_{s2}}{R_s}$$

VENOUS SYSTEM

$$Q = \frac{P_{s2} - P_v}{R_v}$$

$$V_v = \frac{C_v}{2}(P_v + P_{s2})$$

CIRCULATORY SYSTEM

$$V_a + V_v = \tilde{V} = const$$

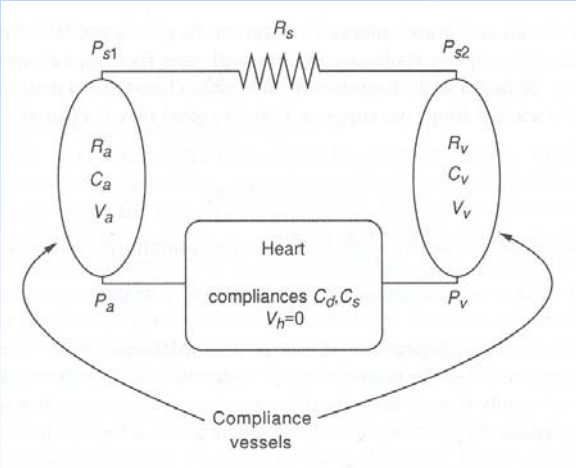
1.5 Simple Linear Circulatory System

equations:

$$Q = F\,C_d\,P_v \qquad Q = \frac{P_a - P_v}{R_s}$$

$$V_a = C_a P_a \qquad V_v = C_v P_v$$

$$V_a + V_v = \tilde{V} = const$$



solution:

$$P_a = \frac{(1 + FC_dR_s)\tilde{V}}{C_v + (1 + FC_dR_s)C_a}$$

$$P_v = \frac{\tilde{V}}{C_v + (1 + FC_dR_s)C_a}$$

$$Q = \frac{F\,C_d\,\tilde{V}}{C_v + (1 + FC_dR_s)C_a}$$

qualitative features:

- increase in heart rate:
  increase in arterial pressure
- decrease in heart rate:
  decrease in arterial pressure,
  increase in venous pressure
- increase in systemic resistance:
  decrease in the cardiac output,
  increase in the arterial pressure,
  decrease in the venous pressure
  shift of the blood volume from the
  venous system to the arterial system

$$P_a \to \frac{\tilde{V}}{C_a}$$

$$P_a \to \frac{\tilde{V}}{C_a + C_v}$$

$$P_v \to \frac{\tilde{V}}{C_a + C_v}$$

1.7 The Arterial Pulse

blood flow – pulsatile flow:

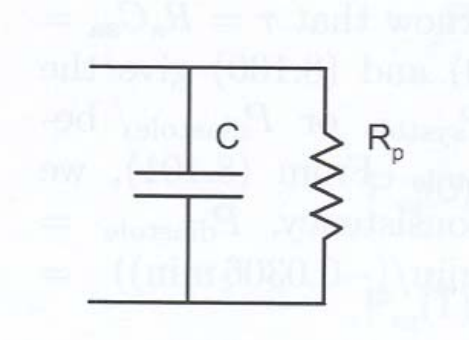
systolic pressure: 120 mm Hg
diastolic pressure: 80 mm Hg

the Windkessel model:

$$\frac{dP(t)}{dt} + \frac{P(t)}{R_p C} = 0$$

after ventricular ejection

two-element Windkessel Model (W2):



analog of blood flow and electrical circuits:

blood circulation parameter	electrical parameter
volume, V_{flow} (m^3)	charge, q (C, coulomb)
blood flow rate, Q (m^3/s)	current, I (A, ampere)
pressure, ΔP (N/m^2)	voltage, V_{elect} (V, volt)
vascular resistance, R_{flow} ($\text{N-s}/\text{m}^5$)	resistance, R_{elect} (Ω, ohm)
inertance, L_{flow} (kg/m^4)	inductance, L_{elect} (H, henry)
compliance, C_{flow} ($\text{m}^5/\text{N-s}$)	capacitance, C_{elect} (F, farad)

2. Blood

non-Newtonian fluid

constituents of human blood:

- PLASMA

  fluid part of the blood

- CELLS (per μl)
  - red blood cells (erythrocytes)

    4.7 to 6.1 million (male),

    4.2 to 5.4 million (female)

    oxygen transport

  - white blood cells (leucocytes)

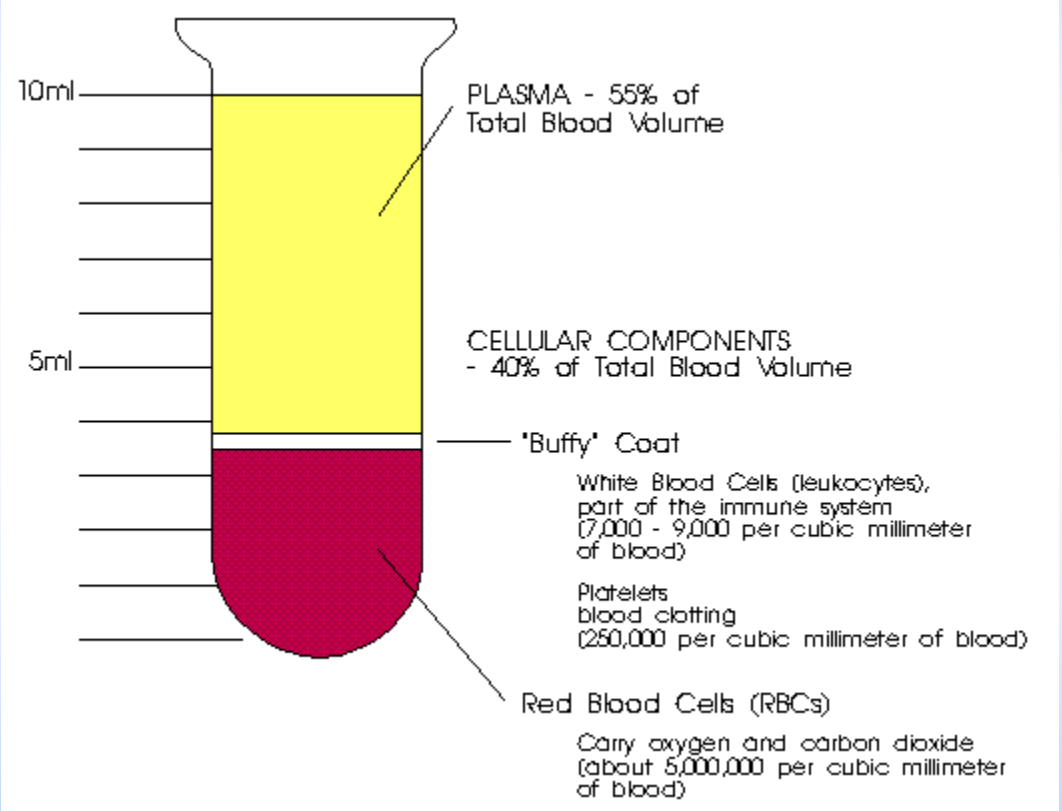
    4.000 - 11.000

    immune system

  - platelets (thrombocytes)

    200.000- 500.000

    blood clotting



"spinning blood down" in a centrifuge

2.1 Blood Plasma

constituents of blood plasma:

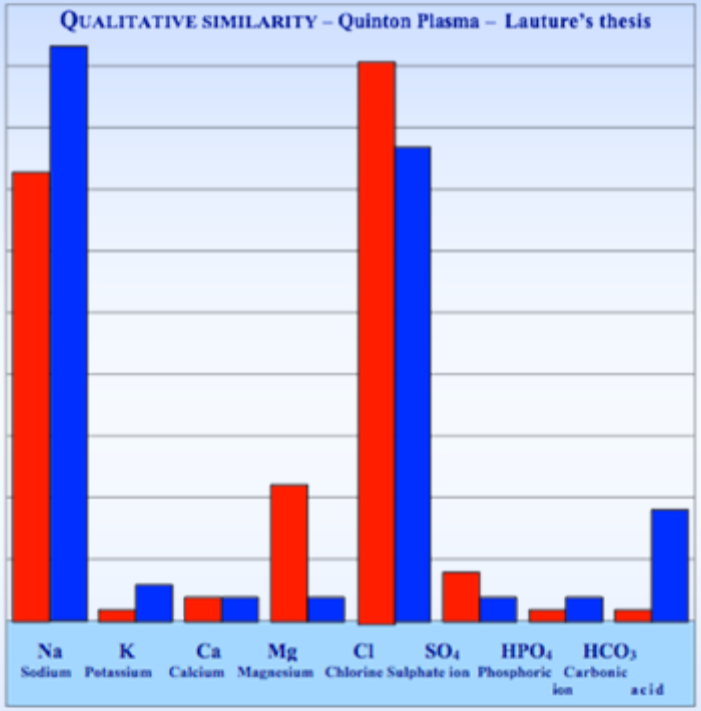
- 90% water
- proteins (albumin, globulins, ...)
- mineral ions
- dissolved gases

ideal gas: $P = CRT$

partial pressure: $P_i = x_i P$

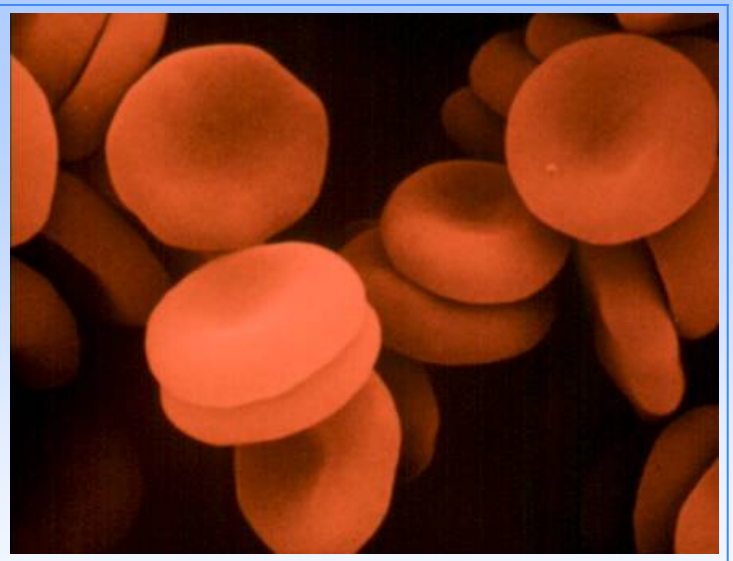
solubility: Henry's law $C_i = \sigma_i P_i$

Substance	σ (Molar/mm Hg)
O_2	1.4×10^{-6}
CO_2	3.3×10^{-5}
CO	1.2×10^{-6}
N_2	7×10^{-7}
He	4.8×10^{-7}

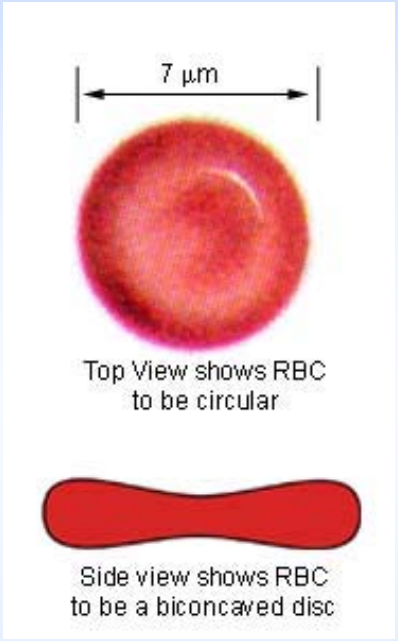


almost identical to "ancient" ocean water

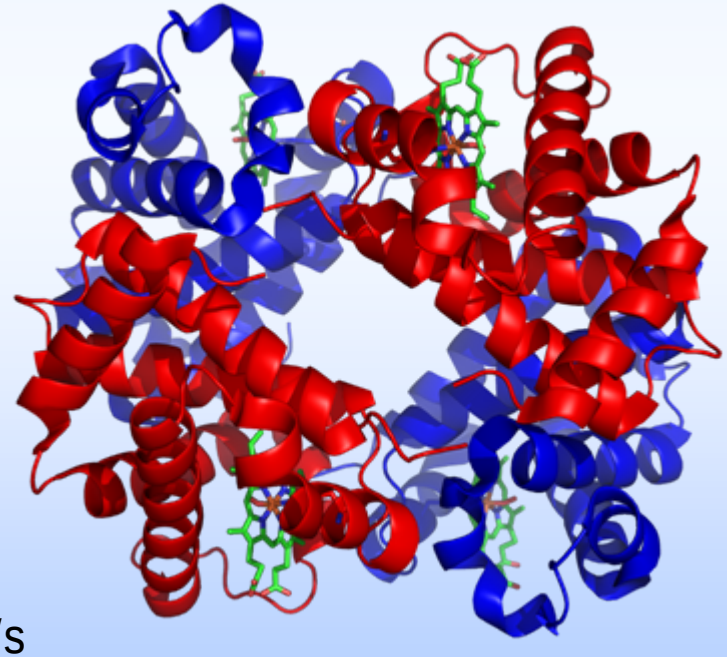
2.1 Erythrocytes



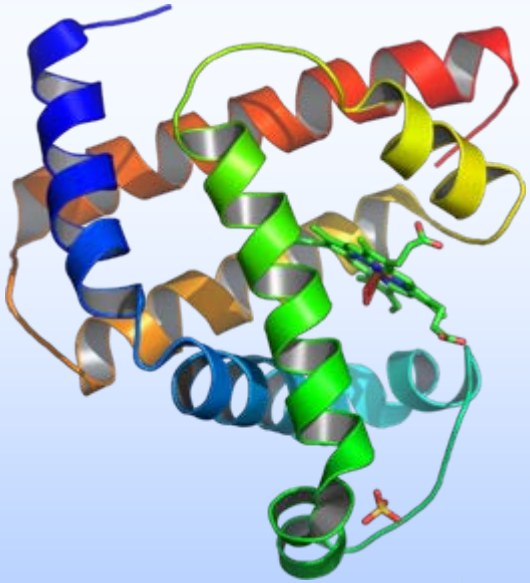
red blood cells (RBCs):



hemoglobin:
90 % of dry mass
total: 2.5 g Fe



myoglobin:

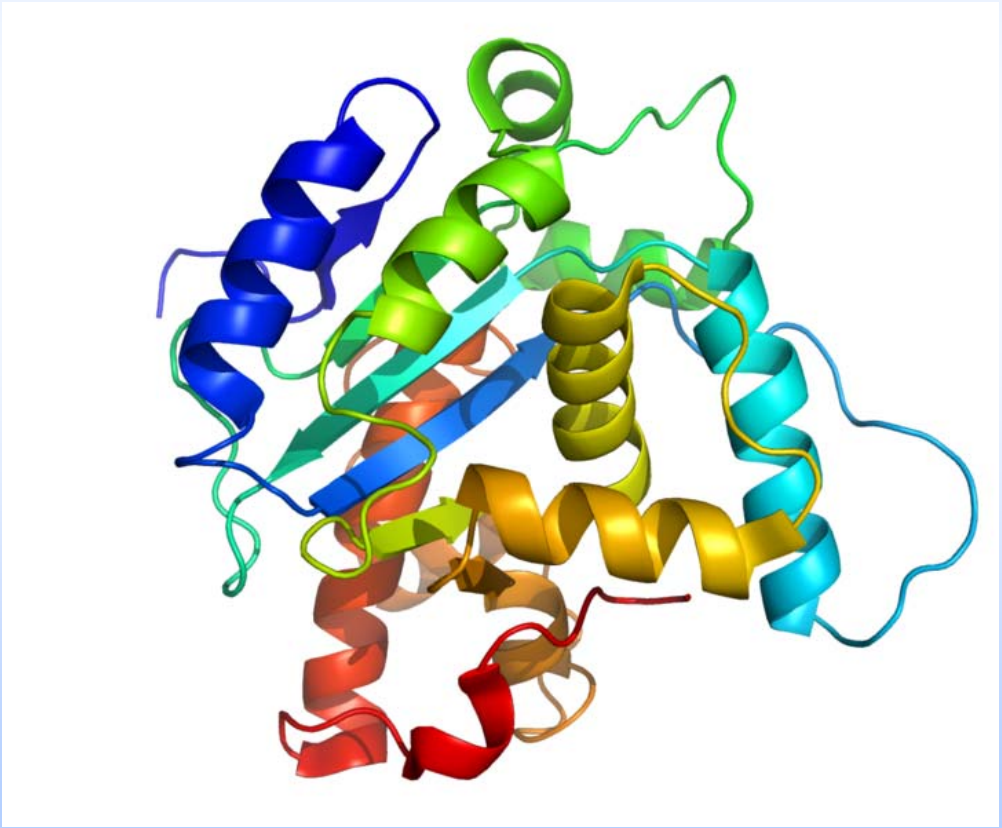


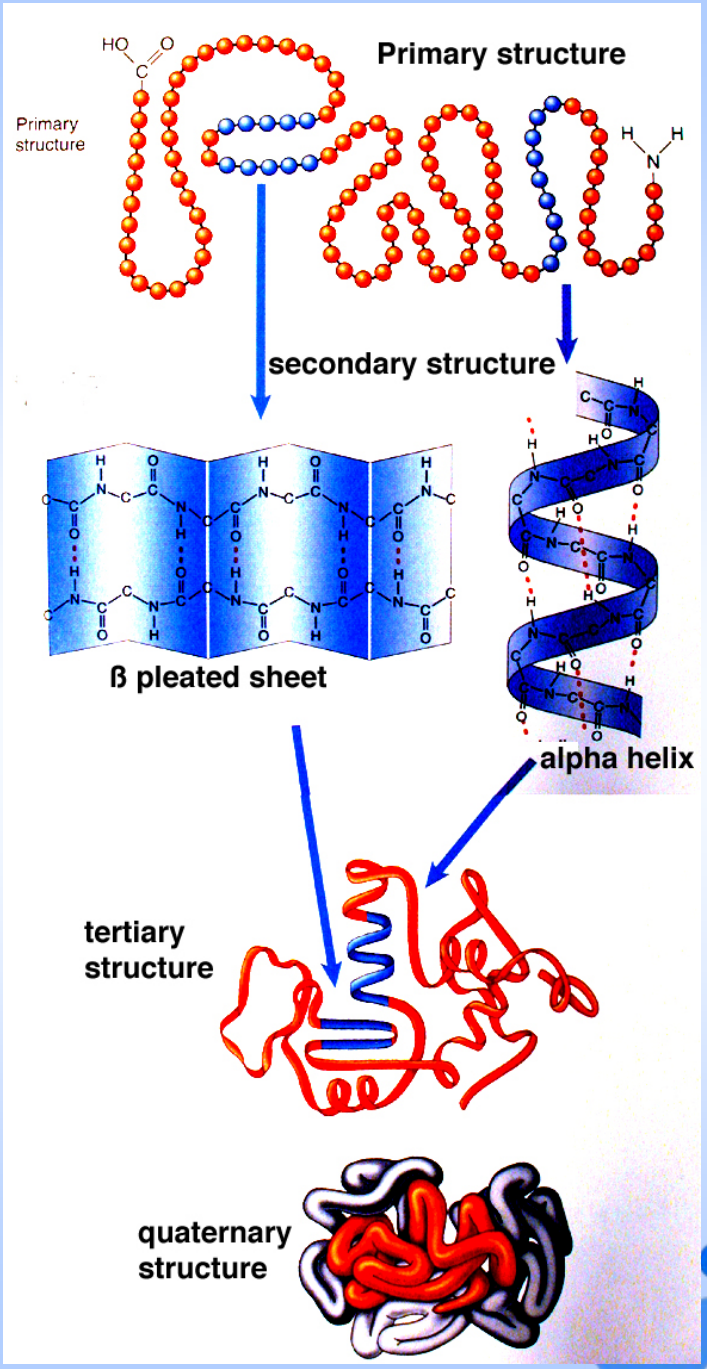
number: $2.5*10^{13}$
life time: 120 days
rate of formation: 10^6/s
total surface > 4000 m^2

Protein Structure

build up of 20 amino acids:
(3 bases in the DNA determines 1 amino acid)

example: S. pombe protein





2.2 Myoglobin vs Hemoglobin

uptake of oxygen by myoglobin and hemoglobin: