Rheological properties of blood

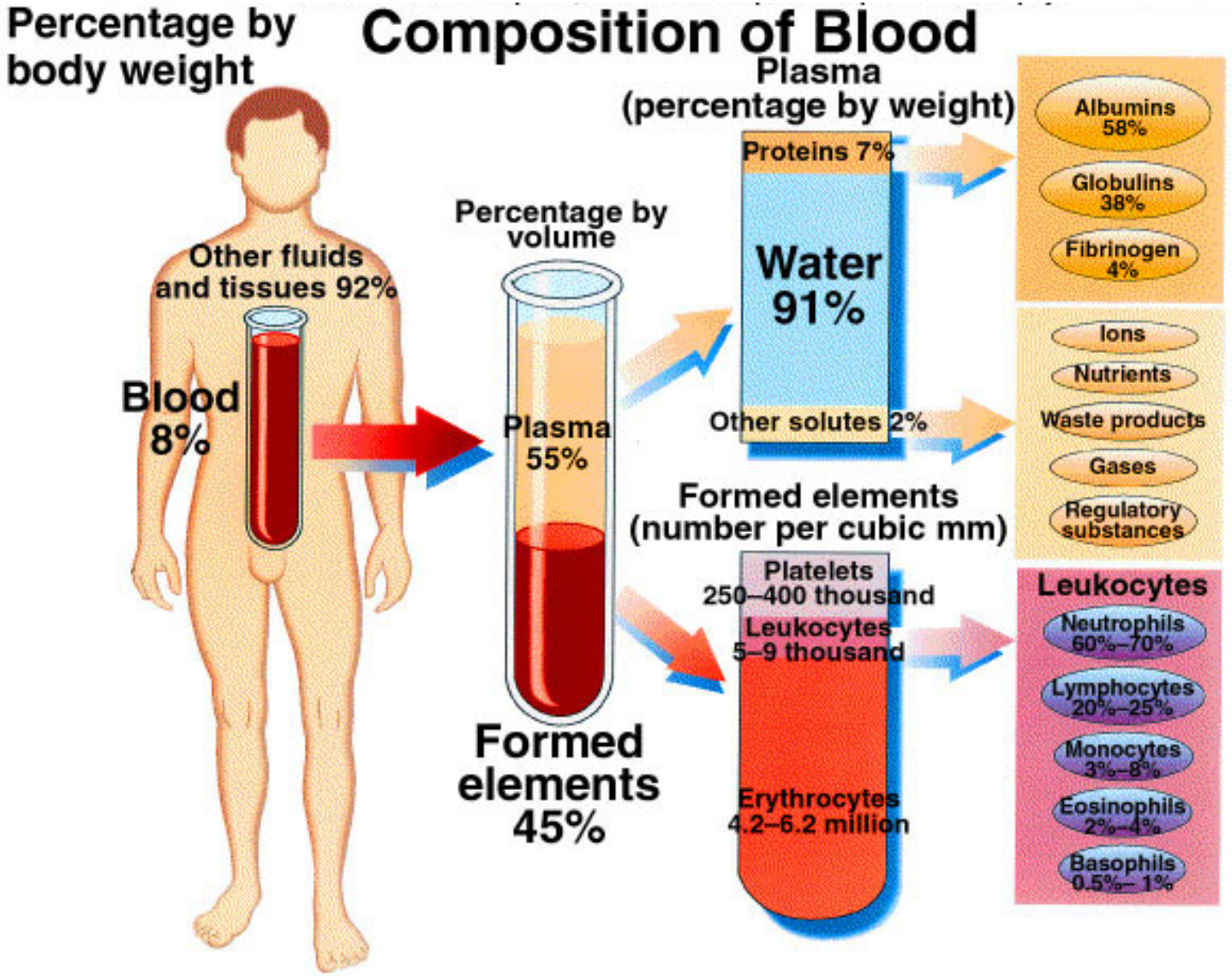
- Function and constituents of blood
- Viscosity
  - Definition
  - Measurement
- Rheological properties
  - Non-Newtonian behavior
  - Aggregates & deformability
  - Fahraeus-Lindqvist Effect

Functions of blood

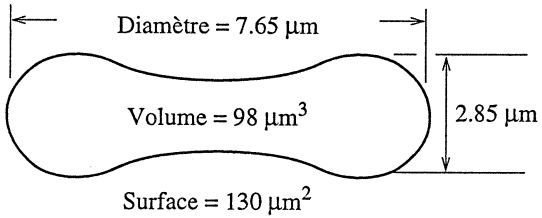
1. Transport of O_2 et CO_2
2. Regulation of acid-base equilibrium
3. Transport of nutrients, hormones, and enzymes
4. Transport of metabolic byproducts
5. Regulation of temperature
6. Defense against microbes

Properties of blood

- Adult: 7-9% body weight
- Mean volume for man: 5-6 liters
- Mean volume for woman : 4-5 liters
- Viscosity: 3.5-5.5 cP vs. 1.0 cP for water
- Density: 1.045-1.065 gr/cm^3
- pH 7.35-7.45
- Temperature: 38°C

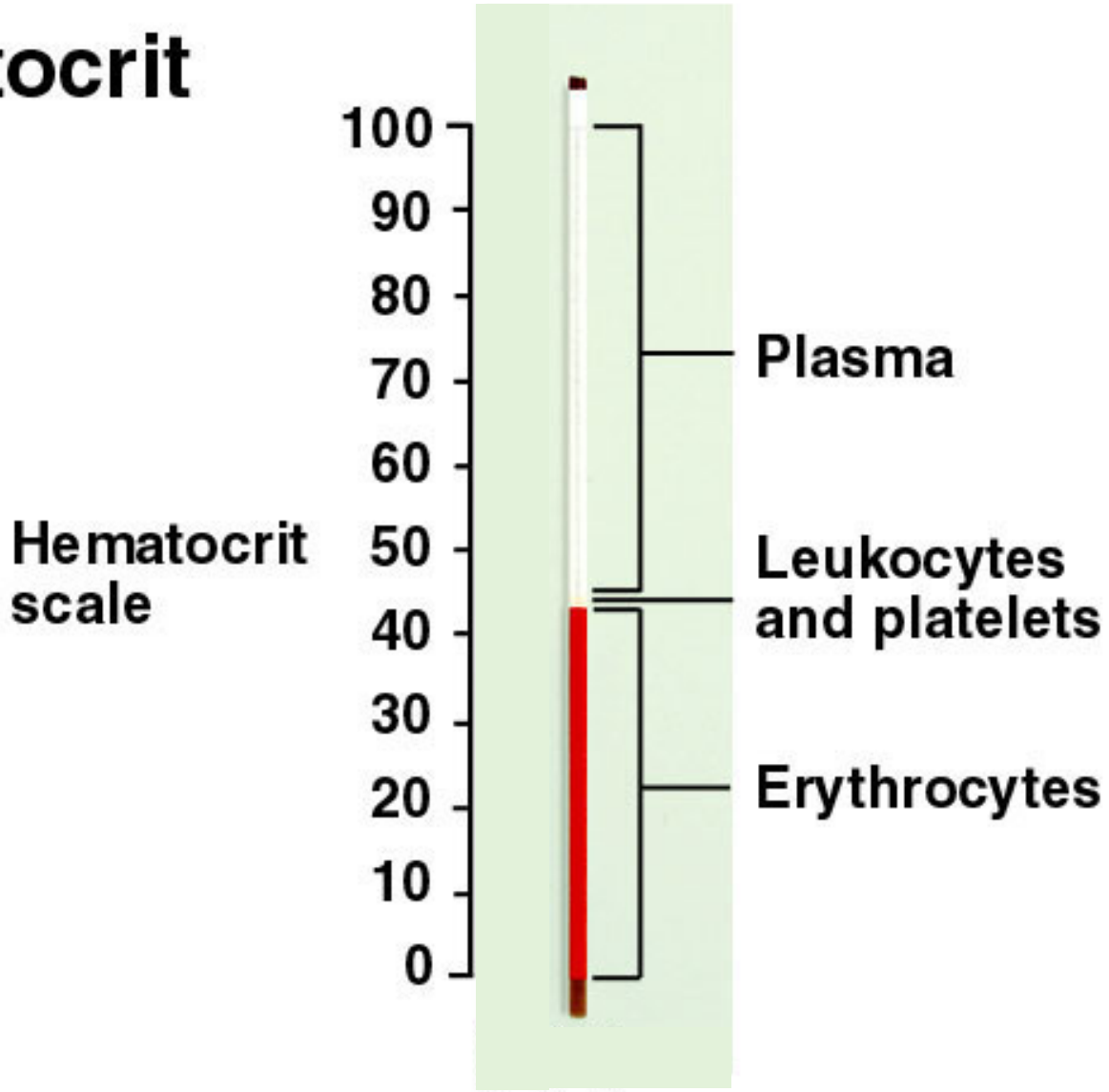

Percentage by body weight
Composition of Blood
Plasma (percentage by weight)
Proteins 7%
Albumins 58%
Globulins 38%
Fibrinogen 4%
Percentage by volume
Other fluids and tissues 92%
Water 91%
Blood 8%
Plasma 55%
Other solutes 2%
Ions
Nutrients
Waste products
Gases
Regulatory substances
Formed elements (number per cubic mm)
Platelets 250–400 thousand
Leukocytes 5–9 thousand
Leukocytes
Neutrophils 60%–70%
Lymphocytes 20%–25%
Monocytes 3%–8%
Eosinophils 2%–4%
Basophils 0.5%–1%
Formed elements 45%
Erythrocytes 4.2–6.2 million

Red Blood Cells (RBC)

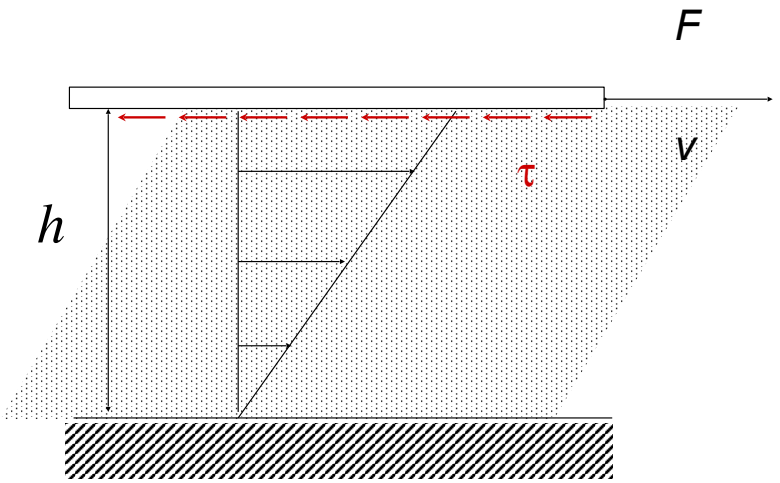


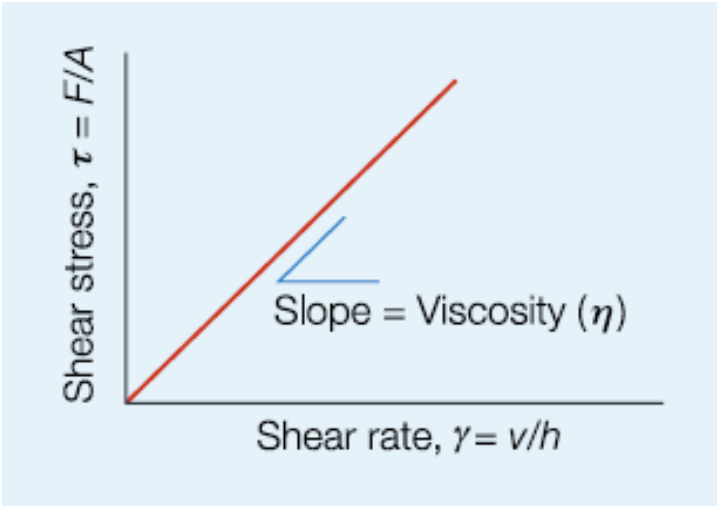
- Biggest number of particles ~$5x10^6/mm^3$
- Contains hemoglobin with primary function to transport O_2 and CO_2
- Density ρ = 1.1 kg/m^3
- Form: biconcave; easy to deform
- Flexible membrane (10 nm), particularly adapted to O_2 transfer

Hematocrit


100
90
80
70
60
50
40
30
20
10
0
Hematocrit scale
Plasma
Leukocytes and platelets
Erythrocytes

Viscosity and shear stress

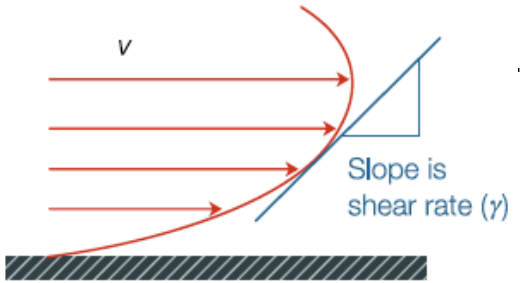




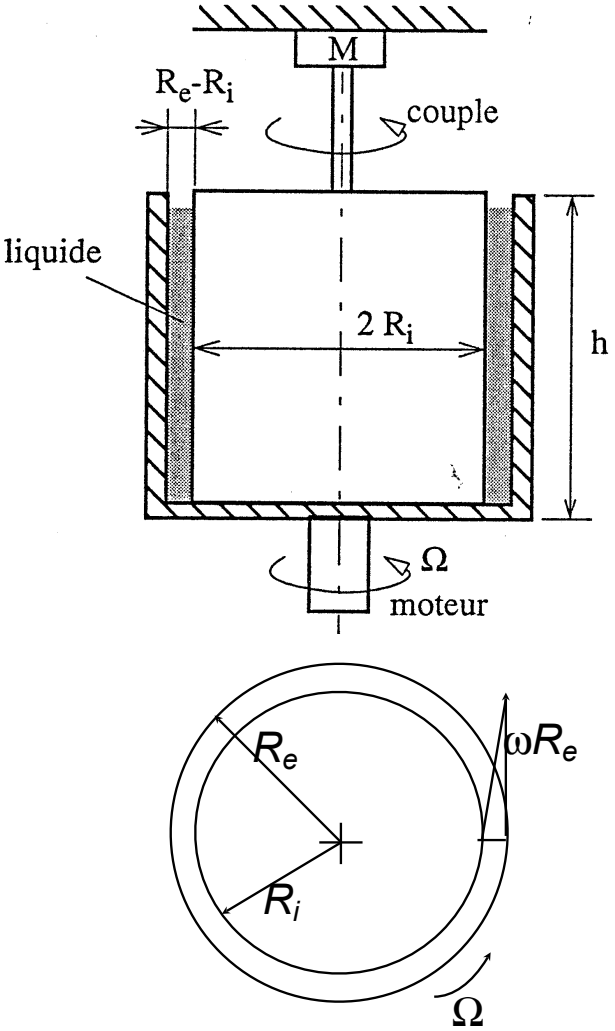
Shear stress: $\tau = F/A$

Shear rate $\dot{\gamma} = v/h = dv/dy$

$$\tau = \mu \cdot \dot{\gamma} \Rightarrow \boxed{\mu = \frac{\tau}{\dot{\gamma}}}$$



Viscocimeter

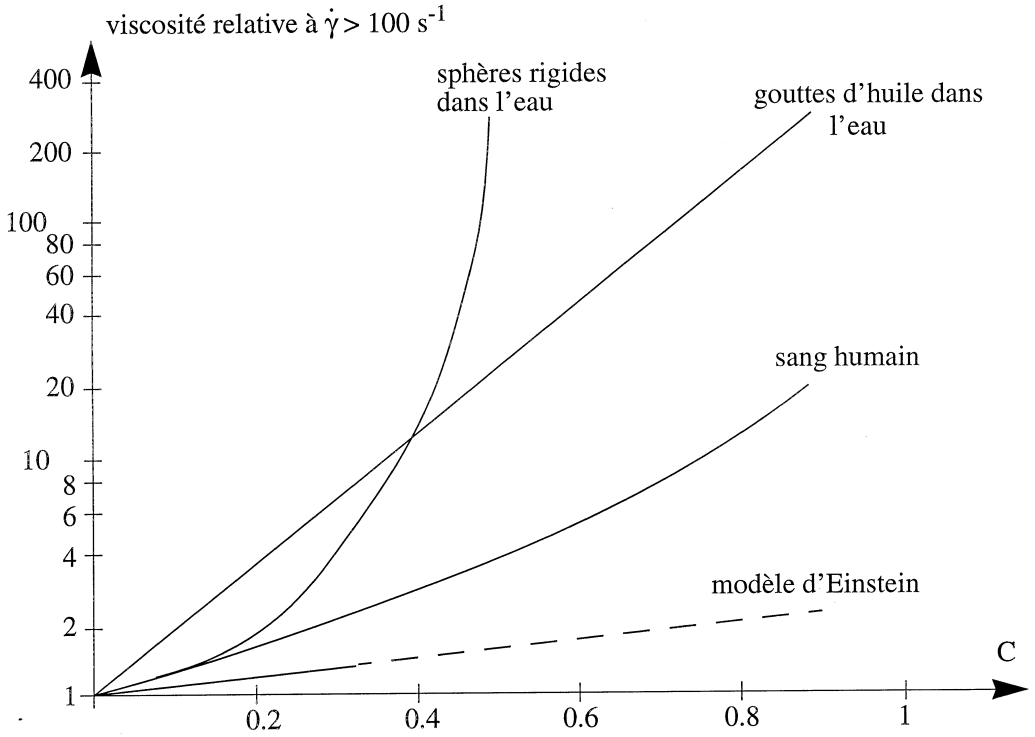


$$\tau = \mu\left(\frac{2\Omega R_e^2}{R_e^2 - R_i^2}\right)$$

$$M = \tau \times 2\pi R_i h \times R_i$$

$$\mu = \frac{M(R_e^2 - R_i^2)}{4\pi\Omega h R_i^2 R_e^2}$$

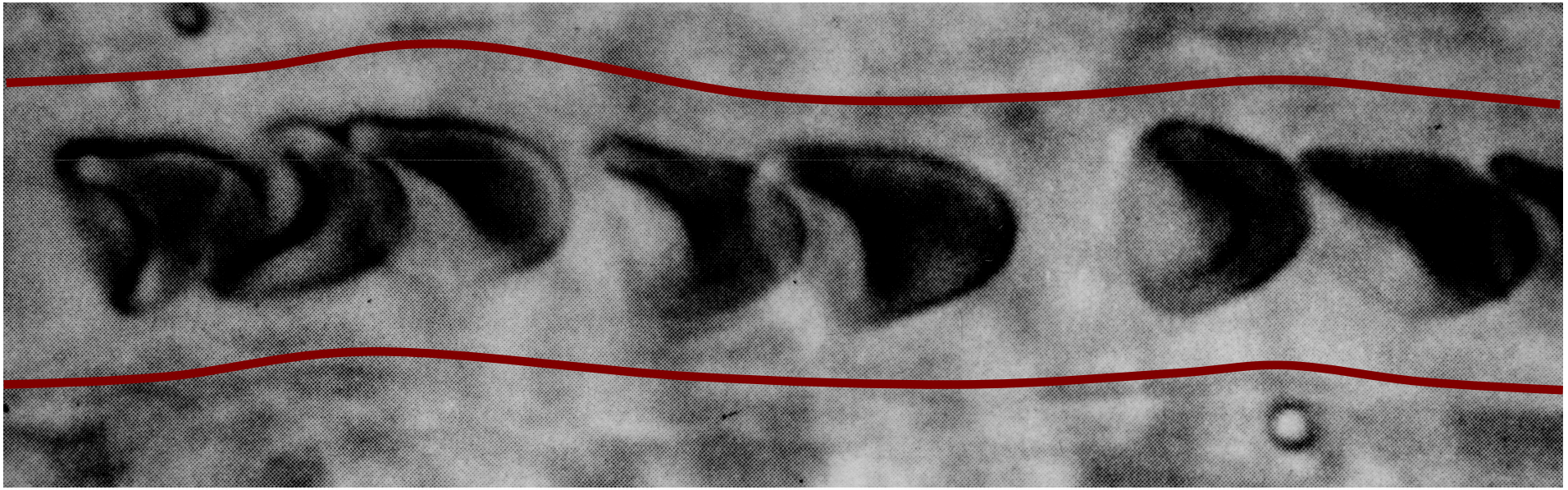
Viscosity as a function of the concentration of particles



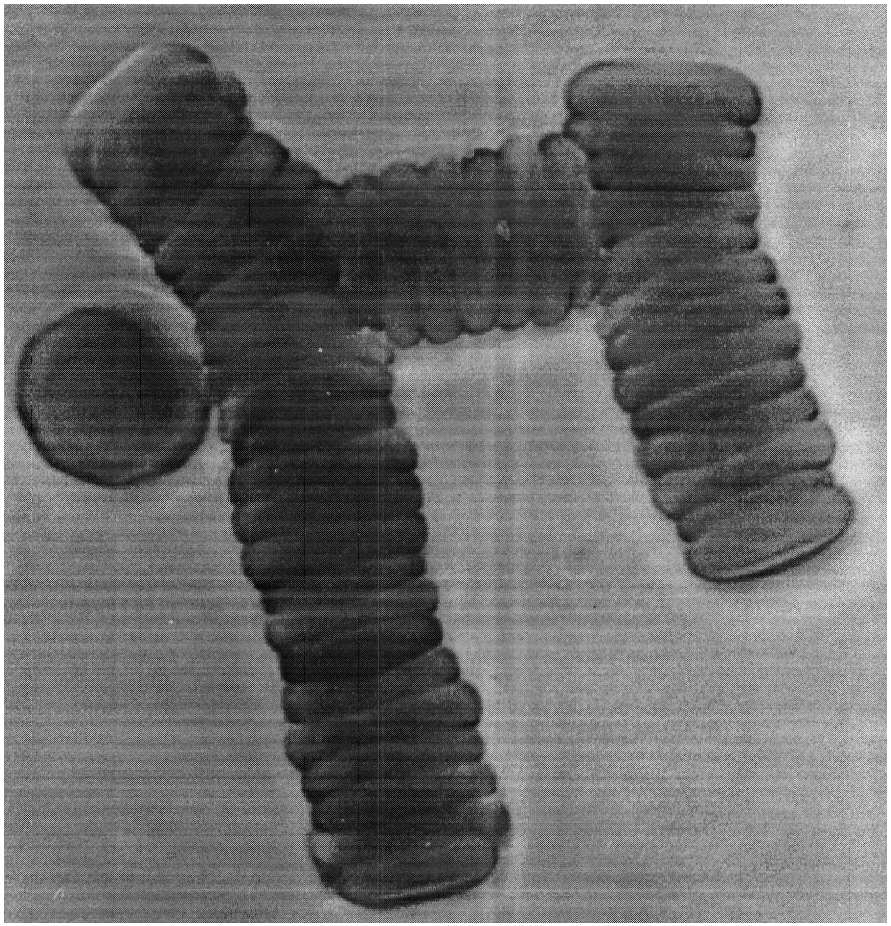
Einstein's model (C<<1)

$$\mu_r = \frac{\mu_s}{\mu_0} = 1 + 2.5C$$

Deformability of red blood cells



Aggregates and rouleaux



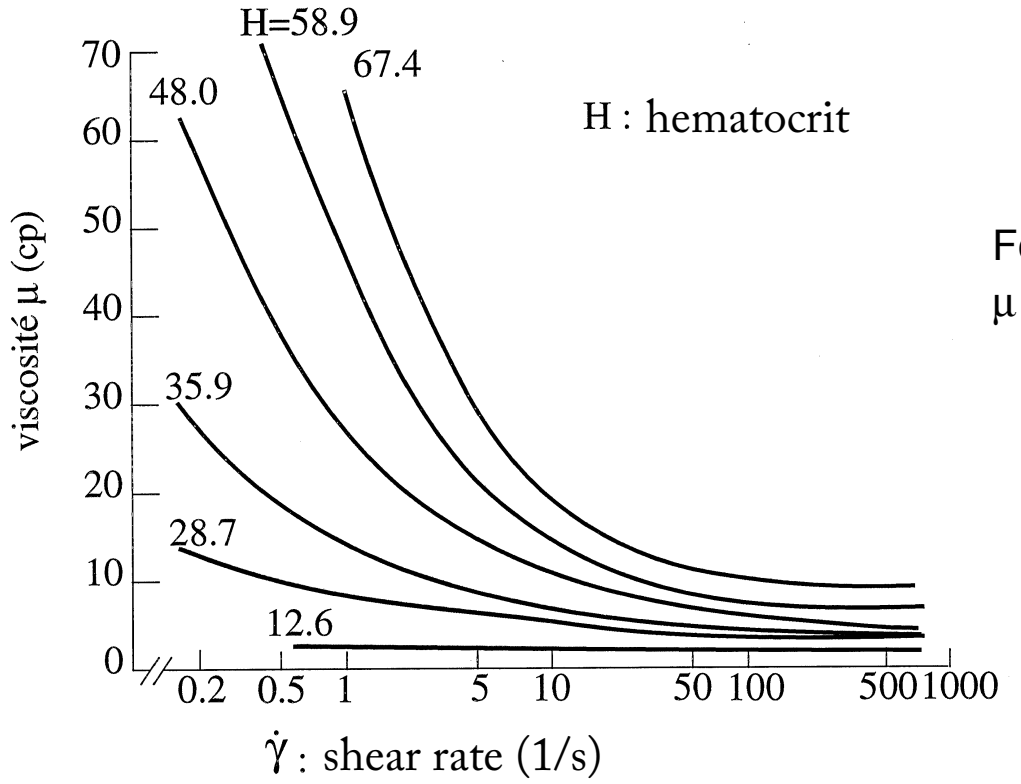
Attractive Forces:

- Van der Waals forces
- Steric forces from the interaction of RBC and plasma with its proteins

Repulsive Forces:

- **Shear stresses**
- Electrostatic forces
- Steric forces

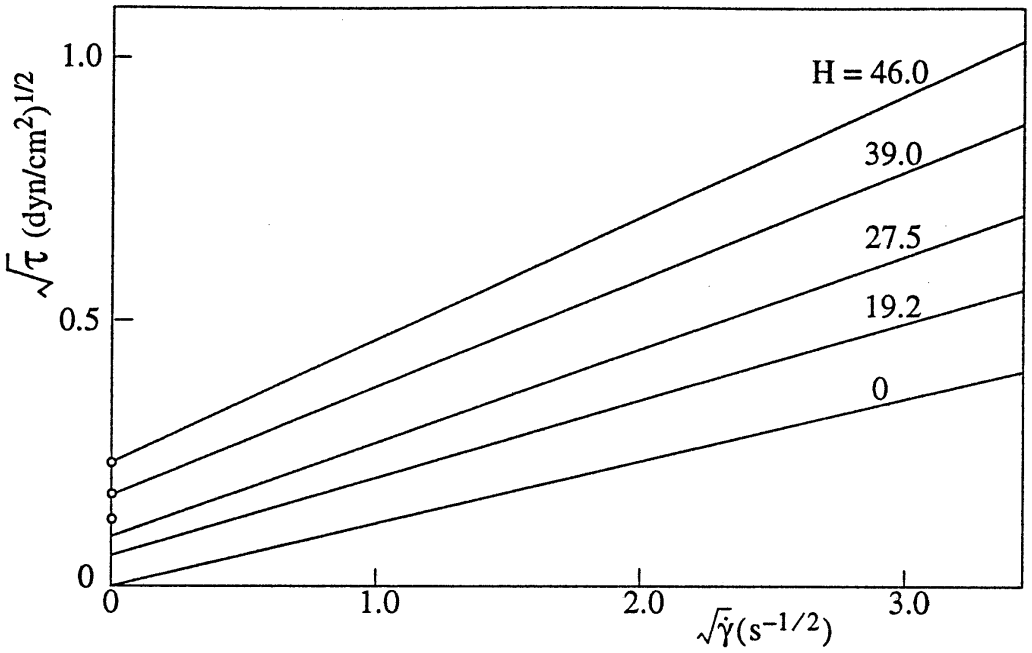
Non-Newtonian proprieties of blood



H : hematocrit

For $\dot{\gamma} > 100\ 1/s^{-1}$
$\mu = 0.035$ Poise

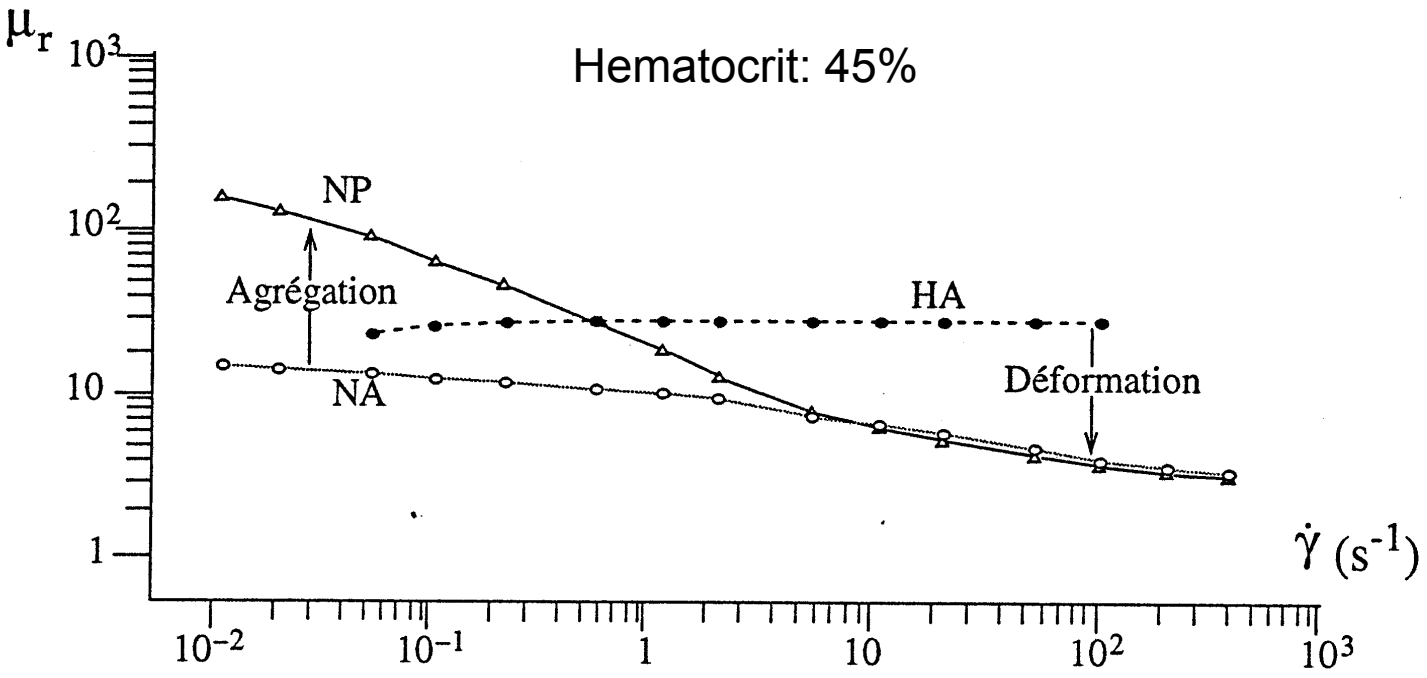
Yield stress



For small shear rate ($\dot{\gamma}$< 10 1/s):

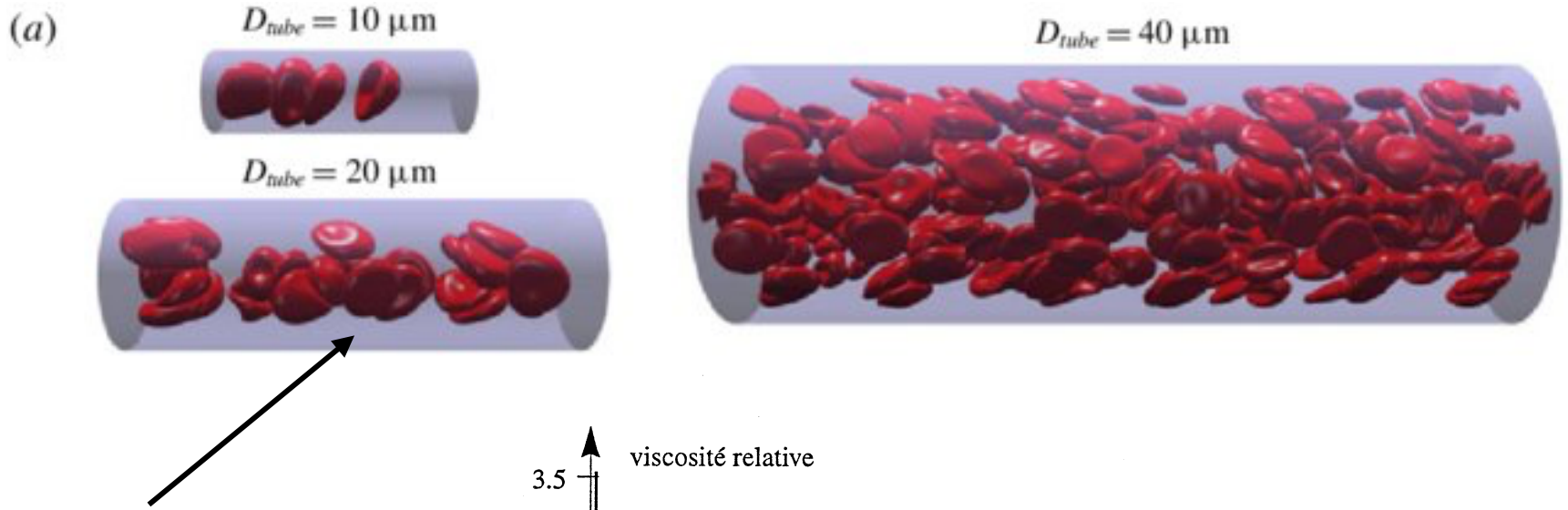
$$\sqrt{\tau} = \sqrt{\tau_y} + \sqrt{\mu\dot{\gamma}}$$ (Casson)

Aggregation - deformability



NP: red blood cells in plasma
NA: red blood cells in a liquid without fibrinogens
HA: red blood cells rigidified in a liquid without fibrinogens

Fahraeus-Lindqvist Effect



Near wall zone:
Free of red blood cells