PULMONARY MECHANICS

GAS TRANSPORT

I. PULMONARY MECHANICS

- RESPIRATORY MUSCLES
- LUNGS ELASTICITY
- COMPLIANCE
- WORK OF BREATHING

II. TRANSPORT OF GASES

- O_2
- CO_2

FORCES PARTICIPATING IN RESPIRATION

- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES represented by:**
  - **lungs elasticity**
  - **chest elasticity**

QUIET RESPIRATION

INSPIRATION - active forces of inspiratory muscles prevail

EXPIRATION - passive (elastic) forces only

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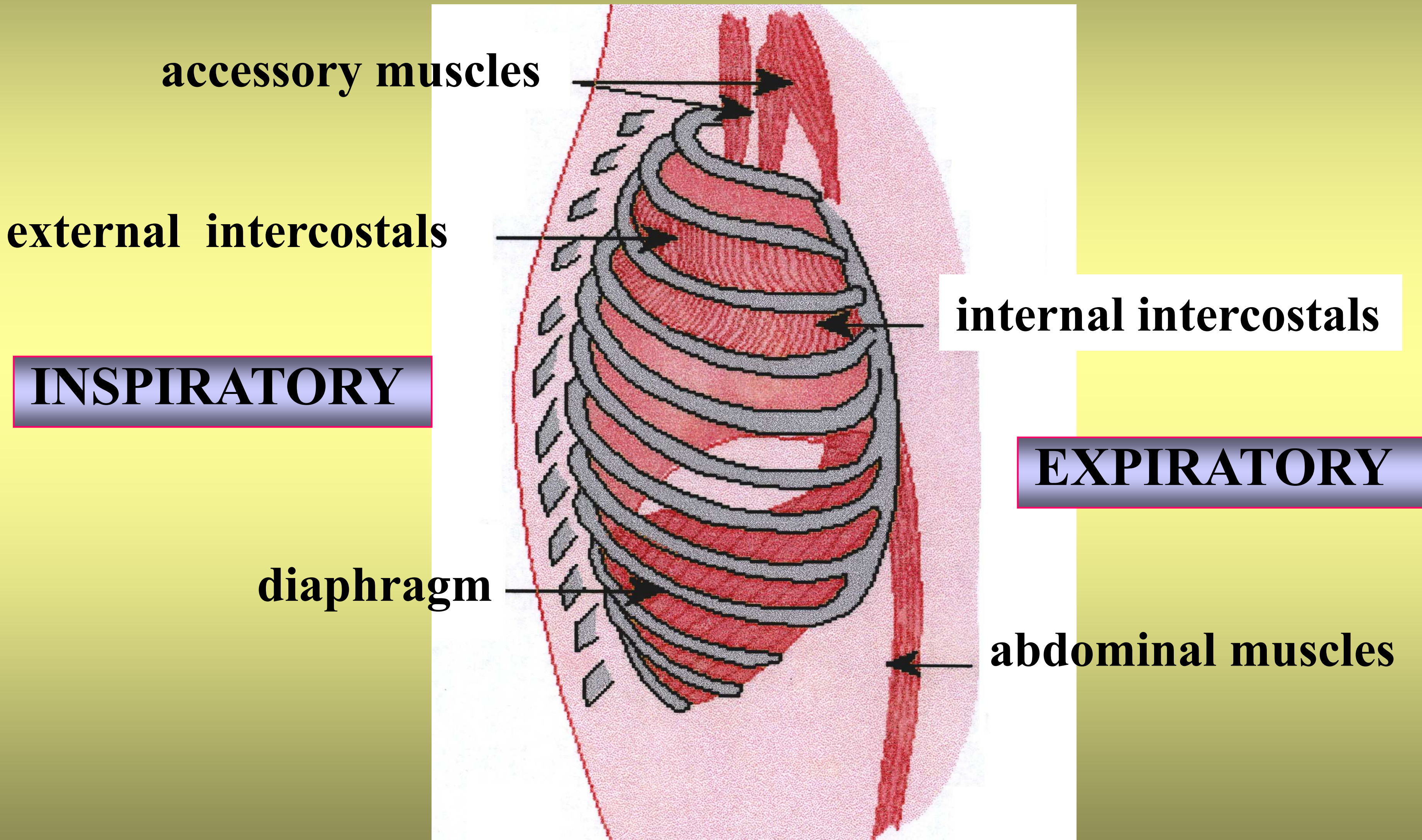
RESPIRATORY MUSCLES



INSPIRATORY muscles

QUIET breathing

- **diaphragm** (≥ 80 %)
- ***external* intercostals** (≤ 20 %)

FORCED breathing

- ***accessory* inspiratory muscles**

  (scalene muscles, …)

EXPIRATORY muscles

Only at FORCED breathing

- ***internal* intercostals**
- **muscles of the anterior *abdominal* wall**

  (abdominal recti, …)

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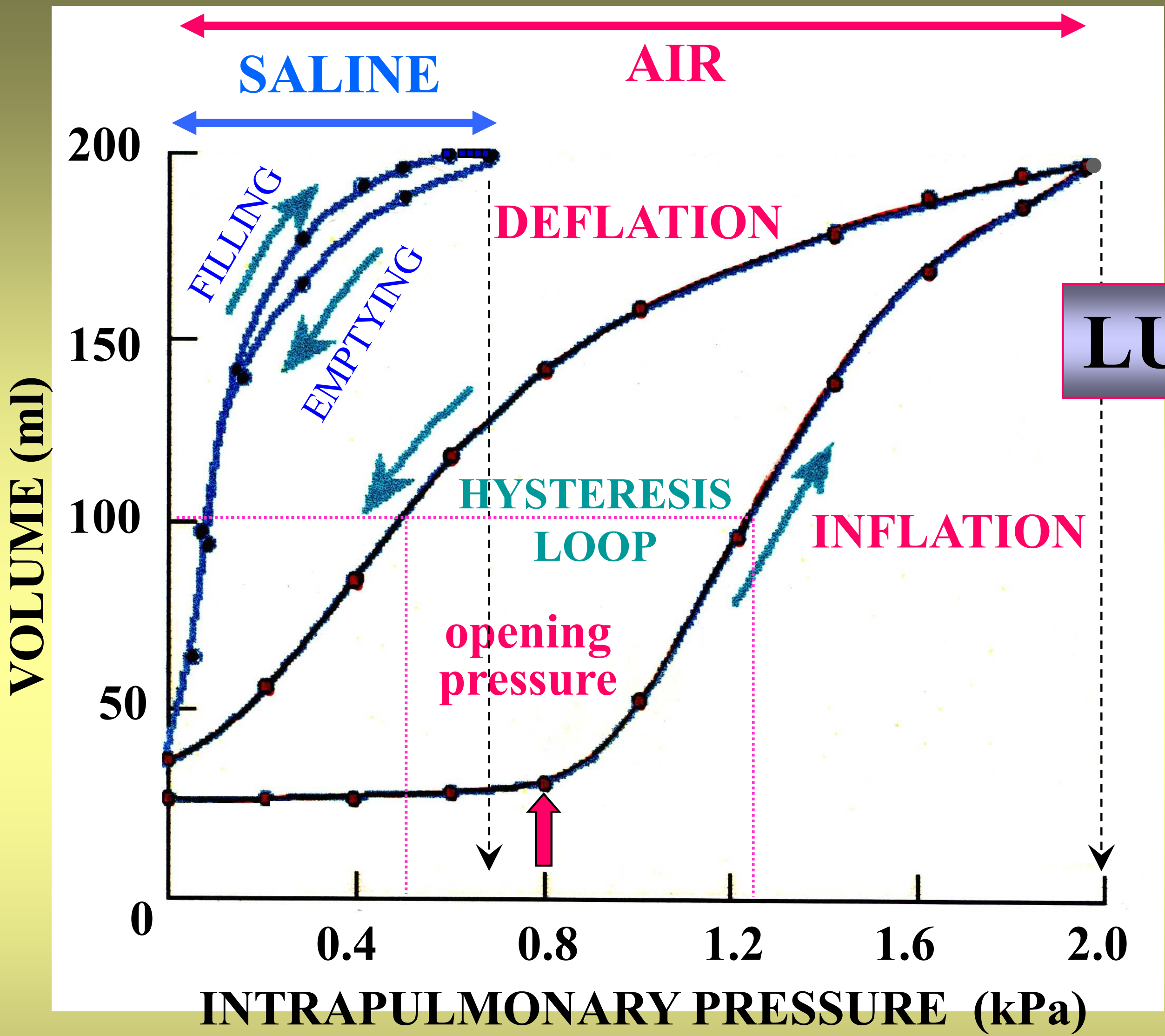


LUNGS ELASTICITY

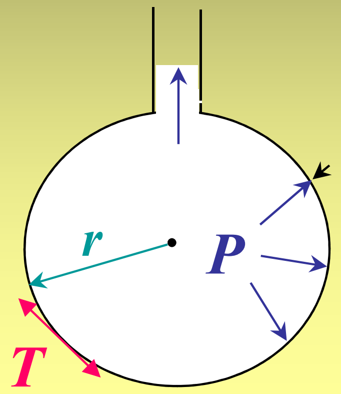
1 *kPa* = 7.5 *mm Hg*

LUNGS ELASTICITY

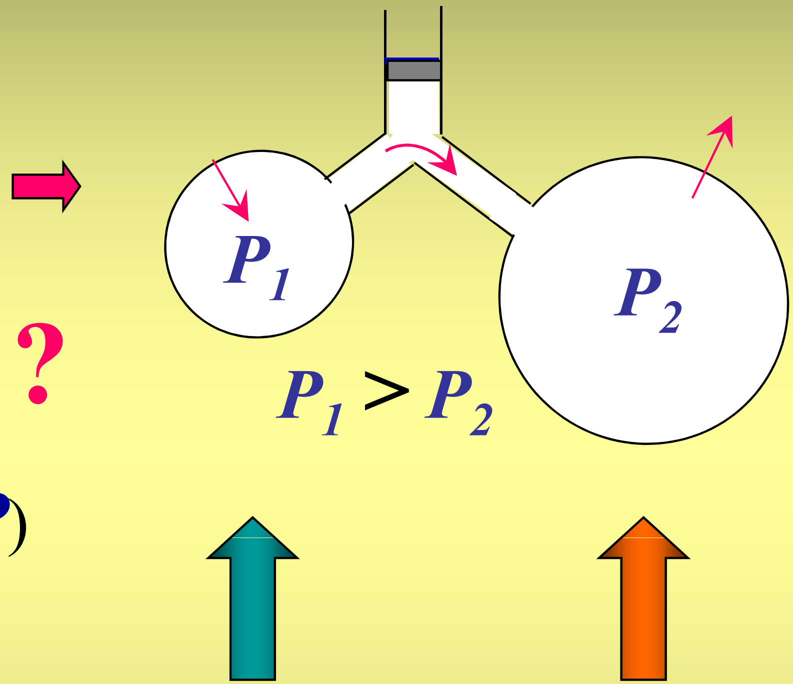
- **INHERENT TISSUE ELASTICITY** (elastin and collagen fibres)
- **SURFACE TENSION FORCES** (physical properties of air-liquid interface)

LAW OF LAPLACE

spherical structures



$$P = \frac{2T}{r}$$



P **distending pressure** (transmural ΔP)

r **radius**

T **surface tension**

PATHOLOGY

- **COLLAPSE OF ALVEOLI** — **ATELECTASIS**
- **EXPANSION OF ALVEOLI** — **BULLOUS EMPHYSEMA**

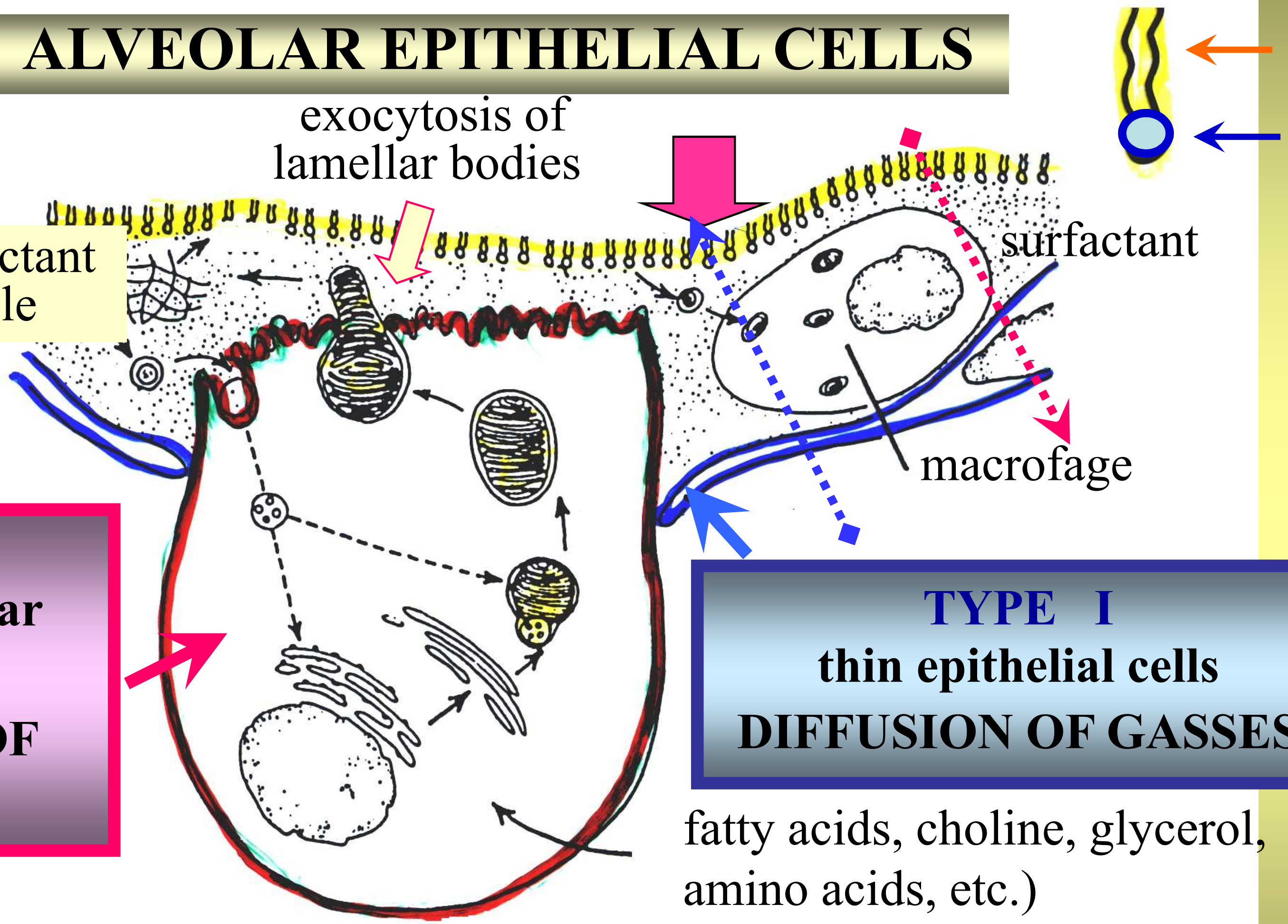
SURFACTANT

SURFACE TENSION LOWERING AGENT

EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID
dipalmitoyl
fosfatidyl cholin

ALVEOLAR EPITHELIAL CELLS



TYPE II
specialized granular epithelial cells

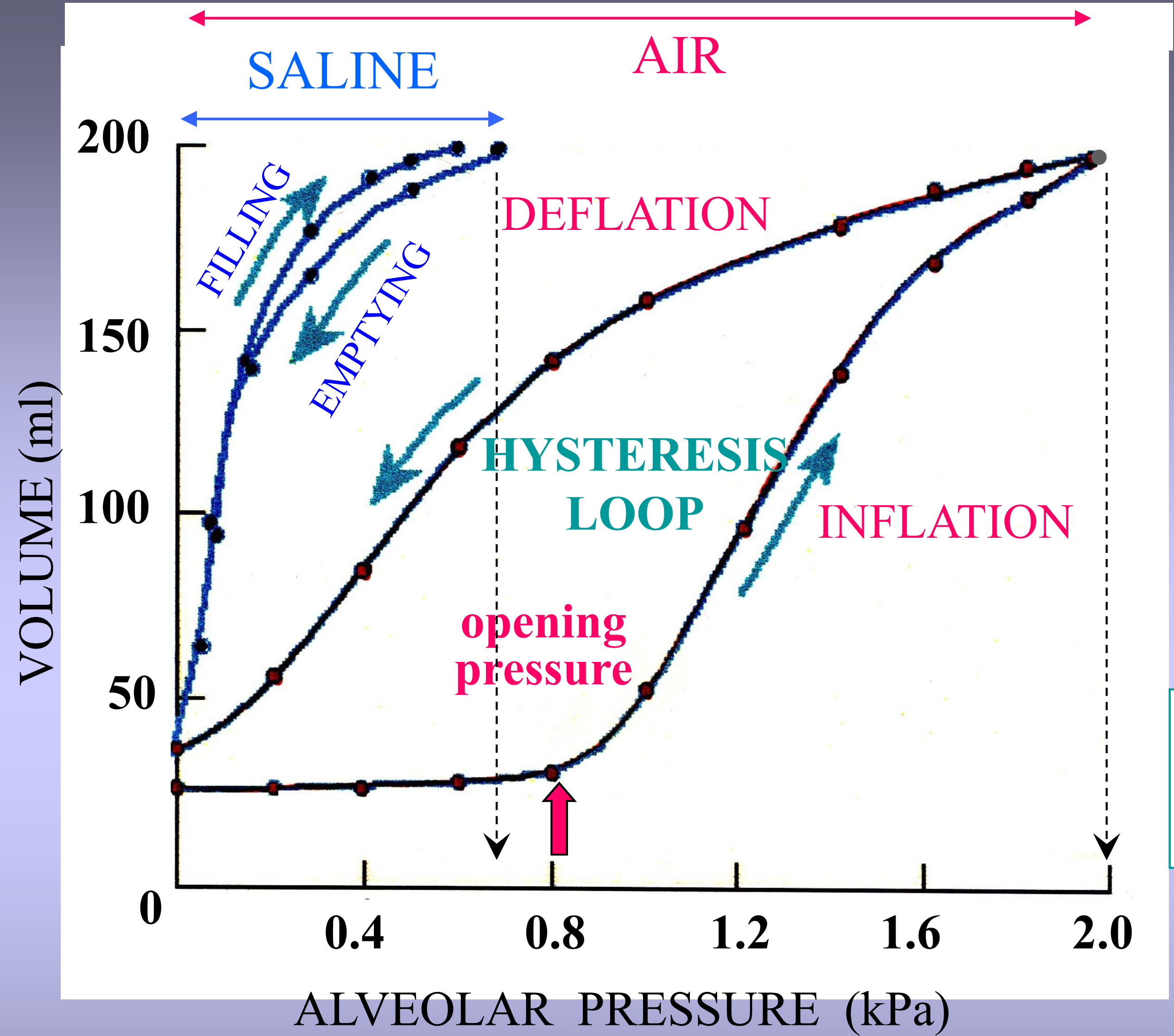
PRODUCTION OF SURFACTANT

TYPE I
thin epithelial cells

DIFFUSION OF GASSES

INFANT RESPIRATORY DISTRESS SYNDROME

PATCHY ATELECTASIS AFTER CARDIAC SURGERY



Factors involved in HYSTERESIS LOOP

- **LAPLACE LAW (opening pressure of alveoli)**
- **Dynamic changes in the DENSITY OF SURFACTANT MOLECULES** during inspiration and expiration

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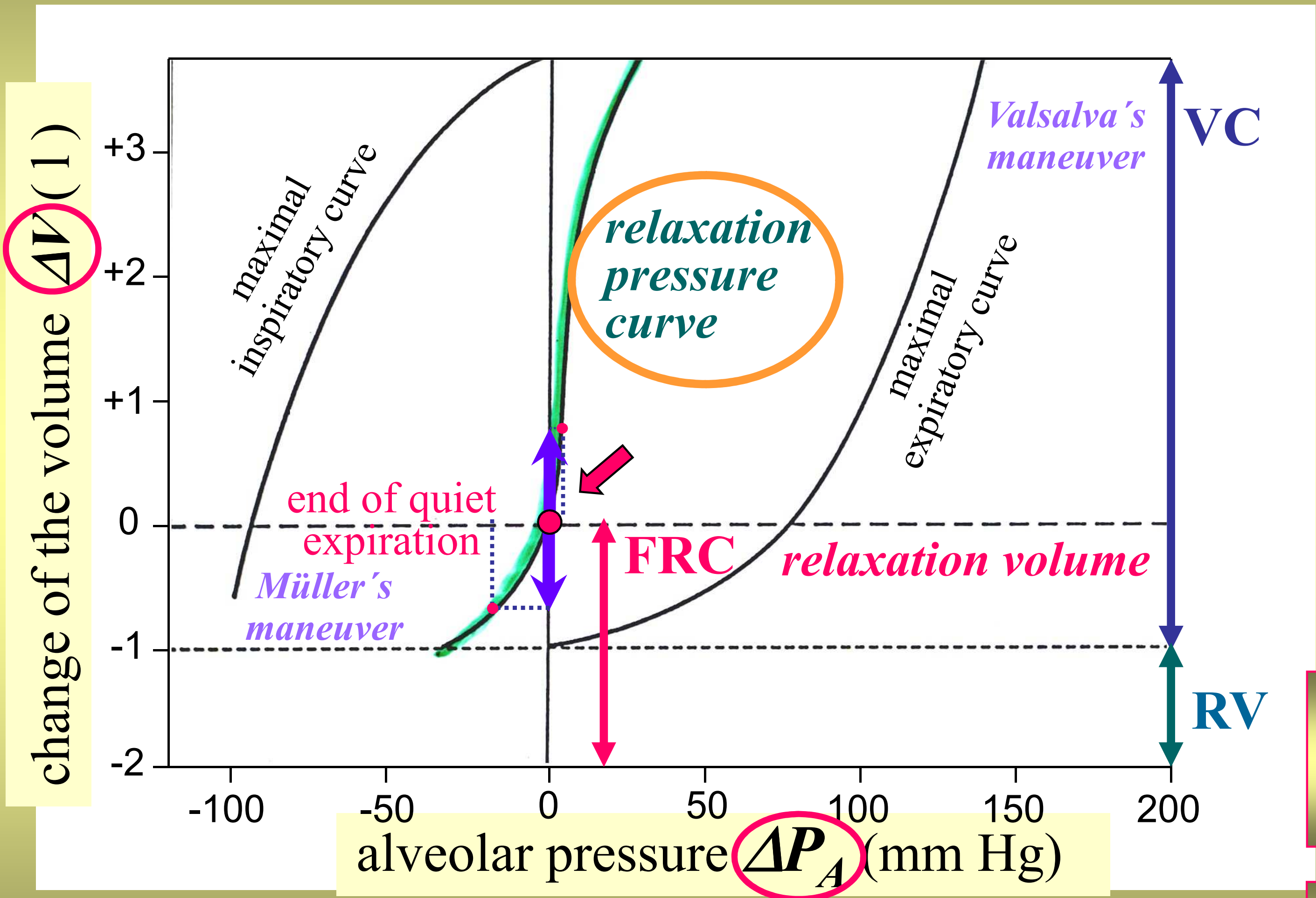
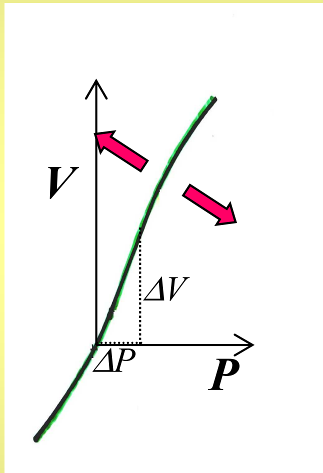
COMPLIANCE (VOLUME STRETCHABILITY)

STATIC MEASUREMENT IN CLOSED SYSTEM

$$C = \frac{\Delta V}{\Delta P}$$





compliance is decreased
↑ stiffness of the tissue

compliance is increased
↓ stiffness of the tissue

TOTAL RESPIRATORY SYSTEM
(lungs and chest)

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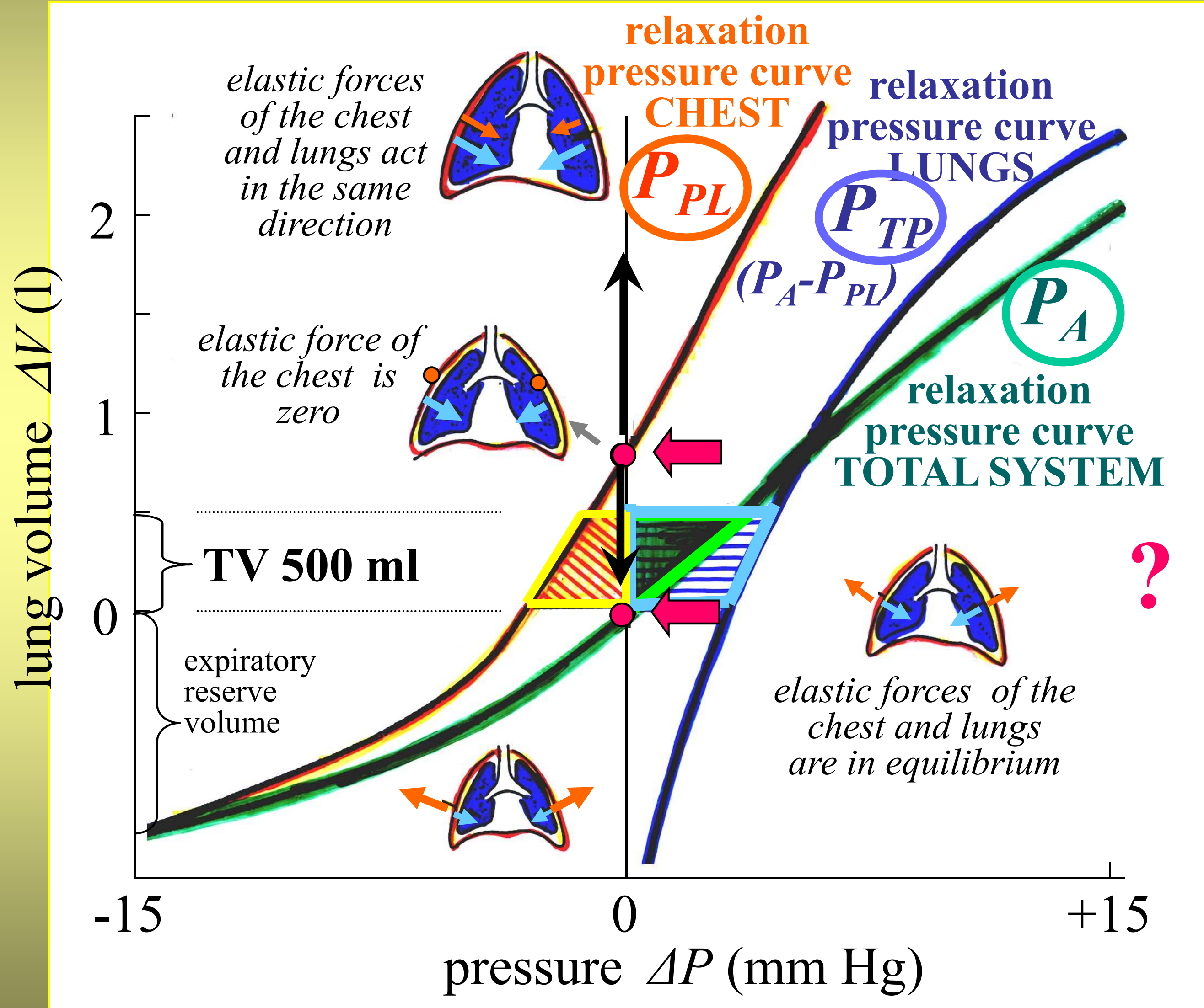
ELASTIC (STATIC) WORK

W_{ELAST} (J)

CLOSED SYSTEM



TOTAL SYSTEM
intrapulmonary pressure
P_A

LUNGS
transpulmonary pressure
$P_{TP} = P_A - P_{PL}$

CHEST
intrapleural pressure
P_{PL}

TOTAL ELASTIC (STATIC) WORK
OF INSPIRATORY MUSCLES

AT QUIET INSPIRATION (V ~ 500 ml)

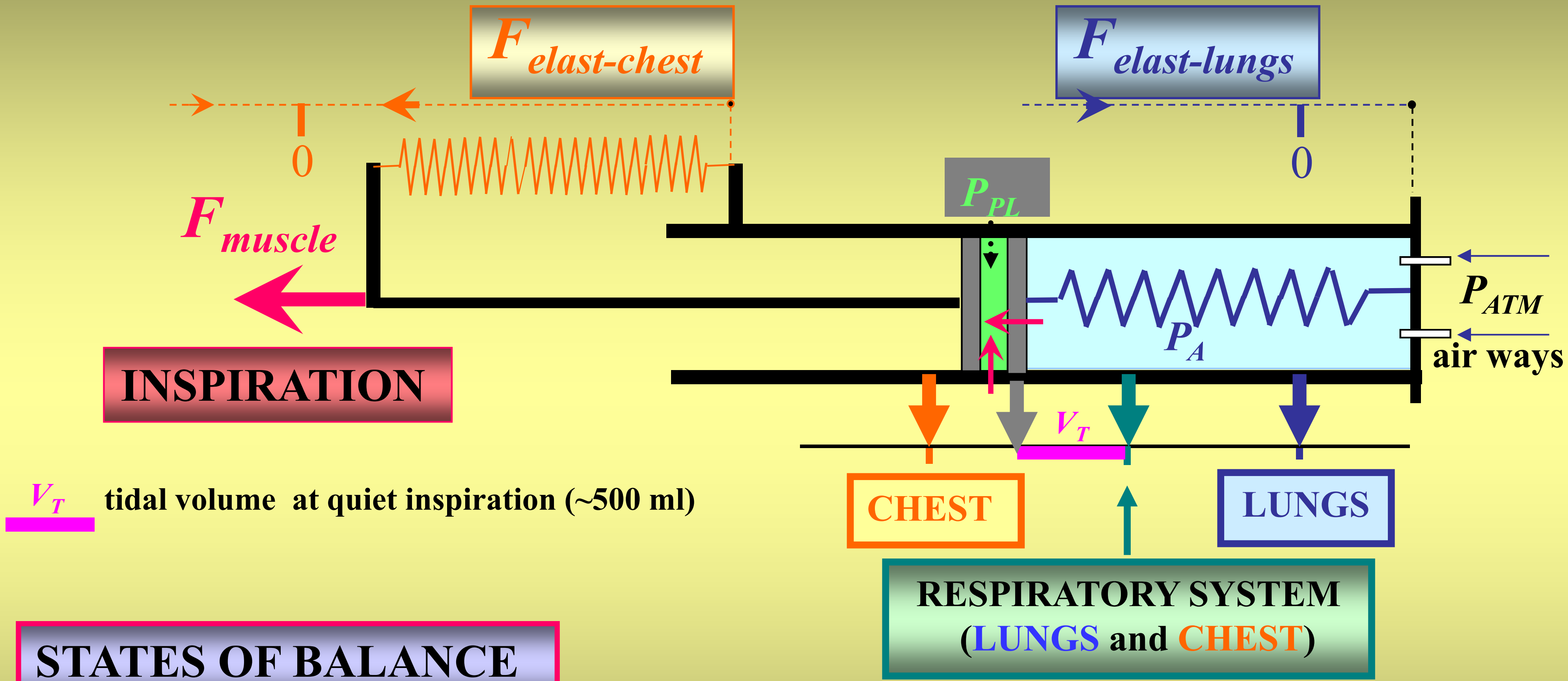
$$W_{TOTAL\ ELASTIC\ insp} = W_{LUNG} + (-W_{CHEST})$$

STRETCHING
against elastic forces of the lungs

ELASTIC RECOIL
of the chest

ELASTIC FORCES OF THE CHEST HELP ***inspiratory muscles to increase thoracic cavity***

ACTIVE AND PASSIVE (ELASTIC) FORCES IN RESPIRATORY SYSTEM



STATES OF BALANCE

RESPIRATORY SYSTEM: elastic forces of lungs and chest are balanced

CHEST: elastic force of the chest alone is zero at $\Delta V \sim 1\ l$

LUNGS: elastic force of the lungs is zero only when $P_{PL} = P_{ATM}$ (*pneumothorax*)

TOTAL WORK OF BREATHING

(total work of respiratory muscles)

ELASTIC (STATIC) WORK **(65%)**

to overcome the elastic forces of the lungs and chest

DYNAMIC WORK **(35%)**

- **to overcome the resistance of air passages during the air movement – AERODYNAMIC RESISTANCE (~ 28%)**
- **to overcome the friction during the mutual movement of inelastic tissues – VISCOUS RESISTANCE (~ 7%)**

RESISTANCE OF AIR PASSAGES

HAGEN-POISEUILLE´S LAW
(laminar flow ***Q***)

$$Q = \frac{\Delta P}{R}$$

Ohm´s law

$$R = \frac{8 \eta l}{\pi r^4}$$

l … **length**
r … **radius**
η … viscosity

Re

LAMINAR FLOW **< 2000 <** **TURBULENT FLOW**

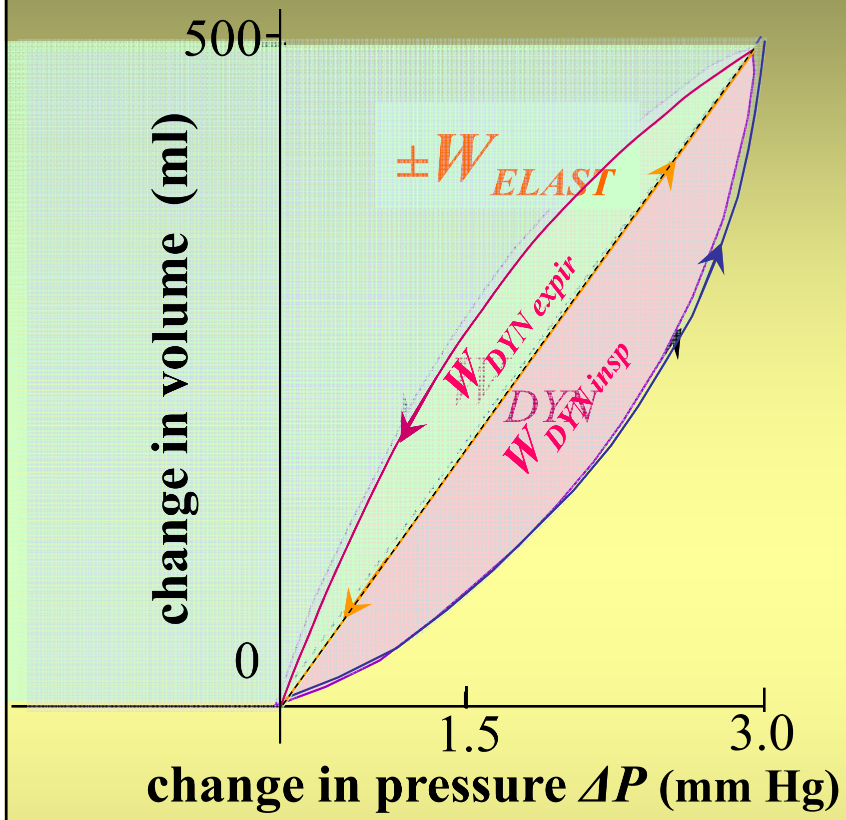
REYNOLDS NUMBER Re

$$Re = \frac{2 r \rho v}{\eta}$$

Critical velocity

r … **radius**
v … **velocity**
ρ … density
η … viscosity

TOTAL WORK OF RESPIRATORY MUSCLES [J] DURING RESPIRATORY CYCLE AT QUIET BREATHING



DYNAMIC PRESSURE-VOLUME DIAGRAM

$$W_{INSPIR} = W_{ELAST} + W_{DYN\ insp}$$

$$W_{EXPIR} = -W_{ELAST} + W_{DYN\ expir}$$

$$W_{DYN} = W_{DYN\ insp} + W_{DYN\ expir}$$

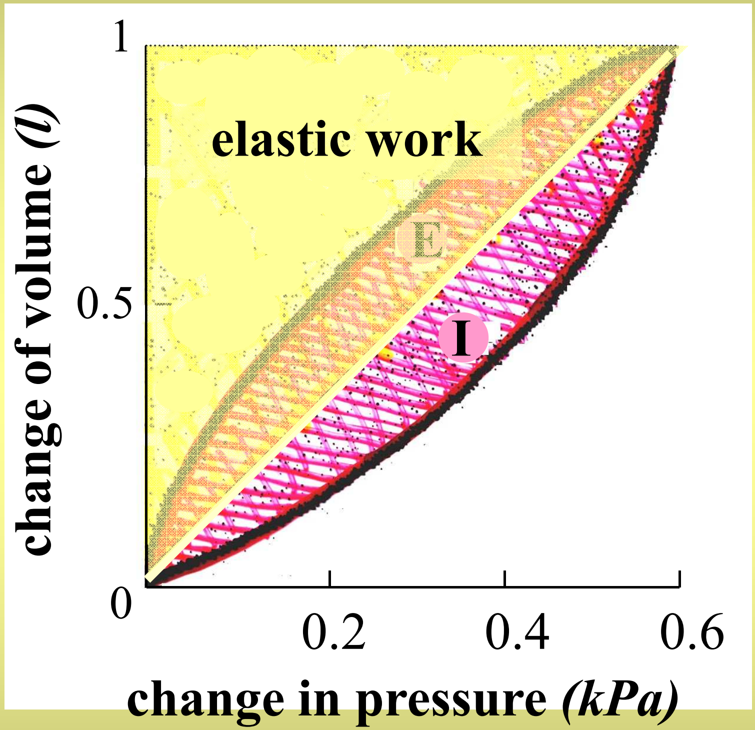
DYNAMIC WORK W_{DYN} is done to overcome

- ***aerodynamic resistance***
- ***frictional (viscose) resistance***

W_{DYN} is finally transformed into heat energy (loss of energy)

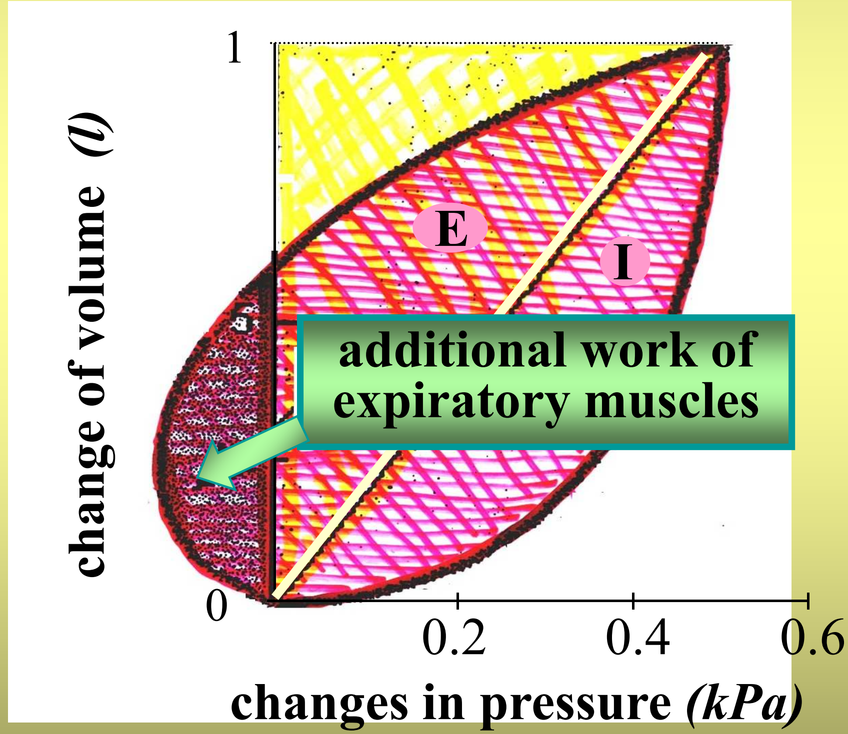
INCREASED RESISTANCE OF AIR PASSAGES

CLINICAL IMPLICATION



NORMAL LUNGS

OBSTRUCTIVE LUNG DISEASE
(asthma bronchial)



Expiratory muscles are active to overcome the resistance of air passages

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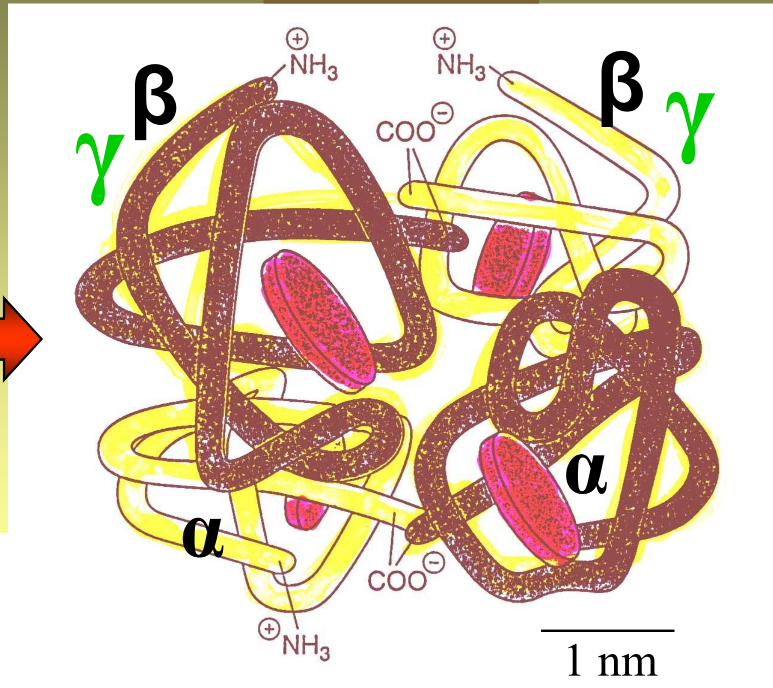
HAEMOGLOBIN

$$Hb_4 + 4\ O_2 \leftrightarrow Hb_4O_8$$

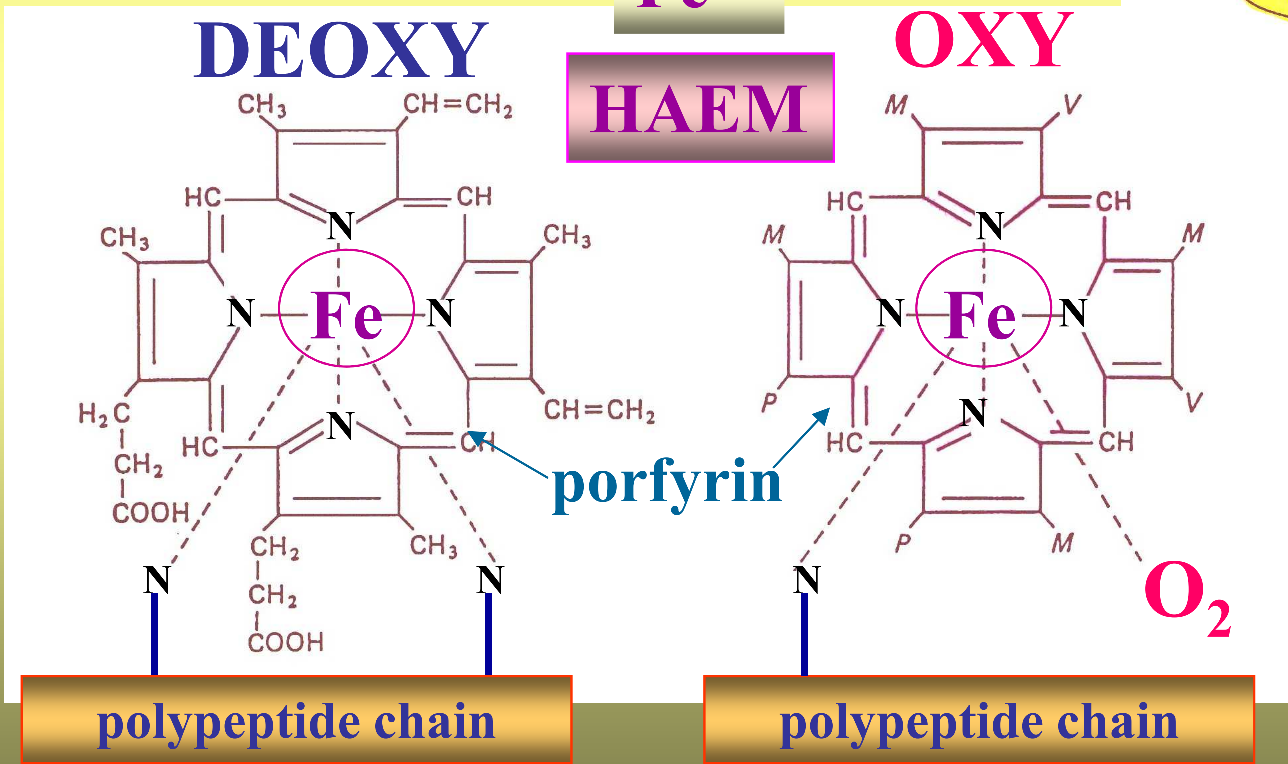
oxygenation

tetramer



Fe^{2+}

HAEM

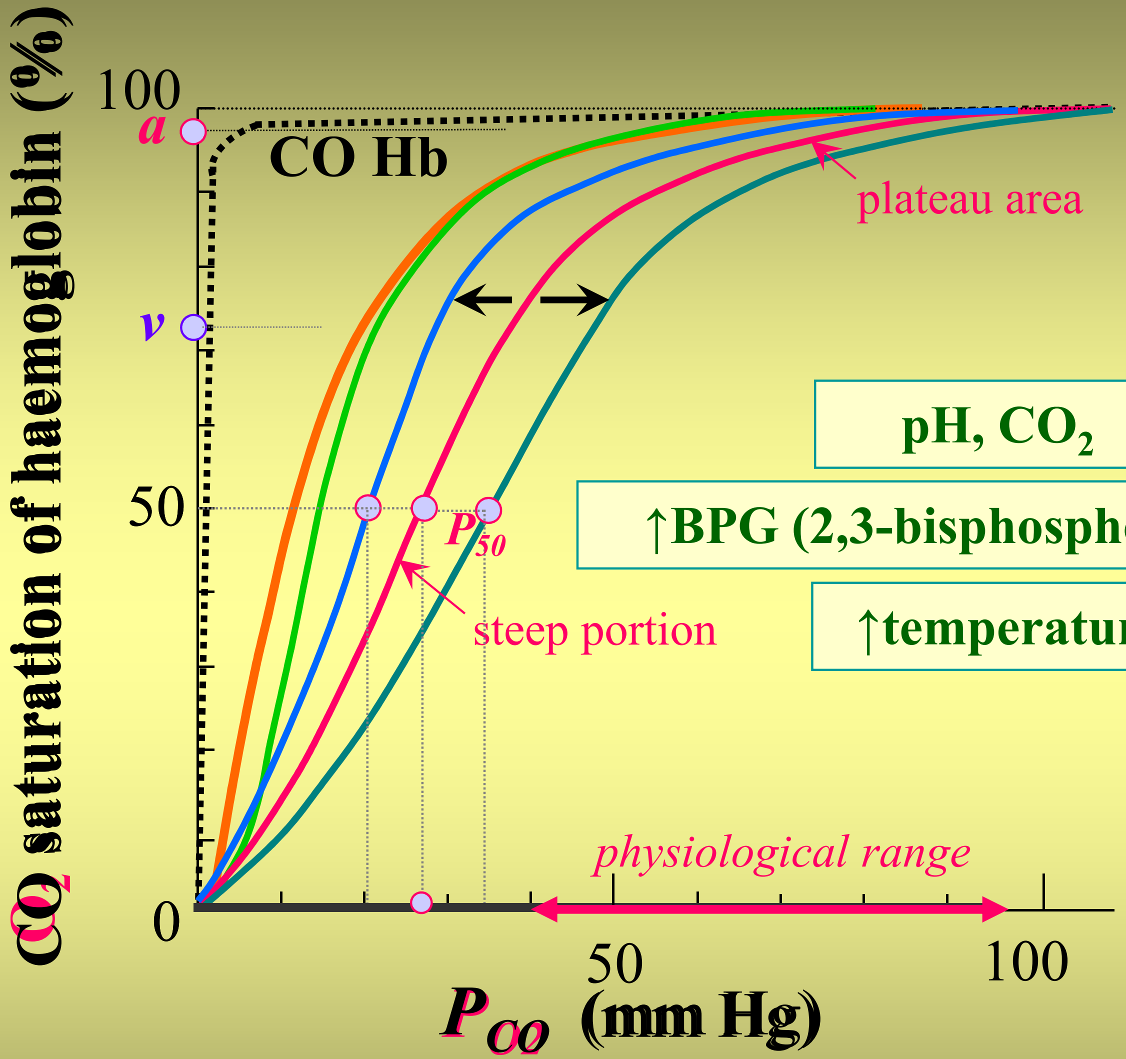


fetal Hb

Fe^{3+} (methaemoglobin)

oxidation

O_2–HAEMOGLOBIN DISSOCIATION CURVE



BOHR EFFECT
(↓pH, ↑CO_2)

deoxyHb$^-$ + H^+ → H-Hb

pH, CO_2

↑BPG (2,3-bisphosphoglycerate)

↑temperature

fetal Hb

myoglobin

methaemoglobin

physically dissolved O_2 (1.4%)

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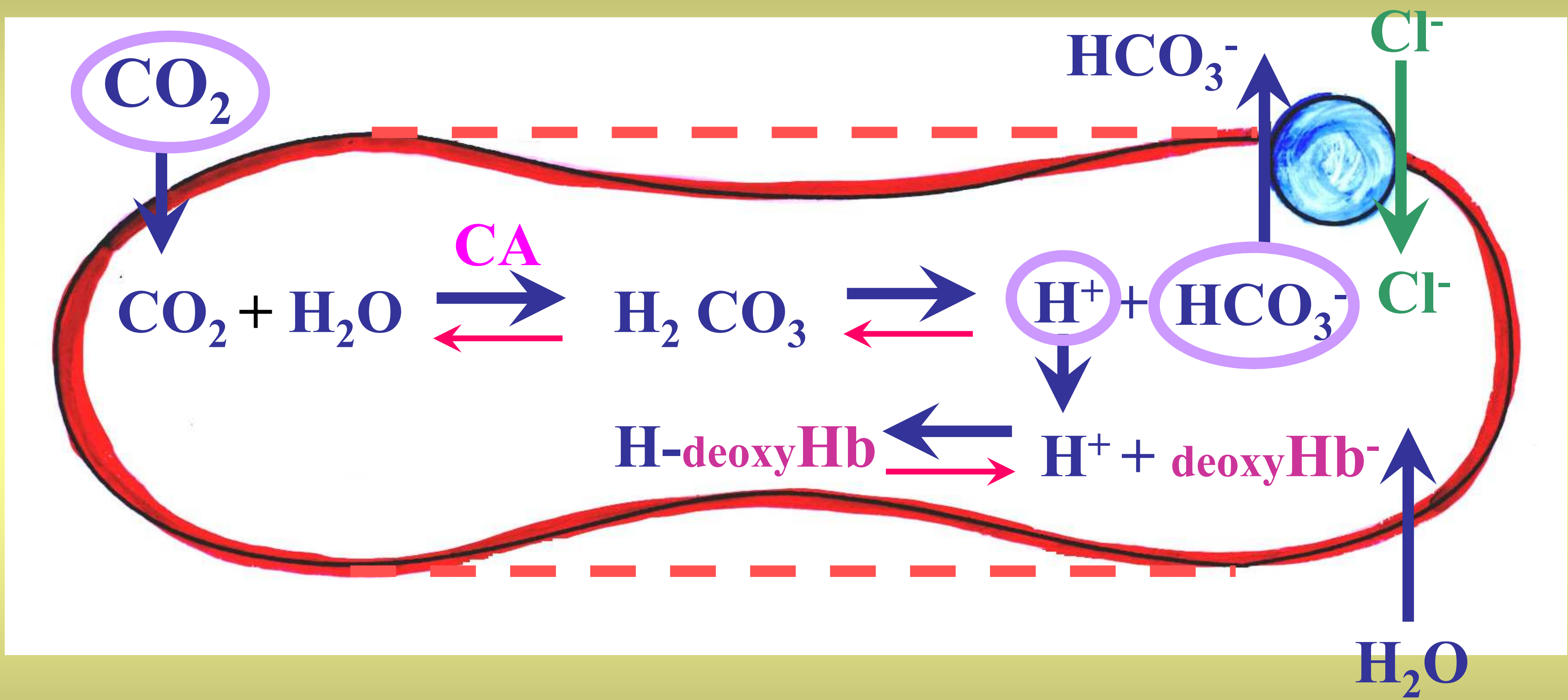
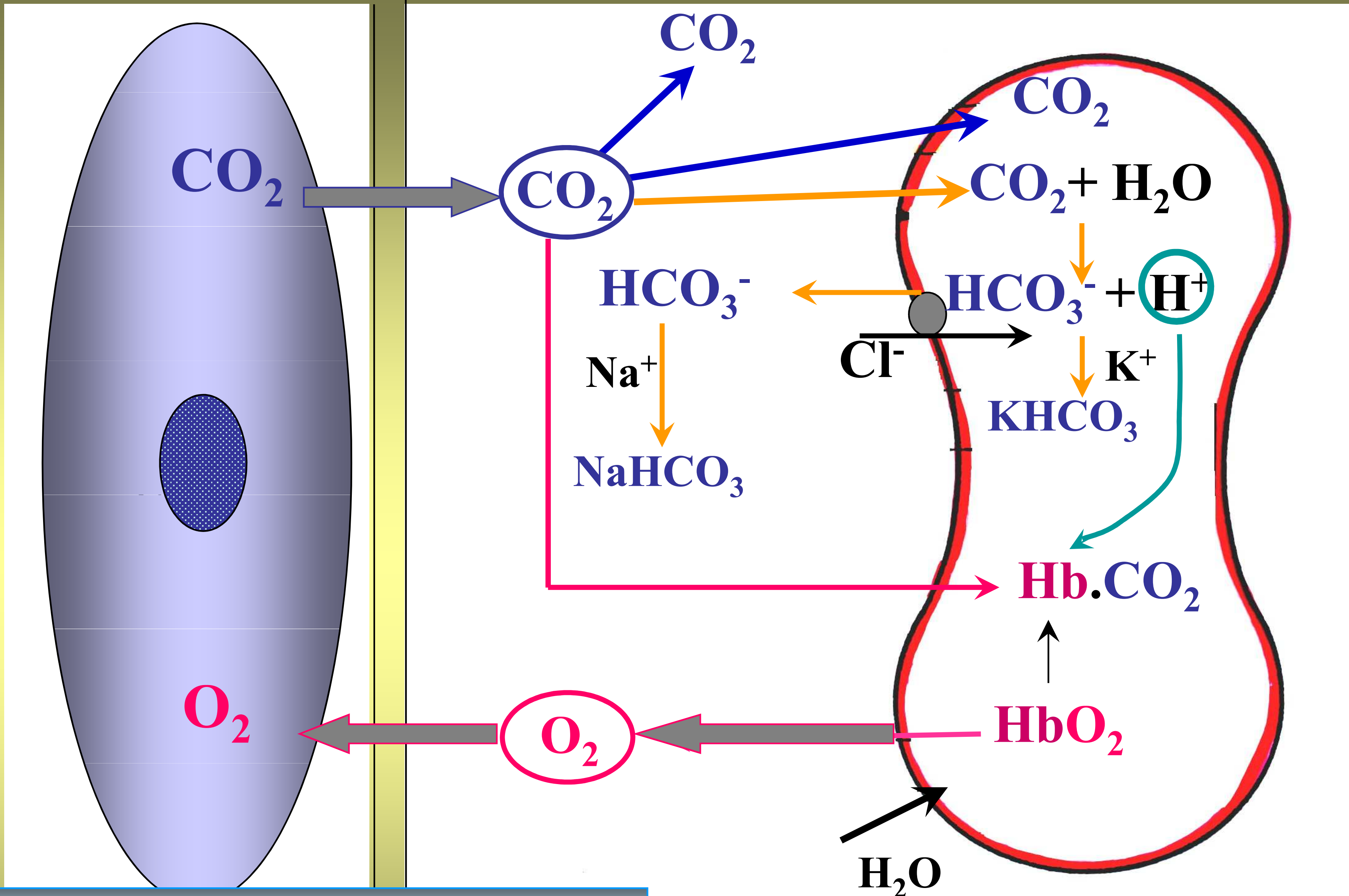
TRANSPORT OF CO_2

HAMBURGER CHLORIDE SHIFT



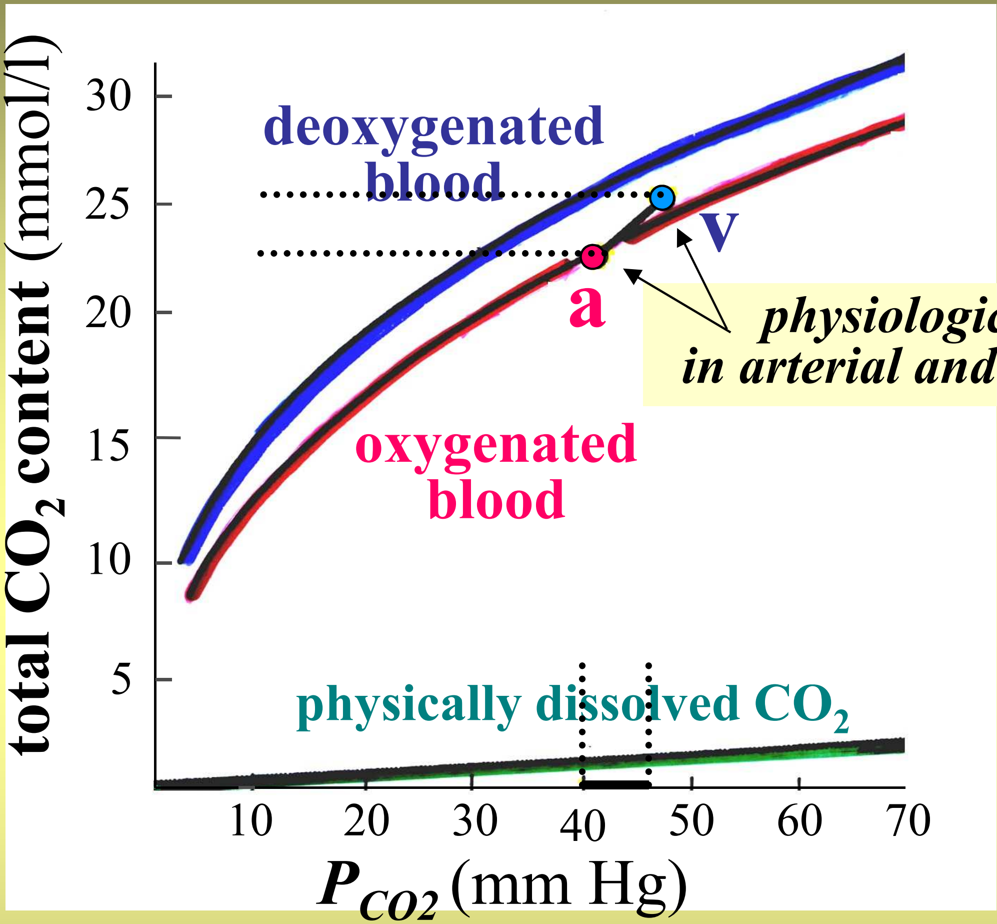
CA – carbonic anhydrase



- CO_2 physically dissolved (~5.3%)
- CO_2 + Hb-NH_2 $\rightleftarrows$ Hb.NH-COO^- (carbamino-Hb) (~5.3%)
- $CO_2 + H_2O \rightleftarrows HCO_3^- + H^+$ (~89.3%)

~60% in plasma, ~29% in red blood cell

CO_2 DISSOCIATION CURVE



HALDANE EFFECT

?

DEOXY-Hb

1 Hb.NH.COO^-

2 $Hb^- + H^+ \rightleftarrows HHb$

→ deoxygenated blood in peripheral tissues

← oxygenated blood in the lungs

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

↑↓

$$Hb^- + H^+ \rightleftarrows HHb$$

TISSUES: **DEOXY-Hb** binds **H^+** more readily (weaker acid) ⇒ ↑ amount of chemically bound CO_2

LUNGS: **H^+** is released from **OXY-Hb** ⇒ ↓ amount of chemically bound CO_2

PROCESSES UNDERLYING TRANSPORT O_2 AND CO_2

IN RED BLOOD CELLS

- **OCCUR SIMULTANEOUSLY**
- **FACILITATE EACH OTHER**

TISSUES

uptake of CO_2 by blood $\rightleftarrows$ release of O_2 from Hb

LUNGS

binding of O_2 to Hb $\rightleftarrows$ release of CO_2 from blood

BOHR´s AND HALDANE´s EFFECTS

END