Biological and Medical Fluid Mechanics I

2. Blood as a Transport Medium

Dr.-Ing. Michael Klaas
Institute of Aerodynamics
RWTH Aachen University

E-Mail: m.klaas@aia.rwth-aachen.de
Telefon: 0241 – 809 5536

AIA Aerodynamisches Institut und Lehrstuhl für Strömungslehre | RWTH AACHEN UNIVERSITY

Lecture contents

2. Blood as a transport medium	Exercise
2.1 Tasks, composition and distribution 2.1.1 Tasks 2.1.2 Composition and distribution 2.1.3 Blood volumes	
2.2 Red Blood Cells (RBC): erythrocytes 2.2.1 Shape and hematocrit 2.2.2 The red blood dye 2.2.3 The membrane of RBC 2.2.4 Decomposition	

2.1 Tasks, composition and distribution

2.1.1 Tasks:

1. transport for supply and disposal: nutrients, respiratory gases, minerals, enzymes, hormones, metabolic products, toxic materials, water,…
2. immune defense
3. hemostasis (stopping bleeding) and blood coagulation for protection against injury

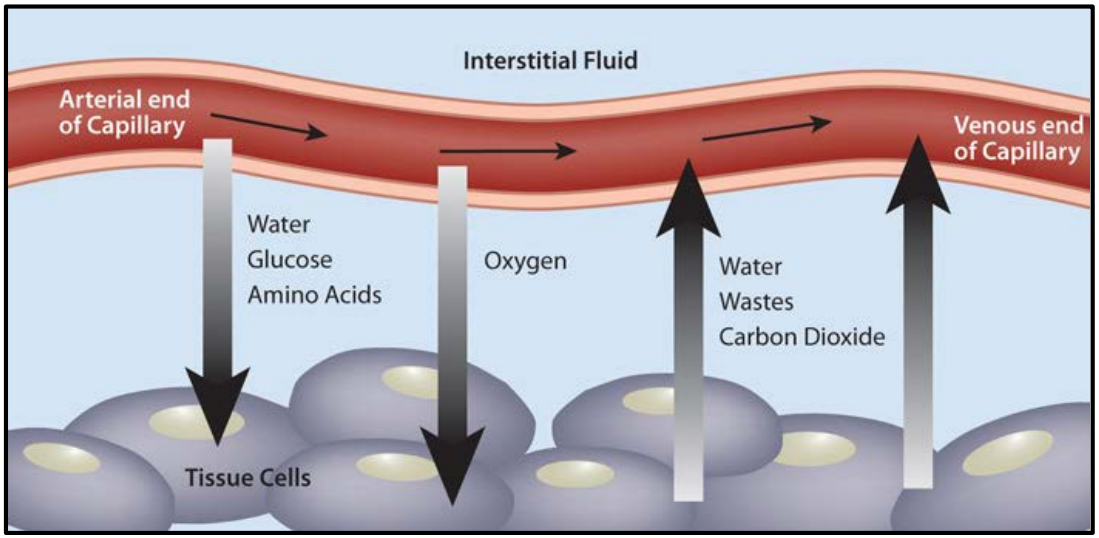
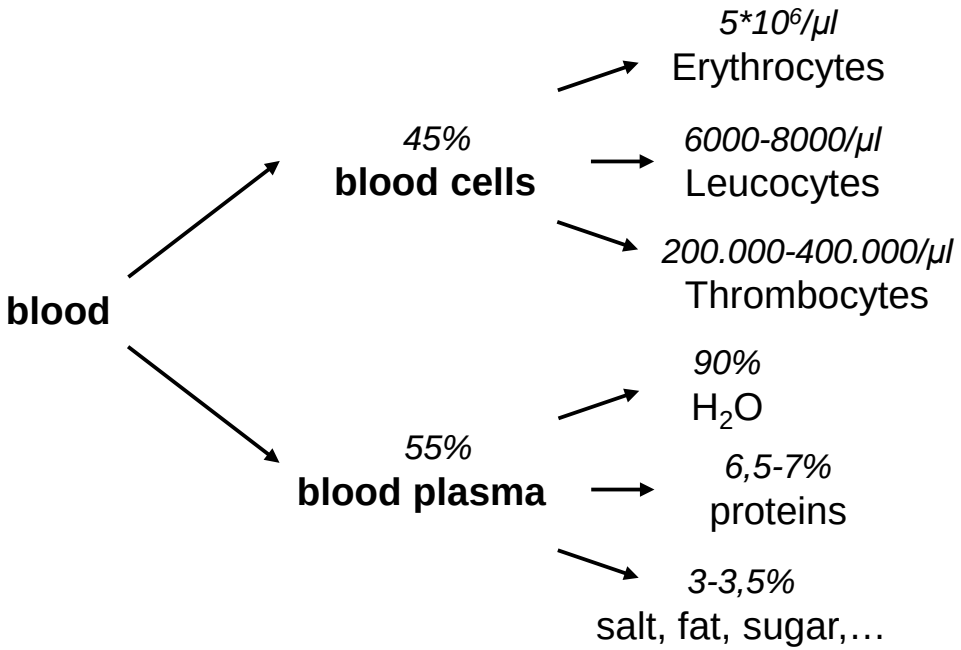


Fig. 2.1 Capillary Exchange – Nutrients in and Wastes out [1]

2.1.2 Composition and distribution:



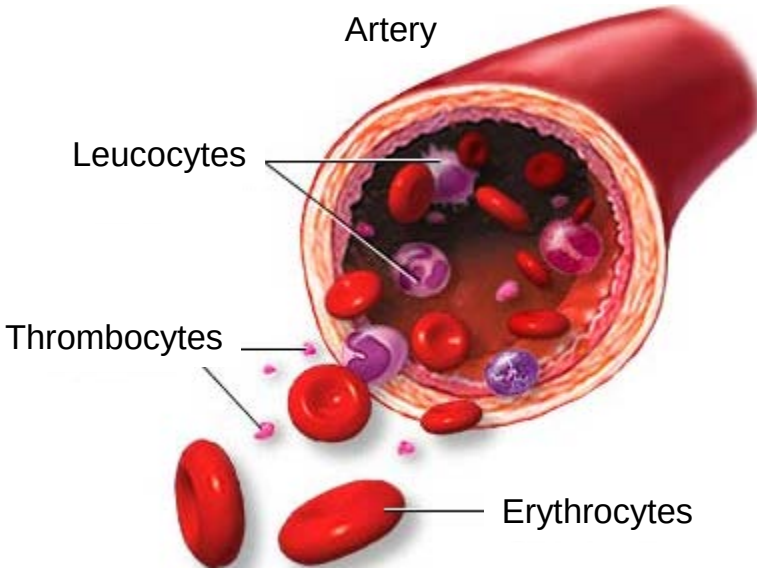


Fig. 2.2 Small blood vessel with blood cells [2]

2.1.2 Composition and distribution: blood cells

1. **Erythrocytes: *Red Blood Cells (RBC)***
   - ~ $5 \cdot 10^6$/µl
   - task: transport of O_2

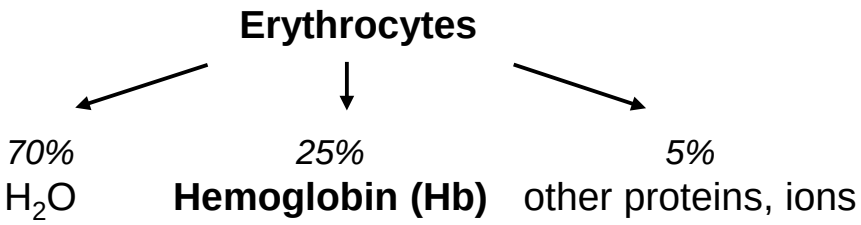
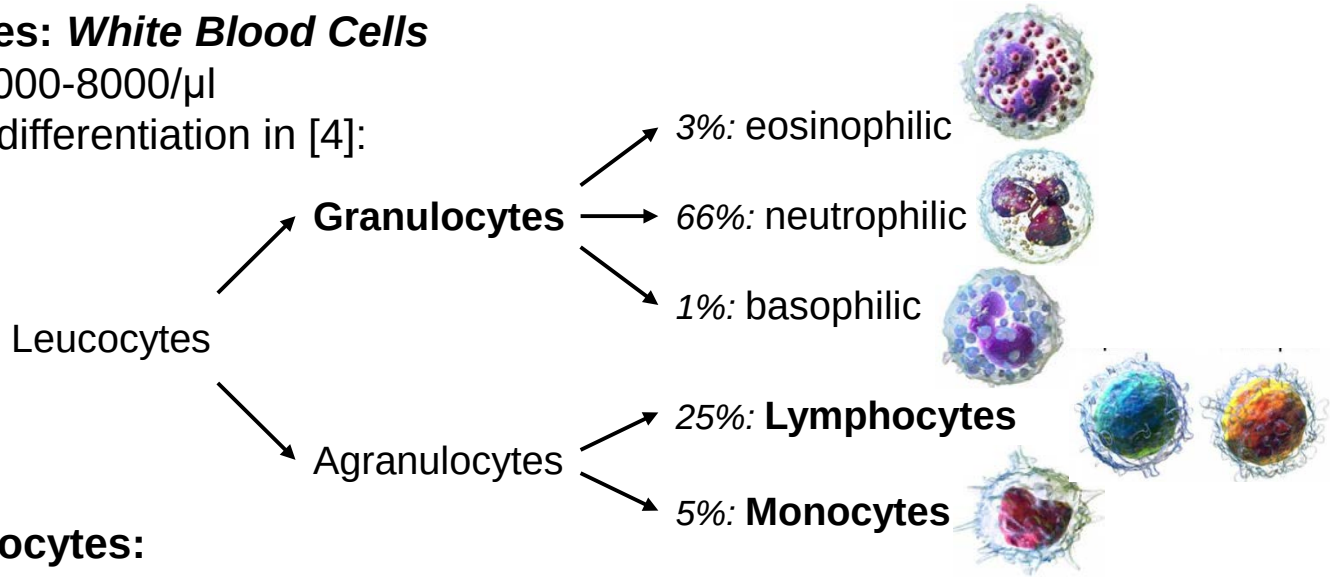


Fig. 2.3 Erythrocytes [3]

2.1.2 Composition and distribution: blood cells

2. **Leucocytes: *White Blood Cells***
   - ~ 6000-8000/µl
   - further differentiation in [4]:



   - **Granulocytes:**
     - destruction of exogenous substances, e.g. bacteria (phagocytosis)
     - properties: migration, tropism, can leave blood circulation
   - **Lymphocytes:**
     - storage cells (phagocytosis), react to antigenic material
     - long-life bearer of the immunological memory (several 100 days)
   - **Monocytes:**
     - defense against exogenous substances (phagocytosis), able to migrate

2.1.2 Composition and distribution: blood cells

3. **Thrombocytes: *Platelets***
   - ~ 200.000-400.000/µl
   - task: primary closing of injured vessels
   - 2nd phase: Fibrinogen → Fibrin (fibrous, elastic) = elastic closing

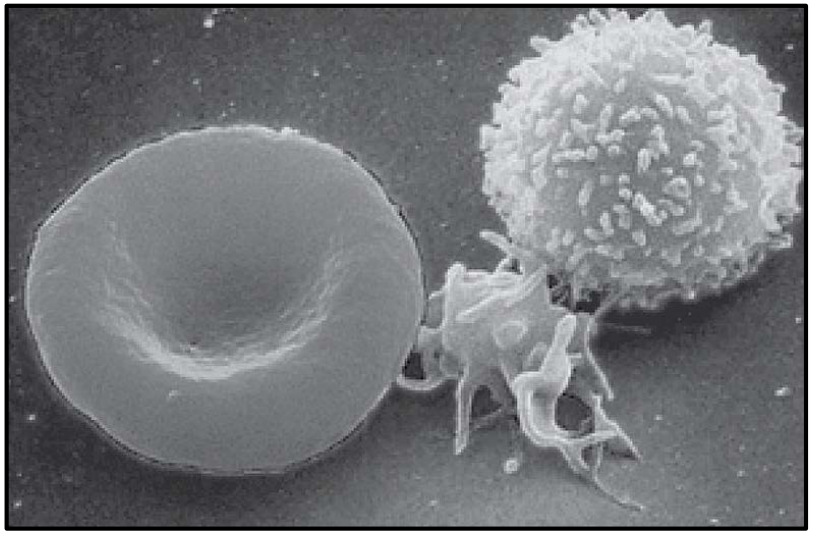
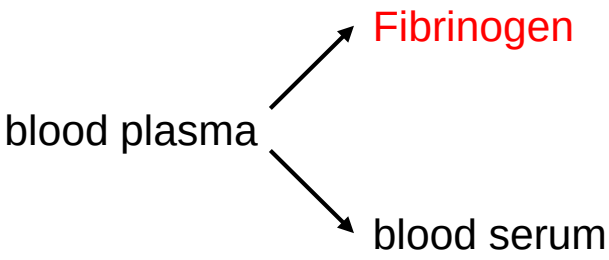


Fig. 2.4 Erythrocyte, Thrombocyte, Leucocyte [5]

2.1.2 Composition and distribution: blood plasma

1. **90% H_2O**

2. **6,5 – 7% proteins: (approx. 50 different kinds)**
   - Albumin (~4%): osmotic function, protein reserve, transport of ions
   - Globulin (~2,5%): antibodies, binding of certain substances
   - Lipoproteins: transport of fat
   - Fibrinogen (~0,2-0,4%): coagulation protein, settles as Fibrin



3. **other components: salt, fat, sugar, …**

2.1.3 Blood volumes:

- **men:** ~ 77 ml/kg body weight ± 10%
  70 kg → ~ 5,4 l blood
- **women:** ~ 65 ml/kg body weight ± 10%
  60 kg → ~ 4,0 l blood
- **blood distribution in the body:**
  - arteries & arterioles: 14%
  - capillaries: 6%
  - veins: 64%
  - lung vessel system: 9%
  - heart: 7%

} 84% in the main (body) circulatory system

Biological and Medical Fluid Mechanics I | Dr.-Ing. Michael Klaas
m.klaas@aia.rwth-aachen.de | http://www.aia.rwth-aachen.de
SS 2016

Lecture contents

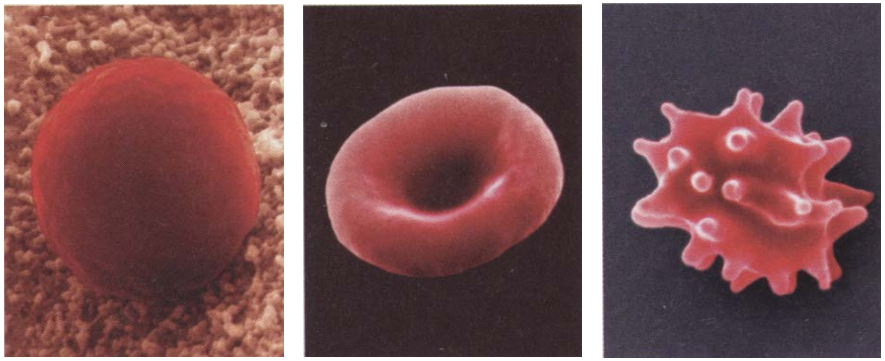
2. Blood as a transport medium	Exercise
2.1 Tasks, composition and distribution 2.1.1 Tasks 2.1.2 Composition and distribution 2.1.3 Blood volumes	
2.2 Red Blood Cells (RBC): erythrocytes 2.2.1 Shape and hematocrit 2.2.2 The red blood dye 2.2.3 The membrane of RBC 2.2.4 Decomposition	

2.2 Red Blood Cells (RBC): erythrocytes

2.2.1 Shape and hematocrit

- **main measures (average):**
  - d = 7,5 – 8,0 µm
  - h = 2,0 – 2,4 µm

- **forms:**



spherical | biconcave *normal* | crenated

Fig. 2.5 Different forms of RBCs [6]

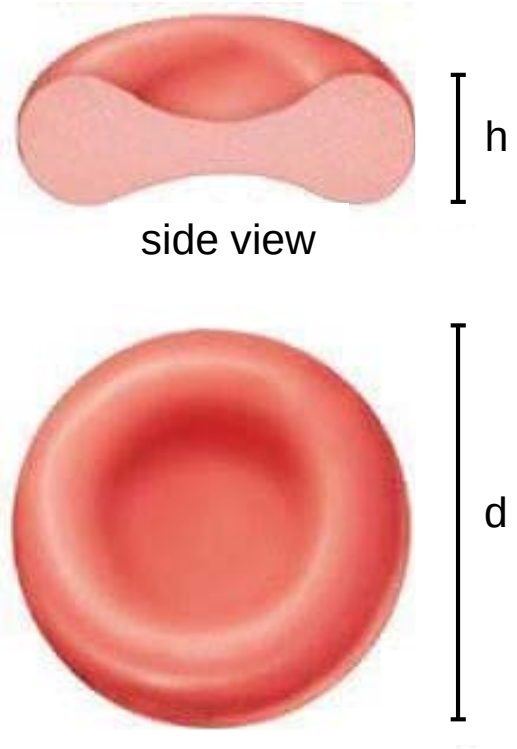


Fig. 2.6 Main measures of a RBC [7]

2.2 Red Blood Cells (RBC): erythrocytes

2.2.1 Shape and hematocrit

- **hematocrit (Hct): volume percentage of red blood cells in blood**
  - determination by centrifuging the blood
  - volume of a single RBC: ~ $0{,}87 \cdot 10^{-7} mm^3$
  - volume of all RBCs/(mm^3 blood): $5 \cdot 10^6 mm^{-3} \cdot 0{,}87 \cdot 10^{-7} mm^3 = 0{,}435$ → 44% (= Hct)
  - 5l blood contain about $25 \cdot 10^{12}$ RBCs
  - surface area of a single RBC: 138-163 μm^2
  - total surface area in 5 l blood: $25 \cdot 10^{12} \cdot 150 \mu m^2 = 3750 m^2$

→ most abundant corpuscles in blood → influence on the flow behavior of blood

Biological and Medical Fluid Mechanics I | Dr.-Ing. Michael Klaas
m.klaas@aia.rwth-aachen.de | http://www.aia.rwth-aachen.de
SS 2016

2.2.2 The red blood dye (hemoglobin: Hb)

- **structure:**
  - ferrous protein complex, binds O_2 in RBC, gives RBC its red color
  - protein fraction (Globin): 96%
  - prosthetic group (Hem): 4%
  - every Heme group can bind one O_2 → one Hb-Molecule can bind 4 O_2 (reversible binding on Fe_{2+}-atom)

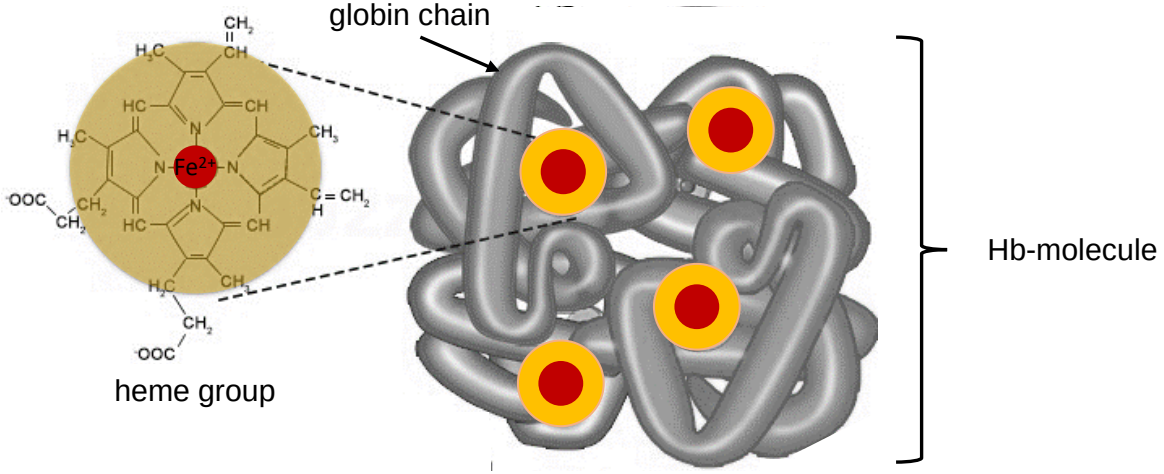


Fig. 2.7 Heme group and globin chains of Hemoglobin [8]

2.2.2 The red blood dye (hemoglobin: Hb)

- **O_2 – dissociation curve of hemoglobin:**
  - **lungs:**
    - temperature low
    - pH high (low CO_2)

    → with relatively low pO_2 already high Hb-saturation (easy O_2 – uptake)
  - **tissues:**
    - temperature high
    - pH low

    → at the same pO_2 lower Hb-saturation (easy O_2 – delivery)

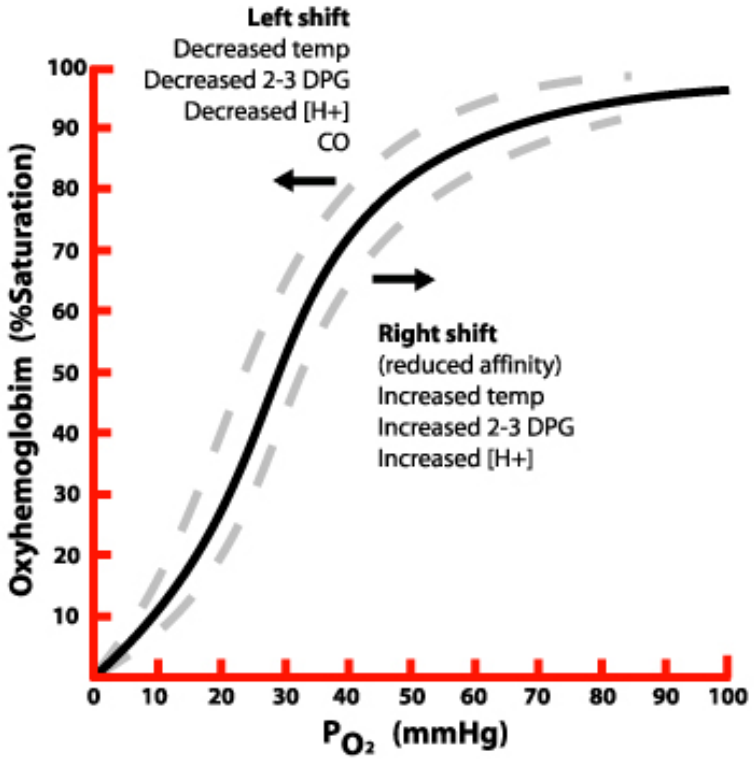


Fig. 2.8 O_2 – Dissociation curve of Hemoglobin

2.2.3 The membrane of RBC

- **structure:**
  - consisting of lipid double layers (fats), in which proteins are embedded
  - layer thickness: 50 – 200 Å
  - hydrophobic ends lay side by side
  - binding through Van der Waals forces

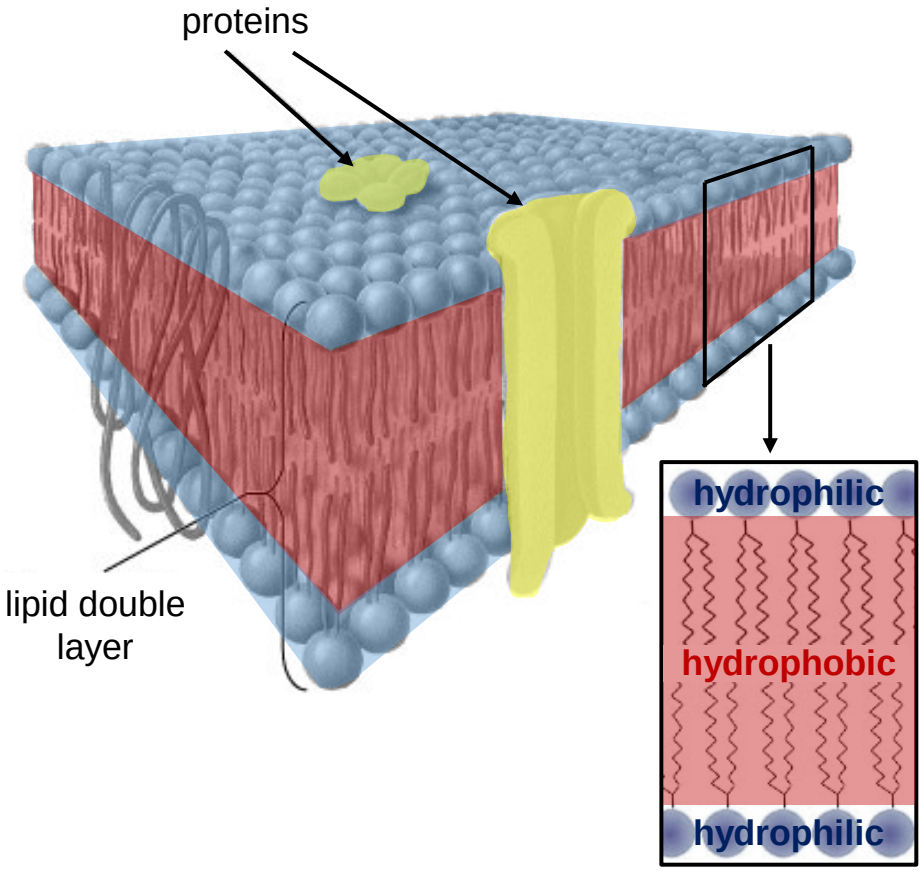


Fig. 2.9 Lipid double layer [9]

2.2.3 The membrane of RBC

- **mechanical behavior:**
  - relatively inelastic → practically no surface enlargement
  - very flexible (similar to soccer ball cover)
  - RBC has no framework or inner structure
    → easily deformable
  - proof of missing inner framework (*Bull*):
    - fixation of RBC at surface
    - marking of a point at surface
    - rolling of the RBC over fixation point

    → shape remains principally unchanged, even if flow forces act upon RBC (caterpillar chain)

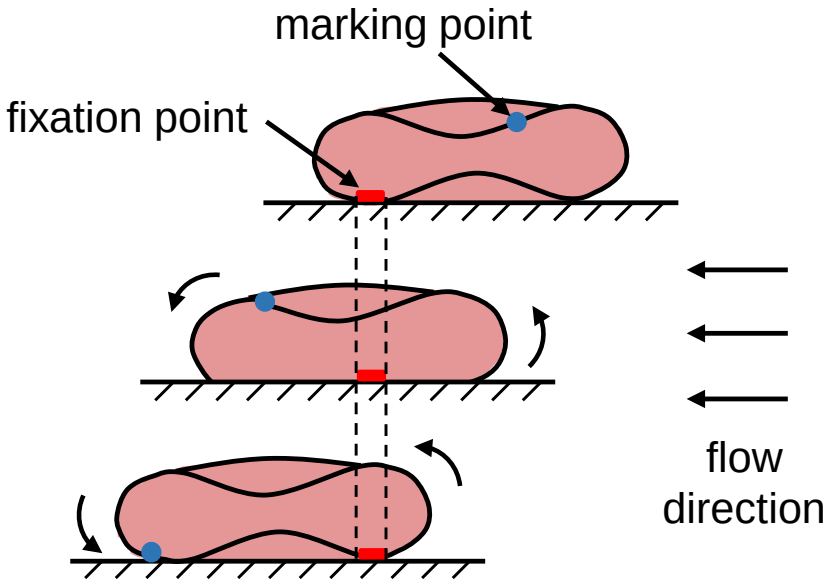


Fig. 2.10 Rolling movement of a RBC

2.2.4 Decomposition

- life span: 3 – 4 months
- decomposition: approx. $2 \cdot 10^{11}$ RBCs/day
- generation of new Erythrocytes (Erythropoiesis) in the red bone marrow

- **How does the body recognize old Erythrocytes?**
  - in RBCs the Na^+-concentration is lower than outside the RBCs
  - through active transport inflowing Na^+ is pumped out of the RBC by using energy supply (active molecule groups are called: Na^+-pumps)
    → RBC stays in normal osmotic balance
  - older RBCs possess less efficient metabolism processes: Na^+-pumps work less effective
    → Na^+-concentration increases: shift of osmotic balance (hypotonic)
    → water flows into RBC until osmotic balance is reestablished
    → volume of RBCs increases (until spherical form)
    → RBC has lower deformation stability

2.2.4 Decomposition

- **How are the old Erythrocytes sorted out?**

1. **filtration of the old RBCs: *spleen***
   - spleen possesses fine pores (d = 2 - 4 µm)
   - only flexible RBCs can pass, older (less flexible) RBCs get stuck
2. **destruction of the RBC membrane:**
   - in the spleen: glucose-poor milieu
   - Na^+-pump fails completely → further swelling of the RBC up to rupture
   - decomposition of the membrane fractions in the cells of the reticular-endothelial-system (RES) in spleen and liver
3. **decomposition of Hb:**
   - binding of the Hb on Haptoglobin
   - Hb-Haptoglobin-complex can not be removed by urine (but Hb)
   - decomposition of the Hb-Haptoglobin-complex in the liver:
     - bilirubin: originated and excreted by intestine as toxic material
     - Fe is retaken and supplied to the red bone marrow for Erythropoiesis

Sources

[1] https://2012books.lardbucket.org/books/an-introduction-to-nutrition/s14-nutrients-important-for-metabo.html
[2] http://circulatorysystemmvb.weebly.com/organs.html
[3] https://www.fi.edu/heart/your-living-blood
[4] https://www.sciencetopia.net/biology/white-blood-corpuscles-leucocytes
[5] https://commons.wikimedia.org/wiki/Category:Blood_cells#/media/File:1900_Blood_cells.jpg
[6] http://www.acbrown.com/neuro/Lectures/Mmbr/NrMmbrWatr.htm
[7] https://lusinagao.wordpress.com/category/cells/page/2/
[8] http://www.namrata.co/structure-of-hemoglobin-an-overview/ (modified)
[9] https://www.spektrum.de/lexika/showpopup.php?lexikon_id=4&art_id=9501&nummer=200 (modified)

Thank you for your attention!