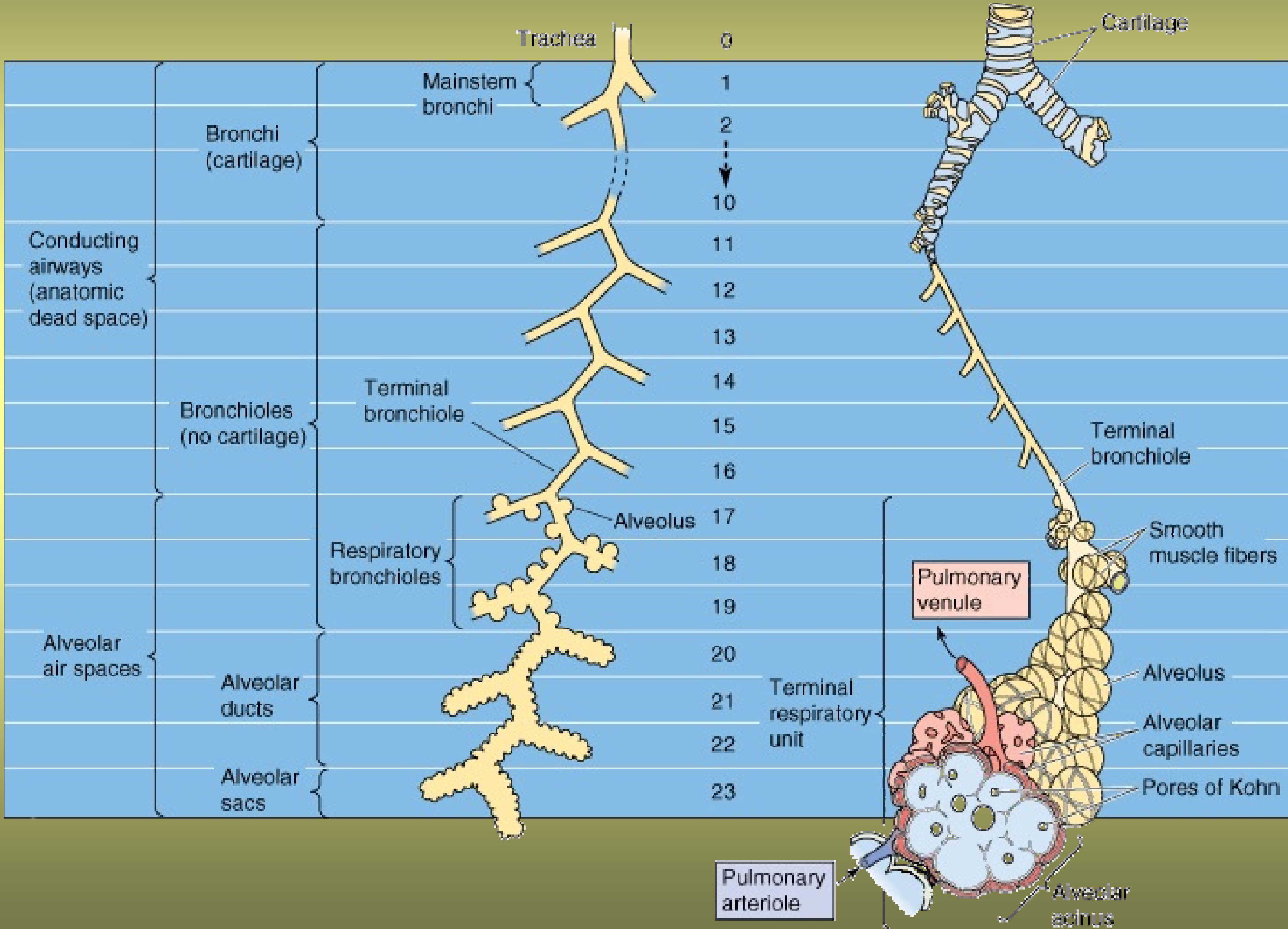
RESPIRATORY SYSTEM

RESPIRATORY FUNCTIONS
MECHANICS OF RESPIRATORY SYSTEM
GAS TRANSPORT

Author of presentation: doc. MUDr. Milena Šimurdová, CSc.

STOMATOLOGY

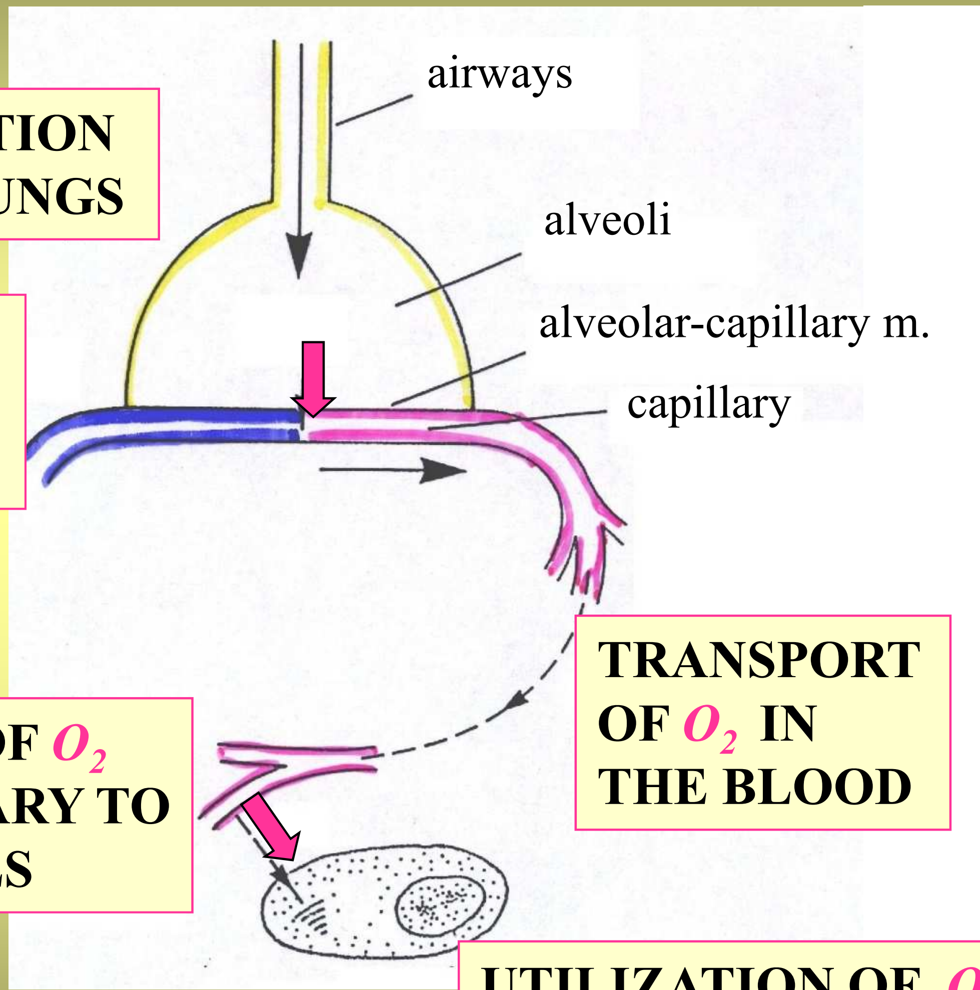


Trachea
0
Mainstem bronchi
1
2
10
Bronchi (cartilage)
11
12
13
14
15
16
Conducting airways (anatomic dead space)
Terminal bronchiole
Bronchioles (no cartilage)
Alveolus
17
Respiratory bronchioles
18
19
Alveolar air spaces
20
Alveolar ducts
21
22
Alveolar sacs
23
Terminal respiratory unit
Cartilage
Terminal bronchiole
Smooth muscle fibers
Pulmonary venule
Alveolus
Alveolar capillaries
Pores of Kohn
Pulmonary arteriole
Alveolar acinus

STEPS IN THE DELIVERY OF O_2 TO THE CELLS

VENTILATION OF THE LUNGS

DIFFUSION OF O_2 ACROSS ALVEOLAR-CAPILLARY MEMBRANE



TRANSPORT OF O_2 IN THE BLOOD

DIFFUSION OF O_2 FROM CAPILLARY TO THE CELLS

UTILIZATION OF O_2 BY MITOCHONDRIA

AT REST

O_2 UPTAKE ~300 ml / min

CO_2 OUTPUT ~250 ml / min

INTERNAL RESPIRATION

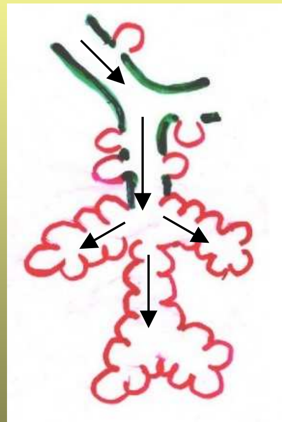
AIR PASSAGES

ANATOMICAL DEAD SPACE – CONDUCTING ZONE

- NASAL PASSAGES
- PHARYNX
- LARYNX
- TRACHEA
- BRONCHI
- BRONCHIOLES
- TERMINAL BRONCHIOLES

Other physiological functions:

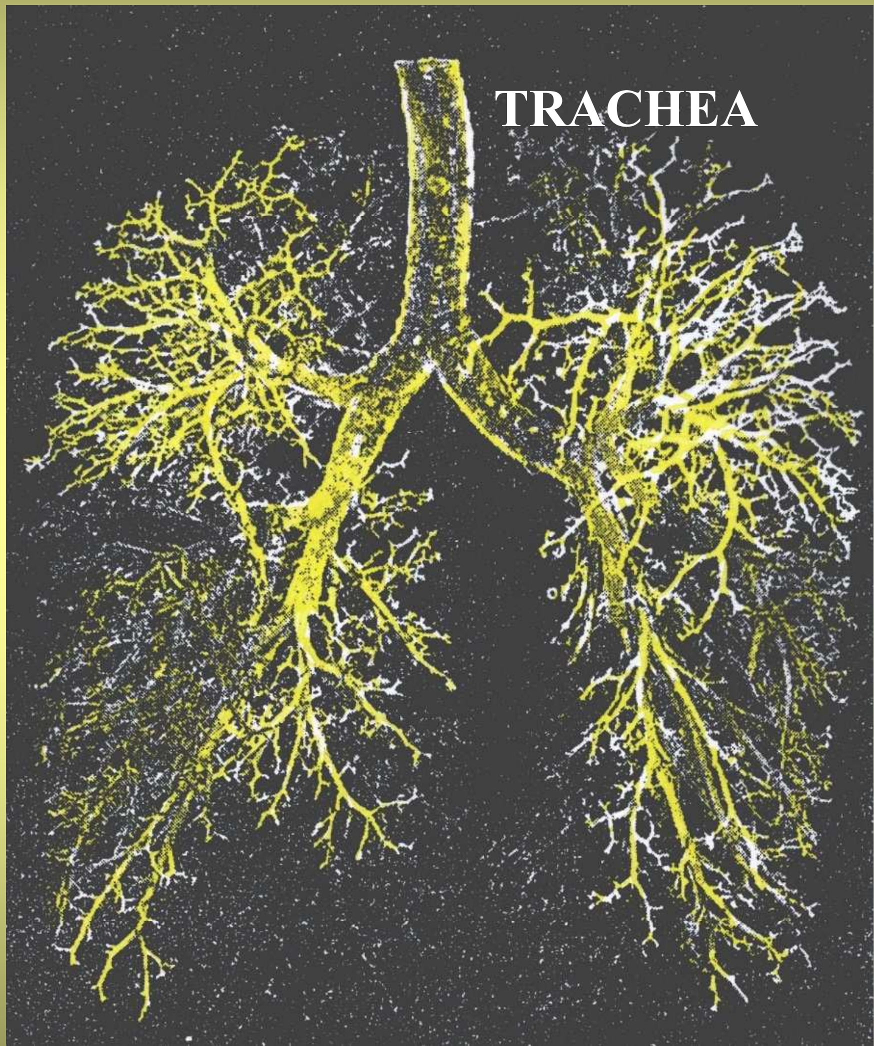
- air is warmed, cleaned and takes up water vapour
- respiratory reflex responses to the irritants
- speech and singing (function of larynx)



RESPIRATORY ZONE
(GAS EXCHANGE)

Total alveolar area ~100 m^2

CAST OF HUMAN AIR PASSAGES



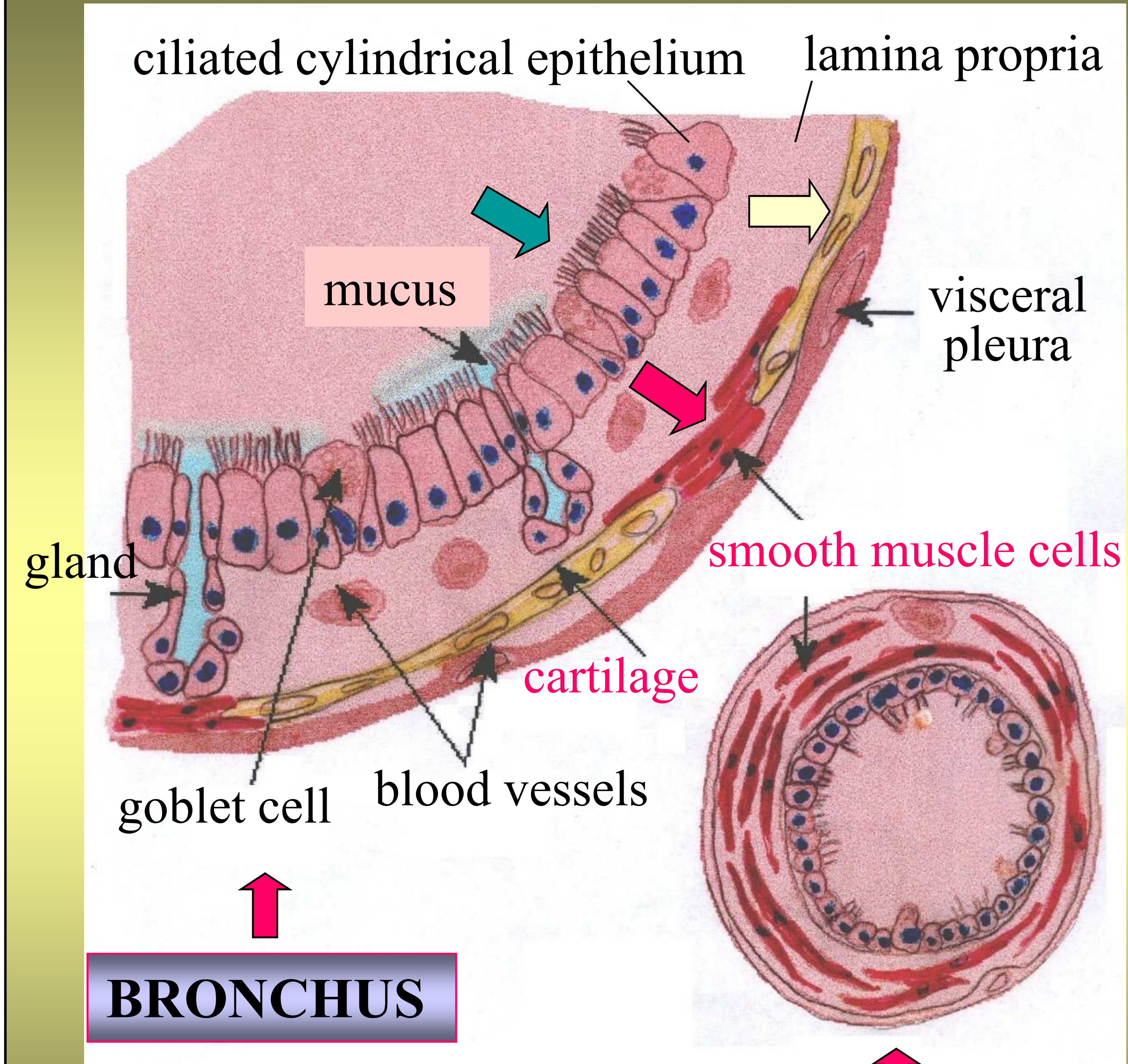
BRONCHI

BRONCHIOLES

TERMINAL BRONCHIOLES

AERODYNAMIC RESISTENCE

AUTONOMIC INNERVATION of smooth muscle cells



Muscarinic receptors:
Acetylcholine activates
bronchoconstriction

β-adrenergic receptors:
Noradrenaline activates
bronchodilatation

∅ < 1 mm

V_T tidal volume ~ **500 ml**

$V_T = V_A + V_D$

V_A part of tidal volume entering alveoli ~ **350 ml**

V_D part of tidal volume remaining in the dead space ~ **150 ml**

f = 12/min

$\dot{V}_A = V_A \times f$

ALVEOLAR VENTILATION

4.2 l/min

$\dot{V} = V_T \times f$

PULMONARY MINUTE VENTILATION

6 l/min

$\dot{V}_D = V_D \times f$

DEAD SPACE VENTILATION

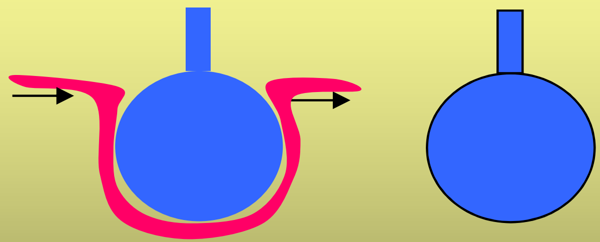
1.8 l/min

DEAD SPACE

TOTAL GAS VOLUME NOT EQUILIBRATED WITH BLOOD
(without exchange of gasses)

- **ANATOMICAL dead space - volume of air passages**
- **FUNCTIONAL (total) dead space**

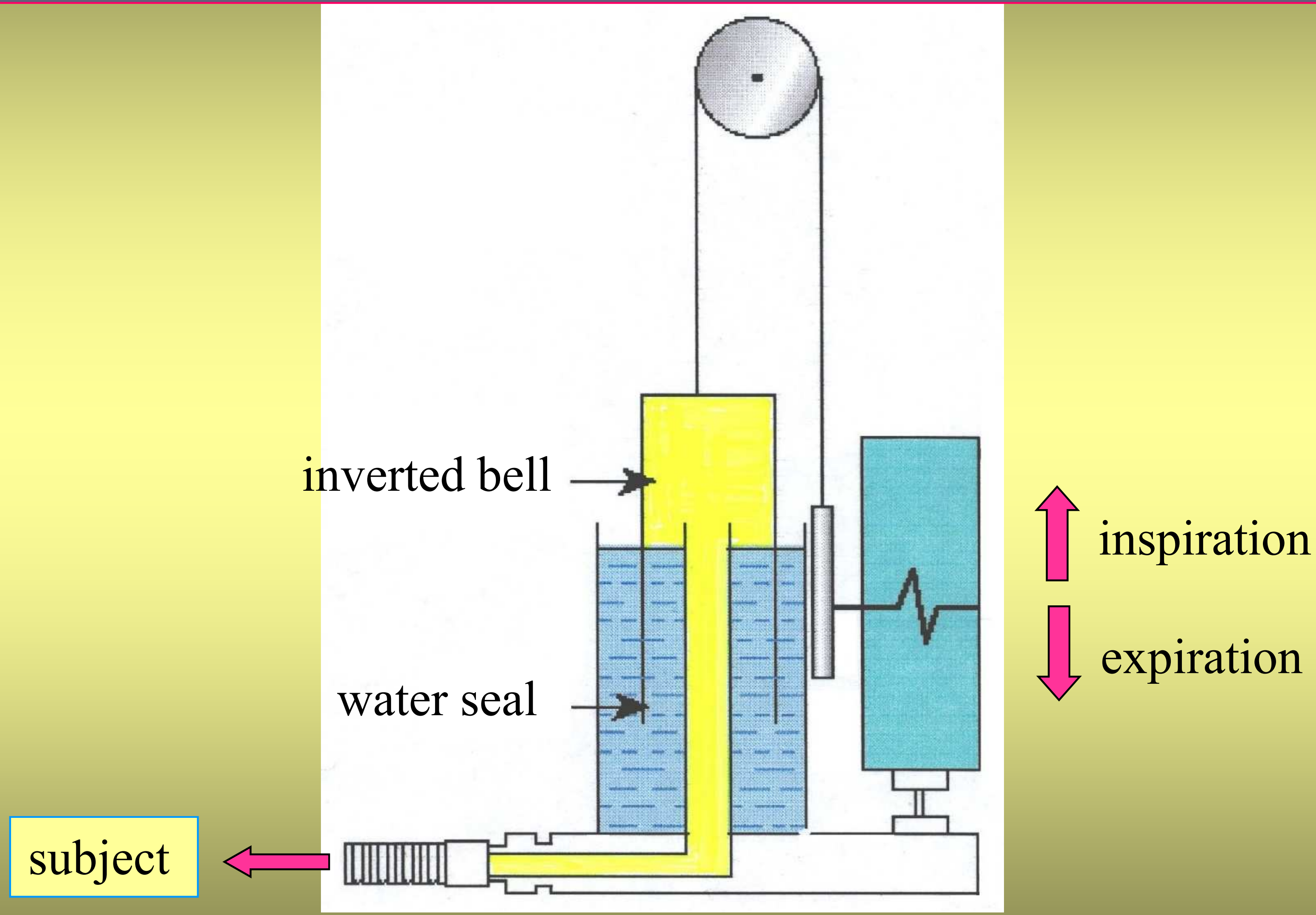
ANATOMICAL dead space + total VOLUME of ALVEOLI without functional capillary bed



IN HEALTHY INDIVIDUALS
both spaces are practically identical

SPIROMETRY

(measurements of lung volumes, capacities, functional investigations, …)



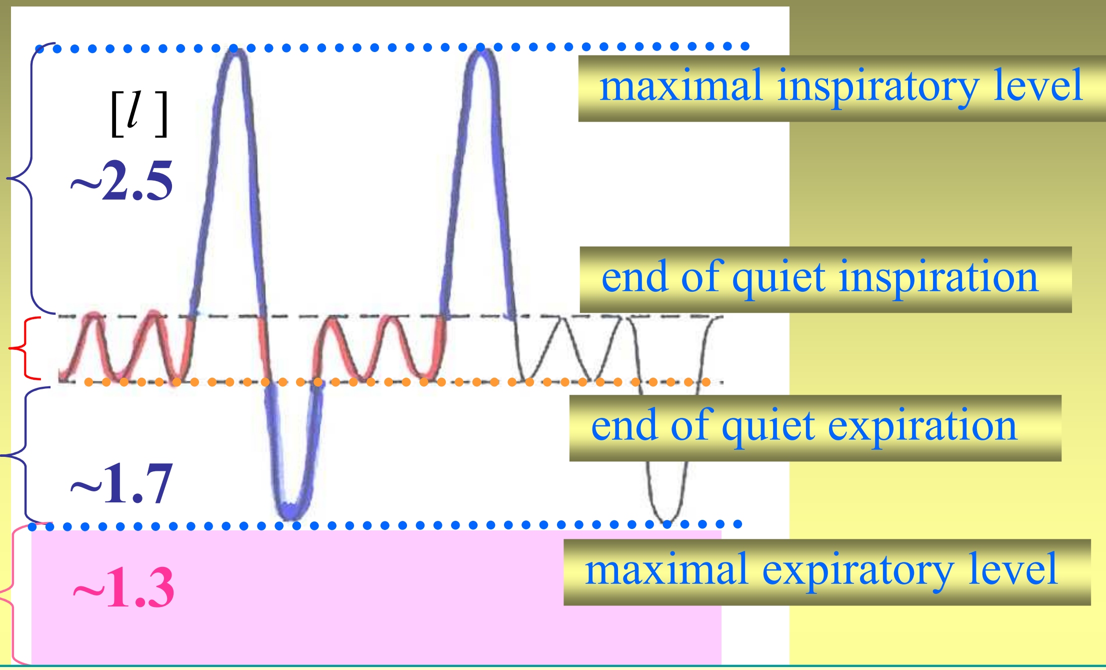
LUNG VOLUMES

INSPIRATORY RESERVE VOLUME *IRV*

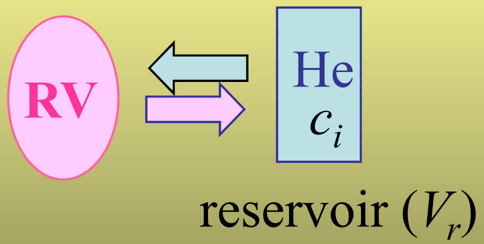
TIDAL VOLUME V_T

EXPIRATORY RESERVE VOLUME *ERV*

RESIDUAL VOLUME *RV*



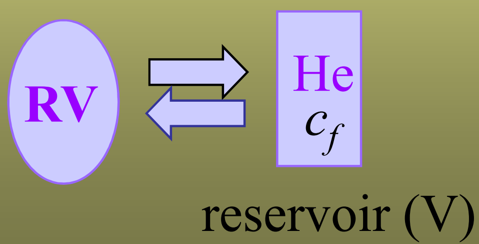
DILUTION METHOD *He*



Principle of method: **1** Maximal expiration, **2** Repeated inspiration from and expiration into a reservoir (known **volume** V_r) with inert gas ***He*** (known concentration c_i)

⇒ Equilibration of the air in the residual volume and reservoir

3 Calculation of **residual volume *RV*** from the initial and final *He* concentrations in reservoir (c_i , c_f).

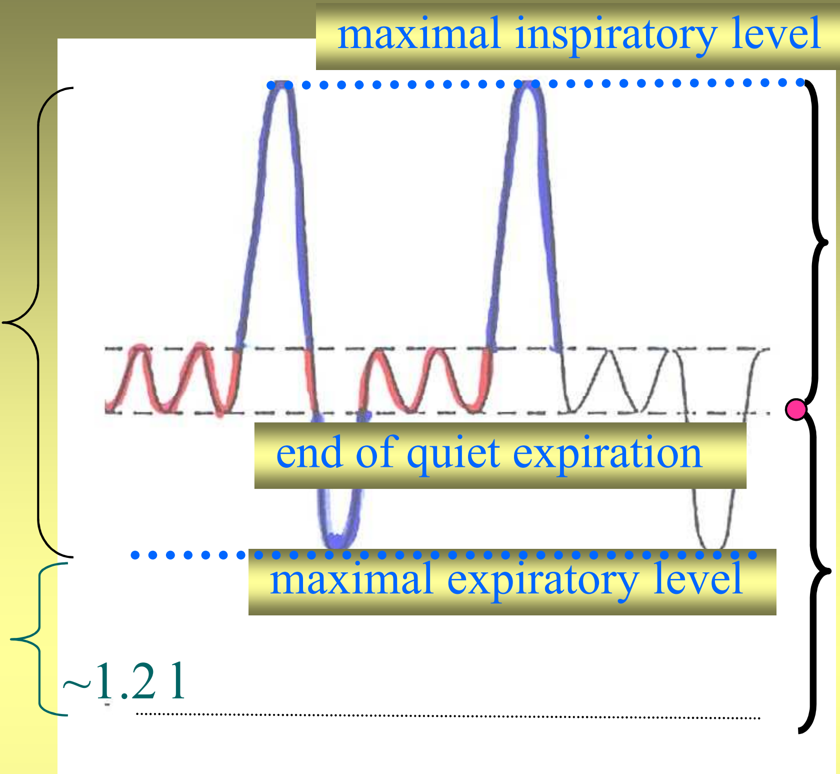


$$RV = V_r \frac{c_{i\,He} - c_{f\,He}}{c_{f\,He}}$$

TLC

VC

RV



INSPIRATORY CAPACITY

>3.0 l

FUNCTIONAL RESIDUAL CAPACITY

<3.0 l

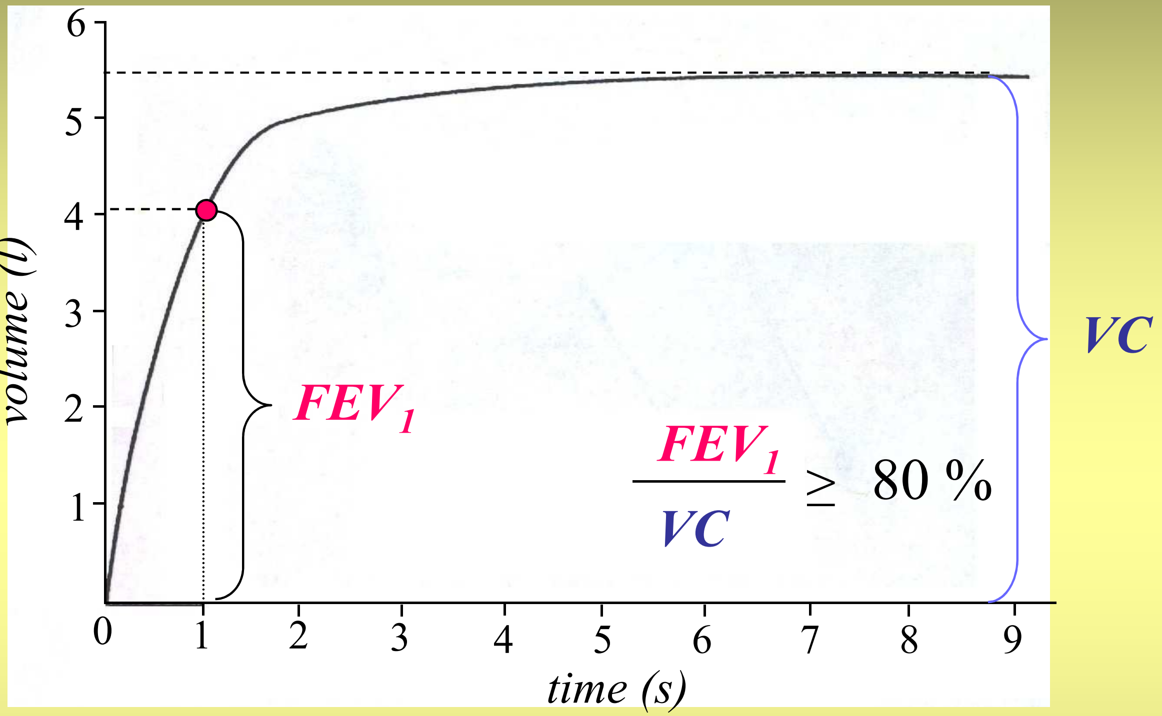
VC | **VITAL CAPACITY = V_T + IRV + ERV** ~ 4.7 l

VC - the largest amount of air that can be expired after maximal inspiration

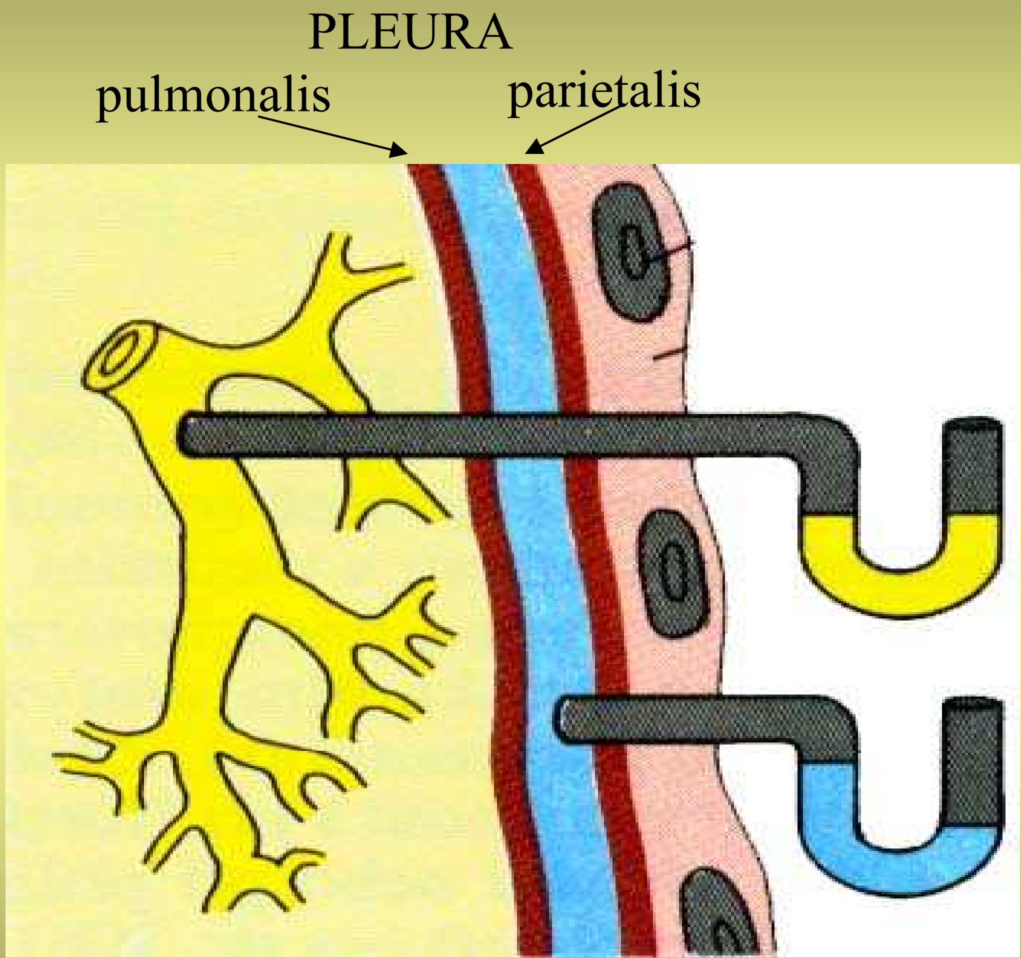
TLC | **TOTAL LUNG CAPACITY = VC + RV** ~ 6.0 l

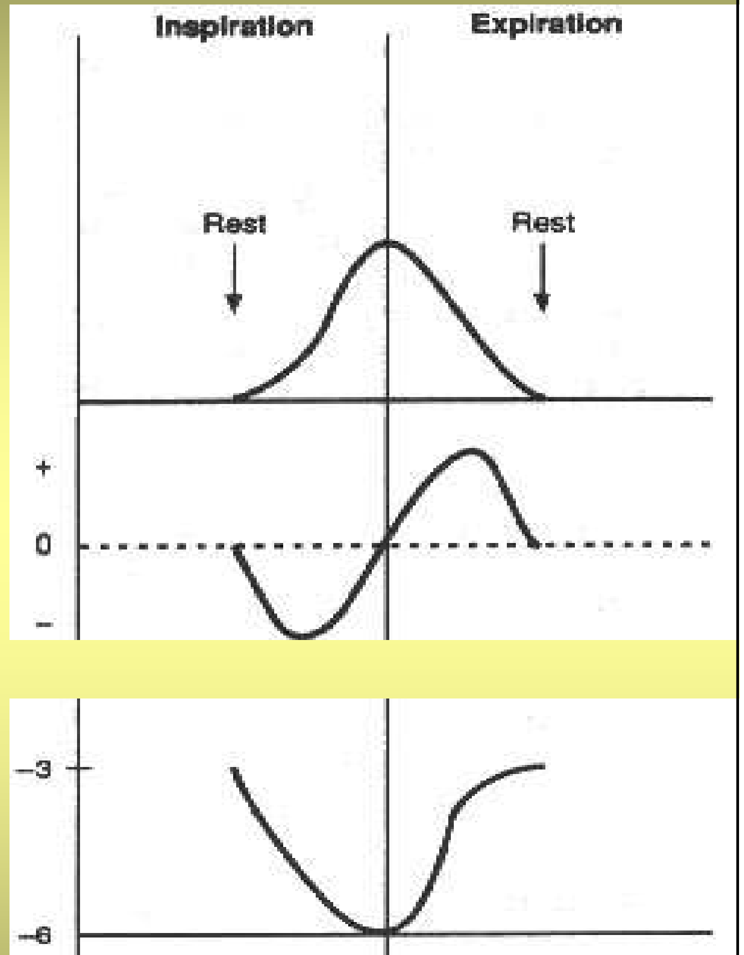
FUNCTIONAL INVESTIGATION OF THE LUNGS

- **TIMED VITAL CAPACITY** (***FEV$_1$*** - forced expiratory volume per 1 s)



- **PULMONARY MINUTE VENTILATION** ***RMV*** **(respiratory minute volume) at rest** (0.5 l x 12 breathes/min = 6 l/min)
- **MAXIMAL VOLUNTARY VENTILATION (*MVV*)** (125-170 l/min)
- **PEAK EXPIRATORY FLOW RATE (*PEFR*)** (~10 l/s)


PLEURA
pulmonalis
parietalis


Inspiration
Expiration
Rest
Rest
+
0
−
−3
−6

FORCES PARTICIPATING IN RESPIRATION

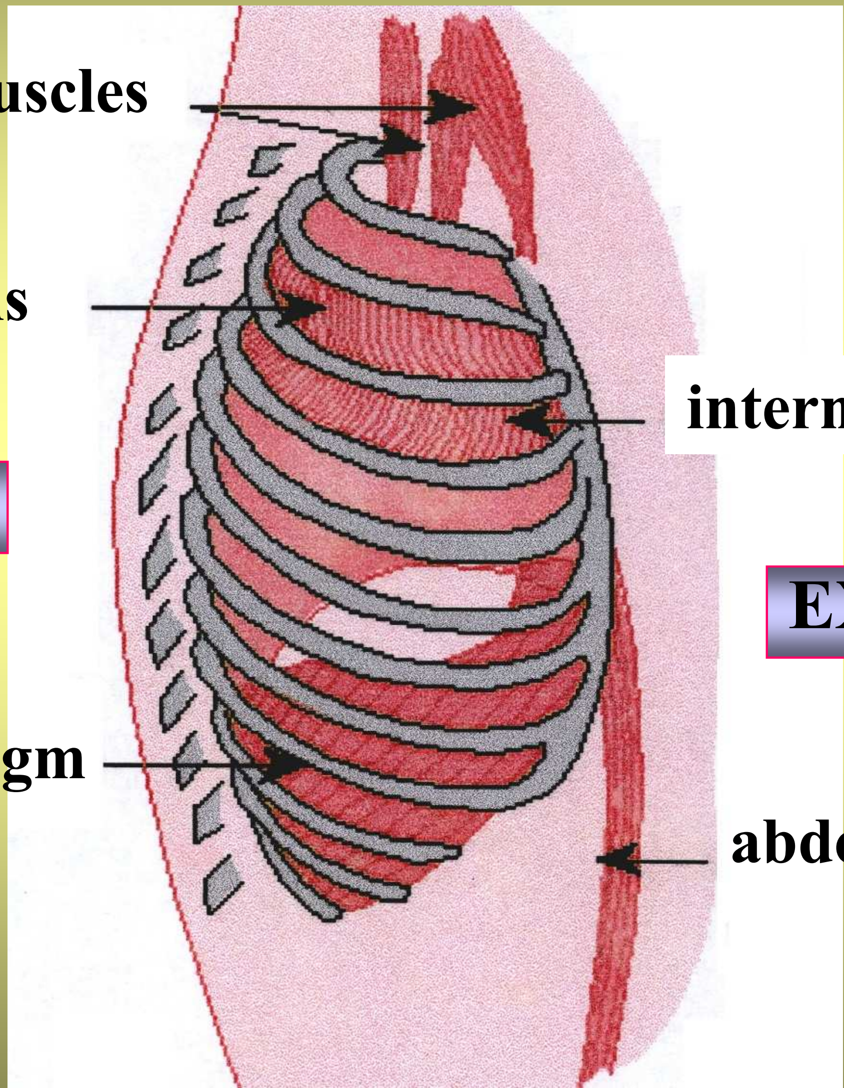
- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES represented by:**
  - **lungs elasticity**
  - **chest elasticity**

QUIET RESPIRATION

INSPIRATION - active forces of inspiratory muscles prevail

EXPIRATION - only passive (elastic) forces are in action

RESPIRATORY MUSCLES



INSPIRATORY muscles

QUIET breathing

- *diaphragm* (> 80 %)
- *external* **intercostals** (< 20 %)

FORCED breathing
in addition

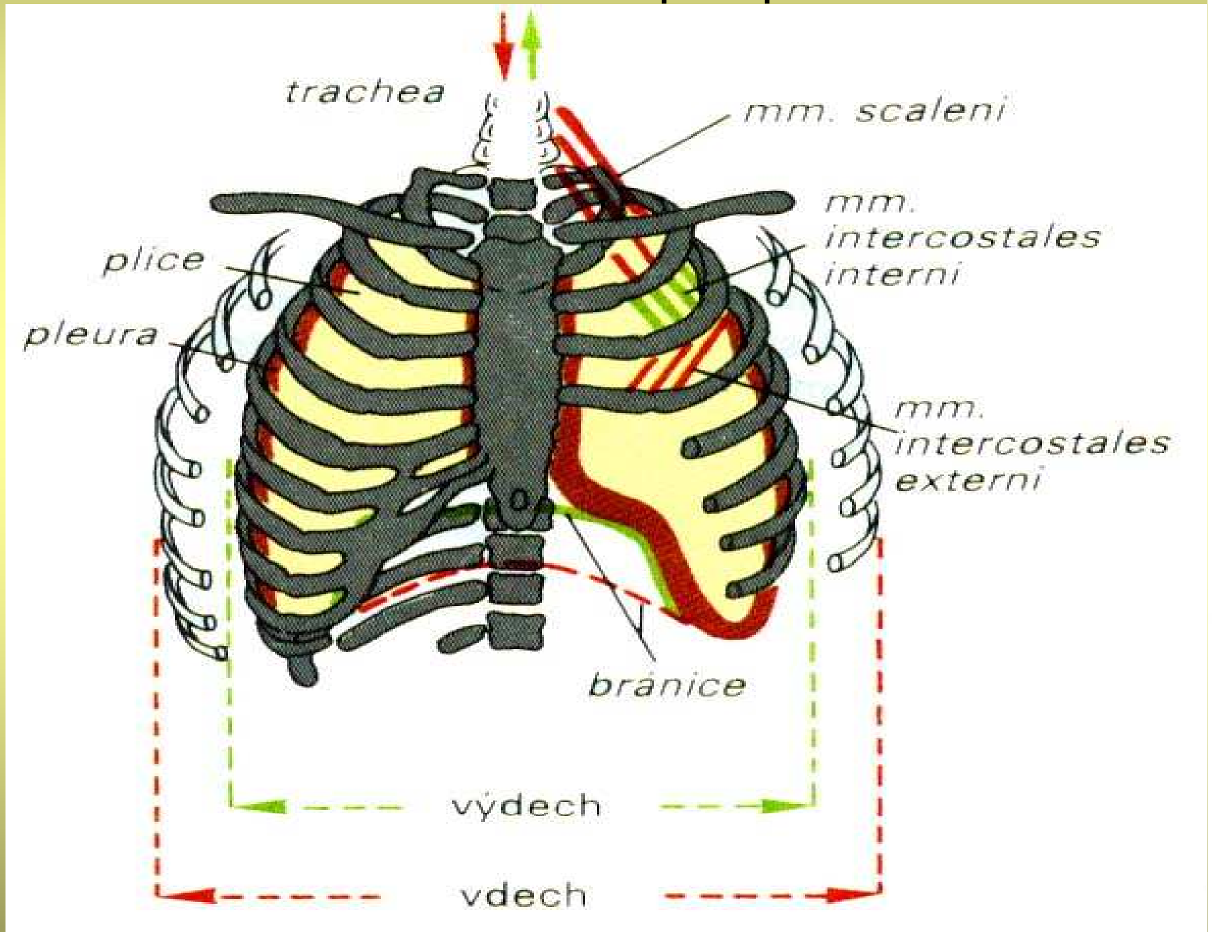
- ***accessory*** **inspiratory muscles** (mm. scalene)

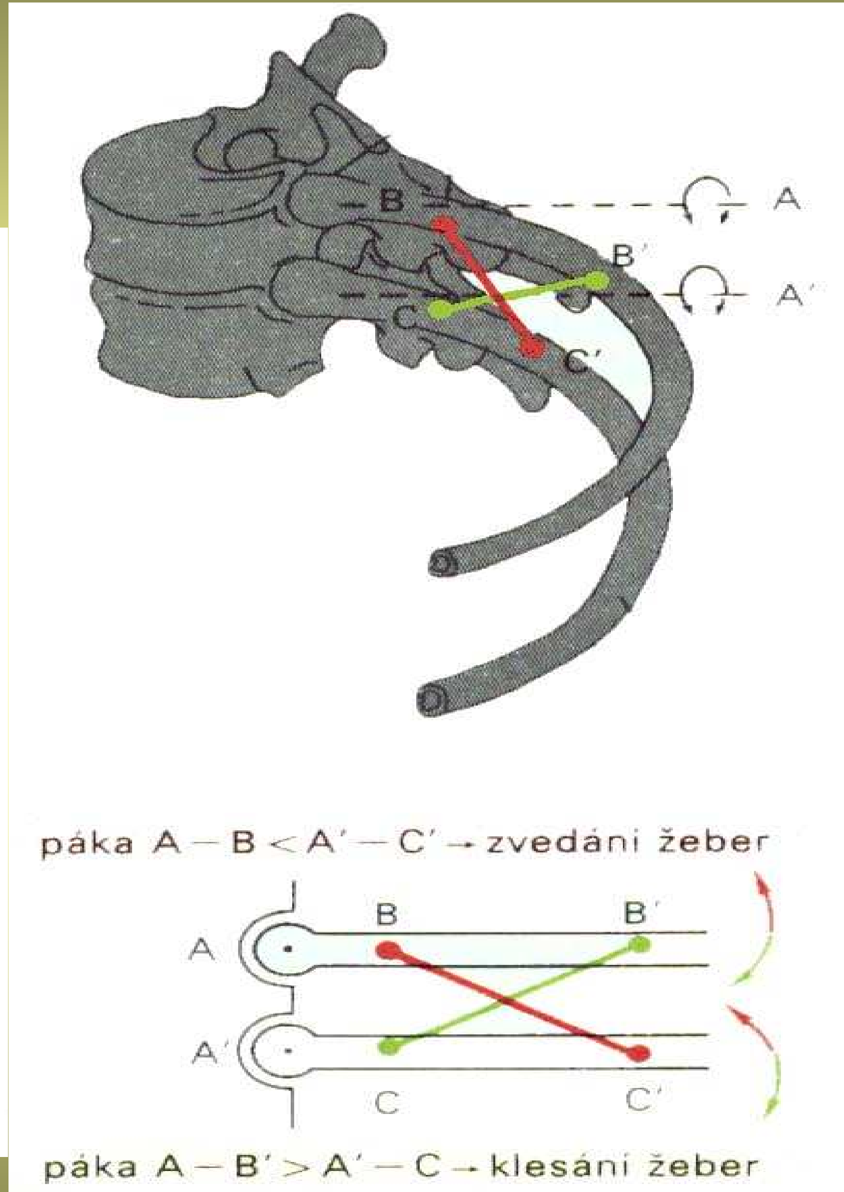
EXPIRATORY muscles

Only at FORCED breathing

- ***internal*** **intercostals**
- **muscles of the anterior *abdominal* wall** (abdominal recti, …)

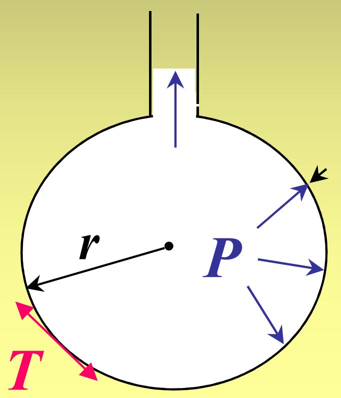
Bucket-handle and water-pump handle effects





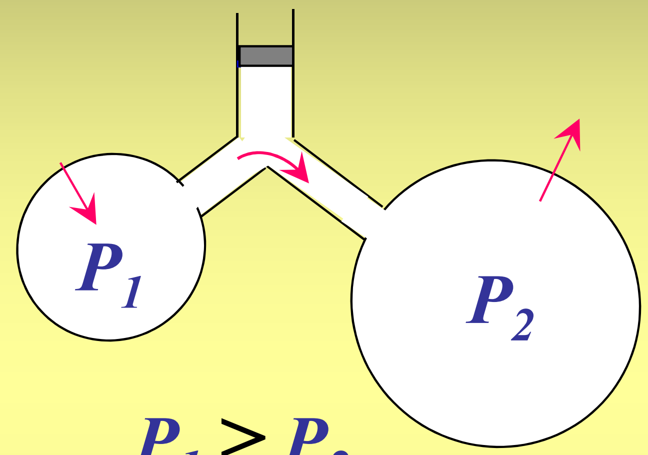
LAW OF LAPLACE

spherical structures



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

?



$$P_1 > P_2$$

P pressure

r radius

T surface tension

PATHOLOGY

- COLLAPSE OF ALVEOLI - ATELECTASIS
- EXPANSION OF ALVEOLI

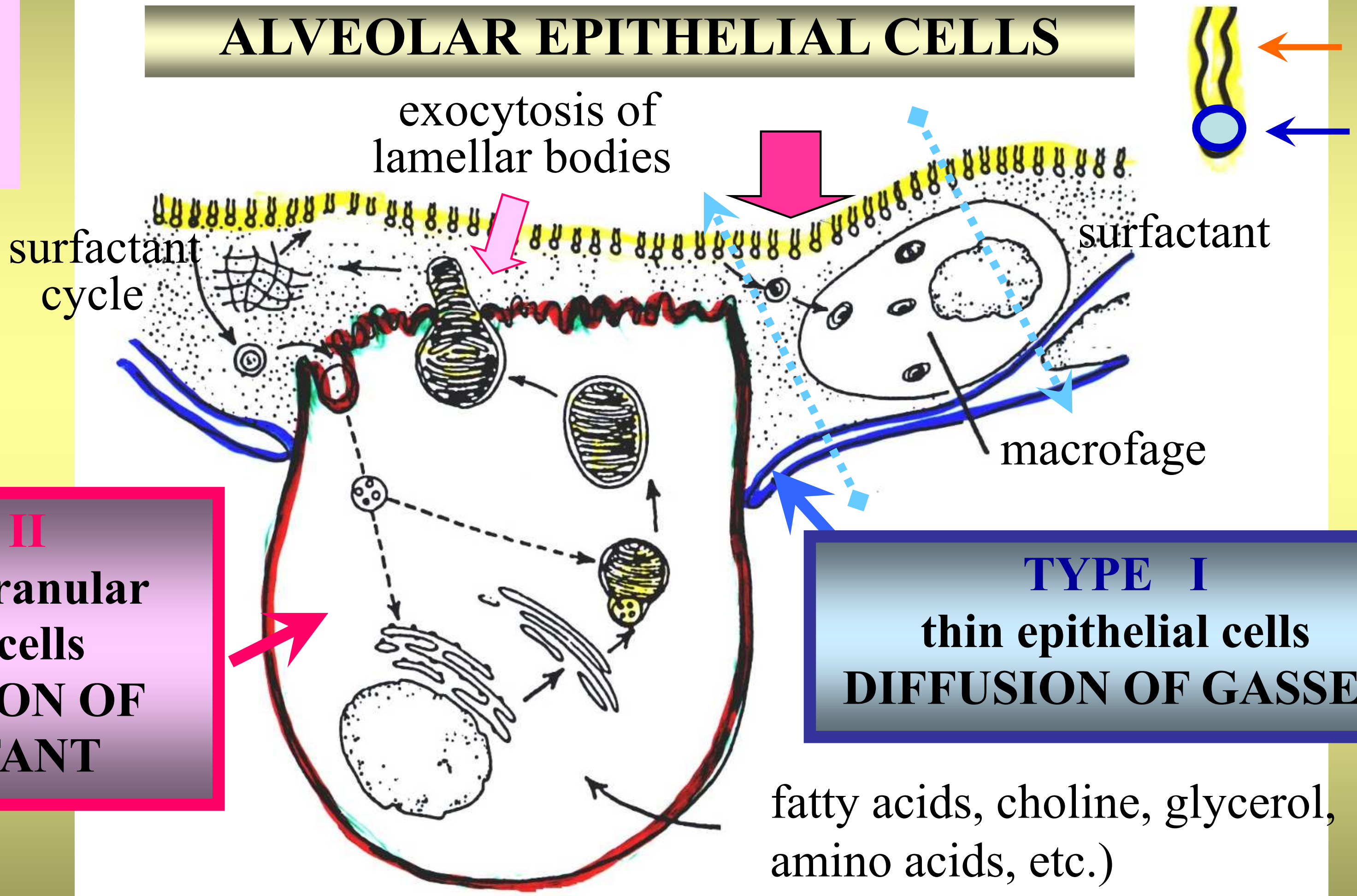
SURFACTANT

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

COMPOSITION OF DRY ATMOSPHERIC AIR

O_2 20.98 % — $F_{O2} \cong 0.21$

N_2 78.06 % — $F_{N2} \cong 0.78$

CO_2 0.04 % — $F_{CO2} = 0.0004$

Other constituents

BAROMETRIC (ATMOSPHERIC) PRESSURE AT SEA LEVEL

1 atmosphere = 760 mm Hg

PARTIAL PRESSURES OF GASSES IN DRY AIR AT SEA LEVEL

P_{O2} = 760 x 0.21 = ~160 mm Hg

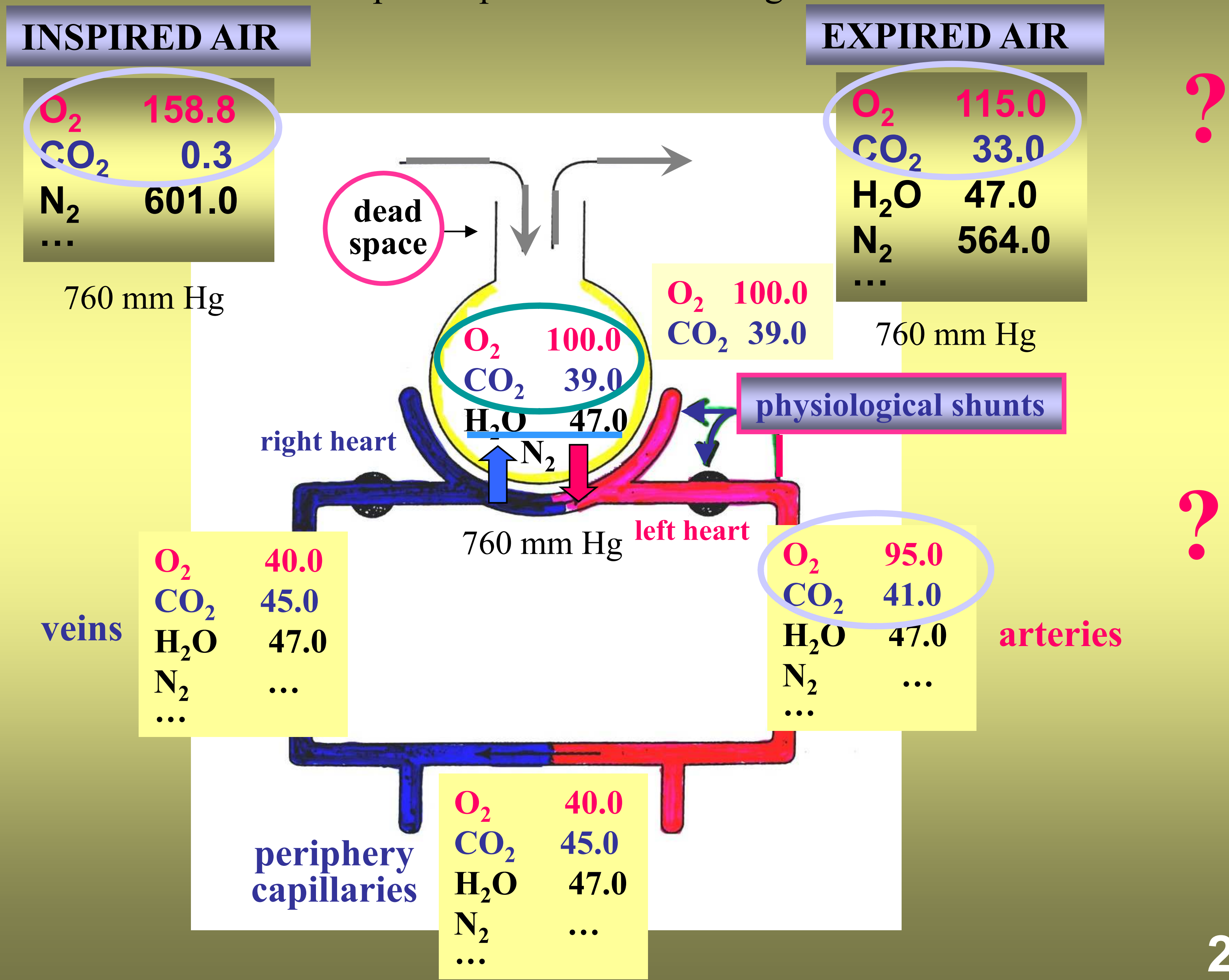
P_{N2} = 760 x 0.78 = ~593 mm Hg

P_{CO2} = 760 x 0.0004 = ~0.3 mm Hg

1 *kPa* = 7.5 *mm Hg (torr)*

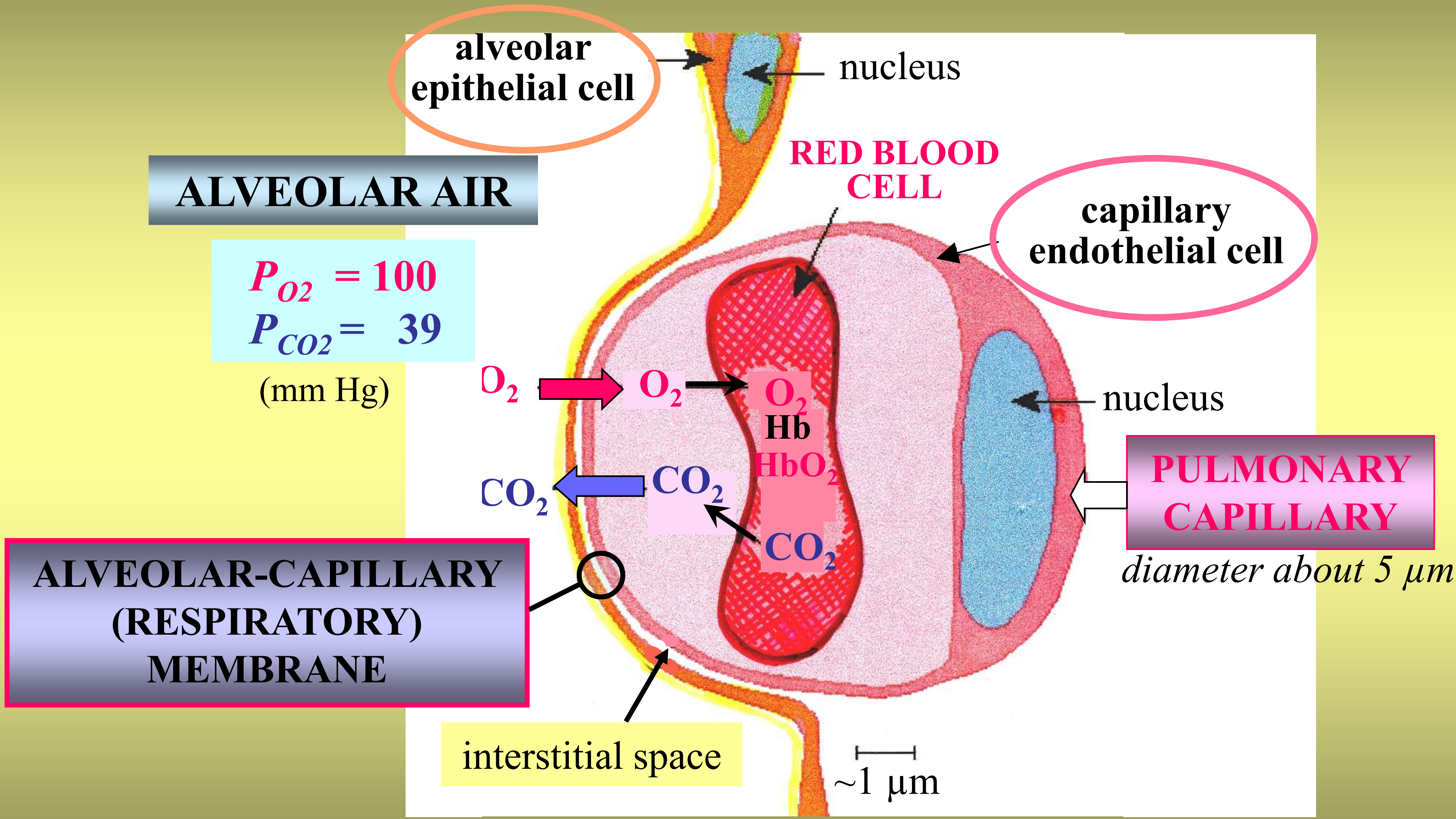
COMPOSITION OF ALVEOLAR AIR

partial pressures in mm Hg



ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

DIFFUSION OF GASES



0.75 s

time interval of erythrocyte contact with respiratory membrane at rest

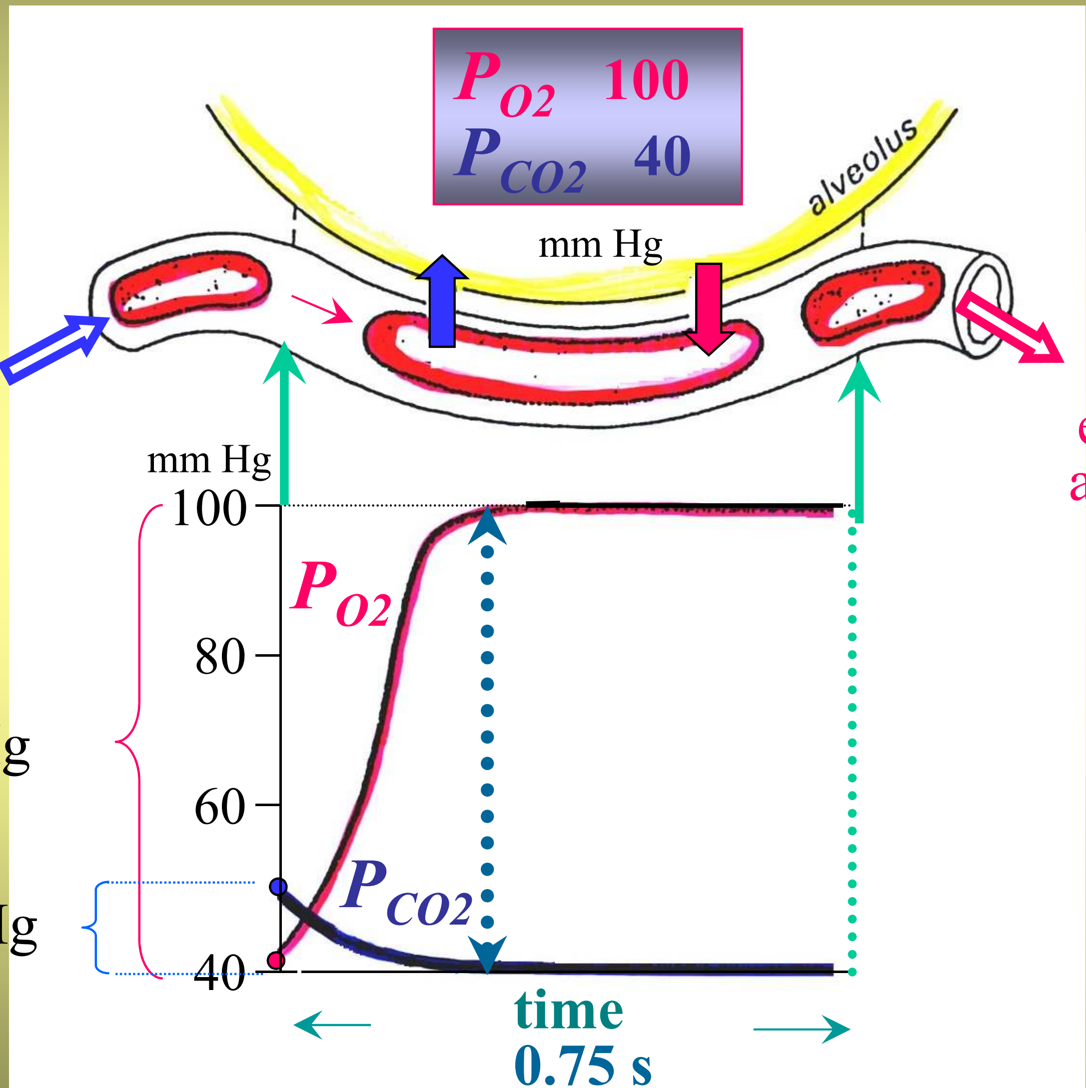
TIME COURSE OF CAPILLARY P_{O2} AND P_{CO2} DURING GRADUAL EQUILIBRATION WITH ALVEOLAR AIR

venous blood

P_{O2} 40
P_{CO2} 46
mm Hg

$\Delta P_{O2} \cong 60$ mm Hg

$\Delta P_{CO2} \cong 6$ mm Hg



P_{O2} 100
P_{CO2} 40
mm Hg

equalization with alveolar pressures

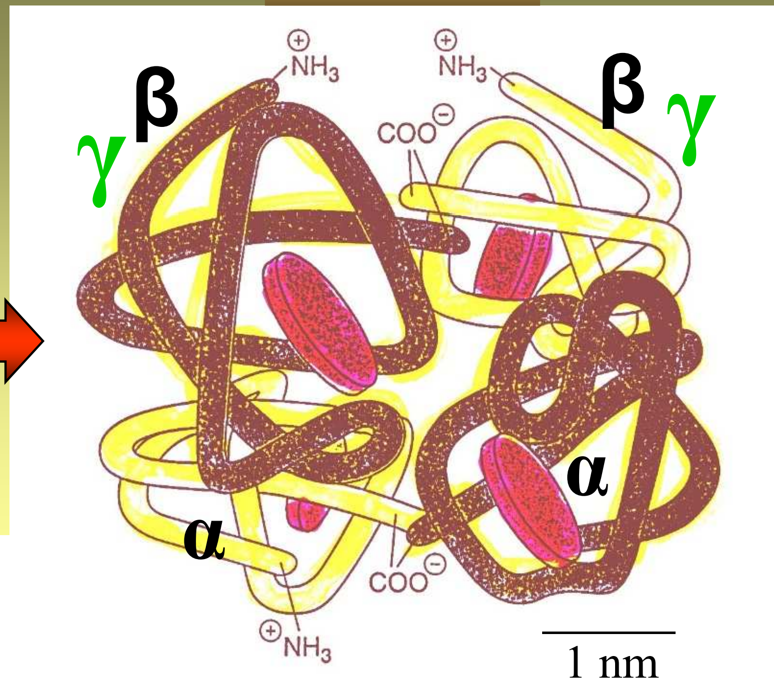
time interval of contact of erythrocyte with respiratory membrane at rest

HAEMOGLOBIN

$Hb_4 + 4\ O_2 \leftrightarrow Hb_4O_8$

oxygenation

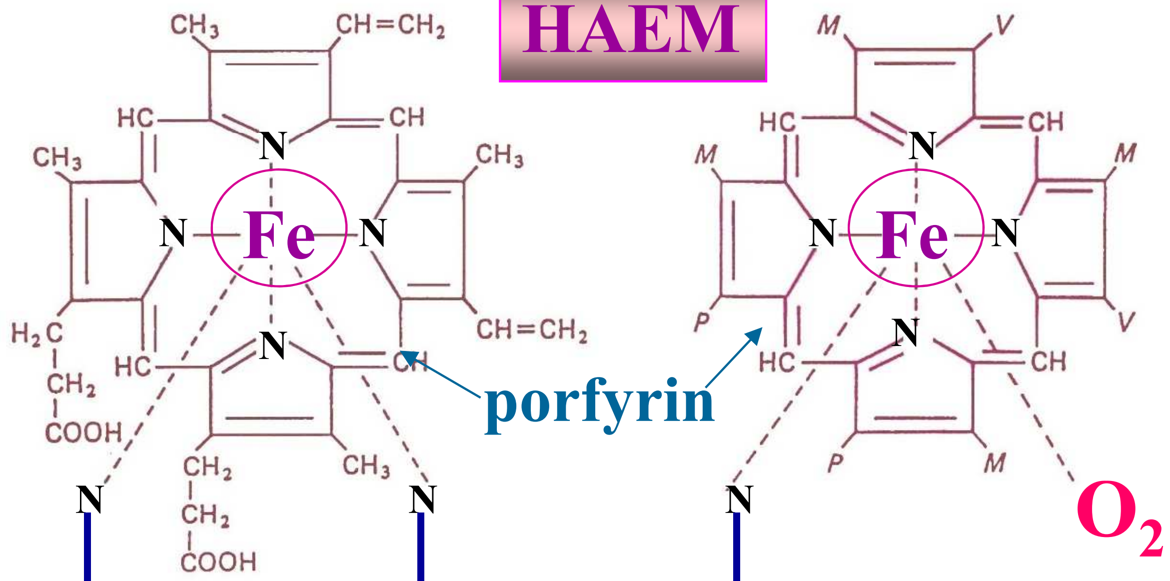
tetramer



Fe^{2+}

HAEM

DEOXY **OXY**



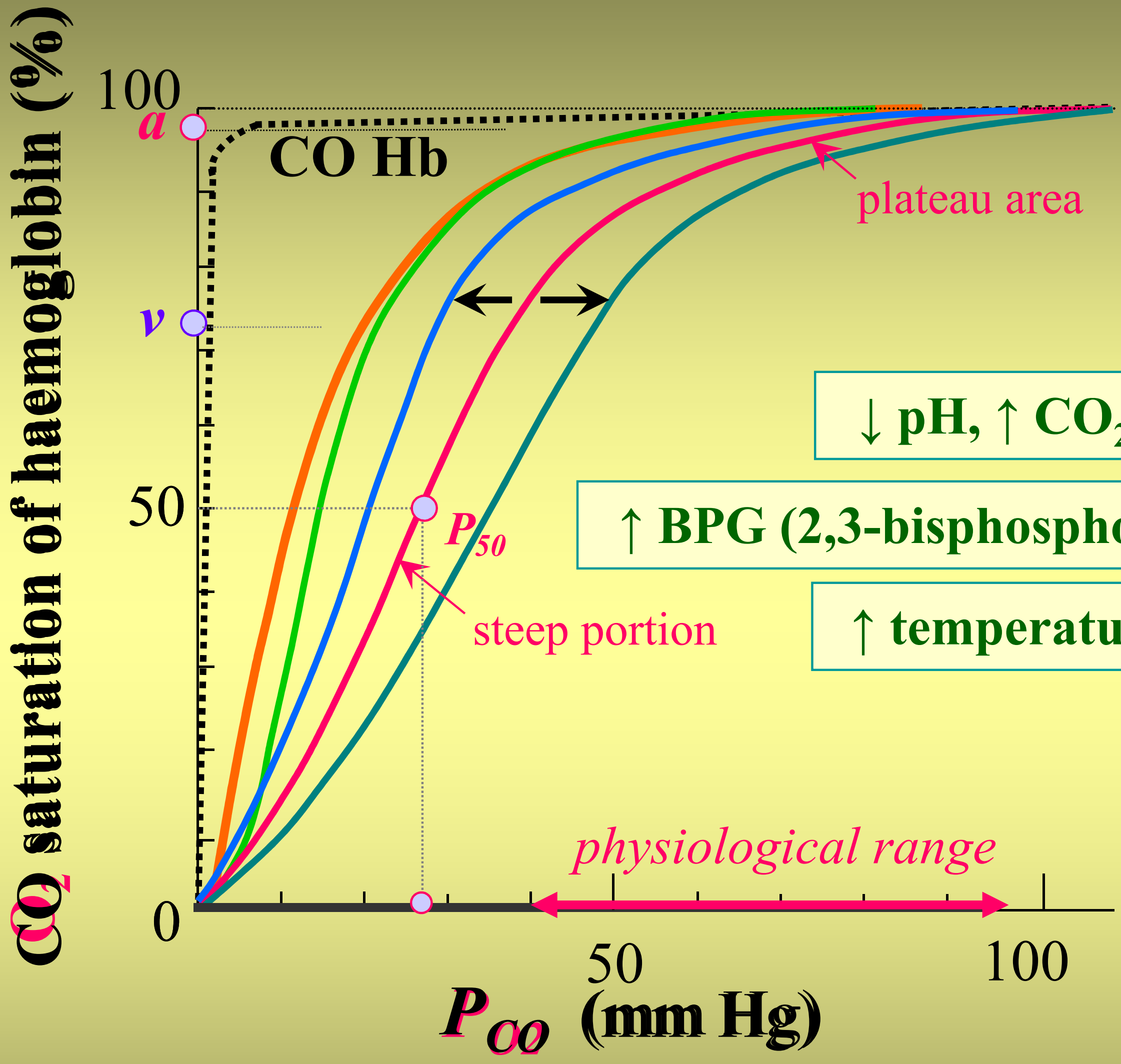
polypeptide chain

polypeptide chain

fetal Hb

Fe^{3+} (methaemoglobin)
oxidation

O_2–HAEMOGLOBIN DISSOCIATION CURVE



BOHR´S EFFECT
(↓ pH, ↑CO_2)

↓ pH, ↑ CO_2

↑ BPG (2,3-bisphosphoglycerate)

↑ temperature

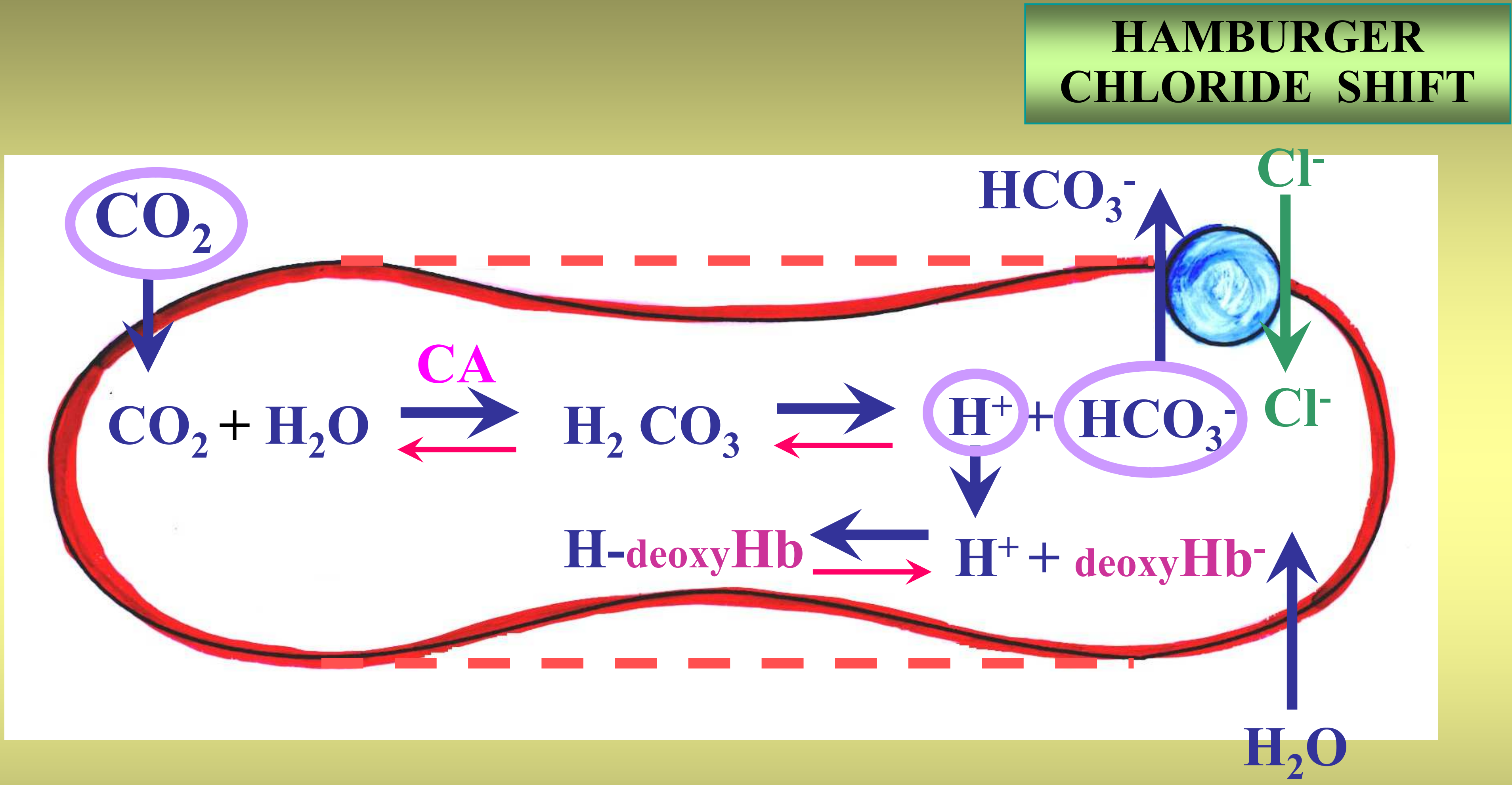
fetal Hb

myoglobin

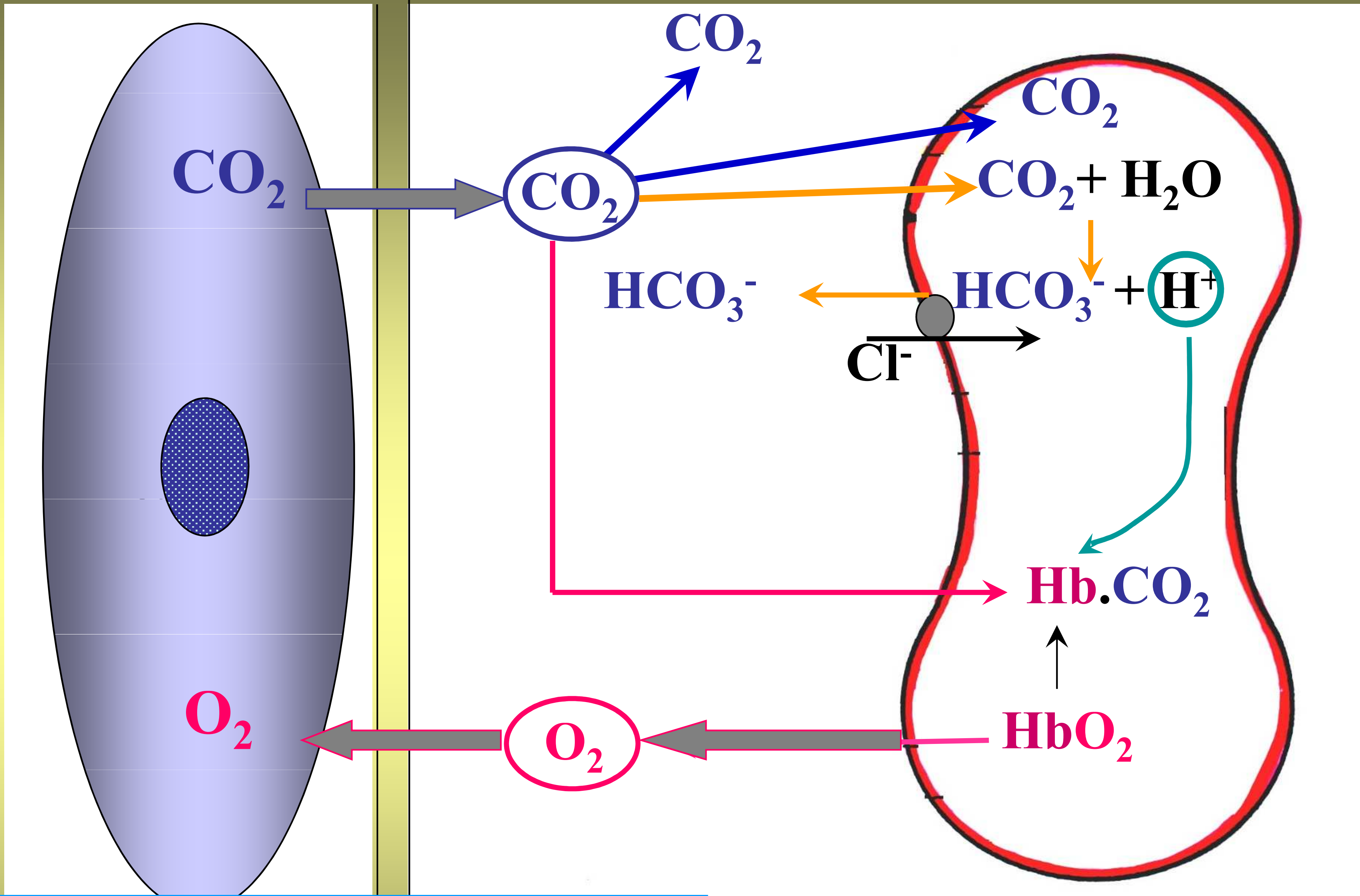
methaemoglobin

physically dissolved O_2 (1.4%)

TRANSPORT OF CO_2

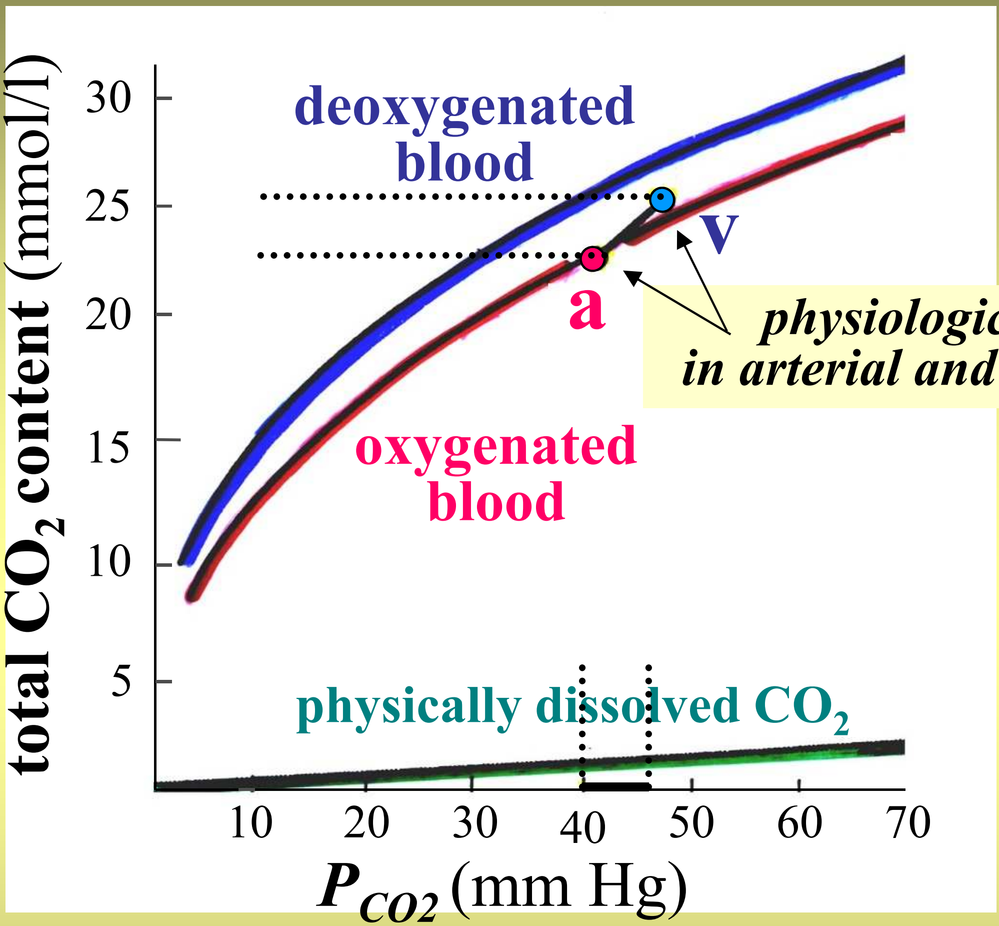


CA – carbonic anhydrase



- CO_2 physically dissolved (~5.3%)
- CO_2 + Hb-NH_2 ⇄ Hb.NH-COO^- (carbamino-Hb) (~5.3 %)
- $CO_2 + H_2O \rightleftarrows HCO_3^- + H^+$ (~89%) 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

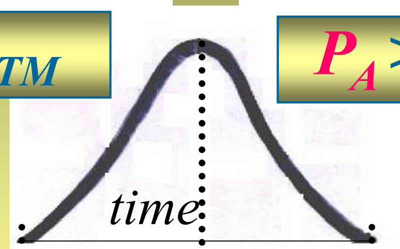
LUNGS: H^+ is released from **OXY-Hb** ⇒ ↓ amount of chemically bound CO_2

$P \cdot V = const$ ⇒ $P = \frac{const}{V}$

TIME COURSE OF PRESSURES AT QUIET RESPIRATION

INSPIRATION $P_A < P_{ATM}$

EXPIRATION $P_A > P_{ATM}$



V_T [l]

+1

[mm Hg]

-1

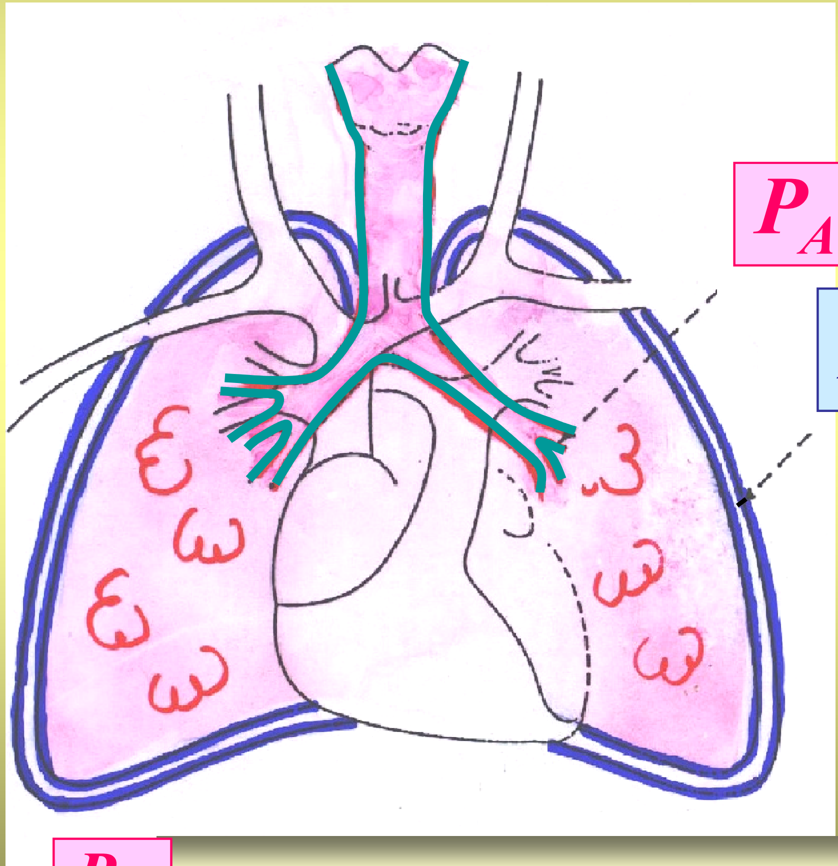
-3

?

[mm Hg]

-6

?



P_A

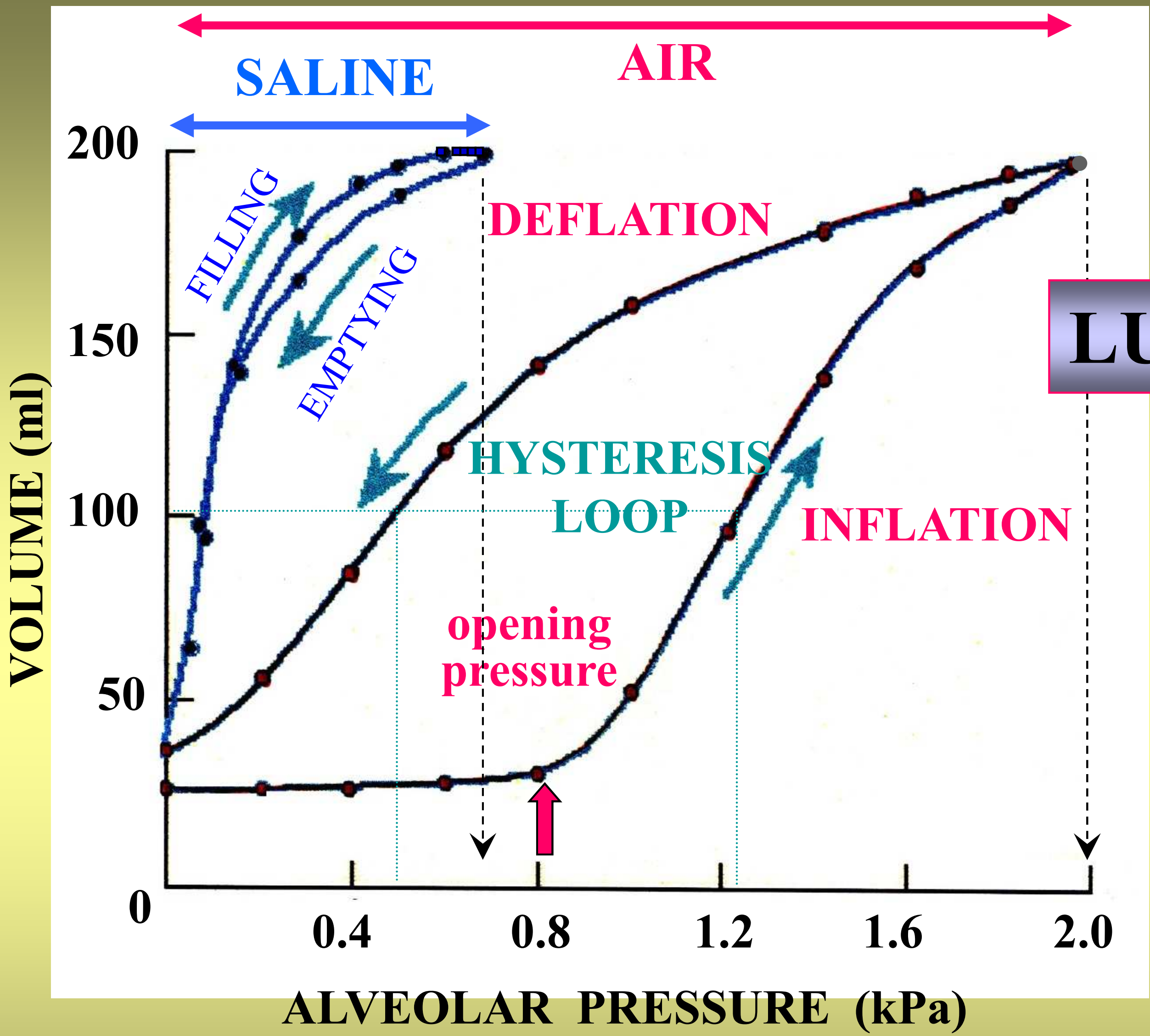
P_{PL}

measured curve

theoretical curve

P_A ALVEOLAR (INTRAPULMONARY, LUNG)

P_{PL} INTRAPLEURAL (INTRATHORACIC)

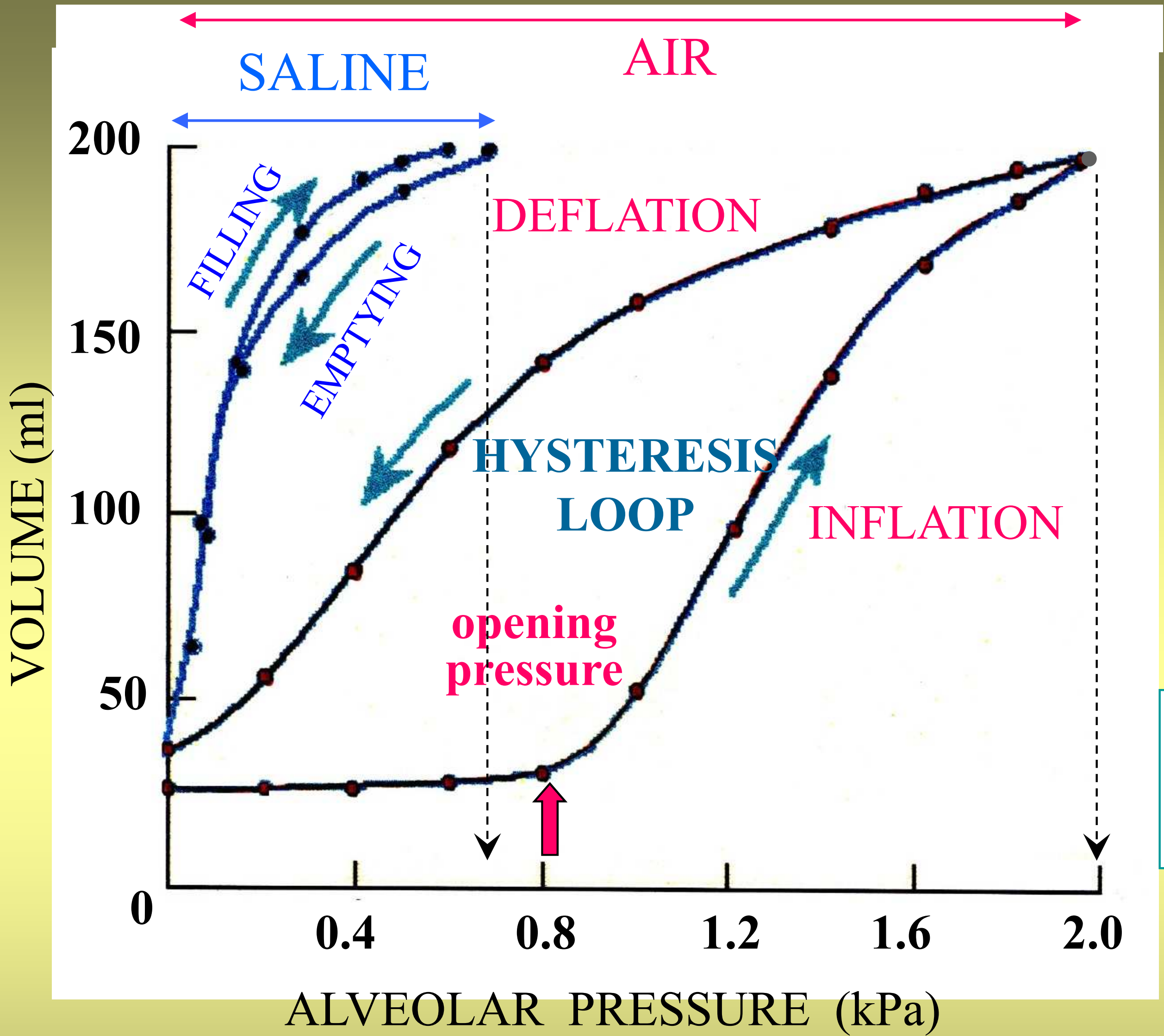


LUNGS ELASTICITY

1 $kPa = 7.5\ mm\ Hg$

LUNGS ELASTICITY

- **INHERENT TISSUE ELASTICITY (elastin and collagen fibres)**
- **SURFACE TENSION FORCES air-liquid interface in alveoli**

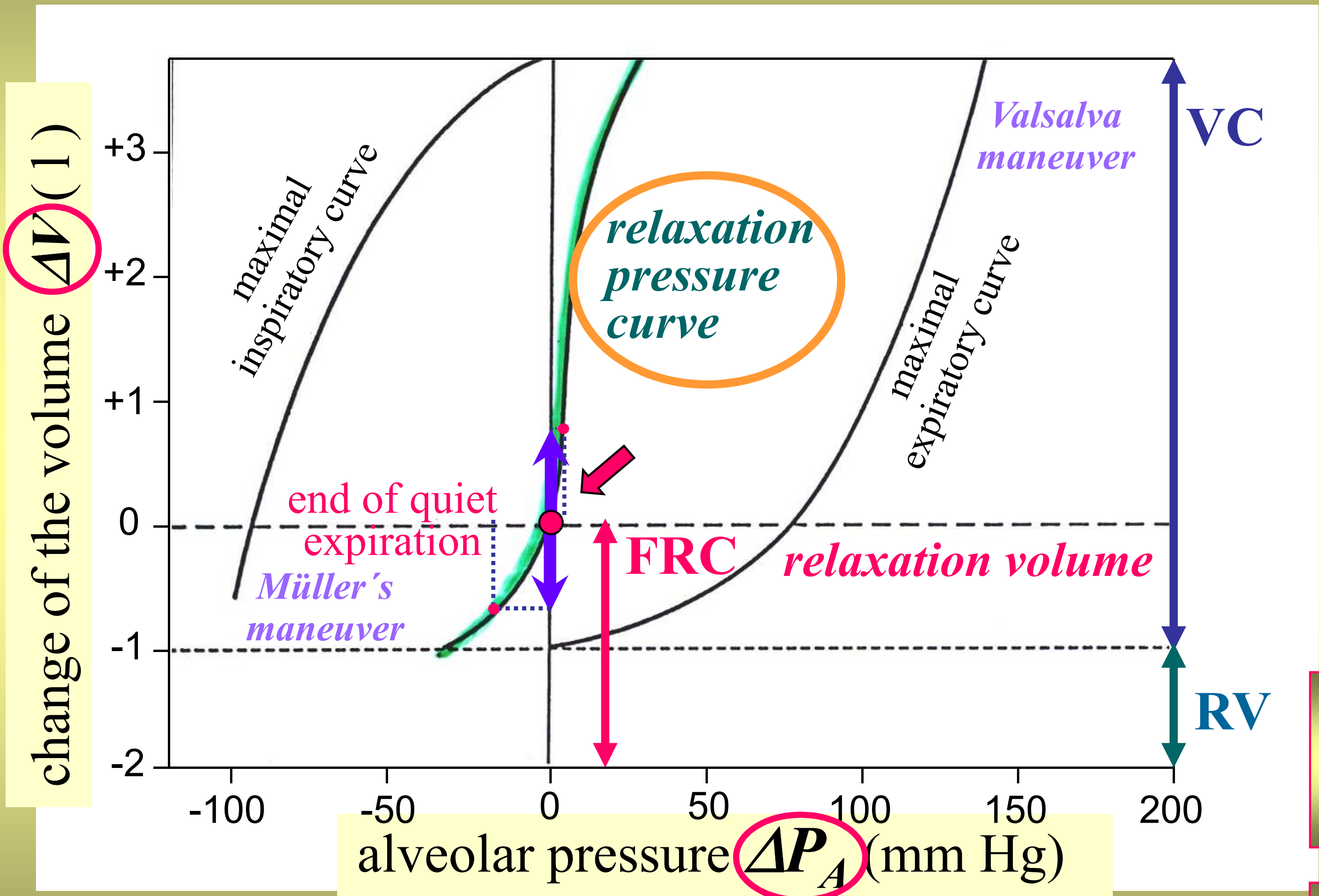


Factors involved in HYSTERESIS LOOP

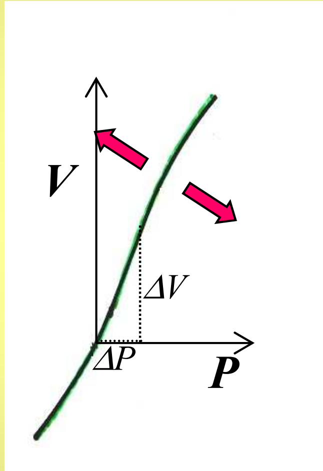
- **LAPLACE LAW (responsible for high opening pressure of alveoli)**
- **Dynamic changes** in the **DENSITY of surfactant molecules** during **INSPIRATION** and **EXPIRATION**

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)

TOTAL WORK OF RESPIRATORY MUSCLES AT QUIET BREATHING

ELASTIC (STATIC) WORK (65%)

to overcome the elastic forces of the chest and lungs

DYNAMIC WORK (35%)

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